CARIBOU MONITORING STUDY FOR THE

ALPINE SATELLITE DEVELOPMENT PROGRAM, 2006

SECOND ANNUAL REPORT

Prepared by

Brian E. Lawhead
Alexander K. Prichard
Matthew J. Macander

ABR, Inc.—Environmental Research & Services

P.O. Box 80410
Fairbanks, Alaska 99708-0410

Prepared for

ConocoPhillips Alaska, Inc.

P.O. Box 100360
Anchorage, Alaska 99510-0360

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EXECUTIVE SUMMARY

- Recent discoveries of oil in the northeastern National Petroleum Reserve–Alaska (NPRA) led to a proposal by ConocoPhillips Alaska (CPAI)—the Alpine Satellite Development Program (ASDP)—to expand development from the Alpine facilities on the Colville River delta and into NPRA. The first ASDP facility to be constructed (winter 2004–2005) was the CD-4 drill site and access road. The North Slope Borough (NSB) development permit for CD-4 stipulated that a 10-year study of the effects of development on caribou distribution and movements be conducted within a 48-km (30-mi) radius of CD-4, which also encompasses CD-3 (constructed in winter 2004–2005) and the planned CD-5, CD-6, and CD-7 pads and associated infrastructure and activities proposed by CPAI.
- This report presents results from the second year of the ASDP caribou monitoring study, combining aerial-transect survey data with analysis of radio-telemetry data. Aerial strip-transect surveys of caribou distribution were conducted in 3 adjacent survey areas (NPRA, Colville River Delta, and Colville East) during April to October 2001–2006. The telemetry analyses used location data from VHF, satellite, and GPS radio-collars in the Central Arctic Herd (CAH) and the Teshekpuk Herd (TH) collected by the Alaska Department of Fish and Game (ADFG), the Bureau of Land Management (BLM), the NSB Department of Wildlife Management, and the U.S. Geological Survey (USGS). VHF-collar data were collected during 1980–2005, satellite-collar data were collected during 1990–2006 for the TH and 1986–1990 and 2001–2005 for the CAH, and GPS-collar data were collected during 2004–2006 for the TH (including 12 new collars deployed specifically for this study in July 2006) and 2003–2006 for the CAH.
- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2002–2006, was used to estimate relative vegetative biomass in the study area and surrounding region during calving (1–10 June; NDVI_calving), peak lactation (21 June; NDVI_621), and during the peak of the growing season (late July 2005–2006; NDVI_peak). The average rate of change in NDVI values between calving and peak lactation was estimated (NDVI_rate). Snow cover (subpixel-scale snow fraction) in spring 2005 and 2006 was calculated for the ASDP study area from MODIS satellite imagery.
- Caribou were present in the 3 aerial-survey areas during all seasons in which surveys were conducted (2001–2006), although distribution and abundance fluctuated substantially. West of the Colville River, the highest densities of caribou typically occurred in fall; large groups of caribou were present occasionally during mosquito and oestrid fly seasons, but their occurrence was highly variable. East of the Colville River, the highest densities occurred during the calving and postcalving seasons. The mean proportion of collared TH caribou within the ASDP study area during each month ranged between 8 and 20% for satellite collars during 1990–2006 and 0 and 70% for GPS collars during2004–2006. The mean proportion of collared CAH caribou within the study area during each month varied between 13 and 51% for satellite collars during 1986–1990 and 2001–2005 and between 0 and 58% for GPS collars during 2003–2006.
- Analysis of VHF, satellite, and GPS telemetry data demonstrated clearly that the Colville River delta and ASDP study area are at the interface of the annual ranges of the TH and CAH. Although caribou from both herds occur on the delta occasionally, large movements across the delta are unusual. Unless CAH movement patterns change in the future, the proposed ASDP pipeline/road corridor extending from Alpine CD-2 into NPRA will have little effect on that herd. TH caribou use the NPRA survey area year-round, however, so detailed analyses focused primarily on the NPRA survey area, in which the proposed road alignment would be located.
- Spatial analysis of caribou distribution among different geographic sections of the NPRA survey area during 2002–2006 showed that the

section near the Beaufort Sea coast contained significantly more caribou groups during the mosquito season than would be expected if caribou distribution were uniform. Riparian areas along Fish and Judy Creeks contained significantly more caribou groups than expected during the postcalving season, oestrid fly season, late summer, and fall migration. The southeastern section of the NPRA survey area, in which the proposed pipeline/road corridor would be constructed, contained significantly fewer groups in all seasons except winter.

- For the years 2002–2006 combined, caribou in the NPRA survey area used tussock tundra significantly more than expected (based on availability) in winter and less than expected in the mosquito and oestrid fly seasons and late summer. Riverine habitats were used more than expected from postcalving through fall migration.
- High-density calving occurred east of the Colville River for the CAH (in the southeastern part of the Colville East survey area) and around Teshekpuk Lake for the TH (west of the NPRA survey area). Although some calving occurs in the western half of the NPRA survey area, it is not an area of concentrated calving for the TH. Persistent cloud cover during the period of snow melt between 24 May and 9 June 2006 prevented acquisition of satellite imagery and analysis of caribou distribution in relation to snow cover. During 2006, caribou in the NPRA survey area selected areas with high rates of increase in vegetative biomass during calving, late summer, and fall migration, but not during the insect (mosquito and oestrid fly) season. Areas with high estimated values of vegetative biomass were selected by caribou in 2006 during postcalving but not other seasons.
- Caribou use of the NPRA survey area varies widely by season. These differences can be described in part by snow cover, vegetative biomass, habitat distribution, and distance to the coast. The number of TH caribou in the area tends to increase in late summer and fall and fluctuates during the insect season as large groups move about in response to weather-mediated levels of insect activity. Because the NPRA survey area is on the eastern edge of the TH range, a natural west-to-east gradient of decreasing density occurs during much of the year. The southeastern section of the NPRA survey area, in which the proposed road alignment would be located, has lower caribou densities than do other sections of the area. There was little evidence for selection or avoidance of specific distance zones within 6 km of the proposed ASDP pipeline/road corridor. Fewer groups than expected occurred around the corridor during the oestrid fly season and late summer, probably because of increased use of riparian habitats along Fish and Judy creeks by caribou when oestrid flies were present. Radio-collared TH caribou have occasionally crossed the proposed ASDP road alignment in past years (not in 2006), primarily during fall migration, but the data collected thus far indicate that the proposed corridor is in an area of low-density use by caribou.

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INTRODUCTION

BACKGROUND

This study was conducted on the Arctic Coastal Plain of northern Alaska and was centered on the Colville River delta, an area that is used at various times of the year by two neighboring herds of barren-ground caribou (*Rangifer tarandus*)—the Teshekpuk Herd (TH) and the Central Arctic Herd (CAH). The TH generally ranges to the west and the CAH to the east of the Colville River delta.

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving is located consistently around Teshekpuk Lake and the primary area of insect-relief habitat in midsummer is the swath of land between Teshekpuk Lake and the Beaufort Sea coast (Prichard and Murphy 2004, Carroll et al. 2005). Most TH caribou winter on the coastal plain, although some caribou occasionally overwinter south of the Brooks Range with the Western Arctic Herd (WAH) (Philo et al. 1993, Kelleyhouse 2001, Carroll 2003, Prichard and Murphy 2004, Carroll et al. 2005). In recent years a substantial portion of the TH has wintered in areas outside of the previous range of the herd, both far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004) and southeast in the winter range of the CAH in 2004–2005 and 2005–2006 (G. Carroll and L. Parrett, ADFG, pers. comm.).

Concentrated calving activity by the CAH tends to occur in two areas of the coastal plain, one located south–southwest of the Kuparuk oilfield and the other east of the Sagavanirktok River and south of Bullen Point, away from most oilfield development (Lawhead 1988, Wolfe 2000, Arthur and Del Vecchio 2004, Lawhead and Prichard 2007). The CAH typically moves to the Beaufort Sea coast during periods of mosquito harassment (White et al. 1975, Dau 1986, Lawhead 1988). In recent years the majority of the CAH has wintered south of the Brooks Range, generally east of the Trans-Alaska Pipeline (Arthur and Del Vecchio 2004).

This caribou monitoring study for the Alpine Satellite Development Program (ASDP) builds on research, funded by ConocoPhillips Alaska, Inc. (CPAI) and its predecessors (ARCO Alaska, Inc., and PHILLIPS Alaska, Inc.), on the Colville River delta and adjacent coastal plain to the east of the delta (Alpine transportation corridor) since 1992 and in the northeastern portion of the National Petroleum Reserve–Alaska (NPRA) since 1999 (see Johnson et al. 2005 for complete listing of CPAI studies). In addition to wildlife surveys, an ecological land survey (ELS) was conducted on the Colville River delta (Jorgenson et al. 1997) and in northeastern NPRA (Jorgenson et al. 2003, 2004) to describe and map features of the landscape. The ELS described terrain units (surficial geology, geomorphology), surface forms (primarily ice-related features), and vegetation, which were used to develop a map of wildlife habitats. The Colville River delta and NPRA studies augmented long-term wildlife studies supported by CPAI and its predecessors since the 1980s in the region of the North Slope oilfields on the central Arctic Coastal Plain. Caribou surveys have been an important part of this research.

Since 1990, contemporaneous studies of caribou in the region west of the Colville River by the Alaska Department of Fish and Game (ADFG), North Slope Borough (NSB), and Bureau of Land Management (BLM), relied primarily on 3 types of radio telemetry (very-high frequency [VHF], satellite, and, since 2004, GPS transmitters) (Philo et al. 1993, Carroll 2003, Prichard and Murphy 2004, Carroll et al. 2005, Lawhead et al. 2006). A consulting firm working for BP Exploration (Alaska), Inc. also conducted aerial transect surveys over much of the TH calving grounds during 1998–2001 (Noel 1999, 2000; Jensen and Noel 2002; Noel and George 2003).

East of the Colville River, ADFG has conducted annual studies of the CAH since the 1980s using VHF, satellite, and, since 2003, GPS telemetry, as well as periodic transect surveys (Cameron et al. 1995, Lenart 2003, Arthur and Del Vecchio 2004). Other oil-company consultants conducted calving surveys of the CAH in the Milne Point oilfield and part of the Kuparuk oilfield in 1991, 1994, and 1996–2001 (Noel et al. 2004).

The current period of oil and gas leasing and exploration in NPRA closely followed the issuance of the Integrated Activity Plan and Environmental Impact Statement (IAP/EIS) for the Northeast NPRA Planning Area (BLM and MMS 1998) and the Record of Decision (ROD) in 1998. Discoveries of oil-bearing geologic formations since the mid-1990s led to strong industry interest in the northeastern portion of the NPRA and a proposal by CPAI—known as the Alpine Satellite Development Plan (BLM 2004)—to extend development westward from the Alpine project facilities into NPRA. In January 2006, after issuance of the Northeast NPRA Planning Area Amended IAP/EIS (BLM 2005), additional leasing was approved by the Secretary of the Interior in parts of northeastern NPRA that previously were off-limits. However, leasing in portions of the area surrounding Teshekpuk Lake has been suspended as a result of a legal challenge while the BLM revises its cumulative effects analysis from the 2005 EIS.

The CD-4 drill site and access road on the inner Colville River delta were the first of the proposed ASDP facilities to be built, beginning in winter 2004–2005, followed closely that winter by the CD-3 pad and airstrip on the outer delta. The NSB issued development permit NSB04-117 for the CD-4 project on 30 September 2004, stipulating that a 10-year study of the effects of development on caribou be conducted by a third-party contractor hired by CPAI (ABR, Inc. subsequently was hired). The study area was specified as the area within a 48-km (30-mile) radius around CD-4 and the study was to include all other satellite drill sites and infrastructure planned for construction within that 10-year time-frame. Therefore, the scope of study also includes the new CD-3 pad constructed in winter 2004–2005 and the planned CD-5, CD-6, and CD-7 pads and all associated infrastructure and activities proposed by CPAI and evaluated in the ASDP EIS (BLM 2004).

PROGRAM GOALS AND STUDY OBJECTIVES

The goal of the 10-year study was specified by the CD-4 permit stipulation: "The purpose of the study will be to evaluate the short- and long-term impacts of CD-4 and other CPAI satellite developments on the movements and distribution of caribou." The study is intended to be cooperative and collaborative in nature and communication of results with NSB stakeholders is a key component: "The study design will be reviewed by the NSB Department of Wildlife Management for review and approval. Additionally, a draft annual report shall be submitted to the North Slope Borough, City of Nuiqsut, Native Village of Nuiqsut, and Kuukpik Corporation for review and comments."

To begin implementing this permit stipulation, representatives of CPAI and ABR met with NSB staff in Barrow on 2 December 2004. The study options discussed at that meeting were developed into a preliminary study design and scope of work that were circulated in early February 2005 for further review. The revised study design and scope of work were approved in late March 2005 and were amended in early July 2005 to accommodate telemetry surveys by ADFG, which were added under the terms of a cooperative agreement among ADFG, CPAI, and ABR that addresses sharing of telemetry data for use in the ASDP caribou monitoring study. Results of the first year of study (Lawhead et al. 2006) were presented to the NSB Department of Wildlife Management on 9 March 2006 and to the village of Nuiqsut on 1 August 2006.

This study addresses specific questions about the potential impacts of petroleum development on caribou in the study area, with the intent of drawing on both scientific knowledge and local and traditional knowledge. The accumulated body of scientific knowledge on the TH and CAH provides a starting point and framework for structuring the study to address the issues identified since North Slope oil development began more than 35 years ago. The extensive knowledge of local residents, most of whom are Iñupiat, has been, and will continue to be, crucial for formulating research questions and ensuring that appropriate study methods are used. The combination of observations from both of these knowledge sources regarding development effects on CAH caribou can be grouped into three general issues (Cameron 1983, Shideler 1986, Murphy and Lawhead 2000, NRC 2003):

- Avoidance of areas of human activities by maternal caribou with young calves during and immediately following the calving period;

- Interference with caribou movements (delays or deflections), mainly during the summer insect season and seasonal migrations, but also including crossings by caribou (and subsistence users) beneath elevated pipelines in winter; and
- Altered availability of caribou for subsistence harvest at the times and places expected, which may vary over time.

In addition, other issues not dealt with in the CAH range east of the Colville River are expected to arise as development expands westward onto the winter range of TH caribou in NPRA, such as the response of caribou to seismic exploration and construction activities during the winter months.

The CD-4 permit stipulation recognizes impacts as falling into two broad categories: those affecting caribou movements and those affecting caribou distribution. Clearly, these categories are linked and not mutually exclusive, but the applicability of study methods differs somewhat between the two. Information on the potential effects of development on caribou distribution can be collected using a variety of methods, including aerial transect surveys, radio telemetry (VHF, satellite, and GPS), and observations by local subsistence users. Information on the potential effects on caribou movements, however, cannot be addressed adequately without employing methods such as radio telemetry that allow tracking of individually identifiable animals.

Several broad study tasks were identified in the scope of work:

1. Evaluate the seasonal distribution and movements of caribou in the study area in relation to existing and proposed infrastructure and activities in the study area, using a combination of historical and current data sets from aerial transect and telemetry surveys. Specific questions included the following:
   a) Which herds use the study area and the vicinity of the proposed pipeline/road corridor that will interconnect the ASDP facilities?
   b) Do the patterns of seasonal use differ between the two herds?
   c) How often do caribou cross the proposed corridor and does this differ by herd?
2. Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snow melt, seasonal flooding (if possible), and estimated biomass of new vegetative growth in the study area, by applying remote-sensing techniques, for comparison with caribou distribution.
3. Evaluate forage availability (above-ground vegetative biomass) and indices of habitat use by caribou in relation to proposed infrastructure, to allow temporal comparisons among years (before and after construction) and spatial comparisons by distance within years. Specific questions included the following:
   a) Does plant biomass and composition vary by habitat type and distance to the proposed road, and how well does remote sensing describe available biomass?
   b) Can caribou distribution be explained in terms of broad geographic areas, habitat availability, snow cover, or plant biomass?
   c) What are the existing patterns of caribou distribution and density around the proposed road corridor prior to construction?
4. Evaluate the feasibility of remote-sensing techniques to detect and map caribou trails for use in delineating movement routes and zones, both before and after construction.

Field sampling of plant biomass (Task 3) was not conducted in 2006; rather, it is scheduled to occur 4 times during the 10-year study and was begun in 2005. Task 4 is not addressed in this report because the high-resolution aerial photography flown in 2006 is not yet available (it is still processed by the vendor at this writing).

STUDY AREA

The general study area was the central Arctic Coastal Plain of northern Alaska (Figure 1, top). The climate in the region is arctic maritime (Walker and Morgan 1964). Winter lasts ~8 months and is cold and windy. The summer thaw period lasts about 90 days (June–August) and the mean summer air temperature is 5° C (Kuparuk oilfield records: National Oceanic and Atmospheric Administration, unpublished data). Monthly mean

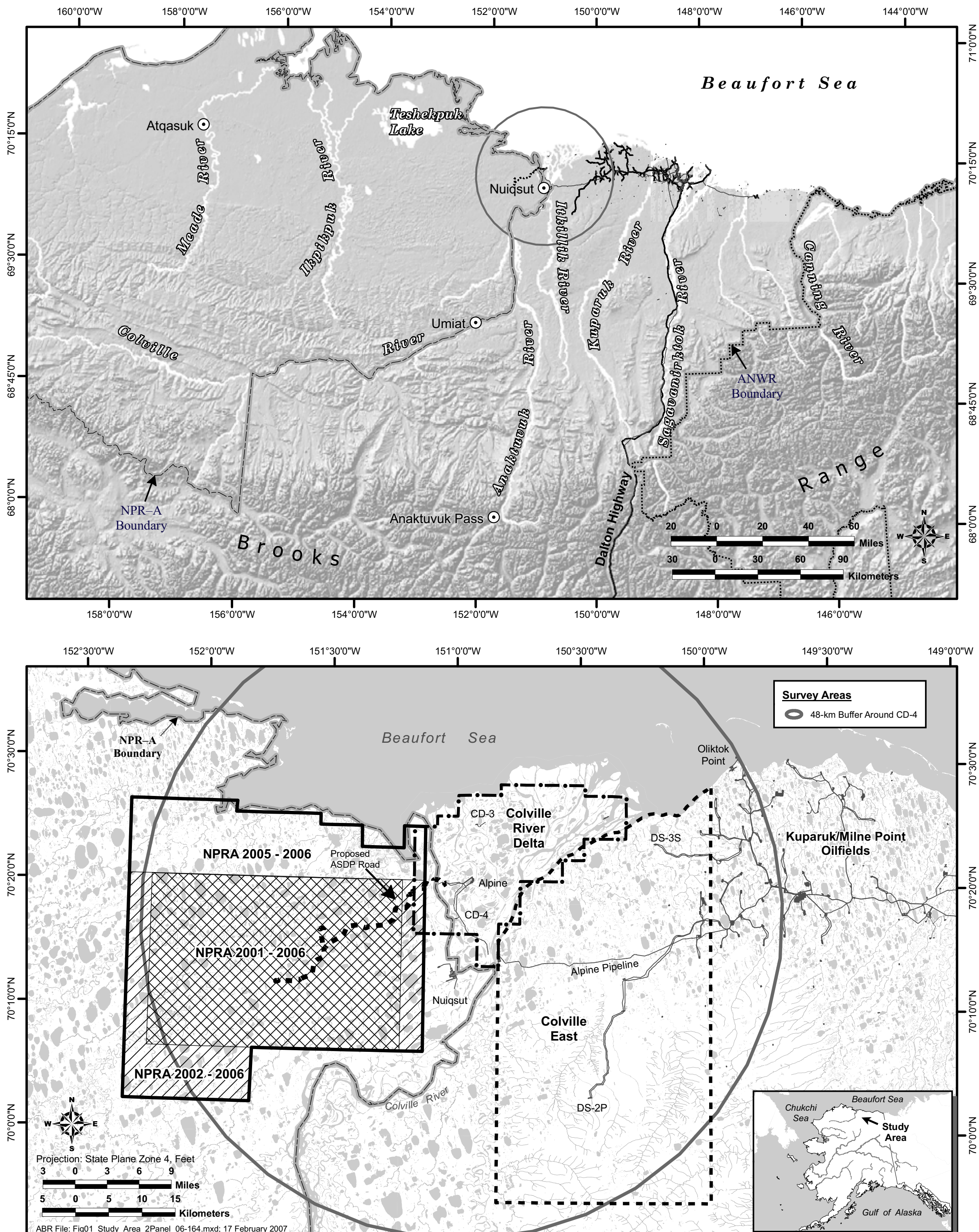

Figure 1. General location of the ASDP caribou monitoring study area (48-km [30-mi] radius around Drill Site CD-4) on the central North Slope of Alaska (top) and detailed view of study area showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2006 (bottom).

temperatures range from –10° C in mid-May to 15° C in July and August (North 1986), with a strong gradient of temperatures increasing with distance inland from the coast (Brown et al. 1975). Mean summer precipitation is <8 cm, most of which falls as rain in August. The soils are underlain by permafrost and the temperature of the active layer of thawed soil above permafrost ranges from 0° to 10° C during the growing season. Spring is brief, lasting ~3 weeks from late May to mid-June, and is characterized by the flooding and breakup of rivers. In late May, water from melting snow flows both over and under the ice on the Colville River, resulting in flooding on the Colville River delta that peaks during late May or the first week of June (Walker 1983). Breakup of the river ice usually occurs when floodwaters are at maximal levels. Water levels subsequently decrease throughout the summer, with the lowest levels occurring in late summer and fall, just before freeze-up (Walker 1983). Summer weather is characterized by low precipitation, overcast skies, fog, and persistent, predominantly northeast winds. The less common westerly winds often bring storms that are accompanied by high wind-driven tides and rain (Walker and Morgan 1964). Summer fog is more common at the coast and on the delta than farther inland.

The specific study area was defined by the NSB permit as the area within a 48-km (30-mi) radius around the CD-4 drill site (Figure 1, bottom). Aerial surveys were conducted in three survey areas, most of which were encompassed by the 48-km radius: Colville East (~1700 km²), Colville River Delta (494 km²), and NPRA (originally 988 km² in 2001, then expanded to 1310 km² in 2002 and to 1720 km² in 2005). The Colville East survey area includes the western and southwestern margins of the Kuparuk oilfield. The Colville River Delta survey area encompasses the original Alpine Development Project facilities CD-1 and CD-2, constructed in 1998–2001, and the newer ASDP facilities CD-3 (previously called Fiord or CD-North) and CD-4 (previously Nanuq or CD-South), for which construction began in winter 2004–2005 and continued in 2005–2006. The CD-3 development is a roadless drill site, accessed only by aircraft (in summer) and connected to CD-1 by an elevated pipeline. A road and adjacent elevated pipeline connects the CD-4 drill site to CD-1. The NPRA survey area encompasses 3 more drill sites—CD-5 (also called Alpine West), CD-6 (also called Lookout), and CD-7 (also called Spark)—and a potential gravel mine site (called Clover) that are planned for NPRA. A road is planned to connect these sites to the Alpine project facilities at CD-2, requiring a new bridge across the Nigliq (Nechelik) Channel of the Colville River.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, we conducted aerial transect surveys in 2006, adding to the NPRA transect database from 2001–2005, and analyzed several telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS) and from new GPS collars deployed specifically for this study in 2006. The aerial surveys provided broad information on caribou density within the study area. The satellite and GPS collars provided accurate location and movement data for a small number of caribou throughout the year. The radio-telemetry data also provided valuable insight into herd identity, which was not available from the aerial survey data. We analyzed caribou locations and densities in relation to an existing habitat map and to estimated plant biomass and snow-cover values derived from remote sensing.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Surveys of the NPRA, Colville River Delta, and Colville East survey areas (Figure 1, bottom) were conducted during April–October 2001–2006 by two observers looking out opposite sides of a Cessna 206 airplane (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; Lawhead et al. 2006, this study). Additional surveys of the Colville East area were conducted during the calving season in 2001–2006 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007). A third observer was present on some surveys to record data. The pilot navigated the airplane on transect lines using a GPS receiver and maintained an altitude of ~150 m (500 ft) agl or ~90 m (300 ft) agl using a radar altimeter. The lower altitude was flown to increase detection of caribou in areas of patchy snow cover during the calving season or occasionally in other seasons when low cloud cover precluded flying at the higher altitude.

Transect lines were spaced at intervals of 3.2 km (2 mi) following section lines on USGS topographic maps (scale 1:63,360) except during the calving season in some areas and years (Colville East in all years and NPRA in 2001), when 1.6-km (1-mi) spacing was used. Observers counted caribou within an 800-m-wide strip on each side of the transect centerline when flying at 150 m agl or a 400-m-wide strip when flying at 90 m agl, thus sampling ~50% of the survey area on each survey. Therefore, the number of caribou observed was doubled to obtain the total estimated number of caribou in the survey area. The strip width was delimited visually for the observers by placing tape markers on the struts and windows of the aircraft, as recommended by Pennycuick and Western (1972).

When caribou were observed within the transect strip, the perpendicular location on the transect centerline was recorded using a GPS receiver, the number of adults (including yearlings) and calves were recorded, and the perpendicular distance from the transect centerline was estimated in 100-m or 200-m intervals, depending on the strip width. For plotting on maps, the midpoint of the distance interval was used (e.g., 300 m for the 200–400-m interval). Thus, the maximal mapping error was estimated to be ~100 m. We calculated confidence intervals for estimates of total caribou and calves with a standard-error formula modified from Gasaway et al. (1986), using transects as the sample units.

RADIO TELEMETRY

VHF Collars

Location data were provided by ADFG for all VHF collars in the CAH and TH during the years 1980–2005 (Table 1). Those locations ranged over much of northern Alaska, but data on the specific areas covered on each radio-tracking flight were not available, so it was not possible to identify dates on which the ASDP study area was surveyed. CPAI contracted ADFG to conduct radio-tracking of VHF-collared caribou during summer 2005 in the study area and surrounding area (Lawhead et al. 2006). Radio-collared caribou were tracked from fixed-wing aircraft using strut-mounted antennas and a scanning radio receiver. Although VHF telemetry does not provide movement data that are as detailed as those from satellite or GPS telemetry, this method provided data on group size and behavior. On some surveys, however, the aircraft remained above the clouds, making visual

Table 1. Characteristics of the VHF, satellite, and GPS telemetry samples from the Teshekpuk and Central Arctic caribou herds analyzed for the ASDP caribou study.

Caribou Herd and Telemetry Sample	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd				
VHF collars [a]	1980–2005	n/a	n/a	212
Satellite collars	1990–2006	81	21	102
GPS collars	2004–2006	22	0	22
Central Arctic Herd				
VHF collars [a]	1980–2005	n/a	n/a	412
Satellite collars, early	1986–1990	16	1	17
Satellite collars, recent	2001–2005	14	3	17
GPS collars [b]	2003–2006	45	0	45

[a] n/a = not available, but most collared animals were females.

[b] Number of different collared caribou within 30 mi (48 km) of CD-4 at least once.

confirmation impossible; locational accuracy was much lower on those surveys. The sex, age, and reproductive status of collared animals were not available for this analysis, but most were adult females (Cameron et al. 1995, Arthur and Del Vecchio 2004). Location error was estimated to be 0.5–1 km (S. Arthur, ADFG, pers. comm.), although the error appeared to be greater for some locations.

