CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2008

FOURTH ANNUAL REPORT

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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 encompasses CD-3 (also 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 fourth year of the ASDP caribou monitoring study, combining analyses of data from aerial-transect surveys, radio telemetry, and remote sensing. Aerial strip-transect surveys of caribou distribution were conducted in three adjacent survey areas (NPRA, Colville River Delta, and Colville East) from April to October 2005–2008, and similar data from earlier studies in those areas during 2001–2004 also were analyzed. The telemetry analyses used location data from VHF, satellite, and GPS radio-collars in the Teshekpuk Herd (TH) and Central Arctic Herd (CAH) 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 1990–2008 for the TH and 1986–1990 and 2001–2005 for the CAH, and GPS-collar data were collected during 2004–2008 for the TH (including 30 new collars deployed specifically for this study in early July 2006, late June 2007, and late June–early July 2008) and during 2003–2006 and 2008 for the CAH (including four new collars deployed specifically for this study in early July 2008).
- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2002–2008, 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 or early August 2005–2008; NDVI_peak). The average daily rate of change in NDVI values between calving and peak lactation was estimated (NDVI_rate). In 2007 and 2008, we also calculated NDVI in late fall. The late-fall NDVI values were used as the baseline NDVI level of standing dead vegetation for individual pixels, thereby improving estimates for NDVI_calving and NDVI_rate over the approach used in 2005 and 2006. Snow cover (subpixel-scale snow fraction) in spring 2005–2008 also was calculated for the ASDP study area from MODIS satellite imagery.
- Caribou were present in the three aerial-survey areas during all seasons in which surveys were conducted (2001–2008), 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 the occurrence of caribou was highly variable among seasons. 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 from 9% to 30% for satellite collars during 1990–2008 and 6% to 49% for GPS collars during 2004–2008. The mean proportion of collared CAH caribou within the study area during each month varied between 12 and 62% for satellite collars during 1986–1990 and 2001–2005 and between 0 and 53% for GPS collars during 2003–2006 and 2008.
- 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 the existing Alpine facilities 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. Although two collared females (one satellite-collared, the other GPS-collared) wintered near Nuiqsut in 2008, no movements by satellite- or GPS-collared caribou into the CD-4 vicinity (between Nuiqsut and the Alpine facilities) were recorded in 2008. In the past, movements by collared TH and CAH caribou into the vicinity of CD-4 have occurred infrequently and sporadically.

- Spatial analysis of caribou distribution among different geographic sections of the NPRA survey area during 2002–2008 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, consistent with use of coastal areas as mosquito-relief habitat. Riparian areas along Fish and Judy Creeks contained significantly more caribou groups than would be expected if caribou distribution were uniform during the postcalving season, oestrid fly season, and late summer. The southeastern section of the NPRA survey area, in which the proposed ASDP pipeline/road corridor would be constructed, contained significantly fewer groups in all seasons.
- For the years 2002–2008 combined, caribou in the NPRA survey area used flooded tundra significantly less than expected (based on availability) during calving, postcalving, and fall. Riverine habitats were used more than expected (based on availability) from postcalving through late summer, possibly for forage availability and oestrid-fly relief.
- High-density calving occurred east of the Colville River for the CAH (in the southeastern part of the ASDP study area) and around Teshekpuk Lake for the TH (west of the ASDP study 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. During 2008, caribou in the NPRA survey area selected areas with high estimated values of vegetative biomass during spring and calving. Areas with high estimated levels of vegetative biomass were used less than expected during late summer. Areas with high rates of increase in vegetative biomass in spring were only selected during late summer, probably due to high use of riverine areas.
- 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 ASDP road alignment would be located, had lower caribou densities than did other sections of the survey 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 would be expected (if caribou were uniformly distributed) occurred around the corridor during the spring migration and oestrid-fly season; the latter is probably due to increased use of riparian habitats along Fish and Judy creeks by fly-harassed caribou. Radio-collared TH caribou have occasionally crossed the proposed ASDP road alignment in past years, 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 (Lawhead et al. 2006, 2007, 2008).

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, Person et al. 2007). 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, Prichard and Murphy 2004, Carroll et al. 2005, Carroll 2007, Person et al. 2007). In recent years, a substantial portion of the TH has wintered in areas outside the previous range of the herd, both far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004, Carroll 2007) and southeast in the winter range of the CAH since 2004–2005 (Carroll 2007; Lenart 2007; Lawhead et al. 2007, 2008).

Concentrated calving activity by the CAH tends to occur in two areas of the coastal plain, one located south and southwest of the Kuparuk oilfield and the other east of the Sagavanirktok River, away from most oilfield development (Wolfe 2000, Arthur and Del Vecchio 2007, 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 2007, Lenart 2007).

This caribou monitoring study for the Alpine Satellite Development Program (ASDP) builds on prior research funded by ConocoPhillips Alaska, Inc. (CPAI, and its predecessors Phillips Alaska, Inc., and ARCO Alaska, Inc.) that was conducted 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. 2009 for most current listing of CPAI wildlife studies on the Colville River delta). 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 three types of radio telemetry (very-high frequency [VHF], satellite, and, since 2004, Global Positioning System [GPS] transmitters) (Philo et al. 1993, Prichard and Murphy 2004, Carroll et al. 2005, Carroll 2007, Lawhead et al. 2008). Consultants 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 late 1970s using a combination of VHF, satellite, and GPS telemetry, as well as periodic transect surveys (Cameron et al. 1995, Arthur and Del Vecchio 2007, Lenart 2007). Consultants working for BP Exploration (Alaska) Inc. 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 expand the Alpine development infrastructure on the Colville River delta and extend westward into NPRA. The area available for leasing in the Northeast NPRA Planning Area was expanded after BLM prepared the Amended IAP/EIS (BLM 2005) and Supplemental IAP/EIS (BLM 2008a) and issued the associated ROD (BLM 2008b).

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 and approved by the North Slope Borough Department of Wildlife Management (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 design was to include all other proposed satellite drill sites and infrastructure planned for construction within that 10-year time-frame. Therefore, the scope of this monitoring study also includes the CD-3 pad, 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 the 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 addressed 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. Results of the second year of study (Lawhead et al. 2007) were presented to the NSB Department of Wildlife Management on 5 April 2007 and to the village of Nuiqsut on 1 May 2007. Results of the third year of study (Lawhead et al. 2008) were presented to the NSB Department of Wildlife Management on 17 March 2008 and to the village of Nuiqsut (at a school science fair during the day and a community open house during the evening) on 20 March 2008.

This study addresses specific issues concerning the potential impacts of petroleum development on caribou in the study area, with the intent of drawing on both scientific knowledge and local/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 nearly 40 years ago. The extensive knowledge of local residents 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 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 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, and observations by local subsistence users. Information about the potential effects on caribou movements, however, cannot be addressed adequately without employing methods such as radio telemetry that allow regular 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 pipeine/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 existing CD-4 pipeline/road corridor and the proposed ASDP pipeline/road corridor in NPRA, 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 data on caribou distribution.

3. Evaluate forage availability (aboveground 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) Do 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 scheduled to occur at least three times during the 10-year study; the first year of sampling was 2005 and the second year is planned for 2010. Task 4 was evaluated in 2005 (Lawhead et al. 2006) but subsequently was dropped from the study, with concurrence by the NSB Department of Wildlife Management, because the resolution of the available imagery was not high enough to accomplish the objective reliably.

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 about eight 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 temperatures on the Colville River delta range from about –10° C in May to 15° C in July and August (North 1986), with a strong regional gradient of summer 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 about three weeks from late May to mid-June, and is characterized by the flooding and break-up of rivers and smaller tundra streams. 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; annual reports to CPAI by Michael Baker Jr., Inc.). Break-up 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; annual reports to CPAI by Michael Baker Jr., Inc.). 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 study area was specified 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 (1,432–1,938 km², depending on the survey and year), Colville River Delta (494 km²), and NPRA (988 km² in 2001, expanded to 1,310 km² in 2002 and to 1,720 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 called Nanuq or CD-South), constructed in 2004–2006. The CD-3 and CD-4 drill sites began producing oil in August and November 2006, respectively. CD-3 is a roadless drill site, accessible by ice road in winter and by aircraft in summer, that is 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 three more proposed 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 (BLM 2004). A new access road is proposed by CPAI to connect these potential sites to the Alpine project facilities, which would require a 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 2008, adding to the transect database compiled for the NPRA survey area since 2001 and for the Colville River Delta and Colville East survey areas since the early 1990s. We also analyzed several telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS) and from GPS collars

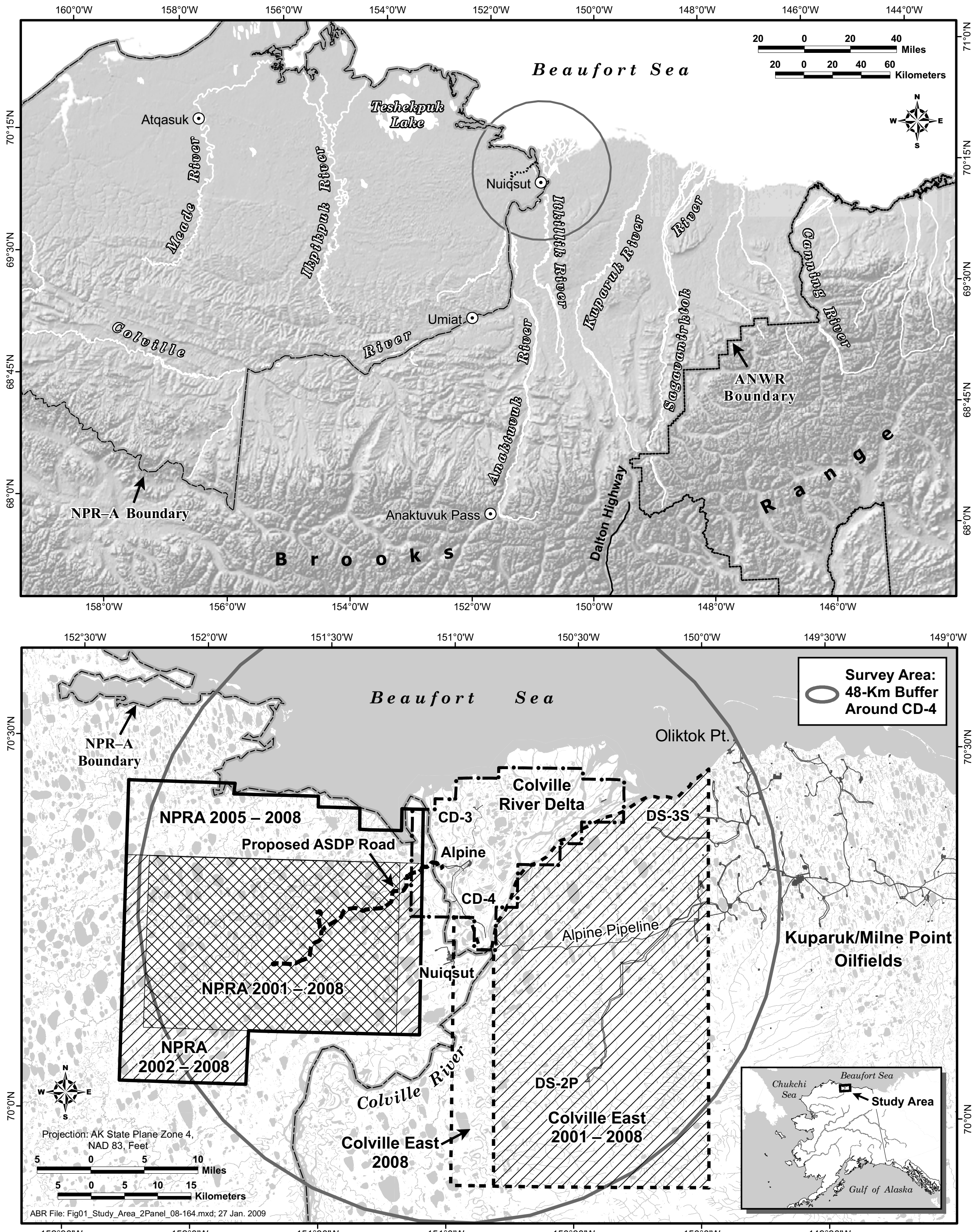

Figure 1. General location of the ASDP caribou monitoring study area (48-km [30-mi] radius around Drill Site CD-4) on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2008 (bottom).

deployed specifically for this study in 2006, 2007, and 2008. The aerial surveys provided broad information on the seasonal distribution and density of caribou in the study area. The satellite and GPS collars provided detailed location and movement data for a small number of known individuals wherever they moved 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 distribution and density in relation to an existing habitat map and to estimated values of plant biomass and snow cover from imagery obtained by satellite 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 from April to October 2008 by two observers looking out opposite sides of a Cessna 206 or 185 airplane, following the same procedures used since 2001 (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; Lawhead et al. 2006, 2007, 2008; this study). The NPRA survey area was expanded in 2002 and again in 2005. The Colville East survey was expanded westward in September 2008. Additional surveys of the Colville East area were conducted during the calving season in 2001–2008 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009). A third observer was present to record data on most calving surveys. 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 during the calving season to increase detection of caribou in areas of patchy snow cover 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. We therefore doubled the number of caribou observed to estimate the total 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 numbers of "large" caribou (adults and yearlings) and calves were recorded, and the perpendicular distance from the transect centerline was estimated in four 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. The number of active collars varied between herds (Table 1). VHF collar locations ranged over much of northern Alaska, but data on the specific areas covered on each radio-tracking flight were not available except in summer 2005, when CPAI contracted ADFG to conduct radio-tracking of VHF-collared caribou in the ASDP 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, visual confirmation was impossible because the aircraft was forced to remain above the cloud cover, so locational accuracy was much lower on those surveys. The sex, age, and reproductive status of

Table 1. Number of radio-collared caribou from the Teshekpuk and Central Arctic herds that provided data for analysis of movements in 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	1990–2008	81	21	102
GPS collars [b]	2004–2008	31	0	31
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 [c]	2003–2006	45	0	45
GPS collars [d]	2008	4	0	4

[a] n/a = not available, but most collared animals were females.
[b] Some individuals were recollared during period; does not include 20 NSB collars deployed in 2008.
[c] Number of different collared caribou that came within 48 km (30 mi) of CD-4 at least once during the period.
[d] Does not include 10 collars deployed by ADFG in 2008.

collared animals were not available for this analysis, but most were adult females (Cameron et al. 1995, Arthur and Del Vecchio 2007). 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–September 2008 (Prichard and Murphy 2004; Lawhead et al. 2006, 2007, 2008, 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) (Table 1). In the TH sample, 102 collared caribou (81 females, 21 males) transmitted signals for a mean duration of 576 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: four TH animals switched to the CAH and five TH animals switched to the WAH. A caribou was assumed to have switched herds if it was in the calving area of another herd during a subsequent calving season. None of these caribou returned to their original herd during the time they were collared.

Satellite telemetry used the Argos system (CLS 2008). Location data from satellite-collar transmitters were received by polar-orbiting satellites and transmitted through command and acquisition stations to data-processing centers originally operated by Service Argos and later by CLS. TH collar locations were transferred monthly to the NSB for data archiving. 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 six 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 (CLS 2008), the data also require screening to remove spurious locations. Using the method of Prichard and Murphy (2004), data were screened to remove duplicate locations, locations obtained before and after collaring or after mortality occurred, and locations for which the Argos system location-quality score (NQ) was zero or "B," indicating unreliability (CLS 2008). 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 three consecutive points. Any three 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 more likely to be accurate. We removed any locations that clearly were inaccurate based on previous and subsequent locations.

In analysis of animal movements, autocorrelation of locations 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 requirement of 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 Laundré 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, therefore, 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 ("xi"; Keating 1994). ξ is similar to our DRA filter because it is calculated using three successive locations and is a measure of the distance between locations, the angle formed by the three locations, and the similarity of length between the two legs (Keating 1994). The CAH data set for October 1986–July 1990 (provided by B. Griffith, USGS) was screened to select the first location each day with the highest NQ score.

GPS Collars

A total of 40 GPS collars (purchased by NSB and CPAI) were successfully deployed on 31 different TH caribou during 2004 and 2006–2008 (Table 1). Four additional GPS collars (purchased by CPAI) were deployed on CAH females in July 2008. GPS collars were deployed on 45 CAH females during 2003–2006, using an interval of 5 h between location fixes (Arthur and Del Vecchio 2007).

GPS collars were deployed only on females because the collar model used (TGW-3680 GEN-III store-on-board configuration with Argos satellite uplink, manufactured by Telonics, Inc., Mesa, AZ) is subject to antenna problems when mounted on expandable collars, which are required for male caribou due to increased neck size during the rutting season (C. Reindel, Telonics, pers. comm.). All location data were stored in the collars for downloading 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 preferable for analysis and archiving). Data were screened to remove any locations obtained prior to collaring or after the collars were removed, as well as any locations that obviously were incorrect because they were far from previous and subsequent locations or were located offshore.

The 2004 TH collars were programmed to record GPS fixes every 3 h (8 locations daily) throughout the entire year. The GPS collars deployed on TH animals in 2006–2008 and on the four CAH animals in 2008 were programmed to record fixes at 2-h intervals (12 locations daily) throughout the year, but battery-life constraints dictated that only 25–50% (depending on the seasonal uplink schedule) of the data collected each day could be transmitted to the Argos satellite. Satellite uplinks were 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 by e-mail from CLS America, Inc. (Largo, MD).

In July 2004, 10 female TH caribou were outfitted by ADFG with GPS collars that were purchased by the NSB. 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. The animals were recaptured and the collars were removed in July 2005. All 10 caribou survived for the entire period; eight had calves in 2005, one of which died soon after birth.

During 8–10 July 2006, 12 female TH caribou were outfitted by ADFG with GPS collars that were purchased by CPAI for this study. The collared sample comprised seven adults aged 3 years or more, three 2-year-olds, and two yearlings. To minimize the risk of injury to animals during collaring, no females with calves were captured in 2006. One of the collared animals died in March 2007 and another in May 2007; those collars were retrieved opportunistically by NPS and ADFG personnel.

The collars on the 10 remaining animals from the 2006 deployment were retrieved during 24–25 June 2007 and 12 more GPS collars (purchased by CPAI) were deployed. The sample collared in 2007 comprised 10 adults, one 2-yr-old, and one yearling. All caribou in the 2007 sample except the yearling were collared previously: six were outfitted with GPS collars in 2006, three were outfitted with satellite collars in 2004 and recollared with satellite collars in 2005, and two were outfitted with satellite collars in 2003 and recollared with satellite collars in 2005. Of the 12 caribou in the 2007 sample, one died in November 2007 and one died in April 2008. Nine of the remaining caribou were recaptured during 29 June–1 July 2008, but the tenth animal (caribou 0624) was with WAH caribou at the western end of the North Slope, too far away to be recaptured.

A total of seven TH and four CAH caribou were outfitted with factory-refurbished GPS collars (purchased by CPAI) in 2008. All of the CAH animals and all but two of the TH animals were new captures; two of the TH animals were recaptures from 2007. Three of the CAH collars also were equipped with Animal Pathfinder™ units (University of Calgary, Alberta), experimental devices that use triaxial accelerometer and magnetometer sensors to estimate the distance and directions of movement between consecutive GPS fixes, thereby providing a continuous movement trace for the collared animals; the devices also take digital photographs periodically for characterization of habitat use. These devices will be retrieved in 2009. ADFG also deployed 10 refurbished GPS collars on CAH females in July 2008, but data from those collars are not included in this report.

All 11 caribou collared in 2008, along with caribou 0624 (collared in 2007 but not recaptured in 2008), were transmitting data at the end of 2008. The last locations used in this report were from 31 December 2008. Due to the differences between collaring and reporting schedules, fewer than half of all GPS locations from caribou collared in 2008 were available for analysis for this report, because it was prepared well before the scheduled retrieval of the collars. The full data set for 2008–2009 will be available after the collars are retrieved in summer 2009 and the data are downloaded.

For the CAH animals outfitted by ADFG with GPS collars during 2003–2005 (Table 1), all location data recorded within the 48-km study area 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 radius. Most of the CAH locations were obtained at 5-h intervals, but occasionally two 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 snowmelt and vegetation green-up over the ASDP study area and a large portion of the surrounding region, due to the wide swath covered on each satellite pass. At least one satellite image over the study area was acquired daily during 20:00–24:00 UT (12:00–16:00 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 Atmospheres 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 µm) and Band 6 (1.628–1.652 µm) as follows:

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

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 can be represented accurately by 500-m pixels. Several algorithms have been proposed to infer subpixel-scale snow cover using MODIS data, including two specific to the Kuparuk River watershed of arctic Alaska. 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 fractions from the MODIS NDSI. Déry et al. (2005) tested this algorithm with two additional Landsat-7 images and added a 9th-order polynomial correction term to the linear model to address underestimation of snow cover at low snow-cover fractions. We calculated snow fractions for late winter and spring 2006, 2007, and 2008 using the algorithm of 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 suitable for our habitat analyses because it includes a corrective intercept term that enforces a minimum of 0.6% snow cover for all pixels, which was not appropriate for our area of primary interest.

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

$$\textit{Snow Fraction} = 0.06 + (1.21 \times \textit{NDSI}).$$

Values less than zero were set to zero, and values greater than one were set to one. 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. Polygons were manually delineated around cloud-affected areas of each image. The MODIS cloud-mask products have been used in the past but these products often mistakenly identify clouds over patchy snow and also miss some cloudy areas, especially at the edges of clouds.

A time series of images covering 12 April–29 September 2008 was processed in this manner. A composite was compiled to identify the first date with 50% or lower snow cover for each pixel. Pixels with >50% water (or ice) cover were excluded from the analysis (see next section for details).

VEGETATIVE BIOMASS

The Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973) is used to estimate the biomass of green vegetation within a pixel of satellite imagery at the time of image acquisition. The rate of increase in NDVI between two images acquired on different days during green-up has been hypothesized to represent the amount of new growth in that time interval (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 values for 2008 were calculated using satellite imagery acquired from the calving period (two days during 1–10 June; NDVI_calving), at the presumed peak of lactation for parturient females (21 June; NDVI_621) (Griffith et al. 2002), and in late July and early August around the peak of the growing season (peak biomass; NDVI_peak).

We calculated the NDVI values from late fall (after senescence but before snowfall) as the baseline level for each pixel. Because of persistent cloud cover and variations in the arrival of snow cover in the fall, the fall NDVI is not calculated for each year. Instead, data from multiple dates are combined to estimate NDVI just before snow covered the landscape (NDVI_fall, referred to as "winter" NDVI by Beck et al. 2006). A maximum value composite was created from two scenes in late September 2007 and two scenes in late September 2008. The snow-free late-fall imagery allowed us to estimate the baseline value of NDVI for non-photosynthetic vegetation, from which we then could estimate the NDVI value of new vegetation based on the increase from that baseline level.

