CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2012

8TH ANNUAL REPORT

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EXECUTIVE SUMMARY

- Discoveries of additional oil reserves on the Colville River delta and in the northeastern National Petroleum Reserve–Alaska (NPRA) in the 1990s led to a proposal by ConocoPhillips Alaska, Inc.(CPAI)—the Alpine Satellite Development Program (ASDP)—to expand development from the original Alpine Project 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. Although the 48-km radius later was dropped from the permit stipulation, the caribou monitoring study was designed using that distance to delineate the primary study area. The study area encompasses the CD3 drill site (also constructed in winter 2004–2005), the planned CD5 drill site (which received agency approval in late 2011), and the proposed GMT1 (formerly CD6) and GMT2 (formerly CD7) pads and associated infrastructure.

- This report presents results from the eighth 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 2005–2012, 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 1990–2012 for the TH and 1986–1990 and 2001–2005 for the CAH; and GPS-collar data were collected during 2004–2012 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 2008–2012 for the CAH (including four collars deployed in early July 2008, six deployed in late June 2009, and 12 deployed in mid-June 2010, all specifically for this study).

- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery from 2000–2012, 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–mid-August; 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 in some previous reports. Subsequent research has indicated that this late-fall baseline overestimated standing dead biomass in the spring. Therefore, we used a baseline value of zero for this report, but are examining alternative ways to measure standing dead biomass. Snow cover (subpixel-scale snow fraction) in spring 2000–2012 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 (2001–2012), although distribution and abundance varied 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 7% to 37% for satellite collars during 1990–2012 and 2% to 43% for GPS collars during 2004–2012. 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 2001–2012 and between 0 and 44% for GPS collars during 2003–2006 and 2008–2012.

- 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). In recent years, large portions of the TH have calved further west between Atqasuk and the Ikpikpuk River. Although some calving occurs in the western half of the NPRA survey area, it is not an area of concentrated calving for the TH. In 2012, the estimated density of caribou in the NPRA survey area during the calving survey was 0.43 caribou/km².
- 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 GPS and Satellite-collared caribou were in the vicinity of CD4 during 2012, but one caribou was near CD3. 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 2002–2012 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, late summer, 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 except winter.
- For the years 2002–2012 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.
- Caribou groups in the NPRA survey area showed selection for areas with high vegetative biomass. Areas with high estimated peak levels of vegetative biomass were used more than expected during winter, calving, and fall 2012.
- 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 road alignment. Fewer groups than expected (assuming a uniform distribution for statistical testing) 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.
- The best model describing the density of calving caribou in the NPRA survey area in 2012 contained the variables for a west-to-east gradient and NDVI_621; caribou density increased with increasing NDVI_621 and declined from west to east.
- The best model describing the density of calving caribou in the Colville East survey area in 2012 contained variables for a west-to-east gradient, the proportion of water, the presence of areas within 2 km of roads, the proportion snow covered on June 1, and the distance to the coast. Based on model-averaged parameter estimates, the density of calving caribou during the calving survey in 2012 increased with distance to the coast and in areas that had greater snow cover on 1 June 2012. Density decreased in areas within 2 km of existing roads.
- Although radio-collared TH caribou have crossed the proposed ASDP road alignment in NPRA occasionally (primarily during fall migration), the data collected thus far indicate that the proposed road/pipeline corridor is in an area of low-density use by caribou.

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INTRODUCTION

BACKGROUND

The caribou monitoring study for the Alpine Satellite Development Program (ASDP) is being conducted on the Arctic Coastal Plain of northern Alaska and is 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, Parrett 2009, 2011, Lawhead et al. 2012, Wilson et al. 2012).

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 (Carroll et al. 2005; Kelleyhouse 2001; Person et al. 2007; Parrett 2007, 2011; Yokel et al. 2009; Wilson et al. 2012). Most TH caribou winter on the coastal plain, generally west of the Colville River, although some caribou occasionally overwinter south of the Brooks Range with the Western Arctic Herd (WAH; Carroll et al. 2005, Person et al. 2007). In recent years, a substantial portion of the TH has wintered in areas outside the previous range of the herd, both far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004, Parrett 2009) and southeast in the winter range of the CAH since 2004–2005 (Lawhead et al. 2007, 2008, 2009, 2010, 2011, 2012; Lenart 2009; Parrett 2009, Lenart 2011). In 2010, much of the TH calved farther west, between Atqasuk and the Itkillik River, outside the area used in most recent years (Parrett 2011). In the years since 2010, the TH has continued to calve over a larger area than had been observed prior to 2010.

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 2012). 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/Dalton Highway corridor (Arthur and Del Vecchio 2009, Lenart 2011).

This monitoring study 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 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. (2012) for the most current listing of other CPAI wildlife studies on the Colville River delta. In addition to wildlife surveys, an ecological land survey (ELS) was conducted on the Colville River delta (Jorgenson et al. 1997) and in northeastern NPRA (Jorgenson et al. 2003, 2004) to describe and map features of the landscape. The ELS described terrain units (surficial geology, geomorphology), surface forms (primarily ice-related features), and vegetation, which were combined in various ways 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) have 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, Person et al. 2007, Parrett 2009, Lawhead et al. 2012, Wilson et al. 2012). 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 2011). 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 original 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). A new planning effort for the entire area of NPRA (Northeast, Northwest, and South planning areas) began in summer 2010. The final IAP/EIS was released in December 2012.

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 and approved). 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 recently approved but not-yet-constructed CD5 pad; the proposed pads for GMT1 (formerly CD6) and GMT2 (formerly CD7); and all associated roads, pipelines, and other 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 NSB, 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 Inc.—Environmental Research and Services (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 this monitoring study. The results of each of the seven preceding years of study (2005–2011) were presented and discussed annually in meetings with the NSB Department of Wildlife Management (9 March 2006, 5 April 2007, 17 March 2008, 14 April 2009, 16 March 2010, and 24 March 2011, and 9 April 2012) and in the village of Nuiqsut on 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 (Mark Ahmakak, James Taalak, Doreen Nukapigak, and Gordon Brown) have participated in some aerial surveys over the years.

The combination of observations from both scientific and local/traditional sources of knowledge regarding development effects on CAH caribou have been 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 questions are expected to arise as exploration and development continue to expand westward into 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:

   a. Which herds use the study area and the vicinity of the proposed pipe-line/road corridor that will interconnect the ASDP facilities?

   b. How do patterns of seasonal use differ between the two herds?

   c. 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:

a. 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?

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

c. What are the existing patterns of caribou distribution and density around the proposed road corridor prior to construction?

4) Evaluate the feasibility of remote-sensing techniques to detect and map caribou trails for use in delineating movement routes and zones, both before and after construction.

Field sampling of plant biomass (Task 3) was scheduled to occur at least three times during the 10-year study; one year of sampling occurred in 2005 but, after further discussion of study design with the NSB Department of Wildlife Management, this task was dropped because the difficulty involved in plant sampling and the high variance in the data collected made adequate sampling impractical. 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 typically 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 northeasterly 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.

Based on the original stipulation of the CD4 permit from the NSB, the study area was specified as the area within a 48-km (30-mi) radius around the CD4 drill site (Figure 1, bottom); that specific radius was later dropped by the NSB but the study area has been retained for comparative purposes for the monitoring program. Aerial transect 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 area. In 2010, these 2 transects were dropped after the June surveys because of concerns about potential disturbance of subsistence hunters and the low density of caribou observed in the area.

The Colville East survey area encompasses the western and southwestern margins of the

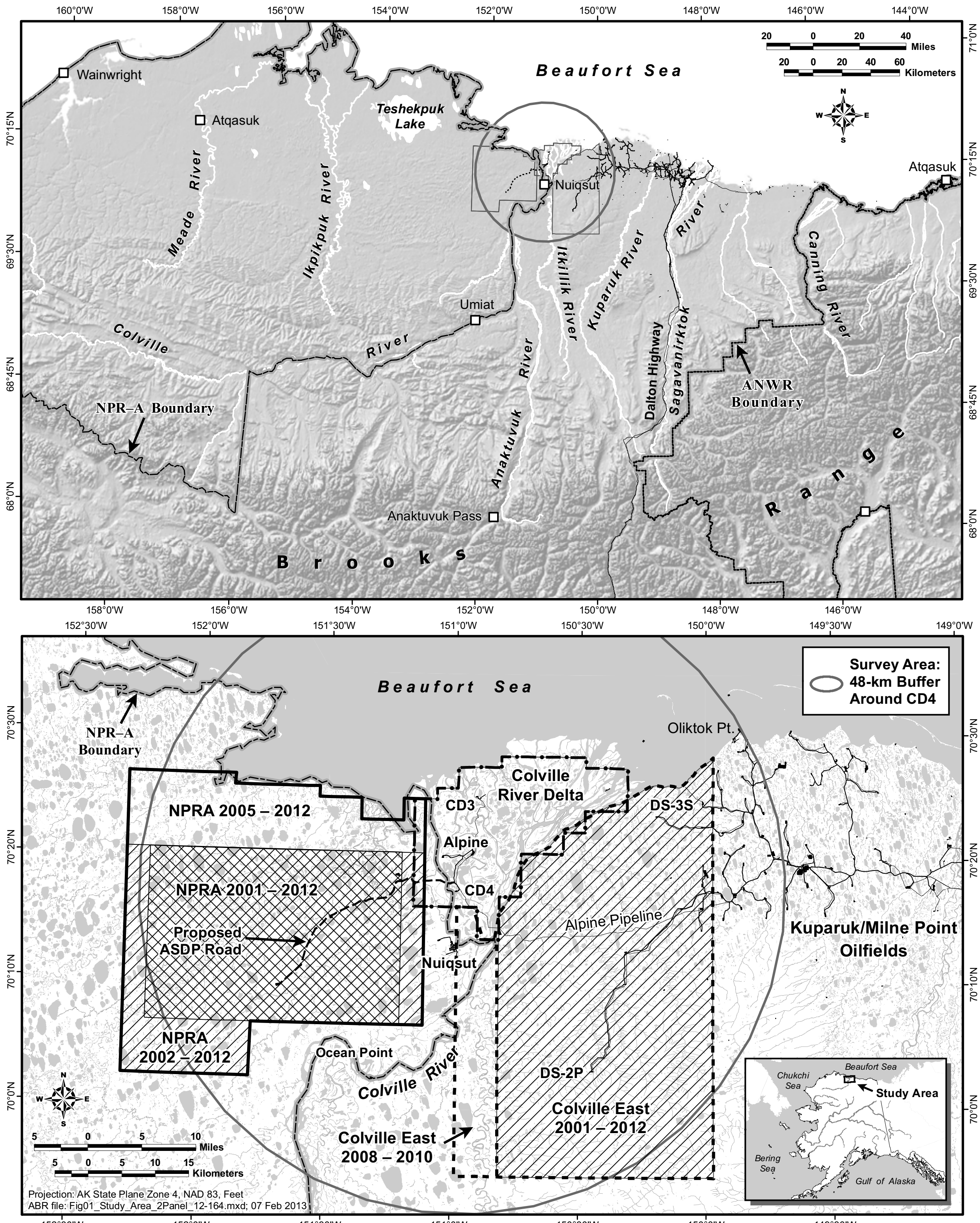

Figure 1. Location of the ASDP caribou monitoring study area (48-km radius around Drill Site CD4) on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2012 (bottom).

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 during 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 all seasons, that is connected to CD1 by an elevated pipeline. A road and adjacent elevated pipeline connect the CD4 drill site to CD1.

The NPRA survey area encompasses three more potential drill sites—CD5 (formerly called Alpine West), GMT1 (formerly CD6 or Lookout), GMT2 (formerly CD7 or Spark)—and a potential gravel mine site (also called Clover) that have been proposed for NPRA (BLM 2004). A new access road has been proposed by CPAI to connect these potential sites to the Alpine project facilities, requiring construction of a new 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 additional aerial transect surveys in 2012 and analyzed existing radio-telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and GPS-collar data from telemetry collars deployed specifically for this study annually in 2006–2010. Transect surveys were added 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. 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 telemetry data also provided valuable insight into herd affiliation, which was not available from the transect survey data. We analyzed caribou distribution and density in relation to an existing habitat map (BLM and Ducks Unlimited 2002) 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 periodically from April to October 2012 in a Cessna 206 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, 2010, 2011, 2012, this study). The NPRA survey area was expanded westward and southward in 2002 and northward in 2005, and the Colville East survey area was expanded westward in 2008. Additional surveys of Colville East were conducted during the calving season in 2001–2012 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, Lawhead et al. 2013). 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 along 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 only during the calving surveys to increase detection of caribou in areas of patchy snow cover in that season, 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), and was checked by measuring distances to recognizable landscape features displayed on maps in the GPS receivers.