Satellite Collars

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–July 2006 (Prichard and Murphy 2004, Lawhead et al. 2006, this study) and for CAH caribou during the periods October 1986–July 1990 and July 2001–September 2005 (Cameron et al. 1989, Fancy et al. 1992, Lawhead et al. 2006, this study) (Table 1). In the TH sample, 102 collared caribou (81 females, 21 males) transmitted signals for a mean duration of 440 days. In the CAH, the 1986–1990 sample included 17 caribou (16 females, 1 male) and the 2001–2005 sample included 17 caribou (14 females, 3 males), transmitting for a mean duration of 546 days. A few caribou moved between herds after collaring (3 TH animals joined the CAH and 5 TH animals joined the WAH); a caribou was assumed to have switched herds if it was in the calving area of another herd during a subsequent calving period.

Data from satellite transmitters were received by polar-orbiting satellites, transmitted through Command and Acquisition Stations to data-processing centers operated by Service ARGOS (Landover, Maryland). TH collar locations were transferred monthly to the NSB for data archiving (Prichard and Murphy 2004). In 1990–1991, the TH satellite transmitters were programmed to transmit 6 h/day for a month after deployment, then 6 h/2 days for 11 months. During 1991–2002, most collars were programmed to transmit every other day throughout the year. After 2002, many collars were programmed to transmit once every 6 days in winter and every other day during summer. Most of the TH collars deployed in 2000 malfunctioned and transmitted data only sporadically. The CAH satellite collars deployed during 1986–1990 were programmed to operate 6 h/day or 6 h/2 days, providing 3–4 locations per day for most collars with a mean location error of 0.48–0.76 km (Fancy et al. 1992).

Although satellite-telemetry locations are considered accurate to within 0.5–1 km of the true locations (Service ARGOS 1988), the data also require screening to remove spurious locations. Data-screening methods followed Prichard and Murphy (2004), removing duplicate data, locations obtained before and after collaring or after mortality occurred, and locations for which the ARGOS-designated location-quality scores (NQ) had a score of zero or “B”, indicating unreliability (Service ARGOS 1988). NQ scores of “A” tend to be more accurate than scores of zero (Hays et al. 2001, Vincent et al. 2002), so they were retained. Locations were removed that obviously were inaccurate because they were offshore or far from other locations. We applied a distance–rate–angle (DRA) filter to remove locations that appeared to be incorrect based on the distance and rate of travel between subsequent points and the angle formed by 3 consecutive points. Any 3 locations with an intervening angle of <20 degrees and both “legs” with speeds greater than 10 km/h were assumed to be inaccurate and were removed, unless the distance of either leg was less than 1 km (Prichard and Murphy 2004). If the distance of any leg was <1 km, then the location was not removed because it was close to a previous or subsequent location and therefore likely to be accurate. We removed any locations that clearly were inaccurate based on previous and subsequent locations.

In analysis of movements, autocorrelation of animal location points that are collected close together in time may introduce bias (Schoener 1981, Swihart and Slade 1985, Solow 1989). Due to the highly directional movements of caribou during much of the year, movement data often do not meet the requirements for statistical independence for home-range analysis without removal of large numbers of data points (McNay et al. 1994). If too many data points are removed, however, biologically important information can be lost (Reynolds and Laundre 1990, McNay et al. 1994). To achieve operational independence of data points, the time between successive samples should approximate the time necessary to travel anywhere else in a seasonal range (Lair 1987, McNay et al. 1994). In addition, systematic sampling of locations over a given time period can remove bias due to dependent data (White and Garrott 1990).

For the TH and recent CAH data, we selected one location during each duty cycle, defined as a period of transmission of location data, which typically was 6 h/2 days. Because caribou are capable of rapid movement, we concluded that one location per duty cycle was infrequent enough to provide adequate independence between locations while still maintaining biologically important information. To select one high-quality location per duty cycle, we identified the records with the highest NQ score for each duty cycle. If multiple records in a duty cycle were tied for the highest NQ score, we chose the location with both the highest NQ score and the lowest value of ξ (Keating 1994). ξ is similar to our DRA filter, because it is calculated using 3 successive locations and is a measure of the distance between locations, the angle formed by the 3 locations, and the similarity of length between the 2 legs (Keating 1994). Although the CAH data set for October 1986–July 1990 was screened before we received it (B. Griffith, USGS, pers. comm.), it was screened further to select the first location each day with the highest NQ score.

GPS Collars

Ten female caribou from the TH were fitted by ADFG with GPS collars in July 2004 (Table 1); the collar model was the Telonics (Mesa, AZ) TGW-3680 GEN 3 store-on-board configuration with ARGOS satellite uplink (purchased by NSB). The animals were recaptured and the collars were removed in July 2005. All 10 caribou survived for the entire period; 7 had calves in 2005, 2 did not, and one had a calf that died soon after calving. The GPS collars recorded locations every 3 h throughout the entire year; all location data were stored onboard the collars and were downloaded after the collars were retrieved, superseding the need to use the location data that had been obtained from the satellite throughout the year (the stored-on-board data provide a higher degree of accuracy and thus are preferred for analysis). Data were screened to remove any locations obtained prior to collaring or after collars were removed, as well as any locations that obviously were incorrect because they were far offshore or far from previous and subsequent locations. For each animal we selected the location closest to noon UT (Universal Time, or 04:00 local time) and used those single daily locations in the analyses.

Twelve more female caribou from the TH were fitted by ADFG with GPS collars (also Telonics model TGW-3680, purchased by CPAI for this study) during 8–10 July 2006 (Table 1). The collared sample comprised 7 adults aged 3 years or more, 3 2-y-olds, and 2 yearlings. Caribou were captured by firing a handheld net-gun from a Robinson R-44 piston-powered helicopter; in keeping with ADFG procedures for the region, no immobilizing drugs were used. To avoid injury to animals during collaring, no females with calves were captured. The planned period of deployment was approximately one year; collars are scheduled to be retrieved in July 2007. The collars were programmed to record locations at 2-h intervals throughout the year, but battery-life constraints required that only 25–50% (depending on the seasonal uplink schedule) of the location data collected each day could be transmitted to the ARGOS satellite. Therefore, only a portion of all locations are available for analysis before the scheduled retrieval of these collars in summer 2007; the full data set will be available for analysis after the collars are retrieved and downloaded. Satellite uplinks are programmed to occur once daily between 16 April and 15 November and once every other day between 16 November and 15 April. Data reports were received daily (summer) or every other day (winter) by e-mail from CLS America (Largo, MD). All 12 collars were still transmitting data at the end of 2006 (the last locations used for this report were from 27 December 2006).

For the CAH animals outfitted with GPS collars during 2003–2005 (Table 1), all location data recorded within a 48-km radius of CD-4 were provided by ADFG. The CAH samples comprised 24, 24, and 33 female caribou in 2003, 2004, and 2005, respectively, of which 19, 18, and 19 collared caribou were recorded at least once within the 48-km study area radius. Most of the CAH locations were obtained at 5-h intervals, but occasionally 2 locations were recorded over a shorter time period. In most such cases, one of the locations appeared to be obviously wrong. We plotted each of those cases individually and removed the location that appeared to be inaccurate based on previous and subsequent locations. The duration between consecutive locations was calculated for every point.

REMOTE SENSING

The Earth-Observing System (EOS) *Terra* and *Aqua* satellites, launched in 1999 and 2002, respectively, each carry a Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor. MODIS data from the *Terra* platform were used to characterize snow melt and vegetation green-up over the ASDP study area (and surrounding region, due to the wide swath covered on each satellite pass). At least one satellite image over the study area was acquired daily between 20:00 and 24:00 UT (12:00 and 16:00 local time). Browse images were reviewed to identify those with substantial cloud-free views of the study area. For each date, the following data products were obtained from the Level 1 and Atmosphere Archive and Distribution System (LAADS, Goddard Space Flight Center, Greenbelt, MD):

- MOD02QKM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath 250 m)
- MOD02HKM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath 500 m)
- MOD021KM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1 km)
- MOD03 (MODIS/Terra Geolocation Fields 5-Min L1A Swath 1 km)
- MOD10_L2 (MODIS/Terra Snow Cover 5-Min L2 Swath 500 m)

SNOW COVER

The MOD10_L2 data product provides a binary snow map at nominal 500-m resolution over the onshore portion of the study area (except for areas obscured by clouds). Snow is one of the only natural materials that is both highly reflective in visible wavelengths and absorbed in the middle infrared, so the MODIS snow-mapping algorithm is based on these properties. The Normalized Difference Snow Index (NDSI) is calculated from MODIS Band 4 (0.545–0.565 m) and Band 6 (1.628–1.652 m) as follows:

$$NDSI = (Band\ 4 - Band\ 6) \div (Band\ 4 + Band\ 6).$$

Pixels are classified as snow if the following conditions are met: NDSI > 0.4, MODIS Band 4 reflectance > 0.10, and MODIS Band 2 reflectance > 0.11.

The binary nature of the standard MODIS snow product limits its usefulness during the period of active snowmelt, when snowdrifts and patchy snow conditions occur at finer scales than 500-m pixels. Several algorithms have been proposed to infer subpixel-scale snow cover using MODIS data, including 2 specific to the Kuparuk River watershed. Salomonson and Appel (2004) compared binary snow maps from 30-m Landsat 7 imagery to MODIS NDSI and developed a simple linear function to calculate subpixel-scale snow fraction from the MODIS NDSI. Déry et al. (2005) tested this algorithm with two additional Landsat-7 images and added a ninth-order polynomial correction term to the linear model to address underestimation of snow cover at low snow-cover fractions.

We calculated snow fraction for late winter and spring 2006 using the first algorithm (Salomonson and Appel 2004). In 2005 we used the Déry et al. (2005) algorithm (Lawhead et al. 2006), which was intended for hydrological studies in the Kuparuk River watershed, but we subsequently concluded that it was not the most appropriate for our habitat analyses because it includes a corrective intercept term that enforces a minimum of 6% snow cover for all pixels. Although this ninth-order correction may make sense when driving a hydrological model with a temporal domain extending through 31 May, it does not reflect reality during early summer when snow cover is clearly absent from most of the landscape.

MOD02HKM swath granules were gridded to 50-m resolution and then aggregated to 500-m resolution. Digital number (DN) values were converted to reflectance using the scale factor from the metadata. NDSI was calculated, and then the subpixel-scale snow fraction was calculated as

$$Snow\ Fraction = 0.06 + (1.21 * NDSI).$$

Missing or otherwise bad data were flagged by the occurrence of DN values over 32,767 (per the L1B EV 500m File Specification–Terra 2005) and any 500-m cells containing data flagged as unusable were masked. Cloud-obscured pixels were identified using the standard cloud mask, which was extracted from the MOD10_L2 snow product. However, that cloud mask frequently misclassified cloud-free pixels having partial snow cover as clouds. Clouds could be distinguished easily from snow visually using a false-color display of MODIS bands 7/6/5, so a polygon was manually delineated around the actual cloud-obscured areas. Outside of the delineated area, "cloud" pixels were treated as false cloud detections and ignored, whereas inside this area, cloud-obscured pixels were masked out.

A time-series of images covering 15 May–21 June 2006 was processed in this manner. A composite image was produced from 13 and 14 June 2006 because both dates had patchy cloud cover. After a cloud mask was applied to both dates, the pixel with the highest NDVI was selected and the snow fraction was calculated. A composite also was compiled to identify the first date with 50% or lower snow cover for each pixel.

VEGETATIVE BIOMASS

The values of the Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973) are used to estimate of the quantity of green vegetation within a pixel at the time of image acquisition. The rate of increase in NDVI between two images acquired on different days during green-up has been considered to represent the amount of new growth over that time frame (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI was calculated as

$$NDVI = (NIR - VIS) \div (NIR + VIS)$$

where *NIR* = near-infrared reflectance (wavelength 0.841–0.876 µm for MODIS) and *VIS* = visible light reflectance (wavelength 0.62–0.67 µm for MODIS) (Rouse et al. 1973; http://modis.gsfc.nasa.gov/about/specs.html).

NDVI was calculated using satellite imagery acquired in June during the calving period (1–10 June), during the presumed period of peak lactation for parturient females (21 June), and finally in late July around the peak of the growing season (peak biomass). The image-processing methods used for the 2004 and 2005 imagery differed somewhat from those used for the 2002 and 2003 imagery because several improvements were implemented in the interim. Because of that difference, some caution should be used in interannual comparisons of absolute values.

Our processing improvements include correcting reflectance for some atmospheric effects, weighted-average resampling, per-pixel cloud masking, and improved compositing (merging data from multiple acquisitions to minimize the effects of cloud cover). Each imaging swath was atmospherically corrected using the MODIS Rapid-Response corrected-reflectance algorithm (*crefl*; Gumley 2003), which removes gross atmospheric effects (2002 and 2003 analyses were based on uncorrected, top-of-atmosphere reflectance). The corrected reflectance swath granules were gridded to 50-m resolution, and then aggregated to 250-m resolution. This procedure is similar to the weighted-average resampling scheme implemented in the MOD13 16-day vegetation index composite products, and it maintained a high level of geolocation accuracy so that no further manual adjustment was necessary. In contrast, the 2002 and 2003 analyses were done using bilinear resampling to 250-m. The geolocation quality of the resulting products was not as precise, so a 3×3-pixel mean smoothing filter was applied to all of the outputs in those years.

Negative NDVI values indicate water, snow, ice, or clouds rather than vegetation conditions, so all negative NDVI values were set to zero. NDVI values near the peak of calving (NDVI_calving, between 1 and 10 June; Griffith et al. 2002) were estimated using imagery from 9 June 2006; in past years the dates used were slightly earlier (4–5 June 2005, 4–8 June 2004, 5 June 2003, and 7 June 2002; Lawhead et al. 2006). A compositing approach was used to minimize the effects of cloud cover in 2004 and 2005. However, persistent cloud cover during early June 2006 restricted the imagery to a single date.

NDVI values near peak lactation for caribou, which occurs around 21 June (NDVI_621) (Griffith et al. 2002), were interpolated from images obtained before and after 21 June in 2002–2005, because the sky was not clear on 21 June in any of those 4 years. In 2006 a substantial area was cloud-free on 21 June, so some of the

NDVI_621 data for 2006 did not need to be interpolated. Both an interpolated image for 21 June (NDVI_621_interp) and the actual data from 21 June (NDVI_621_actual) were calculated, and NDVI_621 was then calculated from the maximum of those two grids. We initially tried using NDVI_621_actual except for the cloudy areas, but the cloud mask was imperfect, causing low NDVI values at cloud edges. The maximum compositing approach is an efficient way to filter clouds that the cloud mask algorithm misses, because even partial cloud cover in a pixel always depresses NDVI.

We calculated the daily rate of change of NDVI (NDVI_rate) between calving and 21 June by subtracting NDVI_calving from NDVI_621 for each pixel and dividing by the number of intervening days. Finally, NDVI_peak was calculated from the late July imagery (2005 and 2006 only).

The presence of waterbodies, snow, and ice depress NDVI values and decouple them from their relationship to vegetation properties (Macander 2005). We removed the effect of large waterbodies in the study area by excluding pixels with 50% or greater water cover (determined by overlaying a regional map layer of lakes and ponds). This correction lessened, but did not eliminate, the negative bias from open water and ice.

CARIBOU DISTRIBUTION ANALYSES

Caribou group locations from aerial transects in the NPRA survey area were analyzed in relation to habitat type, estimated vegetative biomass levels, snow cover, and various geographic sections of the survey area to evaluate which factors influenced caribou distribution before oil development began. We also compared group locations and density within several distance zones around the proposed ASDP road to characterize the preconstruction baseline level of use of the area by caribou.

Because the distribution of caribou is influenced by different factors during different seasons, we grouped the aerial-transect survey data into 8 different seasons (adapted from Russell et al. 1993): winter, 1 December–30 April; spring migration, 1–29 May; calving, 30 May–15 June; postcalving, 16–24 June; mosquito, 25 June–15 July; oestrid fly, 16 July–7 August; late summer, 8 August–15 September; and fall migration, 16 September–30 November.

GEOGRAPHIC LOCATION

Visual inspection of caribou distribution from aerial transects suggested different levels of caribou use across the NPRA survey area, so we tested whether caribou locations varied among different geographic areas. We divided the 2002–2004 and 2005–2006 survey area into 6 sections: (1) the area within 4 km of Fish and Judy creeks (River); (2) the area within 4 km of the Beaufort Sea coast (Coast); (3) the area north of Fish and Judy creeks (North); (4) the area west of Fish and Judy creeks (West); (5) the western half of the area south of Fish and Judy creeks (Southwest); and (6) the eastern half of the area south of Fish and Judy creeks (Southeast) (Figure 2). The proposed ASDP road would be constructed almost entirely in the Southeast section. The number of caribou groups in each section was quantified for all seasons and years and a chi-square goodness-of-fit test was used to test whether the number of groups in each section differed significantly from expected values, assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual sections were compared using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984).

HABITAT USE

To compare habitat use with availability, we overlaid the aerial-transect data from surveys of the expanded 2005–2006 NPRA survey area on the earth-cover classification previously created for NPRA by BLM and Ducks Unlimited (2002; Figure 3). We used the NPRA earth-cover classification for these analyses because it covered our entire NPRA survey area, had fewer habitat classes than did the ELS classification, and the classification system appeared to better reflect habitat characteristics important to caribou. The ELS habitat map (Jorgenson et al. 1997, 2003, 2004) did not cover the entire NPRA survey area and was intended to apply to birds as well as mammals.

The NPRA survey area contained 15 different cover classes (Appendix A). The clear-water,

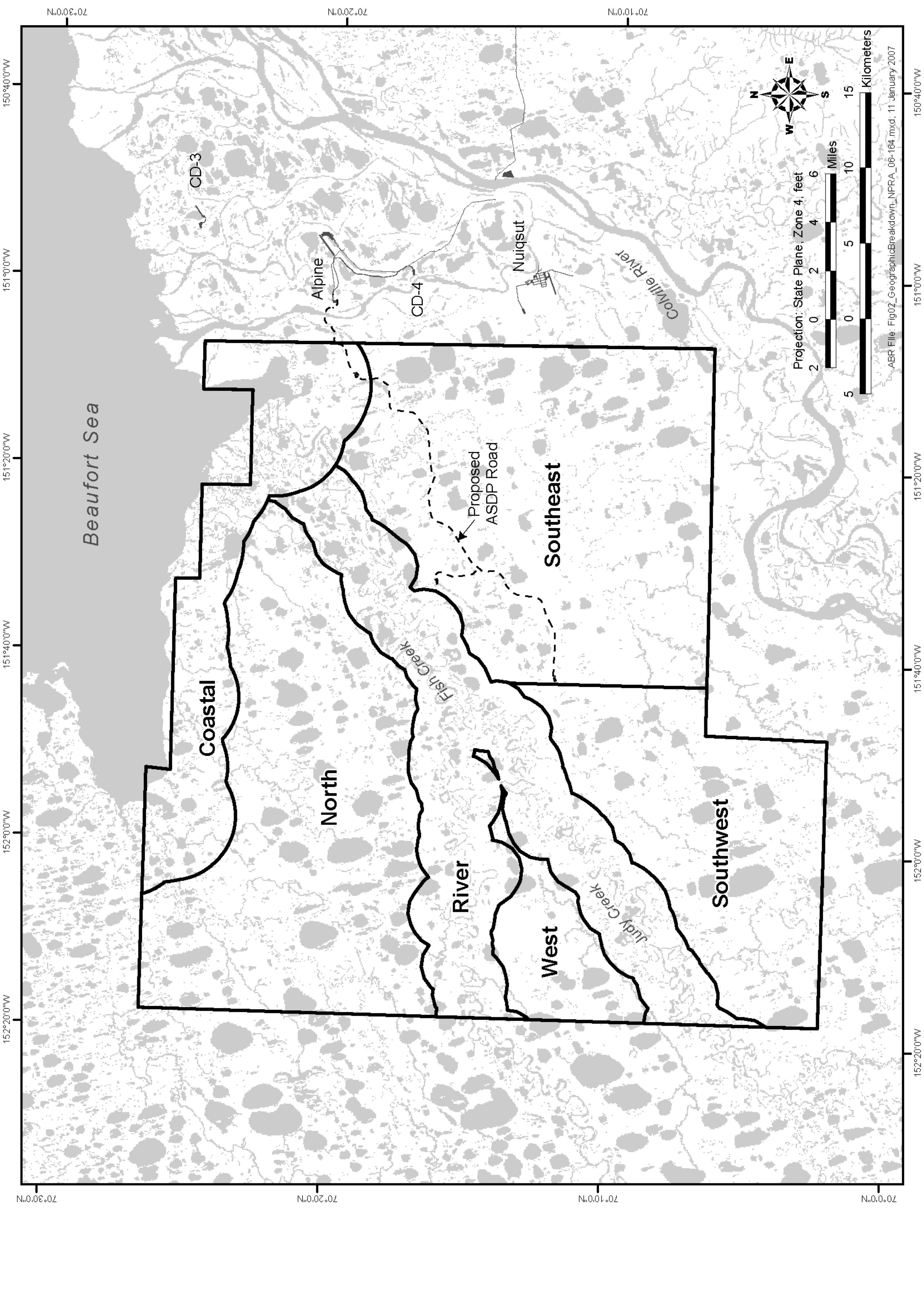

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2006.

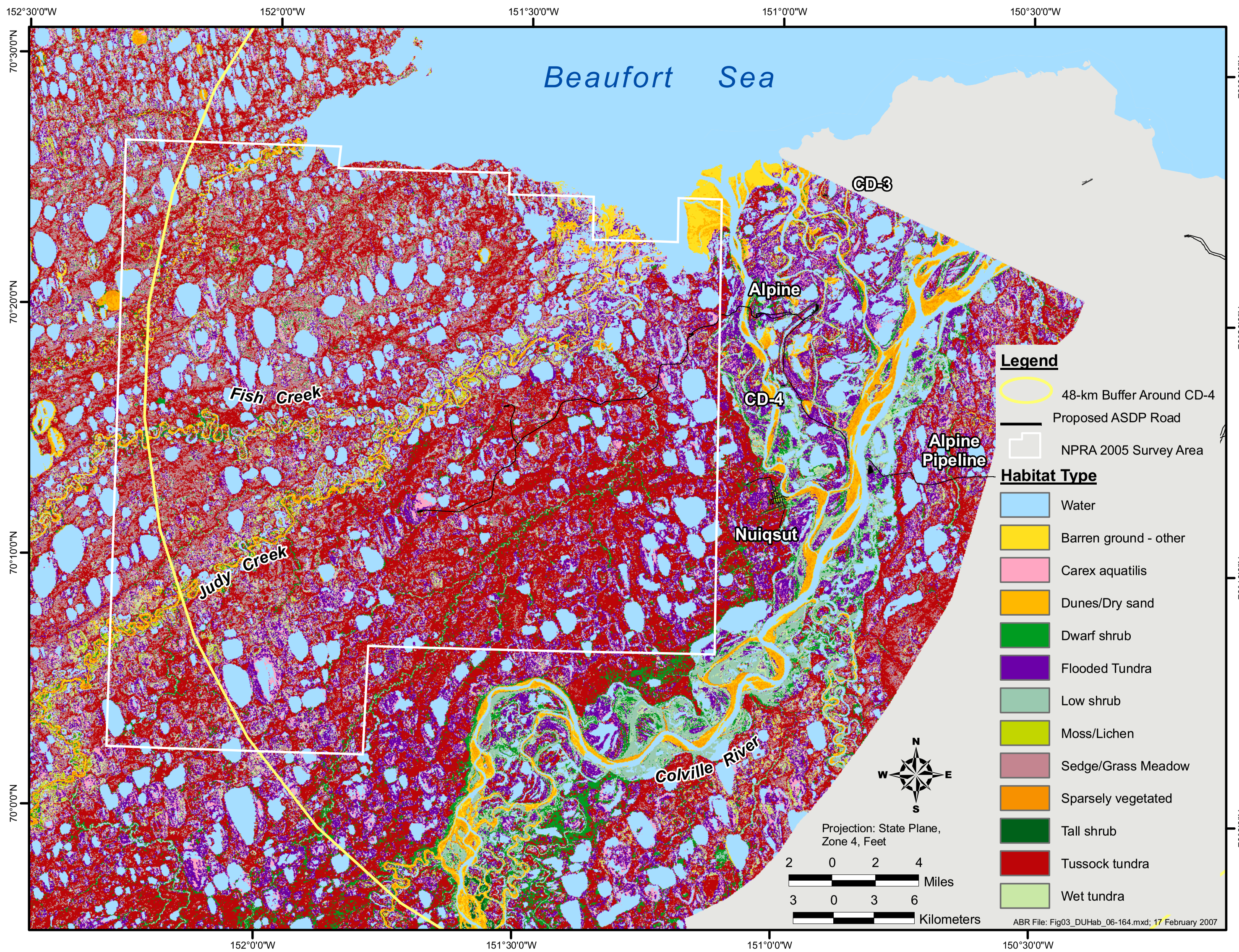

Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2006.

turbid-water, and *Arctophila fulva* classes were combined into a single water class and the 2 different flooded-tundra classes also were combined. For analysis of habitat use, the barren ground/other, dunes/dry sand, and sparsely vegetated classes all were combined into a single "riverine" class; the 3 component classes were found largely along Fish and Judy creeks.

The use of habitat types by caribou was calculated by selecting all pixels within a 100-m radius of the location coordinates for each group, thereby adjusting the percentage to reflect the positional accuracy of the location. We calculated the percentage of each of the habitat types (excluding water) within the selected pixels. Water was treated separately to calculate the proportion of terrestrial habitat used. The mean proportion of each habitat type used in each season then was calculated by taking the mean of all estimated proportions for all groups.

To test whether the observed proportions of habitat use differed significantly from availability, 10,000 random locations were created within the 2005–2006 NPRA survey area using *ArcView 3.2a* GIS software. Locations in lakes were removed, leaving a total of 8268 random locations (6424 in the 2002–2004 survey area). A 100-m-radius buffer was created around each random location and the proportion of each habitat type was calculated. A number of random locations equal to the number of caribou groups observed during the time period of interest were selected randomly (with replacement) and the mean proportion of each habitat type in those locations was calculated. This process was repeated 5000 times. If the proportion of a habitat type for a caribou group location was more extreme than the average of 95% of resampled random locations, we concluded that the observed proportion was significantly different from random at $P = 0.05$.

SNOW COVER

In 2005, caribou group locations were examined in relation to snow cover classes during the calving period (Lawhead et al. 2006). In 2006, however, persistent cloudy weather limited the satellite imagery available to estimate snow melt during calving. We were able to estimate the snow-cover fraction for most of the study area on 24 May and 9 June (see Results and Discussion, below). On 24 May, snow cover in the NPRA survey area was nearly complete (mean 99.5% snow cover), with measurable snow melt only occurring along Fish and Judy creeks. By 9 June, almost all snow was gone from the NPRA survey area (mean 5.7% snow cover) and snow and ice remained only on lakes and where topographic features such as drainages or banks had caused snow drifts. Consequently, the lack of suitable satellite imagery available during the time of snow melt precluded analysis of caribou distribution in relation to snow cover.