NDVI values near peak lactation (NDVI_621) were interpolated from images obtained before and after 21 June in 2002–2005 and 2008, because the sky was not clear on 21 June in any of those five years. In 2006 a maximum-value composite of interpolated data and actual data from 21 June was used. In 2007 a maximum-value composite of data from 20–21 June was used, with most data coming from 21 June. 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 imagery obtained in late July (2005 and 2006), early August (2007), or both (2008).

The presence of snow, ice, and waterbodies depress NDVI values and decouple them from their relationship to vegetation properties (Macander 2005). Therefore, we removed the effect of large waterbodies in the study area by excluding pixels with 50% or greater water cover. Water cover across the study area was mapped from the best available sources of vector data layers. Where available, we used ecological land survey (ELS) mapping for the Colville River delta and NPRA (Jorgenson et al. 1997, 2003, 2004). Nine habitat types derived from the ELS mapping (aquatic grass marsh, aquatic sedge marsh, brackish water, deep open water, open nearshore water, river or stream, riverine complexes, shallow open water, and tapped lakes) were defined as water for this analysis, along with several artificial waterbodies. For other areas, we used 1:63,360 vector mapping prepared in 1997 by AeroMap U.S., Inc. for ARCO Alaska, Inc. and BP Exploration (Alaska), Inc., with water defined by the lake, river, and sea codes in the *hyd_poly* layer. These data were based on USGS quad maps with some updates to facilities and major rives based on aerial photography. Final updates to the vector inputs were made manually to correct errors and inconsistencies in the source data and the vector data then were converted to a grid at

50-m resolution. The number of water cells was tabulated in each 250-m and 500-m cell in the study area and cells with >50% water cover were flagged. To facilitate comparisons between NDVI (calculated at 250-m resolution) and snow cover (calculated at 500-m resolution), the final overlay mask was constructed at 500-m resolution, so that all 500-m cells with >50% water cover and all 500-m cells containing one or more 250-m cells with >50% water cover were excluded.

CARIBOU DISTRIBUTION ANALYSES

Caribou group locations from aerial transects in the NPRA survey area were analyzed among various geographic sections, habitat types, snow cover classes, and estimated values of vegetative biomass to evaluate the relationship of those factors to caribou distribution. We also compared group locations and density among different 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 eight 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 2005–2008 survey areas, which differed in size, into five sections (Figure 2): (1) the area within 4 km of Fish and Judy creeks (River section); (2) the area within 4 km of the Beaufort Sea coast (Coast); (3) the area north of Fish and Judy creeks (North); (4) the western half of the area south of Fish and Judy creeks and the area west of Fish and Judy creeks (Southwest); and (5) the eastern half of the area south of Fish and Judy creeks (Southeast). In previous years we classified the small area to the west of Fish and Judy Creek as a separate area (West) but, given its small area, we lumped it with the Southwest section this year. The proposed ASDP road would be constructed almost entirely in the Southeast section.

A chi-square goodness-of-fit test was used to evaluate whether the number of caribou groups in each section differed significantly among season and years from expected values, which were calculated 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.

HABITAT USE

To compare habitat use with availability in the expanded 2005–2008 NPRA survey area, we overlaid the caribou group locations from transect surveys on the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 3). A different land-cover map product created for CPAI studies—the ELS habitat map (Jorgenson et al. 1997, 2003, 2004)—did not cover our entire NPRA survey area and classified habitats for birds as well as mammals. We chose the NPRA earth-cover classification (30-m pixel size) for the habitat analysis 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.

Using the NPRA earth-cover classification, our NPRA survey area contained 15 cover classes (Appendix A), which we collapsed into 10 types to analyze habitat use. The barren ground/other, dunes/dry sand, and sparsely vegetated classes, which mostly occurred along Fish and Judy creeks, were combined into a single riverine class. The two flooded-tundra classes were combined as flooded tundra and the clear-water, turbid-water, and *Arctophila fulva* classes were combined into a single water class; these largely aquatic types are used little by caribou, so the water class was excluded from the use–availability analysis.

The use of habitat types by caribou was calculated by selecting all map pixels within a 100-m radius of the location coordinates for each group, which adjusted the percentage to reflect the estimated accuracy of the coordinates. We calculated the percentage of each of the habitat

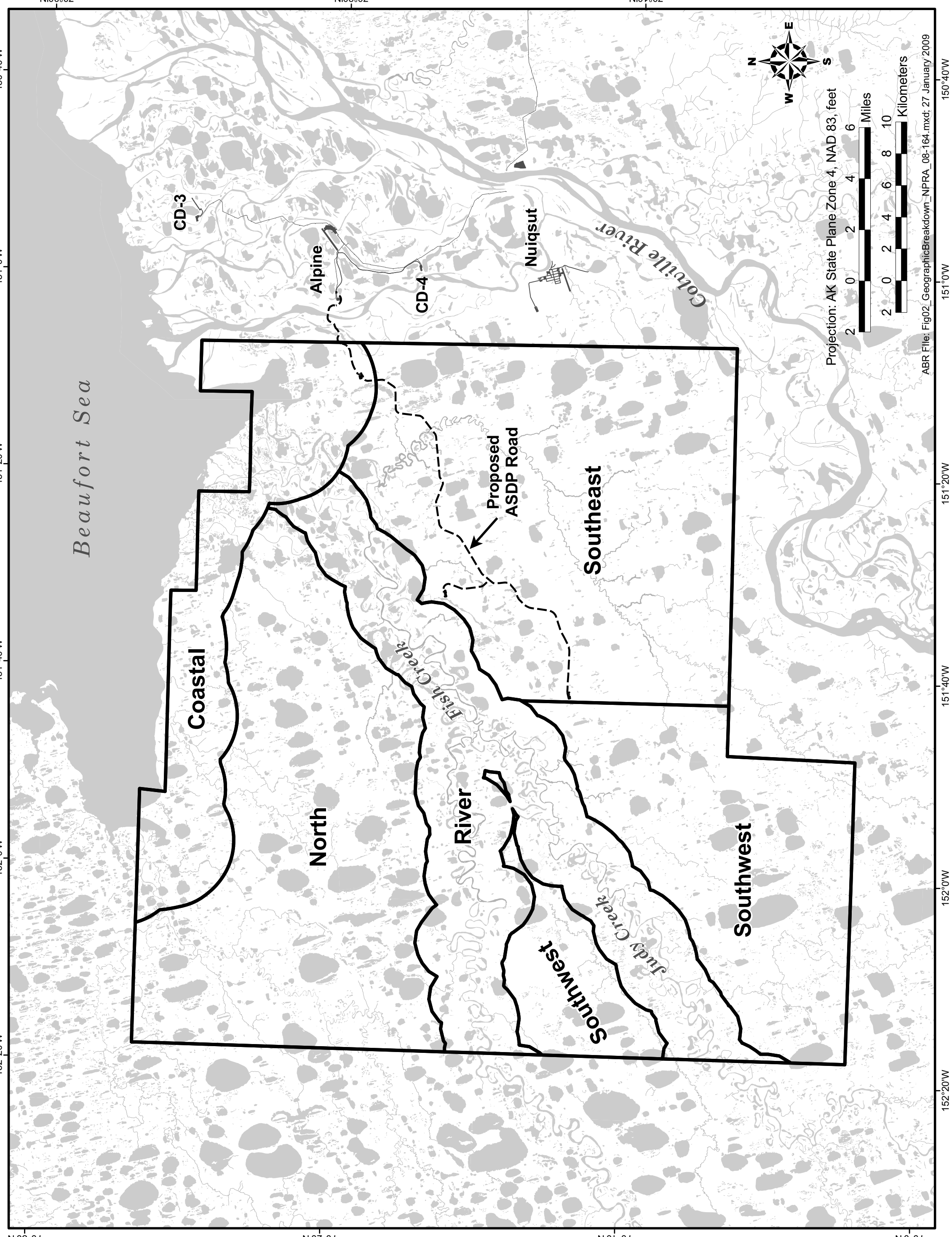

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2008.

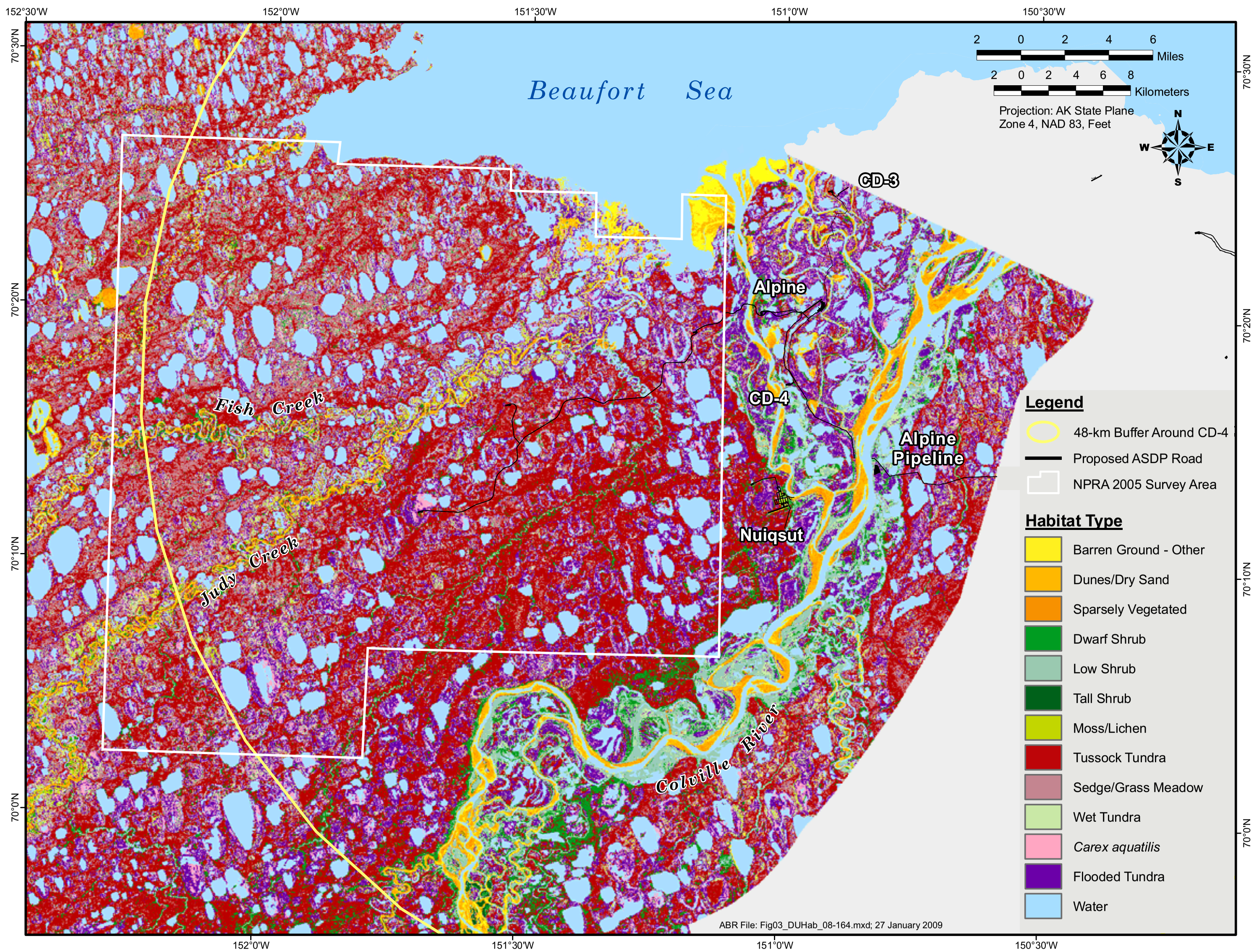

Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2008.

types (excluding water) within the selected pixels. Water was quantified separately to allow calculation of 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, 30,000 random locations were created within the 2005–2008 NPRA survey area using *ArcGIS 9.3* software (ESRI, Redlands, CA). A 100-m-radius buffer was created around each random location and the proportion of each habitat type was calculated. Random locations for which more than 50% of the buffer area was water were removed from the analysis, leaving a total of 25,339 random locations in the 2005–2008 survey area (12,475 in the winter 2008 survey area because it could not be surveyed completely) and 19,470 in the 2002–2004 survey area. In previous years we used a smaller number of random points (10,000) for this analysis. For each time period of interest, we selected from the appropriate survey area (randomly and with replacement) a number of locations equal to the number of caribou groups observed. From that subset of random locations, we calculated the mean proportion of each habitat type. This process was repeated 10,000 times. If the proportion of a habitat type for a caribou group location was more extreme than the average of 95% or 99% of resampled random locations, then we concluded that the observed proportion was significantly different from random at $P = 0.05$ or $P = 0.01$, respectively.

SNOW COVER

The values of snow cover (%) on 21, 22, 23, and 26 May were estimated for each caribou group location from the survey on 9 June (excluding pixels with >50% water); the snow-cover percentages on 26 May were selected for further analysis because that date was the nearest to peak snow melt. The snow-cover percentages for 26 May at all locations where caribou were seen on 9 June were compared with availability using the statistical technique of bootstrapping (Manly 1997), calculated in the following way. From all pixels used by caribou, we selected (randomly and with replacement) a number of samples of snow-cover fractions equal to the number of caribou observed. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 20,000 times to generate mean values. The resulting 20,000 mean values were compared with the availability of snow-cover values in the survey area. If the mean snow-cover value of all pixels within the survey area was more extreme than 95% or 99% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ or $P = 0.01$, respectively.

VEGETATIVE BIOMASS

We compared caribou group locations in the NPRA survey area in 2008 with estimated vegetative biomass (NDVI values). The values of the variables NDVI_calving, NDVI_621, NDVI_rate, and NDVI_peak were determined for each caribou group location (excluding pixels with >50% water) and those values were compared with availability using estimates derived by bootstrapping (Manly 1997). For each season, we selected (randomly and with replacement) a number of samples of NDVI values equal to the number of caribou groups observed, from all pixels used by caribou during that season. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 20,000 times to generate mean values. The resulting 20,000 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 95% or 99% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ or $P = 0.01$, respectively.

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 in relation to natural factors in the road corridor.

The number of groups and the density of caribou by year and by season were calculated within five 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, which were calculated 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.

A Generalized Estimating Equation (GEE) analysis (*SPSS* version 16.0 software, SPSS, Inc., Chicago, IL), using a negative binomial distribution and a log link, was used to test for annual differences in the numbers of caribou among the different distance zones, with each survey as an independent subject, distance zone as a within-subject effect, season as a between-subject effect, and the natural logarithm of the area surveyed as the offset term (to adjust for differences in area among zones, we used a natural-log transformation of area to match the log link in the analysis). This approach differed from previous years, when we used a Generalized Linear Model (GLM) repeated-measures analysis to model natural-log-transformed caribou densities, assuming a normal distribution of the variance. Generalized linear models allow for different forms of variance other than the normal distribution, GEE models further expand generalized linear models to allow for repeated-measures analyses with non-normal variances. Because a GEE model makes more accurate assumptions about the distribution of the variance, it should provide more reliable results.

An autoregressive-1 working correlation matrix was used to model dependencies among distance zones during surveys. Simple contrasts with a Sidak correction for multiple comparisons 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 to look for significant differences among seasons. The single survey in the 2005 oestrid-fly season was removed from this analysis to eliminate the undue influence on the test results that would have resulted from the large groups observed on that single survey. The mosquito and oestrid-fly seasons were combined because the model failed to converge when the mosquito season was included separately, probably as a result of the low numbers of caribou observed during that season.

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 2005–2008 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 numbers for each survey, mean NDVI values from 2008, proportion of tussock-tundra habitat (as a proportion of land area), proportion of wet habitats (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), percent snow cover on 26 May 2008, transect number (as a measure of a west-to-east density gradient; Lawhead et al. 2006), presence or absence of Fish Creek or Judy Creek, and presence or absence of the proposed ASDP road corridor.

The spatial pattern of NDVI_peak was highly correlated across years ($r > 0.9$ for 2005–2008 within the 163 grid cells in the NPRA survey area, after removing one outlier on the Colville River delta composed mostly of barren ground), so we used the value of NDVI_peak from 2008 in multi-year analyses. NDVI_rate from 2008 was used only for analysis of 2008 calving density.

We tested various models for calving density in 2008 and the density in each season for the years 2002–2008 combined. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than in subsequent years. A Generalized Estimating Equation (GEE) analysis (*SPSS* version 16.0 software, SPSS Inc., Chicago, IL) using a negative

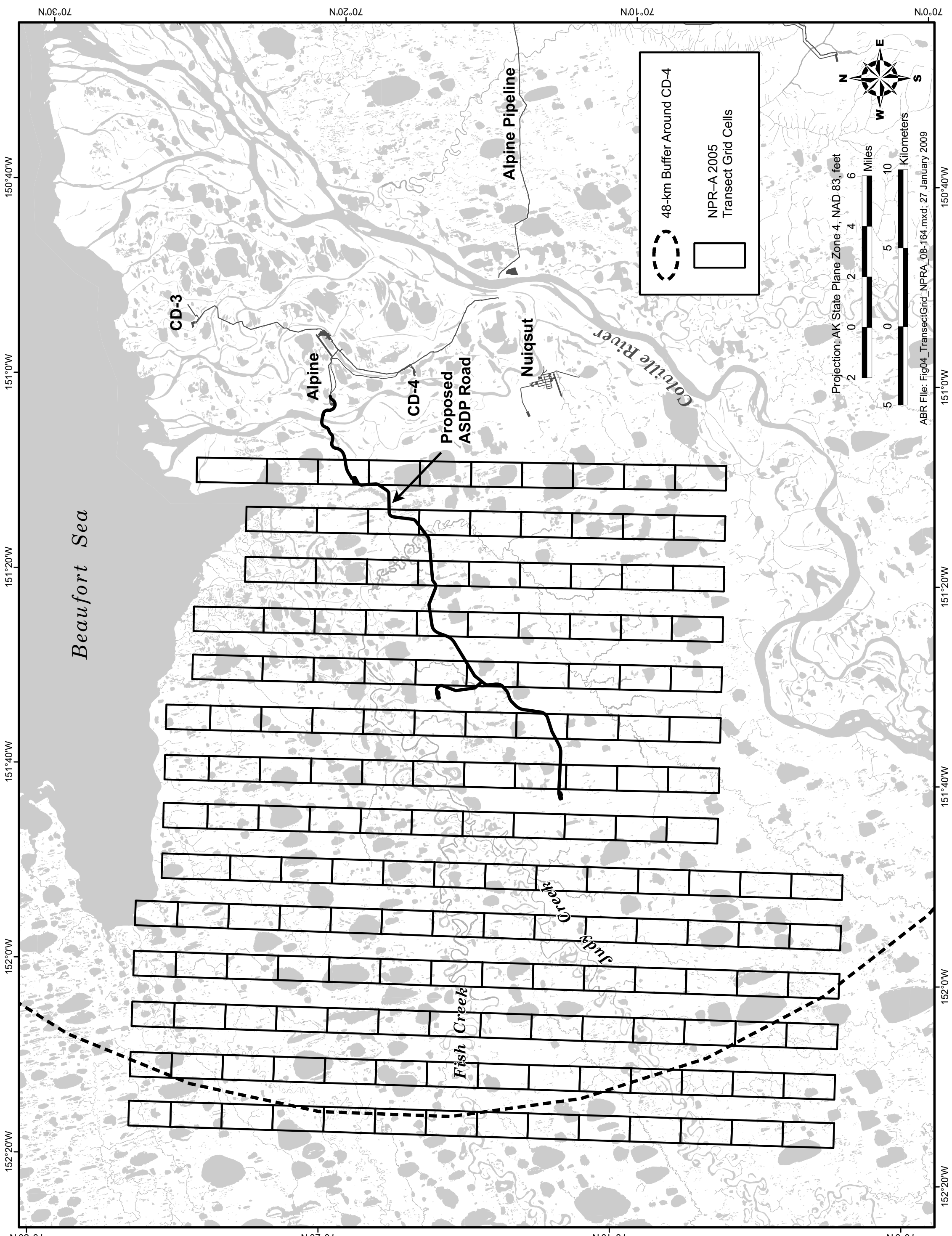

Figure 4. Locations of transect grid-cells (n = 164) used to analyze caribou density in the NPRA survey area, 2005–2008.

binomial distribution and a log link was used to test for differences in the number of caribou among the different grid cells. In this analysis, each survey was treated as independent; various combinations of NDVI_peak, NDVI_rate, snow cover, distance to coast, proportion of tussock tundra, proportion of wet habitats, transect number, presence of Fish or Judy Creeks, and presence of the proposed road were within-subject effects; survey date was a between-subject effect; and the natural logarithm of the area of each grid cell was the offset term. An exchangeable working correlation matrix was used to model dependencies among grid cells during surveys.

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 Quasi-likelihood Information Criteria with the adjustment for small sample size (QIC_c) and used the Akaike weights 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 errors (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 the proposed ASDP road were included in all 20 candidate models for calving density in 2008, but the different models had various combinations of NDVI_peak, NDVI_rate, snow cover on 26 May 2008, transect number (west–east gradient), proportion of tussock tundra, and proportion of wet habitats. Independent variables with Pearson correlations >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. One grid cell located on the Colville River delta was removed because it contained little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

Sixteen candidate models were used for seasonal tests over all years (2002–2008) combined. For these models, the year-specific variables (snow-cover fraction and NDVI_rate) were dropped and the distance-to-coast variable and the survey date (to account for large inter-survey differences in density) were added. Surveys on which <10 caribou were observed were dropped from the analysis because they provided little information on caribou distribution. Two grid cells containing large groups of caribou during the oestrid-fly season were dropped because they were outliers that prevented some models from converging. In addition, one survey during the oestrid-fly season in 2005 was dropped because nearly all caribou seen on that survey were in large groups (1,670–2,400 animals) in only four grid cells.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

The timing of snow melt in spring and the severity of insect harassment in midsummer 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 2003–2007 (Lawhead and Prichard 2009). In 2008, the timing of snowmelt was slightly earlier than average. Daily air temperatures in spring 2008 generally were above average, resulting in the cumulative sum of thawing-degree days (TDD) being above average in late May and early June (Appendix B). Snow depth was close to the long-term average in early April and slightly above average on 15 May. Snow cover was patchy during the spring survey on May 18–19, lowering the sightability of caribou. The complex visual background created by snowmelt required adjustment of the counts for low detectability by applying a sightability correction factor (SCF) for large caribou (Lawhead et al. 1994). The average daily temperature at the Kuparuk airstrip reached 0º C for the first time on 22 May and was between 3 and 6º C for the next eight days; snow had melted by 30 May at the weather station at the Kuparuk airstrip.

