FIFTH ANNUAL REPORT

CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2009

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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 CD4 drill site and access road. The North Slope Borough (NSB) development permit for CD4 stipulated that a 10-year study of the effects of development on caribou distribution and movements be conducted within a 48-km (30-mile) radius of CD4, which encompasses CD3 (also constructed in winter 2004–2005) and the planned CD5, GMT1 (formerly CD6), and GMT2 (formerly CD7) pads and associated infrastructure and activities proposed by CPAI.
- This report presents results from the fifth year of the ASDP caribou monitoring study, combining analyses of data from aerial 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 2005–2009, 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 1990–2009 for the TH and 1986–1990 and 2001–2005 for the CAH; and GPS-collar data were collected during 2004–2009 for the TH (including 37 collars deployed specifically for this study in early July 2006, late June 2007, late June–early July 2008, and late June 2009) and during 2003–2006 and 2008–2009 for the CAH (including four collars deployed specifically for this study in early July 2008 and six deployed in late June 2009).
- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2002–2009, 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 2005–2009; NDVI_peak). The average daily rate of change in NDVI values between calving and peak lactation was estimated (NDVI_rate). In 2007–2008, 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 2005–2009 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 (2001–2009), 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 33% for satellite collars during 1990–2009 and 4% to 39% for GPS collars during 2004–2009. The mean proportion of collared CAH caribou within the study area during each month varied between 12 and 64% for satellite collars during 1986–1990 and 2001–2009 and between 0 and 52% for GPS collars during 2003–2006 and 2008–2009.
- 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. No movements by satellite- or GPS-collared caribou through the CD4 vicinity (between Nuiqsut and the Alpine facilities) were recorded in 2009. In the past, movements by collared TH and CAH caribou through the vicinity of CD4 have occurred infrequently and sporadically.

- Spatial analysis of caribou distribution among different geographic sections of the NPRA survey area during 2002–2009 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, but less groups than expected during winter, calving, postcalving, and fall. 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 2002–2009 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 2009, caribou groups in the NPRA survey area showed little selection for areas with high vegetative biomass. Areas with high estimated peak levels of vegetative biomass were used more than expected during calving, but areas with lower levels of vegetative biomass were used more than expected during postcalving. Areas with high rates of increase in vegetative biomass in spring were only selected during oestrid-fly season, 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 oestrid-fly season, 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 (Person et al. 2007, Arthur and Del Vecchio 2009, Lawhead et al. 2009, Parrett 2009).

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, Parrett 2007, 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, Parrett 2009). 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; Lawhead et al. 2007, 2008, 2009; Lenart 2009; Parrett 2009).

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 current oilfield development (Wolfe 2000, Arthur and Del Vecchio 2009, Lawhead and Prichard 2009). 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 2009, Lenart 2009).

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. [2010] 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 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, using collars outfitted with very-high frequency (VHF) and satellite transmitters and, since 2004, satellite-linked Global Positioning System (GPS) receivers (Philo et al. 1993, Prichard and Murphy 2004, Carroll et al. 2005, Carroll 2007, Lawhead et al. 2009, Parrett 2009). 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 aerial transect surveys (Cameron et al. 1995, 2005; Arthur and Del Vecchio 2009; Lenart 2009). 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 then extend westward into NPRA. The area available for leasing in the Northeast NPRA Planning Area was expanded after BLM prepared an Amended IAP/EIS (BLM 2005) and Supplemental IAP/EIS (BLM 2008a) and issued the ROD (BLM 2008b).

Beginning in winter 2004–2005, the CD4 drill site and access road on the inner Colville River delta were the first of the proposed facilities to be built for the ASDP expansion, followed closely that winter by the CD3 pad and airstrip on the outer delta. The NSB issued development permit NSB 04-117 for the CD4 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 NSB 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 CD4 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 CD3 pad; the planned pads for CD5, GMT1 (formerly CD6), and GMT2 (formerly CD7); 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 CD4 permit stipulation: "The purpose of the study will be to evaluate the short- and long-term impacts of CD4 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. The results of each of the four preceding years of study (2005–2008) were presented and discussed annually in meetings with the NSB Department of Wildlife Management (9 March 2006, 5 April 2007, 17 March 2008, and 14 April 2009) and in the village of Nuiqsut (1 August 2006, 1 May 2007, 20 March 2008, and 13 October 2009).

This study addresses specific issues concerning the potential impacts of petroleum development on caribou in the ASDP 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 about 40 years ago. The extensive knowledge of local residents has been, and will continue to be, important for formulating research questions and ensuring that appropriate study methods are used. In addition to discussions between biologists and local residents at meetings in Nuiqsut, local observers have participated in some aerial surveys; in 2009, James Taalak was part of the survey crew in August. The combination of observations from both scientific and local/traditional 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 exploration and development continue to expand 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 CD4 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 are 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:

   Which herds use the study area and the vicinity of the proposed pipeline/road corridor that will interconnect the ASDP facilities?

   Do the patterns of seasonal use differ between the two herds?

   How often do caribou cross the existing CD4 pipeline/road corridor and the proposed ASDP pipeline/road corridor in NPRA, and does this differ between the herds?

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 (above-ground vegetative biomass) and indices of habitat use by caribou in relation to proposed infrastructure, to allow temporal comparisons among years (before and after construction) and spatial comparisons within years. Specific questions included the following:

   Do plant biomass and composition vary by habitat type and distance to the proposed road, and how well does remote sensing describe the available biomass?

   Can caribou distribution be explained in terms of broad geographic areas, habitat availability, snow cover, or plant biomass?

   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 tentatively planned for 2010, pending further discussion of study design with the NSB Department of Wildlife Management. 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 fine 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 air 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 CD4 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 was expanded 240 km² in 2008 to include two transects in the area of the Itkillik River, south of the Colville River Delta survey areas. The Colville East survey area also encompasses the western and southwestern margins of the Kuparuk oilfield, including parts of the existing oilfield infrastructure.

The Colville River Delta survey area encompasses the original Alpine Development Project facilities CD1 and CD2, constructed in 1998–2001, and the newer ASDP facilities CD3 (previously called Fiord or CD-North) and CD4 (previously called Nanuq or CD-South), constructed in 2004–2006. The CD3 and CD4 drill sites began producing oil in August and November 2006, respectively. CD3 is a roadless drill site, accessible by ice road in winter and by aircraft in summer, that is connected to CD1 by an elevated pipeline. A road and adjacent elevated pipeline connects the CD4 drill site to CD1.

The NPRA survey area encompasses four more potential drill sites—CD5 (also called Alpine West), GMT1 (formerly CD6 or Lookout), GMT2 (formerly CD7 or Spark), and Fiord West—and a potential gravel mine site (also 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 Niġliq (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 2009, adding

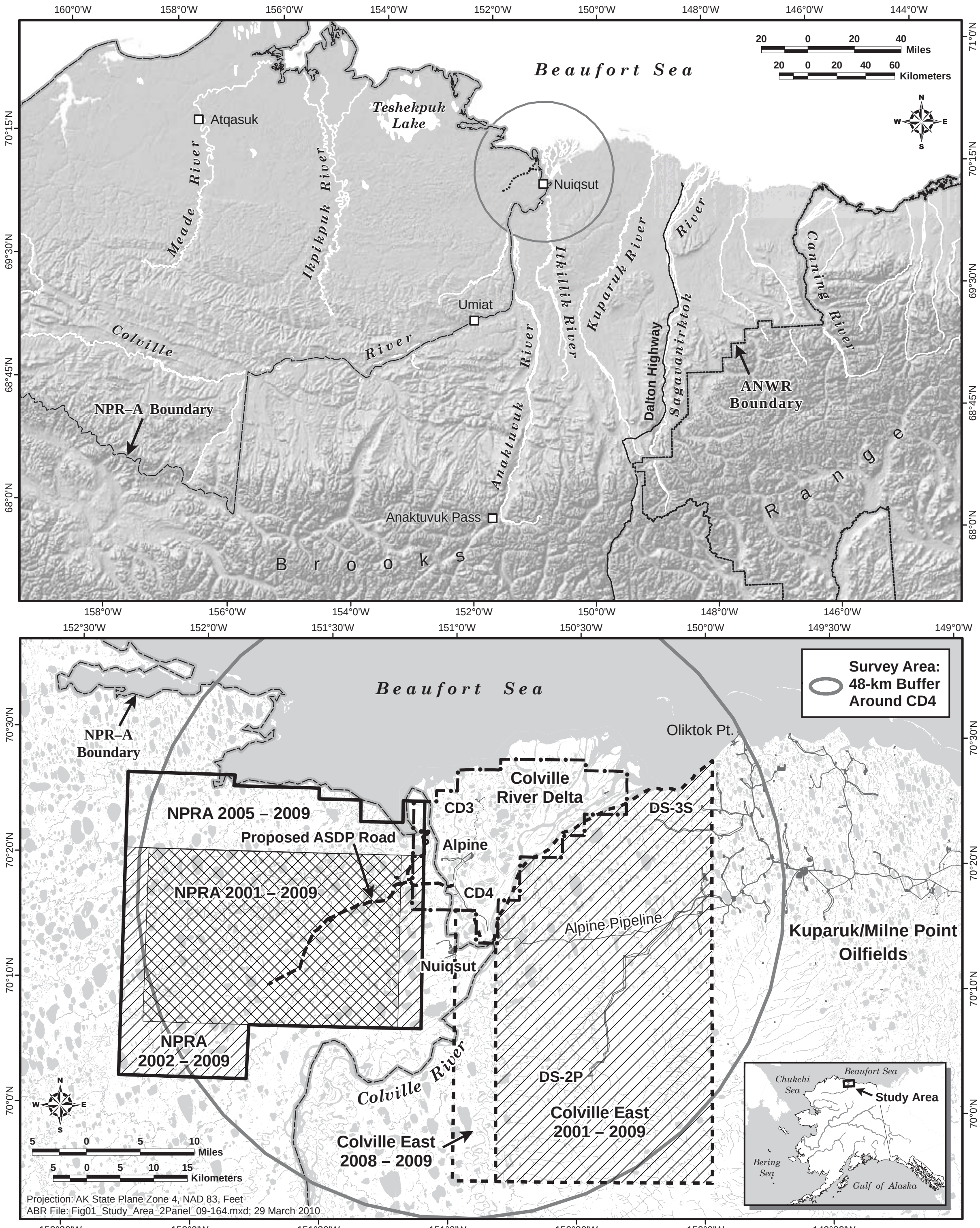

Figure 1. Location of the ASDP caribou monitoring study area (48-km [30-mi] radius around Drill Site CD4) on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2009 (bottom).

to the transect database compiled for the Colville River Delta and Colville East survey areas since the early 1990s and for the NPRA survey area since 2001. We also analyzed several telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and from GPS collars deployed specifically for this study in 2006, 2007, 2008, and 2009. The transect surveys provided broad information on the seasonal distribution and density of caribou in the study area. The radio-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 affiliation, 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 May to August 2009 in 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, 2009, this study). The NPRA survey area was expanded westward and southward in 2002 and northward in 2005 and the Colville East survey was expanded westward in 2008. Additional surveys of Colville East were conducted during the calving season in 2001–2008 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010). Two observers looked out opposite sides of the airplane during all surveys and a third observer usually was present to record data on calving surveys. The pilot navigated the airplane on transect lines using a GPS receiver and maintained an altitude of ~150 m (500 ft) above ground level (agl) or ~90 m (300 ft) agl using a radar altimeter. The lower altitude was used during the calving season to increase detection of caribou in areas of patchy snow cover and 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). Radio-tracking surveys for collared caribou ranged over much of northern Alaska, but data on the specific areas covered on each flight were not available except in summer 2005, when CPAI contracted ADFG to track 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

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	1990–2009	81	34	115
GPS collars [b]	2004–2009	43	0	43
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]	2008–2009	10	0	10

[a] n/a = not available, but most collared animals were females.
[b] Some individuals were recollared during period; totals do not include two NSB collars deployed in 2008 but not yet downloaded or collars funded by ADFG, BLM, or NSB and not yet retrieved.
[c] Number of different collared caribou that came within 48 km (30 mi) of CD4 at least once during the period.
[d] Does not include 10 collars deployed by ADFG in 2008 for retrieval in 2011.

as detailed as those from satellite or GPS telemetry, this method provided data on group size and behavior when the collared caribou could be observed. On some surveys, however, visual confirmation was impossible because the aircraft was forced to remain above the cloud cover, resulting in much lower location accuracy. The sex, age, and reproductive status of collared animals were not available for this analysis, but most were adult females (Cameron et al. 1995, Arthur and Del Vecchio 2009). 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 2009 (Prichard and Murphy 2004; Lawhead et al. 2006, 2007, 2008, 2009, 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, 115 collared caribou (81 females, 34 males) transmitted signals for a mean duration of 539 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 female 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 satellite-collared 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 every 2 days for 11 months. During 1991–2002, most collars were programmed to transmit every other day throughout the year. After 2002, many collars were programmed to transmit once every 6 days in winter and every other day during summer. Most of the TH collars deployed in

2000 malfunctioned and transmitted data only sporadically. The CAH satellite collars deployed during 1986–1990 were programmed to operate 6 h/day or 6 h every 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 due to lack of independence among location fixes (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, it has been suggested that the time between successive samples should approximate the time necessary to travel anywhere else in a home range or seasonal range (Lair 1987, McNay et al. 1994). In addition, systematic sampling of locations over a given time period can remove bias due to autocorrelated 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 every 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 43 female TH caribou were outfitted with GPS collars (purchased by NSB and CPAI) during 2004 and 2006–2009 (Table 1). GPS collars were deployed by ADFG on 45 CAH females during 2003–2006, using an interval of 5 h between location fixes (Arthur and Del Vecchio 2009). Four additional GPS collars (purchased by CPAI) were deployed on CAH females in July 2008 and six were deployed in June 2009.

GPS collars were deployed only on females because the 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 the expandable collars that are required for male caribou due to increased neck size during the rutting season (C. Reindel, Telonics, pers. comm.).

Data reports from satellite uplinks were received by e-mail from CLS America, Inc. (Largo, MD). All location data also were stored in the collars for downloading after the collars were retrieved, however, and those downloaded data replaced the location data that had been obtained via the Argos satellites throughout the year. The stored-on-board data provided the complete data set with a higher degree of accuracy and thus were preferred 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. The GPS collars deployed on six TH and six CAH females in 2009 were programmed to record fixes every 2 h from 16 April to 15 November and every 8 hours during the remainder of the year. The duty cycle was reduced for 2009 to allow a 2-year deployment period, rather the single-year deployments used previously for this study.

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. Two of the collared animals died, one March 2007 and the other in May 2007; the 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 in late June and early July 2008, but the tenth animal (caribou 0624) spent the spring and summer of 2008 with WAH caribou at the western end of the North Slope, too far away to be recaptured until March 2009, while it was wintering near the Dalton Highway.

Twenty TH females were outfitted during 29 June–1 July 2008 with GPS collars purchased by the NSB. Two of those caribou died in March 2009, four others also died but the data are not yet available, six are still active, and the other eight collars were retrieved in late June 2009.

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 used 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 took digital photographs periodically for characterization of habitat use. These devices were 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.

Twelve female caribou (six each from the TH and CAH) were outfitted with CPAI-purchased GPS collars in 2009; an additional CAH animal was collared but died soon after capture. All were adults and three had been collared previously. One collar on a CAH animal stopped transmitting in mid-July 2009 and another CAH animal died in October 2009. The last locations used in this report were from 31 December 2009. Due to the differences between collaring and reporting schedules and the reduced schedule of satellite uplinks this year, fewer than half of the GPS locations from the 2009 collars were available for analysis in this report. The full data set for 2009–2010 will be available after the collars are retrieved in early summer 2011 and the stored-on-board data are downloaded. In addition to the CPAI-funded collars in 2009, another 15 GPS collars were purchased by BLM for deployment on female TH caribou. Those data are not yet available and therefore not included in this report.

For the CAH caribou outfitted by ADFG with GPS collars during 2003–2006, all location data within the 48-km study area radius of CD4 were provided by ADFG. The annual GPS-collar samples (which included some of the same individuals among years) numbered 24, 24, 33, and 29 females in 2003, 2004, 2005, and 2006, respectively, of which 19, 18, 19, and 20 animals were recorded at least once within the 48-km radius; 45 different individuals were located in the study area at least during those four years (Table 1). Most of the CAH locations were obtained at 5-h intervals, but occasionally two locations were recorded over shorter time periods. In most such cases, one of the locations obviously appeared to be 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:

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

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

The binary nature of the standard MODIS snow product limits its usefulness during the period of active snowmelt, when snowdrifts and patchy snow conditions occur at finer scales than 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 ninth-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 6 April–15 September 2009 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 2009 were calculated using satellite imagery acquired from the calving period (three 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, also 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 2008–2009, 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 (2008–2009).

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 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-scale 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. Those 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

To characterize preconstruction conditions in the NPRA study area, caribou group locations from aerial transects 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. The alignment of the proposed ASDP road was changed in 2009, requiring recalculation of the distance buffers around the alignment, as described below.

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 in previous years suggested differing levels of caribou use across the NPRA survey area, so we tested for differences in locations among different geographic sections of the area. We divided the 2002–2004 and 2005–2009 survey areas, which differed in size, into five sections (Figure 2): (1) the area within 4 km of Fish and Judy creeks (called the 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

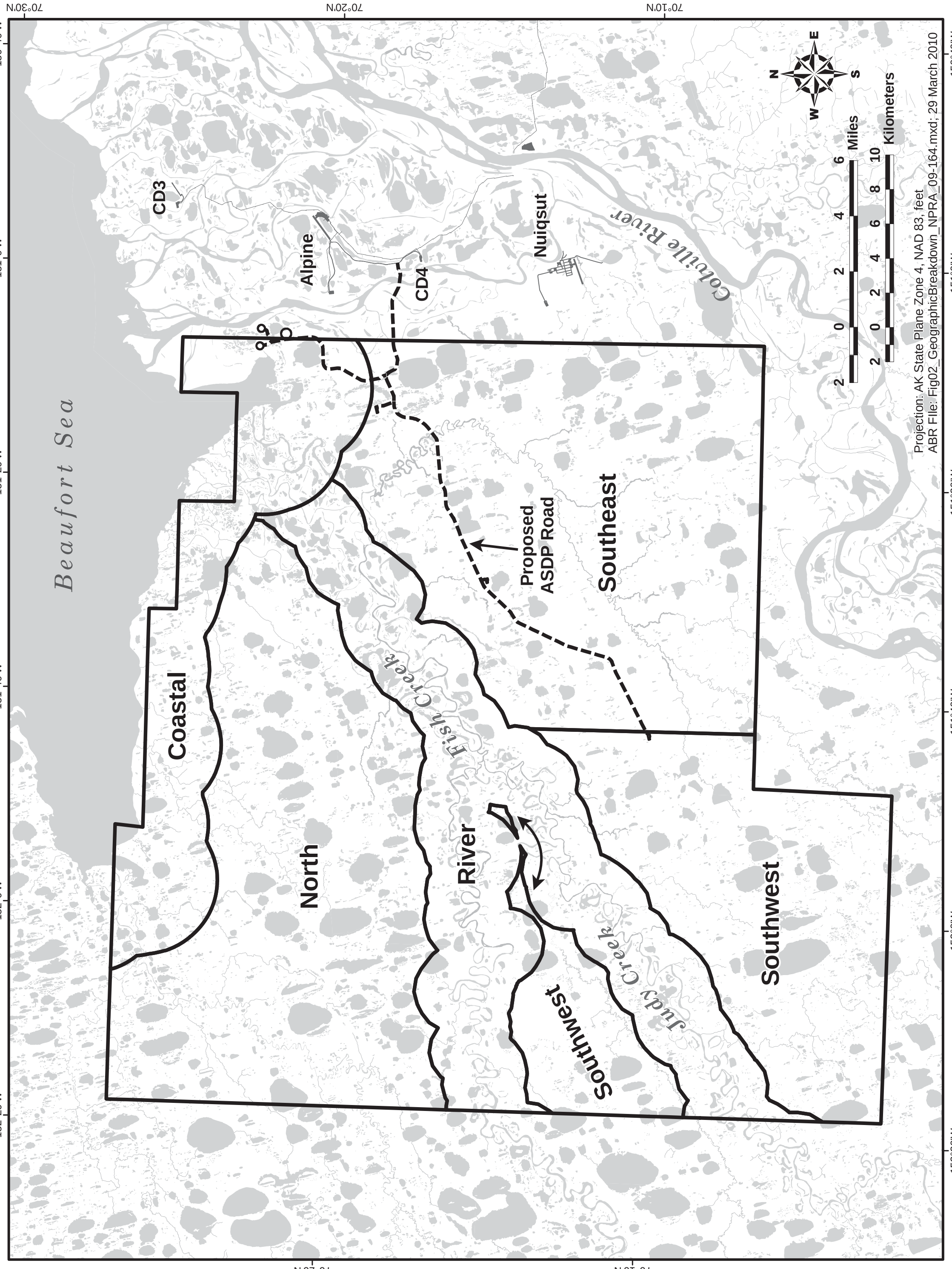

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2009.

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 then were compared using Bonferroni multiple-comparison tests.