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 except that 3.2 km transect segments were used for the sample unit for Colville East calving surveys (Lawhead et al. 2013).

RADIO TELEMETRY

VHF Collars

Location data were provided by ADFG for all VHF collars in the CAH and TH during the years 1980–2005. Sample sizes varied between herds and among years (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 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 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 telemetry used the Argos system operated by CLS America, Inc. (CLS 2008), in which location data from satellite-collar transmitters were received by polar-orbiting satellites and transmitted through command and acquisition stations to data-processing centers, operated originally 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).

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–November 2012 (Prichard and Murphy 2004; Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 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, 148 collaring events of 130 different caribou collared with the TH (84 females, 46 males) transmitted signals for a mean duration of 573 days per caribou (16 of these caribou were outfitted with two or more different satellite collars). In the CAH, the 1986–1990 sample included 17 caribou (16 females, 1 male) and the 2001–2005 sample included 14 caribou collared with the CAH (11 females, 3 males), transmitting for a mean duration of 627 days.

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 Person et al. (2007), 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. Spurious locations were removed if they were far offshore or far outside the herd range. We applied a distance/rate/angle (DRA) filter, based on the distance and rate of travel between subsequent points and the angle formed by three consecutive points, to remove other inaccurate locations. 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 (Person et al. 2007). 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.

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 satellite-collar 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 71 different TH caribou (70 female and one male) were outfitted with GPS collars (purchased by BLM, NSB or CPAI and deployed by ADFG) during 2004 and 2006–2012. Some animals were collared more than once for a total of 122 different collaring events (Table 1). Ten females were collared in 2004, 12 were collared in 2006, 12 were collared in 2007, 27 were collared in 2008, 21 were collared in 2009, 14 were collared in 2010, 9 were collared in 2011, and 17 were deployed in 2012.

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 2006–2009 and on CAH animals in 2008–2010 were programmed to record fixes at 2-h intervals (12 locations daily) throughout the year. The duty cycle was reduced during the winter for GPS collars deployed in 2009 and 2010 to allow a 2-year deployment period, rather than single-year deployments used previously for this study. These collars still recorded locations on a 2-h interval during the summer, but were programmed to record just 3 locations per day in the winter (15 November–15 April). Additional details on collar deployment are given in Lawhead et al. (2012).

Table 1. Number of radio-collar deployments on caribou from the Teshekpuk and Central Arctic herds that provided movement data for the ASDP caribou study. Multiple collar deployments could have occurred on individual animals.

Teshekpuk Herd				
VHF collars [a]	1980–2005	n/a	n/a	212
Satellite collars	1990–2012	95	53	148
GPS collars [b]	2004–2012	121	1	122
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	11	4	15
GPS collars [c]	2003–2006	45	0	45
GPS collars	2008–2012	23	0	23

[a] n/a = not available, but most collared animals were females.
[b] Some individuals were recollared during period; totals do not include collars funded by ADFG, BLM, or NSB, or those not yet retrieved.
[c] Number of different collared caribou located within 48 km (30 mi) of CD4 at least once during the period.

A total of 19 different female CAH caribou were outfitted with GPS collars (purchased by CPAI) during 2008–2010. Four GPS collars were deployed on CAH females in July 2008, seven were deployed in June 2009 (one caribou died soon after capture and one transmitter failed), and 12 were deployed in June 2010. Some of the individual caribou had more than one GPS collar. An additional 45 GPS collars were deployed by ADFG CAH females during 2003–2006, using an interval of 5 h between location fixes (Arthur and Del Vecchio 2009).

GPS collars were all deployed on females, with the exception of one collar accidentally deployed on a TH male, because the models used (TGW-3680 GEN-III or TGW-4680 GEN-IV store-on-board configurations with Argos satellite uplink, manufactured by Telonics, Inc., Mesa, AZ) are 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.). Caribou were captured by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter. In keeping with ADFG procedures for the region, no immobilizing drugs were used.

Data reports from satellite uplinks were received by e-mail from CLS America, Inc. (Largo, MD). All location data were also 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.

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 respectively, were recorded at least once within the 48-km radius. Forty-five different individuals were located in the study area at least once 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 snow melt 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) starting in February 2000 (except for some brief outages due to satellite malfunction, the longest of which was 15 June–2 July 2001). 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)
- MOD35_L2 (MODIS/*Terra* L2 Cloud Mask and Spectral Test Results).

ATMOSPHERIC CORRECTION

The MODIS Corrected Reflectance (CREFL) Science Processing Algorithm (Version 1.7.1) was obtained from the Direct Readout Laboratory (DRL) at the Goddard Space Flight Center in Greenbelt, MD. The CREFL algorithm was used to calculate both top-of-atmosphere reflectance (an input for the snow-fraction algorithm) and atmospherically corrected reflectance (an input for the vegetation-index algorithm).

CREFL performs a simple atmospheric correction of visible, near-infrared, and short-wave infrared bands (MODIS bands 1–16), correcting for Rayleigh scattering and gaseous absorption by water vapor and ozone using climatological values. The CREFL "corrected reflectance" algorithm does not use real-time atmospheric inputs and does not correct for atmospheric aerosols. We are evaluating the DRL MODIS Land Surface Reflectance (MOD09) Science Processing Algorithm, which incorporates real-time climatological inputs, corrects for aerosol absorption, and clarifies (“destripes”) data from some noisy detectors. The MOD09 algorithm may provide better results for vegetation-index calculations, but implementation of MOD09 was not completed in time for use in this year’s analysis.

CLOUD MASKING

Clouds are common in the ASDP study area. Thick clouds prevent the observation of ground conditions by optical remote-sensing instruments such as MODIS. Thin clouds and cloud shadows may allow visual interpretation of the ground conditions, but can cause spectral algorithms to produce spurious results. Therefore, exclusion of areas obscured by clouds is a requirement for efficient analysis of satellite-derived time-series data. The standard (MOD35_L2) cloud mask product provides 1-km resolution, but frequently misidentifies areas with patchy snow and ice as cloud.

Hence, we investigated the cause of these errors in the standard cloud mask and determined that, in the presence of patchy snow, a conservative spectral test for snow presence caused the standard cloud-mask algorithm to take a processing path that assumed snow was absent. Then, a visible reflectance spectral test was applied and the presence of bright snow patches was interpreted as cloud. In contrast, the presence of complete snow cover caused the standard algorithm to take a processing path that did not use the visible reflectance spectral test.

We developed a modified cloud-mask algorithm to address this problem. The International MODIS/AIRS Processing Package (IMAPP) Direct Broadcast algorithm (IMAPP_SPA Version 2.1) was obtained from the DRL. The IMAPP algorithm includes the code for the MOD35 cloud-mask algorithm. We modified the code of the MOD35 cloud-mask algorithm to produce an alternative cloud mask that always used the processing path ("polar day snow") that assumed snow was present. Then, after snow fraction was calculated (as described below), we used information from the snow-fraction time-series to determine, on a pixel-by-pixel basis, whether the standard cloud-mask product or the modified “polar day snow” cloud-mask product should be applied.

GRIDDING

The MODIS data obtained for this study were raw data in swath format (i.e., as viewed by the satellite). The MODIS Reprojection Tool Swath (MRTSwath Version 2.2) was used to grid the swath data to the Alaska Albers coordinate system (WGS-84 horizontal datum). Systematic shifts in geolocation have been attributed to this tool (Macander 2005; Khlopenkov and Trishchenko 2008 [cited by Trishchenko et al. 2009]). We minimized these effects by resampling to 60-m resolution using nearest neighbor resampling, then aggregating to 240-m resolution by averaging. Top-of-atmosphere reflectance and corrected reflectance for MODIS bands 1–7 were gridded in this manner. The sensor view angle for each pixel was also gridded. The two cloud masks were gridded to 60-m resolution and were then aggregated to 960-m resolution, such that the occurrence of any portion of a cloud within a 960-m pixel resulted in the entire pixel being characterized as cloud. The edges of clouds are often difficult to detect by spectral means alone and the liberal aggregation of cloud-masked pixels helped to address this limitation.

SNOW COVER

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 gridded 240-m resolution top-of-atmosphere reflectance in MODIS Band 4 (0.545–0.565 µm) and Band 6 (1.628–1.652 µm), as follows:

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

The binary SnowMap algorithm (Hall et al. 1995) classifies pixels 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 snow melt, when snowdrifts and patchy snow conditions occur at finer scales than can be represented accurately by 240-m pixels. Salomonson and Appel (2004) compared binary snow maps from 30-m Landsat-7 imagery with MODIS NDSI and developed a simple linear function to calculate subpixel-scale snow fractions from the MODIS NDSI.

We calculated snow fractions for late winter and spring annually during 2000–2012 using the algorithm of Salomonson and Appel (2004). NDSI was calculated and then the subpixel-scale snow fraction was calculated as follows:

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

Values less than zero were set to zero, and values greater than one were set to one. The two additional tests from the SnowMap algorithm then were applied (i.e., MODIS Band-4 reflectance >0.10 and MODIS Band-2 reflectance >0.11). If a pixel failed either or both of these tests (i.e., it had very dark visible or near-infrared reflectance), then the snow fraction was set to zero. Dark pixels generally occurred over water, so, without the additional tests, snow and open water often would have been confused. Missing or otherwise bad data were flagged by the occurrence of digital-number values over 32,767 (per the L1B EV 500m File Specification–*Terra* [2005]) and any 240-m cells containing data flagged as unusable were masked.

The time-series of snow fraction then was used to determine the final cloud mask for each scene. For each year during 2000–2012, the starting condition for each pixel was assumed to be snow-covered. The scenes then were processed sequentially, with each pixel assumed to be snow-covered until a cloud-free observation with a snow fraction of zero was encountered. If any pixel with a snow fraction greater than zero occurred within 960 m, the "polar day snow" cloud mask was used to determine the cloud state. Otherwise, the standard MODIS cloud mask was used.

A time-series of images covering March–October 2000–2012 was processed in this manner and a composite was compiled to identify the first date with 50% or lower snow cover for each pixel in each year. Then, the closest prior date with >50% snow cover was identified for each pixel. An unbiased estimate of the snow-melt date (the first date with <50% snow cover) was calculated as the midpoint between the last observed date with >50% snow cover and the first observed date with <50% snow cover. The duration between the dates of the two satellite images with the last observed "snow" date and the first observed "melted" date provided information on the uncertainty in the estimate of snow-melt date. For example, if snow was present in a pixel on 20 May, followed by several weeks with persistent cloud cover, followed by an observation that snow was absent on 17 June, the estimated snow-melt date was 3 June and the uncertainty in the snow-melt date estimate was 28 days. 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 occurring during that time interval (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis.gsfc.nasa.gov/about/specs.html):

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

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).

Occasionally, spurious high values of NDVI were observed in deep cloud shadows over vegetated land surfaces; therefore, NDVI was set to zero for very dark pixels (MODIS Band-1 reflectance <0.025). Such dark pixels occurred only in shadows and clear water. NDVI values for each year during 2000–2012 were calculated using constrained view-angle (sensor zenith angle ≤40°) maximum-value composites derived from corrected reflectance MODIS imagery acquired from the calving period (1–10 June; NDVI_Calving), at the presumed peak of lactation for parturient females (21 June; NDVI_621; Griffith et al. 2002), and at the peak of the growing season (generally late July or early August; NDVI_Peak). For each composite period, the maximum NDVI with no clouds and a sensor view-angle of 40 degrees or lower was selected.

NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) each year for 2000–2012 (there were not adequate cloud-free data to calculate NDVI_Calving over the entire study area in some years, including 2012). NDVI values near peak lactation (NDVI_621) were interpolated based on the linear change from two composite periods (15–21 June and 22–28 June) in each year except 2001, when the MODIS instrument malfunctioned and did not collect data during 15 June–2 July. If the maximum NDVI in the period 15–21 June occurred on 21 June, then no interpolation was performed for that pixel. Finally, NDVI_Peak was calculated from all imagery obtained between 21 June and 31 August for each year during 2000–2012.

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. We identified water-covered pixels in three Landsat images from 2008: one Landsat-5 Thematic Mapper (TM) image from 23 June 2008 and two Landsat-7 Enhanced Thematic Mapper+ (ETM+) images from 29 June 2008 and 16 August 2008. We used a model based on a random selection of 10,000 30-m pixels from locations that were known to be water-covered and 10,000 locations that were known to be vegetated, based on detailed vector mapping of landcover in a portion of the Kuparuk area using aerial photography of 1:12,000 scale or larger (Anderson et al. 1998, 2001; Jorgenson et al. 1997, 2003, 2004; Roth et al. 2007). A classification-tree analysis was used to find the best combination of spectral indices for each Landsat image to identify water-covered pixels.