VEGETATIVE BIOMASS

We compared caribou group locations in the NPRA survey area in 2006 with estimated vegetative biomass (NDVI values). The values of the variables NDVI_calving, NDVI_621, NDVI_rate, and NDVI_peak were determined for the area within 100 m of each caribou group location (not including pixels with >50% water) and those values were compared with availability using bootstrap estimates. For each season, random samples of NDVI values equal to the number of caribou observed were selected with replacement from all pixels used by caribou during that time period. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 5000 times to generate mean values. The resulting 5000 mean values were compared with the availability of NDVI values in the survey area. If the mean NDVI value of all pixels within the survey area was more extreme than 5% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$.

DISTANCE TO PROPOSED ROAD

The group locations from aerial transect surveys in the NPRA survey area constitute the baseline data set on caribou density for the area in which the proposed ASDP road may be constructed. Thus, these data are the primary source of information regarding caribou distribution, including attraction and avoidance, in relation to natural factors in the road corridor.

The number of groups and the density of caribou by year and season were calculated within 5 distance-to-road zones: 0–2 km from the road, 2–4 km north or south of the road, and 4–6 km north or south of the road. All areas within 6 km of existing roads (the Alpine infield road between CD-1 and CD-2) were removed to ensure that they did not influence the results. We calculated the number of groups and the caribou density in each zone for each combination of year and season, then used a chi-square goodness-of-fit test to determine if the observed number of groups in each category differed significantly from expected values, assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual distance categories were compared using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984).

A repeated-measure analysis (*SPSS* version 13.0 software, SPSS Inc., Chicago, IL) was used to test for differences in annual density among the different distance zones, with zone as a within-subject effect and season as a between-subject effect. Simple contrasts were used to determine if density in any of the 2–4-km or 4–6-km zones differed significantly from the 0–2-km zone containing the proposed road alignment. We used Tukey's post-hoc multiple-comparison test for significant differences among seasons. A natural-log transformation (*ln* [*density +1/6*]) was applied to the density data to better meet the assumptions of normality required for parametric statistical testing (Mosteller and Tukey 1977). The single survey in the 2005 oestrid-fly season was removed from the analysis to eliminate the undue influence on the test results that would have resulted from the large groups observed on that survey.

CARIBOU DENSITY ANALYSIS

To test the effects of multiple independent variables on the density of caribou in the NPRA survey area, the transect strips in the 2002–2004 and 2005–2006 NPRA survey areas were subdivided into 124 and 164 grid cells, respectively. Each grid cell was 1.6-km wide by 3.2- or 4.8-km long, depending on the transect length (Figure 4). Within each cell we calculated the caribou density by season, mean NDVI values from 2005 and 2006, proportion of tussock-tundra habitat (as a proportion of land area), proportion of wet habitat (a combination of the *Carex aquatilis*, flooded tundra, wet tundra, and sedge/grass meadow classes as a proportion of land area), distance from the Beaufort Sea coast (km), transect number (a measure of a west-to-east density gradient), presence or absence of Fish or Judy Creek, and presence or absence of the proposed ASDP road corridor.

A natural-log transformation (*ln* [*density + 1/6*]) was applied to density data to better meet the assumptions of normality. The spatial pattern of NDVI_peak was assumed to be similar across years (Lawhead et al. 2004), so we used NDVI_peak in 2005 in multi-year analyses. Other measures of NDVI_rate and NDVI_peak from 2006 were used only in analyses of calving densities in 2006.

We tested various models for calving density in 2006 and the density for each season for the years 2002–2006 combined. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than those covered in subsequent years. A series of models (analysis of covariance, or ANCOVA; Neter et al. 1990) was used to determine which factors had a significant relationship with caribou density. We used an information-theoretic approach (Burnham and Anderson 1998, Anderson et al. 2000) to compare a predetermined set of candidate models with different combinations of independent variables. We calculated Akaike Information Criteria with the adjustment for small sample size (AIC_c) and used the Akaike weights (Burnham and Anderson 1998, Anderson et al. 2000) to estimate the relative probability of each model being the most parsimonious model in the candidate set. We then calculated the model-averaged parameter estimates and standard error (SE) by calculating the mean of the estimated parameter values for each model containing the variable of interest, while weighting the average by the Akaike weight (Burnham and Anderson 1998). These model-averaged parameter estimates and standard errors are preferred over model-specific parameters because they incorporate estimates from all possible models and take into account the uncertainty in choosing the best model. Therefore, it is not necessary to base results on a single "best" model.

The presence of Fish and Judy creeks and of the proposed road were included in all 19 candidate models for calving density in 2006. The different models had various combinations of NDVI_peak,

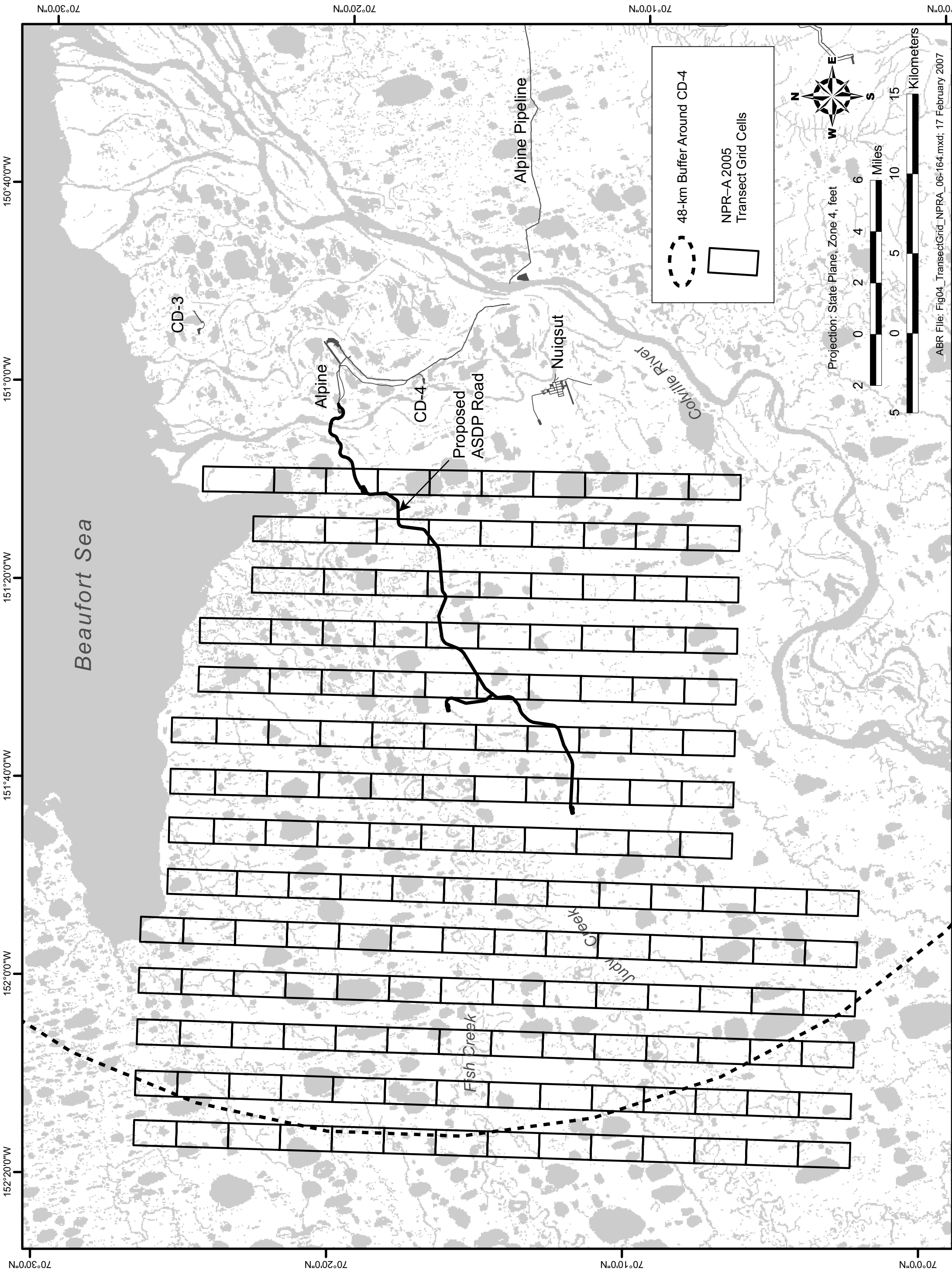

Figure 4. Locations of transect grid-cells ($n = 164$) used to analyze caribou density in the NPRA survey area, 2005–2006.

NDVI_rate, distance to coast, transect number (west–east gradient), proportion of tussock tundra, and proportion of wet habitat. Independent variables with Pearson correlations greater than 0.5 were not included in the same model. NDVI_621 was excluded because it was highly correlated with NDVI_peak, so the latter variable was used instead. We removed one grid cell located on the Colville River delta because it contained very little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

A total of 15 candidate models were used for seasonal tests over all years (2002–2006) combined. For these models, the year-specific variables (snow-cover fraction and NDVI_rate) were dropped and the distance-to-coast variable was added; only those grid cells that were surveyed in all 4 years (n = 124) were included.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

The timing of snow melt and the severity of insect seasons varied considerably during the years in which aerial surveys were conducted in the ASDP study area (Appendix B). The timing of snow melt was delayed in 2001, advanced in 2002, and about average in 2003–2006. Although snow-melt timing was near average in 2006, air temperatures were unusually high in early June and snow disappeared rapidly. Based on visual estimates during aerial surveys, snow cover was ~50% in the area between the Colville and Kuparuk rivers on 2 June, the estimated peak of calving (S. Arthur, ADFG, pers. comm.), when the first calving surveys began in the Kuparuk oilfield area (Lawhead and Prichard 2007). Additional snow fell overnight on 2–3 June and snow cover remained patchy through the end of the first round of calving surveys on 5 June. By the second round of calving surveys during 9–12 June, snow remained only in isolated patches on frozen lake surfaces or as narrow linear drifts along lakeshores, banks, and drainages (Lawhead and Prichard 2007).

June temperatures in 2006 were the highest recorded during the 1983–2006 period of record at the Kuparuk airstrip (as measured by the sum of cumulative thawing-degree days; Appendix B). Temperatures were slightly below average in early July but increased again to the highest on record in late July. Temperatures in early August were slightly below average. The 2006 insect season had favorable conditions for insect activity in the last week of June and the second half of July, but cool temperatures and moderate winds in the first half of July depressed insect activity (Lawhead and Prichard 2007).

Weather conditions can exert strong effects on caribou population dynamics. Deep winter snow and icing events increase the difficulty of travel, decrease forage availability, and increase susceptibility to predation (Fancy and White 1985, Griffith et al. 2002). Severe cold and wind events also can kill caribou directly (Dau 2005). Late melting of snow cover can delay spring migration and cause lower calf survival (Griffith et al. 2002, Carroll et al. 2005) and decrease future reproductive success (Finstad and Prichard 2000). In contrast, hot summer weather can depress weight gain and subsequent reproductive success by increasing insect harassment at an energetically stressful time of year, especially for lactating females (Fancy 1986, Cameron et al. 1993, Russell et al. 1993, Weladji et al. 2003).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

Eight surveys of the NPRA survey area were flown between 3 May and 10 October 2006 (Table 2, Figure 5). The estimated density of caribou ranged from a high of 0.60 caribou/km² on 19 June to a low of 0 only a week later on 26 June (Table 2), illustrating the profound effect of mosquito harassment (which began during 22–25 June) on caribou movements. The density of caribou during calving (0.34 caribou/km²) in the NPRA survey area was essentially identical to early May (0.33 caribou/km²; Table 2), underscoring the relatively low use of the area for calving. The density during calving in 2006 was within the range of 0.15–0.66 caribou/km² (June 6–9) observed in the NPRA

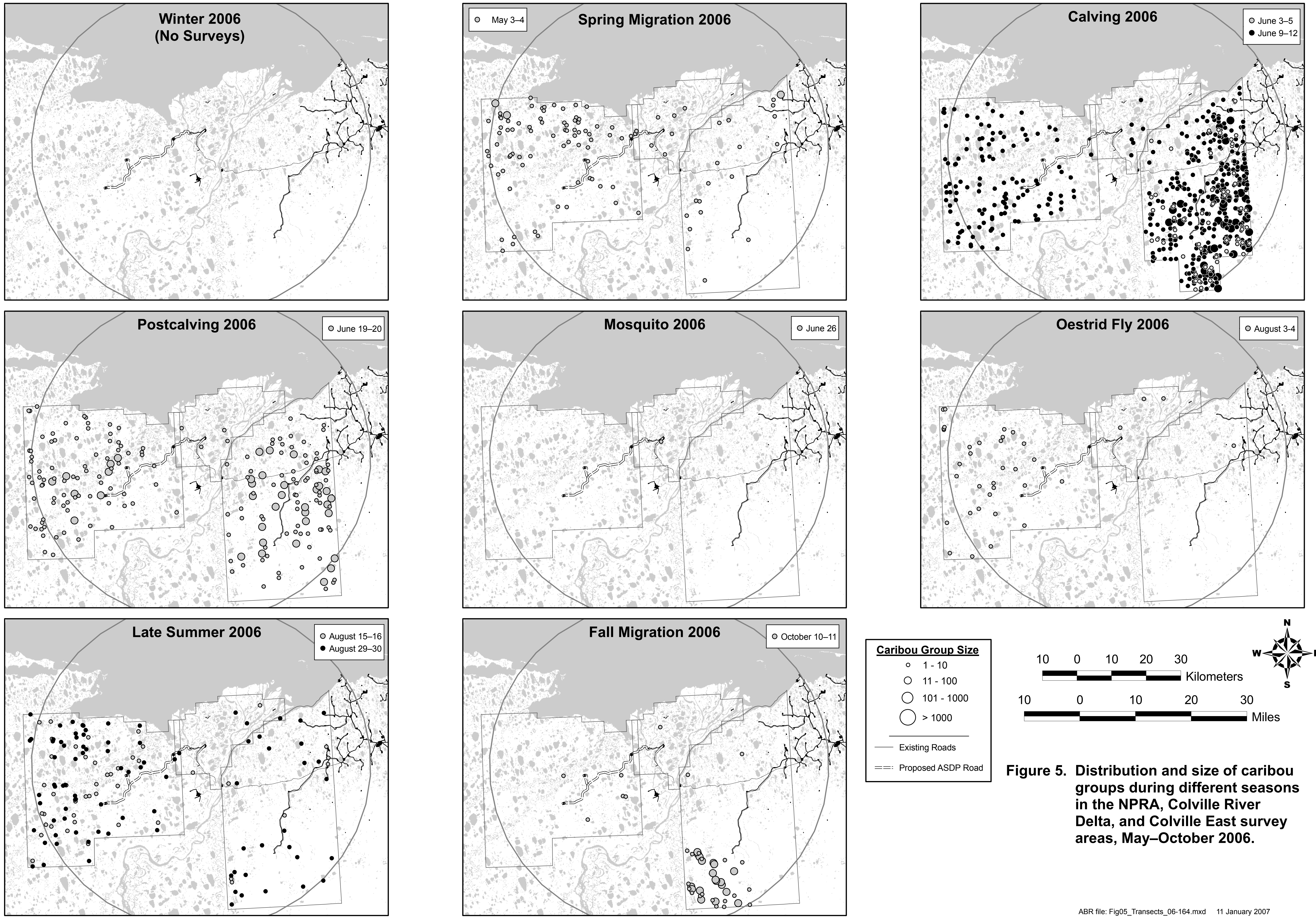

Figure 5. Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2006.

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Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2006.

Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1720 km²) [f]							
May 3	288	0	288	576	74.1	0.33	3.6
June 9	275	21	296	592	76.6	0.34	2.5
June 19	440	75	515	1030	169.9	0.60	5.9
June 26	0	0	0	0	–	0	–
August 4	35	1	36	72	15.4	0.04	1.1
August 15	36	2	38	76	10.7	0.04	1.1
August 30	122	4	126	262	35.9	0.15	2.2
October 10 [f]	11	nr	11	22	12.7	0.01	2.2
COLVILLE R. DELTA (494 km²) [f]							
May 3	16	0	16	32	9.2	0.06	2.3
June 9	13	1	14	28	14.6	0.06	2.3
June 19	10	0	10	20	11.2	0.04	2.5
June 26	1	0	1	2	1.4	<0.01	1.0
August 3	3	0	3	6	2.2	0.01	1.0
August 15	3	0	3	6	3.0	0.01	1.5
August 29	7	0	7	14	4.7	0.03	1.4
October 10 [f]	1	nr	1	2	1.4	<0.01	1.0
COLVILLE EAST (1696 km²) [f]							
May 3–4	49	0	49	98	19.9	0.06	2.6
June 3–5 [g,h]	91	14	105	395	84.8	0.28	1.8
June 11–12 [h]	1517	511	2028	4056	309.2	2.83	6.4
June 20	998	208	1206	2412	398.2	1.42	11.9
June 26–27	0	0	0	0	–	0	–
August 3	1	0	1	2	1.4	<0.01	1
August 15–16	7	0	7	14	5.6	0.01	1
August 29	60	3	63	126	18.0	0.07	2.6
October 11 [f]	593	nr	593	1186	335.9	0.70	15.2

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage) or × 4 (for 25% sampling coverage).
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (860 km² were surveyed in NPRA, 247 km² on the Colville R. Delta, and 848 km² in Colville East).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).
[h] Survey of calving-season transects (1.6-km-spacing) at 90-m altitude for 50% coverage; SE calculated based on 3.2-km-long transect segments (Lawhead and Prichard 2006).

survey area during 2001–2005 (no calving survey was conducted in 2004).

Densities were low (0.01–0.15 caribou/km²) during all subsequent NPRA surveys in 2006. Unlike 2005 (Lawhead et al. 2006), we did not observe large mosquito-harassed groups along the coast during aerial surveys in 2006, although no surveys were conducted in July when mosquito and oestrid fly harassment is most severe. During insect season, transect surveys produce unpredictable results due to the rapid movements by caribou across broad areas in response to fluctuating insect activity levels. Radio-telemetry data provided better information on movements during the insect season, indicating that large groups moved into the NPRA survey area in mid-July 2006. Three GPS-collared caribou and 17 satellite-collared caribou were in the northwestern section of the NPRA survey area during 12–16 July 2006. The large groups that form in response to mosquito harassment result in high variability among surveys during the insect season and large numbers of caribou may occur occasionally in the survey area for short periods of time. Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (1.2–3.5 caribou/km² annual maxima during 2001–2005), although relatively high densities have been recorded occasionally in late winter (2.4 caribou/km² in April 2003) and postcalving (1.5 caribou/km² in late June 2001) (Appendices C–G).

Annual surveys of the NPRA survey area since 2001 demonstrate that it is not a high-density calving area, in contrast to the Colville East survey area (Appendices C–H; Lawhead and Prichard 2007). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area. Although a few CAH caribou have been reported to calve west of the Colville River in certain years (most notably 2001), it is a rare occurrence (Lenart 2003, Arthur and Del Vecchio 2004).

Other Mammals

During aerial surveys in the NPRA survey area in 2006, a group of muskoxen was recorded repeatedly west of the Fish Creek delta near the Tingmeachsiovik River and once near the mouth of the Kalikpik River (Appendix I). The size of that group varied between 13 and 23 muskoxen and included up to 10 calves. A female in the group was ear-tagged in ANWR in 1995 and has been seen previously on the Colville River delta and in northeastern NPRA (G. Carroll, ADFG, pers. comm.). A group of 8–18 muskoxen also was observed repeatedly near the Kalikpik River in 2005 (Lawhead et al. 2006). Previously, muskoxen were observed in our NPRA survey area only in June 2001 (Burgess et al. 2002), although the species occurs regularly on the Colville River delta and adjacent coastal plain to the east (Johnson et al. 1998, 2004; Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Groups of grizzly bears were recorded on 4 different occasions in the NPRA survey area in 2006 (Appendix I). One observation was of 2 adults and the other 3 observations were of a sow with 2 cubs. Observations of muskoxen and grizzly bears on the Colville delta and east of the Colville River in 2006 were reported by Lawhead and Prichard (2007). No moose were observed in any of three survey areas in 2006; a few moose have been seen in the area sporadically in previous years (Lawhead et al. 2006).

Colville River Delta Survey Area

Eight surveys of the Colville River Delta survey area were flown between 3 May and 10 October 2006 (Table 2, Figure 5). The estimated density of caribou was low during all surveys (<0.01–0.06 caribou/km²) and the maximal estimate was 32 caribou (0.06 caribou/km²) on 3 May. Large groups of caribou occasionally move onto the Colville delta, primarily during times of mosquito harassment; the highest number recorded on transect surveys of the delta during 2001–2006 (Appendices C–G) occurred on 2 August 2005, when 994 caribou were found on the Colville delta (2.01 caribou/km²; Appendix G). The calving survey conducted on 9 June 2006 was consistent with survey results in previous years, which found very low numbers of caribou during the calving season on the Colville delta.

Telemetry data provided little evidence of large-scale use of the Colville delta by caribou in 2006. Four GPS-collared CAH caribou moved onto the northeastern corner of the delta near the mouth of the main channel on 14–15 July and 3 different GPS-collared CAH caribou were in the same area during 1–5 August. These numbers suggest that up to several hundred, and possibly a few thousand, caribou may have been present at those times, although our survey on 3 August found very few caribou. Another GPS-collared CAH caribou used the central delta during much of September 2006. Only 2 satellite-collared TH caribou occurred on the Colville delta in 2006, when a bull and a cow crossed the delta in late June while heading west toward Teshekpuk Lake. No GPS-collared TH caribou occurred on the delta in 2006.

Large numbers of caribou have been recorded on the delta during past summers (such as 1992 and 1996) as large aggregations moved onto or across the delta during or after periods of insect harassment (Johnson et al. 1998, Lawhead and Prichard 2002). The most notable such instance in recent years was a large-scale westward movement onto the delta by at least 10,700 CAH caribou in the third week of July 2001, ~6000 of which continued across the delta into northeastern NPRA (Lawhead and Prichard 2002, Arthur and Del Vecchio 2004) and moved west through the area of the proposed ASDP road.

Colville East Survey Area

Eleven surveys of the Colville East survey area were flown between 3 May and 10 October 2006. The estimated density of caribou ranged from a high of 2.8 caribou/km² during calving on 11–12 June to a low of zero on 26–27 June, after mosquito harassment began. The density was low in early May, increased to a relatively high peak during calving, and then decreased during the 2 postcalving surveys (Table 2). No surveys were conducted in July, but telemetry data indicated transitory use by large numbers of caribou in the northern portion of the survey area in mid-July (see below). Density was low on the 3 surveys in August and increased by mid-October (Table 2), when large numbers of TH caribou were migrating through the southwestern corner of the Colville East survey area. A similar fall migration movement of TH caribou through the southern Colville East survey area was recorded on 19 October 2004 (Appendix F; Lawhead and Prichard 2005).

The 11–12 June calving density was within the range of previous calving surveys in the area. Although the Kuparuk South area typically has higher densities of calving caribou, the Colville East survey area consistently has relatively high calving densities (Appendix H); in 2004 and 2005, calving densities were higher there than in the Kuparuk South survey area (Lawhead and Prichard 2005, 2006, 2007). This area also may have high densities of caribou during postcalving as CAH caribou move northward prior to mosquito emergence (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007). Inland portions of the Colville East survey area often are used during the insect season when cooler weather depresses insect activity and caribou move south away from the coast.

RADIO TELEMETRY

Mapping of the telemetry data from VHF, satellite, and GPS collars clearly shows that the ASDP study area is at the interface of the TH and CAH annual ranges (Figure 6; GPS collar movements for the CAH sample are not depicted in this figure because they were available only inside the ASDP study area). The majority of collar locations for the TH and CAH were west and east of the center of the CD-4 study area, respectively. In addition to the summary maps, the monthly proportion of the collared sample from each herd within the ASDP study area was quantified to characterize the pattern of occurrence by each herd (Table 3). Although it is not warranted to consider each collared caribou as representing a certain number of unmarked caribou in the herds, the monthly percentages provide reasonable estimates of the relative abundance of each herd in the study area throughout the year.

VHF Collars

Interpretation of VHF telemetry data is limited by the fact that the locations of collared individuals are restricted by the number, location, and timing of tracking flights. Therefore, the distribution of collars on each flight is a snapshot that allows only general conclusions to be drawn

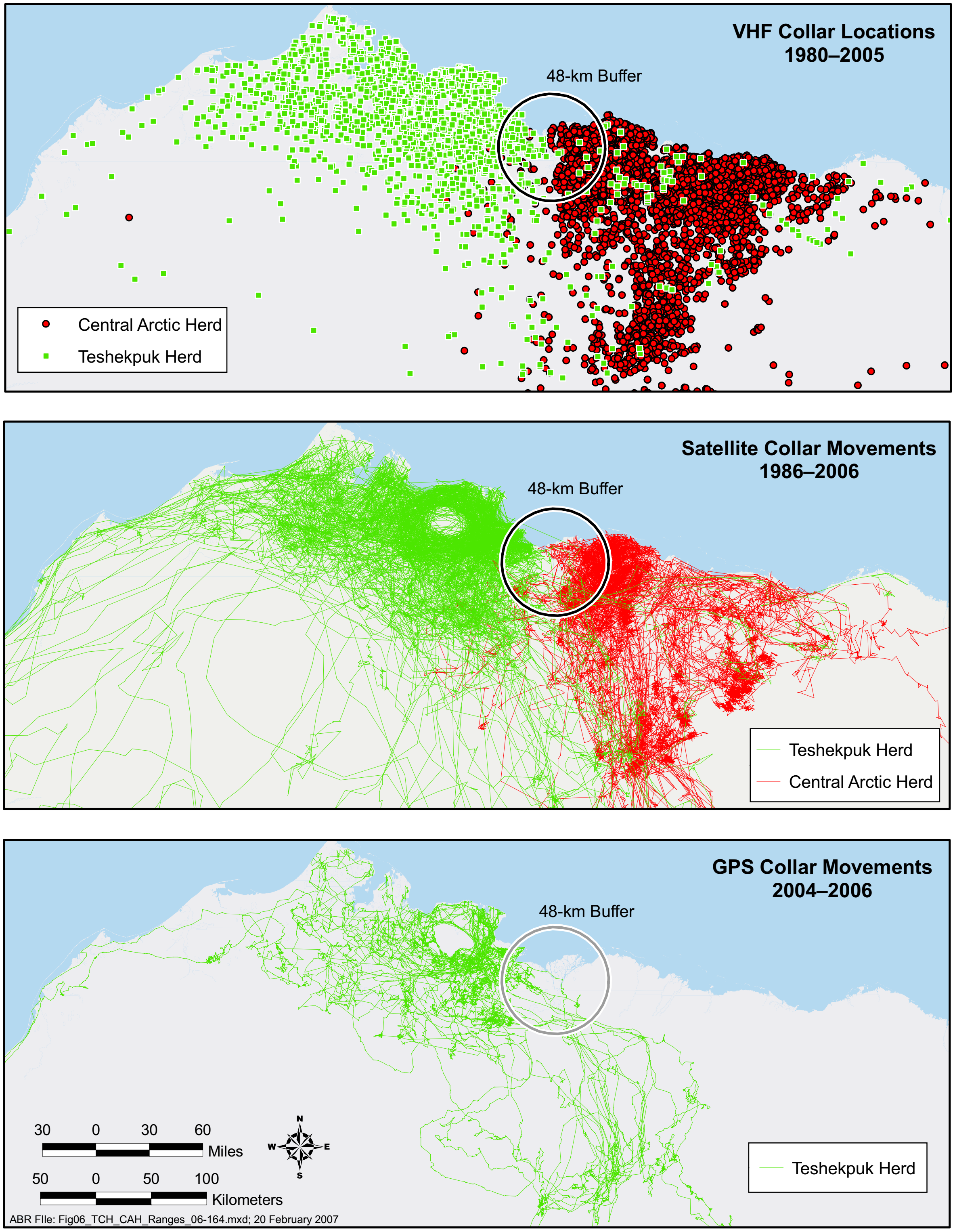

Figure 6. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2006.