Although patchy snow cover remained during the first calving survey in the Colville East survey area on 3–4 June, large areas were snow-free, so we did not use the SCF. Almost all snow cover was gone in the survey areas by the time of the calving surveys on 9 June in NPRA, 11 June in Colville East, and 12 June on the Colville River delta. The snow remaining at that time was in deep linear drifts along upland drainages and lake edges and was not great enough to warrant use of the SCF.

Information on summer weather was compiled for reference in interpreting insect-season conditions and the severity of insect harassment. The occurrence of air temperatures conducive to insect activity (as indicated by TDD sums) in 2008 was above the long-term average during late June and early July, slightly below average in late July, and well below average in early August (Appendix B), indicating cooler-than-normal temperatures in the latter half of the season.

Weather conditions can be used to predict the occurrence of harassment by mosquitoes (*Aedes* spp.) and oestrid flies (*Hypoderma tarandi* and *Cephenemyia trompe*). The estimated probabilities of mosquito activity based on daily maximum temperatures (but ignoring wind speed; Russell et al. 1993) at the Kuparuk airstrip were above average in June and early July, close to average in late July, and well below average in August (Lawhead and Prichard 2009). Thus, the available weather data indicate that the levels of insect activity and resulting harassment of caribou would have been fairly high in late June and early July, but much lower in late July and August.

Variability in weather conditions typically results in large fluctuations in insect activity and caribou density during the insect season as caribou aggregate and move rapidly through the study area. Caribou typically move toward the coast in response to mosquito harassment and then disperse inland when mosquito activity abates in response to colder temperatures or high winds.

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 cause direct mortality of caribou (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 29 April and 25 October 2008 (Table 2, Figure 5). The pattern of caribou occurrence in the survey area fluctuated during the period: relatively high numbers in late April, low in mid-May, relatively high again in June, fewer in August, highest in late September, and low in October. The estimated density of caribou ranged from a high of 1.03 caribou/km² on 24 September to a low of 0.05 on May 18–19 (Table 2). The density of caribou during calving (0.57 caribou/km² on 9 June) in the NPRA survey area was near the middle of the range of 0.15–0.87 caribou/km² (6–9 June) observed during 2001–2007 (no calving survey was conducted in 2004). Only 15 calves (3.1% of the total number of caribou) were observed in the NPRA survey area on 9 June, underscoring the low use of the area for calving compared with neighboring areas such as the Colville East survey area.

Annual surveys since 2001 have shown that the NPRA survey area (used mainly by TH caribou) is not a high-density calving area, in contrast to the Colville East survey area (used mainly by CAH caribou) (Appendices C–I; Lawhead and Prichard 2008). 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 collared CAH caribou have calved west of the Colville River in isolated years (principally 2001), it is a rare occurrence (Arthur and Del Vecchio 2007, Lenart 2007).

Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2008.

Survey Area and Date	Area [a]	Large Caribou [b]	Calves [c]	Total Caribou	Estimated Total [d]	SE [e]	Density (caribou/km²) [f]	Mean Group Size
NPRA								
April 29	860	243	0	243	486	59.9	0.57	4.1
May 18–19 [h]	1720	21	0	21	79	16.7	0.05	2.1
June 9	1720	473	15	488	976	115.6	0.57	3.4
June 19	1720	421	6	427	854	150.2	0.50	5.2
August 21	1720	170	0	170	340	33.6	0.20	1.5
September 24	1720	887	nr	887	1774	211.1	1.03	4.2
October 7	1720	81	nr	81	162	28.1	0.09	5.1
October 25	1720	82	nr	82	164	22.5	0.10	4.6
COLVILLE RIVER DELTA								
April 29	494	89	0	89	178	51.8	0.36	4.5
May 19 [h]	494	5	0	5	19	4.7	0.04	2.5
June 12	494	14	1	15	30	11.6	0.06	2.1
June 19	494	43	1	44	88	24.2	0.18	4
September 24	494	21	nr	21	42	16.1	0.09	7
October 7	324	12	nr	12	24	10.6	0.07	6
October 26	494	14	nr	14	28	13.4	0.06	2.8
COLVILLE EAST								
April 29–30	858	251	0	251	502	77.8	0.59	4.4
May 19 [h]	1326	348	0	348	1306	292.0	0.99	7.9
June 3–4 [i]	1432	1694	211	1905	3810	234.6	2.66	3.7
June 11 [i]	1432	4155	919	5074	10,148	819.5	7.09	7.9
June 19	1696	2138	589	2727	5454	1518.0	3.21	18.9
August 21	1696	119	0	119	238	36.1	0.14	1.5
September 25	1938	482	nr	482	964	87.0	0.50	3.3
October 7–9	622	106	nr	106	212	54.1	0.34	11.8
October 24–25	1938	60	nr	60	120	34.1	0.06	4.3

[a] Survey coverage was 50% (during completed surveys, 860 km² were surveyed in NPRA, 247 km² on the Colville R. Delta, and 848–969 km² in Colville East).
[b] Adults + yearlings.
[c] nr = not recorded; calves not reliably differentiated due to large size.
[d] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage).
[e] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), with transects as sample units.
[f] Density = Estimated Total / Survey Area Size.
[h] Applied Sightability Correction Factor of 1.88 due to patchy snow cover during survey.
[i] 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 2009).

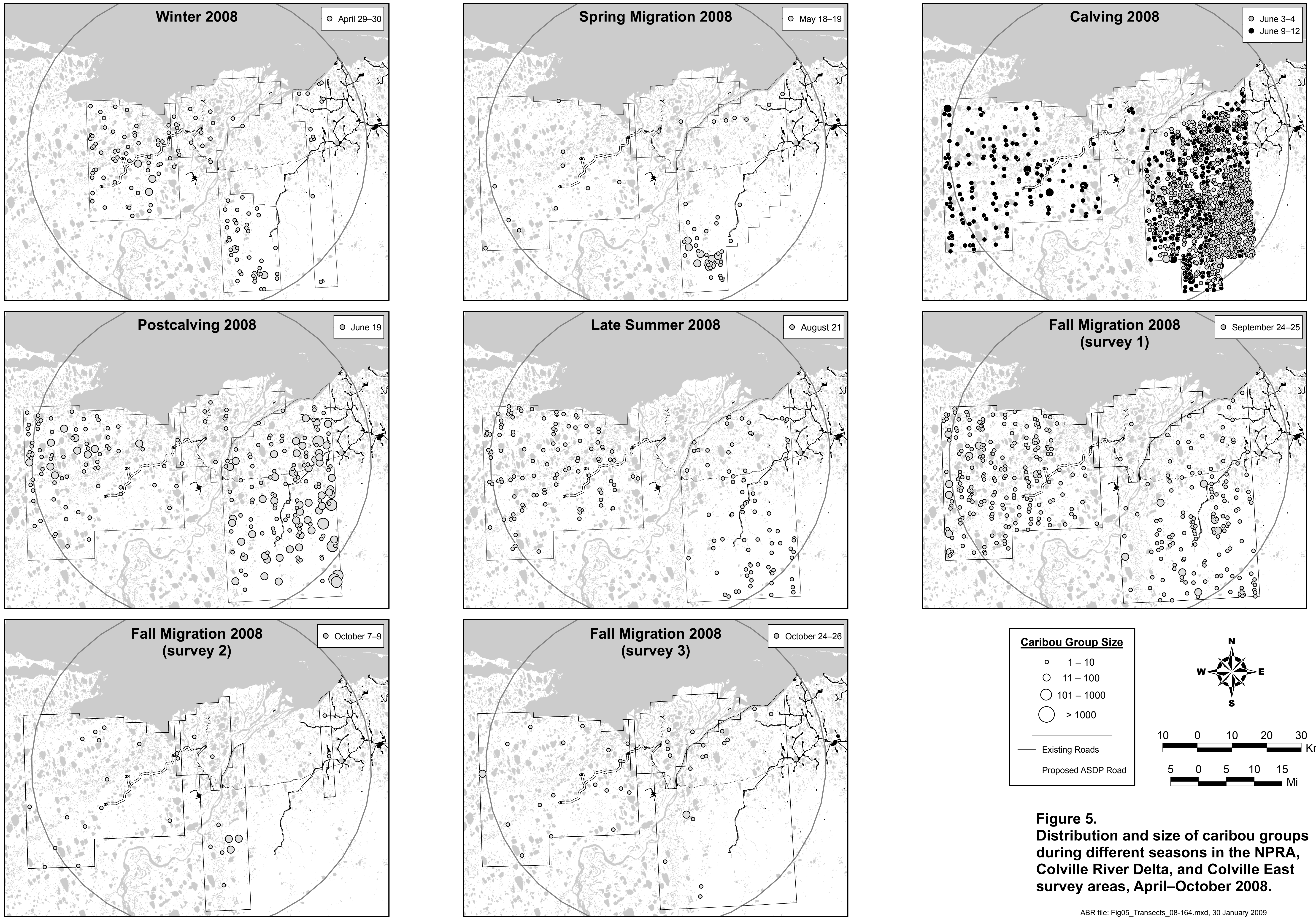

Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2008.

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Large mosquito-harassed groups of caribou were not observed during aerial surveys in late June or August 2008, but no surveys were conducted in July when mosquito and oestrid-fly harassment typically peak. During the insect (mosquito and oestrid-fly) season, transect surveys produce unpredictable results due to the rapid movements by caribou across broad areas in response to fluctuating insect activity levels. Since 2001, the only year in which we found large mosquito-harassed groups in the NPRA survey area was 2005 (Lawhead et al. 2006). Radio-telemetry data provide better information on movements during the insect season (see Radio Telemetry section below).

Caribou densities observed on the NPRA transects were relatively low in August (0.20 caribou/km²) but increased to 1.03 caribou/km² in late September (Table 2). Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (annual maxima of 1.2–3.5 caribou/km² during 2001–2007, except in 2006 when only one survey was conducted after August and the density was only 0.01 caribou/km²) (Figure 6). High densities also 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–I).

Colville River Delta Survey Area

Seven surveys of the Colville River Delta survey area were flown between 29 April and 26 October 2008 (Table 2, Figure 5). Similar to most years, the estimated density of caribou was quite low during all surveys (0.04–0.36 caribou/km²); the maximal estimate recorded in 2008 was 178 caribou (0.36 caribou/km²) on 29 April.

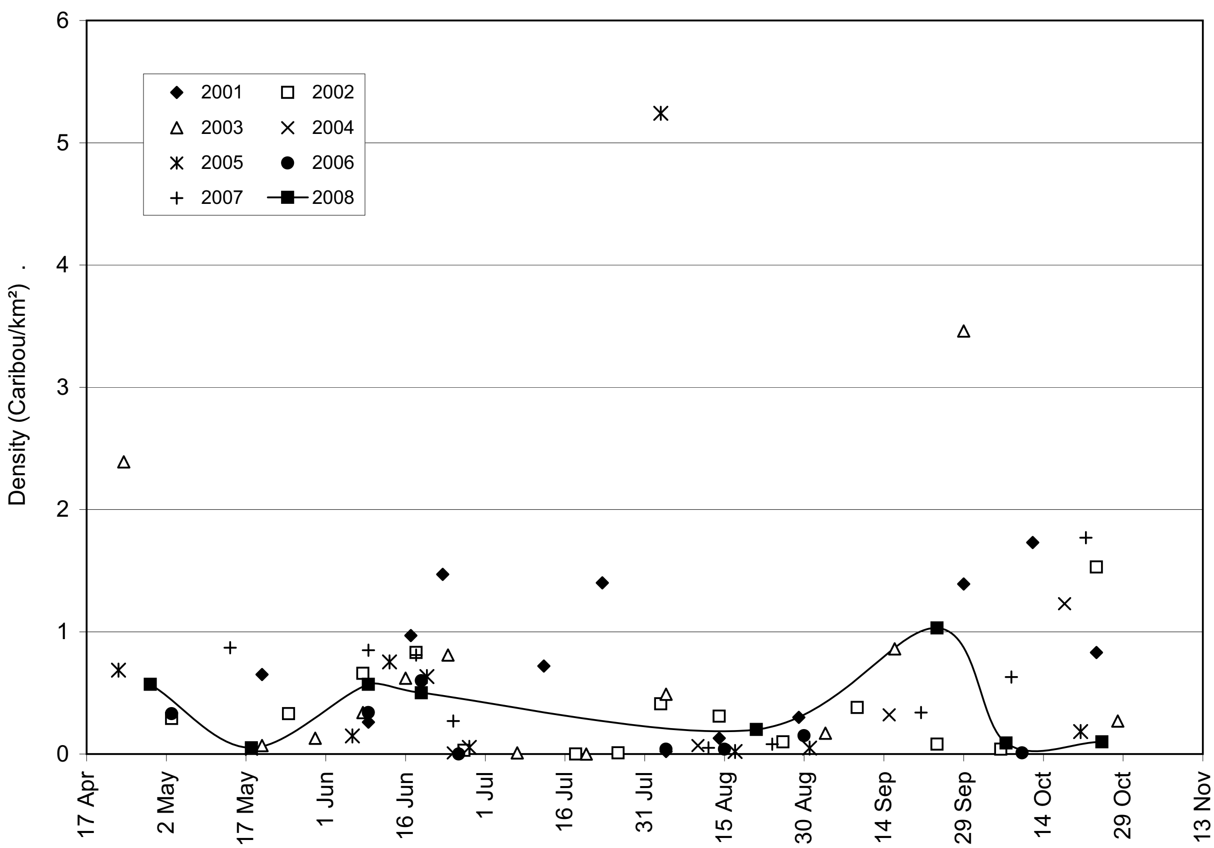

Figure 6. Caribou density observed on 78 surveys of the NPRA area, April–October 2001–2008 (line connects 2008 survey values).

Large numbers of caribou have been recorded occasionally during past summers (such as 1992, 1996, 2001, and 2007) as large aggregations moved onto or across the delta during or after periods of insect harassment (Johnson et al. 1998, Lawhead and Prichard 2002, Lawhead et al. 2008). The most notable such instance was a large-scale westward movement onto the delta by at least 10,700 CAH caribou in the third week of July 2001, ~6,000 of which continued across the delta into northeastern NPRA (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007) and moved west through the area of the proposed ASDP road. At least 3,241 TH caribou were photographed on the outer delta on 18 July 2007 and up to several thousand more may have moved onto the delta by the end of July that year (Lawhead et al. 2008).

It is difficult to record the dynamic movements of insect-harassed caribou with periodic transect surveys. The highest number recorded on transect surveys during 2001–2008 (Table 2, Appendices C–I) occurred on 2 August 2005, when 994 caribou were found on the Colville delta (2.01 caribou/km²; Appendix G).

Colville East Survey Area

Nine surveys of the Colville East survey area were flown between 29 April and 25 October 2008. The highest densities among all three ASDP survey areas in 2008 were recorded in Colville East during calving and postcalving. The estimated density of caribou ranged from the peak of 7.09 caribou/km² during calving on 11 June to a low of 0.06 caribou/km² on 24–25 October (Table 2). The density was moderate in late April, peaked during calving, and had decreased by about half by the time of the postcalving survey. No surveys were conducted in July. Density was low in August, increased to 0.50 caribou/km² by late September, and then decreased to its lowest value (0.06 caribou/km²) by late October.

The overall number and density of caribou during the late calving season (mid-June) in 2008 was the greatest on record in the Kuparuk South survey area and the second highest on record in the Colville East and Kuparuk Field survey areas to the east (Lawhead and Prichard 2009). The overall density for all areas combined was by far the greatest observed thus far during all transect surveys since 1993 (Lawhead and Prichard 2009). The distribution of calving by the western segment of the CAH in 2008 was typical of the pattern seen in most years since 1993, with the highest-density calving activity occurring in the Kuparuk South survey area.

The Colville East survey area also hosts high densities of caribou during postcalving as CAH caribou move northward prior to mosquito emergence (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007, 2008, 2009). Inland portions of the survey area often are used during the insect season when cooler weather depresses insect activity and caribou move south away from the coast.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area in 2008, although a group of 12 was observed east of Nuiqsut (Appendix J and Lawhead and Prichard [2009]). In 2005, 2006, and 2007, a group of muskoxen was observed near the Kalikpik River or west of the Fish Creek delta in the northwestern portion of the survey area, numbering between 8 and 25 animals at various times (Lawhead et al. 2006, 2007, 2008). Before 2005, muskoxen were observed during ABR aerial surveys in NPRA only in June 2001 (Burgess et al. 2002), even though 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, 2008, 2009) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Grizzly bears (*Ursus arctos*) were recorded on six occasions in the NPRA survey area between June and August 2008 (Appendix J and Lawhead and Prichard [2009]). Three different groups were observed on 9 June: two sows with two cubs each near Fish Creek, plus a single adult near Judy Creek. A sow with cubs was also observed on 10 June, 25 June, and 18 August.

No moose were observed in the ASDP study area in 2008. A few moose have been seen in the study area sporadically in previous years (Lawhead et al. 2006).

A single polar bear (*Ursus maritimus*) was seen on 8 August 2008 by an ABR observer who was staying at Colville Village while working on another project (Appendix J and Lawhead and Prichard [2009]). Although polar bears occur annually in the study area during winter, their occurrence during summer has been unusual; however, nine polar bears were observed in five groups in the Colville–Kuparuk region on 21 August 2007 (Lawhead and Prichard 2008). With declining pack-ice cover, more polar bears are expected to occur on the mainland and barrier islands in the Beaufort Sea during the fall open-water season (Schliebe et al. 2008).

On 18 August 2008, a group of 28 spotted seals (*Phoca largha*) was hauled out on a bar off the main channel of the Colville River (Appendix J and Lawhead and Prichard [2009]). The group was hauled out between two consistently used haulout sites where the species was recorded repeatedly in late summer during more intensive surveys of the delta in the 1990s (Johnson et al. 1999).

A gray wolf (*Canis lupus*) was observed along the Miluveach River during a caribou survey on 25 October (Appendix J and Lawhead and Prichard [2009]). Only two wolves have been recorded previously on ABR aerial surveys in the region: along the Kachemach River in July 1997 and near Nuiqsut in July 2003.

One wolverine (*Gulo gulo*) was observed on 26 June 2008 along Fish Creek in NPRA (Appendix J and Lawhead and Prichard [2009]). Wolverines have been observed rarely during ABR aerial surveys in the Colville–Kuparuk region; this was the eighth sighting since 1993 (Lawhead and Prichard 2009). Four of the past sightings occurred in the month of June, one in September, and three in October. The frequency of wolverine observations is heavily influenced by survey timing and conditions.

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 7; GPS collar movements for the CAH sample are not depicted in the figure because they were available only inside the ASDP study area for 2003–2006). The majority of collar locations for the TH and CAH occurred 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 (Tables 3 and 4). Although it is generally not warranted to consider each collared caribou as representing a specific 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 was a snapshot that allows only general conclusions to be drawn 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 2008 season.

Satellite Collars

Combining observations for each month over all years of data, the percentage of satellite-collared TH animals (with at least five active duty cycles per month) in the ASDP study area ranged between 9% and 30% of the total collared samples during each month (Table 3). The greatest use by TH caribou occurred in the western half of the study area. The highest overall percentages occurred in July, August, and October and the lowest percentages were in June and December–April (Table 3, Figure 8). The monthly percentages varied substantially within and among years, largely due to small samples of collared animals in most years. Four satellite-collared TH caribou crossed the alignment of the proposed ASDP road in the NPRA survey area eight times during the period September 2007–September 2008 (the cutoff for inclusion of satellite telemetry data in this report). One crossing occurred in October 2007, two in November 2007, one in December 2007, two in March 2008, and one each in May and July 2008.

The satellite-collar data indicate that many TH caribou occupied the ASDP study area in the latter half of 2007. Between July 2007 and January 2008,

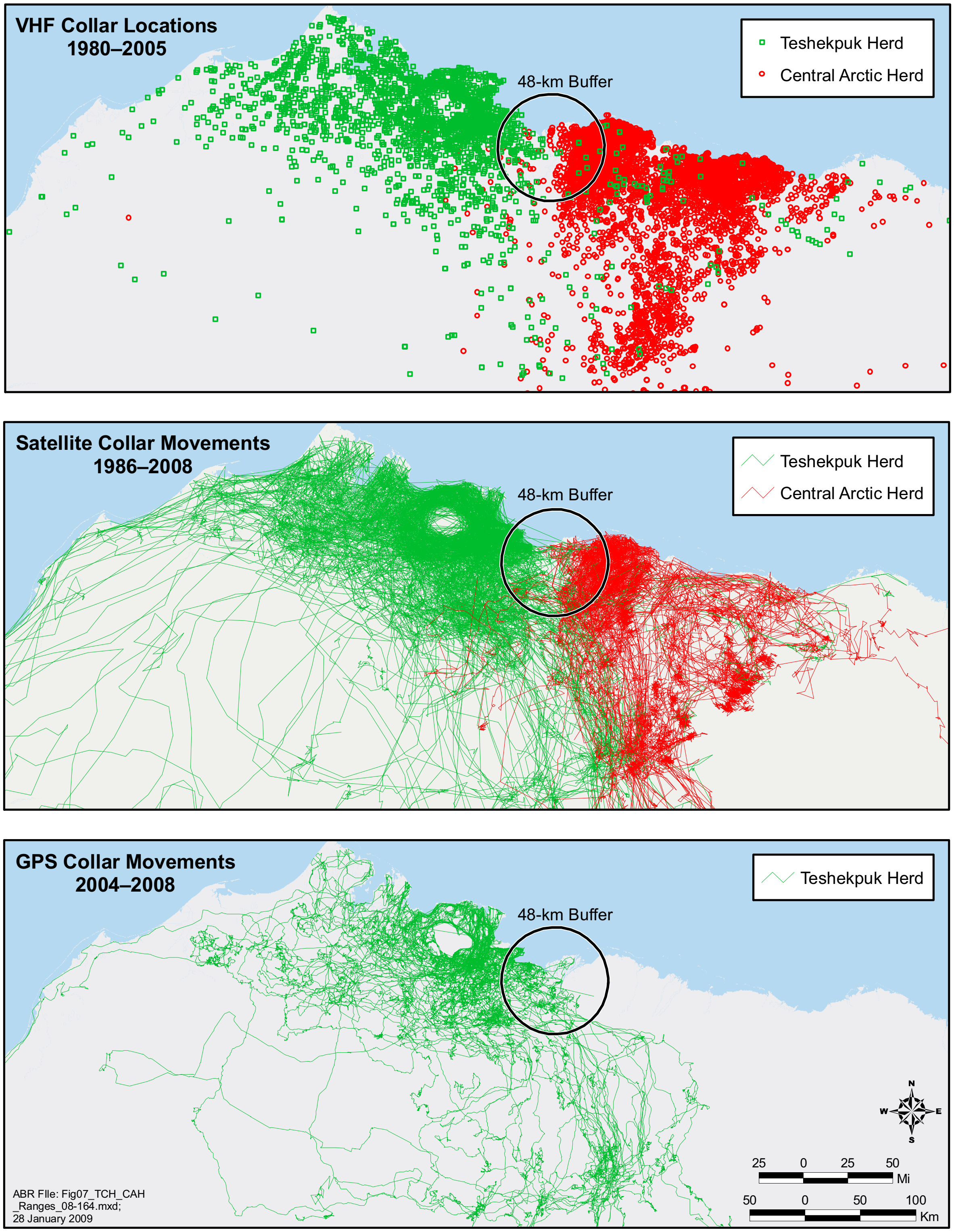

Figure 7. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2008.