The Landsat water maps were merged together, with the 23 June 2008 map taking precedence and the 29 June 2008 map used for areas not covered by the 23 June 2008 map. Remaining gaps were filled using the 16 August 2008 map. The number of 30-m water cells derived from the Landsat water map was tabulated in each 240-m cell, and cells with >50% water cover were eliminated from further NDVI calculations.

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 alignment, extending west from the Colville River delta into NPRA, to characterize the preconstruction baseline level of use of the area by caribou.

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

GEOGRAPHIC LOCATION

Visual inspection of caribou distribution during aerial surveys in previous years suggested differing levels of caribou use across the NPRA survey area, so we tested for distributional differences among geographic sections of the area. We divided the 2002–2004 and 2005–2012 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); 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 2005–2012 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 lumped further 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. Caribou groups located in water bodies were moved to the

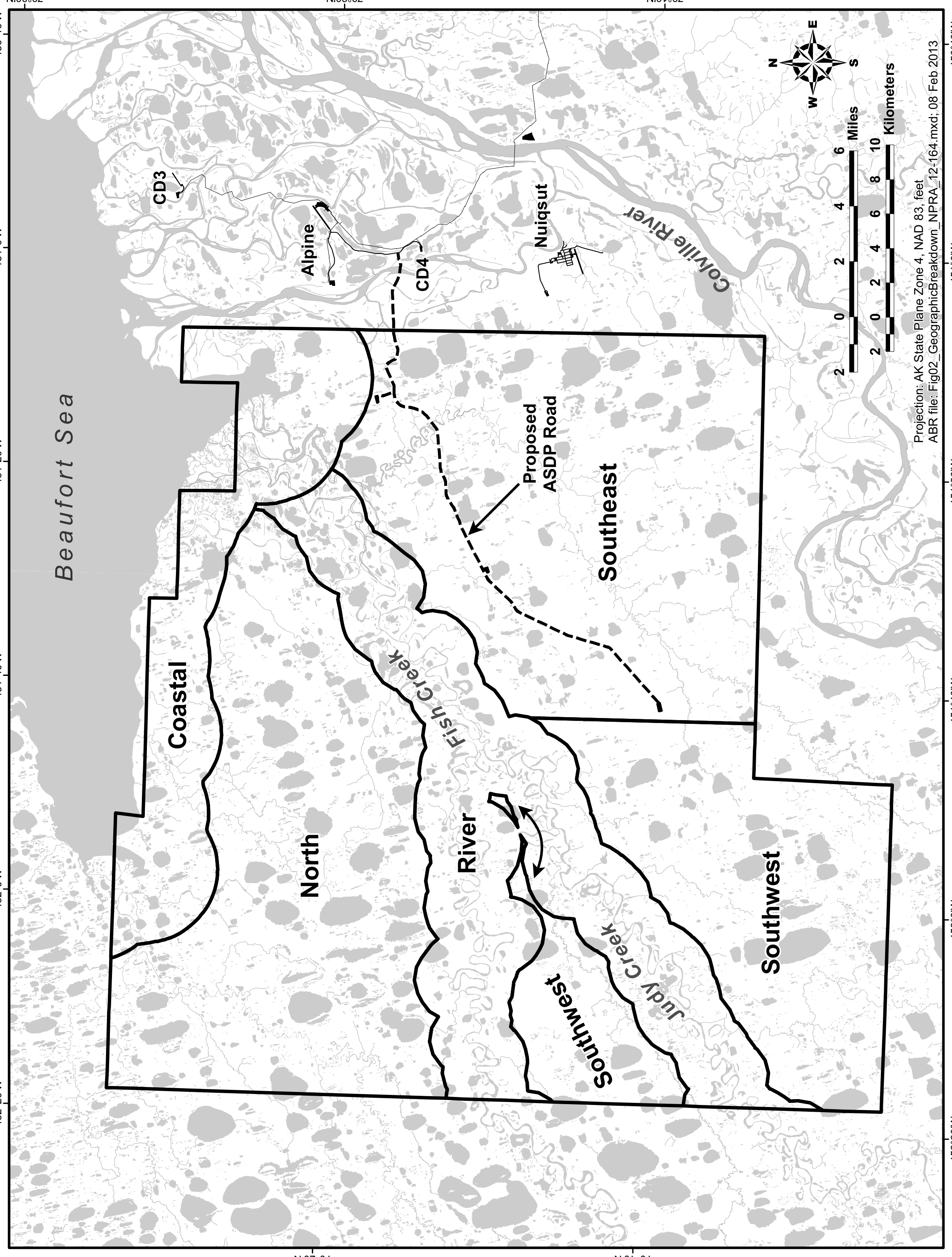

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2012.

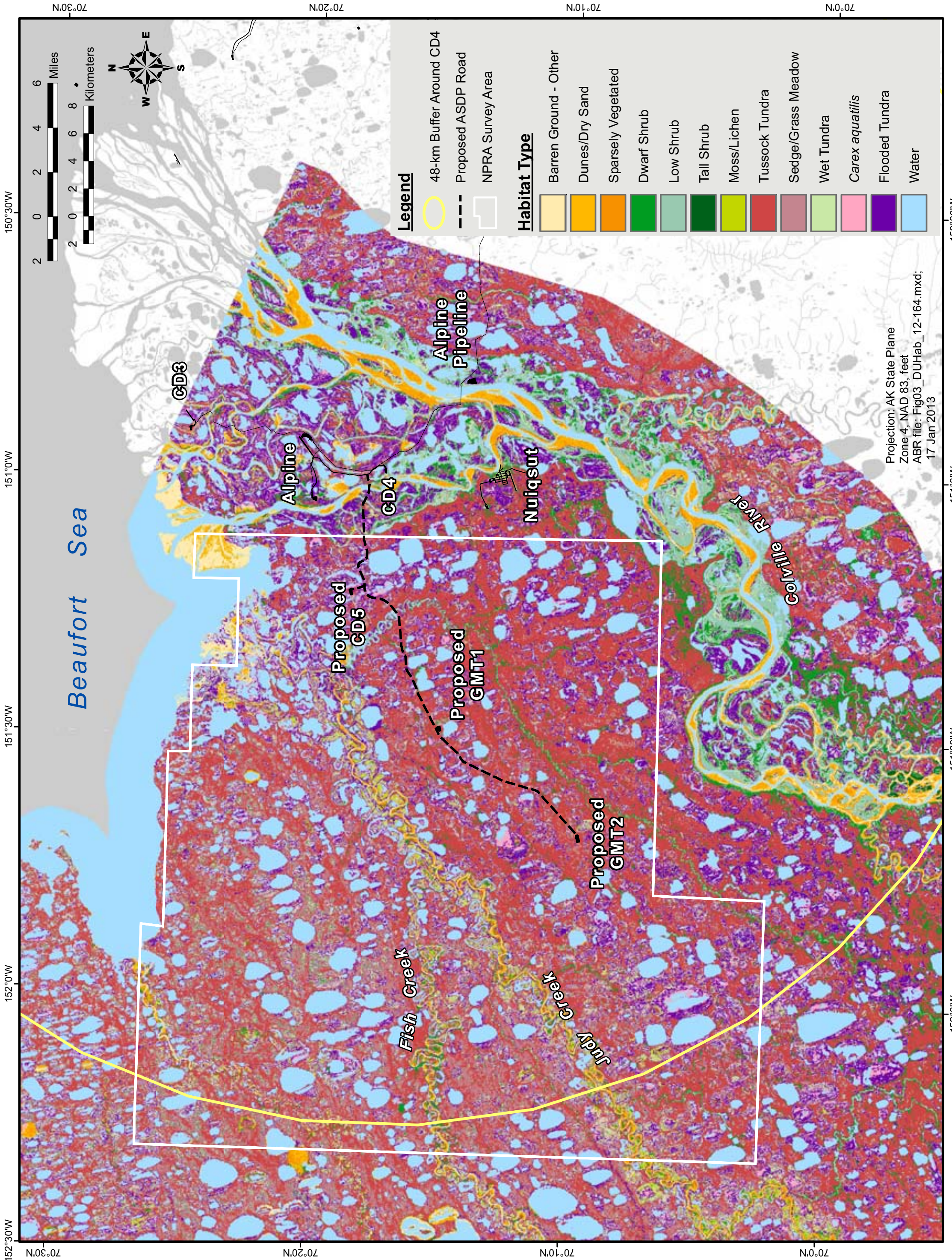

Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2012.

nearest shoreline. 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 2005–2012 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 totals of 25,339 random locations in the 2005–20012 survey area (12,475 in the winter 2008 survey area because it could not be surveyed completely) and 19,470 locations in the 2002–2004 survey area. For each 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

Snow cover at the beginning of the calving season was estimated from two MODIS scenes, acquired on 30 May 2012 and 1 June 2012. The 1 June 2012 data were used to estimate snow cover except that when cloud cover was present on the 1 June image, data from 30 May 2012 was used (there was also data available from 31 May 2012 but it did not add much new cloud-free coverage within the survey areas). The value of snow cover (%) for 1 June 2012 was estimated for each caribou group location (excluding caribou groups located in pixels with >50% water). The estimated snow-cover percentages for 1 June at caribou group locations were compared to all locations available within the study area using the statistical technique of bootstrapping (Manly 1997). The bootstrap was conducted by selecting random samples from all pixels used by caribou group for a given season and comparing the resulting means to the overall snow cover available in the study area. For each simulation we selected (randomly and with replacement) a number of pixels with caribou present equal to the number of caribou groups observed. The mean snow cover of the new data set was calculated and recorded and a new sample was generated in the same manner. This process was repeated 20,000 times to generate values of mean snow cover. These 20,000 mean values were compared with the availability of snow-cover values in the entire 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 2012 with estimated vegetative biomass (NDVI values). Two of the variables (NDVI_Calving and NDVI_Rate) could not be estimated for large portions of the study area in 2012 due to extensive and persistent cloud cover during 1–10 June 2012. The values of the variables NDVI_Calving, NDVI_Rate, NDVI_621, and NDVI_Peak were determined for each caribou group location (excluding pixels with >50% water and missing values) and those values were compared with availability using estimates of variability derived from bootstrapping (Manly 1997). For each season, we selected (randomly and with replacement) a number of samples of NDVI values from all pixels within the study area equal to the number of caribou groups observed in a given season, from all pixels used by caribou during that season. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 20,000 times to generate mean values. The resulting 20,000 mean values were compared with the availability of NDVI values in the survey area. If the mean NDVI value of all pixels within the survey area was more extreme than 95% or 99% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ or $P = 0.01$, respectively.

DISTANCE TO PROPOSED ROAD

The group locations from aerial transect surveys in the NPRA survey area constitute the baseline data set on caribou density for the area in which the proposed ASDP road may be constructed. Thus, these data are the primary source of information regarding caribou distribution in relation to natural factors in the road corridor. The most recent version of the alignment of the proposed ASDP road was provided to ABR Inc. in 2009 (Lawhead et al. 2010), so recent analyses differ somewhat from those reported prior to 2009.

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), employing 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. This offset term adjusts for differences in area among zones. The natural-log transformation of area was used 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 and to test 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 because of the low numbers of caribou observed in that season. No aerial surveys have been flown in the mosquito season since 2007 because of the inefficiency of that survey method when large numbers of caribou aggregate and move rapidly in response to varying weather conditions and insect activity levels.