HABITAT USE

To compare habitat use with availability in the expanded 2005–2009 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 was developed to classify habitats for birds as well as mammals. We chose the NPRA earth-cover classification (30-m pixel size) over the ELS map for this 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 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 2005–2009 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 2005–2009 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 25 May were estimated for each caribou group location from the calving survey on 8 June (excluding pixels with >50% water). The snow-cover percentages on 25 May were selected for further analysis because that date was the nearest to peak snow melt. The snow-cover percentages for 25 May at all locations where caribou were seen on 8 June were compared with availability using the statistical technique of bootstrapping (Manly 1997), calculated in the following way. From all

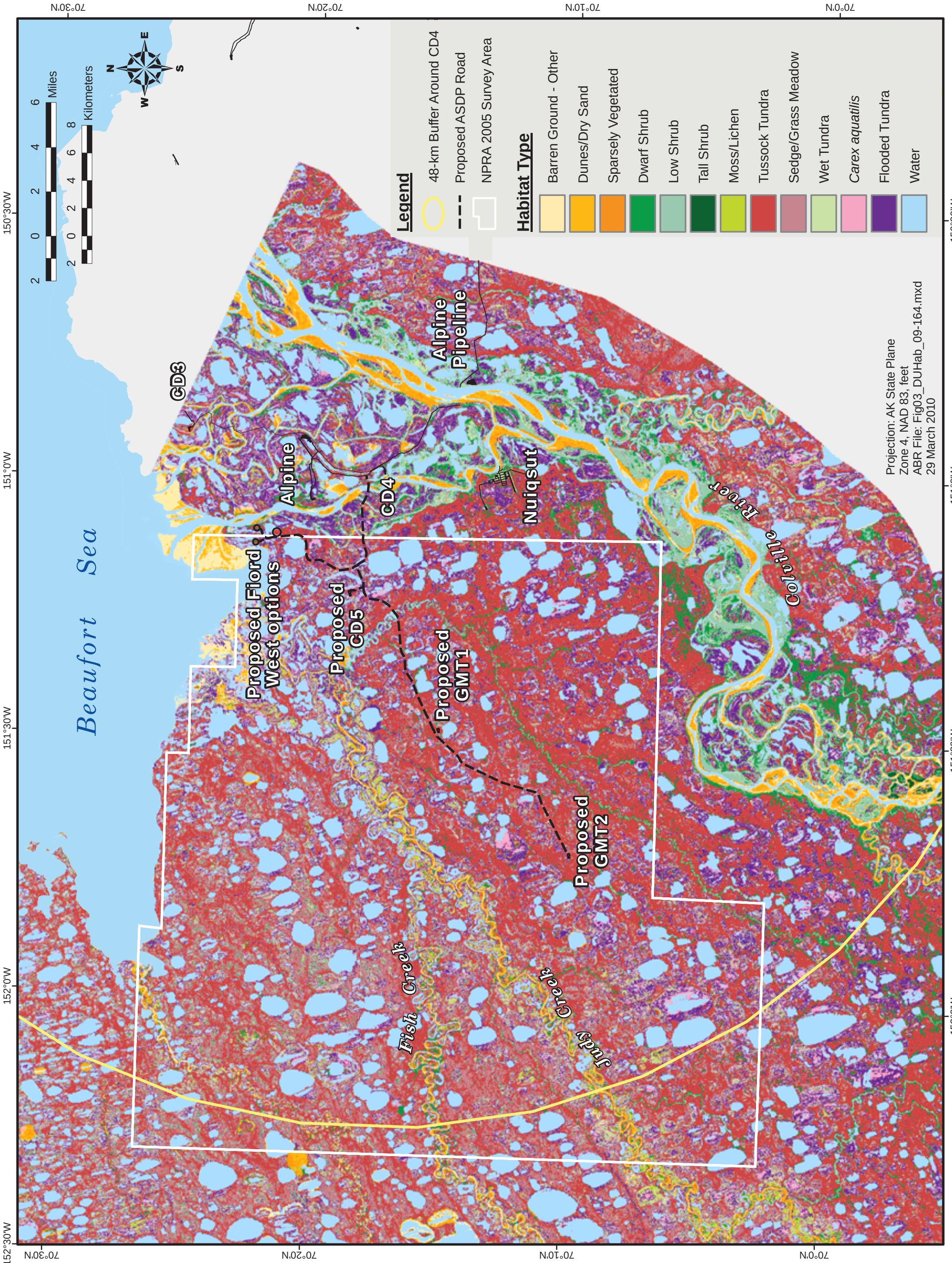

Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2009.

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 aerial-survey area in 2009 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. We received an updated alignment for the proposed road in 2009 and recalculated the distance zone buffers accordingly, so the following analyses differ somewhat from those reported in previous years.

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 4 km of existing roads and pads (Alpine pads CD1, CD2, CD3, CD4, and Nuiqsut) 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 18.0 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.

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 evaluate whether 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. Tukey's *post hoc* multiple-comparison test was used 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, as a result of to the lack of aerial survey coverage in that season of highly unpredictable movements.

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 2005–2009 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 2009, 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 coverage by snow on 25 May 2009, 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 ($r > 0.93$ for 2005–2009 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 2009 in multi-year analyses. NDVI_rate from 2009 was used only for analysis of 2009 calving density.

We tested various models for calving density in 2009 and the density in each season for the combined years 2002–2009. 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 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 (Anderson et al. 2000 Burnham and Anderson 2002) 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 2002). 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 2009, but the different models had various combinations of NDVI_peak, NDVI_rate, snow cover on 25 May 2009, 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.

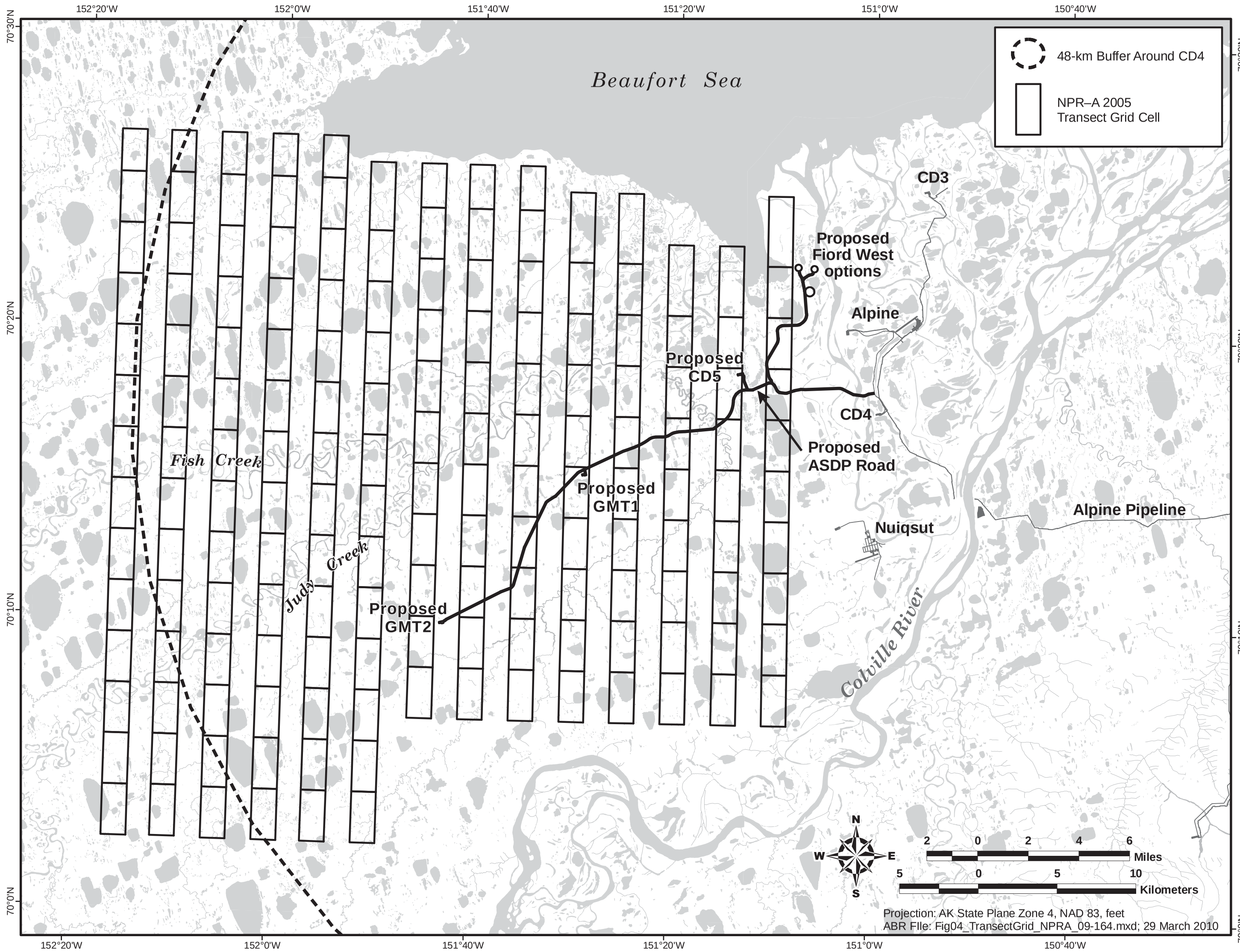

Figure 4. Locations of transect grid-cells (n = 164) used to analyze caribou density in the NPRA survey area, 2005–2009.

Sixteen candidate models were used for seasonal tests over all years (2002–2009) 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. The timing of snow melt was delayed in 2001, advanced in 2002, and about average in 2003–2008 (Lawhead and Prichard 2010). In 2009, the timing of snowmelt was earlier than average. Daily air temperatures in early spring 2009 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 above the long-term average in early April 2009 and was about average on 15 May. The maximum daily temperature at the Kuparuk airstrip was between 5 and 8º C during 26 April–1 May, during which time snow depth decreased from 38 cm to 15 cm (Appendix B). Snow cover was patchy during the spring survey on 13 May, 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). Snow had melted by 20 May at the Kuparuk airstrip, but more snow fell on 26 and 28 May. Patchy snow cover remained during the first calving survey in the Colville East survey area on 2–4 June, requiring use of the SCF to adjust survey counts. Snow was essentially gone in all survey areas by the time of the second round of calving surveys during 8–10 June. The little snow remaining at that time was in linear drifts along upland drainages and lake edges.

Information on summer weather was compiled for reference in interpreting insect-season conditions and the severity of insect harassment between late June and mid-August. The occurrence of air temperatures conducive to insect activity (as indicated by TDD sums) in 2009 were the lowest recorded on record for the Kuparuk Airstrip during late June (Appendix B). Early July was slightly above average, late July was slightly below average, and early August was slightly above average (Appendix B), indicating cooler-than-normal temperatures early in the insect season and about average in the latter half of the season.

These temperature patterns 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 below average in late June and were about average in July and early August (Lawhead and Prichard 2010). Thus, the available weather data indicate that the levels of insect activity and resulting harassment of caribou would have been very low in late June and about average in July and August 2009.

Variability in weather conditions results in large fluctuations in caribou density during the insect season as caribou aggregate and move rapidly through the study area in response to fluctuating insect activity. 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 also 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 snow melt 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

Five surveys of the NPRA survey area were flown between 13 May and 22 August 2009 (Table 2, Figure 5). The surveys planned for September and October could not be conducted due to logistical problems and persistent poor weather. Caribou density in the NPRA survey area was low

Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–August 2009.

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								
May 13 [g]	1,720	16	0	16	60	13.7	0.03	2.7
June 8	1,720	429	11	440	880	120.7	0.51	3.0
June 22	1,720	437	13	450	900	87.0	0.52	5.7
August 3	1,720	286	nr	286	572	293.4	0.33	16.8
August 22	1,720	82	nr	82	164	28.3	0.10	1.4
COLVILLE RIVER DELTA								
June 8	494	6	1	7	14	7.0	0.03	1.8
June 22	494	18	0	18	36	22.5	0.07	6.0
August 3	494	6	nr	6	12	3.1	0.02	1.2
August 22	494	2	nr	2	4	1.9	0.01	1.0
COLVILLE EAST								
May 13 [g, h]	776	7	0	7	26	9.2	0.03	3.5
June 3–4 [g, i]	1,432	831	184	1,015	3,809	806.3	2.66	2.6
June 8 [k]	240	100	0	100	200	59.4	0.83	4.8
June 9–10 [i]	1,432	2,598	921	3,519	7,038	489.0	4.91	7.0
June 22–23	1,938	2,105	614	2,719	5,438	845.2	2.81	16.5
August 3 [h, j]	240	0	0	0	0	–	0	–
August 21–22	1,938	24	nr	24	48	7.5	0.02	1.0

[a] Survey coverage was 50% of this area (860 km² in NPRA, 247 km² on the Colville R. Delta, 848–969 km² in Colville East) for complete surveys.
[b] Adults + yearlings.
[c] nr = not recorded; calves not reliably differentiated due to larger 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), using transects as sample units.
[f] Density = Estimated Total / Survey Area Size.
[g] Applied Sightability Correction Factor of 1.88 due to patchy snow cover during survey.
[h] Survey not completed due to inclement weather.
[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).
[j] Itkillik River survey transects.

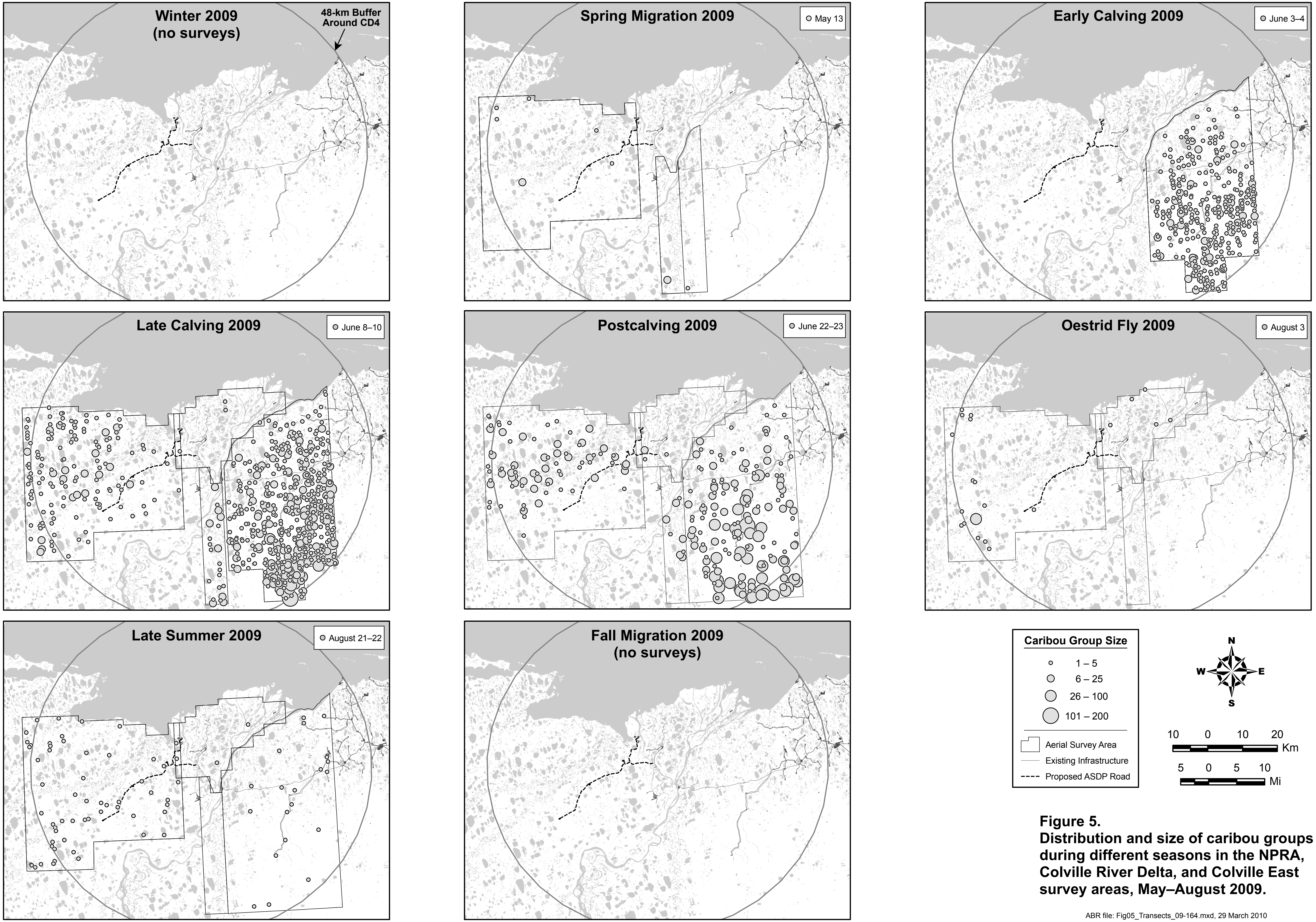

Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, May–August 2009.

ABR file: Fig05_Transects_09-164.mxd, 29 March 2010 in the spring, relatively high during June, and decreased during August. The estimated density of caribou ranged from a high of 0.52 caribou/km² on 22 June to a low of 0.03 on 13 May (Table 2). The density of caribou during calving (0.51 caribou/km² on 8 June) was near the middle of the range of 0.15–0.87 caribou/km² (6–9 June) observed during 2001–2008 (no calving survey was conducted in 2004). Only 11 calves (2.5% of the total number of caribou) were observed in the survey area on 8 June, underscoring the low use of the area for calving compared with other parts of the study area, most notably the Colville East survey area.

Annual surveys since 2001 have shown that the NPRA survey area, which is used mainly by TH caribou, is not a high-density calving area, in contrast to the Colville East survey area, which is used mainly by CAH caribou (Appendices C–J; Lawhead and Prichard 2010). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005, Person et al. 2007), 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 2009, Lenart 2009).

Large mosquito-harassed groups of caribou were not observed during aerial surveys in late June or August 2009, although 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. Radio-telemetry data provide better information on movements during the insect season (see Radio Telemetry section below). Since 2001, the only year in which we found large mosquito-harassed groups in the NPRA survey area was 2005 (Lawhead et al. 2006).

Caribou densities observed on the NPRA transects were relatively low during all surveys in 2009 (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 2001–2008, 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–J).

Colville River Delta Survey Area

Four surveys of the Colville River Delta survey area were flown between 8 June and 22 August 2009 (Table 2, Figure 5). Similar to most years, the estimated density of caribou was quite low during all surveys (0.01–0.07 caribou/km²); the maximal estimate recorded in 2009 was 36 caribou (0.07 caribou/km²) on 22 June.

Use of the delta by large numbers of caribou is uncommon. Large numbers have been recorded occasionally during past summers (such as 1992, 1996, 2001, and 2007) as 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 2009) 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 2001–2009 (Table 2, Appendices C–J) occurred on 2 August 2005, when 994 caribou were found on the Colville delta (2.01 caribou/km²; Appendix G). Thus, it is important to have telemetry data available as well for describing caribou distribution and movements.

Colville East Survey Area

Seven surveys of the Colville East survey area were flown between 13 May and 22 August 2009. The estimated density of caribou on complete surveys ranged from the peak of 4.91 caribou/km²

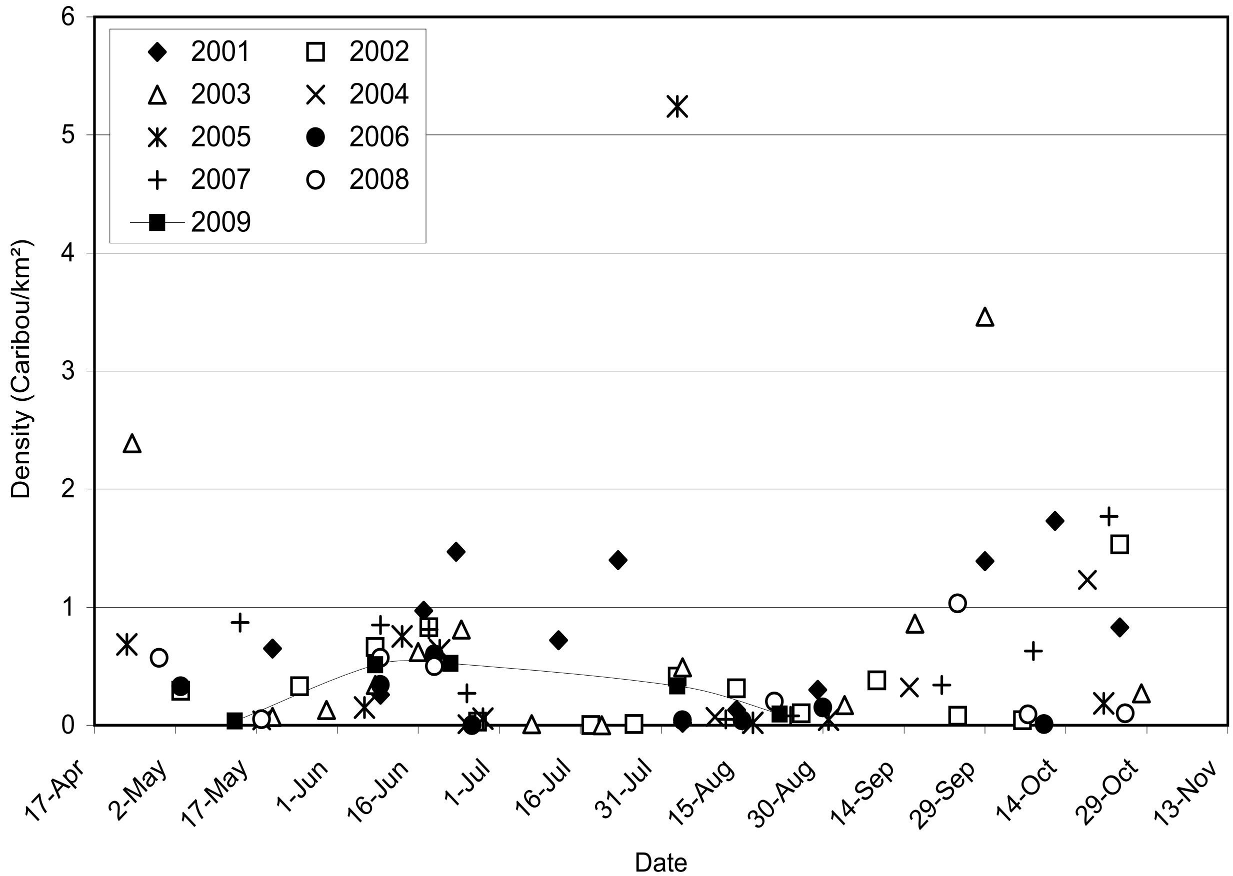

Figure 6. Caribou density observed on 83 surveys of the NPRA survey area, April–October 2001–2009 (line connects 2009 survey values).

during calving on 9–10 June to a low of 0.02 caribou/km² on 21–22 August (Table 2). The highest densities among all three ASDP survey areas in 2009 were recorded in Colville East during calving and postcalving (2.66–4.91 caribou/km²), as is usually the case in that area. No caribou were seen on a partial survey in the Itkillik River area on 3 August, but that survey could not be completed due to poor visibility caused by wildfire smoke from interior Alaska. No surveys were conducted in July, September, or October.