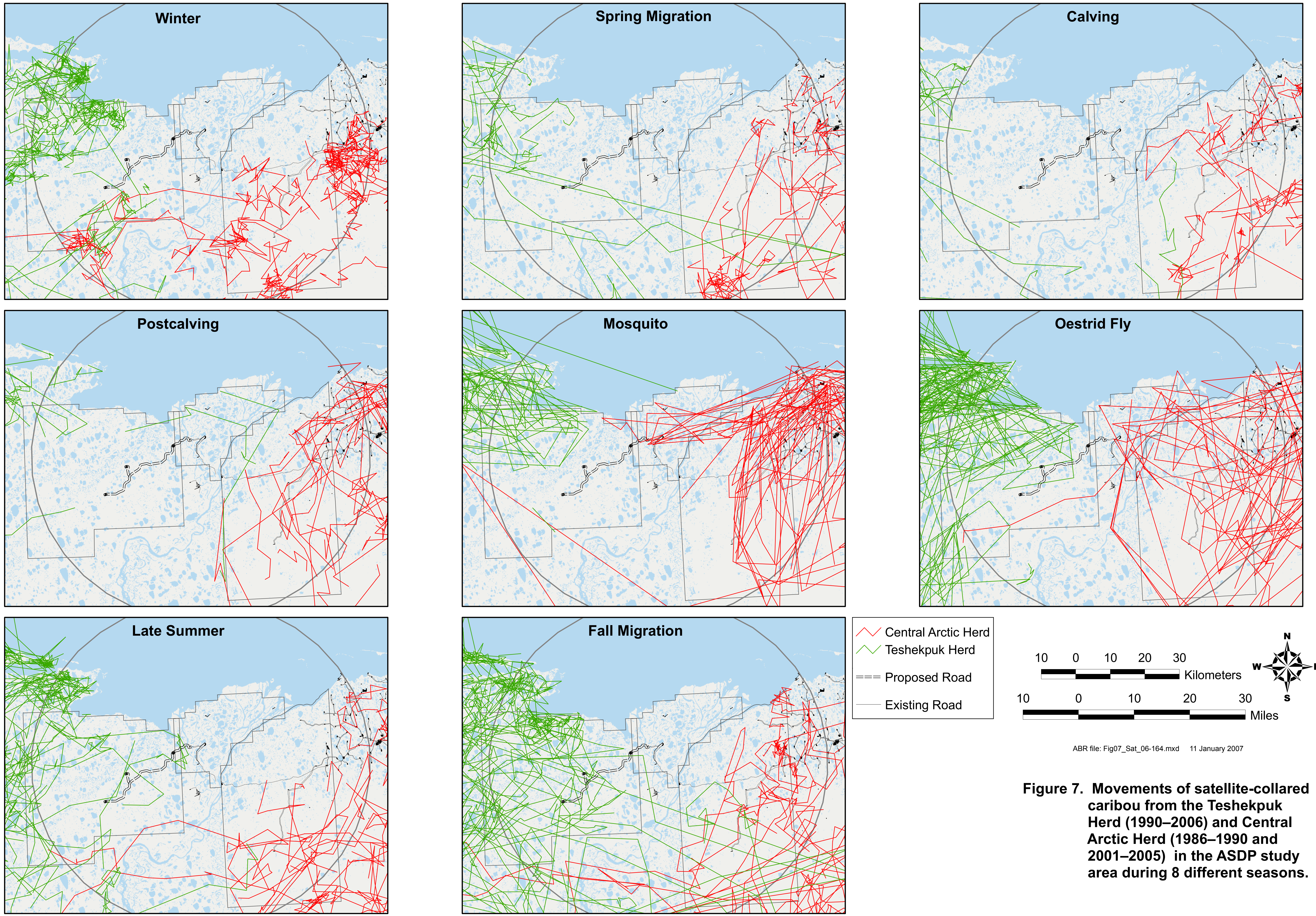

Figure 7. Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2006) and Central Arctic Herd (1986–1990 and 2001–2005) in the ASDP study area during 8 different seasons.

regarding caribou in the area surveyed and movements between successive flights. Previous VHF collar locations were discussed by Lawhead et al. (2006); no new VHF data were available for the 2006 season.

Satellite Collars

The percentage of satellite-collared TH animals (with at least 5 active duty cycles per month) by month in the ASDP study area varied between 9% and 27% of the total collared samples during 1990–2006 (*n* = 96–163; Table 3). The highest percentages occurred in July, August, and October, and the lowest percentages in June and February (Table 3, Figure 7). The monthly percentages varied substantially (0 to 80%) within years, largely due to small samples of collared animals in most years.

Satellite telemetry indicated more use of the ASDP study area by CAH caribou than by TH animals, although virtually all of that use occurred east of the Colville River and not in the area of CD-4 or the other ASDP facilities (Figure 7). The percentage of satellite-collared CAH caribou in the study area ranged from 12% to 62% of the total collared sample among months during 1986–1990 and 2001–2005 combined (*n* = 42–57; Table 3). The highest occurrence of collared CAH caribou was in June and July (51–62%) and the lowest was during October–February (12–18%) (Table 3, Figure 7). As with the TH sample, the monthly percentages varied substantially (0–89%) within years, at least in part due to small samples of collared animals. The number of collared animals using the ASDP study area during the winter months appeared to be higher during 1986–1990 than during 2001– 2005 (Table 3). This difference in winter use may have been affected by the timing and location of collaring, but that information was not available for this analysis. The bulk of available data show that CAH caribou normally move far inland to the foothills and mountains of the Brooks Range during winter.

No satellite-collared TH animal crossed the alignment of the proposed ASDP road during January–August 2006 (no data were available after August). No satellite-collared CAH crossed the proposed road alignment in any year (1986–1990 and 2001–2005), although several collared individuals moved through the vicinity of the Alpine project facilities in July 1989, 9 years before construction began.

Use of the Colville River delta by satellite-collared caribou peaked during the summer insect season (mosquito and oestrid-fly periods, late June to early August) (Figure 7). This timing indicates that the animals harvested on the Colville delta by subsistence hunters from Nuiqsut at that time were from the CAH rather than the TH, whereas caribou harvested in NPRA in October were much more likely to be TH animals migrating to winter range. The annual harvest of caribou by Nuiqsut hunters peaks during July–August and October (Pedersen 1995, Brower and Opie 1997, Fuller and George 1997); lower harvests in September may result from participation of many hunters in fall whaling activities.

GPS Collars

The percentages of the GPS-collared sample from the TH that were present at least once each month in the ASDP study area were similar to the results from satellite-collared caribou. Up to 10% (1 collar) of the sample of GPS-collared TH caribou was in the study area sometime between January and April (Table 4, Figure 8). The monthly percentages increased to 10–32% between May and September and peaked at 68% in October before declining to 14% during November and December. The percentages of the GPS-collared sample from the CAH that were present in the study area at least once during each month in 2003–2006 varied between 0 and 8% during the winter months of October–April (Table 4, Figure 8). The monthly percentage increased to 36% in May and peaked at 53% in June before decreasing to 12–29% in July through September.

The detailed movement tracks of the 12 individual TH caribou fitted with GPS collars in 2006 were examined in relation to the ASDP study area from July through December (Figures 9a and 9b). The area around Teshekpuk Lake was used extensively during the mosquito and oestrid fly seasons before the collared animals dispersed across the coastal plain later in the oestrid fly season and in late summer; several collared caribou moved very little in late summer. Movements increased substantially during fall migration as many TH caribou moved southeast in October. Some of those animals slowed and subsequently

Table 3. Percentage of satellite-collared caribou samples (*n*) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were within 48 km of CD-4 at least once in each month. Caribou with <5 active duty-cycles per month were excluded.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
TH	1990	–	–	–	–	–	–	50 (6)	17 (6)	33 (6)	0 (6)	0 (6)	0 (6)
	1991	0 (6)	0 (5)	0 (5)	0 (5)	20 (5)	33 (3)	67 (3)	67 (3)	33 (3)	50 (4)	50 (4)	0 (3)
	1992	0 (3)	0 (2)	33 (3)	50 (2)	50 (2)	33 (3)	25 (8)	33 (6)	33 (6)	33 (6)	67 (6)	67 (6)
	1993	80 (5)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	0 (6)	0 (5)	0 (5)	25 (4)	0 (3)	0 (3)
	1994	0 (3)	0 (3)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)	50 (2)	0 (2)	0 (1)	0 (1)	0 (1)
	1995	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	13 (8)	38 (8)	25 (8)	25 (8)	14 (7)	14 (7)
	1996	14 (7)	14 (7)	14 (7)	14 (7)	14 (7)	0 (7)	14 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (6)
	1997	0 (6)	0 (4)	0 (4)	0 (4)	0 (3)	0 (3)	0 (3)	–	0 (2)	0 (2)	0 (2)	0 (2)
	1998	0 (2)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	33 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	1999	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	33 (3)	–	0 (2)	0 (2)	0 (2)	0 (1)
	2000	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	67 (3)	0 (2)	0 (2)	0 (2)	–	0 (2)
	2001	0 (3)	0 (3)	0 (1)	0 (3)	0 (4)	25 (4)	0 (1)	9 (11)	0 (11)	9 (11)	9 (11)	9 (11)
	2002	9 (11)	10 (10)	9 (11)	9 (11)	17 (12)	9 (11)	10 (10)	11 (9)	12 (17)	13 (16)	8 (13)	0 (11)
	2003	8 (13)	18 (11)	40 (10)	20 (10)	18 (11)	9 (11)	0 (25)	27 (22)	27 (22)	18 (22)	11 (18)	6 (17)
	2004	6 (17)	8 (13)	7 (15)	7 (14)	13 (15)	0 (15)	0 (13)	8 (13)	17 (12)	73 (11)	45 (11)	40 (10)
	2005	38 (8)	25 (8)	29 (7)	25 (8)	38 (8)	0 (8)	35 (26)	64 (25)	29 (24)	35 (23)	23 (22)	18 (22)
	2006	18 (22)	18 (22)	14 (22)	9 (22)	27 (22)	14 (21)	58 (36)	6 (34)	–	–	–	–
	Total	13 (112)	11 (96)	14 (96)	10 (96)	18 (99)	9 (96)	27 (163)	23 (156)	18 (132)	23 (128)	18 (116)	14 (111)
CAH	1986	–	–	–	–	–	–	–	–	–	0 (3)	38 (8)	50 (8)
	1987	50 (8)	38 (8)	50 (8)	50 (8)	50 (8)	50 (8)	50 (8)	50 (8)	71 (7)	38 (8)	50 (8)	57 (7)
	1988	43 (7)	60 (5)	75 (4)	75 (4)	75 (4)	50 (4)	67 (6)	67 (6)	25 (4)	0 (6)	0 (5)	0 (5)
	1989	0 (4)	0 (4)	0 (4)	0 (4)	17 (6)	60 (5)	75 (8)	13 (8)	0 (7)	22 (9)	0 (7)	0 (7)
	1990	40 (5)	33 (6)	33 (6)	40 (5)	40 (5)	40 (5)	0 (1)	–	–	–	–	–
	2001	–	–	–	–	–	–	–	33 (9)	50 (8)	0 (10)	0 (10)	0 (10)
	2002	0 (10)	0 (9)	0 (9)	0 (9)	56 (9)	89 (9)	78 (9)	22 (9)	18 (11)	0 (11)	0 (11)	0 (11)
	2003	0 (11)	0 (9)	17 (6)	0 (6)	20 (5)	75 (4)	0 (4)	0 (3)	0 (3)	33 (6)	0 (6)	0 (6)
	2004	0 (5)	0 (6)	0 (6)	0 (6)	33 (6)	67 (6)	17 (6)	0 (5)	0 (2)	0 (2)	0 (2)	0 (1)
	2005	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	–	–	–
	Total	18 (51)	17 (48)	23 (44)	21 (43)	41 (44)	62 (42)	51 (43)	29 (49)	28 (43)	13 (55)	12 (57)	15 (55)

Table 4. Percentage of GPS-collared caribou samples (*n*) from the Teshekpuk and Central Arctic herds that were within 48 km of CD-4 at least once in each month.

Month	Teshekpuk Herd (by year)				Central Arctic Herd (by year)				
	2004	2005	2006	Total	2003	2004	2005	2006	Total
Jan.	–	10 (10)	–	10 (10)	–	0 (24)	0 (33)	0 (29)	0 (86)
Feb.	–	0 (10)	–	0 (10)	–	0 (24)	0 (33)	0 (29)	0 (86)
Mar.	–	0 (10)	–	0 (10)	–	0 (24)	0 (33)	0 (29)	0 (86)
Apr.	–	0 (10)	–	0 (10)	4 (24)	4 (24)	0 (33)	0 (29)	2 (110)
May	–	20 (10)	–	20 (10)	54 (24)	33 (24)	24 (33)	38 (29)	36 (110)
June	–	20 (10)	–	20 (10)	75 (24)	58 (24)	45 (33)	38 (29)	53 (110)
July	10 (10)	–	50 (12)	32 (22)	8 (24)	13 (24)	33 (33)	55 (29)	29 (110)
Aug.	20 (10)	–	8 (12)	14 (22)	13 (24)	4 (24)	27 (33)	0 (29)	12 (110)
Sep.	20 (10)	–	0 (12)	9 (22)	21 (24)	42 (24)	21 (33)	34 (29)	29 (110)
Oct.	70 (10)	–	67 (12)	68 (22)	8 (24)	0 (24)	9 (33)	14 (29)	8 (110)
Nov.	30 (10)	–	0 (12)	14 (22)	0 (24)	0 (24)	–	–	0 (48)
Dec.	30 (10)	–	0 (12)	14 (22)	0 (24)	0 (24)	–	–	0 (48)
Total	90 (10)	30 (10)	75 (12)	–	79 (24)	75 (24)	58 (33)	69 (29)	69 (110)

returned west, whereas others continued southeast to winter in the Brooks Range foothills in the range of the CAH. The 12 GPS-collared TH caribou used the margins of the ASDP study area in 2006. GPS-collared caribou moved into the northwestern corner of the ASDP study area during 12–16 July and also traversed the southern edge of the study area around 8–9 October when large numbers of TH caribou crossed the Colville River to the east during fall migration. Individual movements of these 12 caribou are summarized below.

Caribou 0616 — This adult cow was collared east of Teshekpuk Lake on 8 July 2006 and traveled to the area east of Admiralty Bay in late July. It moved generally southeast throughout the late summer and fall and was located ~20 km south of the study area at the end of the year. It did not enter the ASDP study area during 2006.

Caribou 0617— This adult cow was collared east of Teshekpuk Lake on 10 July 2006 and also traveled to the area east of Admiralty Bay in late July before moving south of Teshekpuk Lake during August and September. It migrated southeast in October, passing through the southern portion of the study area. It reached the Dalton Highway near the upper Kuparuk River at the end of October and then returned to the northwest. It was along the Colville River at the end of the year.

Caribou 0618 — After this adult cow was collared near Teshekpuk Lake on 8 July 2006, it moved into the northwestern portion of the ASDP study area briefly in mid-July, then traveled to the area west of the Ikpikpuk River in late July. It spent the rest of the year west and south of the ASDP study area and west of the Colville River, reentering the ASDP study area briefly in early October.

Caribou 0619 — This 2-yr-old cow was collared west of the Ikpikpuk River on 9 July 2006. It used the lower Ikpikpuk and Meade river drainages until early fall. In early October it traveled southeast until it reached the Colville River, then followed the river south and west until late October. It crossed the Colville River near the mouth of the Killik River in late October and traveled east to the Anaktuvuk River where it remained through the end of the year. This animal did not enter the ASDP study area in 2006.

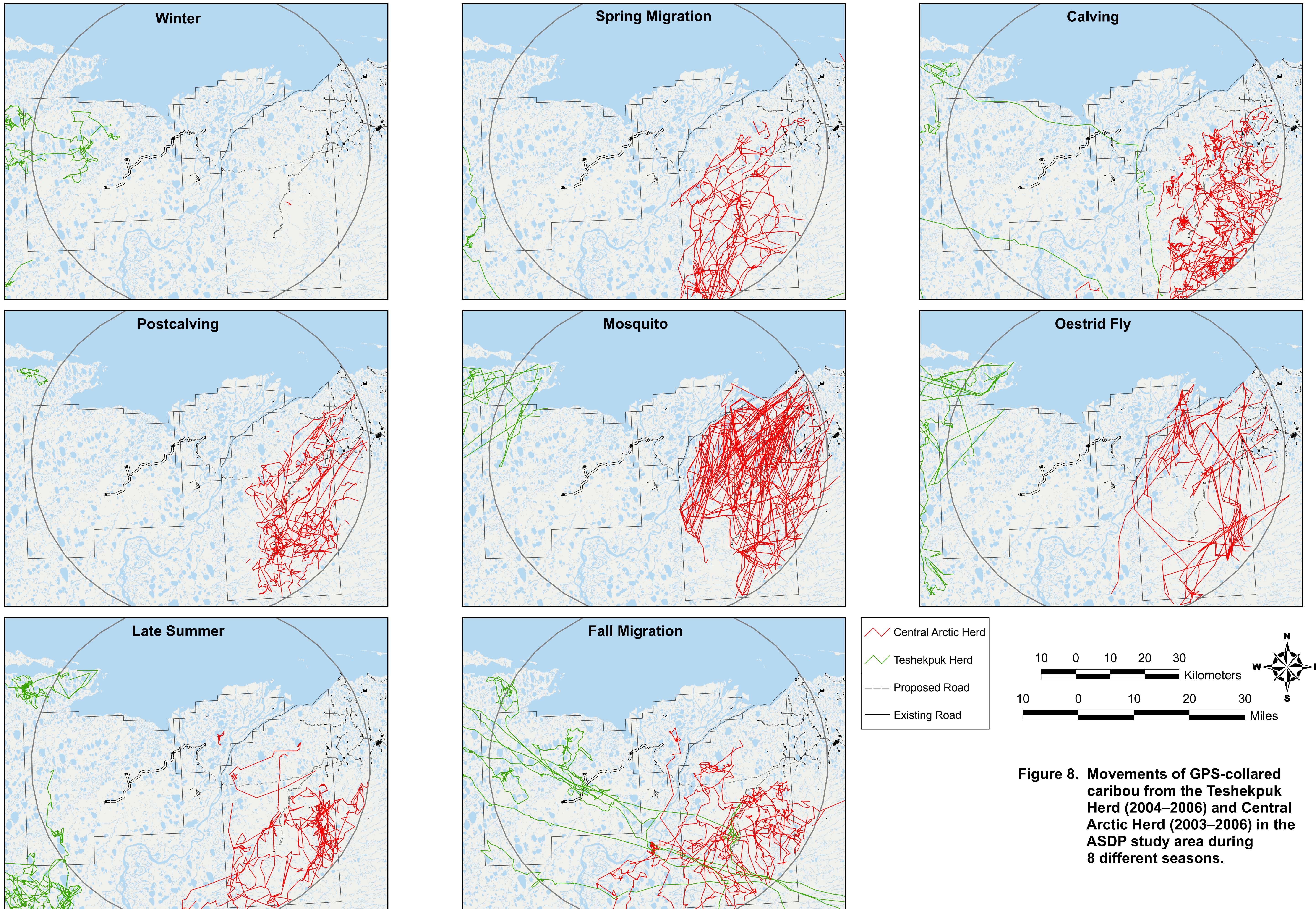

Figure 8. Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2006) and Central Arctic Herd (2003–2006) in the ASDP study area during 8 different seasons.

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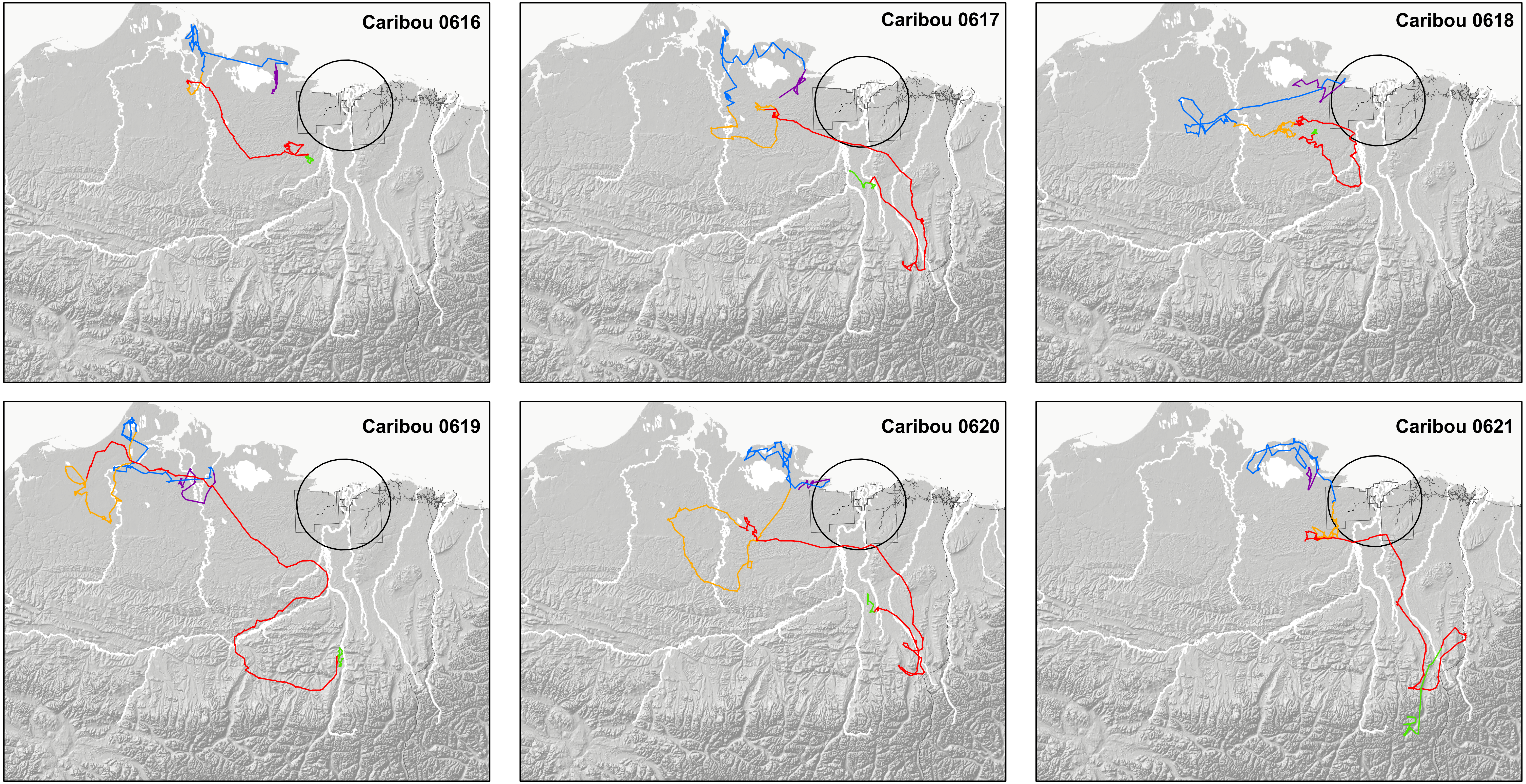

Season

Mosquito (July 9 – 15)
Oestrid Fly (July 16 – Aug 7)
Late Summer (Aug 8 – Sept 15)
Fall Migration (Sept 16 – Nov 29)
Early Winter (Dec 1 – 27)

Proposed Road
Existing Road
48-km Radius around CD-4

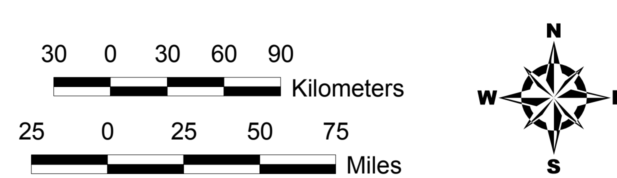

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Figure 9a. Movements of individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons in 2006.

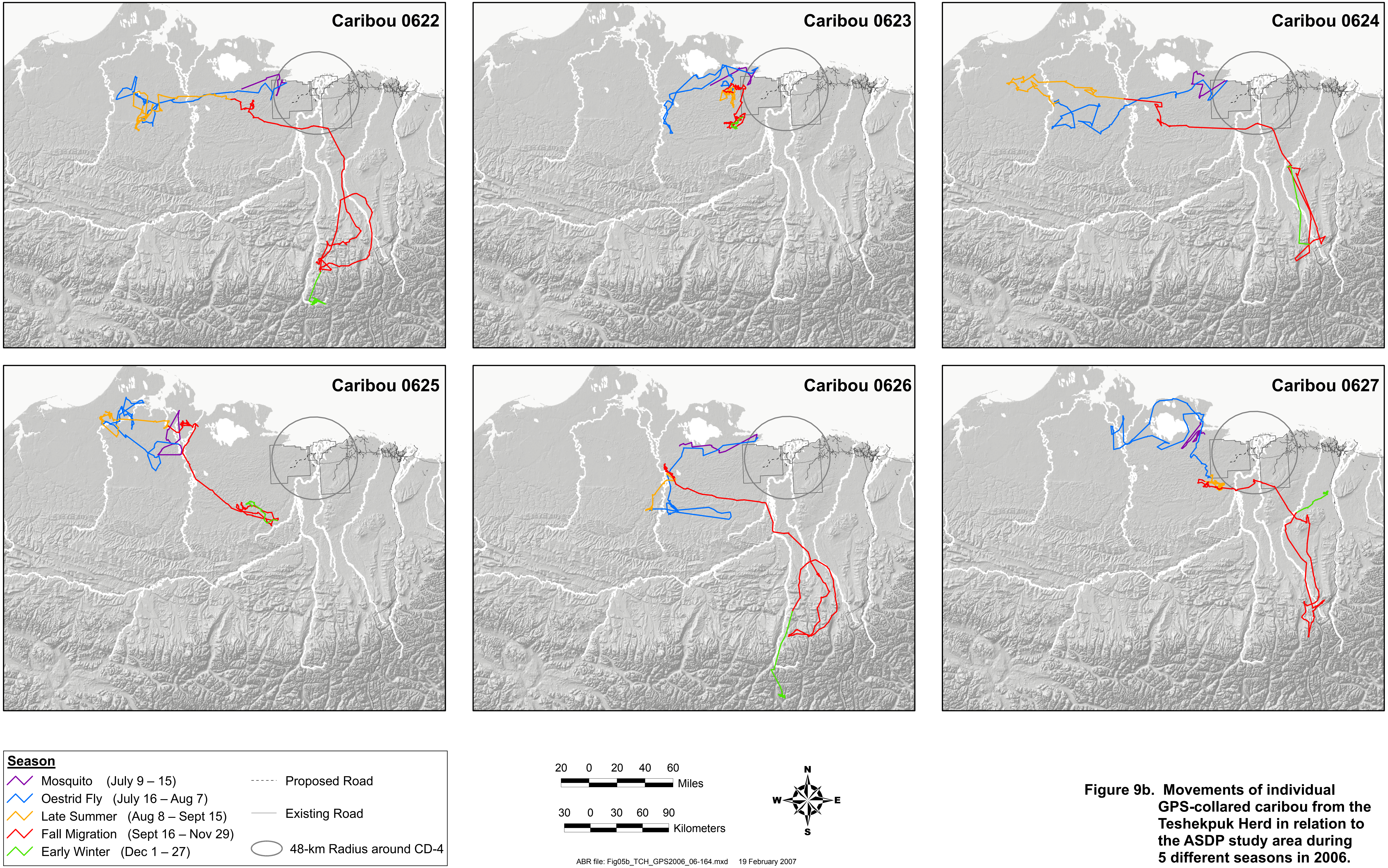


Figure 9b. Movements of individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons in 2006.