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)	29 (21)	14 (21)	58 (36)	6 (34)	13 (32)	34 (29)	0 (27)	0 (27)
	2007	4 (25)	8 (25)	8 (24)	0 (23)	4 (23)	14 (22)	58 (19)	61 (18)	35 (17)	59 (17)	31 (16)	31 (16)
	2008	33 (15)	21 (14)	21 (14)	14 (14)	17 (12)	8 (12)	14 (7)	14 (7)	0 (7)	–	–	–
	Total	14 (152)	12 (135)	13 (134)	9 (133)	16 (133)	10 (130)	30 (189)	27 (181)	18 (188)	29 (174)	16 (159)	13 (154)
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 (TH) and Central Arctic (CAH) herds that were within 48 km of CD-4 at least once in each month.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
TH	2004	–	–	–	–	–	–	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)	90 (10)
	2005	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	–	–	–	–	–	–	30 (10)
	2006	–	–	–	–	–	–	50 (12)	8 (12)	0 (12)	67 (12)	0 (12)	0 (12)	75 (12)
	2007	0 (12)	0 (12)	0 (12)	0 (11)	18 (11)	40 (10)	55 (11)	73 (11)	27 (11)	36 (11)	27 (11)	20 (10)	56 (18)
	2008	20 (10)	20 (10)	20 (10)	30 (10)	33 (9)	11 (9)	63 (8)	13 (8)	13 (8)	13 (8)	0 (8)	0 (8)	50 (16)
	Total	9 (32)	6 (32)	6 (32)	10 (31)	23 (30)	24 (29)	44 (41)	29 (41)	15 (41)	49 (41)	15 (41)	13 (40)	59 (66)
CAH	2003	–	–	–	4 (24)	54 (24)	75 (24)	8 (24)	13 (24)	21 (24)	8 (24)	0 (24)	0 (24)	79 (24)
	2004	0 (24)	0 (24)	0 (24)	4 (24)	33 (24)	58 (24)	13 (24)	4 (24)	42 (24)	0 (24)	0 (24)	0 (24)	75 (24)
	2005	0 (33)	0 (33)	0 (33)	0 (33)	24 (33)	45 (33)	33 (33)	27 (33)	21 (33)	9 (33)	–	–	58 (33)
	2006	0 (29)	0 (29)	0 (29)	0 (29)	38 (29)	38 (29)	55 (29)	0 (29)	34 (29)	14 (29)	–	–	69 (29)
	2008	–	–	–	–	–	–	0 (4)	25 (4)	25 (4)	0 (4)	0 (4)	0 (4)	25 (4)
	Total	0 (86)	0 (86)	0 (86)	2 (110)	36 (110)	53 (110)	28 (114)	12 (114)	29 (114)	8 (114)	0 (52)	0 (52)	68 (114)

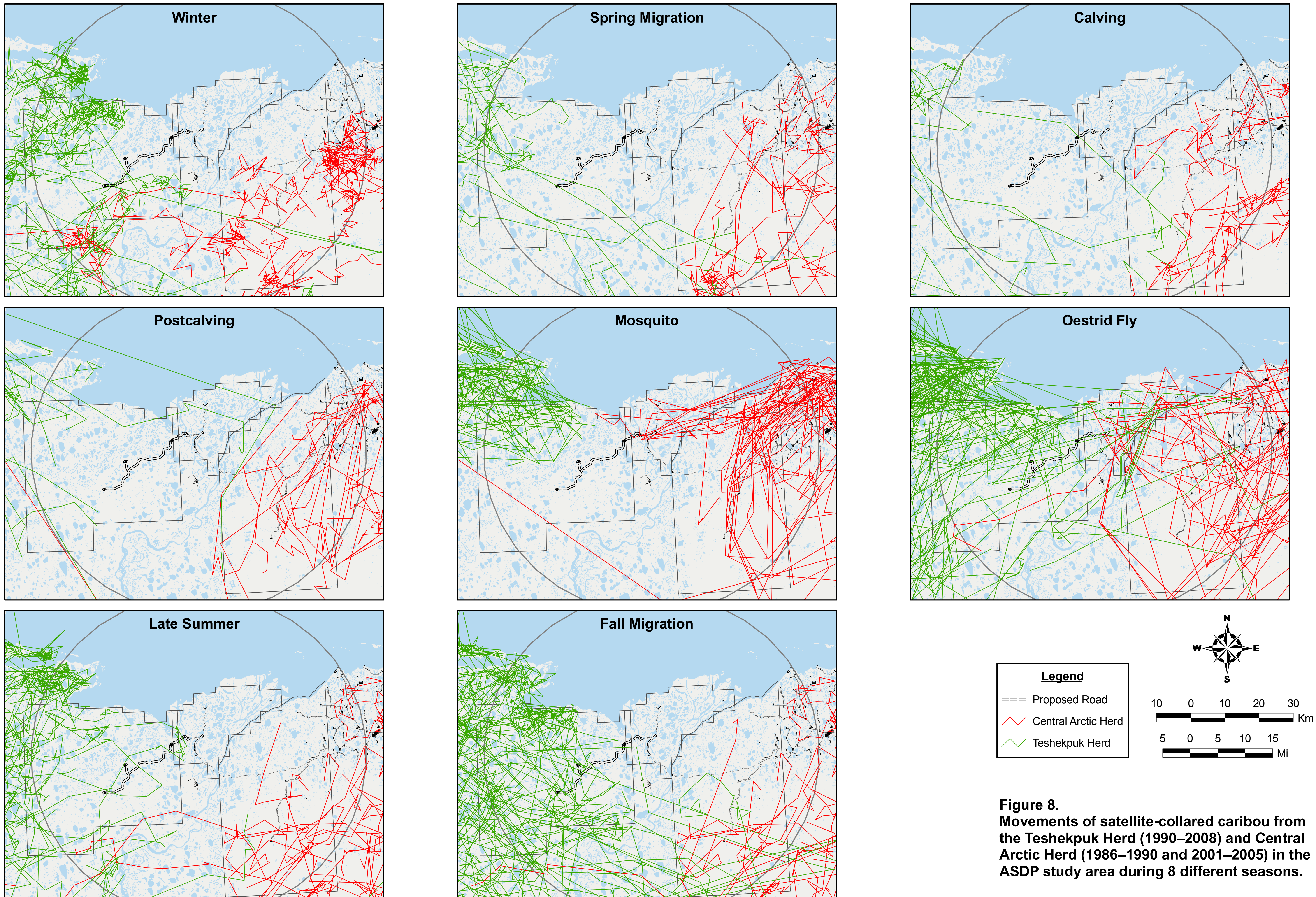

Figure 8.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2008) and Central Arctic Herd (1986–1990 and 2001–2005) in the ASDP study area during 8 different seasons.

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31–68% of all the satellite-collared caribou in the herd were in the study area, whereas only 0–21% of the collared animals were present during February–September 2008.

Satellite-telemetry data showed more use of the eastern half of the ASDP study area (east of the Colville River) by CAH caribou than by TH animals (Figure 8). No satellite-collared CAH animals crossed the proposed ASDP road alignment in the NPRA survey area in any year for which data are available (1986–1990 and 2001–2005). Several collared CAH individuals moved through the vicinity of the Alpine project facilities in July 1989, nine years before construction began. Combining observations for each month over all eight years of data, the percentage of the total sample of satellite-collared CAH caribou in the study area ranged from 12% to 62% each month (Table 3). The highest occurrence of collared CAH caribou was in May, June, and July (41%, 62%, and 51% of the total sample, respectively) 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 CAH animals using the ASDP study area during the winter months appeared to be higher during 1986–1990 than during 2001–2005 (Table 3). The apparent difference in winter use between the two periods may have been affected by the timing and location of collaring, but that information was not available. The bulk of available telemetry data show that CAH caribou normally move far inland to the foothills and mountains of the Brooks Range during winter, so the occurrence of collared animals on the outer coastal plain in winter was unusual.

In most years, 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) and primarily involved CAH animals (Table 3, Figure 8). 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 by many hunters in fall whaling. The timing of hunting in relation to seasonal use of the study area by caribou suggests that caribou harvested on the Colville River delta by hunters in July and August were from the CAH in most years. In contrast, caribou harvested in the study area in October are much more likely to be TH animals migrating to winter range. Summer 2007 provided an exception to this general pattern, however, in that TH caribou appeared to have used the delta more than did CAH caribou during the insect season (Lawhead et al. 2008).

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 during 2004–2008 were similar to those from satellite-collared caribou. Only 6–15% of the total sample of GPS-collared TH caribou was in the study area in winter (January–April and November–December) (Table 4, Figure 9). The monthly percentages increased to 23–44% during May–August, declined to 15% in September, and reached a peak of 49% in October. 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 and 2008 varied between 0 and 8% during the winter months of October–April (Table 4, Figure 9). The monthly percentage increased to 36% in May, peaked at 53% in June, and decreased to 12–29% in July–September.

The detailed movement tracks of the seven TH and four CAH caribou outfitted with GPS collars in 2008, as well as the single TH caribou collared in 2007 that was not recaptured in 2008, were examined in relation to the ASDP study area from the end of June through December (Figures 10 and 11). The seasonal movement patterns of the TH caribou were generally similar to the movement patterns of the 12 TH caribou outfitted with GPS collars from July 2007 to June 2008 (Appendices K and L).

In 2008, the area around Teshekpuk Lake was used extensively during the mosquito and early oestrid-fly seasons before the collared TH animals dispersed across the coastal plain later in the oestrid-fly season and in late summer. Five of the eight transmitting TH collars were in the ASDP study area during July 2008 (Table 4, Figures 10 and 11) but only one remained in August. All eight GPS-collared TH caribou left the area near

Teshekpuk Lake by early October. Of those eight animals, three were on the western coastal plain and five were in the Brooks Range at the end of December (the date cutoff for inclusion in this report). Of the five animals wintering in the Brooks Range, one was near the western end of the range and the other four were in the central portion near the Dalton Highway corridor.

All four CAH caribou outfitted with GPS-collars at the beginning of July 2008 were captured east of Prudhoe Bay; only one entered the ASDP study area later during 2008 (Figure 11). Because virtually the entire CAH was east of Prudhoe Bay at the time of capture, it was not possible to target caribou from the western segment of the CAH for collaring in 2008.

The following accounts briefly summarize the movements of caribou that were collared or recollared in 2008, from the time they were collared at the end of June or beginning of July through the end of December (Figures 10 and 11):

Caribou 0401 — Originally collared in 2004, this adult cow was refitted with a CPAI GPS collar east of Teshekpuk Lake on 25 June 2007. She wintered southeast of Teshekpuk Lake in 2007–2008 and calved successfully in the same area (see Appendix K for 2007–2008 movements). She was recaptured on 29 June 2008 north of Teshekpuk Lake and outfitted with a different CPAI GPS collar. She was southeast of Teshekpuk Lake in late fall 2008, then moved to the Meade River in October.

Caribou 0510— This TH female first was captured and outfitted with a satellite collar in July 2005. She remained on the Arctic Coastal Plain between Dease Inlet and the Itkillik River from 2005 until 2008. She was recaptured without a calf on 29 June 2008 north of Teshekpuk Lake and outfitted with a refurbished GPS collar. She remained near Teshekpuk Lake until October, then moved west of the Meade River and southwest of Barrow. She passed through the western portion of the ASDP study area in mid-July 2008.

Caribou 0624 — This adult cow was recollared north of Teshekpuk Lake on 24 June 2007. She wintered in the central Brooks Range in 2007–2008. She moved west during spring migration, evidently with WAH animals, and was located on the traditional WAH calving grounds and postcalving area in late June and early July. Therefore, she could not be recaptured and her calving status was not determined. She then moved southwest almost to Point Hope by early July and back east to the central Brooks Range in late July. She was along the Meade River in August and the Chipp River in September before moving southeast to winter near the Dalton Highway east of Wiseman. Collar retrieval will be attempted in 2009.

Caribou 0812 — This TH female was accompanied by a calf when she was captured on 29 June 2008 north of Teshekpuk Lake. She remained near Teshekpuk Lake until early October, when she moved west to Wainwright Inlet. She did not enter the ASDP study area in 2008.

Caribou 0813 — This TH female did not have a calf when captured north of Teshekpuk Lake on 1 July 2008. She remained near Teshekpuk Lake and the Meade River until October, entering the western portion of the ASDP study area briefly in mid-July and again in late September. In early October she moved south to the area east of Anaktuvuk Pass.

Caribou 0814 — This TH female was accompanied by a calf when she was captured on 1 July 2008 north of Teshekpuk Lake. She moved between the Meade River and Colville River until October before moving south of the Brooks Range to the area northeast of Bettles. She entered the western portion of the ASDP study area briefly in mid-July.

Caribou 0819 — This TH female was accompanied by a calf when captured on 30 June 2008 east of Barrow. She remained near the Meade River until early October, then moved southwest along the Chukchi Sea coast and crossed the Red Dog mine haul road. In December she was wintering in the Noatak River valley. She did not enter the ASDP study area in 2008.

Caribou 0821 — This TH female was accompanied by a calf when she was captured on 1 July 2008 north of Teshekpuk Lake. She remained on the coastal plain, mostly north and east of Teshekpuk Lake, until October, when she moved south into the central Brooks Range. In December she was along the Dalton Highway near Wiseman. She passed through the western portion of the ASDP study area in mid-July and late August.

Caribou C0819 — This CAH female was accompanied by a calf when collared near the

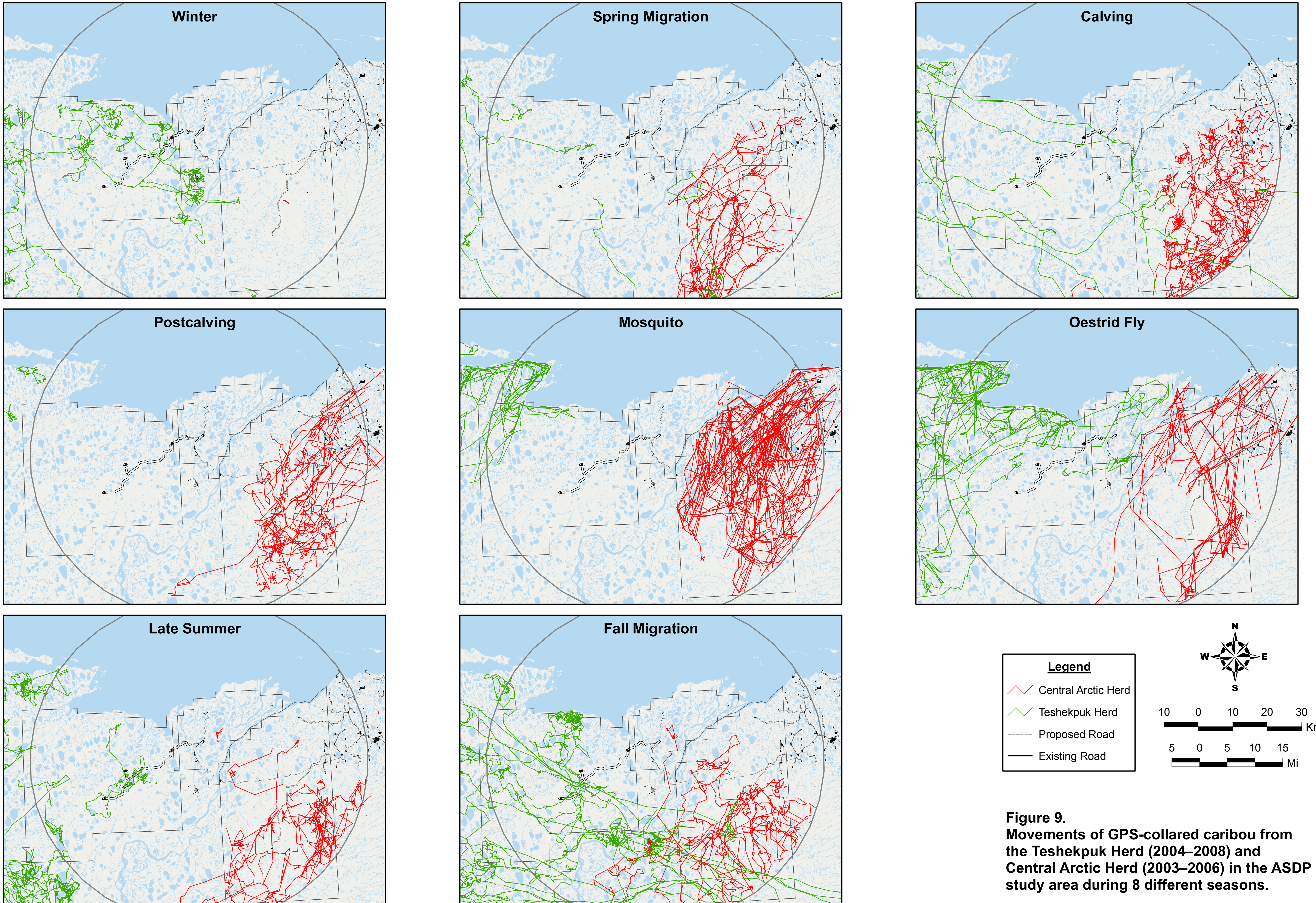

Figure 9.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2008) and Central Arctic Herd (2003–2006) in the ASDP study area during 8 different seasons.

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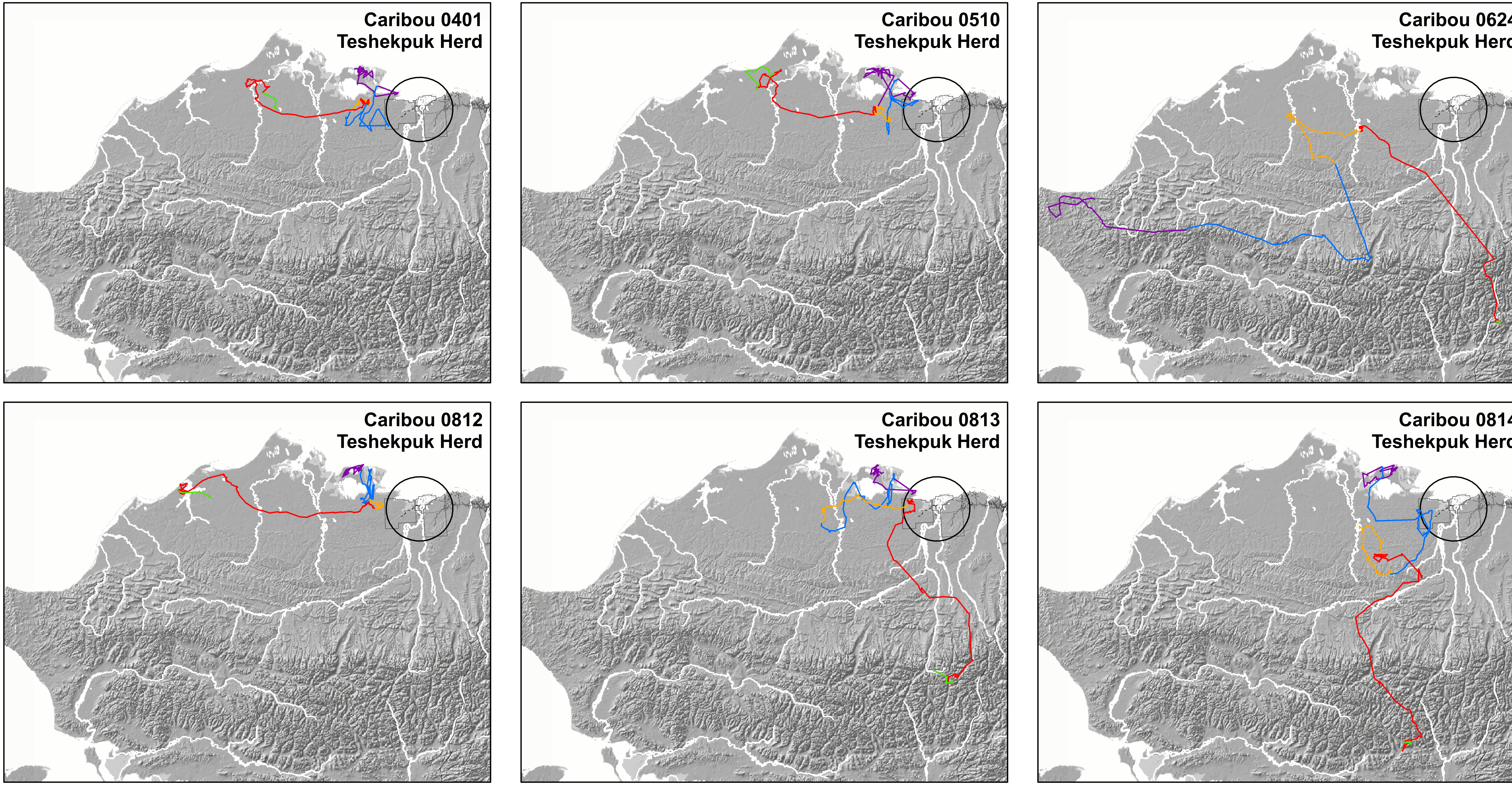

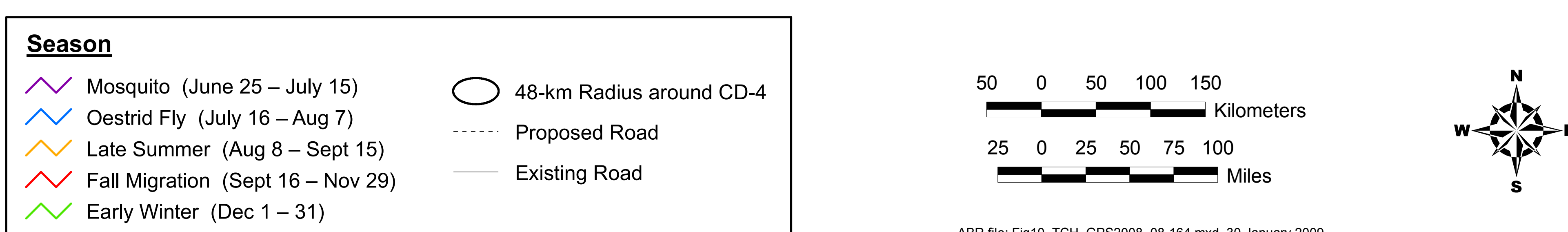

Figure 10.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons, July–December 2008.