The overall number and density of caribou during the late calving season (mid-June) in 2009 were greater in the Colville East survey area than in the Kuparuk South and Kuparuk Field survey areas to the east (Lawhead and Prichard 2010). Caribou distribution during our calving surveys and information from ADFG radio-tracking during calving (E. Lenart, ADFG, pers. comm.) indicated that a number of female caribou were south of the survey areas during calving in 2009, which was unusual for a year of relatively early snow melt.

The Colville East survey area typically has 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. Since 2003, CAH caribou have tended to move farther east in midsummer than in earlier years, with many moving into the Arctic National Wildlife Refuge and even approaching the Alaska–Yukon border.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area in 2009, although a group of 16 was observed east of Nuiqsut; most of the muskoxen in the region extending from the NPRA survey area east to the Prudhoe Bay oilfield were located between the Milne Point Road and the Kuparuk River in 2009 (Appendix K). In 2005, 2006, and 2007, a group of muskoxen was observed near the Kalikpik River and 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 nine occasions in the NPRA survey area between June and August 2009 (Appendix K). Two of the observations were of a female with two cubs, two were a female with one cub, and the rest were single adults. Nine sightings, totaling 12 bears and including one female with two cubs, were recorded on the Colville River delta. The number of repeated observations of the same individuals among surveys was unknown, however. No observations of moose, wolves, wolverines, or polar bears were recorded in the ASDP study area in 2009.

On 22 August 2009, a group of nine spotted seals (*Phoca largha*) was hauled out on a bar off the main channel of the Colville River (Appendix K). The group was hauled out in an area where the species was recorded repeatedly in late summer during more intensive surveys of the delta in the 1990s (Johnson et al. 1999).

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; movements of CAH animals in the ADFG GPS-collar sample during 2003–2006 are not depicted in the figure because they were available only inside the ASDP study area). The majority of collar locations for the TH and CAH occurred west and east, respectively, of the center of the 48-km buffer for the ASDP study area. 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 generally is not warranted to consider each collared caribou as representing a specific number of unmarked caribou in a herd, 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, extent, and timing of radio-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 2009 season.

Satellite Collars

Combining observations 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 from 9% to 33% 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. In 2009, the area east of Teshekpuk Lake was used extensively during the mosquito season. During the oestrid-fly season, most collared caribou moved between Umiat and the coast and 12 of the 14 transmitting TH satellite collars were present in the ASDP study area in July (Table 3).

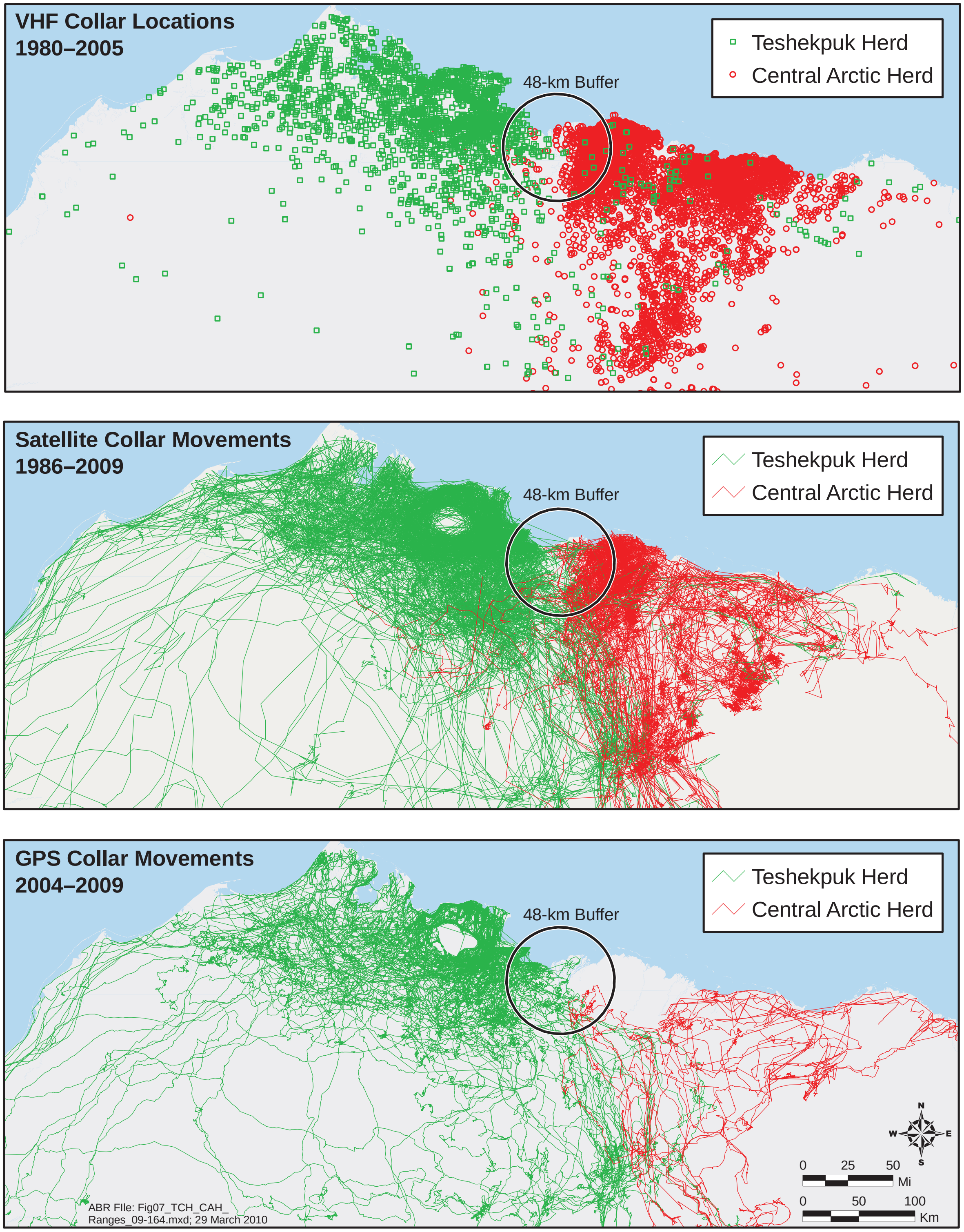

Figure 7. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2009.

Table 3. Percentage of satellite-collared caribou samples (*n*) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were within 48 km of CD4 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)	0 (7)	0 (7)	0 (7)
	2009	0 (7)	0 (5)	0 (7)	0 (7)	0 (7)	0 (7)	86 (14)	7 (14)	8 (12)	–	–	–
	Total	13 (159)	11 (140)	13 (141)	9 (140)	15 (140)	9 (137)	33 (203)	25 (195)	18 (200)	28 (181)	16 (166)	12 (161)
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)	–	–	–
	2007	–	–	–	–	0 (1)	100 (1)	100 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	2008	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	2009	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	–	–	–	–	–	–
	Total	17 (53)	16 (50)	22 (46)	20 (45)	38 (47)	64 (45)	51 (45)	27 (51)	27 (45)	12 (57)	12 (59)	14 (57)

Table 4. Percentage of GPS-collared caribou samples (n) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were within 48 km of CD4 at least once in each month.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
TH	2004	–	–	–	–	–	–	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)
	2005	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	–	–	–	–	–	–
	2006	–	–	–	–	–	–	50 (12)	8 (12)	0 (12)	67 (12)	0 (12)	0 (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)
	2008	20 (10)	20 (10)	20 (10)	30 (10)	33 (9)	11 (9)	39 (18)	6 (18)	6 (18)	6 (18)	0 (18)	0 (18)
	2009	0 (18)	0 (17)	0 (15)	0 (14)	0 (14)	14 (14)	–	–	–	–	–	–
	Total	6 (50)	4 (49)	4 (47)	7 (45)	16 (44)	21 (43)	39 (51)	24 (51)	12 (51)	39 (51)	12 (51)	10 (50)
CAH	2003	–	–	–	4 (24)	54 (24)	75 (24)	8 (24)	13 (24)	21 (24)	8 (24)	0 (24)	0 (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)
	2005	0 (33)	0 (33)	0 (33)	0 (33)	24 (33)	45 (33)	33 (33)	27 (33)	21 (33)	9 (33)	–	–
	2006	0 (29)	0 (29)	0 (29)	0 (29)	38 (29)	38 (29)	55 (29)	0 (29)	34 (29)	14 (29)	–	–
	2008	–	–	–	–	–	–	0 (4)	25 (4)	25 (4)	0 (4)	0 (4)	0 (4)
	2009	0 (4)	0 (4)	0 (4)	0 (4)	25 (4)	25 (4)	–	–	–	–	–	–
	Total	0 (90)	0 (90)	0 (90)	2 (114)	36 (114)	52 (114)	28 (114)	12 (114)	29 (114)	8 (114)	0 (52)	0 (52)

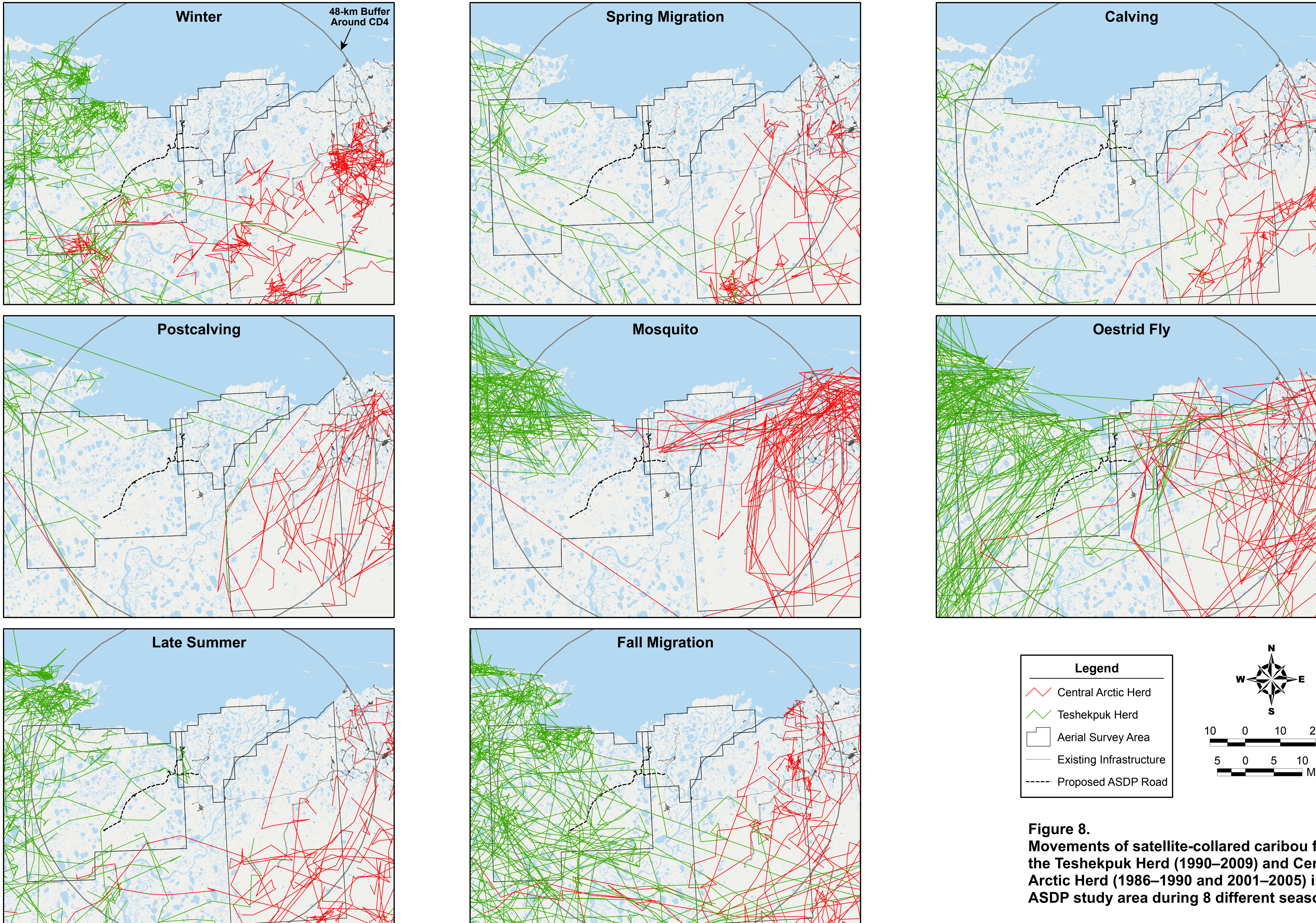

Figure 8.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2009) and Central Arctic Herd (1986–1990 and 2001–2005) in the ASDP study area during 8 different seasons.

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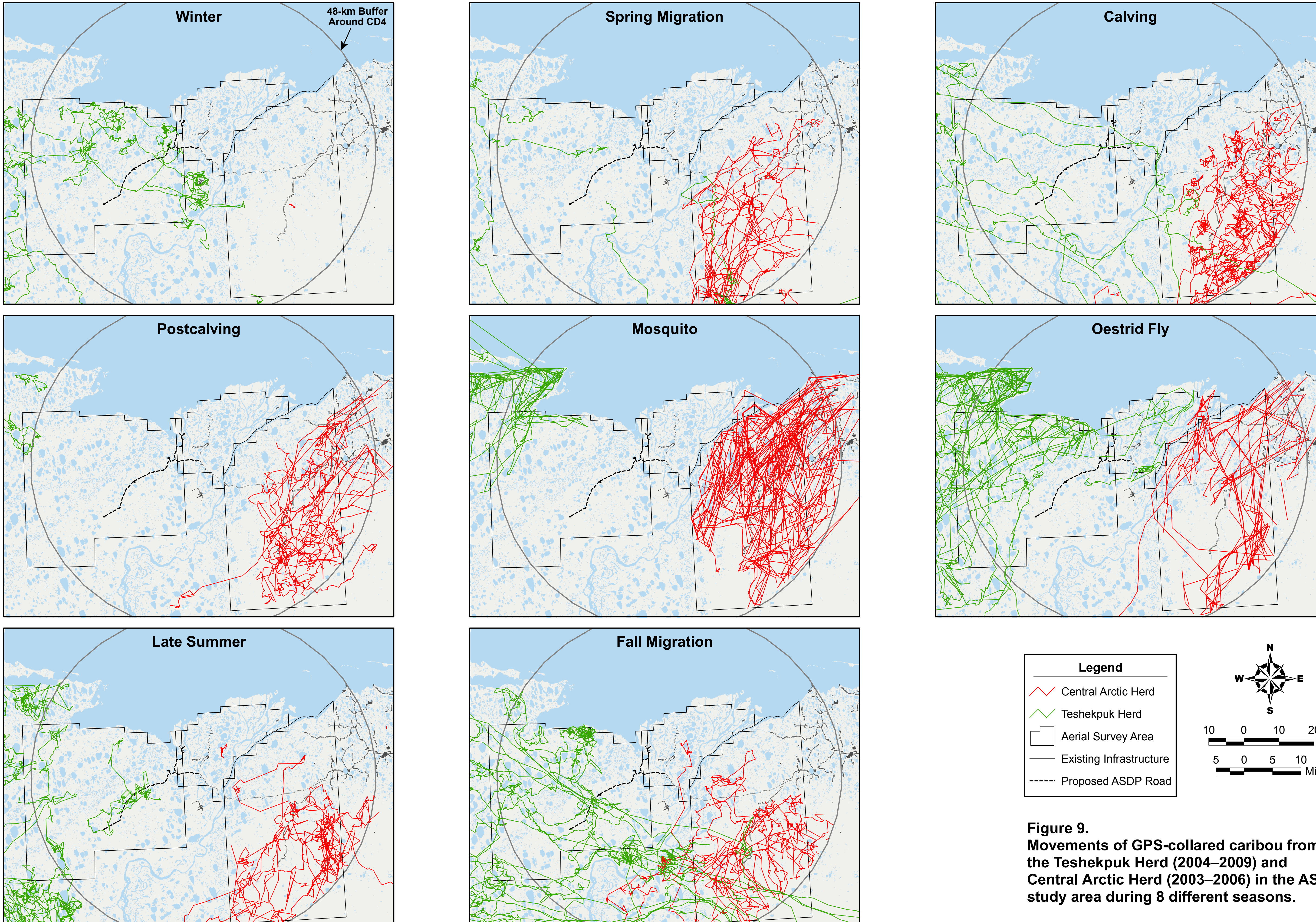


Figure 9.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2009) and Central Arctic Herd (2003–2006) in the ASDP study area during 8 different seasons.

ABR file: Fig09_GPS_09-164.mxd, 29 March 2010

Judging from the straight-line connections between successive locations, only one satellite-collared TH caribou crossed the alignment of the proposed ASDP road in the NPRA survey area during the period September 2008–September 2009 (the cutoff for inclusion of satellite-collar data in this report). Caribou 0910, a male, crossed the end of the proposed road corridor from north to south around 19 July 2009. Eleven other satellite-collared caribou moved parallel to and north of the proposed alignment during July 2009 but did not cross it. Only 7–8 % of the satellite collars were in the study area during August or September 2009.

Satellite-telemetry data show substantially 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, 2001–2005, and 2007–2009). 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 64% each month (Table 3). The highest occurrence of collared CAH caribou was in May, June, and July (38%, 64%, and 51% of the total sample, respectively) and the lowest was during October–February (12–17%) (Table 3, Figure 8). As with the TH sample, the monthly percentages varied substantially (0–100%) 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 2001–2009 (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 that year (Lawhead et al. 2008). The tendency of CAH caribou to move east of the Sagavanirktok River during the insect season in recent years has resulted in fewer caribou from that herd using the delta in summer.

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 2004–2009 were similar to those of satellite-collared caribou. Only 4–12% of GPS-collared TH caribou were in the study area in winter (November–April) (Table 4, Figure 9). The monthly percentages increased to 16–39% during May–August, declined to 12% in September, and tied the peak of 39% 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 2008–2009 varied between 0 and 8% during the months of October–April (Table 4, Figure 9). The monthly percentage increased to 36% in May, peaked at 52% in June due to heavy use of the Colville East area during calving, and decreased to 12–29% in July–September.

The detailed movement tracks of the six TH and six CAH caribou outfitted with GPS collars purchased by CPAI for the ASDP study in 2009 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 19 other TH caribou outfitted with GPS collars from July 2007 to June 2009 (Appendices L–O).

In 2009, the area east of Teshekpuk Lake was used extensively by GPS-collared TH caribou during the mosquito season. During the oestrid-fly season, those collared caribou moved more extensively, either remaining in the Teshekpuk Lake area or moving south, and four of the six TH collars were in the ASDP study area at that time (Figure 10). All six collared caribou traveled west during fall migration in 2009; four were near the Chukchi Sea coast during fall and all six were south of Barrow near Atqasuk in early winter. In contrast, 11 of the 13 male TH caribou outfitted with satellite collars were moving southeast toward Anaktuvuk Pass and the Dalton Highway in September 2009 (the date cutoff for inclusion in this report).

All six CAH caribou that were outfitted with CPAI GPS collars in late June 2009 were captured east of Prudhoe Bay (a seventh caribou was captured south of Kuparuk but died soon after capture) and none entered the ASDP study area in 2009 (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 2009.

The following accounts briefly summarize the movements of caribou that were collared or recollared with CPAI collars in 2009, from the time they were collared at the end of June and beginning of July through the end of December (Figures 10 and 11).

Caribou 0401 — Originally collared in 2004, this adult cow was first outfitted with a GPS collar on 25 June 2007. She stayed in the vicinity of Teshekpuk Lake during the following year (Appendix L). She had a calf when she was recaptured on 29 June 2008 north of Teshekpuk Lake and outfitted with a different GPS collar. Although she had a distended udder and no antlers, no calf was observed, suggesting that she may have lost her calf (L. Parrett, ADFG, pers. comm.). She was southeast of Teshekpuk Lake in late fall 2008, moved to the Meade River in October, then moved east during the winter and was southeast of Teshekpuk Lake during calving (Appendix N). This cow was not accompanied by a calf when she was refitted with another GPS collar southeast of Teshekpuk Lake on 25 June 2009. She moved north of Teshekpuk Lake during the mosquito season, moved as far east as the Fish Creek delta during the oestrid-fly season, moved south of Teshekpuk Lake during late summer, moved west towards Wainwright during fall, and was near Atqasuk during December (Figure 10).