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 2005–2012 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 2012, 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 1 June 2012, 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 is highly correlated across years so we used the value of NDVI_Peak from 2012 in multi-year analyses. NDVI_621 from 2012 was used only for analysis of 2012 calving density. We tested various models for calving density in 2012 and the density in each season for the combined years 2002–2012. Data from 2001 were not included in this analysis

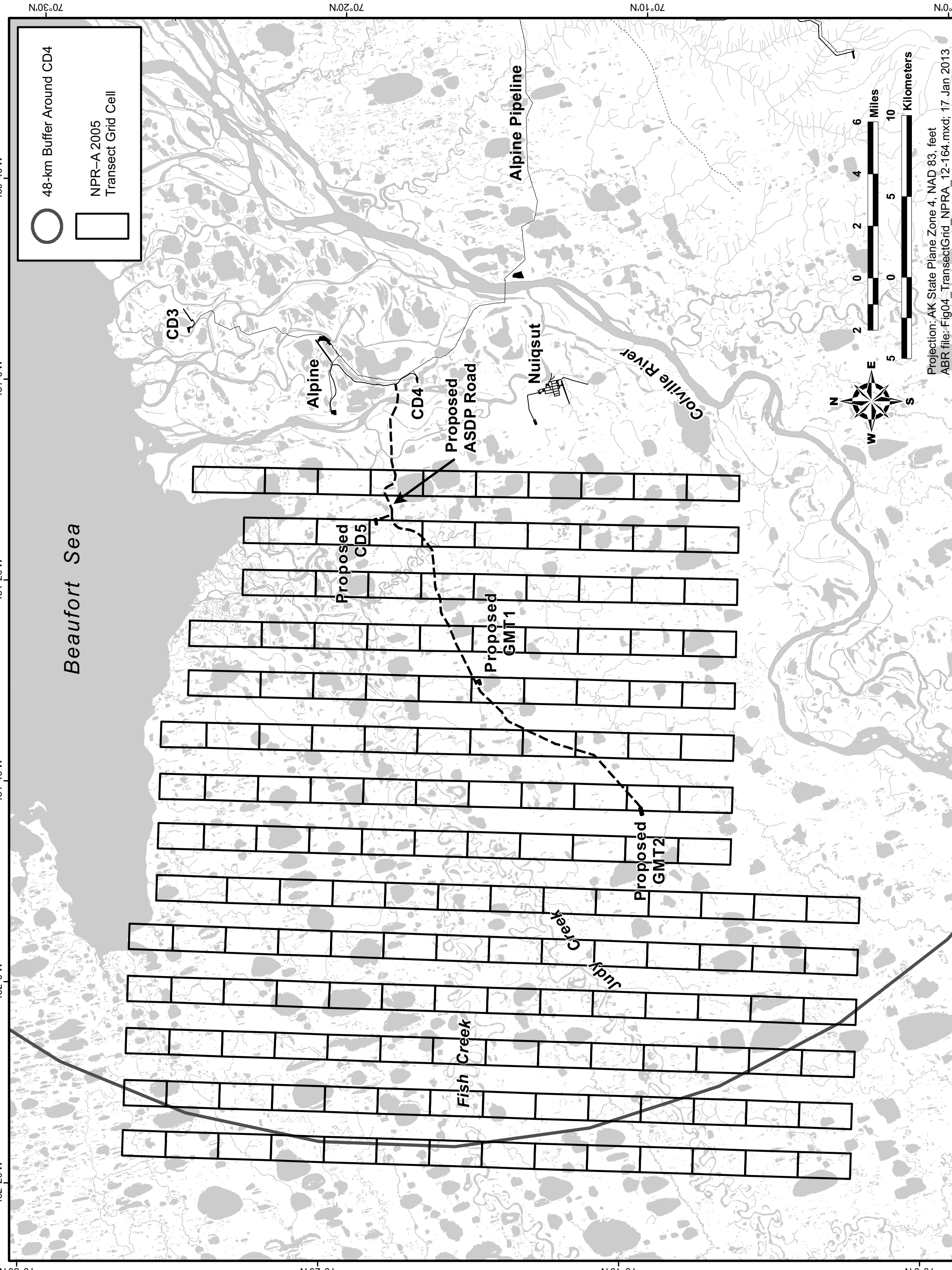

Figure 4. Locations of transect grid-cells (n = 164) used to analyze caribou density in the NPRA survey area, 2005–2012.

because the NPRA survey area that year was smaller than in subsequent years. A 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 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_621, 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. In 2012, we used a Maximum Likelihood Estimate of the negative binomial ancillary parameter and used the mean estimate in all models to facilitate model selection.

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 (Burnham and Anderson 2002).

The presence of Fish and Judy creeks and the presence of the proposed road was included in all 20 candidate models for calving density in NPRA in 2012, but the different models had various combinations of NDVI_Peak, NDVI_621, snow cover on 30 May–1 June 2012, transect number (west–east gradient), proportion of tussock tundra, and proportion of wet habitats. Independent variables with Pearson correlation coefficients >0.5 were not included in the same model. One grid cell located on the outer Colville River delta was removed because it was mostly barren ground and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

Sixteen candidate models were used for seasonal tests over all years (2002–2012) 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. All models contained survey ID (categorical variable accounting for different survey densities), presence or absence of Fish or Judy creeks, and the presence or absence of the proposed road corridor. They also contained all combinations of the variables distance to coast, NDVI_Peak, proportion of tussock tundra, the proportion of wet habitat, and transect number (west-to-east gradient). Surveys on which fewer than 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 (one in 2002 and one in 2009) were dropped for that season 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 and the road variable was dropped from the oestrid fly season analysis because the standard errors of some parameters could not be accurately estimated with road in the model.

We used a similar analysis to model factors related to the calving distribution of CAH caribou in Colville East during the aerial survey on 10–11 June 2012. We divided the survey transects into 552 1.6-km-long segments (three other segments were completely covered by water, so were eliminated from the analysis). For each segment, we calculated the total number of caribou observed, the proportion of area covered by waterbodies, the minimum distance to the coast, the presence of an existing road within 2 km, mean NDVI_Peak in 2012, the proportion of wet graminoid tundra (Muller et al. 1999) in the area, and snow cover on 1 June 2012. The same GEE analysis used for the NPRA calving density analysis was used for the Colville East calving density, producing 31 candidate models containing all possible combinations of five variables (within 2 km of roads, NDVI_Peak, distance to coast, snow cover, and proportion of wet graminoid tundra). The proportion of the grid cells covered by waterbodies and transect number (west-to-east gradient) were included in all models. The waterbody variable was included to adjust for large differences in the amount of land area among transect segments and the transect number was included to account for the expected gradient in calving density across the study area (Lawhead and Prichard 2013). Candidate models were compared and model-averaged parameter estimates were calculated in the same manner as for the NPRA surveys.

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, early in 2002, about average in 2003–2008, early in 2009, and late in 2010–2012 (Lawhead and Prichard 2012). Snow depth was at the deepest level recorded in early May 2012 but melted rapidly at the Kuparuk airstrip after 16 May (Appendix B). Patchy snow cover remained over large parts of the study area, however, and temperatures largely remained around freezing during early June. Snow cover was therefore still patchy in some regions of the Colville East calving surveys conducted on 10–11 June 2012 (Lawhead et al. 2013) lowering the sightability of caribou. The complex visual background created by patchy snow cover required adjustment of the counts for low detectability by applying a sightability correction factor (SCF) for large caribou in areas with patchy snow cover (Lawhead et al. 1994). Snow was essentially gone from all survey areas by the time of the postcalving survey on 21–22 June 2012. The little snow remaining at that time was in linear remnants of drifts along upland drainages and lake edges.

Information on summer weather was compiled for reference in interpreting insect-season conditions and the likely severity of insect harassment between late June and mid-August. Weather data were not recorded at the Kuparuk airstrip during 7 June 2011–9 December 2011 (the initial phase of a project to pave the runway) and during 4–14 August and 30–31 August 2012. To estimate summer weather conditions in the GKA when weather data were not recorded at the Kuparuk airstrip, we acquired daily temperature data from the National Weather Service for the weather stations at Nuiqsut and Deadhorse. Comparisons of temperature data from previous years indicated that Deadhorse summer temperatures tended to be lower than Kuparuk temperatures and Nuiqsut summer temperatures tended to be higher than Kuparuk temperatures. Therefore, we used the average of the Nuiqsut and Deadhorse temperatures as an estimate of Kuparuk summer temperatures. The average difference from daily mean Kuparuk temperatures in July 2004–2010 was –0.48 °C for Deadhorse temperatures, 1.13 °C for Nuiqsut temperatures, and 0.26 °C for the average of Deadhorse and Nuiqsut temperatures.

The occurrence of air temperatures conducive to insect activity (as indicated by thawing degree-days [TDD] sums) was below average in early June, but late June, July and early August were all warmer than average (Appendix B). 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, and thus the expected levels of insect harassment of caribou, based on daily maximum temperatures (but ignoring wind speed; Russell et al. 1993) at Nuiqsut and Deadhorse were below average in early June and above average the rest of the summer (Lawhead et al. 2013).

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 (Murphy and Lawhead 2000, Yokel et al. 2009, Wilson et al. 2012).

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

Six surveys of the NPRA survey area were flown between 26 April and 5 October 2012 (Table 2, Figure 5). The early calving, early-August, mid-September, and late October surveys could not be flown due to persistent poor weather. Caribou density in the NPRA survey area was low in the spring, increased to moderately high densities during calving, was high in late June, and decreased to low densities in late August. In October, densities were moderate. The estimated density of caribou ranged from a high of 0.99 caribou/km² on 21 June to a low of 0.02 caribou/km² on 18 August (Table 2). The density of caribou during calving (0.43 caribou/km² on 10–11 June) was in the middle of the range of densities observed during 2001–2011 (0.06–0.87 caribou/km² for 6–9 June).

Only seventy-three calves (19.8% of the total number of caribou) were observed during the survey. 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 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012; Lawhead et al. 2013). This conclusion is supported by analyses of telemetry data (Carroll et al. 2005, Person et al. 2007, Parrett 2011), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area.

Since 2010, the TH has had an expanded calving distribution with some calving occurring to the west between Atqasuk and the Itkillik River and some females calving east of the Colville River with the CAH (Parrett 2011, Parrett ADFG, pers. comm.). There has also been considerable emigration from the TH. Since 2004, from 4–24% of collared TH caribou have been with other herds during the calving period and since 2008, many of the females calving with other herds have stayed with that herd during the summer (Parrett 2011). A few collared CAH caribou have calved west of the Colville River in isolated years (notably 2001), it is a rare occurrence (Arthur and Del Vecchio 2009, Lenart 2009).

Some fairly large groups of caribou (up to 525) were in the northern Colville East survey area during the late June surveys when caribou moved towards in the coast in response to warm weather and calm conditions conducive to mosquito harassment (Figure 5). No surveys were conducted in July; telemetry data provide better information on movements during the insect season (see Radio Telemetry section below). Since 2001, the only transect survey on which we found large groups of mosquito-harassed caribou in the NPRA survey area was in August 2005 (Lawhead et al. 2006).

Caribou densities observed on the NPRA transects were relatively low during most surveys in 2012, with the exception of late June (Table 2). Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (Figure 6). Only two surveys were conducted in September or October 2009–2012 due to poor weather conditions. 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; Burgess et al. 2002, Johnson et al. 2004, Lawhead et al. 2010).

Colville River Delta Survey Area

Five surveys of the Colville River Delta survey area were flown between 11 May and 5 October 2012 (Table 2, Figure 5). Similar to most previous years, the estimated density of caribou was low on most surveys (0–0.02 caribou/km²),

Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–October 2012.

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 26–27	1,720	56	0	56	112	21.5	0.07	2.8
May 10–11	1,720	82	0	82	164	29.9	0.10	3.6
June 10–11	1,720	296	73	369	738	89.9	0.43	4.0
June 21	1,720	800	54	854	1,708	276.3	0.99	7.8
August 18	1,720	20	nr	20	40	8.2	0.02	1.2
October 4–5	1,720	229	nr	229	458	81.1	0.27	6.2
COLVILLE RIVER DELTA								
May 11	494	0	0	0	0	–	0	–
June 11	494	3	2	5	10	5.7	0.02	2.5
June 21	494	194	25	219	438	234.6	0.89	24.3
August 18	494	0	0	0	0	–	0	–
October 5	494	0	0	0	0	–	0	–
COLVILLE EAST								
May 11–12	1,696	25	0	25	50	18.9	0.03	3.1
June 9–10[g,h]	1,432	725	289	1,014	2,403	324.7	1.68	4.0
June 22	1,696	1,757	616	2,373	4,746	1,076.4	2.80	44.8
August 18–19	1,696	8	nr	8	16	5.9	0.01	1.3
October 4–5	1,696	56	nr	56	112	26.6	0.07	3.1

[a] Survey coverage was 50% of this area (860 km² in NPRA, 247 km² on the Colville River 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 (Lawhead et al. 1994) to some segments due to areas of patchy snow cover during survey.
[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 2012).

however, the density in the area was moderately high on 21 June (0.89 caribou/km²), when insect harassment was likely high. Several large groups were observed during this survey including a group of 170 caribou on transect and groups of 400 and 250 caribou off transect.

Use of the Colville delta by large numbers of caribou is uncommon. Large numbers have been recorded occasionally during past summers (e.g., 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).