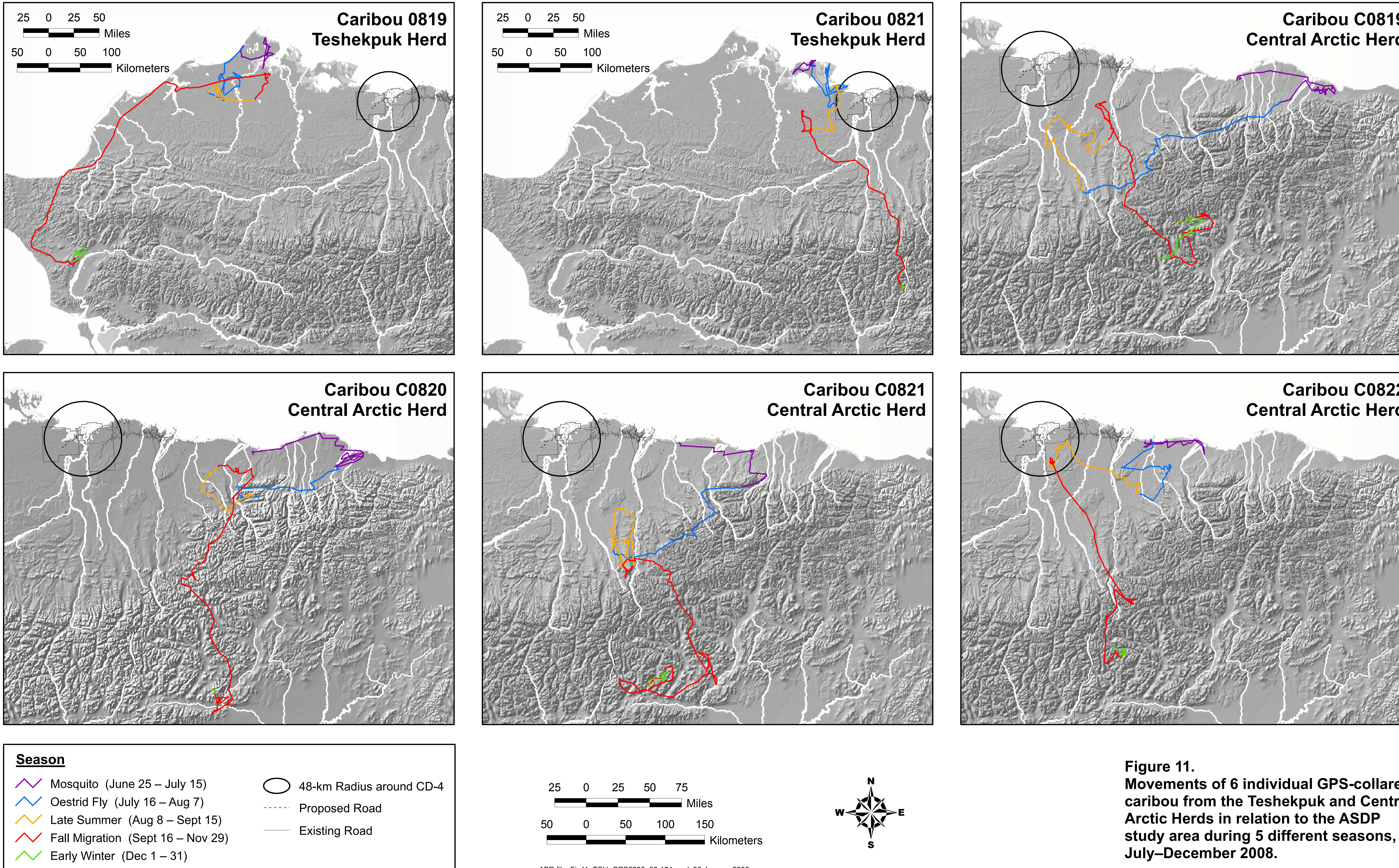

Figure 11.
Movements of 6 individual GPS-collared caribou from the Teshekpuk and Central Arctic Herds in relation to the ASDP study area during 5 different seasons, July–December 2008.

mouth of the Sadlerochit River on 3 July 2008. She moved almost to the Canadian border over the next week, then turned west, crossed the Dalton Highway in early August, and moved to the Itkillik River by late August. She crossed the Dalton Highway again in late August and was in the Brooks Range east of the highway in December. She did not enter the ASDP study area in 2008.

Caribou C0820 — This CAH female was captured in ANWR near the Tamayariak River on 4 July 2008 and outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf. She moved east near the Canadian border until mid-July and then moved back near the Canning River until early October. She migrated south of the Brooks Range and was northwest of Venetie in December. She did not enter the ASDP study area in 2008.

Caribou C0821 — This CAH female was captured between the Shaviovik River and the Badami facilities on 4 July 2008 and outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf. She moved east into ANWR briefly, then moved southwest and crossed the Dalton Highway to the west, remaining between the upper Kuparuk and Sagavanirktok rivers for most of August and September. She crossed the Dalton Highway to the east and was on the south side of the Brooks Range near Wiseman in December. She did not enter the ASDP study area in 2008.

Caribou C0822 — This CAH female was captured east of Prudhoe Bay near the Kadleroshilik River on 4 July 2008 and outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf. She remained east of the Sagavanirktok River until late August, when she crossed the Dalton Highway to the west. She moved into the southeastern portion of the ASDP study area between late August and late September, crossing the DS-2L (Tarn) and DS-2P (Meltwater) access roads several times. She then moved southeast and crossed to the east side of the Dalton Highway in early October near the upper Kuparuk River. She was on the south side of the Brooks Range east of Wiseman in December.

Partial movements (through December 2007) of caribou collared or recollared in 2007 were reported previously (Lawhead et al. 2008), but their complete movements from June 2007 through June 2008 are depicted in this report (Appendices K and L). The following accounts briefly summarize those movements (except for caribou 0401, which is discussed above:

Caribou 0307 — First captured in 2003, this adult cow was recollared north of Teshekpuk Lake on 25 June 2007. She remained west of Teshekpuk Lake until early August, went southwest as far as the Meade River in late summer, then moved back toward Teshekpuk Lake and died south of the study area in late November 2007.

Caribou 0308 — This adult cow was recollared west of Teshekpuk Lake on 25 June 2007. She wintered northwest of Anaktuvuk Pass in 2007–2008. She did not reach the area west of Teshekpuk Lake until mid-June 2008 and did not calve successfully. She was recaptured on 30 June 2008 southeast of Barrow and outfitted with an NSB GPS collar.

Caribou 0402 — This adult cow was recollared west of Teshekpuk Lake on 25 June 2007. She wintered in the area southeast of Teshekpuk Lake in 2007–2008. She calved successfully south of Teshekpuk Lake in 2008. She was recaptured east of Barrow on 30 June 2008 and outfitted with an NSB GPS collar.

Caribou 0404 — This adult cow was accompanied by a calf when she was recollared southeast of Teshekpuk Lake on 24 June 2007. She wintered near the ASDP study area in 2007–2008. She calved successfully east of Teshekpuk Lake in 2008. She was recaptured north of Teshekpuk Lake on 29 June 2008 and her collar was replaced with an NSB GPS collar.

Caribou 0618 — This adult cow was recollared west of Teshekpuk Lake on 25 June 2007. She wintered along the upper Kuparuk River and died east of Anaktuvuk Pass in April 2008.

Caribou 0621 — A 3-year-old cow, this caribou was recollared south of Teshekpuk Lake on 24 June 2007. She wintered near Nuiqsut in 2007–2008 and calved successfully east of Teshekpuk Lake in 2008. She was captured north of Teshekpuk Lake on 29 June 2008 and outfitted with an NSB GPS collar.

Caribou 0622 — This adult cow was recollared on 24 June 2007 south of Teshekpuk Lake but her new GPS collar malfunctioned and never recorded data. She apparently joined the CAH and was observed with a calf east of the

Kuparuk DS-2P (Meltwater) road in June 2008. She was recaptured on 2 July 2008 along the Canning River for collar retrieval but was not outfitted with a new collar.

Caribou 0623 — This adult cow was recollared east of Teshekpuk Lake on 24 June 2007 and wintered near the upper Kuparuk River in 2007–2008. She moved north toward Alpine in the spring and was within 0.5 km of the Alpine Pipeline on 27 May 2008, but apparently never crossed to the north side. She moved west to the eastern side of Teshekpuk Lake in mid-June but did not have a calf. She was recaptured north of Teshekpuk Lake on 29 June 2008 and outfitted with an NSB GPS collar.

Caribou 0626 — This adult female caribou was recollared west of Teshekpuk Lake on 25 June 2007. She wintered near the Chukchi Sea coast near Wainwright Inlet in 2007–2008. She moved back to the area southwest of Teshekpuk Lake and calved successfully in 2008. She was recaptured east of Dease Inlet on 30 June 2008 and outfitted with an NSB GPS collar.

Caribou 0701 — This female was collared as a yearling southeast of Teshekpuk Lake in June 2007. She wintered near the upper Colville River in the winter of 2007–2008. She calved successfully along the southern shore of Teshekpuk Lake in 2008. She was recaptured north of Teshekpuk Lake on 30 June 2008 and her collar was replaced with an NSB GPS collar.

Telemetry Summary

The movement data for both satellite- and GPS-collared animals show that the ASDP study area is used at low to moderate levels by TH caribou throughout most of the year, predominantly in the western half of the study area. During most years, the highest use of the ASDP study area by TH caribou occurred in the fall, the only season in which collared TH animals moved east of the Colville River. That pattern mirrored the results of aerial transect surveys (Table 2, Figures 5–6, Appendices C–I).

In contrast, use of the ASDP study area by CAH caribou is most extensive during the calving and postcalving periods in June, and virtually all of the CAH movements occurred east of the Colville River. Few collared CAH caribou were present in the study 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 2007). 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 prevailing 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 (using all three types of transmitters), the telemetry data demonstrate that the Colville River delta is the only area where the summer ranges of the TH and CAH overlap, and use of that area is infrequent. Most CAH caribou remain east of the delta, most TH caribou stay west of it, and the existing Alpine facilities (including CD-4) are located on the delta at the interface of the herd ranges (Figures 7–9). Exceptional movements by both herds have been documented, however. The most notable instance occurred in July 2001, when at least 10,700 CAH caribou moved west onto the Colville River delta and at least 6,000 of those animals continued across the delta into NPRA, with many remaining there into September (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007).

The ranges of the two herds overlap more in fall and winter, primarily because of the recent expansion of TH caribou into CAH range. Although many of the TH animals typically overwinter on the coastal plain, large numbers have wintered south of the Brooks Range in areas used by the CAH or WAH (Prichard and Murphy 2004, Carroll 2007, Lenart 2007). 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). Since that winter, large numbers of TH animals have continued to spend the winter in the traditional range of the CAH.

Movements by collared TH and CAH caribou into the vicinity of CD-4 (between Nuiqsut and the Alpine processing facilities) have occurred infrequently and sporadically—during calving (early June), the 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 7–9).

None of the 102 satellite collars in the TH were recorded in the immediate vicinity of CD-4 during 1990–2006; the nearest one was a female that moved from northwest of CD-4 to south of Nuiqsut on 30 September 2004, remaining west of the Niġliq Channel. In 2007, four satellite-collared TH caribou moved east past Alpine and CD-4 (based on straight-line distances between satellite locations) as they moved to the eastern Colville delta in late July. Another satellite-collared caribou passed between Nuiqsut and CD-4 as it moved northwest during calving in 2007. In 2008 (January–September), none of the satellite-collared TH caribou were near CD-4, although one caribou was just west of Nuiqsut from January until mid-March.

Of 31 different TH animals equipped with GPS collars during 2004–2008, one crossed the Colville delta westward between CD-4 and Alpine on 6 June 2005 *en route* to Teshekpuk Lake. Caribou 0404 spent 1–6 August 2007 about 2 km south of CD-4 before heading west. Caribou 0621 wintered near Nuiqsut during the winter of 2007–2008 but did not move onto the Colville delta.

Of the sample of 17 satellite collars in the CAH during 1986–1990, one moved into the CD-4 vicinity briefly during 21–23 July 1988 and four were nearby during 11–13 July 1989. Of the sample of 17 CAH satellite collars during 2001–2005, four 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 in the ASDP study area during 2003–2006 moved onto the Colville delta east of CD-4 on 27 September 2004. None of the four CAH caribou outfitted with GPS collars in 2008 was near CD-4.

A greater proportion of radio-collared caribou movements have occurred across the proposed ASDP road alignment in NPRA since 1990 than near CD-4, although such movements were not frequent. As expected on the basis of herd distribution (Figures 7–9), most of the crossings of the proposed road alignment were by TH caribou. Of the TH sample of 102 satellite collars (1990–2008), 26 animals crossed the proposed alignment at least 44 times between September 1990 and September 2008. Crossings occurred in every month except January. Of the TH sample of 31 GPS-collared caribou (2004–2008), five 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). Caribou 0624 crossed near the eastern end of the proposed alignment in June 2007; caribou 0401 crossed near the eastern end of the proposed road in July 2007; caribou 0404 crossed the proposed road corridor at least 38 times in August, September, and December 2007; and caribou 0621 crossed near the western end of the alignment in October 2007. Caribou 0404 crossed the proposed alignment twice in January 2008 and caribou 0621 crossed once in April 2008.

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 (nine years before construction), the only satellite- or GPS-collared caribou from that herd to do so. Some VHF-collared CAH caribou probably crossed the proposed ASDP road alignments (including the CD-4 alignment before construction) with the aggregation of at least 6,000 CAH caribou that moved west across the Colville delta and the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2007), but they were not tracked frequently enough to document their route.

REMOTE SENSING

Because MODIS imagery covers large areas at relatively coarse resolution (250–500-m pixels), we were able to evaluate snow cover and vegetation indices over a much larger region than the ASDP study area with no additional effort or 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 geographic context in terms of snow melt and chronology of vegetation green-up.

SNOW COVER

Snow melt was slightly advanced in 2008, with MODIS data confirming field observations, made during aerial surveys, of substantial patchy snow in late May and mostly snow-free conditions by early June (Figure 12). Hazy cloud cover on 2 June 2008 precluded the application of the subpixel-scale snow-cover algorithm for most of the image, but visual interpretation suggests that nearly all of the snow in the survey area had melted by that date, which was supported by visual observations during the first calving survey in the Colville East survey area. A melt-date image was computed for 2008, as in 2005–2007, but the observed melt date (the first cloud-free date with less than 50% snow cover) was mainly driven by the dates of cloud-free views over different portions of the study area, rather than realistic melt dates. Therefore, the 2008 melt-date estimates were judged to not be useful for any of our analyses this year.

A qualitative comparison of snow melt across years (2008 data in Figure 12; 2005–2007 data in Lawhead et al. 2006, 2007, 2008) suggests that, while the annual timing of melt varies substantially, the spatial pattern is fairly uniform across years. That is, some areas tend to melt first each year, whereas other areas tend to retain snow longer year after year. It may be possible to exploit that spatial pattern to infer snow cover under cloudy portions of scenes. Such an inferential approach could provide a method to improve snow cover estimates even with the patchy cloud conditions that occur in most years.

Previous comparisons of the performance of the MODIS subpixel-scale snow-cover algorithm with aggregated Landsat imagery suggests that the overall performance of the subpixel algorithm is acceptable, but that accuracy degrades near the end of snow melt (Lawhead et al. 2006). Further research comparing MODIS imagery, Landsat imagery, 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 6-year time series of MODIS imagery for the variables NDVI_calving, NDVI_621, and NDVI_rate (2008 data in Figure 13; 2002–2007 data in Lawhead et al. 2006, 2007, 2008). Care must be exercised in comparing NDVI values among the 2002–2003, 2004–2006, and 2007–2008 images because the image-processing approach differed somewhat. The first flush of new vegetative growth that occurs in spring among melting patches of snow is valuable to foraging caribou (Klein 1990, Kuropat 1994, Johnstone et al. 2002), but the spectral signal of snow, and possibly standing water, complicates NDVI-based inferences in patchy snow and recently melted conditions. Snow, water, and lake ice all depress NDVI values. Therefore, estimates of NDVI change rapidly as snow melts and exposes standing dead biomass, which has positive NDVI values (Sellers 1985, cited in Hope et al. 1993; Stow et al. 2004), and as the initial flush of new growth begins to appear (an NDVI value of 0.09 has been 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 value slows.

Before 2007, we used zero-baseline estimation to calculate NDVI_calving (i.e., negative NDVI values were set to zero; Lawhead et al. 2004, 2006, 2007). When that approach was used, the values of NDVI_calving were determined largely by the timing of snow melt. Snow melt typically occurs during calving and can change significantly within just a few days. As a result of changing snow cover, the levels of NDVI_calving vary substantially, based on the timing of satellite imagery relative to melt and how much snow and ice remains to mask the effect of new vegetation.

In 2007 and 2008, we adjusted NDVI_calving to overcome this problem by using the value of NDVI in late September (late-fall baseline estimation) as the minimum value of NDVI_calving. These baseline estimates were obtained after plant senescence occurred but before

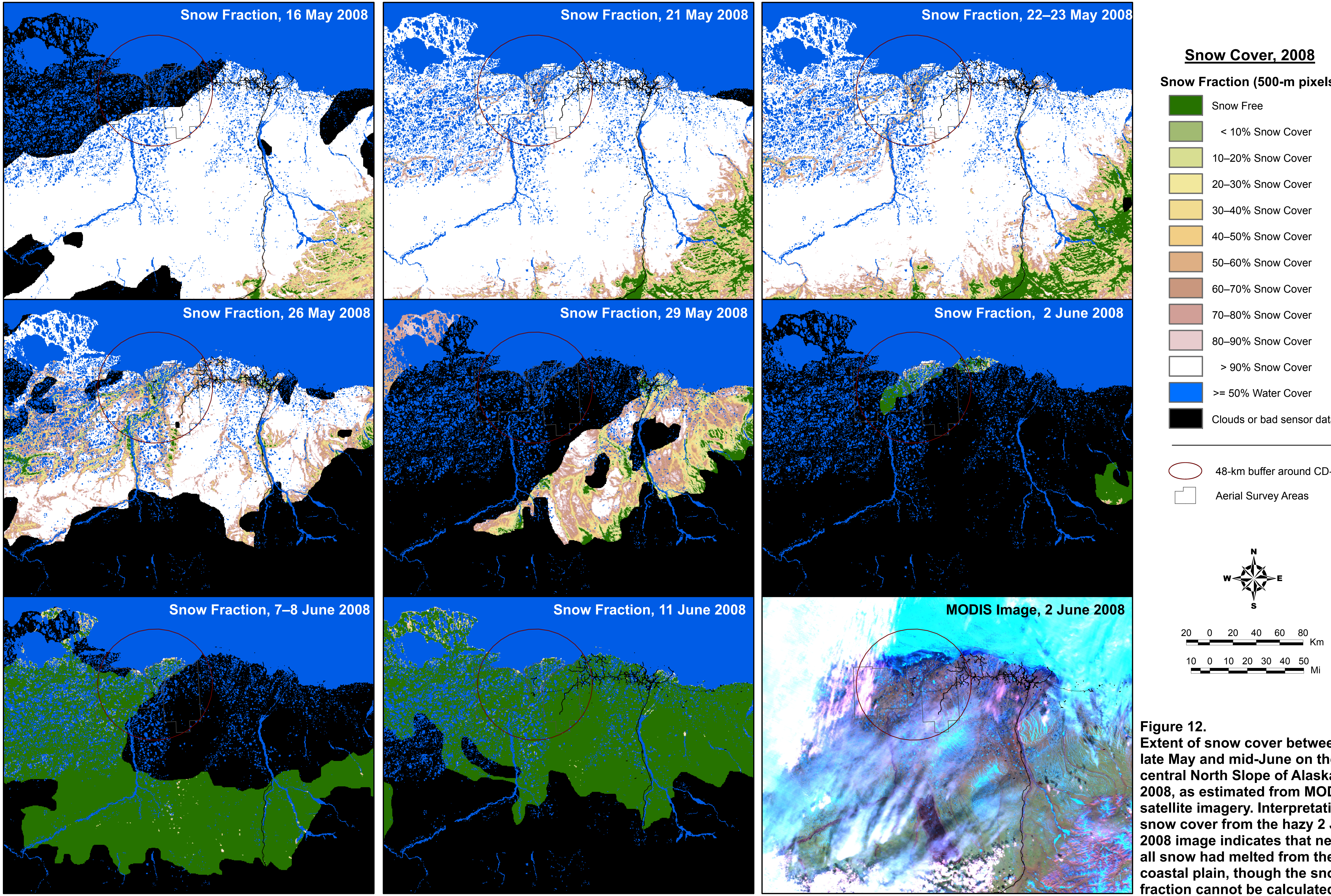

Figure 12.
Extent of snow cover between late May and mid-June on the central North Slope of Alaska in 2008, as estimated from MODIS satellite imagery. Interpretation of snow cover from the hazy 2 June 2008 image indicates that nearly all snow had melted from the coastal plain, though the snow fraction cannot be calculated.