Caribou 0402— This adult TH cow was first collared in July 2004 with a NSB GPS collar. She was recaptured in July 2005 and outfitted with a satellite collar. She was recollared a third time west of Teshekpuk Lake on 25 June 2007 (Appendix L). She wintered in the area southeast of Teshekpuk Lake in 2007–2008 and 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. She was again recollared on 25 June 2009 and outfitted with a CPAI GPS collar. She was not accompanied by a calf in 2009. She spent the mosquito season north of Teshekpuk Lake and moved into the ASDP study area briefly before moving south near Umiat during the oestrid-fly season, moved west near Wainwright during the fall, and was near Atqasuk during December 2009 (Figure 10).

Caribou 0404 — This adult cow was first captured in July 2004. She was accompanied by a calf when she was recollared with a CPAI GPS collar southeast of Teshekpuk Lake on 24 June 2007. She wintered near the ASDP study area in 2007–2008 and calved successfully east of Teshekpuk Lake in 2008 (Appendix L). She was recaptured north of Teshekpuk Lake on 29 June 2008 and her collar was replaced with an NSB GPS collar. She was not accompanied by a calf when recaptured again on 25 June 2009 and outfitted with a CPAI GPS collar. She was north of Teshekpuk Lake during mosquito season, moved into the ASDP study area during the oestrid-fly season, then moved west to the lower Meade River during fall and remained there during December (Figure 10).

Caribou 0612 — This TH female was first captured in July 2006 and outfitted with a satellite collar. She was not accompanied by a calf when she was recaptured on 25 June 2009 and outfitted with a GPS collar. She moved north of Teshekpuk Lake during the mosquito season, moved into the

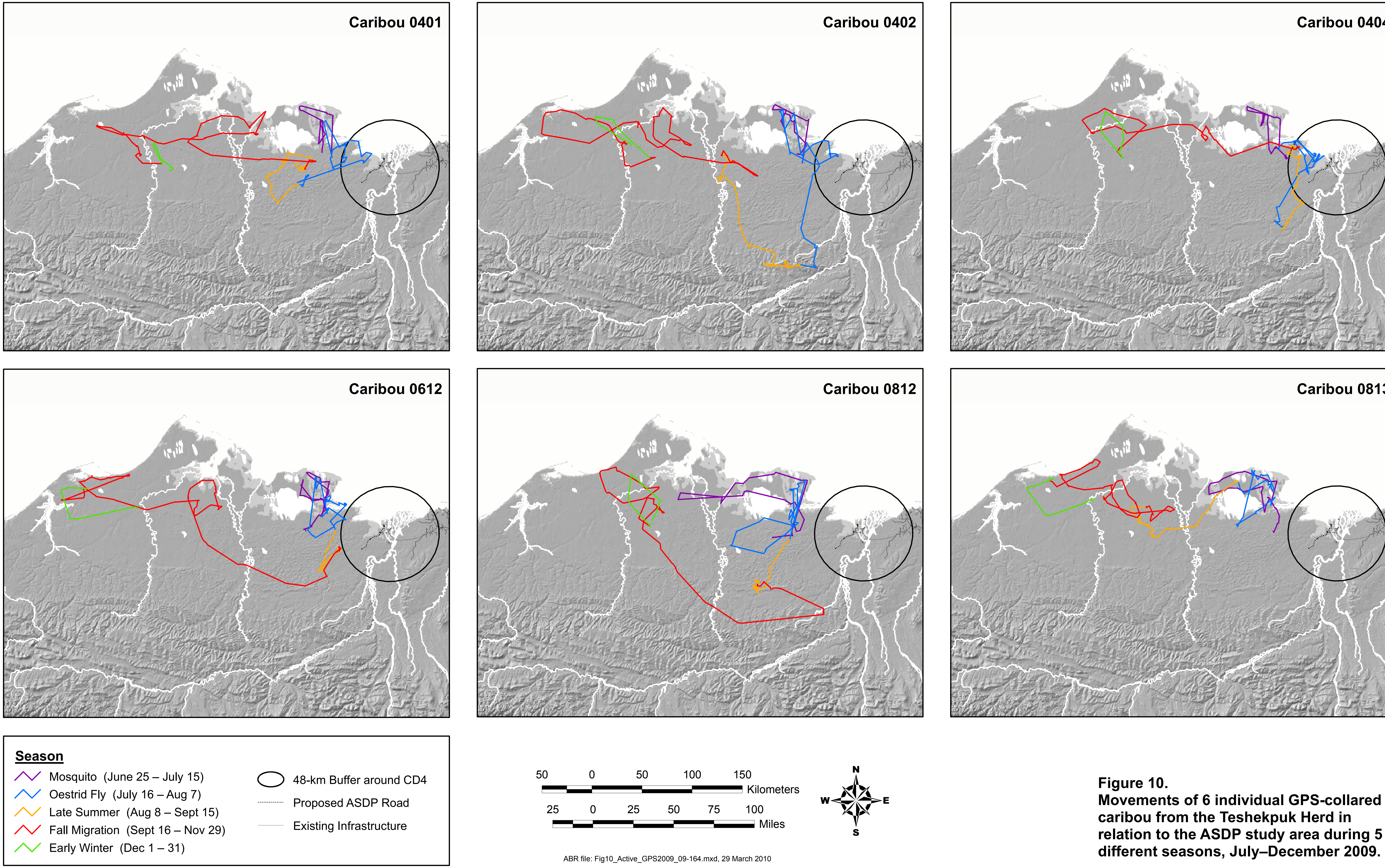


Figure 10.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 5 different seasons, July–December 2009.

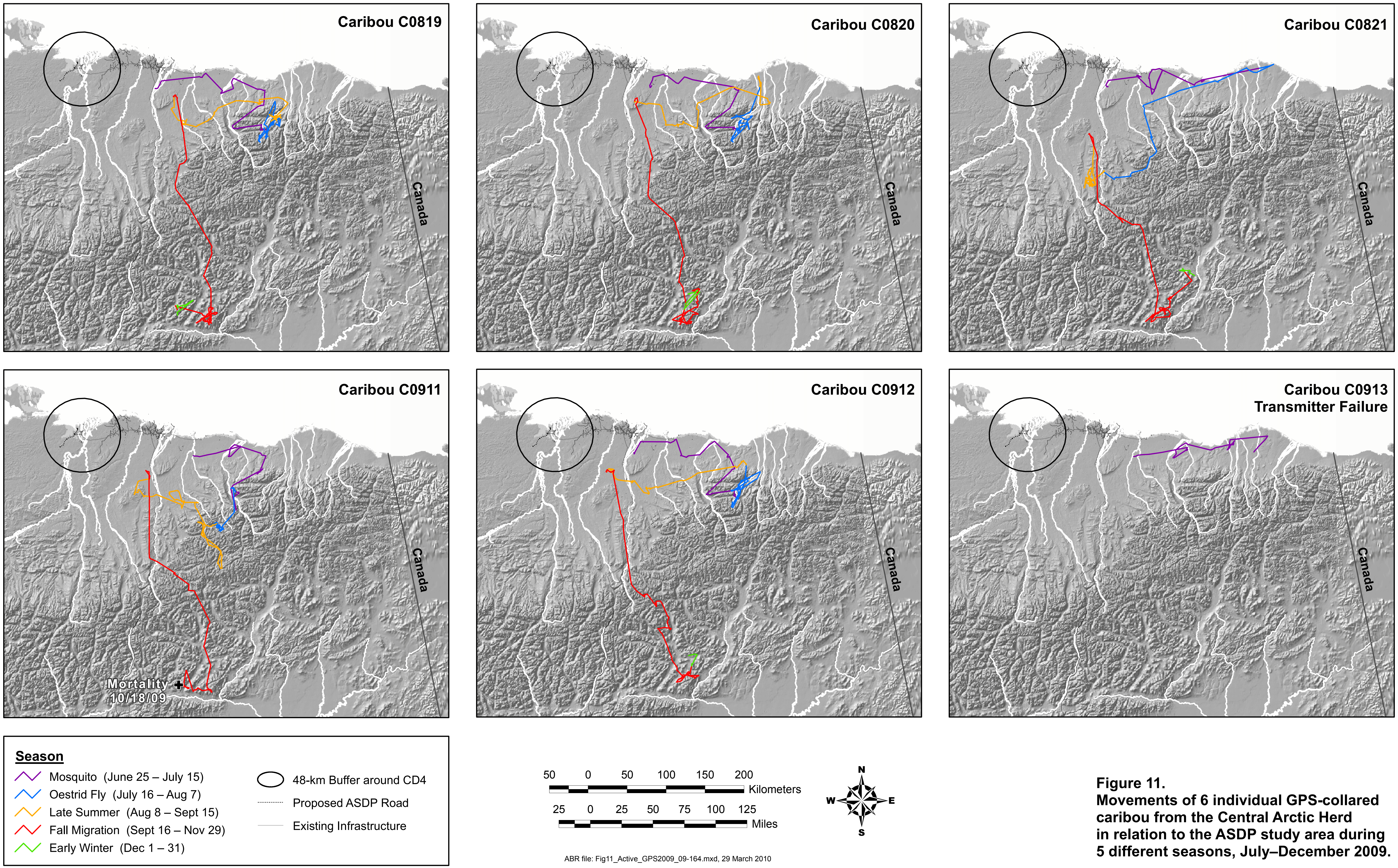


Figure 11.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 5 different seasons, July–December 2009.

survey area briefly during the oestrid-fly season, moved near Wainwright during fall, and then moved to the Meade River during December (Figure 10).

Caribou 0812 — This TH female was accompanied by a calf when she was captured on 1 July 2008 north of Teshekpuk Lake. She remained near Teshekpuk Lake until early October, when she moved west to Wainwright Inlet where she wintered (Appendix N). She returned to the area south of Teshekpuk Lake during calving in 2009 but did not have a calf (L. Parrett, ADFG, pers. comm.). After being recollared on 25 June 2009, she remained near Teshekpuk Lake during the summer, then moved west to the lower Meade River in fall and remained there during December (Figure 10).

Caribou 0813 — Erroneously labeled as caribou 0821 in last year's report (Lawhead et al. 2009), 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 2008, when she moved south into the central Brooks Range and wintered along the Dalton Highway near Wiseman. She moved through the ASDP area on the way back to Teshekpuk Lake in the spring but did not have a calf in 2009 (Appendix N). She stayed near Teshekpuk Lake for the mosquito and oestrdi-fly season, moved to the coast north of Wainwright in fall, and was near the Meade River in December (Figure 10).

Caribou C0819 — This CAH female (the "C" prefix is used to denote CAH animals) was accompanied by a calf when she was first collared near the mouth of the Sadlerochit River on 3 July 2008. She moved almost to the Alaska–Yukon border over the next week, then moved west, crossing the Dalton Highway in early August, and moved to the Itkillik River by late August. She crossed the Dalton Highway again in late August, wintered in the Brooks Range east of the highway and returned to the area southeast of Prudhoe Bay during calving 2009 (Appendix O). She was recaptured without a calf on 28 June 2009 and was outfitted with a different GPS collar. She moved east to the Sadlerochit River during July, moved back toward Prudhoe Bay during late summer, moved south of the Brooks Range in fall, and was in the Brooks Range east of the Dalton Highway in December (Figure 11). She did not enter the ASDP study area during either year.

Caribou C0820 — This CAH female was captured near the Tamayariak River in ANWR on 4 July 2008 and was outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf when collared. She moved east near the Alaska–Yukon border until mid-July and then moved back near the Canning River until early October. She migrated south of the Brooks Range and wintered northwest of Venetie. She returned to the area southeast of the Prudhoe Bay oilfield during calving 2009 (Appendix O) and was accompanied by a calf when recaptured on 28 June 2009. She moved east near Kaktovik during July before returning toward Prudhoe Bay during late summer, moved south of the Brooks Range in fall, and was in the Brooks Range east of the Dalton Highway in December (Figure 11). She did not enter the ASDP study area during either year.

Caribou C0821 — This CAH female was captured between the Shaviovik River and the Badami facilities on 4 July 2008 and was outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf when captured. 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 wintered on the south side of the Brooks Range east of Wiseman before migrating north to the area south of Kuparuk, just outside the ASDP study area, during calving in 2009. She crossed to the east side of the Dalton Highway in late June (Appendix O). She did not have a calf when recollared on 28 June 2009. She moved east of Kaktovik in July, moved west of the Dalton Highway in August, then crossed the highway again during fall migration. She was in the Brooks Range east of the Dalton Highway during December (Figure 11).

Caribou C0911 — This CAH adult female was first captured without a calf southeast of Prudhoe Bay on 28 June 2009. She moved east and then inland during the mosquito season, stayed in the northern edge of the Brook Range during the oestrid-fly season, crossed the Dalton Highway to the west during late summer, and recrossed the highway again while migrating south of the Brooks Range during fall migration. She died east of Wiseman in mid-October 2009 (Figure 11).

Caribou C0912 — This CAH female was captured southeast of the Prudhoe Bay oilfield on 28 June 2009 and was outfitted with a GPS collar. She was not accompanied by a calf when captured. She moved east and then inland during the mosquito season, stayed in the northern edge of the Brook Range during the oestrid-fly season, crossed the Dalton Highway to the west in late summer, recrossed the highway again when moving to the south side of the Brooks Range during fall migration, and was east of Wiseman in December (Figure 11).

Caribou C0913 — This CAH female was captured southeast of Prudhoe Bay on 28 June 2009 and was outfitted with a GPS collar. She was not accompanied by a calf. She moved east into ANWR and toward Kaktovik but her collar stopped transmitting in mid-July (Figure 11). Her VHF frequency has been added to the list of collars being tracked by ADFG and USFWS, in the hope of relocating her and eventually retrieving the collar.

Partial movements (through December 2008) of caribou collared or recollared with GPS collars purchased by CPAI for the ASDP study in 2008 were reported previously (Lawhead et al. 2009), but their complete movements from June 2008 through June 2009 are summarized in this report (Appendices N and O). The following accounts briefly describe those movements, unless summarized above.

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 was outfitted with a GPS collar. She remained near Teshekpuk Lake until October 2008, then wintered on the coastal plain near the Meade River and southwest of Barrow. She had a calf southeast of Teshekpuk Lake in 2009 (Appendix N). This animal was recaptured on 26 June 2009 for collar retrieval and was outfitted with another GPS purchased by BLM.

Caribou 0624 — This adult TH 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 in 2008, 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 then east into 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. She was recaptured by ADFG for collar retrieval on 21 March 2009 (Appendix N).

Caribou 0814 — Erroneously labeled as caribou 0813 in last year's report (Lawhead et al. 2009), this TH female did not have a calf when captured north of Teshekpuk Lake on 1 July 2008. She generally remained in the area between Teshekpuk Lake and the Meade River until October, having entered 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, where she died in February 2009 (Appendix N).

Caribou 0815 — This TH female was erroneously labeled as caribou 0814 in last year's report (Lawhead et al. 2009). She was accompanied by a calf when first captured north of Teshekpuk Lake on 1 July 2008. She used the area between the Ikpikpuk and Colville rivers until October, then migrated south of the Brooks Range to winter in the area northeast of Bettles. She moved to the western side of Teshekpuk Lake during calving in 2009 but did not have a calf (Appendix O). She was recaptured on 26 June 2009 for collar retrieval and was outfitted with a GPS collar purchased by BLM.

Caribou 0819 — This TH female was accompanied by a calf when captured east of Barrow on 30 June 2008. She remained near the Meade River until early October, then moved southwest along the Chukchi Sea coast and crossed the DeLong Mountains Transportation System corridor between the Red Dog mine and port site. She wintered in the Noatak River valley and migrated north in 2009 to the area southwest of

Barrow (Appendix O), where she had a calf. She was recaptured for collar retrieval on 27 June 2009 and was fitted with a GPS collar purchased by BLM.

Caribou C0822 —This CAH female was captured east of the Prudhoe Bay oilfield, near the Kadleroshilik River, on 4 July 2008 and was outfitted with a GPS collar and an Animal Pathfinder™ unit. She was accompanied by a calf when captured. 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 the Dalton Highway to the east in early October near the upper Kuparuk River. She wintered on the south side of the Brooks Range east of Wiseman. She returned to the Kuparuk area during calving and calved successfully in 2009, but died soon after being recollared in late June 2009 (Appendix O).

Telemetry Summary

The movement data for both satellite- and GPS-collared animals show that the ASDP study area has been 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 midsummer or fall. That pattern mirrored the data obtained from aerial transect surveys (Table 2, Figures 5–6, Appendices C–J).

In contrast, CAH caribou have used the ASDP study area most extensively 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 2009). Use of the eastern half of the ASDP 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 moved onto the Colville River delta in the past. In recent years, most CAH caribou have moved east of the Sagavanirktok River during the insect season and have remained far east or south of the study area until the following spring migration and calving season.

For all three types of transmitters combined, 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 the delta by either herd is infrequent. Most CAH caribou remain east of the delta, most TH caribou stay west of it, and the existing Alpine facilities (including CD4) 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 2009).

The ranges of the two herds overlap more in fall and winter, primarily because of the recent expansion of TH caribou into the CAH winter range. Although most 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 in some years (Prichard and Murphy 2004, Carroll 2007, Person et al. 2007, Lawhead et al. 2009, Lenart 2009, Parrett 2009). In a highly unusual movement in 2003–2004, a large proportion (perhaps up to a third) of the TH moved east across the Colville and Sagavanirktok rivers during fall migration and wintered in and near ANWR (Carroll et al. 2004, Carroll 2007). In subsequent winters, some 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 CD4 (between Nuiqsut and the Alpine processing facilities) have occurred infrequently and sporadically—during calving (early June), the mosquito and oestrid-fly seasons (mid-July to early August), 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 115 satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006; the nearest one was a female that moved from northwest of CD4 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 CD4 (judging from 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 CD4 as it moved northwest during calving in 2007. In 2009 (January–September), no satellite-collared TH caribou were in the CD4 vicinity.

Of 43 TH animals equipped with GPS collars during 2004–2009, one crossed the Colville delta westward between CD4 and Alpine on 6 June 2005 *en route* to Teshekpuk Lake. Caribou 0404 spent 1–6 August 2007 about 2 km south of CD4 before heading west. Caribou 0621 wintered near Nuiqsut during the winter of 2007–2008, but did not move onto the Colville delta. In 2009, no GPS-collared caribou moved onto the Colville River delta.

Of the sample of 17 CAH satellite collars during 1986–1990, one moved into the CD4 vicinity briefly during 21–23 July 1988 and four moved 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. The single CAH caribou outfitted with a satellite collar during 2007–2009 did not move into the vicinity of CD4. Only one of the 45 CAH GPS collars in the ASDP study area during 2003–2006 moved onto the Colville delta, east of CD4 on 27 September 2004. None of the 10 CAH caribou outfitted with GPS collars in 2008 and 2009 moved into the vicinity of CD4 (Appendix O, Figure 11).

A greater proportion of radio-collared caribou movements since 1990 have occurred across the proposed ASDP road alignment in NPRA than occurred near CD4, although such movements were not frequent (Figure 12). As expected on the basis of herd distribution (Figures 7–9), all of the crossings of the proposed road alignment were by TH caribou (Figure 12). Of the TH sample of 115 satellite collars (1990–2009), 25 animals (22%) crossed the proposed alignment at least 46 times between September 1990 and July 2009. Crossings occurred in every month except January. Of the TH sample of 43 GPS-collared caribou (2004–2009), five animals crossed the alignment near the western end during fall migration between 2 October and 18 November 2004 and another caribou crossed in early June 2005 near Alpine (the same animal mentioned above that passed between CD4 and Alpine). Caribou 0620 crossed near the western end of the alignment in May 2007; caribou 0624 crossed near the eastern end in June 2007; caribou 0401 crossed near the eastern end in July 2007; caribou 0404 crossed the proposed alignment at least 27 times between late July and early September 2007 and 16 more times in December 2007 and January 2008; caribou 0621 crossed at least three times near the western end in October 2007 and once in April 2008; and caribou 0813 crossed once near the western end in June 2009.

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 CD4 alignment before construction) with the aggregation of at least 6,000 CAH caribou that moved west across the Colville River delta and into the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2009), but they were not tracked frequently enough to document their route of travel.