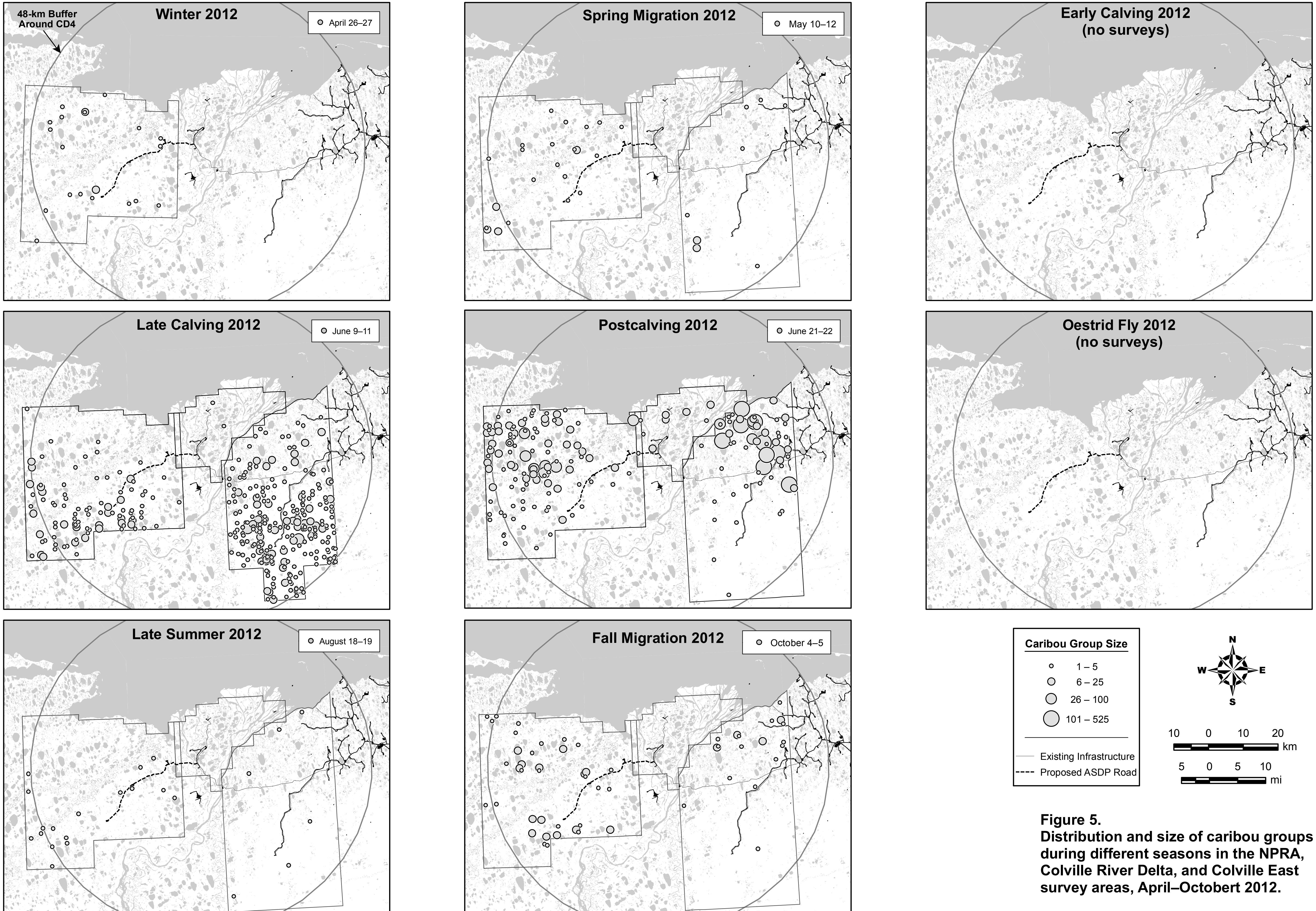

Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–Octobert 2012.

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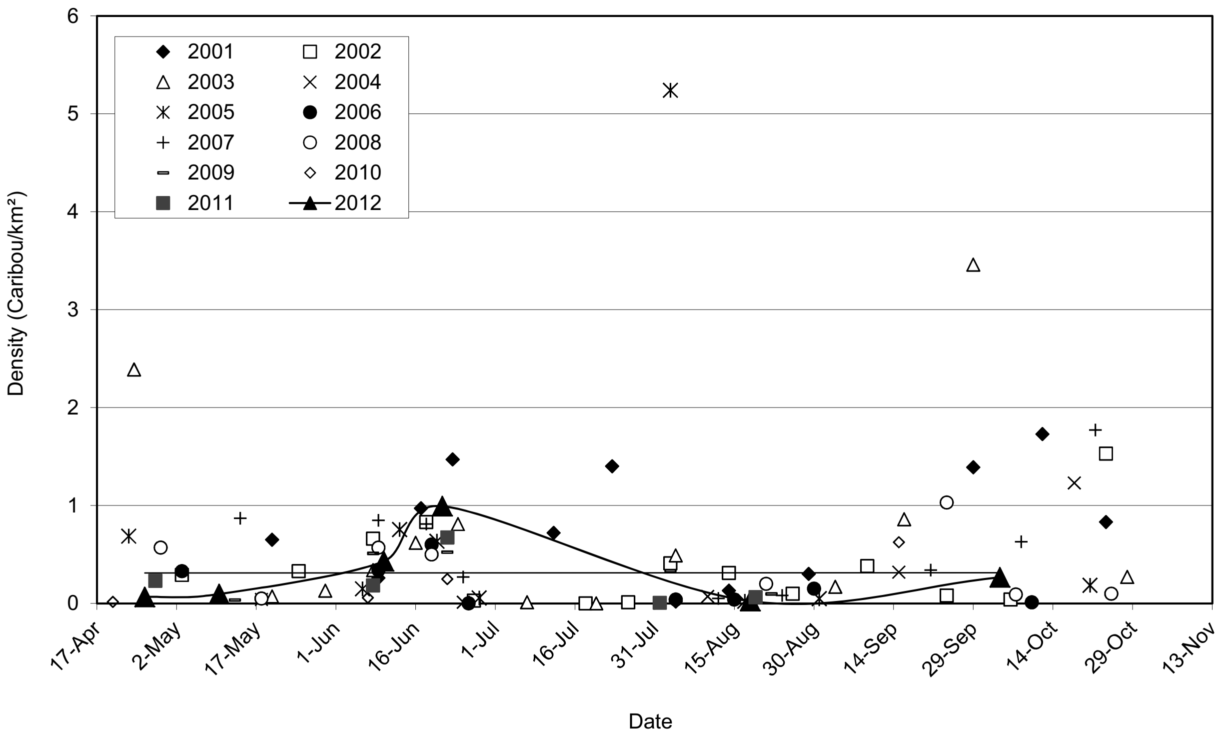


Figure 6. Caribou density observed on 100 surveys of the NPRA survey area, April–October 2001–2012 (line connects 2012 survey values).

Two large groups of caribou (>1,000 each) were recorded on time-lapse cameras on the Colville delta in July 2010 (Lawhead et al. 2011).

The highest number of caribou recorded on transect surveys during 2001–2012 (Table 2) was recorded on 2 August 2005, when 994 caribou were found on the Colville delta (2.01 caribou/km²; Lawhead et al. 2006). Thus, it is important to have telemetry data available as well for describing caribou distribution and movements during the insect season.

Colville East Survey Area

Five surveys of the Colville East survey area were flown between 11 May and 5 October 2012 (Figure 5). The estimated density of caribou on complete surveys ranged from 2.80 caribou/km² on 22 June to a low of 0.01 caribou/km² 18–19 August April (Table 2). The highest densities among all three ASDP survey areas in 2012 were recorded in Colville East during calving and postcalving (1.68–2.80 caribou/km²), which is typical for that part of the ASDP study area. During the late calving survey (mid-June) in 2012, caribou were concentrated in the southern portion of the Colville East survey area, similar to the distribution in 2010–2011, but farther west than in previous years. Caribou density was much greater in the Colville East survey area than in the adjacent Kuparuk South and Kuparuk Field survey areas to the east (Lawhead and Prichard 2012).

The Colville East survey area typically hosts high densities of caribou during postcalving as CAH caribou move northward in advance of emerging mosquitoes (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007, 2008, 2009, 2010, 2011, 2012). 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 caribou moving into the ANWR and some even crossing the Alaska–Yukon border.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area in 2012, although groups totaling 3–21 muskoxen were seen repeatedly east of the Colville River delta between 27 April and 4 October. One group of muskoxen reportedly moved west from the Colville River delta into NPRA west of our survey area during the summer (J. Hamilton, Arctic Air Alaska, personal communication). As in previous years, most of the muskoxen seen in the region were on the Colville River delta, along the Kuparuk River, or along the coast near Beechey Point (Appendix C; Lawhead et al. 2013). 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, we observed muskoxen during 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, 2010, 2011, 2012, Lawhead et al. 2013) 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 from 26 April–4 October, including four sightings on 10 May and two sightings on 19 June (Appendix C; Lawhead et al. 2013). Three observations were of a female with two cubs and the other sightings were of single adults. One sighting of an adult bear with two cubs was recorded on the Colville River delta (Appendix C; Lawhead et al. 2013). There were also multiple sightings of bears in the Itkillik Hills, near the Meltwater Pad (DS–2P), and in the CPF–3/DS–3P area. The number of repeated observations of the same individuals among surveys was unknown, however.

One adult wolverine was observed on the Fish Creek delta on 16 June, 2012. Also, one adult polar bear with a cub was observed on a barrier island in the Beechy Point region on 16 August, 2012. No observations of moose or wolves were recorded in the ASDP study area on our surveys in 2012.

RADIO TELEMETRY

Mapping of the telemetry data from VHF, satellite, and GPS collars clearly shows that the ASDP study area is located at the interface of the annual ranges of the TH and CAH (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. No new VHF data were available for the 2012 season; VHF collar locations from previous years were discussed by Lawhead et al. (2006).

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 7% to 37% 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–October (15–37%) and the lowest percentages (7–14%) occurred in November–June (Table 3, Figure 8). The monthly percentages varied substantially within and among years, largely due to small samples of collared animals in most years.

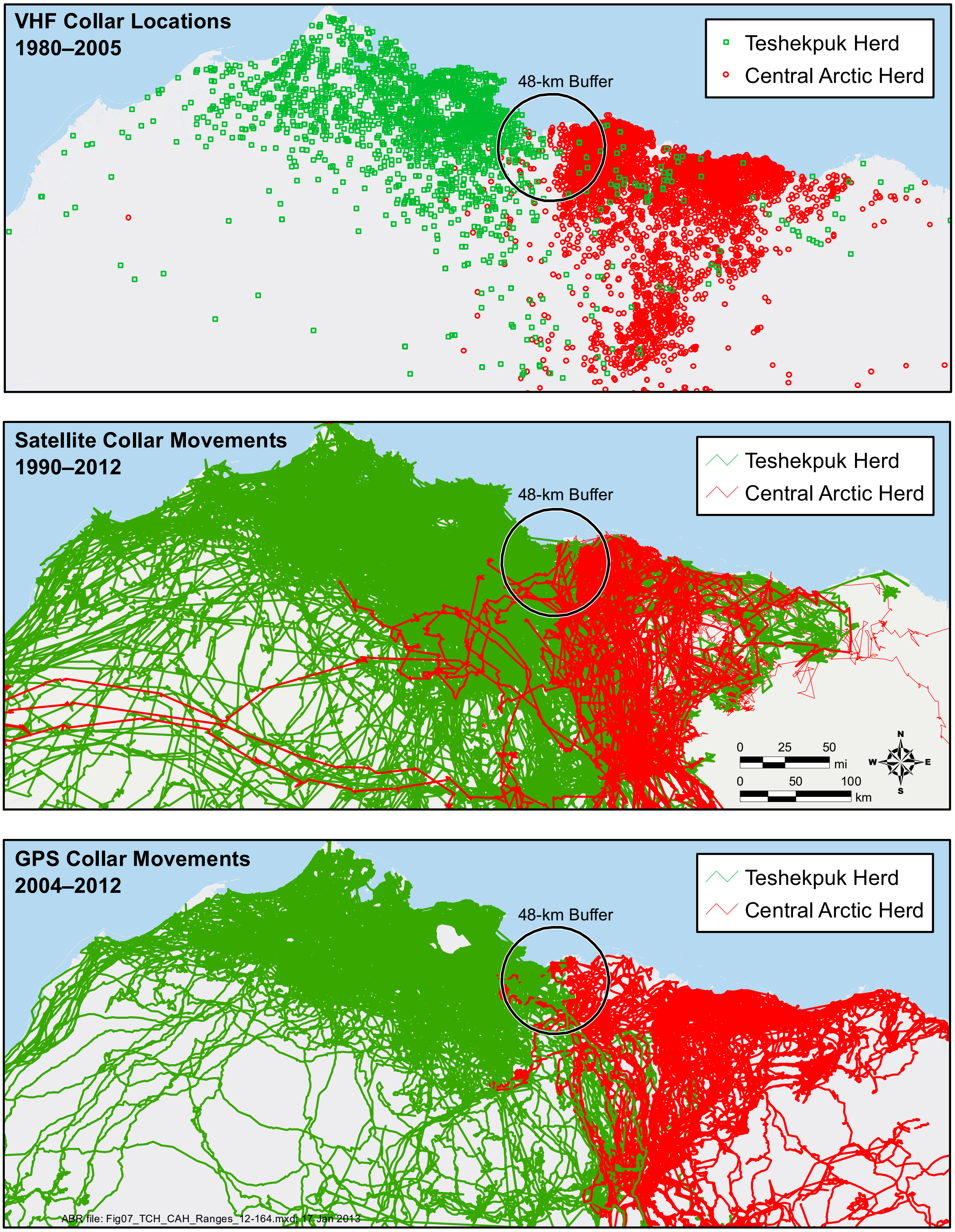


Figure 7. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2012.