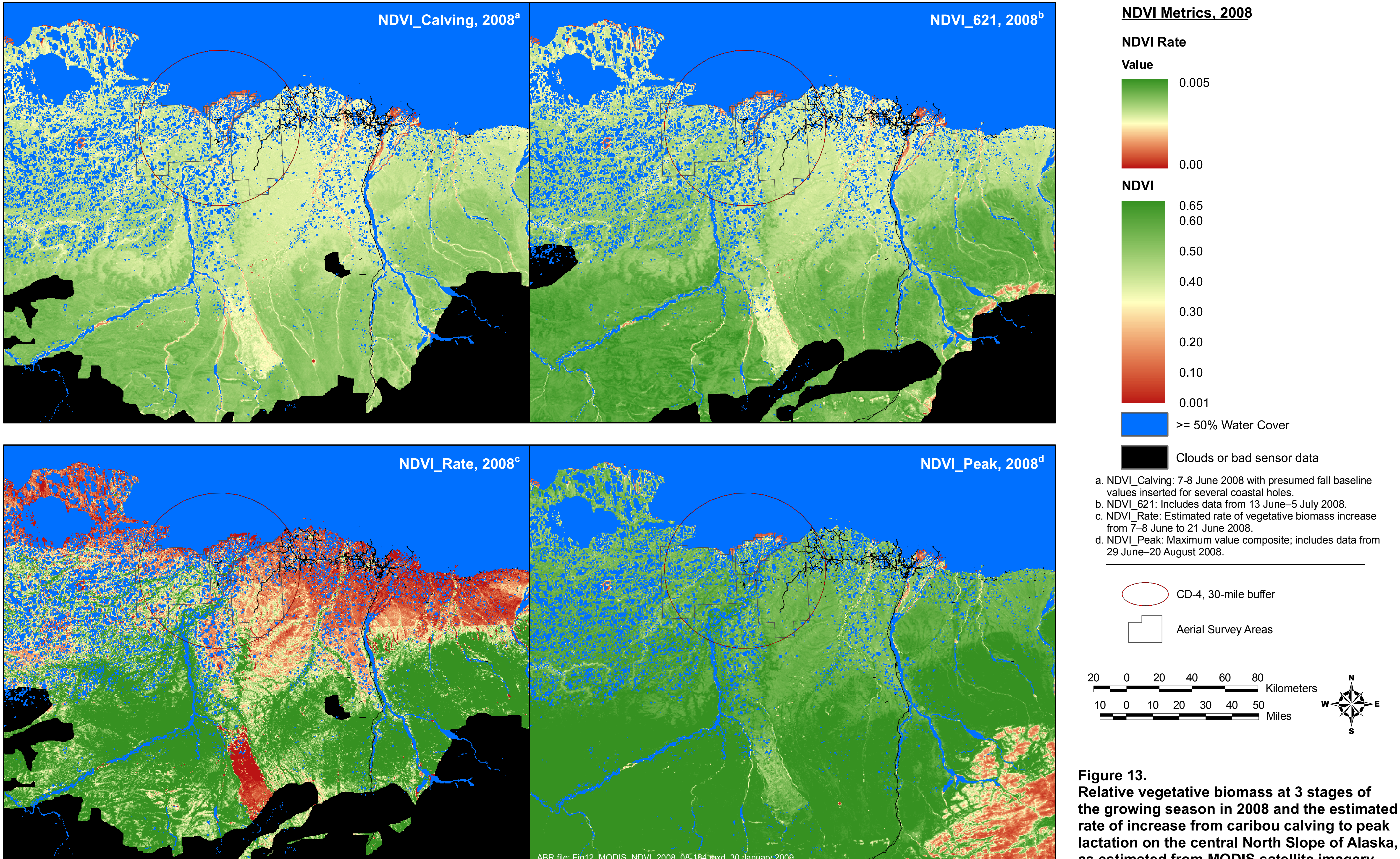

Figure 13.
Relative vegetative biomass at 3 stages of the growing season in 2008 and the estimated rate of increase from caribou calving to peak lactation on the central North Slope of Alaska, as estimated from MODIS satellite imagery.

snow began to accumulate, so they are the best available representation of the NDVI value of standing dead biomass. Using this alternative correction approach provided better estimates of the amount and pattern of new vegetative growth in early June. Consequently, the resulting values of NDVI_calving are quite different from estimates obtained using the zero-baseline approach (Figure 14) and are more accurate estimates of the true level of vegetative biomass.

Numerous cloud-free days during calving in 2007 allowed us to examine the relationship between snow melt and NDVI empirically. We calculated the variables NDVI_calving and NDVI_rate using the same method as in 2002–2006 (using a baseline of zero) for several different days during the 2007 calving period. During the period of snow melt, most NDVI estimates were lower than the fall baseline. Therefore, the resulting estimates of NDVI_calving and NDVI_rate varied widely depending on the date of the calving image, demonstrating the profound influence of snow cover on NDVI estimates at that time of year (Figure 14; Lawhead et al. 2008). Using the late-fall baseline estimation approach had the effect of eliminating negative bias in NDVI caused by snow, water, and ice. Until the spring NDVI exceeds the fall NDVI baseline value, vegetative biomass cannot be measured accurately with NDVI, but the phenology of vegetation can be inferred from the subpixel-scale snow-cover fraction. We did not have enough cloud-free images in spring 2008 to repeat this comparison.

In most of our study area, the measured NDVI during calving is generally lower than the fall baseline NDVI, so NDVI_rate is approximately equal to NDVI_621 minus the fall baseline, divided by the number of days between the date the calving imagery was taken and 21 June. The denominator in this equation is thus an arbitrary number (the number of days), which confounds

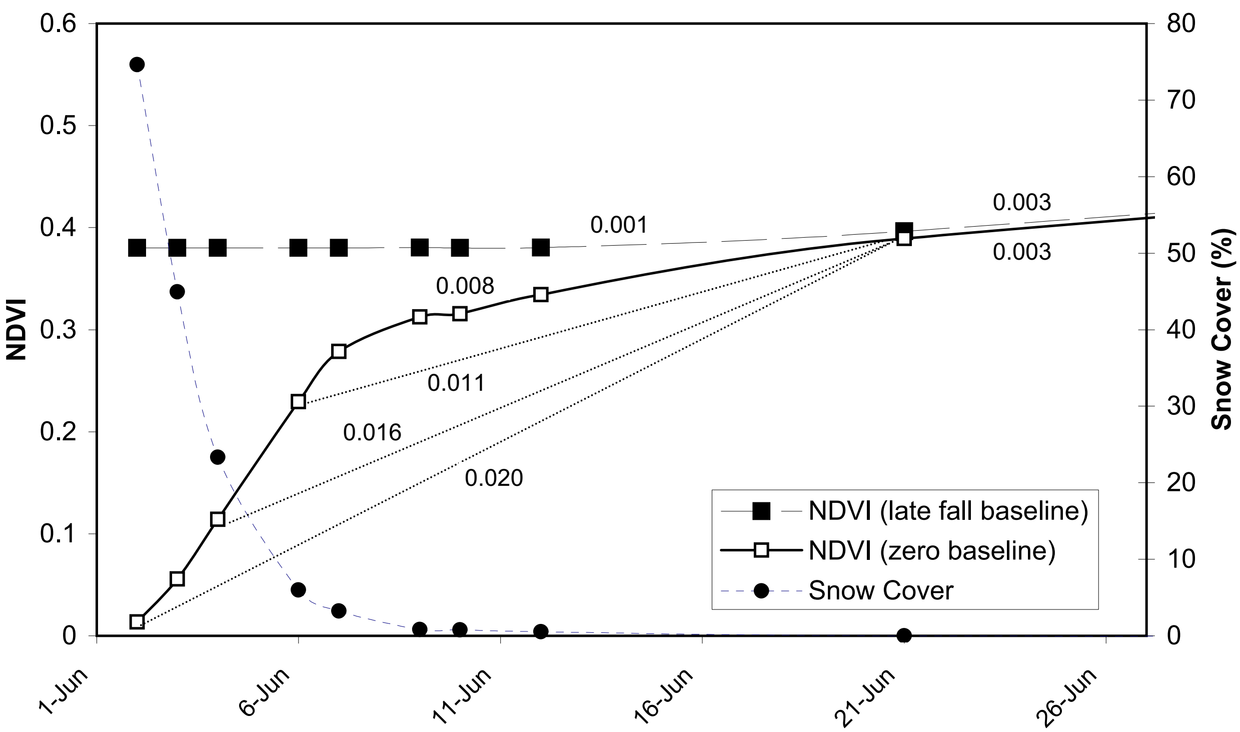

Figure 14. Change in relative vegetative biomass (NDVI, as estimated from MODIS satellite imagery) by date in the NPRA survey area during 2007, illustrating the difference between using zero (solid line) or the late-fall NDVI value (long dashed line) as the baseline for calculating the estimated rate of increase (NDVI_rate) from calving (1–10 June) to peak lactation (21 June). The estimated rate of increase (dotted lines) was influenced substantially by the amount of snow cover remaining at different starting dates during the caribou calving period.

interannual comparisons of NDVI_rate. We suggest that, to make NDVI_rate a more meaningful metric of the rate of phenological change, it should be calculated by dividing the change in NDVI by the number of days since snow melt was complete or by the number of days since NDVI surpassed the fall baseline. Both of these measures are difficult to determine if the study area is obscured by clouds during calving, however, which is a common problem.

An alternative to NDVI_rate that avoids the need to use NDVI_calving values would be to derive a measure of the phenological stage of vegetative growth that has been completed by the time of peak lactation (estimated as 21 June) each year, expressed as a proportion of the total annual growth. The following equation could be used to estimate the proportion of phenological change (PPC) occurring by 21 June:

$$PPC = (NDVI\_621 - NDVI\_fall) \div (NDVI\_peak - NDVI\_fall).$$

This metric would allow more meaningful comparison of the progression of vegetative growth among years.

Although snow melt was earlier in 2008 than in 2007, NDVI values in most of the NPRA survey area during calving still were equal to or lower than the late fall values, suggesting that little new vegetative growth was detected on the satellite imagery. The value of NDVI_621 for the NPRA survey area (0.4164) was greater than in 2007 (0.4014; Lawhead et al. 2008), probably reflecting earlier growth of vegetation after the earlier snow melt in 2008. The NDVI_peak values were actually higher in 2007 (0.5428) than in 2008 (0.5370), however. This difference could be due to different growing conditions in mid-summer or possibly differences in the timing of imagery between years.

A major tundra fire in late summer and fall 2007 within the area of satellite imagery resulted in a fire scar with low NDVI in fall 2007 and spring 2008 and somewhat higher NDVI by fall 2008 (see lower center of all four panels in Figure 13). The presence of a major disturbance such as a recent fire scar invalidates the fall NDVI baseline method in the disturbed area. Because the fire scar was outside of our analytical area, however, we did not attempt to correct this problem.

CARIBOU DISTRIBUTION ANALYSES

GEOGRAPHIC LOCATION

The distribution of caribou groups during aerial-transect surveys was highly variable among the five geographic sections analyzed in the NPRA survey area (Figure 2) in most seasons and years (Table 5, Appendix N). In this analysis, habitat availability differed between the 2002–2004 and 2005–2008 survey areas. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix M) influenced the seasonal differences in caribou distribution. We focus here on analytical results using the pooled 7-year transect data set (2002–2008; Table 5); the differences seen using the pooled data set generally were similar within individual years but often were not significant due to smaller sample sizes.

For the pooled 2002–2008 sample, significantly more groups of caribou occurred in the North, River, and Southwest sections than would be expected if caribou were distributed uniformly among sections (Table 5). The North section contained fewer groups during winter and more groups during spring migration, the postcalving and mosquito seasons, and late summer. The River section contained more groups during the postcalving season, oestrid-fly season, and late summer. The Southwest section contained more groups during winter, calving and fall migration, but fewer during the mosquito and oestrid-fly seasons and late summer.

During all seasons, the Southeast section, which includes nearly the entire length of the proposed ASDP road alignment, contained fewer groups than would be expected if caribou distribution were uniform (Table 5). The Coast section also tended to contain fewer groups, with the differences being significant during winter, calving, postcalving, and fall migration (Table 5). During the mosquito season, however, caribou groups were significantly more numerous in the Coast 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 Coast 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 Coast section

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).

Year	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South east	South west	Chi-square	*P*-value
2008	Winter	1[a]	60	6	10	15	27	2	10.15	0.038
	Spring	1	10	1	0	2	2	5	6.47	0.167
	Calving	1	145	5--	33	26	36	45 +	13.58	0.009
	Postcalving	1	82	5	43++	18	6--	10	48.08	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	112	13	37	35 +	21	6--	29.75	<0.001
	Fall Migration	3	245	21	70	57	43--	54	14.44	0.006
	Total	8	654	51	193++	153 +	135--	122	48.97	<0.001
2002–2008	Winter	3	471	18--	57--	105	138--	153++	76.56	<0.001
	Spring	7	392	28	114++	72	81--	97	49.17	<0.001
	Calving	8	776	16--	159	139	164--	298++	132.78	<0.001
	Postcalving	7	815	19--	204++	269++	146--	177	136.09	<0.001
	Mosquito	6	102	18 +	43++	24	11--	6--	80.35	<0.001
	Oestrid Fly	7	197	9	23	98++	34--	33--	84.67	<0.001
	Late Summer	13	631	31	149 +	231++	111--	109--	124.65	<0.001
	Fall Migration	15	1288	47--	237	312	300--	392++	69.19	<0.001
	Total	66	4672	186--	986++	1250++	985--	1265++	299.36	<0.001
Available area, 2002–2004 (km²)				8.9	64.8	133.7	191.0	148.2		
Available area, 2005–2008 (km²)				70.7	160.9	136.0	191.0	148.4		

[a] Only part of the area surveyed.
\+ 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 ($P < 0.01$).

on 2 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. Over all years combined, caribou used the River zone more than expected if distribution were uniform. Results for 2008 were generally consistent with the patterns observed for all years combined.

These results are interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain. During calving, the highest densities of TH females calve near Teshekpuk Lake, so densities decrease with increasing distance from the lake (Prichard and Murphy 2004, Carroll et al. 2005); hence, more caribou would be expected in the western portion of the NPRA survey area in that season than in the eastern portion. 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 begin to 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 M) 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 underlying this difference may include the greater distance of the latter section from Teshekpuk Lake and its location on the fringe of the TH range, differences in habitat quality, or avoidance of human activity (near Nuiqsut or avoidance of infrastructure at a scale not documented). Whatever the reason(s), it is important to recognize that this pattern of distribution exists before construction of the proposed 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 Unlimited 2002). The numerous combinations of seasons, years, and habitat classes resulted in a complex matrix of test results (Table 6, Appendix O) 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.

Across all seasons and years (2002–2008), the proportions of caribou groups using riverine habitats and the moss/lichen and dwarf-shrub types—three of the four least abundant classes—were significantly greater than expected based on the relative availability of those habitats, whereas the proportions of groups using flooded tundra—the second most abundant class—was significantly less than expected (Table 6). Riverine habitats were used more than expected during the postcalving, mosquito, and oestrid-fly seasons and in late summer, consistent with the geographic analysis above, and dwarf shrub was used more than expected during late summer and fall migration. The proportion of caribou groups using tussock tundra was less than expected during summer (mosquito, oestrid-fly, and late summer seasons), but more than expected during calving. The highest proportions of tussock tundra occurred in the Southeast section of the study area, which had contained fewer caribou groups during calving (Table 5). Hence, it appears that although caribou were underrepresented in the Southeast section, they selected tussock tundra habitat within geographic sections in the calving season. The wet-sedge (*Carex aquatilis*) type was used more than expected during the mosquito and oestrid-fly seasons but less than expected during postcalving. Flooded tundra was used less during calving, postcalving, and fall migration. Wet tundra was used less than expected during calving but did not differ from expected during any other season. Use of sedge/grass meadow was greater than expected during spring migration, calving, and postcalving but less during oestrid-fly season and late summer. The moss/lichen class occurred in higher proportions in riverine areas and was used more than expected during the postcalving, mosquito season, oestrid-fly season, late summer, and fall migration but less than expected during calving.

During calving, caribou may seek dry, snow-free areas, but habitat type generally was a poor predictor of group location during calving in the NPRA survey area 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 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 NPRA survey area (which is not an important calving area), we found that caribou used areas with sedge/grass and tussock tundra more than expected and used wet, flooded, and riverine areas less than expected.

After mosquitoes and oestrid flies emerged, caribou distribution was dominated by the profound influences of insect harassment. The drainages of Fish and Judy creeks are important landscape features affecting caribou distribution, particularly during the insect season. The selection of coastal and riverine areas by caribou as insect-relief habitat predominated over selection of other classes with greater forage availability.

The distribution of habitats differs among the various distance zones around the proposed ASDP road alignment (Table 7) due mainly to the presence of Fish and Judy creeks to the north of the proposed road and to the generally decreasing

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 in 2008 alone and 2002–2008 combined.

				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]
2008	Winter	1[c]	60	0.90	1.34	1.50	1.24	0.83	1.46	1.19	1.35	0.09 -
	Spring Migration	1	10	1.28	1.08	0.66	0.48	1.28	0.19	1.68	3.10	0.00
	Calving	1	145	0.88	1.01	0.84	1.23 +	1.10	0.53 -	0.49--	0.42	0.32 -
	Postcalving	1	82	1.02	0.91	0.98	1.23	1.01	1.42	0.69	0.70	0.45
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	1	112	0.77	0.93	0.98	0.65--	0.84 -	2.31++	1.54+	1.44	4.08++
	Fall Migration	3	245	0.83 -	0.89	0.91	1.17 +	1.05	1.51+	1.11	0.20	0.66
	Total	8	654	0.88	0.97	0.95	1.07 +	1.01	1.40++	1.02	0.74	1.05
2002–2008	Winter	3	471	0.99	1.02	1.01	0.95	1.04	0.77	1.25+	0.83	0.50-
	Spring Migration	7	392	1.08	1.02	0.96	1.27++	0.94	0.94	0.81	0.85	0.48--
	Calving	8	776	0.93	0.88--	0.93 -	1.17++	1.07++	0.76 -	0.89	0.67	0.67--
	Postcalving	7	815	0.87--	0.86--	1.01	1.07 +	1.00	1.32 +	1.03	1.32	1.67++
	Mosquito	6	102	1.52++	0.95	0.93	1.17	0.70--	1.88 +	1.06	0.67	2.52 +
	Oestrid Fly	7	197	1.34++	1.09	1.05	0.65--	0.64--	2.49++	1.29	1.75	4.73++
	Late Summer	13	631	0.99	0.96	1.04	0.81--	0.78--	2.10++	1.48++	1.69	3.69++
	Fall Migration	15	1288	1.01	0.93--	0.99	1.01	1.02	1.37++	1.15+	1.03	0.92
	Total	66	4672	1.00	0.93--	0.99	1.02	0.96	1.32++	1.12++	1.10	1.50++
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–1008				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.
[c] Partial survey.
\+ 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 ($P < 0.01$).

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 Zone (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).

proportion of tussock tundra from south to north. The proportions of the dune, 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 after construction of the proposed infrastructure will need to incorporate these differences in habitat availability.

SNOW COVER

Comparison of snow cover with the locations of caribou groups during calving indicated that caribou groups on 9 June 2008 used areas that had significantly more snow than the average snow cover estimated over the entire NPRA survey area on 26 May ($P < 0.01$). The average snow cover in the NPRA survey area on 26 May was 74.1%; on 9 June, caribou were using areas that had a mean snow cover of 81.4% (99% C.I. = 75.5–86.7%) on 26 May. By 9 June, almost all snow had melted in the survey area, but these results suggest that caribou were using areas where snow melt had occurred more recently, which is consistent with selection of foraging areas with newly emerged green vegetation.

Previous studies have not provided consistent results concerning the calving distribution of northern Alaska herds in relation snow cover. Kelleyhouse (2001) concluded that TH females selected areas of low snow cover during calving and Carroll et al. (2005) reported that TH caribou calved farther north in years of early snow melt. Wolfe (2000) did not find any consistent selection for snow-cover classes during calving by the CAH, whereas Eastland et al. (1989) and Griffith et al. (2002) reported that calving caribou of the Porcupine Herd preferentially used areas with 25–75% snow cover. 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, Griffith et al. 2002, Johnstone et al. 2002) and it also may increase dispersion of 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 caribou do not require snow-free areas in which to calve and are able to find nutritious forage even in patchy snow cover. Interpretation also is complicated by high annual variability in the extent of snow cover and the timing of snow melt among years, as well as by variations in our ability to detect melt dates on satellite imagery because of cloud cover.

VEGETATIVE BIOMASS

Among seasons, caribou appeared to select areas with high values of estimated biomass (NDVI_calving, NDVI_621, and NDVI_peak) during spring migration and calving but selected areas with low estimated biomass (NDVI_calving, NDVI_621, and NDVI_peak) during late summer (Table 8). In general, the more inland areas (Southeast and Southwest sections of the NPRA survey area) had higher estimated biomass than did the Coast, North, and River sections (Appendix M). In 2005 and 2007, caribou also selected areas of higher estimated biomass during calving. In 2006, however, caribou selected areas with lower biomass (NDVI_calving and NDVI_621) during calving. The reason for the difference in the 2006 results is not readily explainable, because caribou otherwise showed similar patterns of habitat use and geographic distributions among the four years of study (Tables 5–6, Appendices N–O).

NDVI was used to estimate biomass in this study 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 (estimated by NDVI_rate) than was available over 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 an estimated 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).

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) at locations used by caribou groups in the NPRA survey area in 2008, compared with availability using a bootstrap analysis.

Season	*n*[a]	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak
Winter	47	0.3805	0.4203	0.0030	0.5458
Spring Migration	9	0.4046 ++	0.4404 +	0.0027	0.5736 ++
Calving	125	0.3970 ++	0.4341 ++	0.0028	0.5522 ++
Postcalving	62	0.3739	0.4129	0.0029	0.5376
Late Summer	85	0.3587 --	0.4013 --	0.0032 ++	0.5242 -
Fall Migration	201	0.3846	0.4204	0.0027	0.5438 +
Total Use	529	0.3821	0.4200 +	0.0028 +	0.5426 ++
Available		0.3806	0.4164	0.00269	0.5370
Available Winter		0.3784	0.4146	0.00274	0.5364

[a] Caribou groups in pixels with >50% water fraction were not included in analysis.
\+ 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 ($P < 0.01$).

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 geographical differences in 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 the period of snow melt 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 study area of 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 snow melt. In years when 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.

None of the previous analyses described above adjusted NDVI_calving and NDVI_rate with fall baseline NDVI values, so their results probably are more strongly related to temporal and spatial patterns of snow melt than to differences in vegetative biomass.

DISTANCE TO PROPOSED ROAD

In most seasons and years, the number of caribou groups observed in each distance-to-road zone around the proposed ASDP road alignment did not differ significantly from those expected based on a uniform distribution among zones (Table 9, Appendix P). For all years combined (2001–2008; Figure 15), however, fewer caribou groups than expected (based on a uniform distribution) occurred within 2 km of the road alignment during spring migration and the oestrid-fly season and more caribou than expected occurred 4–6 km north of the road alignment during the oestrid-fly season and late summer. The area 2–4 km north of the road was used more than expected during late summer, and the area south of the road alignment was used less than expected during the mosquito and oestrid-fly seasons and late summer. Significantly more groups than expected occurred 4–6 km north of the road during

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
2008	Winter	1[a]	31	3	7	11	5	5	2.24	0.692
	Spring Migration	1	3	2	0	0	1	0	5.58	0.233
	Calving	1	28	4	3	10	7	4	2.94	0.567
	Postcalving	1	7	2	1	3	0	1	1.69	0.793
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	30	10	6	4 -	1 --	9	11.27	0.024
	Fall Migration	3	50	12	10	9	10	9	4.16	0.385
	Total	8	149	33	27	37	24	28	2.78	0.595
2001–2008	Winter	3	121	17	17	32	27	28	8.31	0.081
	Spring Migration	8	83	20	17	13 --	15	18	10.06	0.039
	Calving	9	171	27	18	61	28	37	6.63	0.157
	Postcalving	9	289	73	40	95	35	53	9.29	0.054
	Mosquito	7	20	8	4	5	0 -	3	8.47	0.076
	Oestrid Fly	9	60	24 ++	16	7 --	4 -	9	30.69	<0.001
	Late Summer	15	192	54 +	48 +	47	13 --	30	32.19	<0.001
	Fall Migration	18	314	68	57	121	55	63	0.54	0.969
	Total	78	1307	291 +	217	381	177	241	14.83	0.005
Area surveyed, 2001 (km^2)				35.2	30.0	60.6	28.0	31.4		
Area surveyed, 2002–2004 (km^2)				34.5	29.5	61.9	31.4	35.1		
Area surveyed, 2005–2008 (km^2)				41.6	31.3	61.9	31.4	35.1		

[a] Partial survey.
\+ 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 ($P < 0.01$).