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

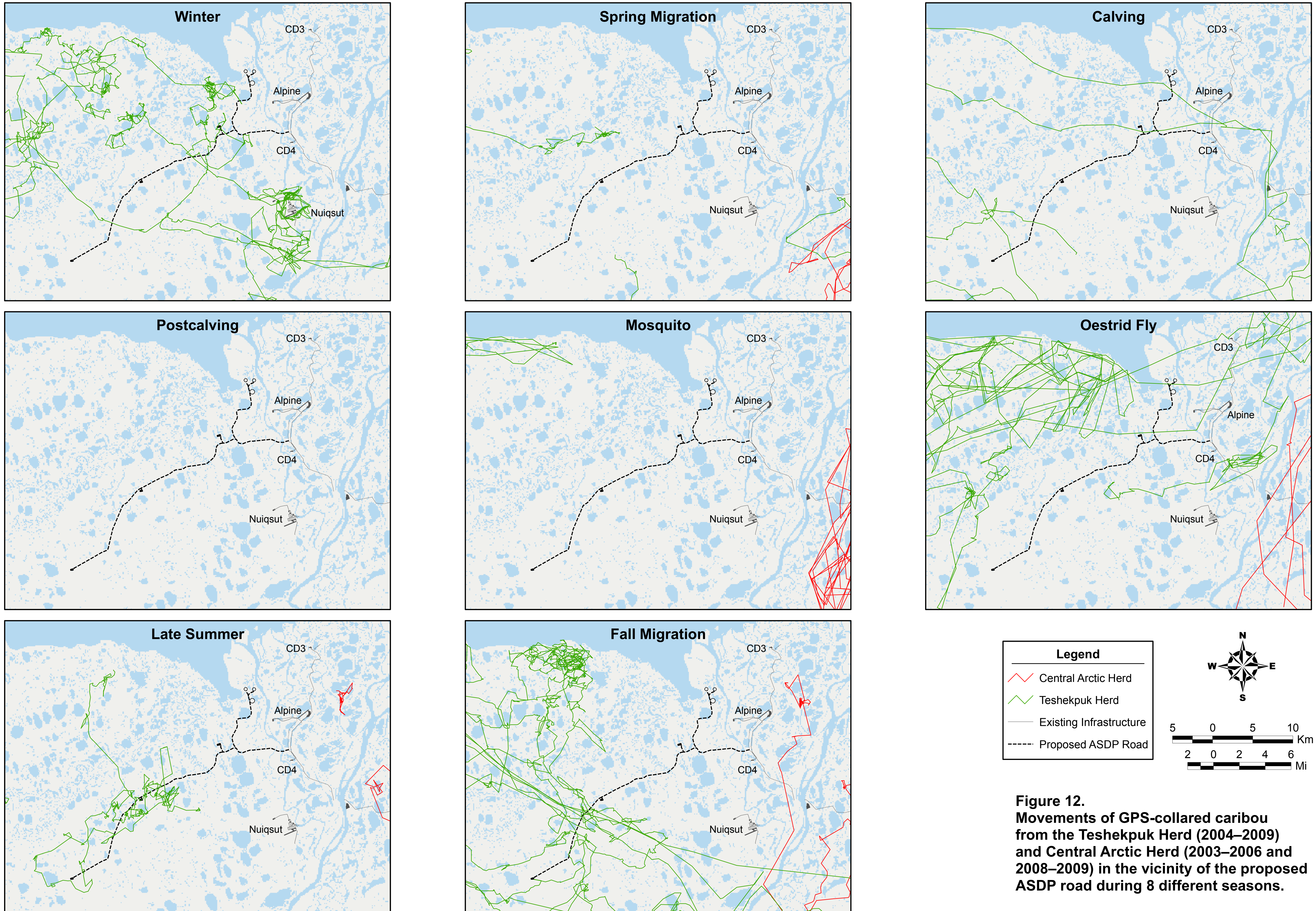


Figure 12.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2009) and Central Arctic Herd (2003–2006 and 2008–2009) in the vicinity of the proposed ASDP road during 8 different seasons.

ABR file: Fig12_GPS_Road_09-164.mxd, 30 March 2010

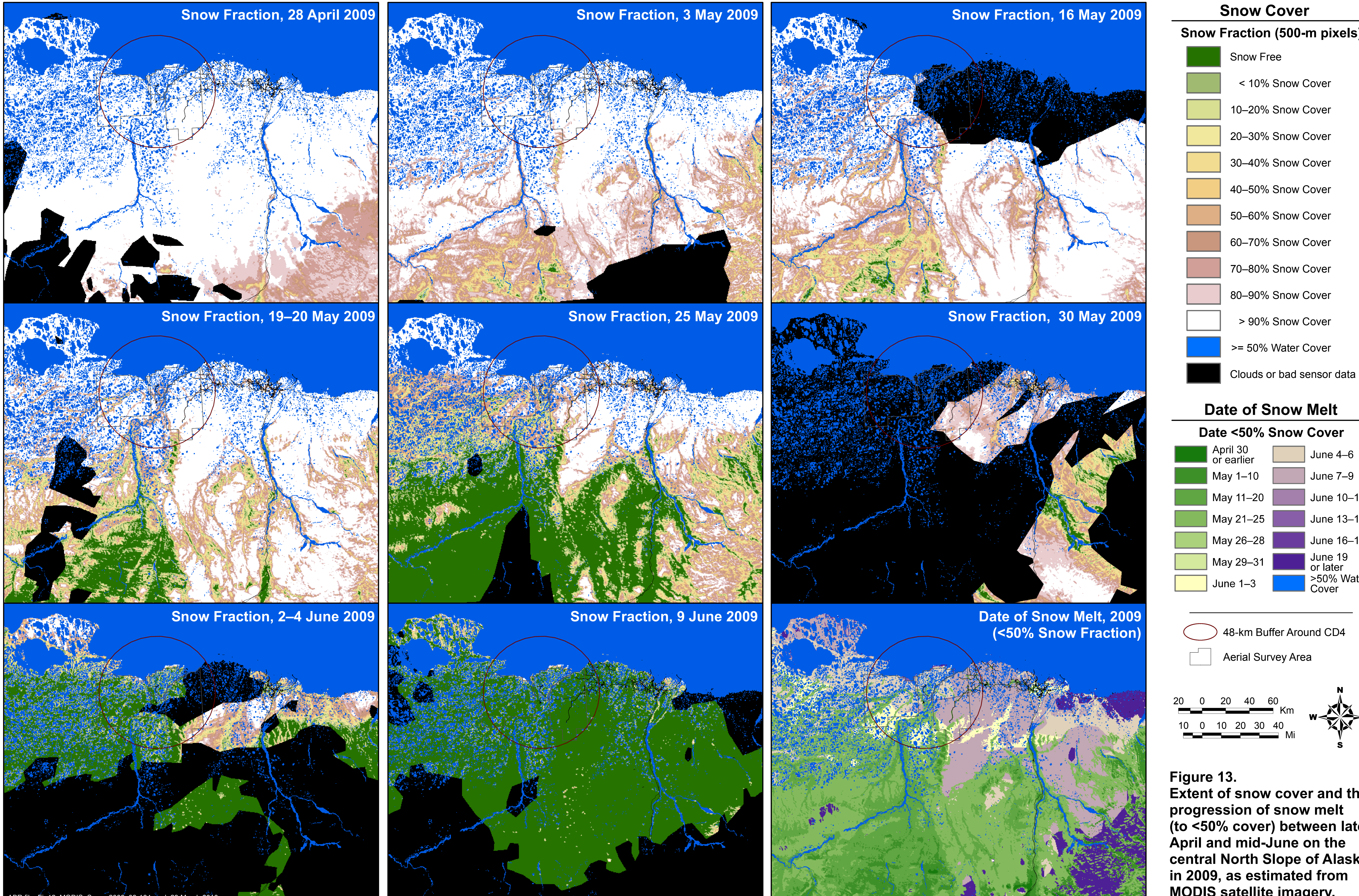
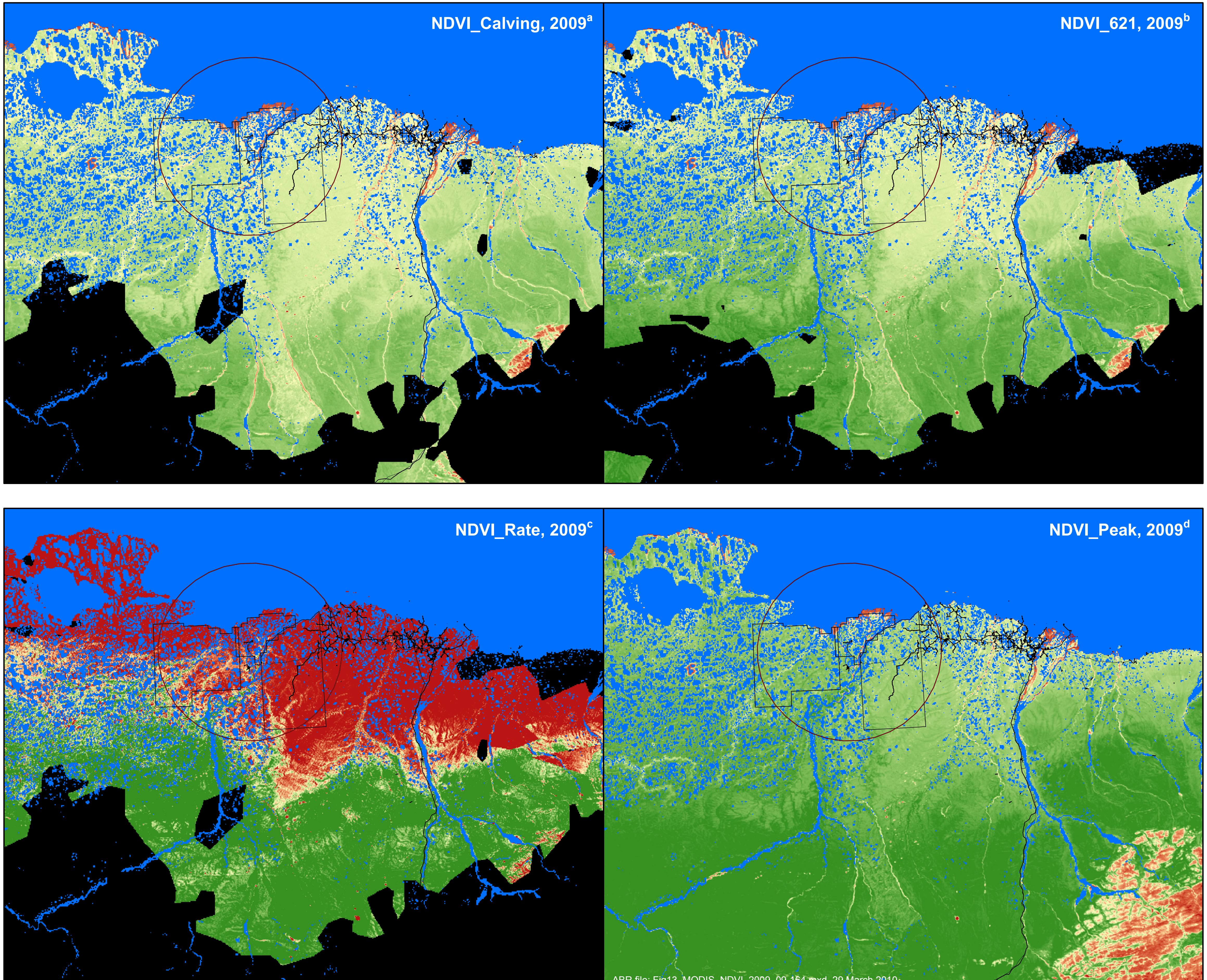


Figure 13.
Extent of snow cover and the progression of snow melt (to <50% cover) between late April and mid-June on the central North Slope of Alaska in 2009, as estimated from MODIS satellite imagery.



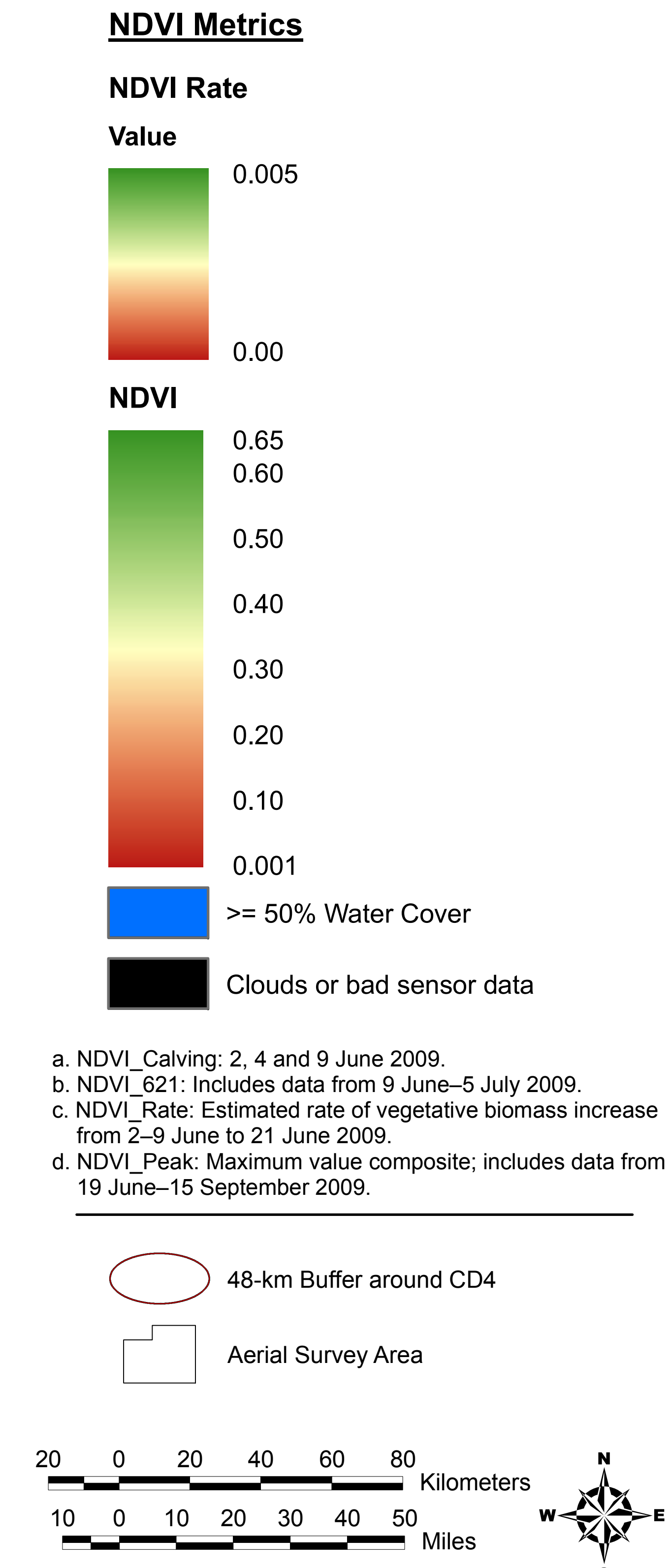


Figure 14.
Relative vegetative biomass at 3 stages of the growing season in 2009 and the estimated rate of increase from caribou calving to peak lactation on the central North Slope of Alaska, as estimated from MODIS satellite imagery.

cost. The region evaluated extends from the western edge of Teshekpuk Lake east to the Alaska–Yukon 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 early in 2009; MODIS data for 25 May reflected the field observations of a substantially patchy snow pattern on the 13 May aerial survey. New snowfall was evident on imagery from 30 May, but conditions were mostly snow-free by early June (Figure 13). A melt-date image for 2009 indicated that the early snow melt was particularly evident in the foothills south of the study area and along the drainages within the study area.

A qualitative comparison of snow melt across years (2009 data in Figure 13; 2005–2008 data in Lawhead et al. 2006, 2007, 2008, 2009) suggests that, although 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 consistently tend to retain snow longer. It may be possible to exploit that spatial pattern to infer snow cover under cloudy portions of satellite scenes; such an inferential approach could provide a method to improve snow-cover estimates even with the patchy cloud coverage that complicates remote sensing 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). A new MODIS algorithm, based on multiple end-member spectral mixture analysis (Painter et al. 2009), may provide more accurate estimates of snow fraction. 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 (2009 data in Figure 14; 2002–2008 data in Lawhead et al. 2006, 2007, 2008, 2009). Care must be exercised in comparing NDVI values among the 2002–2003, 2004–2006, and 2007–2009 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 2007–2009, 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 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 15) and are considered to be 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 15; 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.

In most of our study area, the NDVI measured during calving is generally lower than the fall baseline, 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 interannual comparisons of NDVI_rate. The estimated

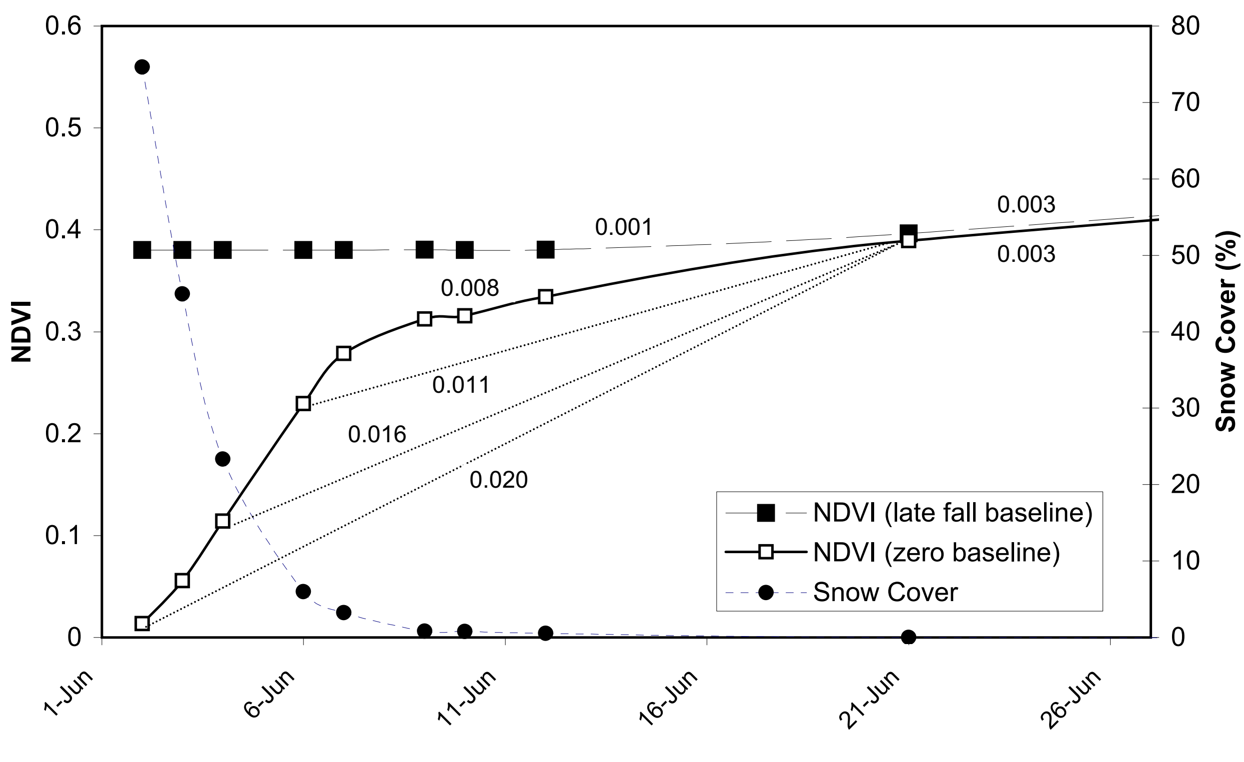


Figure 15. Change in relative vegetative biomass (NDVI, as estimated from MODIS satellite imagery) by date in the NPRA survey area during 2007, illustrating the difference between using zero (solid line) or the late-fall NDVI value (long dashed line) as the baseline for calculating the estimated rate 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.

NDVI_621 value for 2007 and 2009 was also equal to or less than the fall baseline NDVI across much of the study area (in a band extending inland 20–60 km from the coast). For these areas the NDVI_rate was zero. This suggests that vegetative growth must exceed some threshold before it can be detected by MODIS NDVI. In some areas and some years, the vegetative growth has not exceeded this threshold by 21 June—for example, along the coast in 2009 when the early growth was slowed by unusually cool weather in June. Even though it may have been below the detection threshold, some vegetative growth had occurred in the coastal fringe by 21 June 2009. We expect that the timing of snow melt is a more sensitive predictor of the earliest vegetative growth than is NDVI. NDVI_rate still is useful for detecting the magnitude of vegetative growth above a set threshold.

To make NDVI_rate a more meaningful metric of the rate of phenological change, it could 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, however, if the study area is obscured by clouds during calving, which is a common problem. Another 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.

NDVI values in most of the NPRA survey area during calving in 2009 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 (0.3926) was lower than in 2007 (0.4014; Lawhead et al. 2008) and 2008 (0.4164; Lawhead et al. 2009), presumably reflecting cold weather in late June 2009. The NDVI_peak values were also lower in 2009 (0.4853) than in 2007 (0.5428) and 2008 (0.5370). This difference could have resulted from different growing conditions in midsummer or, to some extent, from differences in the timing of imagery among years.

A major tundra fire in late summer and fall 2007 within the area of satellite imagery resulted in an obvious fire scar(see lower center of all panels except NDVI_rate in Figure 14), which still had depressed NDVI in spring and summer 2009; NDVI values in the scar were somewhat higher by fall 2008, however. 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). In this analysis, availability differed between the 2002–2004 and 2005–2009 survey areas. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix P) influenced the seasonal differences in caribou distribution. We focus here on analytical results using the pooled 8-year transect data set (2002–2009; 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 (Appendix Q).

For the pooled 2002–2009 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

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
2009	Winter	0	–	–	–	–	–	–	–	–
	Spring	1	6	1	2	2	1	0	2.68	0.613
	Calving	1	149	15	51+	43+	16--	24	32.07	<0.001
	Postcalving	1	79	1--	30+	32++	10--	6--	45.41	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	17	0	6	6	1--	4	8.01	0.091
	Late Summer	1	59	5	13	8	14	19	4.91	0.296
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	310	22	102++	91++	42--	53	56.14	<0.001
2002–2009	Winter	3	471	18--	57--	105	138--	153++	76.56	<0.001
	Spring	8	398	29	116++	74	82--	97	42.34	<0.001
	Calving	9	925	31--	210	182	180--	322++	116.98	<0.001
	Postcalving	8	894	20--	234++	301++	156--	183	169.93	<0.001
	Mosquito	6	102	18+	43++	24	11--	6--	80.35	<0.001
	Oestrid Fly	8	214	9	29	104++	35--	37-	89.06	<0.001
	Late Summer	14	690	36	162+	239++	125--	128--	109.05	<0.001
	Fall Migration	15	1,288	47--	237	312	300--	392++	69.19	<0.001
	Total	71	4,982	208--	1,088++	1,341++	1,027--	1,318++	336.35	<0.001
Available area 2002–2004 (km²)				8.9	64.8	133.7	191.0	148.2		
Available area 2005–2009 (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 ($P < 0.01$).