Caribou 0620 — After being collared east of Teshekpuk Lake on 9 July 2006, this adult cow remained north and east of Teshekpuk Lake for the rest of July, briefly entering the northwestern corner of the ASDP study area near the Kogru River in mid-July. It used the area south of Teshekpuk Lake in August and September. This caribou migrated east across the Colville River in October, briefly entering the southern edge of the study area in early October before continuing southeast. It reached the area near the Dalton Highway along the upper Kuparuk River by late October, then moved northwest slowly in November. In December it was along the Itkillik River.

Caribou 0621 — This yearling cow was collared east of Teshekpuk Lake on 9 July 2006 and remained north and east of Teshekpuk Lake for the rest of July, then crossed the west edge of the ASDP study area in mid-August. It remained southwest of the study area during late August and September, then crossed the southern edge of the study area in early October and moved southeast to the Dalton Highway near the upper Kuparuk River. It crossed the Dalton Highway and Sagavanirktok River to the east briefly in mid-November and recrossed to the west of the highway in late November. It was located east of Anaktuvuk Pass at the end of the year.

Caribou 0622 — An adult cow, this caribou was collared east of Teshekpuk Lake on 10 July 2006 and briefly moved into the western portion of the ASDP study area in mid-July. It moved west and spent the period from late July to mid-September between the Ikpikpuk and Meade rivers. Eastward migration in early October brought it across the southern edge of the ASDP study area. It used the area between the Dalton Highway and the Anaktuvuk River from late October through November and was near Anaktuvuk Pass at the end of the year.

Caribou 0623 — This 2-yr-old cow was collared near Teshekpuk Lake on 9 July 2006 and moved into the far western portion of the ASDP study area in mid-July, then moved west to the Ikpikpuk River by late July. It spent the rest of the year just west of the ASDP study area, briefly crossing the western edge of the study area in early October.

Caribou 0624 — This adult cow was collared near Teshekpuk Lake on 9 July 2006. It moved into the western edge of the ASDP study area in mid-July and then moved west of the Meade River by late August. In early October, it migrated east, traversing the southern portion of the ASDP study area and moving to the upper Kuparuk River drainage west of the Dalton Highway, where it remained through the end of the year.

Caribou 0625 — A yearling cow, this caribou was collared near the Ikpikpuk River on 9 July 2006 and remained in the area between the Ikpikpuk and Meade rivers until migrating in early October to the vicinity of the Kikiakrorak River, southwest of the ASDP study area. It did not enter the ASDP study area during 2006.

Caribou 0626 — This adult female was collared west of Teshekpuk Lake on 9 July 2006. It was briefly in the far western portion of the ASDP study area in mid July then moved to an area along the Ikpikpuk River in August and September. It moved east and south in October. It was between the upper Kuparuk River and the Anaktuvuk River for most of November and then moved south of Anaktuvuk Pass in December.

Caribou 0627 — A 2-yr-old cow, this caribou was collared east of Teshekpuk Lake on 9 July 2006 and remained in the Teshekpuk Lake area in July, then moved southwest of the ASDP study area in August and September. It migrated east in fall, traversing the southern portion of the ASDP study area in early October and traveling southeast to the upper Kuparuk River near the Dalton Highway by November. It crossed the Dalton Highway (but not the Trans-Alaska Pipeline) briefly in mid-November and subsequently traveled north. It was located ~5 km west of the Dalton Highway and ~50 km south of the Prudhoe Bay oilfield at the end of the year.

In contrast to the westerly distribution of the TH caribou, all of the GPS-collared CAH caribou remained east of the Colville River in 2006, making extensive movements through the Kuparuk oilfield and surrounding area during the mosquito and oestrid fly seasons. At least 4 different GPS-collared caribou briefly moved onto the northeastern corner of the Colville delta in mid-July, but no locations of GPS-collared CAH caribou were recorded within 9 km of CD-4 in 2006.

Telemetry Summary

The overall patterns of monthly occurrence by collared caribou show that the ASDP study area is used at low levels by the TH throughout most of the year, predominantly in the western half of the study area. The highest level of use by collared caribou occurred in the fall, the only season in which collared TH animals moved east of the Colville River. This pattern mirrors the results of aerial transect surveys (Table 2, Figure 5, Appendices C–G).

In contrast, the ASDP study area was used most extensively by CAH caribou during the calving and postcalving periods in June; virtually all of the CAH movements were east of the Colville River. Few collared CAH caribou were present in the area during winter, especially in recent years; previous work found that few CAH caribou winter on the coastal plain (Murphy and Lawhead 2000, Arthur and Del Vecchio 2004). Use of the eastern half of the study area by CAH caribou was sporadic during the mosquito and oestrid fly seasons, consistent with previous research that documented a strong relationship between local CAH movements on summer range in relation to temperature and wind conditions (White et al. 1975, Dau 1986, Lawhead 1988, Cameron et al. 1995). During mosquito harassment, CAH caribou typically head north to the coast and then move into the wind, which usually blows from the east–northeast. During less common periods of westerly winds, however, large numbers of CAH caribou occasionally move onto the Colville River delta.

Taken together, the telemetry data (using all 3 types of transmitters) reveal little overlap in the summer ranges of the TH and CAH. Most CAH caribou remain east of the Colville River, most TH caribou stay west of it, and CD-4 is located between the normal herd ranges (Figure 6). In recent years, however, several unusual movements by both herds have been noted. The most notable instance occurred in July 2001, when thousands of CAH caribou moved west onto and across the Colville River delta and far into NPRA, with many remaining there into September (Lawhead and Prichard 2002, Arthur and Del Vecchio 2004). The herd ranges overlap in fall and winter, primarily due to the eastward expansion of TH caribou into CAH range. Although most of the TH usually winters on the coastal plain, large numbers recently wintered south of the Brooks Range in areas used by the CAH or WAH (Prichard and Murphy 2004). In a highly unusual movement in 2003–2004, a large proportion of the TH moved east across the Colville River in the fall and wintered in and near ANWR (Carroll et al. 2004).

The available telemetry data show that movements by TH and CAH caribou into the immediate vicinity of CD-4 (between Nuiqsut and Alpine) have occurred sporadically and infrequently—during calving (early June), mosquito and oestrid-fly seasons (mid- to late July), and fall migration (late September)—since monitoring began in the late 1980s–early 1990s for satellite collars and in 2003–2004 for GPS collars (Figures 6–9b). None of the 102 TH satellite collars moved into the immediate vicinity of CD-4 during 1990–2006; the nearest was one female that moved from northwest of CD-4 to south of Nuiqsut on 30 September 2004, remaining west of the Nigliq Channel. Of the 22 TH GPS collars during 2004–2006, one crossed the delta westward between CD-4 and Alpine on 6 June 2005 en route to the area near Teshekpuk Lake. Of the sample of 17 CAH satellite collars during 1986–1990, one was in the CD-4 vicinity briefly during 21–23 July 1988 and 4 were nearby during 11–13 July 1989. Of the sample of 17 CAH satellite collars during 2001–2005, 4 moved through the vicinity while heading inland on 28–30 July 2001, evidently after having been collared on the outer Colville delta. One of the 45 CAH GPS collars within the ASDP study area during 2003–2006 moved onto the Colville delta east of CD-4 on 27 September 2004.

A greater proportion of radio-collared caribou movements have occurred across the proposed ASDP road alignment since 1990 than near CD-4, although crossings were not frequent. As would be predicted on the basis of herd distribution, most of the crossings of the proposed road alignment were by TH caribou. Fifteen of the 102 satellite-collared TH animals (1990–2006) crossed the alignment at least 25 times between September 1990 and August 2005. Those crossings occurred in winter (February, April), spring (May), oestrid-fly season (late July), late summer (August–September), and fall migration (September, October, November). Of the sample of 22 GPS-collared TH caribou

(2004–2006), 5 animals crossed the alignment near its western terminus during fall migration between 3 October and 18 November 2004 and another caribou crossed in early June 2005 near Alpine (the same animal mentioned above that passed between CD-4 and Alpine). Two of 16 satellite-collared CAH caribou in the late 1980s crossed the alignment near the present location of the Alpine facilities on 12 July 1989 (9 years before construction), the only satellite- or GPS-collared CAH caribou to have done so. Some VHF-collared CAH caribou must have crossed the road alignment while moving west with the aggregation of ~6000 CAH caribou through the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2004), but they were not tracked frequently enough to document their route; it is possible that all of that aggregation crossed the alignment.

REMOTE SENSING

Because MODIS imagery covers large areas at relatively coarse resolution (500-m pixels), we were able to evaluate snow cover and vegetation indices over a much larger region than the ASDP study area at no additional cost. The region evaluated extends from the western edge of Teshekpuk Lake east to the Canadian border and from the Beaufort Sea inland to the northern foothills of the Brooks Range. The ability to examine this large region allowed us to place the ASDP caribou study area into a larger context in terms of variability in snow cover and chronology of vegetation green-up.

SNOW COVER

The progression and pattern of snow melt in 2006 were depicted and analyzed as a time series (Figure 10). In the first 7 map tiles of Figure 10, white represents complete snow cover, dark green depicts snow-free areas, and intermediate shades of green correspond to intermediate levels of subpixel snow cover. Black indicates unreliable data caused by clouds or sensor malfunction and blue was used for pixels in which >50% of the area was pond, lake, river, or ice cover. Because the snow fraction is most relevant to caribou habitat conditions, water-dominated pixels were masked out for the analysis.

Persistent cloud cover during late May and early June 2006 obscured the exact timing and distribution of snow melt. A comparison of the observed dates of snow melt in 2005 and 2006 (Figure 10, two tiles at lower right) demonstrates the lack of specificity in the 2006 melt dates. In 2005, snow melt clearly occurred sooner along the lower elevation river valleys. This pattern most likely occurred in 2006 as well, but no cloud-free views of the northern coastal plain were available between 24 May and 9 June. Due to the cloud cover and resulting lack of MODIS imagery, the observed melt date of 9 June in the 2006 snow melt composite actually indicates that snow melt occurred on 9 June or on any of the 15 days prior. Field observations from transect surveys indicated that the last 50% of snow cover melted between 2 and 9 June, consistent with the warm air temperatures recorded in the first half of June.

Comparison of the performance of the MODIS subpixel snow algorithm with aggregated Landsat imagery suggests that the overall performance of the subpixel-scale snow-cover algorithm is acceptable but that accuracy degrades near the end of snowmelt (Lawhead et al. 2006). Further research comparing Landsat data and oblique aerial photography will improve the accuracy and understanding of errors in subpixel-scale snow-cover mapping.

VEGETATIVE BIOMASS

To examine the chronological dynamics of vegetation green-up, we examined a 5-year time series for the variables NDVI_calving, NDVI_621, and NDVI_rate (2006 data in Figure 11; 2002–2005 data in Lawhead et al. 2006). Care must be exercised in comparing NDVI values between the 2002–2003 images and the 2004–2006 images because the image-processing approach used with the earlier data differed somewhat. Reprocessing of archived data by NASA to the current Version 5 format facilitated reanalysis of the older data.

The values of NDVI_calving (9 June imagery) were fairly high across most of the coastal plain (including the ASDP study area) in 2006 (Figure 11) and were similar to the level observed in 2002, a year of early snowmelt (Lawhead et al. 2006). These high NDVI values indicated that snow cover was largely gone and some plant growth had begun; comparison with the subpixel-scale snow-cover map for 9 June (Figure 10) confirmed that snow cover was largely gone. The areas of lowest NDVI_calving occurred along streams and the coast (Figure 11) and some snow cover persisted north of Teshekpuk Lake on 9 June (Figure 10). NDVI_calving values were low in 2003 and 2005, slightly higher in 2004, and substantially higher in 2002 and 2006. The aerial-survey areas had very low values of NDVI_calving in 3 (2003–2005) of the 5 years.

The first flush of vegetative growth that occurs among melting patches of snow cover is valuable to foraging caribou (Klein 1990, Kuropat 1994, Johnstone et al. 2002), but the spectral signal of snow complicates NDVI-based inferences in patchy snow conditions. Variation in dates with clear sky conditions in early June also can confound interpretation of the effect of snow cover on NDVI values. For example, the dates of imagery in 2002, 2004, and 2006 were a few days later than in 2003 and 2005. Snow cover can change rapidly in early June. Studies using a handheld spectrometer (Stow et al. 2004) and spectral mixture models (Macander 2005) have demonstrated a large increase in NDVI associated solely with snow melt. Therefore, it may be more appropriate to infer habitat conditions from the subpixel-scale snow fraction until all detectable snow in a pixel has melted, and then to incorporate NDVI metrics after pixels are snow-free. Beck et al. (2006) proposed that the NDVI value of senesced vegetation is more appropriate to use as a baseline for vegetation phenology calculations than are early-season NDVI values affected by snow. The NDVI of senesced vegetation can be calculated from imagery acquired in late fall after vegetation has senesced and before snow accumulation begins, but it cannot be calculated reliably in the spring because snowmelt and vegetation green-up commonly coincide. We reviewed imagery from late summer and fall 2006 but persistent cloud cover precluded the acquisition of a suitable baseline image.

By 21 June 2006, the date considered to represent peak lactation (Griffith et al. 2002), the study area is generally free of snow (other than incised valleys) but lake ice remains a prominent feature, particularly in the northern portion of the region. In calculating NDVI_621 values, a fringe of lower NDVI values was evident around many lakes on the northern coastal plain even with the water mask applied to pixels containing >50% water. The late-July image used to calculate NDVI_peak was nearly ice-free (except for Teshekpuk Lake) and a fringe of lower NDVI values around lake edges was no longer evident. This change indicates that the presence of lake ice decreases NDVI values in pixels adjacent to lakes, suggesting that removal of the negative bias caused by subpixel-scale lake ice may require masking more pixels around waterbodies. Another promising approach would be to apply spectral tests to determine the presence of snow or ice on the raw swath imagery. Then, snow-affected pixels could be excluded before the imagery is registered to a common coordinate system.

The estimated rate of change in biomass from calving in early June to 21 June, represented by the variable NDVI_rate, is highest where NDVI_calving was low (often zero or lower) and is lowest in areas where NDVI_calving was high. This relationship suggests that NDVI_rate is strongly influenced by the nonlinear increase in NDVI associated with snow melt and the exposure of senesced vegetation. NDVI_rate in 2006 was low throughout the study area because most of the snowmelt occurred prior to the date used for NDVI_calving (9 June).

After snow melt is complete, the spatial pattern of relative NDVI values in a given area remains remarkably similar. NDVI_621, although lower overall, is highly correlated with NDVI_peak, which was highly correlated and similar in value in both 2005 and 2006. This pattern suggests that the absolute value of NDVI is influenced by the phenological stage of the vegetation in the early stages of growth and by remnant snow and ice cover, but that the peak value of NDVI relative to surrounding pixels is determined by the proportion of water and type of vegetation in the pixel, factors that change very little among years.

CARIBOU DISTRIBUTION ANALYSES

GEOGRAPHIC LOCATION

The distribution of caribou groups during aerial transect surveys was not uniform across the 6

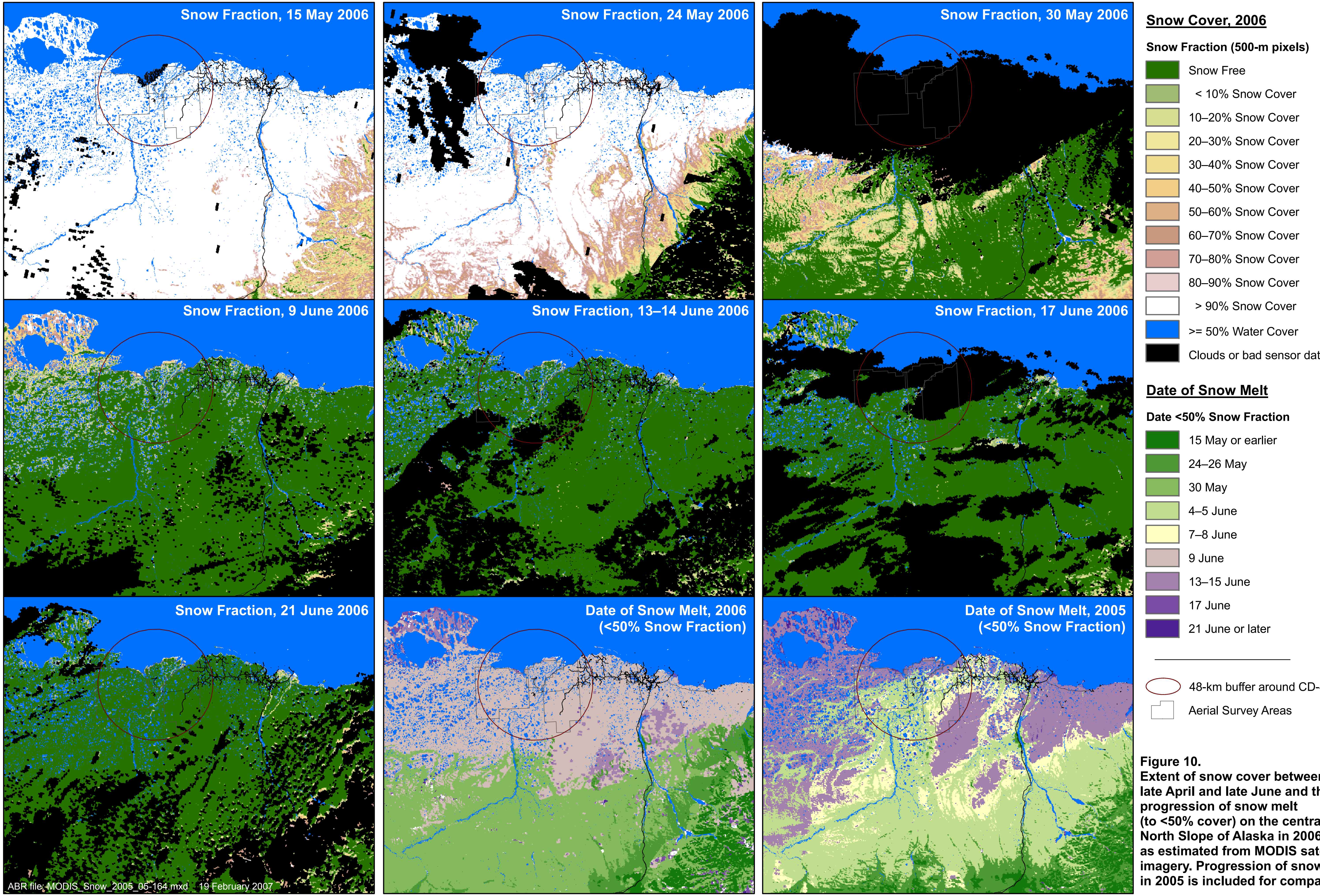
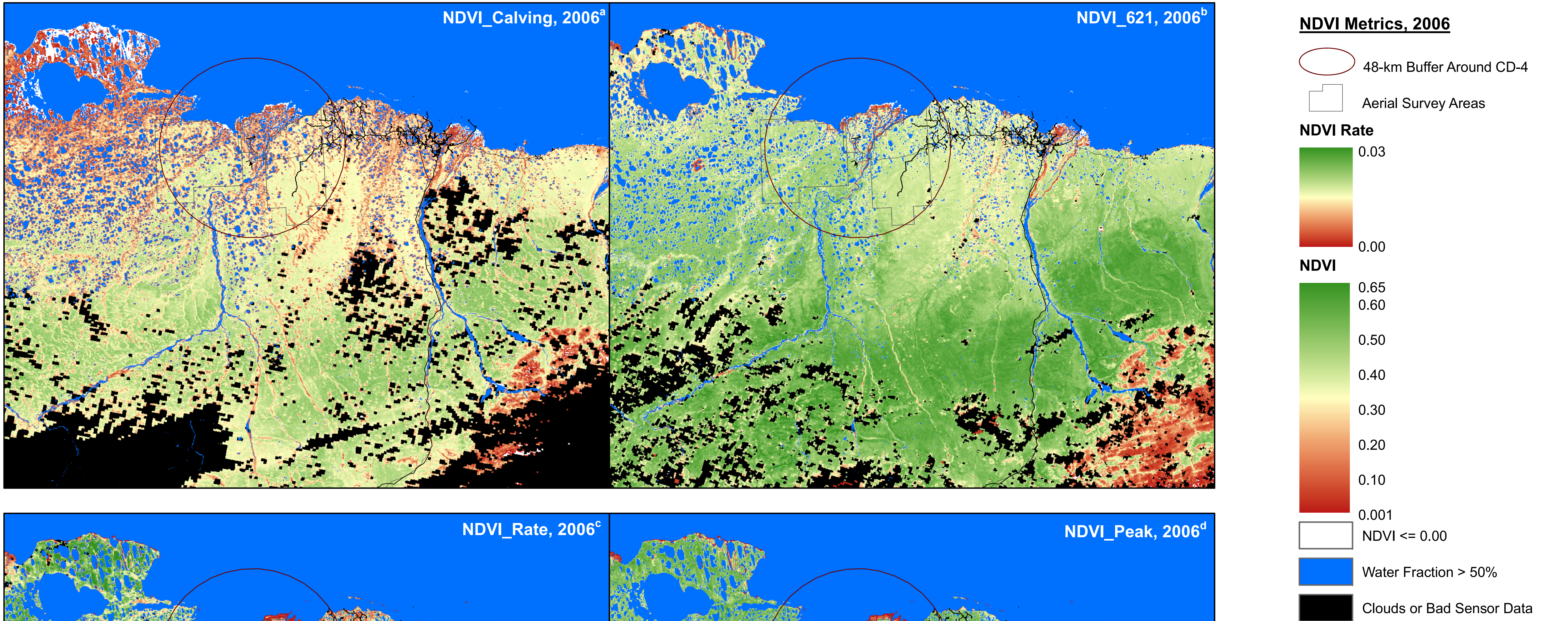


Figure 10.
Extent of snow cover between late April and late June and the progression of snow melt (to <50% cover) on the central North Slope of Alaska in 2006, as estimated from MODIS satellite imagery. Progression of snowmelt in 2005 is included for comparison.



a. NDVI_Calving: 9 June 2006.
b. NDVI_621: Includes data from 21 June 2006 as well as data interpolated to 21 June 2006 from prior and subsequent cloud-free images. Full date range of contributing images is 13–27 June 2006.
c. NDVI_Rate: Estimated rate of vegetative biomass increase from 9 June to 21 June, 2006.
d. NDVI_Peak: 25 July 2006.

Figure 11. Relative vegetative biomass at 3 stages of the growing season in 2006 and the estimated rate of increase from caribou calving to peak lactation on the central North Slope of Alaska, as estimated from MODIS satellite imagery.

ABR file: Fig11_MODIS_NDVI_2006_06-164.mxd 19 February 2007 geographic sections of the NPRA survey area (Figure 3) for most combinations of season and year (Table 5). The difference between the 2002–2004 and 2005–2006 survey areas resulted in different areas of availability for this analysis. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix J) influenced the seasonal differences in caribou distribution. We focus here primarily on the analytical results using the pooled 5-year transect data set (2002–2006; Table 5); the patterns of significance found within individual years generally were similar but often not significant due to smaller sample sizes.

For the pooled 2002–2006 sample, significantly more groups of caribou occurred in the River and Southwest sections than would be expected on the basis of a uniform distribution (Table 5). The River section contained more groups during the postcalving season, oestrid fly season, late summer, and fall migration but fewer groups during spring migration. The Southwest section also contained more groups during several seasons, with significantly more occurring in winter, calving, and fall migration, but fewer during the mosquito season.

The North and West sections showed only minor departures from a uniform distribution of caribou occurrence (Table 5). The North section contained fewer groups than expected during winter and fall migration and more groups during spring migration. The West section contained more groups during postcalving and fewer during the oestrid fly season; this section had the fewest departures from a uniform distribution.

Among all years, the Southeast section, which includes nearly the entire length of the proposed ASDP road alignment, contained fewer groups than expected in all seasons except winter (Table 5). The Coastal section also tended to contain fewer groups than expected, with the differences being significant during winter, calving, postcalving, late summer, and fall migration (Table 5). During the mosquito season, however, caribou groups were significantly more numerous in the Coastal section, which is consistent with the well-documented use of coastal mosquito-relief habitat by caribou. During the oestrid-fly season, the number of groups in the Coastal section did not differ from expected values, but this group-based analysis does not reflect the large numbers of caribou found in a few groups in the Coastal zone on 2 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. The results for 2006 were generally consistent with the patterns observed for all years combined, although large numbers of caribou were not encountered during any of the 2006 aerial surveys.

These results are interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain of northern Alaska. During calving, the highest densities of TH females calve near Teshekpuk Lake, so densities decrease farther from the lake (Prichard and Murphy 2004, Carroll et al. 2005); thus, more caribou would be expected in the western portion of the NPRA survey area in that season. When mosquito harassment begins in late June or early July, caribou move toward the coast where lower temperatures and higher wind speeds prevail. When oestrid flies emerge, typically by mid-July, the large groups that formed in response to mosquito harassment break up and caribou disperse, seeking elevated or barren habitats such as sand dunes, mudflats, and river bars (Lawhead 1988, Prichard and Murphy 2004). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3, Appendix J) that provide good fly-relief habitat near foraging areas.