Table 3. Percentage of satellite-collared caribou samples (n) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were located 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)	20 (5)	0 (4)	0 (4)
	1994	0 (4)	0 (4)	0 (4)	0 (3)	0 (3)	0 (3)	0 (3)	33 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	1995	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	11 (9)	33 (9)	22 (9)	22 (9)	11 (9)	11 (9)
	1996	11 (9)	11 (9)	11 (9)	11 (9)	13 (8)	0 (8)	13 (8)	0 (8)	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)	20 (5)	0 (2)	9 (11)	0 (10)	9 (11)	9 (11)	10 (10)
	2002	10 (10)	10 (10)	10 (10)	10 (10)	17 (12)	8 (12)	10 (10)	10 (10)	11 (18)	11 (18)	7 (15)	0 (13)
	2003	7 (14)	15 (13)	33 (12)	17 (12)	14 (14)	7 (14)	0 (28)	27 (26)	23 (26)	28 (25)	8 (25)	4 (24)
	2004	4 (23)	5 (19)	5 (21)	5 (20)	14 (22)	5 (22)	0 (19)	6 (17)	13 (16)	50 (14)	36 (14)	33 (12)
	2005	33 (9)	20 (10)	22 (9)	20 (10)	30 (10)	0 (10)	32 (28)	59 (27)	27 (26)	35 (23)	22 (23)	17 (23)
	2006	17 (23)	18 (22)	14 (22)	9 (23)	27 (22)	14 (21)	58 (36)	6 (34)	13 (32)	34 (29)	0 (27)	0 (26)
	2007	4 (25)	8 (25)	8 (24)	0 (24)	4 (24)	17 (23)	60 (20)	58 (19)	28 (18)	56 (18)	29 (17)	29 (17)
	2008	31 (16)	20 (15)	20 (15)	13 (15)	17 (12)	15 (13)	13 (8)	13 (8)	0 (8)	0 (8)	0 (8)	0 (8)
	2009	0 (8)	0 (6)	0 (8)	0 (8)	0 (8)	13 (8)	86 (14)	21 (14)	8 (12)	0 (11)	0 (10)	0 (9)
	2010	0 (9)	0 (8)	0 (9)	0 (9)	0 (9)	20 (10)	92 (13)	8 (12)	8 (12)	0 (12)	0 (6)	0(6)
	2011	0 (6)	0 (6)	0 (6)	0 (7)	0 (6)	27 (11)	75 (12)	0 (12)	8 (12)	8 (12)	0 (7)	0 (9)
	2012	0 (8)	0 (8)	0 (9)	0 (8)	22 (9)	56 (9)	50 (14)	7 (14)	7 (14)	0 (14)	0 (10)	
	Total	11 (197)	9 (179)	10 (181)	7 (182)	13 (183)	14 (188)	37 (259)	22 (249)	15 (252)	22 (244)	12 (219)	10 (202)
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	–	–	–	–	–	–	–	30 (10)	44 (9)	0 (11)	0 (11)	0 (11)
	2002	0 (11)	0 (10)	0 (10)	0 (10)	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	19 (54)	16 (51)	21 (47)	20 (46)	38 (47)	64 (45)	51 (45)	27 (52)	26 (46)	12 (58)	12 (60)	14 (58)

Table 4. Percentage of GPS-collared caribou samples (n) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were located within 48 km of CD4 at least once in each month. Only data downloaded from retrieved collars are included (i.e., currently deployed collars are excluded).

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)	33 (9)	33 (9)	11 (9)	32 (28)	7 (28)	7 (28)	4 (28)	0 (28)	0 (27)
	2009	0 (27)	0 (25)	0 (24)	0 (21)	5 (21)	14 (21)	38 (21)	38 (21)	19 (21)	0 (20)	0 (20)	0 (20)
	2010	0 (20)	0 (19)	0 (19)	0 (19)	0 (19)	0 (17)	75 (16)	13 (16)	7 (15)	7 (14)	0 (13)	0 (13)
	2011	0 (13)	0 (11)	0 (10)	0 (8)	13 (8)	14 (7)	50 (4)	0 (4)	0 (3)	67 (3)	0 (3)	0 (3)
	2012	0 (3)	0 (1)	0 (1)	0 (1)				–	–	–	–	–
	Total	3 (95)	2 (88)	2 (86)	4 (79)	12 (78)	15 (74)	43 (102)	23 (102)	12 (100)	23 (98)	6 (97)	5 (95)
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)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)
	2010	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	6 (16)	31 (16)	7 (15)	7 (15)	0 (14)	0 (14)	0 (14)
	2011	0 (14)	0 (14)	0 (14)	0 (14)	21 (14)	21 (14)	30 (10)	20 (10)	10 (10)	10 (10)	0 (10)	0 (10)
	2012	0 (10)	0 (10)	0 (10)	0 (10)	–	–	–	–	–	–	–	–
	Total	0 (118)	0 (118)	0 (118)	1 (142)	33 (132)	44 (144)	28 (144)	12 (143)	24 (143)	7 (142)	0 (80)	0 (80)

In 2012, 7 of the 14 transmitting TH satellite collars were present in the ASDP study area in July. Over 50% of satellite-collared animals were in the ASDP study area during July in 7 of the last 8 years (Table 3).

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 caribou (Figure 8). 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 (12–19%) (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, from 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, with lower numbers being taken in June and September–October, and the smallest harvests occurring in the other months (Pedersen 1995, Brower and Opie 1997, Fuller and George 1997, SRBA 2010). Lower harvests in September may result from participation by many hunters in fall whaling, but the percentage of caribou in the study area also appears to be lower in that month. 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 primarily were from the CAH in most years, although large groups of TH occasionally occur on the delta in the summer. In contrast, caribou harvested in the study area in October are much more likely to be TH animals migrating to winter range. An exception to this general pattern occurred in summer 2007 when TH caribou used the delta more during the insect season than did CAH caribou (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. Some large movements of moderate numbers of CAH caribou onto the Colville delta have occurred in July of the last 2 years.

GPS Collars

The percentages of the GPS-collared sample from the TH (with at least 10 days of locations) that were present at least once each month in the ASDP study area during 2004–2012 were similar to those of satellite-collared caribou. Only 2–6% of GPS-collared TH caribou were in the study area in winter (November–April; Table 4, Figure 9). The monthly percentages increased to 12–43% during May–August, declined to 12% in September, and rose again to 23% 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 2008–2012 varied between 0 and 1% during the months of November–April (Table 4, Figure 9). The monthly percentage increased to 33% in May, peaked at 44% in June due to heavy use of the Colville East area during calving, and decreased to 7–28% in July–October.

The detailed movement tracks of 10 CAH caribou outfitted with GPS collars purchased by CPAI for the ASDP study in 2010 were examined in relation to the ASDP study area from June 2010 through April 2012 (Figures 10–11). Also, previous movements from 4 TH and 4 CAH caribou outfitted with GPS collars purchased by CPAI from June 2009–June 2011 were examined in relation to the ASDP study area (Appendices D and E). The seasonal movement patterns of the TH and CAH caribou were generally similar to the previous movement patterns of the caribou

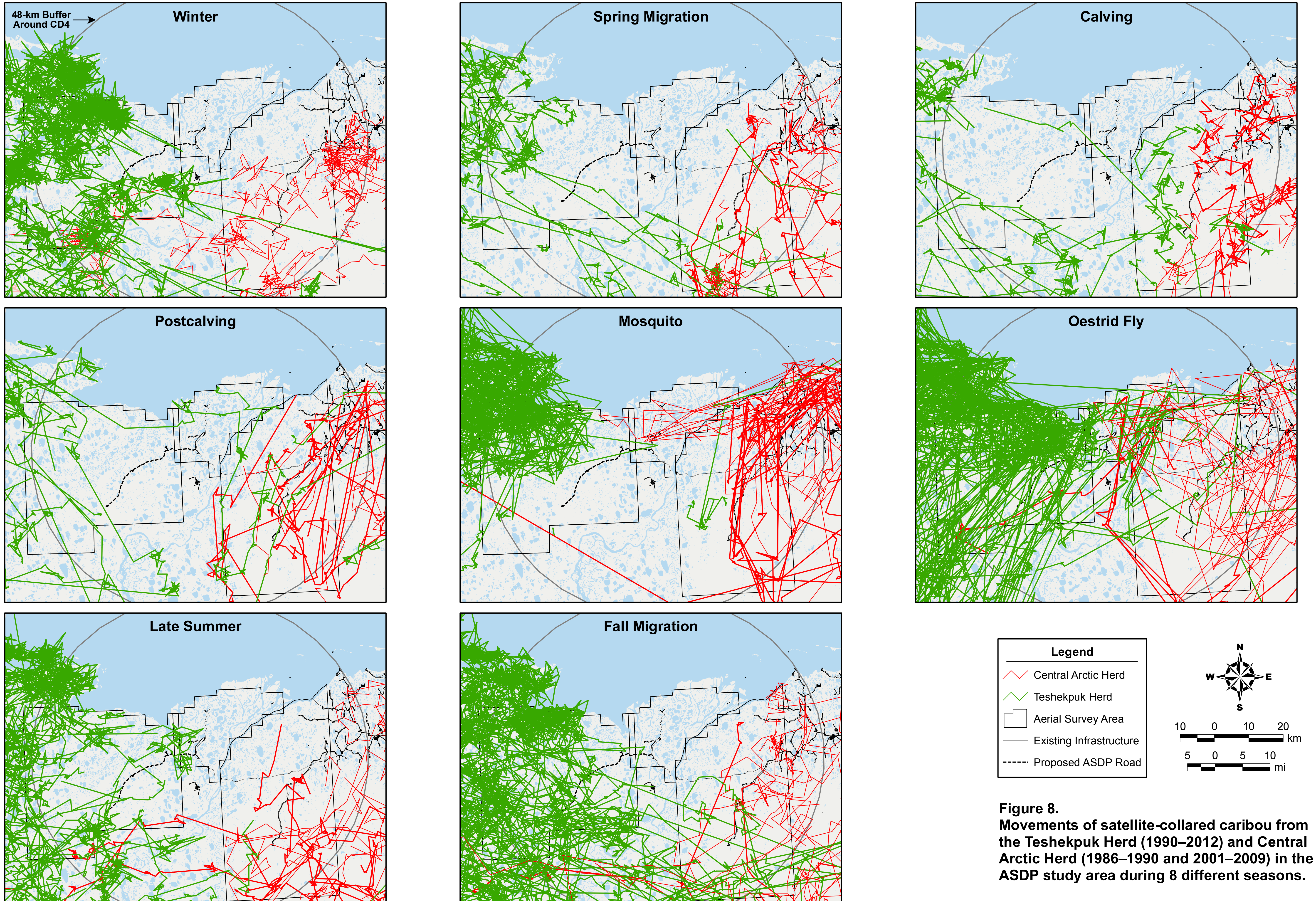


Figure 8.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2012) and Central Arctic Herd (1986–1990 and 2001–2009) in the ASDP study area during 8 different seasons.