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. 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 on 2 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. Results for 2009 were generally consistent with the patterns observed for all years combined, although sample sizes were small.

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 P) 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 R) 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 than on individual years with smaller sample sizes.

Across all seasons and years (2002–2009), 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 and tussock tundra—the two most abundant classes—were significantly less than expected. Sedge/grass was used more 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 described 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 was more than expected during calving. This selection of tussock tundra occurred in geographic sections other than then the Southeast section, which contained fewer caribou groups during calving than expected (Table 5), despite the fact that the highest proportion of tussock tundra occurred in that section of the study area (Appendix P). 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 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.

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 vegetation 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 our NPRA survey

Table 6. Seasonal use of different habitat types by caribou in the NPRA survey area in 2009 alone and 2002–2009 combined, expressed as use (% of the area within 100 m of each group) divided by availability (% of area, excluding water).

Year	Season	No. of Surveys	No.of Groups	Habitat Type [a]								
				Carex aquatilis	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2009	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	6	1.38	0.86	0.48	0.93	1.26	1.46	0.89	0	0
	Calving	1	149	1.03	0.82--	0.95	1.21^{++}	0.93-	1.43^{+}	1.26	0.64	1.40
	Postcalving	1	79	0.89	0.86-	1.18^{+}	1.23^{++}	0.81--	1.64	1.30	6.51^{++}	1.50
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	17	0.68	1.03	1.15	0.59	0.73	3.12^{+}	1.38	0	4.52+
	Late Summer	1	59	1.39	1.08	1.15	0.67	0.86-	2.59^{++}	1.27	0	1.42
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	5	310	1.05	0.89--	1.05^{+}	1.07^{++}	0.88--	1.80^{++}	1.27^{+}	1.97	1.57
2002– 2009	Winter	3 [c]	471	0.99	1.02	1.01	0.95	1.04	0.77	1.25^{+}	0.83	0.50-
	Spring Migration	8	398	1.09	1.02	0.96	1.25^{++}	0.94	0.95	0.81	0.85	0.45^{--}
	Calving	9	925	0.95	0.87--	0.93-	1.18^{++}	1.05^{+}	0.87	0.95	0.67	0.80
	Postcalving	8	894	0.87--	0.86--	1.03	1.08^{+}	0.98	1.35^{+}	1.05	1.75^{+}	1.64++
	Mosquito	6	102	1.52^{++}	0.95	0.93	1.17	0.70--	1.88^{+}	1.06	0.67	2.52++
	Oestrid Fly	8	214	1.28^{+}	1.09	1.06	0.64--	0.65--	2.54^{++}	1.30	1.65	4.62++
	Late Summer	14	690	1.02	0.97	1.05	0.80--	0.79--	2.14^{++}	1.46^{++}	1.56	3.47++
	Fall Migration	15	1,288	1.01	0.93--	0.99	1.01	1.02	1.37^{++}	1.15^{+}	1.03	0.92
	Total	71	4,982	1.01	0.93--	0.99	1.02^{+}	0.96-	1.35^{++}	1.13^{++}	1.15	1.50++
Availability 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability 2005–2009				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] One 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 ($P < 0.01$).

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.

Harassment by mosquitoes and oestrid flies strongly affects caribou distribution and habitat selection. The sea coast and the drainages of Fish and Judy creeks are important landscape features affecting caribou distribution during the insect season. The selection of coastal and riverine areas as insect-relief habitat appeared to be more important in that season than selection of other classes having greater forage availability.

The distribution of habitats differs among the various distance zones we created around the proposed ASDP road alignment (Table 7), due mainly to the presence of Fish and Judy creeks to the north of the proposed alignment and to the generally decreasing 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 used areas on 8 June 2009 that had significantly less snow than the average snow cover estimated over the entire NPRA survey area on 25 May ($P < 0.05$). The average snow cover in the NPRA survey area on 25 May was 67.1% and caribou on 8 June were using areas that had a mean snow cover of 61.4% (99% C.I. = 55.6–67.0%) on 25 May. Almost all snow had melted in the survey area by 8 June, but these results suggest that caribou were using areas where snow melt occurred earlier, which is not consistent with the conclusions of some previous research on caribou selection of foraging areas.

Caribou showed the opposite pattern of use in the study area in 2008, selecting areas with more recent snow melt during calving (Lawhead et al. 2009). Previous studies have not provided consistent results concerning the calving distribution of northern Alaska herds in relation to 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 low values of estimated biomass (NDVI_calving and NDVI_621) during postcalving and the oestrid-fly season (Table 8) probably as a result of higher use of the northern and riverine areas (Table 5). During calving caribou used areas with higher than expected NDVI_peak. 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 P). In 2005, 2007, and 2008, caribou selected areas of higher estimated biomass during calving. In 2006, however, caribou appeared to select areas with lower biomass (NDVI_calving and NDVI_621) during calving.

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.

Table 7. Area (percentage) of water and non-water habitat types, calculated separately, 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	6–4	17.8	9.2	23.2	12.7	10.2	33.2	3.1	2.2	0.2	1.9	1.9	2.2
	4–2	17.7	9.4	27.4	11.2	9.7	37.0	0.7	3.0	0.7	0.3	0.2	0.4
	0–2	9.4	9.0	25.0	12.0	9.8	41.7	0.5	1.7	0.2	0.0	0.0	0.1
South	0–2	21.3	6.9	18.3	9.8	9.6	51.4	0.6	2.9	0.3	0.0	0.0	0.1
	2–4	15.5	7.0	18.2	8.9	6.9	53.1	0.3	4.8	0.7	0.0	0.0	0.1
	4–6	10.0	7.0	20.2	7.7	5.7	55.9	0.2	3.0	0.3	0.0	0.0	0.0

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

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) at locations used by caribou groups in the NPRA survey area in 2009, compared with availability using a bootstrap analysis.

Season	n^a	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak
Spring Migration	3	0.3779	0.3841	0.0005	0.4898
Calving	115	0.3826	0.3963	0.0011	0.4919 +
Postcalving	67	0.3680 --	0.3824 --	0.0010	0.4853
Oestrid Fly	13	0.3426 --	0.3721	0.0024 +	0.4645
Late Summer	46	0.3761	0.3892	0.0011	0.4846
Total Use	244	0.3752 -	0.3897	0.0012 +	0.4873
Available		0.3805	0.3926	0.0010	0.4853

[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 ($P < 0.01$).

(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).

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), caribou use of areas of high NDVI_rate 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 as we did by using fall baseline NDVI values, so their results probably are more strongly related to temporal and spatial differences in 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 S). For all years combined (2001–2009), however, fewer caribou groups than

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
2009	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	1	0	0	0	1	0	5.29	0.259
	Calving	1	20	4	5	8	2	1	3.28	0.512
	Postcalving	1	16	7	4	4	1	0	9.89	0.042
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	1	0	0	1	0	0	2.02	0.732
	Late Summer	1	14	3	3	5	0	3	2.81	0.591
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	52	14	12	18	4	4	7.93	0.094
2001–2009	Winter	3	122	21	19	36	27	19	3.17	0.529
	Spring Migration	9	82	15	8	25	16	18	3.99	0.407
	Calving	10	210	53	28	65	33	31	6.84	0.145
	Postcalving	10	286	58	53	91	36	48	4.38	0.357
	Mosquito	7	17	4	4	5	1	3	2.07	0.722
	Oestrid Fly	10	46	15	8	8 -	5	10	10.27	0.036
	Late Summer	16	165	41	35	48	18	23	11.35	0.023
	Fall Migration	18	382	74	57	132	56	63	1.06	0.900
	Total	83	1310	281 +	212	410	192	215	10.55	0.032
Area surveyed 2001 (km²) [a]				31.4	27.9	52.8	26.7	27.0		
Area surveyed 2002–2004 (km²)				35.0	29.4	67.5	33.1	33.5		
Area surveyed 2005–2009 (km²)				39.4	33.4	69.1	33.2	33.6		

[a] Average of different survey areas.
+ 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 ($P < 0.01$).

expected (based on a uniform distribution) occurred within 2 km of the road alignment during the oestrid-fly season and more caribou than expected occurred 4–6 km north of the road alignment during all seasons combined. These results were consistent with greater use of areas near Fish and Judy creeks during the postcalving to late summer seasons, as detected in our geographic-section and habitat-use analyses.

Caribou density among the distance-to-road zones (Figure 16) showed a significant zone-by-season interaction (Wald chi-square *P*-value < 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 $P < 0.01$; 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 calving ($P = 0.016$), postcalving ($P = 0.001$), and fall ($P = 0.012$). No other seasons differed significantly ($P > 0.05$).

Over all seasons combined, there were no significant differences among zones ($P > 0.05$). Significant differences in density were found

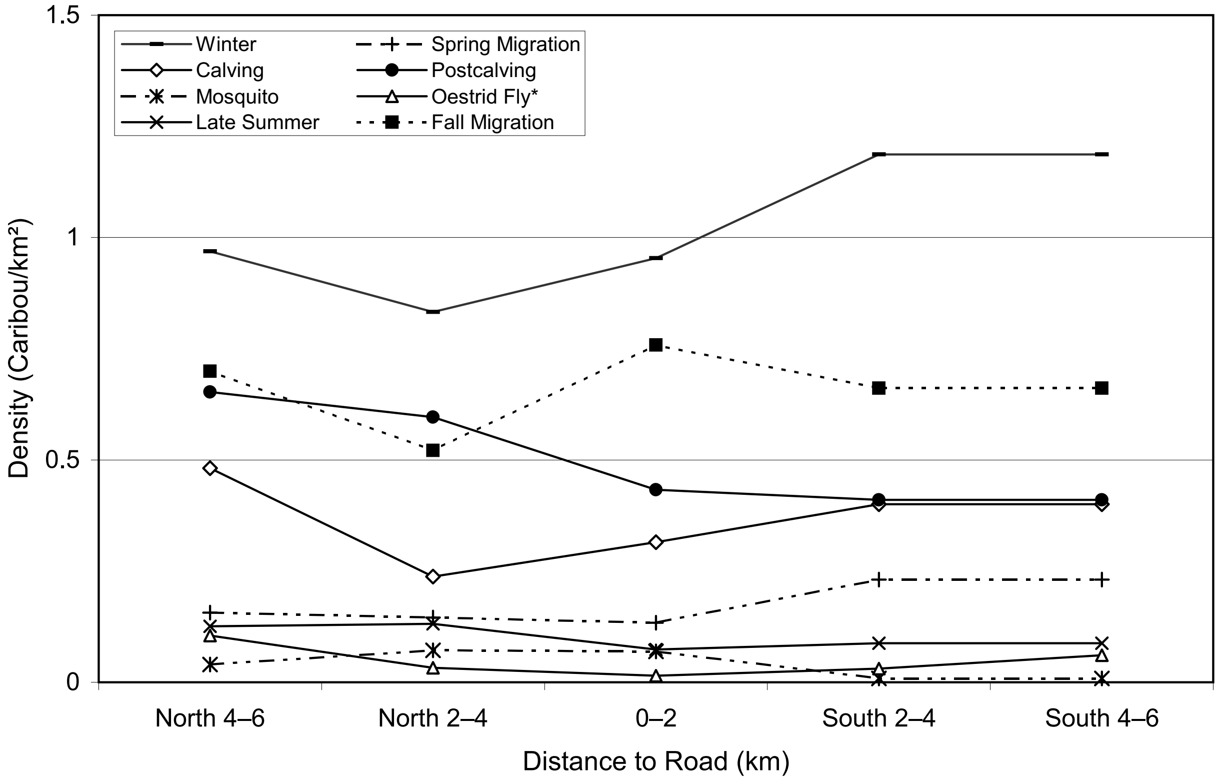


Figure 16. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2009.

among calving (P = 0.014) and late summer (P = 0.002). During calving the density in the 4–6 km north zone was significantly higher than in the 2–4 km north zone. There were no significant differences among zones during late summer after applying multiple comparison tests.

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 2009 and among all seasons for the years 2002–2009. A number of variables used in the grid-cell analyses were correlated; therefore, we examined the relationships among vegetation, snow, and habitat variables calculated for the 164 grid-cells before conducting the density analyses.

After removing one outlier, the estimated peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 (r = 0.922; P < 0.001) and NDVI_calving (r = 0.847; P < 0.001), but was not highly correlated with NDVI_rate (r = 0.375; P < 0.001). These results indicate that the spatial pattern of NDVI values after snowmelt is consistent throughout all phenological stages. NDVI_peak in 2009 was highly correlated with the NDVI_peak in 2008 ($r = 0.943$; $P < 0.001$). The spatial pattern of NDVI_peak can be explained largely by differences among habitat types. NDVI_peak increased with increasing proportion of tussock tundra ($r = 0.693$; $P < 0.001$) but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $r = –0.450$; $P < 0.001$) and in riverine habitats ($r = –0.622$; $P < 0.001$). 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 significant ($r = –0.502$; $P < 0.001$), suggesting that even small waterbodies artificially depressed NDVI values.

The proportion of tussock tundra alone explained 48.1% of the variation in NDVI_peak values and the combination of tussock tundra with the proportion of wet habitat, the proportion of riverine habitat, and the proportion of water explained 71.2% of the variation. Distance from the coast also had an effect: NDVI_peak values were higher in grid-cells farther from the coast (slope = 0.0016; $P < 0.001$).

The snow-cover fraction on 25 May 2009 was highly correlated with NDVI_rate (r = –0.777, $P < 0.001$), suggesting that areas with early snow melt had more advanced vegetative growth by 21 June. The correlation between snow cover on 25 May and NDVI_calving (r = 0.163; $P = 0.038$) and NDVI_621 (r = –0.135; $P = 0.086$) were weak, however, perhaps because variation in the NDVI of standing dead vegetation swamped the signal from new growth. The percentages of snow cover on 26 May 2008 and 25 May 2009 were strongly correlated (r = 0.741; $P < 0.001$) suggesting that spatial patterns of snow melt are similar among years.

Caribou Density During the Calving Season

The best model describing caribou density in the 2009 calving season in the NPRA survey area included five 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 25 May, the proportion of tussock tundra, and transect number (as a metric of west to east location); this model had a 35.6 % chance of being the best model ($w_i = 0.356$; Appendix T). The second-best model included four of the same variables, but replaced the proportion of tussock tundra with the proportion of wet habitat; this model had a 26.7% chance of being the best model ($w_i = 0.267$) (Appendix T). The model-weighted parameter estimates indicated that presence of creeks and snow cover on 25 May were related positively to calving density, whereas transect number was negatively related to calving density ($P < 0.05$; Table 10). NDVI_peak ($P = 0.685$), NDVI_rate ($P = 0.229$), presence of the proposed road alignment ($P = 0.932$), proportion of tussock tundra ($P = 0.076$), and proportion of wet habitats ($P = 0.105$) were not significant factors in the 2009 results.

For all years combined (2002–2009), analysis of calving density provided generally similar results to those for 2009 alone, albeit with a few differences. The best model included survey, presence of creeks, and presence of the proposed road alignment (these three variables were in all models, so were included in the best model by default) and transect number (west to east), proportion of tussock tundra, and distance to coast (Appendix U). The model-weighted parameter estimates indicated that caribou density during calving was greater for increasing NDVI_peak values ($P < 0.001$) and proportion of tussock tundra ($P < 0.001$), and was lower for proportion of wet habitat ($P = 0.012$; Appendix V) and in the eastern transects ($P < 0.001$). The distance to coast (positive relationship, $P = 0.089$) was a moderately significant factor and the presence of the creeks ($P = 0.110$) and the proposed road ($P = 0.352$) were not significant (Table 11, Appendix V).

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 did moist sedge–shrub tundra, but that difference disappeared when evergreen shrubs, which are unpalatable caribou forage, were excluded

Table 10. Model-weighted parameter estimates for calving caribou density in the NPRA survey area, 8 June 2009.

Variable	Coefficient	SE	*P*-value
Intercept	0.917	1.153	0.426
Presence of creeks	1.142	0.462	0.002
Presence of proposed road	–0.049	0.573	0.932
NDVI_peak	2.241	5.529	0.685
NDVI_rate	–206.975	172.131	0.229
Snow cover on May 25 (%)	0.014	0.007	0.050
Tussock tundra (%)	1.851	1.042	0.076
Wet habitat (%)	–1.790	1.105	0.105
Transect number (W to E)	–0.188	0.039	<0.001

(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 2005–2009 (Spearman's rho = –0.076–0.411), 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, different variables were significantly related to caribou density in the NPRA survey area among seasons (Table 11, Appendix V). During winter, caribou density was lower in the eastern portion than in the western portion of the survey area. During spring migration, caribou density decreased with increasing distance from the coast and was lower in the eastern portion of the survey area. During postcalving, density was higher near the creeks and in areas with higher NDVI_peak and decreased inland from the coast and from west to east. During the mosquito season, caribou density was higher near creeks, near the coast and in the western portion of the survey area. During the oestrid-fly season, density was higher near the creeks. 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, most likely 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 the postcalving season through late summer. The riverine area is characterized by a mosaic of habitats, including abundant willows and forbs that provide forage, as well as barrens, dunes, and river bars that provide some relief from oestrid-fly harassment. Caribou densities near the coast were 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 no evidence that the area around the proposed ASDP road alignment in NPRA was used by caribou to a different degree than adjacent areas.

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, 2002–2009.

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

ns Not significant.
\+ 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 ($P < 0.01$).

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 CD4) are at the interface of the annual ranges of the TH and CAH. The CD4 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. The distribution of the CAH during the insect season has shifted farther eastward in recent years, so fewer caribou from that herd are using the Colville River delta than did in earlier years.

Movements by satellite- and GPS-collared TH and CAH caribou into the vicinity of CD4 (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, years before the CD4 infrastructure was built. None of the satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006 or 2008–2009. In 2007, a satellite-collared TH female passed between Nuiqsut and CD4 during calving and four satellite-collared TH caribou moved east past Alpine and CD4 in late July. Of 43 GPS-collared TH females during 2004–2009, one crossed the delta between CD4 and Alpine in June 2005, one crossed the delta between CD4 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 CD4. One satellite-collared CAH caribou moved into the CD4 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 CD4 vicinity while heading inland in late July 2001 and one CAH GPS collar moved onto the Colville delta east of CD4 in late September 2004.

Radio-collared TH caribou occasionally crossed the proposed ASDP pipeline/road-corridor alignment extending from CD4 to the proposed GMT2 drill site in NPRA, primarily during fall migration, but the proposed alignment is located in a geographic area that currently receives low-density use by caribou from that herd. Radio-collared CAH caribou crossed the proposed alignment very rarely and it is not likely that the proposed pipeline/road corridor would have any 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, 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 within the study area, 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 throughout 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 distribution and 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 m). 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, 1983–2009. Some values changed from previous reports due to different rounding error in average temperature calculations.

	Snow Depth (cm)			Cumulative Thawing Degree-days (° 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	73.3	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	169.7	113.3	127.5	118.6
2001	23	30	5	0	0.8	51.9	72.2	80.0	183.9	131.7
2002	30	trace	0	4.2	30.3	57.8	70.3	92.2	134.4	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	8.9	26.4	185.6	148.1	151.4	153.3
2005	23	13	0	0	2.5	14.2	78.1	67.5	79.4	176.7
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
2007	25	46	5	0	0	46.4	81.7	115.0	138.9	134.4
2008	20	18	0	0	32.8	71.7	138.9	172.2	132.5	86.1
2009	36	13	0	0	16.7	71.7	44.4	142.8	126.4	133.6
Mean	22	13	3	0.6	11.6	42.5	99.0	125.0	140.5	125.9

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	918	77.3	0.97	3.5
June 23 [h]	654	43	697	1,394	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	1,272	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	1,376	214.8	1.39	10.6
October 12 [g]	826	30	856	1,712	353.2	1.73	10.7
October 24 [g]	377	35	412	824	99.7	0.83	5.7
COLVILLE EAST (1,700 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

[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 (1,310 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	1,080	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	1,001	2,002	345.3	1.53	7.8
COLVILLE RIVER 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	–	–	–
COLVILLE EAST (1,700 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

[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), using 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 (1,310 km²) [f]							
April 24	1,565	0	1,565	3,130	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	1,060	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	1,130	204.8	0.86	6.7
September 29	nr	nr	2,262	4,524	756.9	3.46	7.0
October 28	nr	nr	176	352	75.4	0.27	7.0
COLVILLE RIVER 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
COLVILLE EAST (1,700 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

[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), using 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 (1,310 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	1,604	229.3	1.23	12.2
COLVILLE RIVER 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
COLVILLE EAST (1,700 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	1,335	nr	1,335	2,670	743.7	1.57	17.8

[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), using 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 (1,720 km²) [f]							
April 23	590	0	590	1,180	184.6	0.69	6.0
June 6 [g]	64	6	70	263	54.5	0.15	2.6
June 13 [h]	279	45	324	648	296.9	0.75	4.6
June 20	476	69	545	1,090	151.8	0.63	4.9
June 28	47	0	47	94	17.2	0.06	1.5
August 3 [i]	nr	nr	8,947	9,015	51.5	5.24	357.9
August 17	16	2	18	36	7.3	0.02	2.0
August 31	41	0	41	82	14.0	0.05	2.1
October 21	144	14	158	316	54.6	0.18	3.4
COLVILLE RIVER 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 (1,696 km²) [f]							
April 24	39	0	39	78	20.9	0.05	3.0
June 5–6 [g,i]	290	79	369	1,387	164.4	0.97	2.18
June 10–11 [j]	1,010	363	1,373	2,746	332.3	1.92	5.12
June 21	2,172	842	3,014	6,028	624.1	3.55	10.3
June 29 [k]	366	34	400	800	867.7	0.82	15.4
August 2–3	nr	nr	1,915	1,962	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), using 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 (1,720 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	1,030	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 RIVER 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 (1,696 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]	1,517	511	2,028	4,056	309.2	2.83	6.4
June 20	998	208	1,206	2,412	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	1,186	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 (1,720 km²) [f]							
May 14	746	0	746	1,492	175.6	0.87	4.7
June 9	686	47	733	1,466	188.0	0.85	3.7
June 18	645	49	694	1,388	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	1,092	225.3	0.63	5.2
October 22	1,519	nr	1,519	3,038	282.6	1.77	8.2
COLVILLE RIVER 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 (1,696 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]	4,015	1,298	5,313	10,626	597.9	7.42	7.7
June 18	3,389	569	3,958	7,916	1,086.0	4.67	11.7
June 24	1,555	347	1,902	3,804	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.