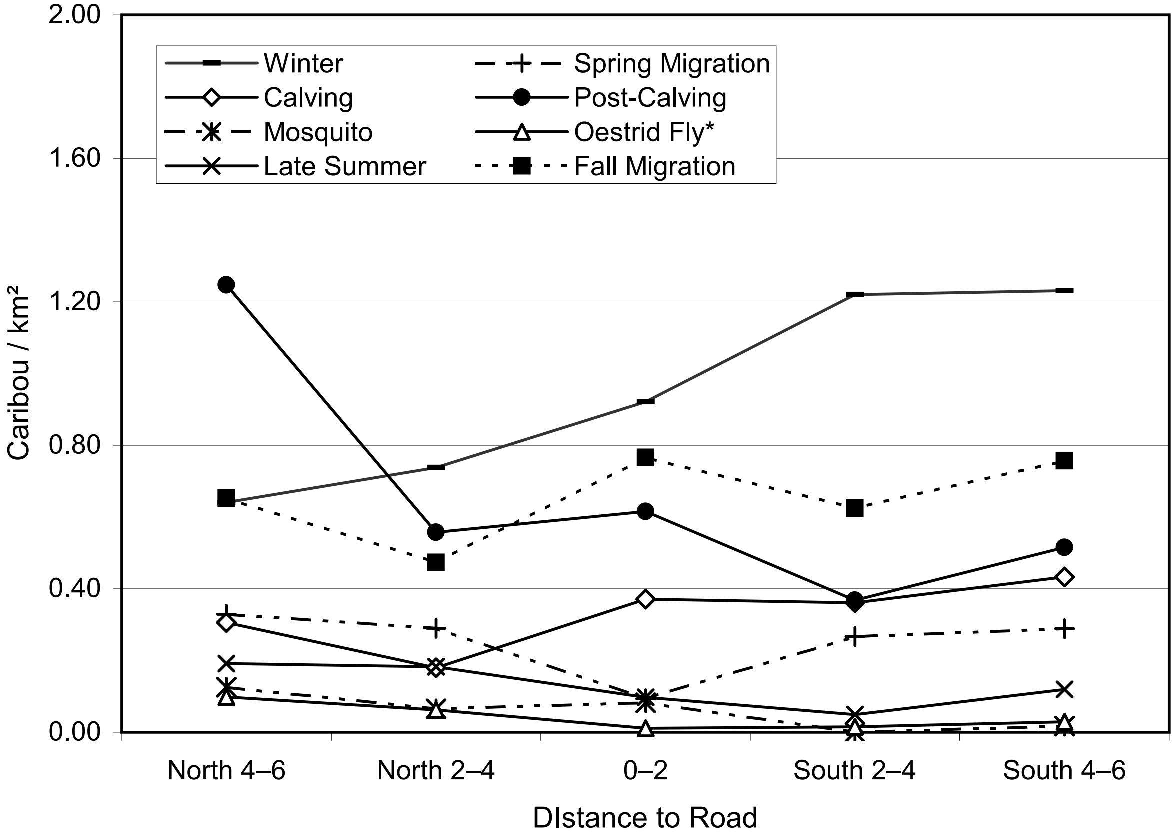

Figure 15. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2008.

all seasons combined. These results were consistent with greater use of areas near Fish and Judy creeks during oestrid-fly season and late summer, as was described above for the geographical and habitat-use analyses.

Caribou density also differed significantly among distance zones (Wald chi-square *P*-value < 0.001) and showed a significant zone-by-season interaction ($P < 0.001$) and significant differences among seasons ($P < 0.001$). Caribou density within 6 km of the proposed alignment was significantly lower during the combined mosquito and oestrid-fly seasons than it was during calving, postcalving, and fall migration (all $P < 0.004$; the 2005 oestrid-fly season survey was dropped from the analysis to avoid undue influence on test results). Density was significantly lower in late summer than during postcalving ($P < 0.001$) and fall ($P = 0.011$). No other seasons differed significantly ($P > 0.05$).

Over all seasons combined, the North 4–6-km zone had the highest caribou density and was significantly higher than the North 2–4-km zone ($P = 0.014$) and the South 2–4-km zone ($P = 0.001$), but there were no other significant differences among zones ($P > 0.05$). Significant differences in density were found among zones during each season except fall migration and the combined mosquito and oestrid-fly season (all $P < 0.05$), although the pattern varied among seasons. The density within 2 km of the proposed road was significantly higher than in the North 2–4-km zone during calving ($P = 0.006$), lower than both northern zones during late summer (both $P < 0.012$), and higher than the North 4–6 km zone during winter ($P = 0.005$). No other zones differed significantly from the zone near the road ($P > 0.05$).

Because caribou aggregate into large groups when mosquitoes are present and move quickly when harassed by insects, density during the mosquito and early part of the oestrid-fly seasons fluctuates widely. Caribou density in the area of the proposed road generally was 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. Aerial-transect survey coverage during the mosquito and oestrid-fly seasons has been sparse due to the difficulty and expense of adequately sampling the highly variable occurrence and movements of caribou at that time of year. Caribou density in other seasons was fairly consistent and did not exhibit a pattern with regard to distance from the proposed road alignment.

CARIBOU DENSITY ANALYSIS

Grid-cell analysis of the NPRA aerial-transect data examined the influence of geographic location, snow cover, vegetative biomass, habitat type, and distance to the proposed ASDP road alignment on caribou density during the calving season in 2008 and among all seasons for the years 2002–2008. A number of variables used in the grid-cell analyses were correlated.

After removing one outlier, the estimated peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 (r = 0.942; P < 0.001) and NDVI_calving (r = 0.849; P < 0.001), but was not highly correlated with NDVI_rate (r = 0.390; P < 0.001). These results indicate that the spatial pattern of NDVI values is consistent throughout all phenological stages. The spatial pattern of NDVI_peak can be explained largely by differences among habitat types. NDVI_peak increased with increasing proportion of tussock tundra (r = 0.794; P < 0.001) but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; r = –0.496; P < 0.001). Despite the masking used to eliminate bias from large waterbodies in NDVI calculations, the correlation between NDVI_peak and the proportion of water in remaining pixels was large (r = –0.706; P < 0.001), suggesting that even small ponds artificially depressed NDVI values.

The proportion of tussock tundra alone explained 63.1% of the variation in NDVI_peak values, and the combination of tussock tundra with the proportion of wet habitat and the proportion of water explained 81.8% of the variation. Distance from the coast also had an effect: NDVI_peak values were higher in grid-cells farther from the coast (slope = 0.0010; P < 0.001).

The snow-cover fraction on 26 May 2008 was highly correlated with NDVI_rate (r = –0.695, P < 0.001), suggesting that areas with early snow melt had more advanced vegetative growth by 21 June. The correlation between snow cover on 26 May and NDVI_621 was weak (r = 0.107; P = 0.176), however, perhaps because variation in the NDVI of standing dead vegetation swamped the signal from new growth.

Caribou Density During the Calving Season

The best model for caribou density during the 2008 calving season in the NPRA survey area included four independent variables: presence of Fish or Judy creeks (included in all models), presence of the proposed road alignment (included in all models), snow cover on 26 May, and NDVI_peak; this model had a 63.2 % chance of being the best model (w_i = 0.632; Appendix Q). The second-best model included the same variables as the best model, plus transect number (west to east); this model had a 35.9% chance of being the best model (w_i = 0.359) (Appendix Q). The model-weighted parameter estimates indicated that presence of creeks, NDVI_peak, NDVI_rate, snow cover on 26 May, and proportion of tussock tundra all were related positively to calving density (P < 0.05; Table 10). Selection for areas with high NDVI_peak values may reflect selection for areas with high biomass, for tussock tundra, and/or against wet habitats. The transect number (P = 0.404), the presence of the proposed road alignment (P = 0.245), and the proportion of wet habitats (P = 0.067) were not significant factors in the 2008 results.

For all years combined (2002–2008), analysis of calving density provided generally similar results to those for 2008 alone, albeit with a few differences. The best model included the presence of the creeks and the proposed road alignment (both variables were in all models so were included in the best model by default) and the transect number (west to east), NDVI_peak value, and distance to coast (Appendix R). The

Table 10. Model-weighted parameter estimates for calving caribou density in the NPRA survey area, 9 June 2008.

Variable	Coefficient	SE	*P*-value
Intercept	–13.096	2.620	<0.001
Presence of creeks	0.931	0.420	0.027
Presence of proposed road	–0.662	0.570	0.245
NDVI_peak	20.956	4.664	<0.001
NDVI_rate	338.052	157.889	<0.032
Snow cover on 26 May (%)	0.021	0.006	0.001
Tussock tundra (%)	2.727	0.900	0.002
Wet habitat (%)	–1.701	0.927	0.067
Transect number (W to E)	–0.025	0.030	0.404

model-weighted parameter estimates indicated that caribou density during calving was greater with increasing NDVI_peak values ($P < 0.001$), proportion of tussock tundra ($P < 0.001$), and distance to coast ($P = 0.015$; Appendix S) and caribou density was lower in the eastern transects ($P < 0.001$). The proportion of wet habitat (negative relationship, $P = 0.067$) was a moderately significant factor and the presence of the creeks ($P = 0.301$) and the proposed road ($P = 0.855$) were not significant (Table 11, Appendix S).

Caribou densities in the NPRA survey area during calving indicate a preference for areas with higher NDVI_peak values in most years. Given the high correlation between NDVI values and habitat type, it is difficult to distinguish whether caribou were selecting specific habitat types and 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 between-year correlations of caribou density during calving were low for 2005, 2006, and 2007 (r = 0.181–0.421; natural-log transformed), suggesting that different factors influenced caribou distribution among years at this scale.

Caribou Density Among Seasons

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

Overall, strong seasonal patterns in caribou density were evident. A west-to-east gradient of decreasing density was evident throughout the entire year, 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 higher densities from postcalving through late

Table 11. Significance levels of model-weighted parameter estimates of independent variables used in analyses of seasonal caribou density within 163 grid cells in the NPRA survey area, 2002–2008.

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

\+ Greater than zero ($P < 0.05$).
++ Greater than zero ($P < 0.01$).
\- Less than zero ($P < 0.05$).
-- Less than zero ($P < 0.01$).
** Significantly different among surveys ($P < 0.01$).

summer. The riverine area is characterized by a mosaic of habitats, including abundant willows and forbs that provide forage and barrens, dunes, and river bars that provide fly-relief habitat. Caribou densities near the coast were lower during the calving season and higher during spring migration, the postcalving and mosquito seasons, and late summer, which are generally consistent with increased use of coastal areas during mosquito harassment. Caribou densities in areas with high proportions of tussock tundra were greater during calving and lower during late summer than other areas. 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 alignment in NPRA was used by caribou to a different degree than adjacent areas, although the density of caribou groups in grid cells containing the road alignment was lower during winter and higher during the mosquito season.

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 in the NPRA survey area during calving, highly variable 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 Colville East survey area), postcalving, 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. In general, 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. The movements by large numbers of TH caribou onto the Colville delta in July 2007 were a notable exception to this generalization, however.

Movements by satellite- and GPS-collared TH and CAH caribou into the vicinity of CD-4 (between Nuiqsut and the Alpine processing facilities) have occurred sporadically and infrequently during the calving, mosquito, and oestrid-fly seasons and fall migration since monitoring began. None of the satellite collars in the TH were recorded in the immediate vicinity of CD-4 during 1990–2006 or 2008. In 2007, a satellite-collared TH female passed between Nuiqsut and CD-4 during calving and four satellite-collared TH caribou moved east past Alpine and CD-4 in late July.

Of 31 GPS-collared TH females during 2004–2008, one crossed the delta between CD-4 and Alpine in June 2005, one crossed the delta between CD-4 and Alpine in June 2007, one crossed just west of Alpine in July 2007, and another spent several days in August 2007 about 2 km south of CD-4.

One satellite-collared CAH caribou moved into the CD-4 vicinity briefly in July 1988 and four others were nearby briefly in July 1989, more than a decade before construction. Four CAH satellite collars moved through the CD-4 vicinity while heading inland in late July 2001 and one CAH GPS collar moved onto the Colville delta east of CD-4 in late September 2004.

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 located in a geographic area with low-density use by caribou. Collared CAH caribou crossed the alignment very rarely and the proposed corridor would 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, 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) and higher proportions of tussock tundra. 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, mosquito, 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 both 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 monitor caribou movements in relation to the existing facilities in the ASDP study area and to compile predevelopment baseline data on caribou density and movements in the portion of the NPRA survey area where further development is planned. 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. The data reported here provide an important record for evaluating and mitigating the potential impacts of ASDP development on caribou distribution and movements, as well as providing ongoing results to refine the study effort in future years of the program.

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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 1 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; 1 April–31 May) and cumulative thawing degree-days (° C above freezing; 1 May –15 August) at the Kuparuk airstrip, 1983–2008.

	Snow Depth (cm)			Cumulative Thawing Degree-days (º C)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
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
2007	25	46	5	0	0	48.3	83.3	115.0	138.9	134.4
2008	20	18	0	0	33.9	73.3	141.1	173.3	135.0	88.3 [b]
Mean	22	12	3	0.6	11.6	41.8	101.7	124.7	141.5	126.0

[a] Value for June 1
[b] Preliminary data.

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. 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	252	35.9	0.15	2.2
October 10	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	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	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).
[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).

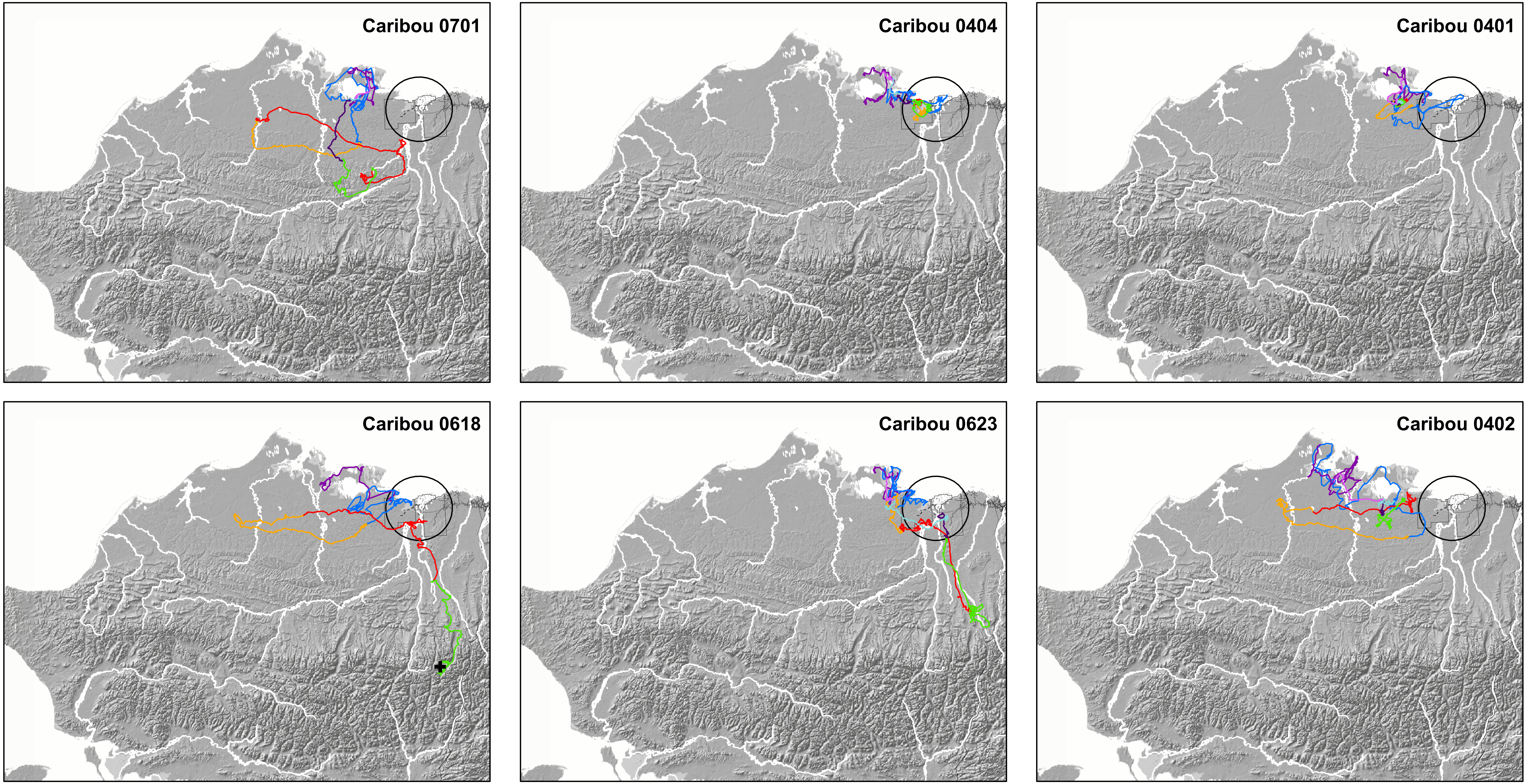
Appendix I. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2007.

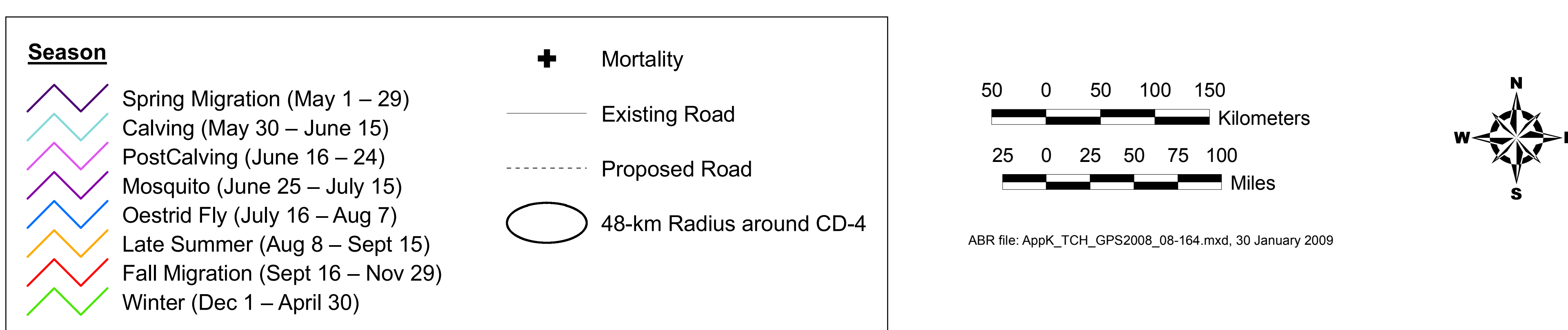
Survey Area (Size) and Date	Large Caribou [a]	Calves [b]	Total Caribou	Estimated Total [c]	SE [d]	Density (caribou/km²) [e]	Mean Group Size
NPRA (1720 km²) [f]							
May 14	746	0	746	1492	175.6	0.87	4.7
June 9	686	47	733	1466	188.0	0.85	3.7
June 18	645	49	694	1388	173.9	0.81	3.9
June 25	229	0	229	458	62.8	0.27	3.7
August 12	41	1	42	84	10.6	0.05	1.4
August 24	64	2	66	132	20.4	0.08	1.2
September 21	286	5	291	582	66.9	0.34	2.7
October 8 [g]	291	nr	291	1092	225.3	0.63	5.2
October 22	1519	nr	1519	3038	282.6	1.77	8.2
COLVILLE R. DELTA (494 km²) [f]							
May 15	28	0	28	56	20.4	0.11	5.6
June 19	19	2	21	42	14.5	0.09	2.6
June 25	78	1	79	158	53.0	0.32	4.9
August 13	10	0	10	20	11.2	0.04	2.0
August 24	4	1	5	10	4.3	0.02	1.7
September 21	3	0	3	6	3.0	0.01	1.5
October 8–9 [g]	17	nr	17	64	17.8	0.13	8.5
COLVILLE EAST (1696 km²) [f]							
May 15	380	0	380	760	105.1	0.45	4.9
June 2, 4–5 [g,h]	558	51	609	2290	477.3	1.60	1.9
June 11–12 [h]	4015	1298	5313	10,626	597.9	7.42	7.7
June 18	3389	569	3958	7916	1086.0	4.67	11.7
June 24	1555	347	1902	3804	800.5	2.24	24.1
August 13	80	1	81	162	38.3	0.10	2.3
August 23	33	1	33	66	10.1	0.04	1.3
September 21-22	215	14	229	458	42.9	0.27	2.8
October 9 [g]	84	nr	84	315	76.1	0.19	7.0
October 24 [i]	147	nr	147	735	304.5	0.43	6.4

[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 2008).
[i] Partial survey only (339 km²) due to fog.