ABR file: Fig08_Sat_12-164.mxd; 07 Mar 2013

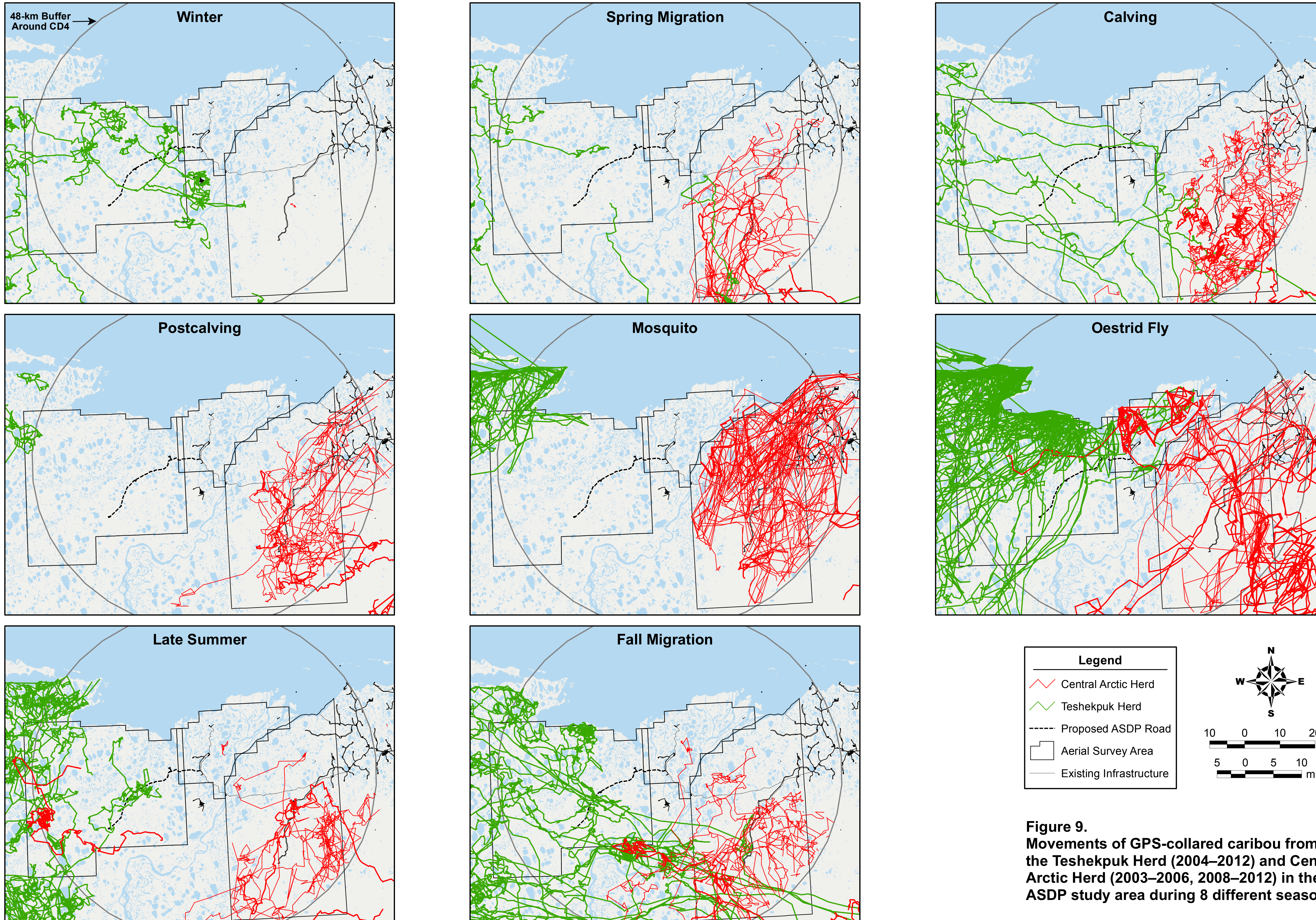


Figure 9.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2012) and Central Arctic Herd (2003–2006, 2008–2012) in the ASDP study area during 8 different seasons.

ABR file: Fig09_GPS_12-164.mxd; 07 Mar 2013

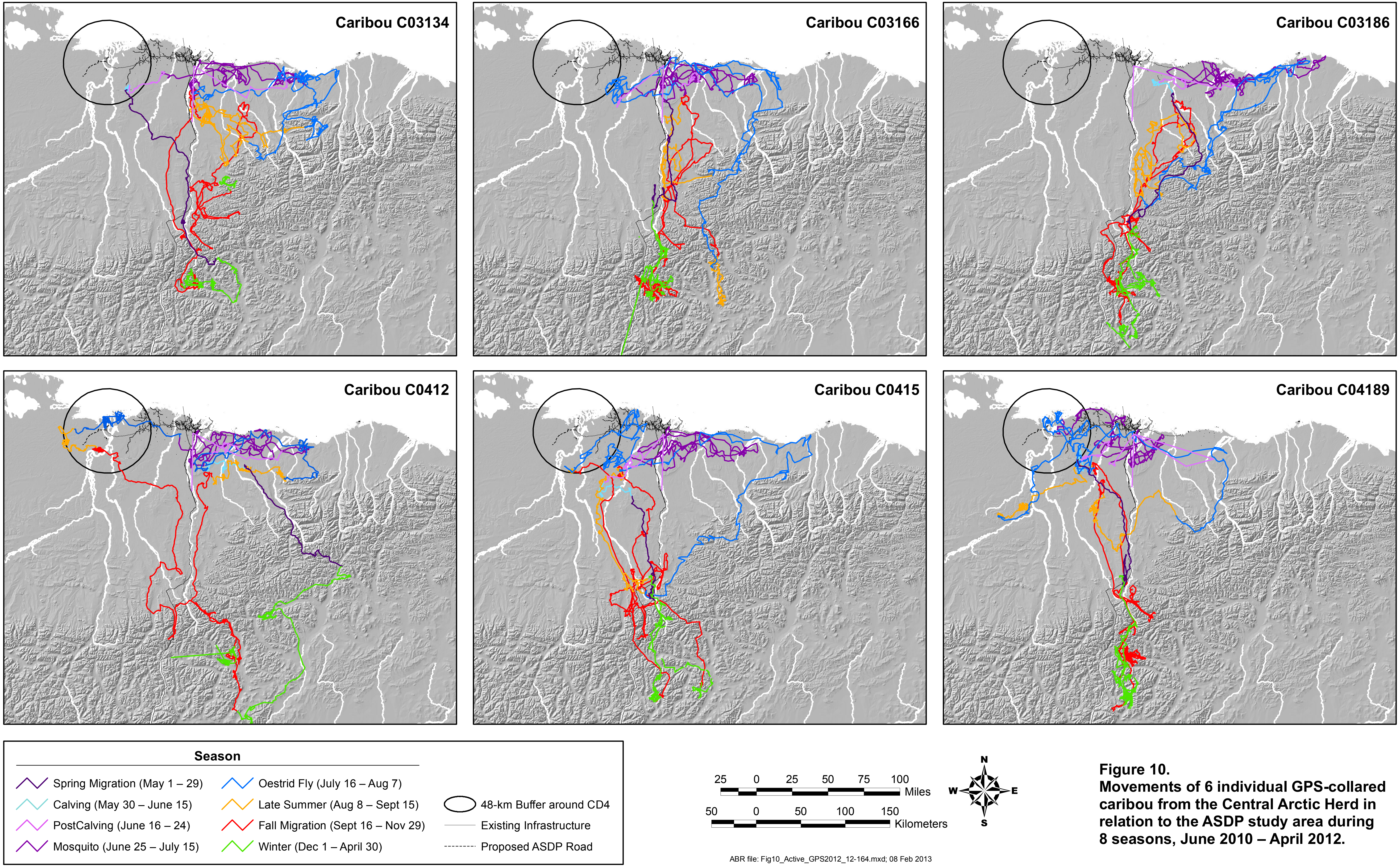
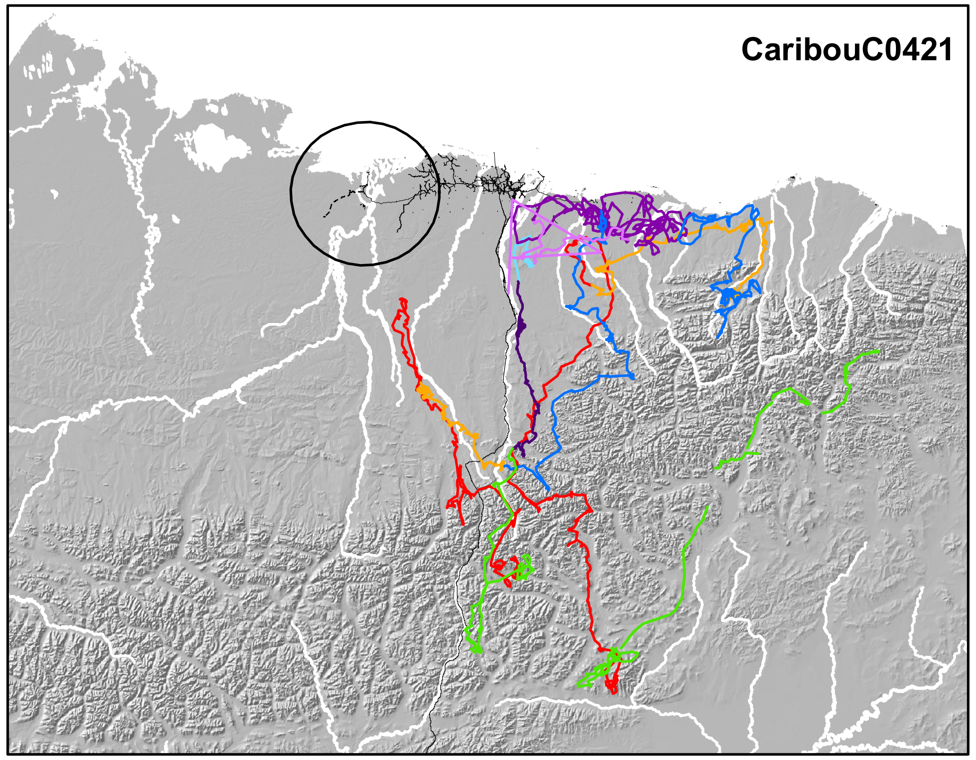
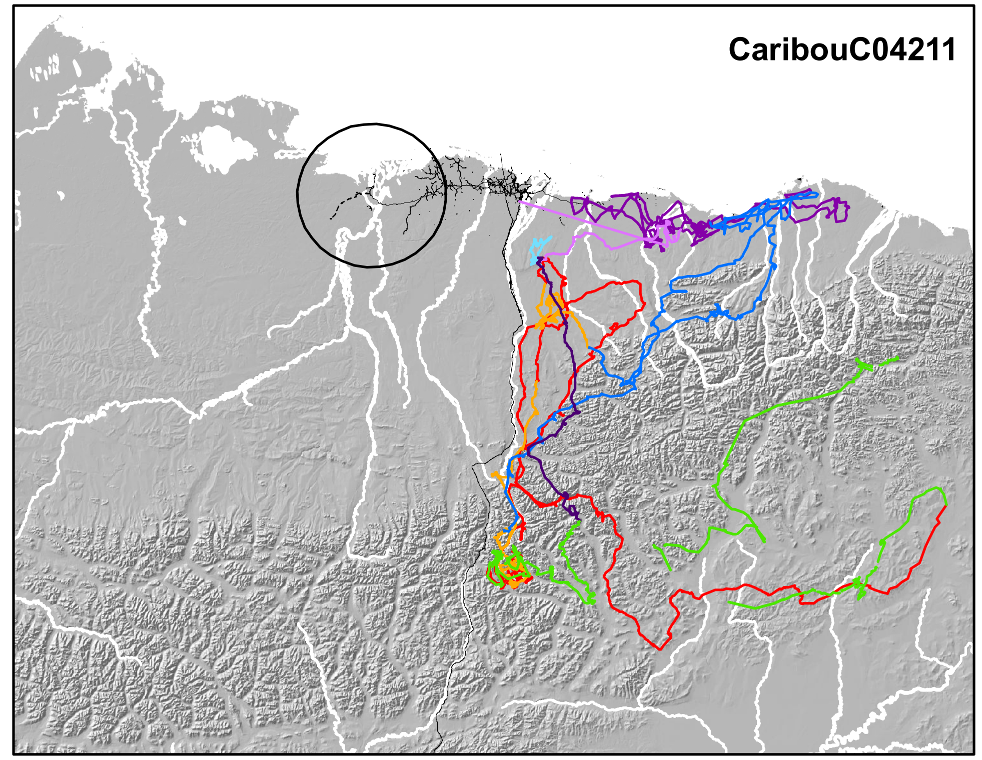
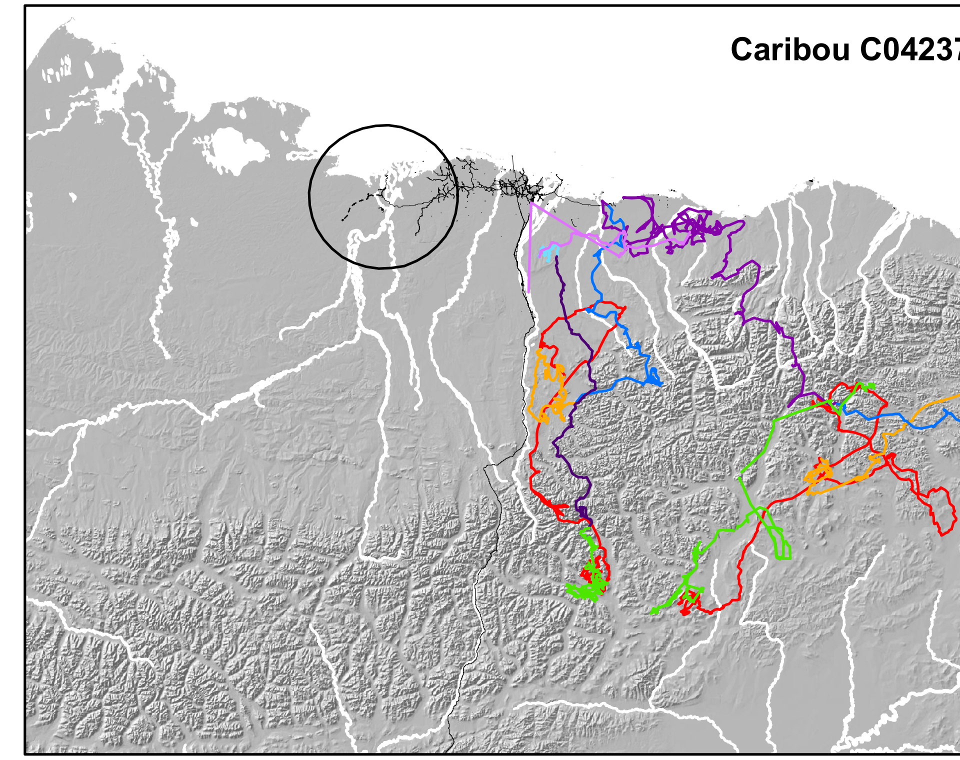
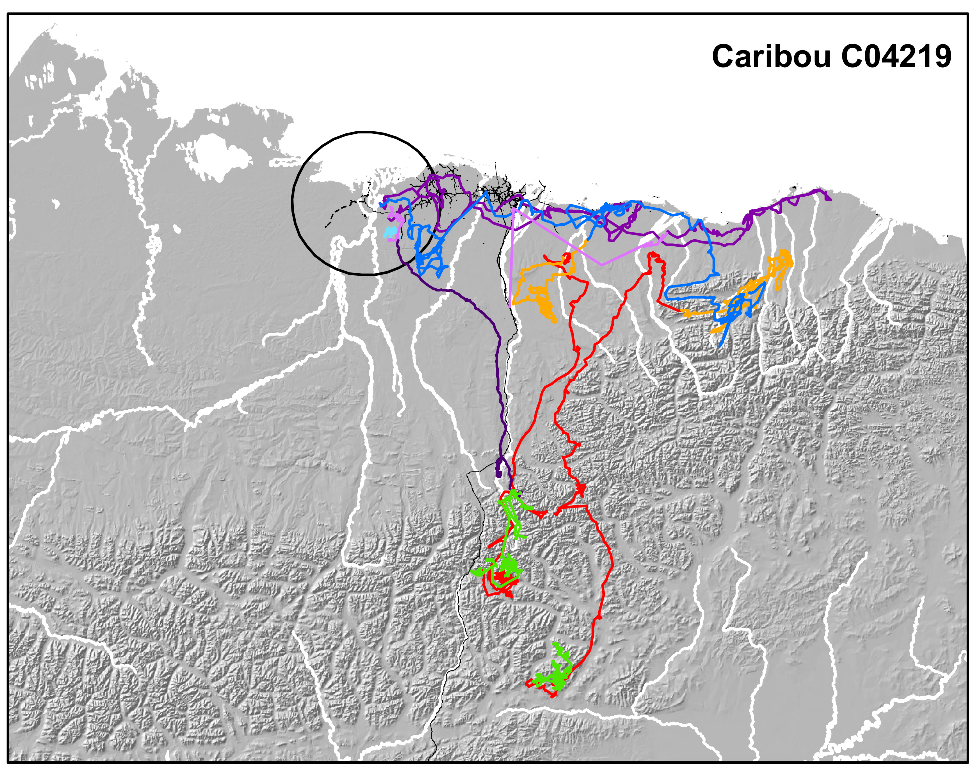