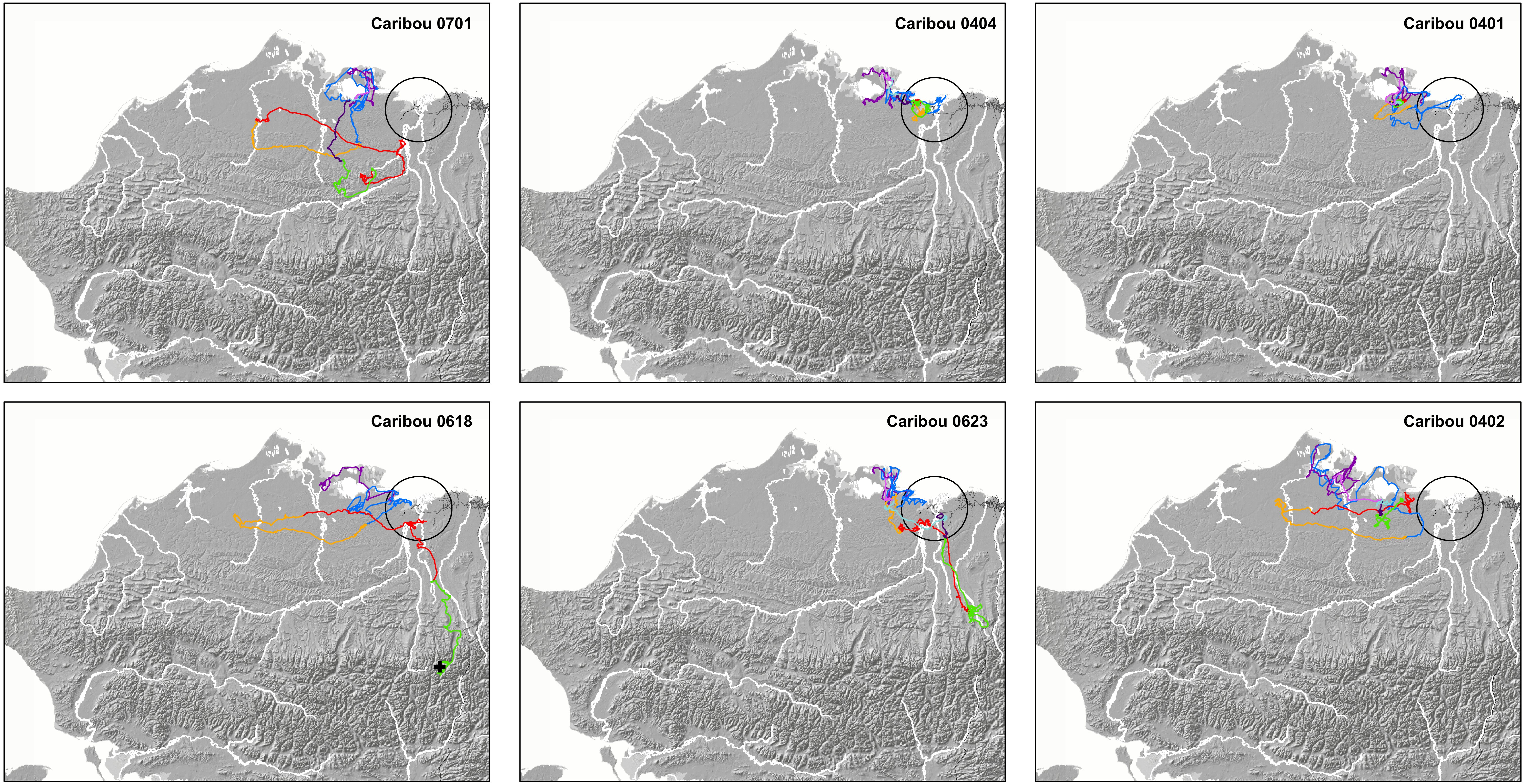
Appendix J. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, May–October 2008.

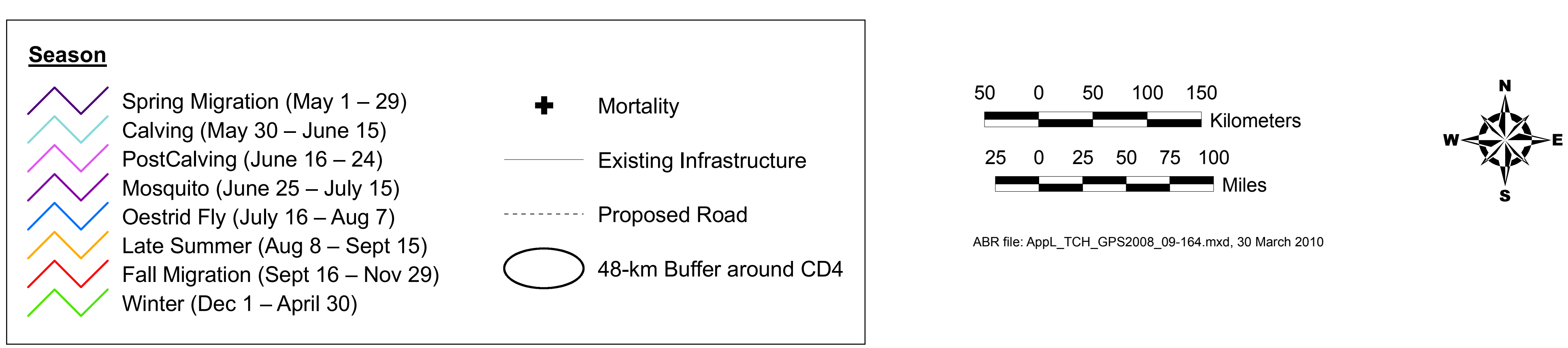
Survey Area and Date	Area [a]	Large Caribou [b]	Calves [c]	Total Caribou	Estimated Total [d]	SE [e]	Density (caribou/km²) [f]	Mean Group Size
NPRA								
April 29	860	243	0	243	486	59.9	0.57	4.1
May 18–19 [h]	1,720	21	0	21	79	16.7	0.05	2.1
June 9	1,720	473	15	488	976	115.6	0.57	3.4
June 19	1,720	421	6	427	854	150.2	0.50	5.2
August 21	1,720	170	0	170	340	33.6	0.20	1.5
September 24	1,720	887	nr	887	1,774	211.1	1.03	4.2
October 7	1,720	81	nr	81	162	28.1	0.09	5.1
October 25	1,720	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]	1,326	348	0	348	1,306	292.0	0.99	7.9
June 3–4 [i]	1,432	1,694	211	1,905	3,810	234.6	2.66	3.7
June 11 [i]	1,432	4,155	919	5,074	10,148	819.5	7.09	7.9
June 19	1,696	2,138	589	2,727	5,454	1,518.0	3.21	18.9
August 21	1,696	119	0	119	238	36.1	0.14	1.5
September 25	1,938	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	1,938	60	nr	60	120	34.1	0.06	4.3

[a] Survey coverage was 50% of this area (860 km² in NPRA, 247 km² on the Colville R. Delta, 848–969 km² in Colville East) for complete surveys; some surveys could not be completed due to fog or poor weather.
[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).

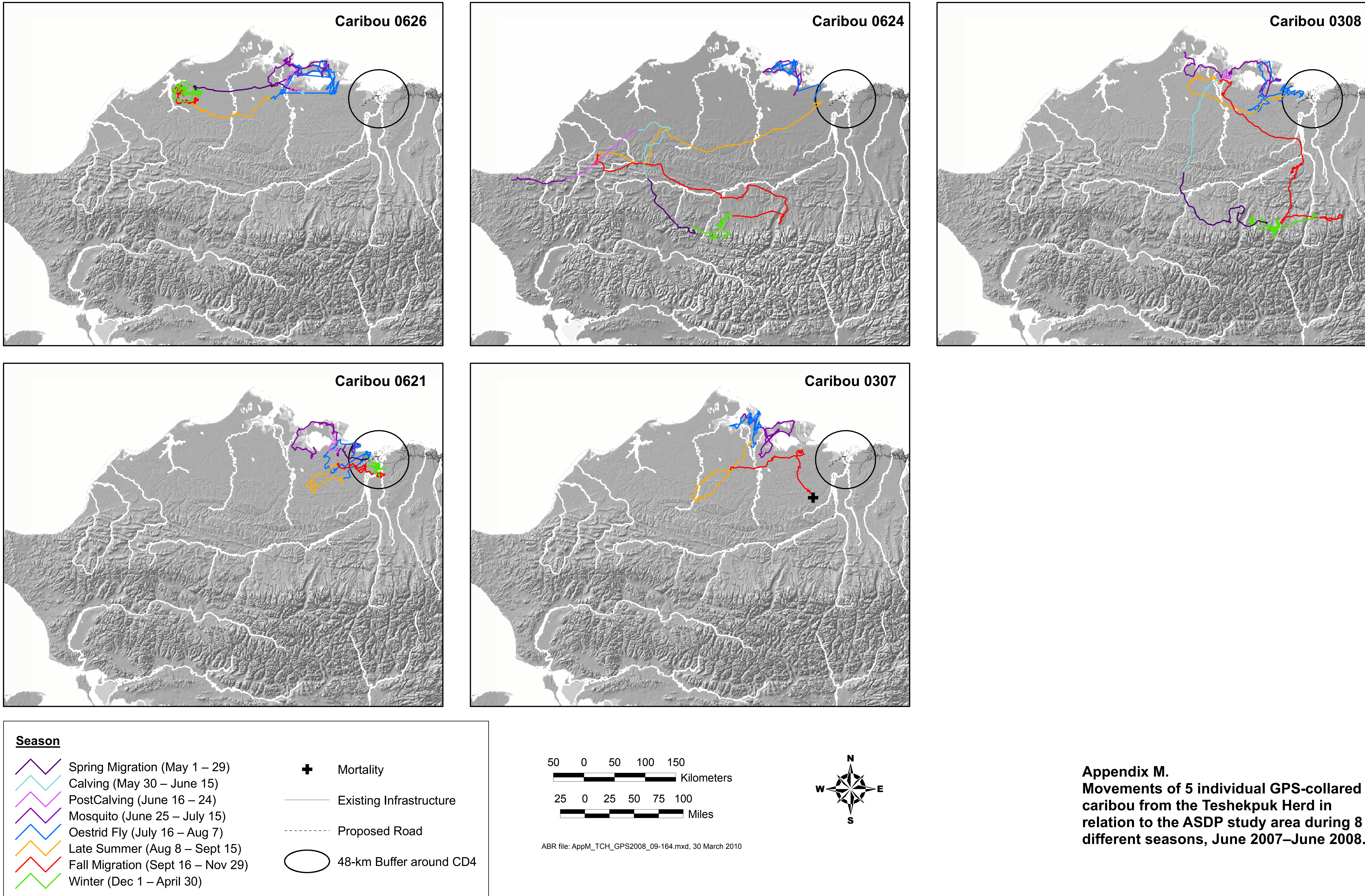
Appendix K. Locations and number of other mammals observed during aerial surveys in the NPRA–Kuparuk region, May–August 2009.

Species	General Location	Date	Adults	Young	Total	Specific Location
Muskox	Colville River	June 9	11	5	16	N of Alpine pipeline
		August 22	3	0	3	mouth of Itkillik River
	Kuparuk Oilfield	June 4	1	0	1	near DS-2N
		June 9	8	1	9	E of Milne Point Rd.
		June 9	5	3	8	E of Milne Point Rd.
	Kuparuk River	June 2	2	0	2	near Spine Rd.
		June 9	4	1	5	N of Spine Rd.
		June 9	1	0	1	near Spine Rd.
		June 9	1	0	1	near Spine Rd.
		June 9	6	1	7	12 km S of Spine Rd.
		June 20	3	2	5	N of Spine Rd.
		June 20	7	3	10	near Spine Rd.
		June 23	3	2	5	S of Spine Rd.
		June 24	4	0	4	near Spine Rd.
		August 18	1	1	2	N of Spine Rd.
		August 19	5	1	6	near Spine Rd.
		August 19	5	0	5	near Spine Rd.
		August 19	2	1	3	near Spine Rd.
		August 19	4	1	5	near Spine Rd.
		August 19	2	0	2	S of Spine Rd.
	Oliktok/Milne Points	June 2	12	3	15	E of Milne Point Rd.
		June 2	2	0	2	E of Milne Point Rd.
		June 2	8	0	8	E of Milne Point Rd.
		June 2	4	0	4	E of Milne Point Rd.
		June 9	11	3	14	E of Milne Point Rd.
		August 18	3	3	6	E of Oliktok Point Rd.
		August 18	3	0	3	E of Milne Point Rd.
		August 18	10	1	11	E of Oliktok Point Rd.
Grizzly bear	NPRA	June 8	1	0	1	W of Fish Creek
		June 9	1	0	1	Fish Creek delta
		June 10	1	2	3	N of Fish Creek
		June 11	1	0	1	E of Fish Creek
		June 13	1	1	2	S of Fish Creek
		June 22	1	1	2	Judy Creek
		June 22	1	2	3	S of Fish Creek
		June 26	1	0	1	Fish Creek delta
		August 24	1	0	1	N of Fish Creek
	Colville River delta	June 8	1	0	1	E of delta along coast
		June 9	1	0	1	central delta
		June 9	1	0	1	E of delta
		June 10	1	0	1	E of delta
		June 20	1	0	1	N of Alpine pipeline
		June 22	2	0	2	near Itkillik River
		June 26	1	0	1	central delta
		June 29	1	0	1	N of Alpine
		August 22	1	2	3	near Itkillik River
	Kuparuk Oilfield	June 3	1	0	1	E of DS-2P
		June 9	2	0	2	S of CPF-1
		June 9	1	0	1	NE of DS-2P
		June 10	1	3	4	SE of DS-2P
		June 11	2	0	2	S of CPF-1
		June 20	1	0	1	N of Spine Rd.
		August 20	1	0	1	N of DS-2T
	Kuparuk River	August 20	1	0	1	S of Spine Rd.
Spotted seal	Colville River delta	August 22	9	9	0	eastern delta

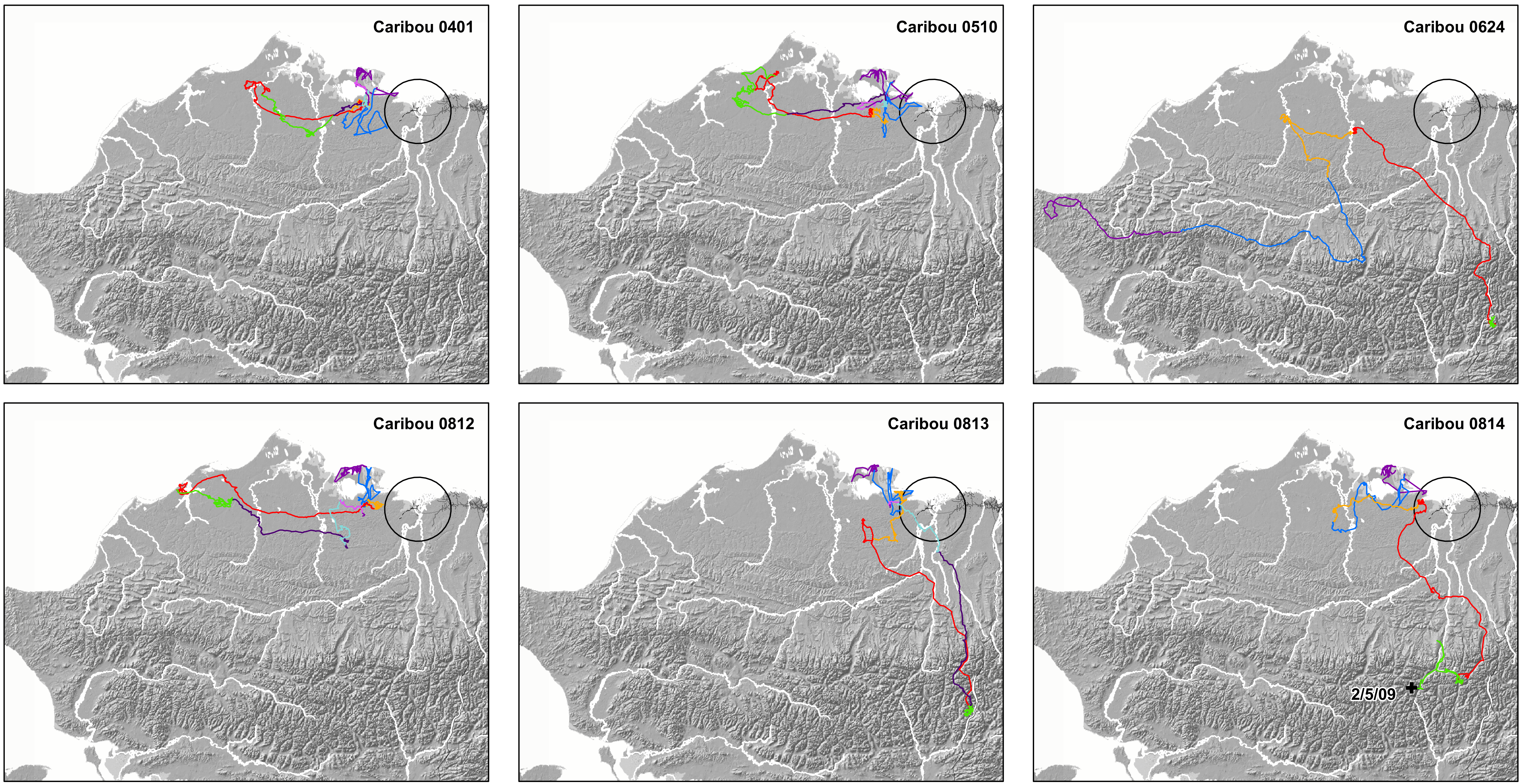


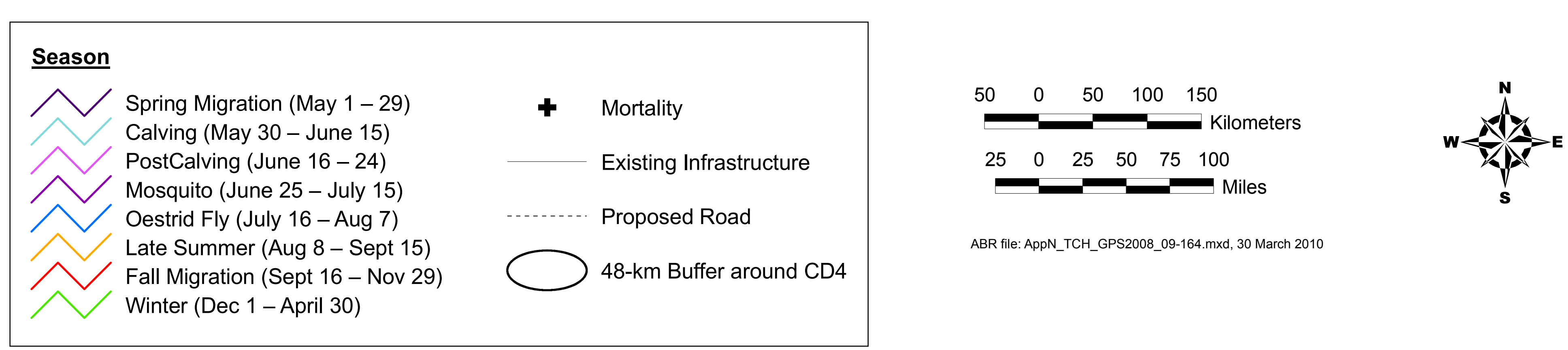


Appendix L.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, June 2007–June 2008.