The Southwest section consistently contained higher densities of caribou than did the Southeast section. The reasons for this difference are unknown but possible explanations may include distance from Teshekpuk Lake and location on the fringe of the TH range, differences in habitat quality, or avoidance of human activity (hunting pressure from Nuiqsut or avoidance of infrastructure at a scale not documented). Whatever the reason, it is important to recognize that this pattern of distribution exists before construction of the ASDP pipeline/road corridor.

HABITAT USE

Caribou group locations during transect surveys were significantly related to the distribution of habitat types in the NPRA earth-cover classification (BLM and Ducks

Table 5. Number of caribou groups in different geographic sections of the NPRA survey area, by year and season, with results of chi-square goodness-of-fit tests (assuming a uniform distribution).

				Geographic Section							
Year(s)	Season	No. of Surveys	Total Groups	Coast	North	River	South east	South west	West	Chi-square	*P*-value
2002	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0	26	13--	40	36	11	25.80	<0.001
	Calving	1	116	1	23	42	22--	21	7	22.18	<0.001
	Postcalving	1	82	0	13	45^{++}	12--	3--	9	58.61	<0.001
	Mosquito	1	5	0	4^{++}	1	0	0	0	22.81	<0.001
	Oestrid Fly	3	24	0	0	18^{++}	2--	3	1	34.14	<0.001
	Late Summer	3	201	1	32	82^{++}	42--	35	9	39.71	<0.001
	Fall Migration	3	148	0	7--	33	23--	72^{++}	13	79.44	<0.001
	Total	14	702	2--	105	234^{++}	141--	170	50	85.02	<0.001
2003	Winter	1	313	1--	28	75	97	97^{++}	15	21.64	<0.001
	Spring Migration	1	13	0	3	4	1--	4	1	5.19	0.393
	Calving	2	101	0	12	26	22--	32	9	13.44	0.020
	Postcalving	2	273	1--	37	90^{+}	64^{--}	54	27	29.29	<0.001
	Mosquito	1	1	0	1	0	0	0	0	7.44	0.190
	Oestrid Fly	2	116	1	6--	61^{++}	24--	23	1--	54.15	<0.001
	Late Summer	1	37	0	10	15	7	4	1	16.95	0.005
	Fall Migration	3	431	2--	46	140^{++}	64^{--}	152^{++}	27	105.28	<0.001
	Total	13	1285	5--	143	411^{++}	279^{--}	366^{++}	81	138.82	<0.001
2004	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0	1	1	3	0	0	2.66	0.753
	Calving	0	–	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–	–
	Mosquito	1	2	0	0	2	0	0	0	6.18	0.289
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–
	Late Summer	2	75	0	14	34^{++}	9--	16	2	30.14	<0.001
	Fall Migration	1	66	2	9	10	41^{++}	4--	0	28.35	<0.001
	Total	5	148	2	24	47	53	20^{-}	2--	15.05	0.010
2005	Winter	1	98	11	19	15	14--	32^{++}	7	24.46	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–	–
	Calving	2	98	3--	15	10-	21	43^{++}	6	57.94	<0.001
	Postcalving	1	112	7	29	27	16--	25	8	14.15	0.015
	Mosquito	1	32	10	7	6	4	1--	4	24.81	<0.001
	Oestrid Fly	1	25	8	3	8	5	1--	0	19.44	0.002
	Late Summer	2	29	2	11	3	6	6	1	5.23	0.388
	Fall Migration	1	46	2	11	8	13	10	2	2.40	0.791
	Total	9	440	43	95	77	79--	118^{++}	28	46.44	<0.001
2006	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	79	14	40^{++}	8-	9--	7	1	46.85	<0.001
	Calving	1	118	3--	32	13-	23	35^{++}	12	34.87	<0.001
	Postcalving	1	88	3--	22	40^{++}	11--	9	3	44.63	<0.001
	Mosquito	1	0	0	0	0	0	0	0	–	–
	Oestrid Fly	1	32	0	14	11	3--	4	0	18.65	0.002
	Late Summer	2	94	7	26	31^{+}	12--	14	4	18.04	0.003
	Fall Migration	1	5	0	0	1	4^{+}	0	0	7.89	0.163
	Total	8	416	27--	134^{++}	104^{+}	62--	69	20	51.25	<0.001
2002–2005	Winter	2	411	12--	47--	90	111	129^{++}	22	55.92	<0.001
	Spring Migration	4	144	0	30^{+}	18--	44	40	12	25.67	<0.001
	Calving	5	315	4--	50	78	65--	96^{++}	22	46.44	<0.001
	Postcalving	4	467	8--	79	162^{++}	92--	82	44^{+}	73.91	<0.001
	Mosquito	5	40	10^{+}	12	9	4--	1--	4	61.56	<0.001
	Oestrid Fly	5	165	9	9--	87^{++}	31--	27	2--	89.08	<0.001
	Late Summer	8	342	3--	67	134^{++}	64--	61	13	75.52	<0.001
	Fall Migration	8	691	6--	73	191	141--	238^{++}	42	121.45	<0.001
	Total	41	2575	52--	367	769^{++}	552--	674^{++}	161	228.59	<0.001

Table 5. Continued.

Year(s)	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South east	South west	West	Chi-square	*P*-value
All	Winter	2	411	12^{--}	47^{--}	90	111	129^{++}	22	54.16	<0.001
	Spring Migration	5	223	14	70^{++}	26^{--}	53^{--}	47	13	66.51	<0.001
	Calving	6	433	7^{--}	82	91	88^{--}	131^{++}	34	68.49	<0.001
	Postcalving	5	555	11^{--}	101	202^{++}	103^{--}	91	47^{+}	106.17	<0.001
	Mosquito	6	40	10^{+}	12	9	4^{--}	1^{--}	4	44.91	<0.001
	Oestrid Fly	6	197	9	23	98^{++}	34^{--}	31	2^{--}	87.89	<0.001
	Late Summer	10	436	10^{--}	93	165^{++}	76^{--}	75	17	91.61	<0.001
	Fall Migration	9	696	6^{--}	73^{--}	192^{+}	145^{--}	238^{++}	42	133.04	<0.001
	Total	49	2991	79^{--}	501	873^{++}	614^{--}	743^{++}	181	266.01	<0.001
Available area, 2002–2004 (km²)				8.9	64.8	133.7	191.0	115.9	32.3		
Available area, 2005–2006 (km²)				70.7	160.9	136.0	191.0	116.1	32.3		

$^{+}$ Use greater than expected ($P < 0.05$).
$^{++}$ Use greater than expected ($P < 0.01$).
$^{-}$ Use less than expected ($P < 0.05$).
$^{--}$ Use less than expected ($P < 0.01$).

Unlimited 2002). The numerous combinations of seasons, years, and habitat classes resulted in a complex matrix of test results (Table 6) with variable data among years. As in the geographic analysis above, the pooled-year samples provided larger sample sizes, so this section focuses primarily on those results. The results in this year's analysis vary slightly from those reported last year (Lawhead et al. 2006) due to an error in the calculation of habitat use in that report, which had the effect of underweighting caribou near lake shores. That error predominantly affected the results for the *Carex aquatilis* habitat class, which occurs along lake margins and in areas of flooded tundra.

Across all seasons and years (2002–2006), the proportions of caribou groups using riverine habitats and the moss/lichen and dwarf-shrub types—3 of the 4 least abundant classes—were significantly greater than expected based on the relative availability of those habitats, whereas the proportions of groups using flooded tundra and tussock tundra—the 2 most abundant classes—were significantly less than expected (Table 6). The proportion of caribou groups in tussock tundra was less than expected during summer (mosquito, oestrid fly, and late summer seasons). Riverine habitats were used less than expected during spring migration but more than expected from postcalving through fall migration, consistent with the geographic analysis above. *Carex aquatilis* was used more than expected during the mosquito and oestrid fly seasons, flooded tundra was used less during calving and postcalving, and dwarf shrub was used more than expected during late summer and fall migration. Use of sedge/grass meadow was greater than expected during spring migration and calving, but less during oestrid fly season. The moss/lichen class was used less in winter and more than expected during the oestrid fly season, late summer, and fall migration. The moss/lichen class occurred in higher proportions in riverine areas; the reason for avoidance of that type in winter is unknown.

During calving, caribou may seek dry, snow-free areas, but habitat type generally was a poor predictor of group location during calving in this area and at the scale of our analysis. Comparison across studies is complicated by the fact that different investigators have used different habitat classifications. Kelleyhouse (2001) reported that TH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid classes; both of those studies used the classification by Muller et al. (1998, 1999). Using a classification similar to the ELS scheme developed by Jorgenson et al. (2003), Lawhead et al. (2004) found that CAH caribou in

Table 6. Seasonal use of different habitat types by caribou, expressed as use (% of the area within 100 m of each group) divided by availability (% of area, excluding water), in the NPRA survey area, 2002–2006.

				Habitat Type [a]								
Year	Season	No. of Surveys	No. of Groups	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2002	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0.99	0.91	0.89	1.42^{++}	1.03	0.14--	0.83	1.17	0.06--
	Calving	1	116	1.01	0.90	1.04	1.05	0.91	1.31	1.55^{+}	0.29	1.92
	Postcalving	1	82	0.91	0.70--	1.01	1.07	1.03	1.87	0.78	0.29	2.70^{++}
	Mosquito	1	5	0.69	0.98	1.49	1.14	0.75	0.42	1.47	0	2.98
	Oestrid Fly	3	24	1.13	0.79	1.05	0.64	0.69	1.08	1.96	1.00	7.97^{++}
	Late Summer	3	201	1.02	1.02	0.99	0.80--	0.74--	2.18^{++}	1.44^{+}	2.14	4.89^{++}
	Fall Migration	3	148	1.24	1.01	1.15	0.98	0.86	1.34	1.32	0.34	1.25
	Total	14	702	1.05	0.93	1.02	1.02	0.88--	1.41^{+}	1.26^{+}	1.01	2.60^{++}
2003	Winter	1	313	1.01	0.89	0.93	0.93	1.07	0.76	1.35^{+}	0.77	1.06
	Spring Migration	1	13	0.85	1.02	0.83	1.46	0.91	1.68	1.14	0.00	0.46
	Calving	2	101	1.12	0.75-	1.01	0.99	1.00	1.60	1.01	0.62	2.49^{++}
	Postcalving	2	273	0.93	0.91	0.96	1.05	0.95	1.19	1.01	1.05	2.69^{++}
	Mosquito	1	1	2.77	1.57	1.04	2.22	0.07	0	0	0	0
	Oestrid Fly	2	116	1.02	1.05	1.08	0.57--	0.69--	3.34^{++}	1.39	2.56	5.66^{++}
	Late Summer	1	37	0.90	1.00	0.95	1.59^{+}	0.82	1.39	0.77	0.00	1.15
	Fall Migration	3	431	1.08	0.90	1.00	0.94	0.97	1.66^{++}	1.30	1.92	1.49^{+}
	Total	13	1285	1.02	0.91--	0.98	0.96	0.96	1.48^{++}	1.22^{++}	1.33	2.08^{++}
2004	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0.80	1.56	0.87	0.58	0.41	14.20^{++}	0.35	8.29	2.03
	Calving	0	–	–	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–	–	–
	Mosquito	1	2	3.68	2.10	0.61	1.24	0.04	0	0	0	0.70
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	75	1.03	0.93	1.14	0.85	0.72--	2.45^{+}	1.45	0.76	4.80^{++}
	Fall Migration	1	66	1.20	0.98	0.86	0.69-	1.08	1.01	1.19	1.39	1.28
	Total	5	148	1.14	0.99	1.00	0.78-	0.86-	2.17^{++}	1.28	1.28	3.08^{++}
2005	Winter	1	98	1.20	1.12	0.90	1.00	1.04	0.42-	0.93	0.32	0.14--
	Spring Migration	0	–	–	–	–	–	–	–	–	–	–
	Calving	2	98	0.64-	0.77-	0.86	1.17	1.23^{+}	0.55	0.99	1.76	0.47
	Postcalving	1	112	0.80	0.73-	0.97	1.24	1.11	1.08	1.19	2.13	0.49
	Mosquito	1	32	2.18^{++}	0.95	0.78	0.96	0.51--	2.88^{+}	1.29	2.39	3.33^{++}
	Oestrid Fly	1	25	3.33^{++}	1.47^{+}	0.72	0.29--	0.25--	2.51	0.30	0	4.86^{++}
	Late Summer	2	29	1.75^{+}	1.00	0.91	0.70	0.93	1.56	1.74	0	0.78
	Fall Migration	1	46	0.97	0.97	0.98	1.20	0.99	0.61	0.72	0	0.98
	Total	9	440	1.18^{+}	0.93	0.90	1.06	1.00	1.01	1.03	1.18	0.93
2006	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	79	1.00	0.89	1.10	1.23	0.97	0.94	0.81	0	0.75
	Calving	1	118	0.96	0.89	0.87	1.33^{++}	1.08	0.64	0.71	0.77	0.08--
	Postcalving	1	88	0.60-	0.93	1.27^{+}	1.00	0.85	1.67	1.24	4.40^{+}	2.35^{++}
	Mosquito	1	0	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	32	1.10	1.15	1.18	1.19	0.73	0.51	1.17	0	1.46
	Late Summer	2	94	0.80	0.79	1.12	1.08	0.87	2.69^{++}	1.47	0.65	2.06^{+}
	Fall Migration	1	5	0.84	0.32	0.51	0.14-	1.39	0.57	3.04	9.56	4.06
	Total	8	416	0.86	0.89	1.08	1.16^{+}	0.94	1.37	1.07	1.41	1.29
2002–2005	Winter	2	411	1.05	0.97	0.94	0.90	1.08	0.67-	1.27	0.73	0.65
	Spring Migration	4	144	0.97	0.94	0.89	1.39^{+}	1.00	0.77	0.84	1.31	0.16--
	Calving	5	315	0.93	0.82--	0.98	1.05	1.04	1.16	1.22	0.82	1.38
	Postcalving	4	467	0.89	0.83--	0.97	1.09	1.00	1.28	1.02	1.14	1.91^{++}
	Mosquito	4	40	2.10^{++}	0.99	0.85	1.10	0.49--	2.38	1.18	1.62	3.90^{++}
	Oestrid Fly	6	165	1.39^{++}	1.08	1.03	0.53--	0.63--	2.88^{++}	1.32	2.03	5.64^{++}
	Late Summer	8	342	1.07	1.01	1.02	0.86	0.77--	2.09^{++}	1.41^{++}	1.52	3.55^{++}
	Fall Migration	8	691	1.11^{+}	0.95	1.02	0.93	0.96	1.46^{++}	1.26^{+}	1.45	1.31^{+}
	Total	41	2575	1.06^{+}	0.93-	0.98	0.97	0.94--	1.42^{++}	1.21^{++}	1.24	1.89^{++}

Table 6. Continued.

Year	Season	No. of Surveys	No. of Groups	Habitat Type [a] *Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
All	Winter	2	411	1.05	0.97	0.94	0.90	1.08	0.67-	1.27	0.73	0.65
	Spring Migration	5	223	0.99	0.92	0.96	1.35++	0.98	0.83	0.82	0.89	0.46-
	Calving	6	433	0.93	0.84--	0.95	1.14+	1.05	1.02	1.08	0.80	0.98
	Postcalving	5	555	0.84-	0.85--	1.02	1.07	0.98	1.34	1.05	1.61	1.95++
	Mosquito	6	40	2.09++	1.00	0.85	1.07	0.50--	2.38	1.19	1.68	3.62++
	Oestrid Fly	6	197	1.34++	1.09	1.05	0.65--	0.64--	2.49++	1.29	1.75	4.73++
	Late Summer	10	436	1.01	0.97	1.04	0.91	0.79--	2.22++	1.42++	1.36	3.14++
	Fall Migration	9	696	1.11+	0.95	1.02	0.91	0.97	1.45++	1.28++	1.53	1.27+
	Total	49	2991	1.03	0.93--	1.00	0.99	0.95--	1.41++	1.19++	1.28	1.75++
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–2006				8.4%	18.7%	10.5%	16.5%	37.3%	1.5%	3.2%	0.2%	3.7%

[a] NPRA earth-cover classification (BLM and Ducks Unlimited 2002).
[b] Riverine type comprises Dry Dunes, Sparsely Vegetated, and Barren Ground subtypes.
\+ Use greater than expected ($P < 0.05$).
++ Use greater than expected ($P < 0.01$).
\- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

the Meltwater study area in the southwestern Kuparuk Oilfield and the adjacent area of concentrated calving selected moist sedge–shrub tundra, the most abundant type, during calving. Using the NPRA earth-cover classification (BLM and Ducks Unlimited 2002) in the ASDP study area (which is not an important calving area), we found less evidence for selection for specific habitat types during calving than during other seasons.

After mosquitoes and oestrid flies emerged, caribou distribution was dominated by the profound influences of insect harassment. The selection of coastal and riverine areas by caribou as insect-relief habitat predominated over selection of other classes with greater forage availability. The drainages of Fish and Judy creeks are important landscape features affecting caribou distribution. In addition, the proportions of different habitat types around the proposed ASDP road alignment are strongly influenced by the presence of Fish and Judy creeks to the north of the proposed road (Table 7) and by the generally decreasing proportion of tussock tundra from north to south. The proportions of dunes, sparsely vegetated, and barren-ground types all are higher north of the road alignment, with only small amounts of these habitat types near or south of the alignment. Future evaluations of caribou distribution in relation to the proposed infrastructure will need to account for these habitat differences.

SNOW COVER

Due to the lack of suitable satellite imagery during the period of rapid snow melt between 24 May and 9 June, we were unable to analyze caribou distribution in 2006 with respect to snow cover. In 2005, however, snow cover at locations used by collared caribou (VHF, satellite, and GPS samples) during calving did not differ significantly from the overall availability of snow-covered ground (as defined by the 95% kernel-density contour for each herd) for the TH ($P = 0.099$), although it did for the CAH ($P = 0.023$). CAH caribou selected for areas of greater snow cover in 2005. The proportion of CAH caribou in the 0–25% cover class was significantly lower than expected ($P < 0.01$). The 50% kernel-density contour (an estimate of the concentrated calving area based on telemetry locations) encompassed a higher proportion of the 76–100% snow cover class and lower proportions of the other classes than did the 95% kernel-density contour for both herds (Lawhead et al. 2006).

The results of previous studies have differed among northern Alaska herds and appeared to be contradictory for adjacent herds. Kelleyhouse (2001) reported that TH females selected areas of low snow cover and Carroll et al. (2005) found that

Table 7. Area (percentage) of habitat types within distance-to-road zones north and south of the proposed ASDP road in the NPRA survey area.

Zone	Distance to Road (km)	Water	Habitat Type [a]										
			Carex aquatilis	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Dry Dunes	Sparsely Vegetated	Barren Ground
North	6–5	30.0	8.6	18.1	8.8	4.5	13.7	3.0	1.9	0.1	2.7	2.4	6.2
	5–4	26.8	7.1	18.1	9.2	4.5	19.8	2.8	1.9	0.1	2.9	3.8	2.9
	4–3	21.5	6.1	20.6	11.5	5.0	20.4	4.3	2.3	0.6	2.3	3.1	2.2
	3–2	17.0	5.8	20.3	11.0	8.9	30.9	2.2	2.2	0.3	0.3	0.4	0.5
	2–1	14.7	7.0	19.5	8.9	10.9	36.6	0.4	1.9	0.2	0	0	0
	0–1	10.1	9.4	18.9	9.4	9.4	40.2	0.3	2.0	0.1	0	0	0
South	0–1	13.8	8.2	18.8	7.9	8.5	40.2	0.4	2.0	0.2	0	0	0.1
	2–1	19.3	6.4	17.5	8.1	8.8	37.3	0.2	2.1	0.2	0	0	0.1
	3–2	12.9	5.7	18.6	7.7	5.4	47.4	0.2	2.0	0.1	0	0	0
	4–3	11.7	5.4	15.8	7.8	6.2	47.6	0.1	4.6	0.7	0	0	0.1
	5–4	12.6	4.7	14.4	6.9	7.0	49.6	0.4	3.9	0.4	0	0	0
	6–5	9.3	5.0	16.1	8.1	6.8	50.6	0.2	3.7	0.2	0	0	0

[a] NPRA earth-cover classification by BLM and Ducks Unlimited (2002).

TH caribou calved farther north in years of early snow melt. Wolfe (2000) did not find any consistent selection for snow-cover classes by the CAH. Eastland et al. (1989) and Griffith et al. (2002) reported that calving caribou of the Porcupine Herd used areas with 25–75% snow cover to a greater degree than expected based on availability. The presence of patchy snow in calving areas is associated with the emergence of highly nutritious new growth of forage species such as the tussock cottongrass *Eriophorum vaginatum* (Kuropat 1984, Johnstone et al. 2002, Griffith et al. 2002) and it also may disperse caribou and create a complex visual pattern that reduces predation (Bergerud and Page 1987, Eastland 1989). Interpretation of analytical results is complicated by the fact that calving caribou do not require snow-free areas and are able to find nutritious forage in patchy snow cover, as well as by high variability in the extent of snow cover and the timing of melt among years.

VEGETATIVE BIOMASS

For each of 6 seasons, values of the 4 NDVI variables (NDVI_calving, NDVI_621, NDVI_rate and NDVI_peak) at caribou group locations were compared with their availability in the 2006 NPRA survey area (Table 8). In general, caribou appeared to avoid areas with high values of estimated biomass (NDVI_calving, NDVI_621, and NDVI_peak) during calving, oestrid fly season, and late summer but selected areas with high estimated biomass during postcalving (Table 8). The selection or avoidance of areas with high NDVI_rate was almost the opposite, reflecting the inverse relationship between NDVI_calving and NDVI_rate. In general, the more inland areas (Southeast, Southwest, and West sections) had higher estimated biomass and lower NDVI_rate than the Coastal, North, and River sections (Appendix J). The selection for low NDVI_calving and high NDVI_rate during calving may reflect selection of areas with late snow melt that would be expected to have high-quality new vegetative growth. By postcalving, caribou tended to use areas with higher estimated biomass. Because there was little snow in the study area during calving in 2006, NDVI_calving was not strongly influenced by snow melt and was highly correlated with NDVI_621 (r = 0.901, n = 163 grid cells) and NDVI_peak (r = 0.840).

The values of NDVI_621, NDVI_rate, and NDVI_peak all were correlated, so results were similar for all 3 variables (Table 8). Caribou used areas with greater values of NDVI_621 during calving, postcalving, and fall migration but used areas with lower values during the mosquito, oestrid fly, and late summer seasons. Areas with greater values of NDVI_rate were used during calving and postcalving but areas with lower NDVI_rate were used in the mosquito and oestrid-fly seasons. NDVI_peak values at caribou locations were greater during winter, calving, and postcalving, whereas areas with lower values of

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) at locations used by caribou groups in the NPRA survey area in 2006, compared with availability using a bootstrap analysis.

Season	*n*	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak
Calving	118	0.2468 --	0.3965 -	0.0124 ++	0.5307
Postcalving	88	0.3000 ++	0.4284 ++	0.0107	0.5566 ++
Mosquito	0	–	–	–	–
Oestrid Fly	32	0.2362 --	0.3798 --	0.0120	0.5063 --
Late Summer	94	0.2228 --	0.3756 --	0.0127 +	0.5218 -
Fall Migration	5	0.2389 --	0.4090	0.0142 ++	0.5410
Total Use	416	0.2647	0.4053	0.0117	0.5373
Available		0.2681	0.4049	0.0114	0.5325

\+ Use greater than expected ($P < 0.05$).
++ Use greater than expected ($P < 0.01$).
\- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

NDVI_peak were used during the mosquito and oestrid fly seasons. Overall, caribou use of areas with higher NDVI values exceeded availability during calving and postcalving, seasons when caribou presumably selected areas with high forage availability and quality. When mosquitoes and oestrid flies were present, caribou used areas with lower plant biomass as they moved to the coast, river bars, and barren areas to avoid insect harassment.

NDVI was used in this study to estimate biomass because other researchers have reported significant relationships between caribou distribution and NDVI_calving, NDVI_621, and NDVI_rate during the calving period. Griffith et al. (2002) reported that the annual calving grounds used by the Porcupine Herd during 1985–2001 generally were characterized by a higher daily rate of change in biomass (NDVI_rate) than was available in the entire calving grounds. In addition, the area of concentrated calving contained higher NDVI_calving and NDVI_621 values than was available in the annual calving grounds. They concluded that caribou used calving areas with high forage quality (inferred from a high daily rate of change) and that, within those areas, caribou selected areas of high biomass. The relationship between annual NDVI_621 and June calf survival for the Porcupine Herd was strongly positive, as was the relationship between NDVI_calving and the percentage of marked females calving on the coastal plain of ANWR (Griffith et al. 2002).

Female caribou of both the CAH and TH have been reported to select areas of high NDVI_rate (Wolfe 2000, Kelleyhouse 2001). In contrast, female caribou of the WAH selected areas with high NDVI_calving and NDVI_621 (Kelleyhouse 2001). Kelleyhouse suggested that differences in spring phenology may account for the differences among herds. The calving grounds of the CAH and TH typically are colder and covered with snow later than are those of the WAH, so the chronology of forage development and selection in early June likely differs accordingly. Caribou select areas of patchy snow cover and high NDVI_rate during calving but select high biomass (NDVI_621) after tussock cottongrass (*E. vaginatum*) flowers are no longer available.

In the eastern portion of the ASDP study area (the Meltwater area studied by Lawhead et al. 2004), use of areas of high NDVI_rate by caribou varied according to the timing of snow melt during 2001–2003. NDVI_calving and NDVI_rate are inversely correlated, so the values differ greatly between years of early and late melt. In years when snow melt occurred early, NDVI_calving was high and NDVI_rate was low throughout the region. In years when snow cover lingered through calving, NDVI_calving was low and NDVI_rate was high. NDVI increases rapidly during snow melt due to the inherent NDVI value of standing dead biomass (Sellers 1985, cited in Hope et al. 1993; Stow et al. 2004) and the initial flush of new growth (an NDVI value of 0.09 is considered a threshold value indicating "onset of greenness" in arctic tundra; Reed et al. 1994). Following snow melt (and possibly seasonal runoff flooding), the rate of increase in NDVI values slows.

DISTANCE TO PROPOSED ROAD

In most seasons and years (2001–2006), the numbers of caribou groups observed in each distance-to-road zone did not differ significantly from those expected based on a uniform distribution among zones (Table 9). For all years combined, however, significantly more groups than expected occurred 4–6 km north of the road and fewer groups than expected occurred 2–4 km south of the road during the oestrid-fly and late summer seasons. Fewer caribou groups than expected occurred within 2 km of the road alignment during both spring migration and the oestrid fly season. These results were consistent with greater use of areas near Fish and Judy creeks during those seasons, as was found above in the geographical and habitat-use analyses.

Caribou density did not differ significantly by distance zone (Greenhouse Geisser P-value = 0.118; Figure 12), but there was a significant zone-by-season interaction (P = 0.013) and significant differences in density were found among seasons ($P < 0.001$). Caribou density in the NPRA survey area was significantly lower during the mosquito and oestrid-fly seasons than it was during fall migration, postcalving, and winter (all $P < 0.035$; the 2005 oestrid-fly season was dropped from the analysis to avoid undue influence on test results) and densities were significantly lower in late summer than in winter (P = 0.039). The only significant zone-by-season interaction involved the zone within 2 km of the proposed road and the North 2–4-km zone (P = 0.014). This interaction appeared to be based largely on calving and fall migration, when densities were lowest in the North 2–4-km zone. In all other seasons the densities were similar between those 2 zones.