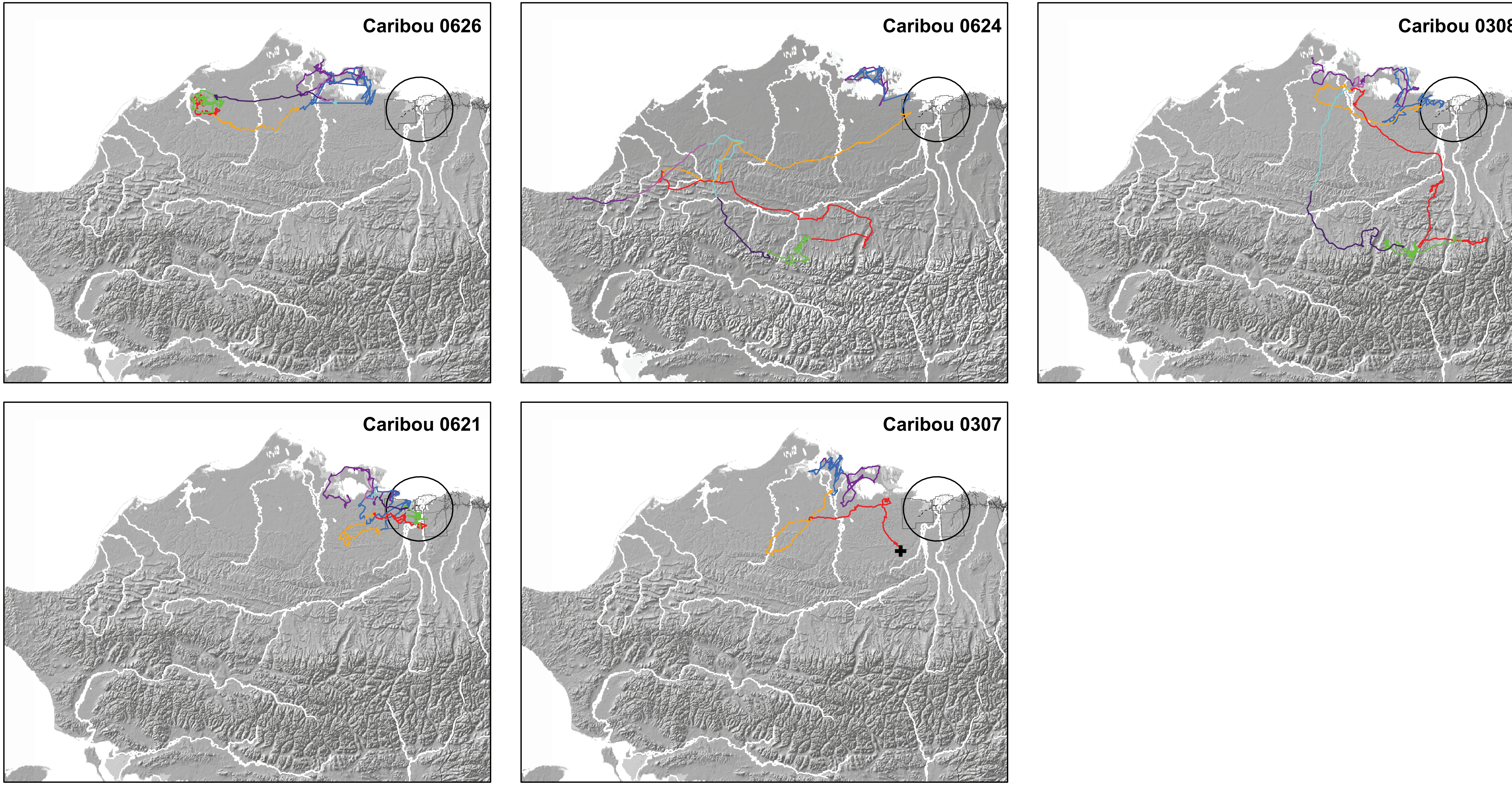
Appendix J. Locations and number of other mammals observed during aerial surveys in the NPRA–Kuparuk region, April–October 2008.

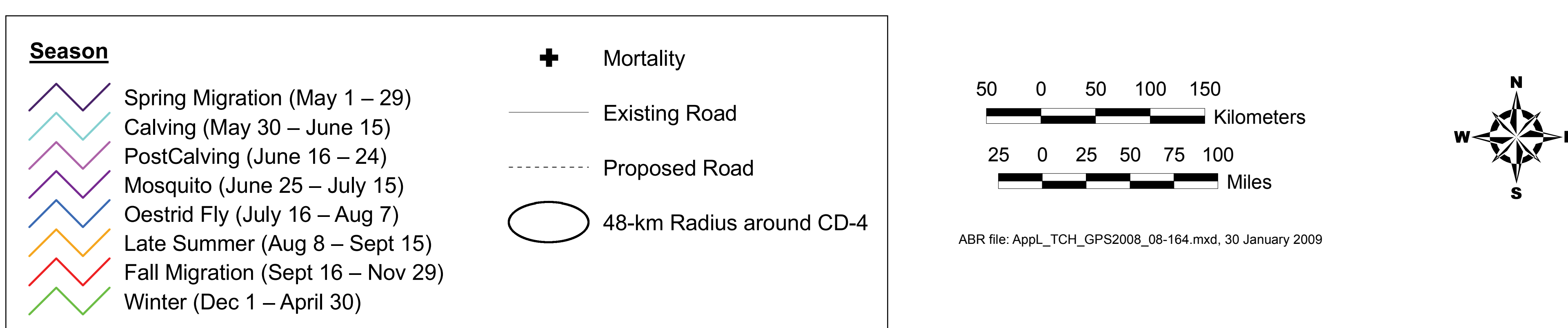
Species	General Location	Date	Total	Adults	Young	Specific Location
Muskox	Colville River	April 29	12	10	2	E of Nuiqsut
		June 4	3	2	1	N of Kuparuk DS-3S
		September 25	2	2	0	Mouth of Miluveach R.
		October 25	11	9	2	E of Nuiqsut
		October 25–26	2	2	0	Mouth of Kachemach R.
	Central GKA	May 19	26	22	4	SE of Kuparuk CPF-1
		June 2	26	22	4	E of Kuparuk CPF-1
		June 5	25	21	4	E of Kuparuk CPF-1
		June 7	25	21	4	E of Kuparuk CPF-1
		June 10	26	22	4	S of Kuparuk CPF-1
		June 18	7	5	2	N of Spine Rd., E of Milne Pt. Rd.
		June 19	7	5	2	W of Kuparuk R.
	Milne Point	June 2	1	1	0	Milne Point
		June 2	11	11	0	E of Milne Pt. Rd.
		June 2	14	12	2	E of Milne Pt. Rd.
		June 10	9	6	3	E of Milne Pt. Rd.
		June 10	1	1	0	E of Milne Pt. Rd.
		August 18	3	3	0	E of Milne Pt. Rd.
	Kuparuk River	June 10	31	26	5	N of Spine Rd.
		June 24	6	4	2	S of Spine Rd.
		June 24	7	5	2	S of Spine Rd.
		June 24	11	8	3	N of Spine Rd.
		June 24	1	1	0	N of Spine Rd.
		June 24	9	7	2	N of Spine Rd.
		July 2	≥7	≥6	1	Near Spine Rd.
		August 19	10	8	2	N of Spine Rd.
		August 20	1	1	0	N of Spine Rd.
		September 25	4	3	1	S of Spine Rd.
Grizzly Bear	NPRA	June 9	3	1	2	Upper Fish Creek
		June 9	1	1	0	Upper Judy Creek
		June 9	3	1	2	Lower Fish Creek
		June 10	3	1	2	Upper Fish Creek
		June 25	3	1	2	Lower Fish Creek
		August 18	3	1	2	Lower Fish Creek
	Colville River Delta	June 24	1	1	0	Outer delta
		August 19	1	1	0	E of Alpine CD-4
	Upper Colville River	May 18	2	1	1	E of Colville R. near Ocean Pt.
		October 7	1	1	0	Between Colville R. & Itkillik R.
	Western Kuparuk Area	June 4	4	1	3	Upper Sakonowyak R.
		June 11	1	1	0	Upper Miluveach R.
		June 19	1	1	0	Lower Miluveach R.
		June 19	1	1	0	S of Kuparuk DS-2M
		September 25	1	1	0	Lower Kachemach R.
		September 25	4	1	3	Upper Miluveach R.
	Eastern Kuparuk Area	June 10	1	1	0	S of Kuparuk CPF-1
		June 10	3	1	2	E of Milne Point Rd.
		August 19	1	1	0	Kuparuk R.
Polar Bear	Colville River Delta	August 8	1	1	0	Colville Village
Spotted Seal	Colville River delta	August 18	28	28	0	Eastern delta
Gray Wolf	Western Kuparuk Area	October 25	1	1	0	Miluveach R.
Wolverine	NPRA	June 26	1	1	0	Fish Creek





Appendix K.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, June 2007–June 2008.





Appendix L.
Movements of 5 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, June 2007–June 2008.

Appendix M. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2008 and for habitat type (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2008 NPRA survey areas.

Survey Area	Variable	Statistic	Coast	North	Rivers	Southeast	Southwest
2002–2004	Area	km²	9.8	88.3	156.1	232.2	167.2
	Vegetative Biomass	NDVI_calving	0.3739	0.3835	0.3587	0.3964	0.4034
		NDVI_621	0.4057	0.4115	0.4063	0.4379	0.4402
		NDVI_rate	0.0024	0.0021	0.0036	0.0032	0.0028
		NDVI_peak	0.5263	0.5289	0.5275	0.5597	0.5569
	Snow Cover 21 May	Mean %	99.5	98.6	89.7	99.4	100.0
	Snow Cover 23 May	Mean %	98.1	97.9	83.0	98.3	99.9
	Snow Cover 26 May	Mean %	52.3	87.7	44.4	68.6	90.8
	Habitat Type (% area)	Water	9.9	26.6	14.4	17.7	11.4
		Carex aquatilis	11.5	6.3	6.4	6.2	8.4
		Flooded Tundra	33.0	11.5	14.9	18.3	18.2
		Wet Tundra	12.3	7.5	11.5	7.3	10.3
		Sedge/Grass Meadow	7.4	22.0	14.2	5.3	13.5
		Tussock Tundra	23.7	22.0	25.1	41.3	34.2
		Moss/Lichen	1.4	0.9	3.3	0.3	0.7
		Dwarf Shrub	0.2	1.9	3.2	2.9	2.8
		Low Shrub	0	<0.1	0.1	0.3	0.2
		Dry Dunes	0.1	0.1	2.0	0.1	0
		Sparsely Vegetated	<0.1	0.5	2.9	0.1	<0.1
		Barren Ground	0.4	0.7	2.1	0.1	0.1
2005–2008	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_calving	0.3328	0.3804	0.3583	0.3965	0.4034
		NDVI_621	0.3508	0.4061	0.4057	0.4380	0.4401
		NDVI_rate	0.0013	0.0019	0.0036	0.0031	0.0028
		NDVI_peak	0.4753	0.5266	0.5269	0.5598	0.5570
	Snow Cover 21 May	Mean %	99.4	98.7	89.7	99.4	100.0
	Snow Cover 23 May	Mean %	99.1	98.3	83.0	98.4	99.9
	Snow Cover 26 May	Mean %	86.1	85.4	44.4	68.6	90.8
	Habitat Type (% area)	Water	24.2	22.1	15.3	17.7	11.4
		Carex aquatilis	8.3	6.3	6.4	6.2	8.4
		Flooded Tundra	15.0	10.1	14.9	18.3	18.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.3
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	13.5
		Tussock Tundra	19.7	25.5	24.8	41.3	34.3
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1
		Low Shrub	<0.1	<0.1	0.1	0.3	0.2
		Dry Dunes	3.2	0.3	2.0	0.1	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1
		Barren Ground	8.0	0.8	2.1	0.1	0.1

Appendix N. 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
2007	Winter	0	–	–	–	–	–	–	–	–	–
	Spring Migration	1	159	13	44	44	26--	24	8	15.02	0.010
	Calving	1	198	4--	44	22--	40	72^{++}	16	76.16	<0.001
	Postcalving	1	178	3--	60^{+}	49	37	23	6	32.47	<0.001
	Mosquito	1	62	8	31^{++}	15	7--	1--	0	38.30	<0.001
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–
	Late Summer	2	83	8	19	31^{++}	14	8	3	19.81	0.001
	Fall Migration	3	347	20--	94	63	112	48	10	16.42	0.005
	Total	9	1027	56--	292^{++}	224	236-	176	43	46.10	<0.001

$^{+}$ 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 ($P < 0.01$).

Appendix O. 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, 2002–2007.

				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
2007	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	159	1.21	1.18	0.99	1.19+	0.85-	1.14	0.74	0.68	0.49
	Calving	1	198	0.97	0.92	0.96	1.13	1.12+	0.37--	0.77	0.61	0.27--
	Postcalving	1	178	0.86	0.86-	1.00	0.99	1.04	1.19	1.10	0.57	1.53
	Mosquito	1	62	1.15	0.94	1.00	1.16	0.85	1.55	0.99	0.00	1.60
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	83	1.18	0.98	1.08	0.51--	0.66--	1.17	1.76^{+}	4.14+	5.21^{++}
	Fall Migration	3	347	0.93	0.91-	0.97	1.06	1.09+	1.11	0.91	0.44	0.59-
	Total	9	1027	1.00	0.95	0.99	1.04	1.00	1.02	0.96	0.81	1.11

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

[b] Riverine type comprises Dry Dunes, Sparsely Vegetated, and Barren Ground subtypes.

[c]. Partial survey

$^{+}$ 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 ($P < 0.01$).

Appendix P. Number of caribou groups in distance-to-proposed-road zones by year and season, 2001–2007, 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

Appendix P. 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
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	29	8	9	4 -	6	2	10.16	0.038
	Calving	1	34	5	4	16	4	5	4.32	0.364
	Postcalving	1	48	14	3 -	16	6	9	4.80	0.309
	Mosquito	1	11	5	4	2	0	0	10.52	0.033
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	19	2	8	5	2	2	10.50	0.033
	Fall Migration	3	74	10	14	24	13	13	2.63	0.622
	Total	9	215	44	42	67	31	31	3.51	0.477

+ 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 ($P < 0.01$).

Appendix Q. Model selection results (General Estimating Equations) for analyses of caribou density during calving 2008 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), percent snow cover on May 26 (Snow Cover), and peak NDVI value (NDVI_peak).

Model [a]	*n* [b]	K [c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
Creek, Road, Snow Cover, NDVI_peak	**163**	**7**	**699.06**	**0.00**	**0.632**
Creek, Road, W to E, Snow Cover, NDVI_peak	163	8	700.19	1.13	0.359
Creek, Road, W to E, NDVI_peak	163	7	708.85	9.79	0.005
Creek, Road, W to E, Snow Cover, Tussock	163	8	711.04	11.99	0.002
Creek, Road, NDVI_peak	163	6	712.14	13.09	0.001
Creek, Road, Snow Cover, Tussock	163	7	712.17	13.12	0.001
Creek, Road, Snow Cover, NDVI_rate	163	7	715.95	16.89	0.000
Creek, Road, Snow Cover, Wet Habitats	163	7	717.46	18.40	0.000
Creek, Road, W to E, Snow Cover, NDVI_rate	163	8	717.81	18.75	0.000
Creek, Road, W to E, Snow Cover, Wet Habitats	163	8	717.91	18.85	0.000
Creek, Road, W to E, Tussock	163	7	718.68	19.63	0.000
Creek, Road, Snow Cover	163	6	719.47	20.42	0.000
Creek, Road, W to E, Snow Cover	163	7	721.06	22.00	0.000
Creek, Road, Tussock	163	6	725.01	25.95	0.000
Creek, Road, W to E	163	6	725.49	26.44	0.000
Creek, Road, W to E, Wet Habitats	163	7	725.52	26.47	0.000
Creek, Road	163	5	727.02	27.96	0.000
Creek, Road, W to E, NDVI_rate	163	7	727.31	28.26	0.000
Creek, Road, Wet Habitats	163	6	728.68	29.63	0.000
Creek, Road, NDVI_rate	163	6	729.00	29.94	0.000

[a] Coast = distance from coast; Tussock = proportion of tussock tundra; Wet Habitats = combined proportions of four types; see text.
[b] Sample size.
[c] Number of estimable parameters in the approximating model.
[d] Quasi-likelihood Information Criterion, corrected for small sample size.
[e] Difference in value between the QIC_c of the current model and that of the best approximating model.
[f] Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix R. Model selection results for Generalized Estimating Equation analyses of caribou density in different seasons during 2002–2008 in the NPRA survey area (163 grid cells). Bold type denotes the best model for each season.

		Model [a]															
Season	Value	S,C,R	S,C,R,DC	S,C,R,NP	S,C,R,TT	S,C,R,WH	S,C,R,TR	S,C,R,TR,NP	S,C,R,TR,TT	S,C,R,DC,NP	S,C,R,DC,TT	S,C,R,DC,WH	S,C,R,TR,DC	S,C,R,TR,WH	S,C,R,TR,DC,NP	S,C,R,TR,DC,TT	S,C,R,TR,DC,WH
All Seasons	*n* [b]	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163
Winter	K [c]	6	7	7	7	7	7	8	**8**	8	8	8	8	8	9	9	9
	QIC_c [e]	2010	2003	2010	2011	2012	1988	1989	**1987**	2004	2004	2004	1989	1989	1990	1989	1990
	w_i [f]	0.000	0.000	0.000	0.000	0.000	0.167	0.109	**0.271**	0.000	0.000	0.000	0.129	0.093	0.054	0.120	0.056
Spring	K	10	11	11	11	11	11	12	12	12	12	12	12	12	13	**13**	13
	QIC_c	2776	2773	2777	2778	2777	2754	2756	2755	2775	2775	2775	2741	2756	2739	**2737**	2741
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.087	0.000	0.164	**0.658**	0.091
Calving	K	11	12	12	12	12	12	13	13	13	13	13	13	13	**14**	14	14
	QIC_c	4265	4152	4196	4258	4265	4140	4065	4095	4139	4153	4153	4090	4120	**4056**	4071	4086
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	**0.983**	0.001	0.000
Postcalving	K	10	11	11	11	11	11	12	12	12	12	12	12	12	**13**	13	13
	QIC_c	4730	4731	4730	4720	4726	4578	4579	4580	4732	4722	4728	4550	4580	**4548**	4550	4550
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.227	0.000	**0.450**	0.157	0.165
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11	11
	QIC_c	915	825	887	904	912	903	873	894	826	825	826	**784**	901	786	786	786
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.462**	0.000	0.173	0.194	0.171
Oestrid Fly	K	6	7	7	7	7	7	8	8	8	8	8	8	8	**9**	9	9
	QIC_c	715	709	709	706	713	695	689	692	696	698	706	697	696	**689**	693	698
	w_i	0.000	0.000	0.000	0.000	0.000	0.017	0.341	0.092	0.012	0.005	0.000	0.007	0.010	**0.453**	0.059	0.004
Late	K	16	17	17	17	17	17	18	18	18	18	18	18	18	**19**	19	19
Summer	QIC_c	3876	3862	3823	3836	3867	3820	3767	3797	3825	3830	3856	3771	3818	**3751**	3763	3772
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.996**	0.003	0.000
Fall	K	18	19	19	19	19	19	20	20	20	20	20	20	**20**	21	21	21
Migration	QIC_c	8246	8246	8247	8236	8229	8221	8221	8218	8245	8234	8227	8222	**8212**	8223	8220	8214
	w_i	0.000	0.000	0.000	0.000	0.000	0.011	0.007	0.038	0.000	0.000	0.001	0.005	**0.659**	0.003	0.014	0.263

[a] S=Survey, 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] QIC_c = Quasi Likelihood 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 S. 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, 2002–2008. Asterisks denote significance of *P*-value (* < 0.05, ** <0.01, *** <0.001).

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–0.489	0.762	0.521
	Presence of Creek	–0.247	0.216	0.252
	Includes Proposed Road	–0.646	0.313	0.039*
	NDVI_peak	2.375	3.190	0.457
	Distance to Coast (km)	0.006	0.009	0.480
	Tussock Tundra (%)	0.786	0.581	0.176
	Wet Habitat (%)	–0.371	0.593	0.531
	Transect Number (West to East)	–0.087	0.022	<0.001***
Spring Migration	Intercept	–3.793	0.950	<0.001***
	Presence of Creek	–0.401	0.236	0.090
	Includes Proposed Road	–0.424	0.377	0.261
	NDVI_peak	4.146	3.955	0.295
	Distance to Coast (km)	–0.023	0.009	0.010*
	Tussock Tundra (%)	1.000	0.683	0.143
	Wet Habitat (%)	–0.568	0.664	0.392
	Transect Number (West to East)	–0.089	0.025	<0.001***
Calving	Intercept	–6.834	1.500	<0.001***
	Presence of Creek	0.167	0.162	0.301
	Includes Proposed Road	–0.049	0.269	0.855
	NDVI_peak	13.011	2.900	<0.001***
	Distance to Coast (km)	0.016	0.007	0.015*
	Tussock Tundra (%)	1.654	0.485	0.001***
	Wet Habitat (%)	–0.860	0.469	0.067
	Transect Number (West to East)	–0.112	0.017	<0.001***
Postcalving	Intercept	0.702	1.316	0.593
	Presence of Creek	0.981	0.161	<0.001***
	Includes Proposed Road	–0.035	0.279	0.899
	NDVI_peak	3.641	2.830	0.198
	Distance to Coast (km)	–0.026	0.007	<0.001***
	Tussock Tundra (%)	0.364	0.499	0.465
	Wet Habitat (%)	–0.363	0.495	0.464
	Transect Number (West to East)	–0.155	0.018	<0.001***
Mosquito	Intercept	3.078	1.138	0.007**
	Presence of Creek	0.811	0.313	0.010**
	Includes Proposed Road	0.981	0.480	0.041*
	NDVI_peak	0.526	5.308	0.921
	Distance to Coast (km)	–0.117	0.015	<0.001***
	Tussock Tundra (%)	–0.542	1.035	0.601
	Wet Habitat (%)	0.225	1.041	0.829
	Transect Number (West to East)	–0.177	0.035	<0.001***
Oestrid Fly [a]	Intercept	4.383	3.637	0.228
	Presence of Creek	1.254	0.289	<0.001***
	Includes Proposed Road	–0.462	0.753	0.540
	NDVI_peak	–0.150	0.168	0.371
	Distance to Coast (km)	1.799	0.119	<0.001***
	Tussock Tundra (%)	0.021	0.015	0.160
	Wet Habitat (%)	–14.494	5.420	0.007**
	Transect Number (West to East)	0.700	0.963	0.467
Late Summer	Intercept	4.949	1.292	<0.001***
	Presence of Creek	0.663	0.137	<0.001***
	Includes Proposed Road	0.139	0.258	0.589
	NDVI_peak	–8.916	2.471	<0.001***
	Distance to Coast (km)	–0.021	0.007	0.002**
	Tussock Tundra (%)	–1.082	0.452	0.017*
	Wet Habitat (%)	0.138	0.459	0.764
	Transect Number (West to East)	–0.106	0.016	<0.001***

Appendix S. Continued.

Season	Variable	Mean	SE	*P*-value
Fall Migration	Intercept	–2.014	0.413	<0.001***
	Presence of Creek	0.143	0.144	0.319
	Includes Proposed Road	0.048	0.231	0.835
	NDVI_peak	–1.348	2.325	0.562
	Distance to Coast (km)	0.001	0.006	0.834
	Tussock Tundra (%)	–0.494	0.425	0.245
	Wet Habitat (%)	0.749	0.428	0.080
	Transect Number (West to East)	–0.038	0.015	0.010*

[a.] Two outliers removed prior to analysis.