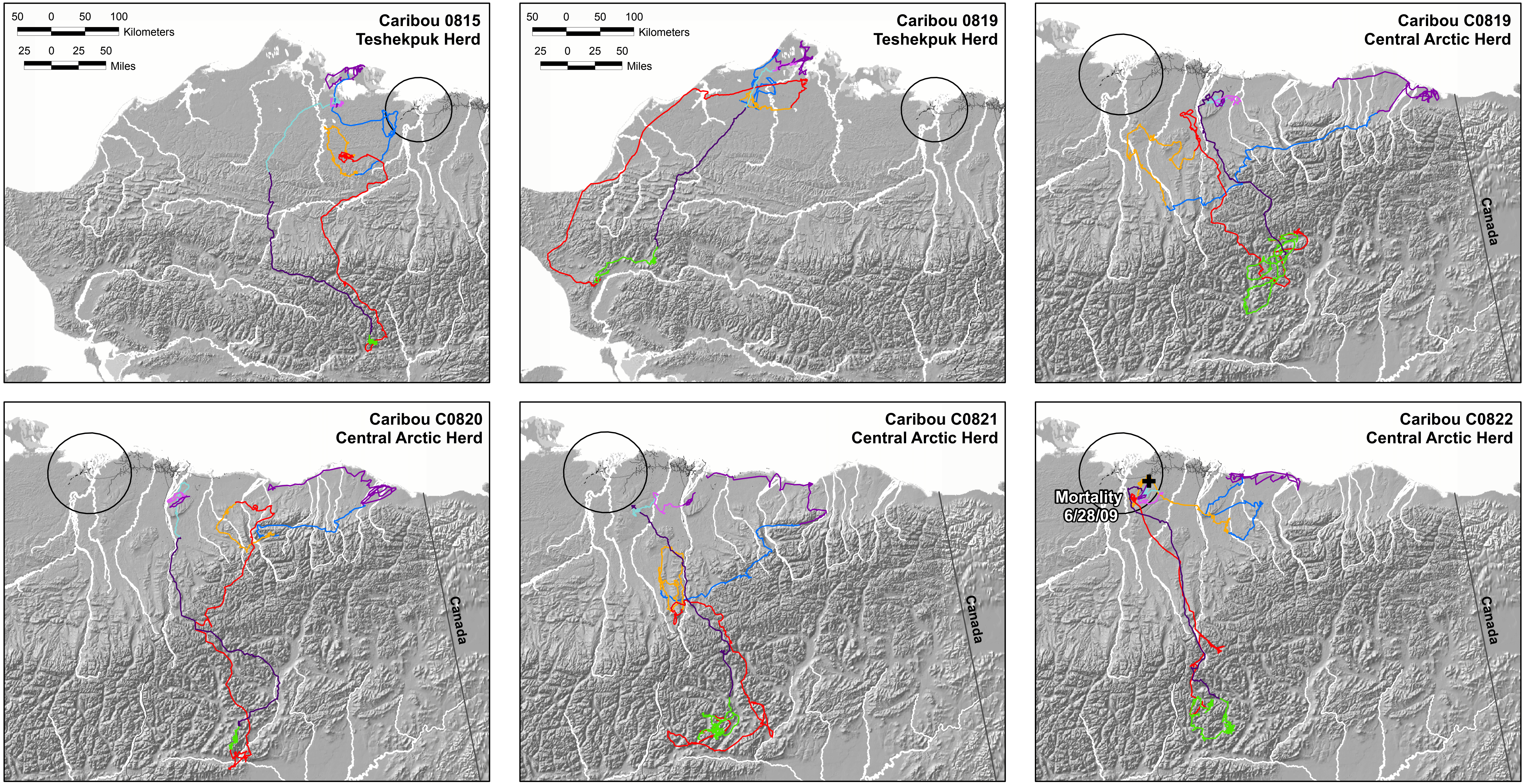


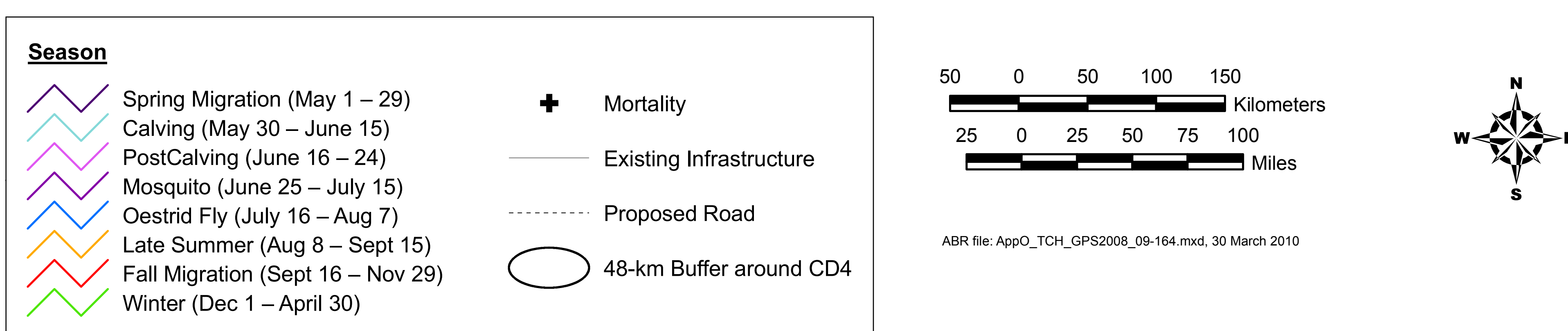
Appendix M.
Movements of 5 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, June 2007–June 2008.





Appendix N.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, July 2008–June 2009.





Appendix O.
Movements of 6 individual GPS-collared caribou from the Teshekpuk and Central Arctic herds in relation to the ASDP study area during 8 different seasons, July 2008–June 2009.

Appendix P. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2009 and for habitat types (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2009 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	0.3588	0.3964	0.4034
		NDVI_621	0.3785	0.3862	0.3825	0.4056	0.4248
		NDVI_rate	0.0004	0.0002	0.0019	0.0007	0.0017
		NDVI_peak	0.4712	0.4787	0.4794	0.5004	0.5140
	Snow Cover 21 May	Mean %	75.3	80.0	32.2	73.1	60.6
	Snow Cover 23 May	Mean %	3.0	6.1	2.6	1.8	2.0
	Snow Cover 26 May	Mean %	0.9	2.0	1.2	1.1	1.1
	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
2005–2009	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_calving	0.3321	0.3804	0.3583	0.3965	0.4034
		NDVI_621	0.3333	0.3817	0.3819	0.4057	0.4248
		NDVI_rate	0.0001	0.0001	0.0019	0.0007	0.0017
		NDVI_peak	0.4185	0.4775	0.4789	0.5005	0.5140
	Snow Cover 25 May	Mean %	90.0	82.4	32.6	73.2	60.6
	Snow Cover 4 June	Mean %	19.7	6.2	2.7	1.8	2.0
	Snow Cover 9 June	Mean %	7.4	1.7	1.2	1.1	1.1
	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 Q. 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	Chi-square	*P*-value
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0	26	13--	40	47	25.70	<0.001
	Calving	1	116	1	23	42^{+}	22--	28	22.02	<0.001
	Postcalving	1	82	0	13	45^{++}	12--	12--	47.85	<0.001
	Mosquito	1	5	0	4^{++}	1	0	0	22.81	<0.001
	Oestrid Fly	3	24	0	0-	18^{++}	2--	4	34.13	<0.001
	Late Summer	3	201	1	32	82^{++}	42--	44	39.67	<0.001
	Fall Migration	3	148	0	7--	33	23--	85^{++}	75.01	<0.001
	Total	14	702	2--	105	234^{++}	141--	220	84.88	<0.001
2003	Winter	1	313	1--	28	75	97	112^{++}	15.55	0.004
	Spring Migration	1	13	0	3	4	1--	5	5.18	0.269
	Calving	2	101	0	12	26	22--	41^{+}	13.44	0.009
	Postcalving	2	273	1--	37	90+	64--	81	22.35	<0.001
	Mosquito	1	1	0	1	0	0	0	7.44	0.115
	Oestrid Fly	2	116	1	6--	61^{++}	24--	24	50.81	<0.001
	Late Summer	1	37	0	10	15	7	5	16.94	0.002
	Fall Migration	3	431	2--	46	140^{++}	64--	179^{++}	98.07	<0.001
	Total	13	1,285	5--	143	411^{++}	279--	447^{++}	134.33	<0.001
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0	1	1	3	0	2.66	0.617
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	2	0	0	2	0	0	6.18	0.186
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	75	0	14	34^{++}	9--	18	29.07	<0.001
	Fall Migration	1	66	2	9	10	41^{++}	4--	28.10	<0.001
	Total	5	148	2	24	47	53	22--	13.91	0.008
2005	Winter	1	98	11	19	15	14--	39^{++}	23.82	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	98	3--	15	10-	21	49^{++}	51.71	<0.001
	Postcalving	1	112	7	29	27	16--	33	13.99	0.007
	Mosquito	1	32	10+	7	6	4	5	17.40	0.002
	Oestrid Fly	1	25	8	3	8	5	1--	19.38	0.001
	Late Summer	2	29	2	11	3	6	7	4.97	0.291
	Fall Migration	1	46	2	11	8	13	12	2.17	0.704
	Total	9	440	43	95	77	79--	146^{++}	45.53	<0.001
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	79	14	40^{++}	8-	9--	8--	46.65	<0.001
	Calving	1	118	3--	32	13-	23	47^{++}	34.13	<0.001
	Postcalving	1	88	3--	22	40^{++}	11--	12	44.58	<0.001
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	32	0-	14	11	3--	4	17.99	0.001
	Late Summer	2	94	7	26	31^{+}	12--	18	18.04	0.001
	Fall Migration	1	5	0	0	1	4^{+}	0	7.89	0.096
	Total	8	416	27-	134^{++}	104^{+}	62--	89	51.22	<0.001
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	159	13	44	44	26--	32	14.84	0.005
	Calving	1	198	4--	44	22--	40	88^{++}	74.75	<0.001
	Postcalving	1	178	3--	60^{+}	49	37	29	32.45	<0.001
	Mosquito	1	62	8	31^{++}	15	7--	1--	38.28	<0.001
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	83	8	19	31^{++}	14	11	19.69	0.001
	Fall Migration	3	347	20--	94	63	112	58	15.86	0.003
	Total	9	1,027	56--	292^{++}	224	236-	219	45.50	<0.001

Appendix Q. Continued.

Year(s)	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 Migration	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

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 ($P < 0.01$)..

Appendix R. 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, 2002–2008.

				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	1,285	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	1,027	1.00	0.95	0.99	1.04	1.00	1.02	0.96	0.81	1.11

Appendix R. Continued.

Year	Season	No. of Surveys	No. of Groups	Habitat Type [a] *Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
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

[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 S. 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), 2001–2008.

				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	10	1	1	2	1	1	8.32	0.080
	Calving	1	14	2	1	8	3	2	6.58	0.160
	Postcalving	2	104	17	23	32	14	17	3.42	0.489
	Mosquito	1	4	0	1	1	1	0	1.14	0.888
	Oestrid Fly	2	2	0	0	2	0	0	4.25	0.373
	Late Summer	2	38	13	6	10	3	13	6.46	0.167
	Fall Migration	3	79	14	12	32	10	14	2.82	0.589
	Total	12	251	47	44	87	32	47	2.44	0.655
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	26	4	3	7	4	8	3.63	0.458
	Calving	1	28	9	6	8	3	2	6.59	0.159
	Postcalving	1	18	4	4	7	1	2	2.70	0.609
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	3	3	1	0	0	1	1	2.86	0.581
	Late Summer	3	37	5	10	13	6	3	5.78	0.216
	Fall Migration	3	24	6	1-	8	6	3	3.86	0.426
	Total	14	136	29	24	43	21	19	2.83	0.587
2003	Winter	1	71	11	9	21	19	11	5.23	0.265
	Spring Migration	1	1	1	0	0	0	0	4.67	0.322
	Calving	2	22	3	5	9	1-	4	3.40	0.494
	Postcalving	2	72	13	7	26	11	15	2.11	0.715
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	2	29	11	4	3--	3	8	14.24	0.007
	Late Summer	1	8	3	0	3	0	2	4.65	0.325
	Fall Migration	3	101	21	19	30	16	15	2.50	0.645
	Total	13	304	63	44	92	50	55	3.19	0.526
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	2	1	0	1	0	0	2.31	0.679
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	11	4	1	5	1	0	5.10	0.277
	Fall Migration	1	35	5	6	14	5	5	0.98	0.913
	Total	5	48	10	7	20	6	5	2.81	0.591
2005	Winter	1	21	4	5	6	3	3	1.01	0.909
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	21	6	2	4	3	6	4.91	0.296
	Postcalving	1	14	3	5	4	1	1	4.90	0.298
	Mosquito	1	3	1	0	1	0	1	1.84	0.765
	Oestrid Fly	1	7	2	3	2	0	0	5.78	0.216
	Late Summer	2	5	0	1	3	1	0	2.94	0.567
	Fall Migration	1	13	1	1	5	1	5	6.12	0.190
	Total	9	84	17	17	25	9	16	3.20	0.525
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	11	2	0	5	3	1	3.50	0.478
	Calving	1	26	9	0-	6	3	8	12.15	0.016
	Postcalving	1	16	6	3	3	1	3	5.02	0.285
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	4	1	1	0	1	1	2.01	0.734
	Late Summer	2	14	3	5	1--	2	3	6.56	0.161
	Fall Migration	1	2	0	0	1	0	1	2.61	0.624
	Total	8	73	21	9	16	10	17	9.73	0.045

Appendix S. 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	28	5	4	10	5	4	0.25	0.993
	Calving	1	47	14	5	10	12	6	8.87	0.064
	Postcalving	1	40	7	7	12	7	7	0.32	0.988
	Mosquito	1	10	3	3	3	0	1	3.73	0.444
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	17	5	5	5	2	0	5.90	0.207
	Fall Migration	3	77	12	11	26	12	16	1.64	0.801
	Total	9	219	46	35	66	38	34	1.45	0.835
2008	Winter	1	30	6	5	9	5	5	0.69	0.953
	Spring Migration	1	3	1	0	0	2	0	7.15	0.128
	Calving	1	32	6	4	12	6	4	0.86	0.931
	Postcalving	1	6	1	0	3	0	2	3.55	0.470
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	21	5	4	3	3	6	4.70	0.320
	Fall Migration	3	51	15	7	16	6	7	3.94	0.414
	Total	8	143	34	20	43	22	24	3.15	0.532

+ 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 T. Model selection results (General Estimating Equations) for analyses of caribou density during calving 2009 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 25 (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, W to E, Snow Cover, Tussock	**163**	**8**	**652.41**	**0.00**	**0.356**
Creek, Road, W to E, Snow Cover, Wet	163	8	652.99	0.58	0.267
Creek, Road, W to E, NDVI_rate	163	7	654.86	2.45	0.105
Creek, Road, W to E, Snow Cover	163	7	654.96	2.55	0.100
Creek, Road, W to E, Snow Cover, NDVI_rate	163	8	656.23	3.82	0.053
Creek, Road, W to E, Snow Cover,	163	8	656.50	4.09	0.046
Creek, Road, W to E	163	6	657.69	5.28	0.025
Creek, Road, W to E, Tussock	163	7	657.77	5.36	0.024
Creek, Road, W to E, Wet Habitat	163	7	658.90	6.49	0.014
Creek, Road, W to E, NDVI_peak	163	7	659.40	6.99	0.011
Creek, Road	163	5	681.49	29.08	0.000
Creek, Road, NDVI_peak	163	6	682.69	30.28	0.000
Creek, Road, Tussock	163	6	683.02	30.61	0.000
Creek, Road, Wet Habitat	163	6	683.13	30.73	0.000
Creek, Road, NDVI_rate	163	6	683.25	30.84	0.000
Creek, Road, Snow Cover	163	6	683.49	31.08	0.000
Creek, Road, Snow Cover, NDVI_peak	163	7	684.23	31.82	0.000
Creek, Road, Snow Cover, Tussock	163	7	684.97	32.56	0.000
Creek, Road, Snow Cover, NDVI_rate	163	7	685.00	32.59	0.000
Creek, Road, Snow Cover, Wet Habitat	163	7	685.04	32.63	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 U. Model selection results for Generalized Estimating Equation analyses of caribou density in different seasons during 2002–2009 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	11	12	12	12	12	12	13	13	13	13	13	13	13	14	**14**	14
	QIC_c	2883	2878	2885	2885	2884	2862	2862	2863	2876	2880	2880	2845	2864	2845	**2842**	2845
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.000	0.117	**0.668**	0.098
Calving	K	12	13	13	13	13	13	14	14	14	14	14	14	14	15	**15**	15
	QIC_c	4950	4864	4844	4940	4949	4806	4749	4757	4833	4864	4866	4777	4784	4749	**4748**	4768
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.315	0.004	0.000	0.000	0.000	0.000	0.000	0.234	**0.447**	0.000
Postcalving	K	11	12	12	12	12	12	13	13	13	13	13	13	13	**14**	14	14
	QIC_c	5416	5413	5414	5408	5415	5259	5259	5261	5396	5407	5413	5211	5261	**5203**	5211	5210
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	**0.913**	0.027	0.038
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11	11
	QIC_c	916	825	889	906	913	906	860	897	825	826	826	**789**	904	791	791	791
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.471**	0.000	0.174	0.183	0.172
Oestrid Fly	K	7	8	8	8	8	8	9	9	9	9	9	9	**9**	10	10	10
	QIC_c	1462	1487	1448	1464	1451	1454	1433	1467	1542	1701	1551	1478	**1430**	1546	1448	1507
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.000	0.000	0.000	0.000	0.000	**0.789**	0.000	0.000	0.000
Late	K	17	18	18	18	18	18	19	19	19	19	19	19	19	**20**	20	20
Summer	QIC_c	4189	4179	4162	4154	4182	4134	4075	4112	4164	4150	4174	4093	4133	**4070**	4085	4095
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.069	0.000	0.000	0.000	0.000	0.000	0.000	**0.930**	0.000	0.000
Fall	K	18	19	19	19	19	19	20	20	20	20	20	20	**20**	21	21	21
Migration	QIC_c	8241	8242	8243	8233	8226	8220	8218	8218	8242	8232	8224	8221	**8212**	8220	8220	8214
	w_i	0.000	0.000	0.000	0.000	0.001	0.012	0.025	0.036	0.000	0.000	0.001	0.006	**0.646**	0.011	0.013	0.248

[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 (four 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 V. 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, 2002–2009. Asterisks denote significance of *P*-value (* < 0.05, ** <0.01, *** <0.001).

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–0.172	0.686	0.802
	Presence of Creek	–0.245	0.216	0.257
	Includes Proposed Road	–0.412	0.279	0.140
	NDVI_peak	1.076	3.383	0.750
	Distance to Coast (km)	0.007	0.009	0.417
	Tussock Tundra (%)	0.834	0.583	0.153
	Wet Habitat (%)	–0.406	0.594	0.494
	Transect Number (West to East)	–0.087	0.023	<0.001***
Spring Migration	Intercept	–4.113	0.786	<0.001***
	Presence of Creek	–0.445	0.246	0.070
	Includes Proposed Road	–0.536	0.367	0.144
	NDVI_peak	3.430	4.400	0.436
	Distance to Coast (km)	–0.025	0.009	0.009**
	Tussock Tundra (%)	0.940	0.714	0.188
	Wet Habitat (%)	–0.496	0.691	0.472
	Transect Number (West to East)	–0.088	0.026	<0.001***
Calving	Intercept	–3.559	2.807	0.205
	Presence of Creek	0.233	0.146	0.110
	Includes Proposed Road	–0.214	0.230	0.352
	NDVI_peak	12.460	2.598	<0.001***
	Distance to Coast (km)	0.012	0.007	0.089
	Tussock Tundra (%)	1.837	0.443	<0.001***
	Wet Habitat (%)	–1.077	0.428	0.012*
	Transect Number (West to East)	–0.115	0.020	<0.001***
Postcalving	Intercept	–0.525	1.549	0.735
	Presence of Creek	1.139	0.162	<0.001***
	Includes Proposed Road	0.320	0.245	0.192
	NDVI_peak	6.160	2.973	0.038*
	Distance to Coast (km)	–0.036	0.008	<0.001***
	Tussock Tundra (%)	0.484	0.499	0.332
	Wet Habitat (%)	–0.519	0.494	0.293
	Transect Number (West to East)	–0.150	0.017	<0.001***
Mosquito	Intercept	2.782	1.138	0.014*
	Presence of Creek	0.761	0.314	0.015*
	Includes Proposed Road	0.625	0.480	0.193
	NDVI_peak	–1.104	5.631	0.845
	Distance to Coast (km)	–0.115	0.015	<0.001***
	Tussock Tundra (%)	–0.381	1.041	0.714
	Wet Habitat (%)	0.093	1.043	0.929
	Transect Number (West to East)	–0.168	0.035	<0.001***
Oestrid Fly [a]	Intercept	1.568	6.337	0.805
	Presence of Creek	1.889	0.735	0.010*
	Includes Proposed Road	–3.250	4.922	0.509
	NDVI_peak	–18.552	13.608	0.173
	Distance to Coast (km)	–0.021	0.036	0.556
	Tussock Tundra (%)	0.870	2.630	0.741
	Wet Habitat (%)	–3.337	2.629	0.204
	Transect Number (West to East)	–0.109	0.092	0.238

Appendix V. Continued.

Season	Variable	Mean	SE	*P*-value
Late Summer	Intercept	4.143	1.212	<0.006**
	Presence of Creek	0.573	0.131	<0.001***
	Includes Proposed Road	–0.084	0.245	0.732
	NDVI_peak	–10.052	2.541	<0.001***
	Distance to Coast (km)	–0.013	0.007	0.043*
	Tussock Tundra (%)	–1.029	0.431	0.017*
	Wet Habitat (%)	0.126	0.436	0.773
	Transect Number (West to East)	–0.114	0.016	<0.001***
Fall Migration	Intercept	–2.130	0.450	<0.001***
	Presence of Creek	0.133	0.144	0.355
	Includes Proposed Road	0.105	0.216	0.625
	NDVI_peak	–2.574	2.402	0.284
	Distance to Coast (km)	0.001	0.006	0.877
	Tussock Tundra (%)	–0.475	0.425	0.264
	Wet Habitat (%)	0.738	0.427	0.084
	Transect Number (West to East)	–0.036	0.015	0.017*

[a.] Two outliers removed prior to analysis.