Because caribou aggregate into large groups when mosquitoes are present and move quickly when harassed by insects, densities during the mosquito and oestrid-fly seasons tend to fluctuate widely as groups move through an area. Densities in the area of the proposed road generally were low during the mosquito and oestrid-fly seasons, but large groups did occur in the NPRA survey area occasionally, as documented by the aerial survey on 2 August 2005 and the large movement of CAH caribou into the NPRA survey area in July 2001. Caribou densities in other seasons were fairly consistent and did not show any pattern in relation to the proposed road corridor.

CARIBOU DENSITY ANALYSIS

Grid-cell analysis of the aerial-survey transect data examined the influence of geographic section, snow cover, vegetative biomass, habitat type, and distance to the proposed ASDP road on caribou density during the calving season in 2006 and among all seasons for the years 2002–2006. A number of variables used in the grid-cell analyses were correlated. Estimated peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 (r = 0.892; $P < 0.001$), NDVI_calving (r = 0.840; $P < 0.001$), and NDVI_rate (r = –0.609; $P < 0.001$). NDVI_peak increased with increasing proportions of tussock tundra (r = 0.814; $P <$ 0.001) but decreased with increasing proportions of water (r = –0.567; $P < 0.001$), riverine habitats (dunes, sparsely vegetated, and barren classes combined; r = –0.544; $P < 0.001$), and wet habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; r = –0.624; $P < 0.001$). The proportion of tussock tundra alone explained 66.3% of the variation in NDVI_peak values, and the combination of tussock tundra with the proportion of water explained 75.3% of the variation. Distance from the coast also had an effect; NDVI_peak values were higher in grid-cells farther from the coast (slope = 0.0011; $P < 0.001$).

Snow melt in 2006 was nearly complete at the time the NDVI_calving imagery was taken on 9 June. NDVI_rate was negatively correlated with NDVI_calving (r = –0.892) in 2006, so areas with low NDVI_calving had higher rates of increase in NDVI than did areas with high NDVI_calving. This difference may have been due to more rapid vegetative growth in those areas, more melting of lake ice in those grid-cells, or a combination of the two. The proportion of water and NDVI_rate were

Table 9. Number of caribou groups in distance-to-proposed-road zones by year and season, with results of a chi-square goodness-of-fit test (assuming a uniform distribution).

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
2001	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	16	6	3	0 -	2	5	10.18	0.037
	Calving	1	14	0	2	4	4	4	5.20	0.268
	Postcalving	2	105	13	24	39	10	19	5.62	0.229
	Mosquito	1	3	0	0	2	0	1	3.12	0.538
	Oestrid Fly	2	3	1	0	0	1	1	3.08	0.544
	Late Summer	2	42	11	9	11	3	8	4.46	0.347
	Fall Migration	3	86	17	11	39	8	11	7.60	0.107
	Total	12	269	48	49	95	28 -	49	5.33	0.255
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	20	0 -	2	5	5	8	10.37	0.035
	Calving	1	32	6	5	12	4	5	0.71	0.950
	Postcalving	1	28	13 +	3	8	2	2	16.51	0.002
	Mosquito	1	1	1	0	0	0	0	–	–
	Oestrid Fly	3	5	4 ++	1	0	0	0	14.14	0.007
	Late Summer	3	49	13	13	12	4	7	9.36	0.053
	Fall Migration	3	16	1	0	6	2	7	9.65	0.047
	Total	14	151	38	24	43	17	29	7.51	0.111
2003	Winter	1	71	11	7	15	18	20	11.66	0.020
	Spring Migration	1	1	1	0	0	0	0	4.57	0.334
	Calving	2	25	7	2	9	3	4	2.75	0.600
	Postcalving	2	70	15	2 --	22	12	19	10.63	0.031
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	2	39	14	10	5 --	2 --	8	17.37	0.002
	Late Summer	1	10	4	1	3	1	1	3.53	0.473
	Fall Migration	3	93	21	17	27	15	13	2.87	0.580
	Total	13	309	73	39	81	51	65	11.72	0.020
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	2	0	1	1	0	0	2.82	0.588
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	21	9	4	6	0	2	11.85	0.019
	Fall Migration	1	33	4	5	12	6	6	0.87	0.928
	Total	5	56	13	10	19	6	8	2.73	0.605
2005	Winter	1	19	3	3	6	4	3	0.61	0.961
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	16	3	0	5	2	6	6.32	0.177
	Postcalving	1	16	7	2	3	3	1	6.21	0.184
	Mosquito	1	5	2	0	1	0	2	4.11	0.391
	Oestrid Fly	1	10	5	3	2	0	0	9.17	0.057
	Late Summer	2	5	0	1	3	1	0	3.43	0.489
	Fall Migration	1	10	2	0	3	1	4	4.69	0.321
	Total	9	81	22	9	23	11	16	3.28	0.512
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	12	3	2	3	1	3	1.05	0.902
	Calving	1	22	2	2	5	4	9	9.54	0.049
	Postcalving	1	22	9	5	4	2	2	7.68	0.104
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	3	0	2	0	1	0	7.70	0.103
	Late Summer	2	16	5	6	3	1	1	8.60	0.072
	Fall Migration	1	2	1	0	1	0	0	2.04	0.728
	Total	8	77	20	17	16	9	15	6.57	0.161

Table 9. Continued.

Year	Season	No. of Surveys	Total Groups	Distance to Proposed ASDP Road (km) North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	P-value
2001–2005	Winter	2	90	14	10	21	22	23	10.70	0.030
	Spring Migration	4	39	7	6	6 -	7	13	8.62	0.071
	Calving	5	87	16	9	30	13	19	2.74	0.602
	Postcalving	4	219	48	31	72	27	41	4.42	0.352
	Mosquito	4	9	3	0	3	0	3	5.37	0.252
	Oestrid Fly	5	57	24^{++}	14	7 --	3 --	9	31.11	<0.001
	Late Summer	8	127	37^{+}	28	35	9 --	18	18.94	0.001
	Fall Migration	8	238	45	33	87	32	41	2.87	0.580
	Total	41	866	194^{+}	131	261	113	167	14.36	0.006
All	Winter	2	90	14	10	21	22	23	10.70	0.030
	Spring Migration	5	51	10	8	9 -	8	16	8.48	0.075
	Calving	6	109	18	11	35	17	28	6.49	0.165
	Postcalving	5	241	57	36	76	29	43	6.05	0.195
	Mosquito	6	9	3	0	3	0	3	5.19	0.269
	Oestrid Fly	6	60	24^{++}	16	7 --	4 -	9	30.69	<0.001
	Late Summer	10	143	42^{+}	34	38	10 --	19	24.30	<0.001
	Fall Migration	9	240	46	33	88	32	41	3.21	0.523
	Total	49	943	214^{+}	148	277	122 -	182	16.46	0.002
Area surveyed, 2002–2004 (km²)				34.5	29.5	61.9	31.4	35.1		
Area surveyed, 2005–2006 (km²)				41.6	31.3	61.9	31.4	35.1		

$^{+}$ Use greater than expected ($P < 0.05$).
$^{++}$ Use greater than expected ($P < 0.01$).
- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

highly correlated ($r = 0.746$). NDVI_rate in 2006 was negatively correlated with NDVI_rate in 2005 ($r = –0.544$).

The best model for caribou density in the NPRA survey area during the 2006 calving season included 4 independent variables: presence of Fish or Judy creek (included in all models), presence of the proposed road (included in all models), transect number (west to east), and distance to coast; this model had a 26.2% chance of being the best model ($w_i = 0.262$; Appendix K). Alternative models with strong support included a fifth variable, wet habitat ($w_i = 0.151$) or NDVI_peak ($w_i = 0.105$) (Appendix K). Caribou density during calving was greater farther inland and was lower near creeks and in the eastern transects. The model-weighted parameter estimates indicated that the presence of Fish or Judy creek ($P = 0.007$) and transect number ($P < 0.001$) were significantly related to caribou density during calving (Table 10). Distance to coast was marginally significant ($P = 0.051$), but the presence of the proposed road, NDVI_peak, NDVI_rate, proportion of tussock tundra, and proportion of wet habitats were not significantly related to caribou density.

For all years combined (2002–2006), the analysis of calving densities provided similar results, but with a few differences. The best model included the presence of the creeks and the proposed road (both variables were in all models) and the transect number (west to east), but included NDVI_peak value (Appendix L) rather than distance to coast. The model-weighted parameter estimates indicated that caribou density during calving was greater with increasing NDVI_peak values ($P = 0.010$) and proportion of tussock tundra ($P = 0.009$). Caribou density was lower in areas of wet habitats ($P = 0.037$) and in the eastern transects ($P < 0.001$). The presence of the creeks, the proposed road, and distance to coast were not significant factors ($P > 0.05$; Table 11, Appendix M).

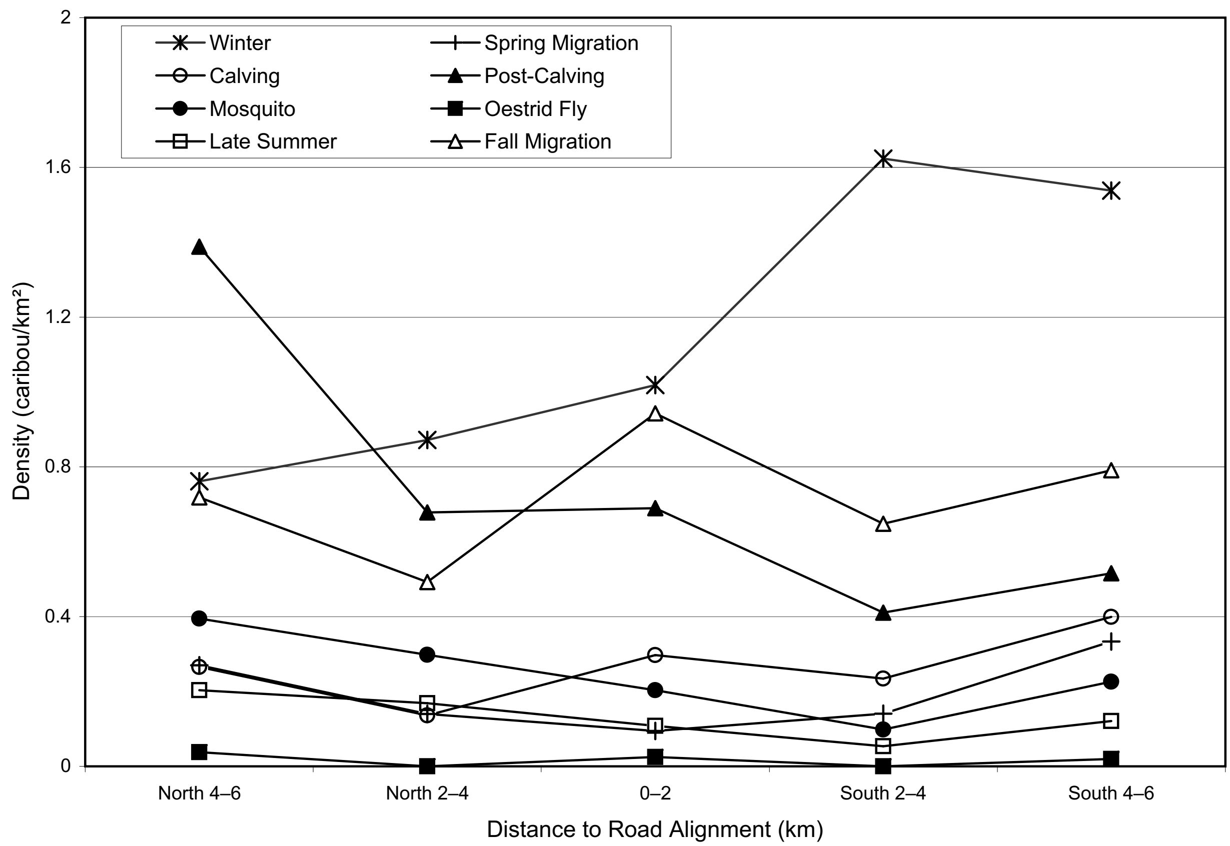


Figure 12. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2006.

Table 10. Model-weighted parameter estimates for calving caribou density (*ln* [*calving density + 1/6*]) in the NPRA survey area, June 2006.

Variable	Coefficient	SE	*P*-value
Intercept	–1.485	0.742	0.045
Presence of creeks	–0.525	0.195	0.007
Presence of proposed road	–0.124	0.306	0.685
NDVI_peak	2.279	2.725	0.403
NDVI_rate	–3.147	26.888	0.907
Distance to coast (km)	0.014	0.007	0.051
Tussock tundra (%)	0.381	0.581	0.513
Wet habitat (%)	0.523	0.580	0.367
Transect number (W to E)	–0.074	0.020	<0.001

These results for the calving season are consistent with those from the Meltwater study area in the eastern portion of the ASDP study area (Lawhead et al. 2004), which indicated that NDVI during calving was strongly influenced by snow cover. As snow cover melts, it reveals standing dead biomass that has an NDVI value substantially greater than zero (Stow et al. 2004). After snow melt, the spatial pattern of NDVI is strongly influenced by habitat type and the spatial pattern of relative NDVI values does not vary much from year to year. The absolute value of NDVI for a given pixel, after snow melt, appears to reflect the chronology of green-up and plant growth.

Caribou densities in the NPRA survey area during calving indicate a weak preference for areas with higher NDVI_peak values in most years but not in 2006. Given the high correlation between NDVI and habitat type, it is difficult to determine if caribou were selecting specific habitat types or areas with greater vegetative biomass or were simply avoiding wet areas and barrens. Vegetation sampling in 2005 indicated that moist tussock tundra had higher biomass than moist–sedge shrub tundra, but that difference disappeared when evergreen shrubs, which are unpalatable caribou forage, were excluded (Lawhead et al. 2006). Tussock tundra does contain higher biomass of plant species that are preferred by caribou, such as *E. vaginatum*, forbs, and lichens, however. The correlation between caribou density during calving in 2005 and 2006 was low ($r = 0.186$; $P = 0.018$; natural-log transformed), suggesting that different factors influenced caribou abundance between years.

In the combined sample across all years and seasons, the variables that were significantly related to caribou density in the NPRA survey area varied among seasons (Table 11, Appendix M). During winter, caribou density was lower near the proposed road and higher farther from the coast and in areas with more tussock tundra. During spring migration, caribou density was lower near Fish and Judy creeks. During postcalving, density was higher near the creeks and decreased both inland from the coast and from west to east. During the mosquito season, caribou density was higher near the coast and in the western portion of the survey area. During the oestrid-fly season, density was lower in areas with higher vegetative biomass and higher proportions of tussock tundra. In late summer, density was higher near the creeks and in

Table 11. Significance levels of model-weighted parameter estimates of independent variables used in analyses of caribou density within 124 grid cells in the NPRA survey area, 2002–2006.

Variable	Winter	Spring Migration	Calving	Post-calving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
Intercept		--		++	--			
Presence of creeks		--		++			++	+
Presence of proposed road	--							
NDVI_peak			+			--	--	
Distance to coast	++			--	--			++
Tussock tundra (%)	+		++			--		
Wet habitats (%)			-					
Transect number (W to E)			--	--	--		--	--

+ Greater than expected ($P < 0.05$).
++ Greater than expected ($P < 0.01$).
- Less than expected ($P < 0.05$).
-- Less than expected ($P < 0.01$).

the west and was lower in areas with higher biomass values. During fall migration, caribou density was higher near the creeks, inland from the coast, and in the western portion of the survey area.

Overall, strong seasonal patterns in caribou density were evident. Throughout most of the year a west-to-east gradient of decreasing density was evident, probably because the NPRA survey area is located on the eastern edge of the TH range. The riverine area of Fish and Judy creeks had lower densities during the spring but higher densities during postcalving, late summer, and fall migration. The riverine area is characterized by a habitat mosaic of abundant willows and forbs that provide forage during postcalving and which are located near barrens, dunes, and river bars that provide fly-relief habitat. Caribou densities near the coast were lower in winter and fall and higher during postcalving and mosquito season, consistent with increased use of coastal areas during mosquito harassment. Caribou densities during winter and calving were higher in areas with high proportions of tussock tundra. During winter, caribou presumably feed on the abundant lichens in tussock tundra habitat and may select windblown areas with less snow. During calving, tussock tundra provides abundant forage, such as *E. vaginatum*, as well as drier conditions during the seasonal flooding that accompanies snow melt in wet habitats. Throughout most of the year there was little evidence that the area around the proposed ASDP road in NPRA was used by caribou to a different degree than adjacent areas, although caribou group density during winter was lower in grid cells containing the road.

CONCLUSIONS

Analysis of the VHF, satellite, and GPS telemetry data sets clearly demonstrates that the Colville River delta and ASDP study area (48-km radius circle centered on CD-4) are at the interface of the annual ranges of the TH and CAH. The CD-4 drill site is located in an area that is used relatively little by caribou from either herd. The TH consistently uses the western half of the ASDP study area to some extent during all seasons of the year; caribou numbers generally are low during calving, vary substantially during the insect season, and then tend to increase in the fall. In contrast, the CAH uses the eastern half of the ASDP study area primarily during calving (including concentrated calving in the southeastern part of the study area) and the insect season. Although caribou from both herds occur on the Colville delta occasionally, large movements onto or across the delta are uncommon for either herd. CAH caribou are more likely to occur on the delta in summer and TH caribou are more likely to occur during fall or spring migration.

Radio-collared TH caribou occasionally crossed the proposed ASDP pipeline/road corridor alignment extending from Alpine CD-2 to the proposed CD-7 drill site in NPRA, primarily during fall migration, but the road alignment is in an area of low-density use. Collared CAH caribou crossed the alignment very rarely and the proposed corridor will have little or no effect on the CAH unless movement patterns change substantially in the future. Because TH caribou use the western half of the ASDP study area year-round, however, our detailed analyses of caribou distribution and density focused primarily on the NPRA survey area, which encompasses the proposed ASDP road alignment.

Use of the NPRA survey area by TH caribou varies widely among seasons. These differences can be described in part by snow cover, vegetative biomass, habitat distribution, and distance to the coast. During calving, caribou generally use areas of higher plant biomass (estimated from NDVI values), higher proportions of tussock tundra, and lower proportions of wet habitats. Calving tends to occur in areas of patchy snow cover, although calving habitat selection appears to vary depending on snow-melt timing and plant phenology, and may vary between adjacent herds.

The riverine habitats along Fish and Judy creeks were selected by caribou in the postcalving, oestrid fly, and late summer seasons. The complex mosaic of riverine habitats provides opportunities both for foraging and for relief from oestrid-fly harassment. The presence of these streams was a significant variable explaining the distribution and density of caribou in the NPRA survey area, affecting the geographic-section and distance-zone analyses.

Because the NPRA survey area is on the eastern edge of the TH range, a natural west-to-east gradient of decreasing density occurs during much of the year. Caribou density is typically lowest in the southeastern section of the NPRA survey area, in which the proposed road alignment is located, than in other sections of the survey area. We found little evidence for selection or avoidance of specific distance zones within 6 km of the proposed road alignment.

The current emphasis of this study is to compile predevelopment baseline data on caribou density and movements in the ASDP study area. Detailed analyses of the existing patterns of seasonal distribution, density, and movements are providing a useful record of the way in which caribou use the study area. Besides focusing efforts in future years of the research program, the data reported here will be important for evaluating and mitigating the potential impacts of ASDP development on caribou distribution and movements.

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Appendix A. Cover-class descriptions of the NPRA earth-cover classification (BLM and Ducks Unlimited 2002).

Cover Class	Description
Clear Water	Fresh or saline waters with little or no particulate matter. Clear-water areas are typically deep (greater than one meter). The clear-water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage by these species.
Turbid Water	Waters that contain particulate matter or shallow (<1 m), clear waterbodies that are spectrally different from clear water. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. The turbid-water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis* but generally less than 15% surface coverage by these species.
Carex aquatilis	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Carex aquatilis*. A small percentage of *Arctophila fulva, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may be present.
Arctophila fulva	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Arctophila fulva*. A small percentage of *Carex aquatilis, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may also be present.
Flooded Tundra–Low-centered Polygons	Polygon features that retain water throughout the summer. This class is composed of 25–50% water; *Carex aquatilis* is the dominant species in permanently flooded areas. The drier ridges of polygons are composed mostly of *Eriophorum russeolum, Eriophorum vaginatum, Sphagnum* spp., *Salix* spp., *Betula nana, Arctostaphylos* spp., and *Ledum palustre*.
Flooded Tundra–Non-pattern	Continuously flooded areas composed of 25–50% water. *Carex aquatilis* is the dominant species. Other species may include *Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris*. Non-pattern is distinguished from low-centered polygons by the lack of polygon features and associated shrub species that grow on dry ridges of low-centered polygons.
Wet Tundra	Associated with areas of super-saturated soils and standing water. Wet tundra often floods in early summer and generally drains of excess water during dry periods, but remains saturated throughout the summer. It is composed of 10–25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum angustifolium*, and other sedges, grasses, and forbs.
Sedge/Grass Meadow	Dominated by the sedge family. This class commonly consists of a continuous mat of sedges and grasses with a moss and lichen understory. The dominant species are *Carex aquatilis, Eriophorum angustifolium, Eriophorum russeolum, Arctagrostis latifolia* and *Poa arctica*. Associated genera include *Cassiope* spp., *Ledum* spp., and *Vaccinium* spp..
Tussock Tundra	Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Tussock tundra is common throughout the Arctic Foothills and may be found on well-drained sites in all areas of the NPRA. Cottongrass tussocks are the dominant landscape elements and moss is the common understory. Lichen, forbs, and shrubs are also present in varying densities. Associated genera include *Salix* spp., *Betula nana*, *Ledum palustre*, and *Carex* spp.
Moss/Lichen	Associated with low-lying lakeshores and dry sandy ridges dominated by moss and lichen species. As this type grades into a sedge type, graminoids such as *Carex aquatilis* may increase in cover, forming an intermediate zone.
Dwarf Shrub	Associated with ridges and well-drained soils and dominated by shrubs less than 30 cm in height. Because of the relative dryness of the sites on which this cover type occurs, it is the most species-diverse. Major species include *Salix* spp., *Betula nana*, *Ledum palustre, Dryas* spp., *Vaccinium* spp., *Arctostaphylos* spp., *Eriophorum vaginatum, and Carex aquatilis.* This class frequently occurs over a substrate of tussocks.

Appendix A. Continued.

Cover Class	Description
Low Shrub	Associated with small streams and rivers, but also occurs on hillsides in the southern portion of the NPRA. This class is dominated by shrubs between 30 cm and 1.5 m in height. Major species included *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre.*
Dunes/Dry Sand	Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with less than 10% vegetation. Plant species may include *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Sparsely Vegetated	Occurs primarily along the coast in areas affected by high or storm tides, in recently drained lake or pond basins, and where there is bare mineral soil that is being recolonized with vegetation. Dominated by non-vegetated material with 10–30% vegetation. The vegetation in these areas may include rare plants, but the more commonly found species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes.*
Barren Ground/Other	Associated with river and stream gravel bars, mountainous areas and urban areas. Includes less than 10% vegetation. May incorporate dead vegetation associated with salt burn from ocean water.

Appendix B. Snow depth (cm; April 1–May 31) and cumulative thawing degree-days (° C above freezing; May 1–August 15) at the Kuparuk airstrip, 1983–2006.

Year	Snow Depth (cm)			Cumulative Thawing Degree-days (° C)						
	April 1	May 15	May 31	May 1–15	May 16–31	June 1–15	June 16–30	July 1–15	July 16–31	August 1–15
1983	10	5	0	0	3.6	53.8	73.4	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	20	10	0	0	5.0	100.8	112.2	124.7	109.4
1987	15	8	3	0	0.6	6.7	61.4	112.2	127.8	93.1
1988	10	5	5	0	0	16.7	78.1	108.3	143.1	137.5
1989	33	–	10 [a]	0	5.6	20.6	109.4	214.7	168.1	215.8
1990	8	3	0	0	16.1	39.7	132.2	145.0	150.0	82.5
1991	23	8	3	0	7.8	14.4	125.0	73.3	115.0	70.6
1992	13	8	0	0.3	20.3	55.0	85.3	113.9	166.1	104.2
1993	13	5	0	0	8.6	33.6	94.4	175.8	149.7	96.1
1994	20	18	8	0	4.4	49.2	51.7	149.7	175.8	222.2
1995	18	5	0	0	1.1	59.4	87.5	162.8	106.9	83.3
1996	23	5	0	8.1	41.7	86.1	121.1	138.9	168.1	95.8
1997	28	18	8	0	20.8	36.1	109.7	101.7	177.8	194.2
1998	25	8	0	3.6	45.8	74.2	135.0	158.9	184.4	174.4
1999	28	15	10	0	1.4	30.3	67.8	173.3	81.1	177.5
2000	30	23	13	0	0	36.7	173.3	115.0	130.0	120.6
2001	23	30	5	0	1.1	53.3	75.0	82.2	185.6	135.0
2002	30	trace	0	4.4	31.1	59.4	72.8	93.9	136.1	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	10.0	27.8	188.3	150.0	153.3	155.0
2005	23	13	0	0	3.3	16.1	80.0	69.4	81.7	178.9
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
Mean	22	11	3	0.7	11.2	40.3	100.9	123.1	141.8	127.2

[a] Value for June 1

Appendix C. Number and density of caribou in the NPRA and Colville East survey areas, May–October 2001.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (906–988 km²) [f]							
May 20 [g]	319	0	319	638	87.9	0.65	5.8
June 9 [h]	117	6	123	246	49.2	0.26	3.6
June 17 [h]	447	12	459	908	77.3	0.97	3.5
June 23 [h]	654	43	697	1394	117.0	1.47	4.3
July 12 [i]	302	24	326	652	150.9	0.72	8.4
July 23 [i]	nr	nr	636	1272	614.2	1.40	127.2
August 4 [g]	10	0	10	20	10.0	0.02	2.0
August 14 [g]	59	3	62	124	20.7	0.13	2.1
August 28 & 30 [g]	139	8	147	294	34.6	0.30	1.7
September 29 [g]	652	36	688	1376	214.8	1.39	10.6
October 12 [g]	826	30	856	1712	353.2	1.73	10.7
October 24 [g]	377	35	412	824	99.7	0.83	5.7
Total	4538	197	4735			0.82	6.2
COLVILLE EAST (1700 km²) [f]							
August 4–5	10	1	11	22	7.5	0.01	2.75
August 15	7	0	7	14	4.4	0.01	1.17
August 28 & 30	132	3	135	270	72.7	0.16	2.60
September 30 [j]	64	5	69	138	41.2	0.09	6.27
October 12–13	71	6	77	154	23.9	0.09	5.13
October 24 & 26	139	8	147	294	61.3	0.17	5.07
Total	423	23	446			0.09	3.81

[a] Adults + yearlings.
[b] nr = not recorded.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (453–494 km² in NPRA and 850 km² in Colville East).
[g] Total area = 988 km².
[h] Total area = 948 km².
[i] Total area = 906 km².
[j] Part of transects not flown due to fog.

Appendix D. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2002.

Survey Area (Size) and Date	Large Caribou [a]	Calves	Total Caribou	Estimated Total [b]	SE [c]	Density (caribou/km²) [d]	Mean Group Size
NPRA (1310 km²) [e]							
May 3	190	0	190	380	36.1	0.29	3.1
May 25–26	215	0	215	430	72.6	0.33	3.3
June 8	422	8	430	860	129.2	0.66	3.7
June 18	536	4	540	1080	170.6	0.83	6.6
June 27	17	0	17	34	12.0	0.03	3.4
July 18	0	0	0	0	–	0	–
July 26	9	0	9	18	5.3	0.01	1.5
August 3	239	31	270	540	329.0	0.41	15.0
August 14	170	36	206	412	89.5	0.31	2.3
August 26	63	1	64	128	19.3	0.10	1.3
September 9	231	20	251	502	104.7	0.38	4.0
September 24	48	2	50	100	34.0	0.08	6.3
October 6	29	0	29	58	15.9	0.04	2.6
October 24	959	42	1001	2002	345.3	1.53	7.8
Total	3128	144	3272	6544		0.38	4.7
COLVILLE R. DELTA (494 km²) [e]							
July 13	74	0	74	148	49.2	0.30	9.25
July 18	0	0	0	0	–	–	–
July 25	0	0	0	0	–	–	–
August 3	0	0	0	0	–	–	–
August 14	6	0	6	12	3.7	0.02	1.20
August 26	4	0	4	8	3.1	0.02	1.33
September 9	0	0	0	0	–	–	–
Total	84	0	84	168	–	0.05	5.25
COLVILLE EAST (1700 km²) [e]							
May 3	26	0	26	52	13.4	0.03	1.73
August 3–4	6	2	8	16	4.6	0.01	1.33
August 14–15	5	0	5	10	4.3	0.01	1.67
August 27	18	1	19	38	9.5	0.02	2.71
September 9–10	244	11	255	510	76.0	0.30	3.23
September 24 [f]	7	0	7	19	9.9	0.01	7.00
October 6–7	64	0	64	128	32.7	0.08	5.82
October 25–26	66	8	74	148	45.1	0.09	4.93
Total	436	22	458	921		0.07	3.34

[a] Adults + yearlings.
[b] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[c] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[d] Density = Estimated Total / Survey Area Size.
[e] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East).
[f] Part of area not flown due to fog.

Appendix E. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2003.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1310 km²) [f]							
April 24	1565	0	1565	3130	263.0	2.39	5.0
May 20	46	0	46	92	25.5	0.07	3.5
May 30 [g]	81	2	83	166	53.1	0.13	2.3
June 8	225	0	225	450	78.1	0.34	2.7
June 16	401	7	408	816	129.9	0.62	3.0
June 24	521	9	530	1060	130.6	0.81	3.8
July 7	1	1	2	4	2.8	<0.01	2.0
July 20	0	0	0	0	–	0	–
August 4	296	23	319	638	144.4	0.49	2.8
September 3	nr	nr	108	216	39.5	0.17	2.9
September 16	nr	nr	565	1130	204.8	0.86	6.7
September 29	nr	nr	2262	4524	756.9	3.46	7.0
October 28	nr	nr	176	352	75.4	0.27	7.0
Total			6289	12,578	–	0.74	4.9
COLVILLE R. DELTA (494 km²) [f]							
June 28	31	0	31	62	22.4	0.13	4.4
July 7	1	1	2	4	2.8	0.01	2.0
July 20	3	0	3	6	2.2	0.01	1.0
September 16	nr	nr	13	26	14.2	0.05	6.5
Total			49	98	–	0.05	3.8
COLVILLE EAST (1700 km²) [f]							
April 24	314	0	314	628	172.4	0.37	5.5
May 14	121	0	121	242	79.1	0.16	3.6
October 28–29	nr	nr	426	852	182.3	0.50	7.0
Total			861	1722	–	0.34	5.7

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East were surveyed).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).

Appendix F. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2004.

Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1310 km²) [f]							
May 18	29	0	29	58	17.0	0.04	5.8
June 25	2	0	2	4	2.8	<0.01	1.0
August 10	45	0	45	90	11.0	0.07	1.1
September 15	183	27	210	420	81.9	0.32	6.0
October 18	802	nr	802	1604	229.3	1.23	12.2
Total	1061	27	1088	2176	–	0.33	7.4
COLVILLE R. DELTA (494 km²) [f]							
June 25	316	13	329	658	418.7	1.33	82.3
August 11	4	0	4	8	3.1	0.02	1.0
Total	320	13	333	666	–	0.67	41.6
COLVILLE EAST (1700 km²) [f]							
August 11	22	1	23	46	13.0	0.03	1.5
September 16	193	19	212	424	76.9	0.25	4.9
October 19	1335	nr	1335	2670	743.7	1.57	17.8
Total	1550	20	1570	3140	–	0.62	11.8

[a] Adults + yearlings.
[b] nr = not recorded; calves not reliably differentiated due to large size.
[c] Estimated Total = Total Caribou × 2, to adjust for 50% sampling coverage.
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Survey coverage was 50% (654 km² in NPRA, 247 km² on the Colville R. Delta, and 850 km² in Colville East were surveyed).

Appendix G. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2005.

Survey Area (Size) and Date	Large Caribou [a,b]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1720 km²) [f]							
April 23	590	0	590	1180	184.6	0.686	6.0
June 6 [g]	64	6	70	263	54.5	0.149	2.6
June 13 [h]	279	45	324	648	296.9	0.753	4.6
June 20	476	69	545	1090	151.8	0.634	4.9
June 28	47	0	47	94	17.2	0.055	1.5
August 3 [i]	nr	nr	8947	9015	51.5	5.241	357.9
August 17	16	2	18	36	7.3	0.021	2.0
August 31	41	0	41	82	14.0	0.048	2.1
October 21	144	14	158	316	54.6	0.184	3.4
COLVILLE R. DELTA (494 km²) [f]							
April 24	4	0	4	8	4.3	0.02	2
June 11 [h]	1	0	1	2	3.4	0.01	1
June 20	9	0	9	18	10.0	0.04	4.5
June 28	170	12	182	364	85.0	0.74	6.1
August 2	nr	nr	881	994	71.0	2.01	55.1
August 17	22	1	23	46	18.7	0.09	5.8
August 31	9	1	10	20	8.4	0.04	2.5
October 21 & 23	0	0	0	0	–	0	–
COLVILLE EAST (1696 km²) [f]							
April 24	39	0	39	78	20.9	0.05	3.0
June 5–6 [g,i]	290	79	369	1387	164.4	0.97	2.18
June 10–11 [j]	1010	363	1373	2746	332.3	1.92	5.12
June 21	2172	842	3014	6028	624.1	3.55	10.3
June 29 [k]	366	34	400	800	867.7	0.82	15.4
August 2–3	nr	nr	1915	1962	74.1	1.16	95.8
August 15–16	34	4	38	76	19.8	0.05	3.8
August 31 [k]	19	1	20	40	18.4	0.05	2.0
October 4 [k]	32	3	35	70	116.3	0.20	4.4
October 21 & 23 [k]	82	4	86	172	59.3	0.12	5.7

[a] Adults + yearlings.
[b] nr = not recorded (calves not differentiated).
[c] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage) or × 4 (for 25% sampling coverage).
[d] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[e] Density = Estimated Total / Survey Area Size.
[f] Typical survey coverage was 50% (860 km² in NPRA, 247 km² on the Colville R. Delta, and 848 km² in Colville East).
[g] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994).
[h] Flown at 90-m altitude and 25% coverage due to low cloud ceiling.
[i] Assumes all large groups along the coast were found.
[j] Survey of calving transects (1.6-km spacing) at 90-m altitude and 50% coverage (Lawhead and Prichard 2006).
[k] Survey shortened due to poor weather.

Appendix H. Estimated numbers and densities of caribou in the Colville East and Colville River Delta calving survey areas, June 1993 and 1995–2006 (from Lawhead and Prichard 2007).

Survey Area	Date	Total Area (km²)	Estimated Total Caribou [a]	Total Density (per km²)	Estimated Total Calves [a]	Calf Density (per km²)	Snow Cover
Colville East [b,c,d,e,f]	26 May 1993	650	60	0.09	0	0	High; SCF not used
	27 May 1993	1050	87	0.08	0	0	High; SCF not used
	3 June 1993	1050	542	0.52	0	0	Patchy; SCF used
	8 June 1993	709	914	1.29	148	0.21	Low; SCF not used
	11 June 1993	910	2181	2.40	558	0.61	None
	4–5 June 1995	1057	315	0.30	41	0.04	Patchy; SCF used
	12–13 June 1995	1349	2057	1.52	305	0.23	None
	3–4 June 1996	1362	800	0.59	159	0.12	None
	12–13 June 1996	1358	2670	1.97	786	0.58	None
	1–2 June 1997	1362	555	0.41	60	0.04	Patchy; SCF used
	10–12 June 1997	1321	4035	3.05	1214	0.92	Patchy; SCF used
	3 June 1998	1370	1840	1.34	284	0.21	None
	11–12 June 1998	1370	1902	1.39	310	0.23	None
	11 June 1999	1478	2166	1.47	544	0.37	Low; SCF not used
	11–12 June 2000	1478	966	0.65	192	0.13	Patchy; SCF used
	5–6 June 2001	1478	169	0.11	0	0	Patchy; SCF used
	10–11 June 2001	1478	1148	0.78	192	0.13	Patchy; SCF not used
	6–7 June 2002	1432	5584	3.90	830	0.58	None
	10–11 June 2002	1432	6232	4.35	1034	0.72	None
	3–4 June 2003	1432	1162	0.81	120	0.08	Patchy; SCF used
	10 & 12 June 2003	1432	2790	1.95	614	0.43	Low; SCF not used
	5 June 2004	1262	1092	0.61	350	0.28	Patchy; SCF used
	16 June 2004	1323	6982	5.28	2286	1.73	None
	5–6 June 2005	1432	1387	0.97	297	0.21	Patchy; SCF used
	10–11 June 2005	1432	2746	1.92	726	0.51	Low; SCF not used
	3–5 June 2006	1432	395	0.28	53	0.04	Patchy, SCF used
	11–12 June 2006	1432	4056	2.83	1022	0.71	None
Colville R. Delta	28 May 1993	637	27	0.04	0	0	High; SCF not used
	10 June 1993	637	0	0	0	0	Low; SCF not used
	3 June 1995	637	18	0.03	0	0	Low; SCF not used
	2 June 1996	637	58	0.09	0	0	None
	13 June 1996	637	10	0.02	1	<0.01	None
	1 June 1997	637	0	0	0	0	High; SCF not used
	12 & 20 June 1997	637	0	0	0	0	Patchy; SCF used
	9 June 2006	637	6	0.01	1	<0.01	None

[a] Estimate adjusted for low sightability (Sightability Correction Factor = 1.88; Lawhead et al. 1994) where indicated.
[b] Extended south to 70° N latitude in 1995, thus incorporating much of 1993 Colville Inland survey area.
[c] Extended south in 1999 to incorporate Meltwater South study area.
[d] Dropped westernmost transect in 2002.
[e] Unable to survey 3 westernmost transects on 5 June 2004.
[f] Unable to survey 2 westernmost transects on 16 June 2004.

Appendix I. Location and number of muskoxen and grizzly bears observed in the NPRA survey area, May–October 2006.

Species	Date	Total Number	Number of Adults	Number of Young	General Location
Muskox	May 3	14	14	0	Tingmeachsiovik River
	June 10	13	13	0	Tingmeachsiovik River
	June 26	23	13	10	Near Kalikpik River
	August 15	22	16	6	Tingmeachsiovik River
	August 30	21	18	3	Tingmeachsiovik River
Grizzly bear	June 10	2	2	0	Near Kalikpik River
	June 14	3	1	2	Near Ublutuoch River
	June 14	3	1	2	Near Fish Creek
	August 15	3	1	2	Near Kalikpik River

Appendix J. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2006 and for habitat type (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2006 NPRA survey areas.

Survey Area	Variable	Statistic	Coast	North	Rivers	Southeast	Southwest	West
2002–2004	Area	km²	9.8	88.2	156.1	232.2	130.9	36.4
	Vegetative Biomass	NDVI_calving	0.2615	0.2351	0.2533	0.3012	0.3126	0.2965
		NDVI_621	0.4029	0.3845	0.3904	0.4322	0.4299	0.4305
		NDVI_rate	0.0118	0.0124	0.0114	0.0109	0.0098	0.0112
		NDVI_peak	0.5265	0.5277	0.5262	0.5552	0.5476	0.5606
	Snow Cover 24 May	Mean %	100.0	99.2	98.4	99.9	100.0	100.0
	Snow Cover 9 June	Mean %	5.9	9.7	3.0	4.1	5.1	4.5
	Habitat Type (% area)	Water	9.7	26.5	14.4	17.7	11.4	11.3
		Carex aquatilis	11.5	6.4	6.4	6.2	9.3	5.1
		Flooded Tundra	33.2	11.6	14.9	18.3	19.9	12.2
		Wet Tundra	12.4	7.6	11.5	7.3	10.7	9.0
		Sedge/Grass Meadow	7.3	21.9	14.2	5.4	9.3	28.7
		Tussock Tundra	23.8	22.0	25.0	41.3	35.1	31.1
		Moss/Lichen	1.4	0.9	3.3	0.3	0.7	0.5
		Dwarf Shrub	0.2	1.9	3.2	2.9	3.1	1.8
		Low Shrub	0	<0.1	0.1	0.3	0.3	0.1
		Dry Dunes	0.1	0.1	2.1	0.1	0	0
		Sparsely Vegetated	<0.1	0.5	2.9	0.1	<0.1	<0.1
		Barren Ground	0.4	0.7	2.1	0.1	0.1	0.1
2005–2006	Area	km²	93.2	206.6	160.7	232.2	130.9	36.4
	Vegetative Biomass	NDVI_calving	0.1974	0.2399	0.2512	0.3012	0.3125	0.2965
		NDVI_621	0.3474	0.3910	0.3892	0.4322	0.4299	0.4305
		NDVI_rate	0.0125	0.0126	0.0115	0.0109	0.0098	0.0112
		NDVI_peak	0.4694	0.5259	0.5255	0.5552	0.5475	0.5607
	Snow Cover 24 May	Mean %	99.9	99.5	98.4	99.9	100.0	100.0
	Snow Cover 9 June	Mean %	12.2	7.0	3.4	4.1	5.1	4.5
	Habitat Type (% area)	Water	24.1	22.1	15.4	17.7	11.4	11.3
		Carex aquatilis	8.3	6.3	6.4	6.2	9.3	5.1
		Flooded Tundra	15.1	10.1	14.9	18.3	19.9	12.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.7	9.0
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	9.3	28.7
		Tussock Tundra	19.6	25.5	24.8	41.3	35.1	31.1
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7	0.5
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1	1.8
		Low Shrub	<0.1	<0.1	0.1	0.3	0.3	0.1
		Dry Dunes	3.2	0.3	2.0	0.1	0	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1	<0.1
		Barren Ground	8.0	0.8	2.1	0.1	0.1	0.1

Appendix K. Model selection results for ANCOVA tests of caribou density during calving 2006 in the NPRA survey area (163 grid cells). The best model (bold type) contained the variables indicating the presence or absence of Fish or Judy creeks (Creek), presence or absence of the proposed ASDP road (Road), transect number west to east (W to E), and distance to coast (Coast).

Model [a]	RSS [b]	*n* [c]	K [d]	AIC_c [e]	ΔAIC_c [f]	w_i [g]
Creek, Road, W to E, Coast	**114.69**	**163**	**6**	**–44.76**	**0**	**0.262**
Creek, Road, W to E, Coast, Wet Habitat	113.93	163	7	–43.66	1.10	0.151
Creek, Road, W to E, Coast, NDVI_peak	114.48	163	7	–42.87	1.89	0.102
Creek, Road, W to E, Coast, Tussock	114.55	163	7	–42.77	1.98	0.097
Creek, Road, W to E, Coast, NDVI_rate	114.68	163	7	–42.58	2.17	0.088
Creek, Road, W to E	117.80	163	5	–42.56	2.20	0.087
Creek, Road, W to E, NDVI_peak	116.35	163	6	–42.42	2.34	0.081
Creek, Road, W to E, Tussock	116.84	163	6	–41.73	3.03	0.058
Creek, Road, W to E, NDVI_rate	117.45	163	6	–40.89	3.87	0.038
Creek, Road, W to E, Wet Habitat	117.66	163	6	–40.59	4.17	0.033
Creek, Road, Coast, Wet Habitat	122.36	163	6	–34.20	10.56	0.001
Creek, Road, Coast	125.38	163	5	–32.39	12.36	0.001
Creek, Road, Coast, Tussock	124.93	163	6	–30.82	13.94	<0.001
Creek, Road, Coast, NDVI_peak	125.37	163	6	–30.25	14.51	<0.001
Creek, Road, Coast, NDVI_rate	125.37	163	6	–30.24	14.51	<0.001
Creek, Road, NDVI_peak	132.20	163	5	–23.76	21.00	<0.001
Creek, Road, NDVI_rate	132.52	163	5	–23.37	21.39	<0.001
Creek, Road, Wet Habitat	132.83	163	5	–22.98	21.78	<0.001
Creek, Road, Tussock	134.14	163	5	–21.38	23.37	<0.001

[a] Coast = distance from coast; Tussock = proportion of tussock tundra; Wet Habitat = combined proportions of 4 types; see text).
[b] Residual Sum of Squares.
[c] Sample size.
[d] Number of estimable parameters in the approximating model.
[e] Akaike's Information Criterion corrected for small sample size.
[f] Difference in value between the AIC_c of the current model and that of the best approximating model.
[g] Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix L. Model selection results for ANCOVA tests of caribou density in different seasons during 2002–2006 in the NPRA survey area (124 grid cells). Bold type denotes the best model for each season.

		Model [a]														
Season	Value	C,R,NP	C,R,DC	C,R,TT	C,R,WH	C,R,TR	C,R,DC,NP	C,R,DC,TT	C,R,DC,WH	C,R,TR,DC	C,R,TR,NP	C,R,TR,TT	C,R,TR,WH	C,R,TR,DC,NP	C,R,TR,DC,TT	C,R,TR,DC,WH
All Seasons	n [b]	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124
	K [c]	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7
Winter	RSS [d]	100.5	85.9	107.4	108.3	98.9	83.7	83.7	84.3	84.9	90.6	88.3	90.1	82.4	**80.7**	81.7
	AIC_c [e]	–15.5	–35.0	–7.3	–6.3	–17.5	–36.0	–36.0	–35.1	–34.2	–26.2	–29.3	–26.9	–35.7	**–38.3**	–36.8
	w_i [f]	0	0.06	0	0	0	0.11	0.11	0.07	0.04	0	0	0	0.09	**0.35**	0.16
Spring	RSS	40.0	40.1	40.1	39.9	**39.0**	40.0	40.1	39.9	38.7	39.0	39.0	39.0	38.5	38.6	38.7
	AIC_c	–129.8	–129.4	–129.4	–130.0	**–132.9**	–127.6	–127.2	–127.9	–131.6	–130.8	–130.7	–130.8	–130.1	–129.7	–129.3
	w_i	0.05	0.04	0.04	0.06	**0.24**	0.02	0.01	0.02	0.12	0.09	0.08	0.09	0.06	0.05	0.04
Calving	RSS	43.2	38.3	47.2	47.2	30.9	37.5	38.2	38.2	30.1	**29.0**	29.2	29.6	28.8	29.0	29.2
	AIC_c	–120.2	–135.3	–109.4	–109.3	–161.7	–135.6	–133.2	–133.4	–163.0	**–167.4**	–166.6	–165.1	–165.9	–165.4	–164.2
	w_i	0	0	0	0	0.02	0	0	0	0.04	**0.31**	0.21	0.10	0.15	0.12	0.06
Postcalving	RSS	62.0	61.7	60.7	61.1	45.5	61.7	60.2	60.8	**41.0**	45.1	45.5	45.5	41.0	40.6	40.4
	AIC_c	–75.5	–76.0	–78.2	–77.2	–113.9	–73.8	–76.8	–75.7	**–124.4**	–112.6	–111.7	–111.7	–122.3	–123.5	–124.2
	w_i	0	0	0	0	0	0	0	0	**0.34**	0	0	0	0.12	0.22	0.31
Mosquito	RSS	4.0	4.0	4.1	4.1	4.1	4.0	4.0	4.0	**3.7**	3.9	4.0	4.1	3.6	3.6	3.6
	AIC_c	–414.6	–415.3	–412.5	–410.9	–413.0	–414.6	–414.3	–413.1	**–424.4**	–416.0	–411.8	–410.8	–423.2	–422.2	–423.5
	w_i	0	0	0	0	0	0	0	0	**0.39**	0.01	0	0	0.21	0.13	0.25
Oestrid Fly	RSS	**90.3**	96.8	92.2	97.2	97.7	90.3	91.5	96.1	96.8	90.3	90.3	96.2	96.2	90.3	95.9
	AIC_c	**–28.8**	–20.2	–26.2	–19.6	–19.0	–26.6	–25.0	–18.9	–18.0	–26.7	–26.6	–18.7	–16.5	–24.4	–16.9
	w_i	**0.38**	0.01	0.10	0	0	0.13	0.06	0	0	0.13	0.13	0	0	0.04	0
Late Summer	RSS	21.7	22.0	21.0	21.6	17.3	20.9	20.5	21.2	16.5	**16.1**	17.0	17.2	15.8	16.5	16.5
	AIC_c	–205.7	–204.0	–209.9	–206.3	–233.8	–207.9	–210.3	–206.3	–237.1	**–240.7**	–234.0	–232.2	–240.3	–235.5	–234.9
	w_i	0	0	0	0	0.01	0	0	0	0.07	**0.46**	0.02	0.01	0.37	0.03	0.02
Fall Migration	RSS	60.4	48.7	59.1	59.2	46.1	47.9	45.5	45.7	43.4	46.1	46.0	46.0	42.9	**42.5**	42.6
	AIC_c	–78.7	–105.3	–81.5	–81.1	–112.3	–105.3	–111.6	–111.0	–117.4	–110.1	–110.3	–110.3	–116.7	**–117.7**	–117.6
	w_i	0	0	0	0	0.02	0	0.01	0.01	0.23	0.01	0.01	0.01	0.17	**0.28**	0.26

[a] C = presence or absence of Fish or Judy creeks, R = presence or absence of proposed road, NP = NDVI_peak, DC = distance to coast, TT = proportion of tussock tundra, WH = proportion of wet habitat (4 types combined; see text), and TR = transect number (west to east).
[b] n = sample size.
[c] K = number of estimable parameters in the approximating model.
[d] RSS = Residual Sum of Squares.
[e] AIC_c = Akaike's Information Criterion corrected for small sample size.
[f] w_i = Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix M. Model-weighted parameter estimates, standard error (SE), and *P*-value of variables included in the grid-cell analyses of caribou densities in the NPRA survey area, 2002–2006. Asterisks denote significance of *P*-value (* < 0.05, ** <0.01, *** <0.001).

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–2.143	1.274	0.093
	Presence of Creek	–0.174	0.225	0.439
	Includes Proposed Road	–1.000	0.308	0.001***
	NDVI_peak	6.030	3.285	0.066
	Distance to Coast (km)	0.040	0.011	<0.001***
	Tussock Tundra (%)	1.427	0.65	0.028*
	Wet Habitat (%)	–1.182	0.634	0.062
	Transect Number (West to East)	–0.048	0.027	0.072
Spring Migration	Intercept	–1.810	0.548	0.001***
	Presence of Creek	–0.468	0.143	0.001***
	Includes Proposed Road	–0.350	0.210	0.096
	NDVI_peak	1.341	2.170	0.537
	Distance to Coast (km)	–0.005	0.008	0.516
	Tussock Tundra (%)	0.074	0.426	0.862
	Wet Habitat (%)	0.200	0.410	0.626
	Transect Number (West to East)	–0.028	0.015	0.066
Calving	Intercept	–1.185	1.380	0.391
	Presence of Creek	0.146	0.136	0.282
	Includes Proposed Road	0.066	0.181	0.717
	NDVI_peak	4.765	1.861	0.010**
	Distance to Coast (km)	0.007	0.006	0.306
	Tussock Tundra (%)	1.028	0.393	0.009**
	Wet Habitat (%)	–0.747	0.357	0.037*
	Transect Number (West to East)	–0.093	0.015	<0.001***
Postcalving	Intercept	1.818	0.515	<0.001***
	Presence of Creek	0.852	0.148	<0.001***
	Includes Proposed Road	–0.078	0.216	0.718
	NDVI_peak	0.914	2.318	0.693
	Distance to Coast (km)	–0.027	0.007	<0.001***
	Tussock Tundra (%)	0.499	0.439	0.256
	Wet Habitat (%)	–0.604	0.428	0.158
	Transect Number (West to East)	–0.133	0.018	<0.001***
Mosquito	Intercept	–1.456	0.202	<0.001***
	Presence of Creek	–0.038	0.044	0.386
	Includes Proposed Road	–0.084	0.065	0.192
	NDVI_peak	–0.716	0.697	0.304
	Distance to Coast (km)	–0.008	0.002	0.001***
	Tussock Tundra (%)	0.028	0.134	0.832
	Wet Habitat (%)	–0.144	0.149	0.336
	Transect Number (West to East)	–0.017	0.005	0.001***
Oestrid Fly	Intercept	2.339	2.602	0.369
	Presence of Creek	0.406	0.223	0.068
	Includes Proposed Road	–0.287	0.314	0.360
	NDVI_peak	–9.998	3.173	0.002**
	Distance to Coast (km)	–0.003	0.010	0.748
	Tussock Tundra (%)	–1.772	0.624	0.005**
	Wet Habitat (%)	0.689	0.620	0.267
	Transect Number (West to East)	0.022	0.026	0.387
Late Summer	Intercept	1.442	0.911	0.113
	Presence of Creek	0.355	0.098	<0.001***
	Includes Proposed Road	0.165	0.136	0.223
	NDVI_peak	–3.697	1.421	0.009**
	Distance to Coast (km)	–0.007	0.005	0.148
	Tussock Tundra (%)	–0.278	0.288	0.334
	Wet Habitat (%)	0.036	0.283	0.900
	Transect Number (West to East)	–0.060	0.010	<0.001***
Fall Migration	Intercept	0.573	0.710	0.420
	Presence of Creek	0.321	0.157	0.042*
	Includes Proposed Road	0.152	0.223	0.496
	NDVI_peak	–2.840	2.398	0.236
	Distance to Coast (km)	0.023	0.008	0.004**
	Tussock Tundra (%)	–0.720	0.463	0.120
	Wet Habitat (%)	0.680	0.452	0.132
	Transect Number (West to East)	–0.059	0.019	0.002**