Figure 10.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 8 seasons, June 2010 – April 2012.









Season

- Spring Migration (May 1 – 29)
- Calving (May 30 – June 15)
- PostCalving (June 16 – 24)
- Mosquito (June 25 – July 15)
- Oestrid Fly (July 16 – Aug 7)
- Late Summer (Aug 8 – Sept 15)
- Fall Migration (Sept 16 – Nov 29)
- Winter (Dec 1 – April 30)

- 48-km Buffer around CD4
- Existing Infrastructure
- Proposed ASDP Road

N
W E
S

25 0 25 50 75 100 Miles

50 0 50 100 150 Kilometers

Figure 11.
Movements of 4 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 8 seasons, June 2010 – April 2012.

ABR file: Fig11_Active_GPS2012_12-164.mxd; 06 Feb 2013

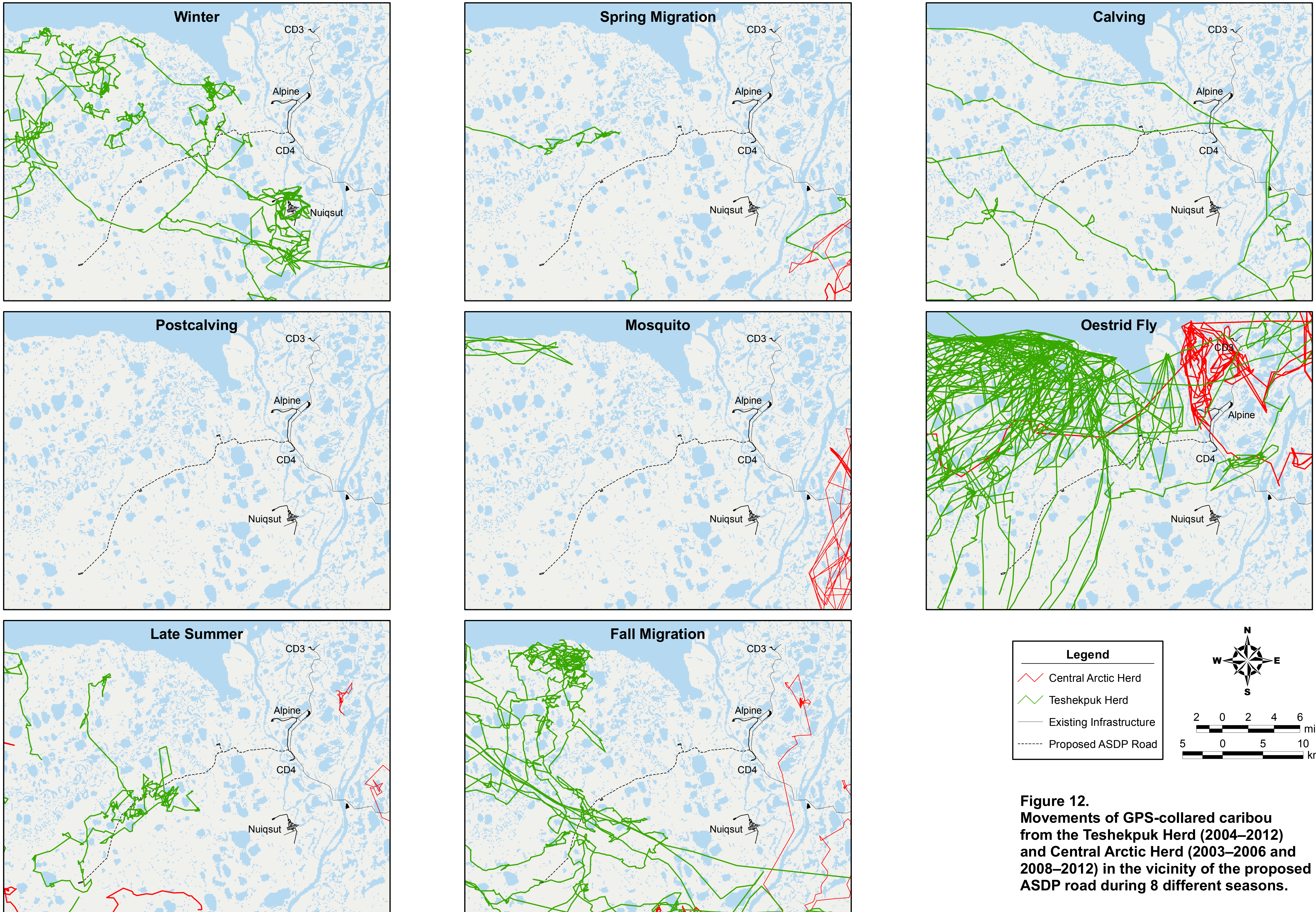


Figure 12.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2012) and Central Arctic Herd (2003–2006 and 2008–2012) in the vicinity of the proposed ASDP road during 8 different seasons.

ABR file: Fig12_Road_GPS_12-164.mxd; 18 Jan 2013

outfitted with GPS collars from July 2007 to December 2010 (Lawhead et al. 2012).

The 10 CAH GPS-collared caribou that were collared in 2010 wintered in the Brooks Range east of the Dalton Highway during the winter of 2011–2012. This distribution was similar to the winter distribution of CAH caribou in 2010–2011 (Figure 10–11; Lawhead et al. 2012). All GPS-collared CAH caribou were captured in April 2012 and collars were removed.

Movements Near CD4

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 satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006. 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 2010 (January–October), no satellite-collared TH caribou were in the CD4 vicinity. In 2011, two satellite collared male TH caribou were near CD4. One caribou apparently crossed the road between CD1 and CD4 on 13 July and a second caribou on July 24–25 moved along the western edge of CD3 from east to west and then headed south to within 4 km of CD4 before heading away to the southwest. In 2012, one female TH caribou with a satellite-collar was close to CD-3 while moving west in NPRA in late July after moving with the CAH during the summer, but no collared caribou were near CD4.

Of the sample of 17 CAH satellite collars deployed during 1986–1990, one moved into the CD4 vicinity briefly during 21–23 July 1988 and four moved near CD-4 during 11–13 July 1989. Of the sample of 15 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. 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.

Of 71 different TH animals equipped with GPS collars during 2004–2012, one crossed the Colville delta westward between CD4 and Alpine on 6 June 2005 *en route* to Teshekpuk Lake. One caribou spent 1–6 August 2007 about 2 km south of CD4 before heading west and one caribou wintered near Nuiqsut during the winter of 2007–2008, but did not move onto the Colville delta. In 2012, no GPS-collared TH caribou for which data are currently available moved onto the Colville River delta.

None of the 19 CAH caribou outfitted with GPS collars in 2008–2011 moved into the vicinity of CD4 from 2008–2010, but two were located near CD4 in late July 2011 (Figure 10). Caribou C04189 and C0412 came near the Alpine facilities on 25 July 2011 and C0412 was near Alpine again on 4 August. Both appeared to cross the roads or airstrip between CD1 and CD2 and between CD1 and CD4. The timing of these movements corresponded with the incidental observation (during bird surveys) of two groups of caribou totaling approximately 600 animals on the delta on 25 July, 2011 plus a group of about 140 animals on 1 August (J. Parrett, ABR, pers. comm.). All CAH GPS collars were removed in April, 2012 so no collared-CAH caribou were in the study area in 2012.

Movements Near Proposed Road Alignment

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 130 different satellite collared caribou (1990–2012), 39 animals (30%) crossed the proposed alignment at least 128 times between September 1990 and August 2012. Crossings occurred in every month except January. In 2012, one female TH caribou crossed five times during 2–3 August. This caribou was moving with CAH animals during much of the summer, but then moved west to rejoin the TH in late July and early August.

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), although two collared CAH individuals moved through the vicinity of the Alpine project facilities in July 1989, nine years before construction began. 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.

Of the TH sample of 70 different GPS-collared caribou (2004–2012), a total of 25 collared caribou crossed the alignment 65 times. Crossings occurred in all months except February and March. Seven caribou crossed in July (all in 2010), six caribou crossed the alignment in October (five in 2004 and one in 2007), and three crossed in May (in 2007, 2009, and 2011). The other months had less than three crossings. No GPS-collared caribou crossed the alignment in 2012.

Telemetry Summary

The movement data for both satellite- and GPS-collared animals show that the ASDP study area is used at low to moderate levels by TH caribou throughout most of the year, predominantly in the western half of the study area. During most years, the highest use of the ASDP study area by TH caribou occurred in midsummer or fall. That pattern mirrored the data obtained from aerial transect surveys (Table 2, Figures 5 and 6).

In contrast, CAH caribou use the ASDP study area most extensively during the calving and postcalving periods in June. 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, Yokel et al. 2009). 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 moved far to the east during midsummer and often remain far to the east or south of the study area until the following spring migration and calving season (Lenart 2011).

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 large numbers of animals from 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 (Person et al. 2007), 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 2011, Parrett 2011). 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 or near the traditional range of the CAH south of the Brooks Range. During the winter of 2011–2012, collared animals from all four arctic caribou herds wintered along the Dalton Highway (L. Parrett, ADFG, pers. comm.).

REMOTE SENSING

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

SNOW COVER

In 2012, snow melt was underway in areas inland from the ASDP study area by early June, but substantial snow remained in the study area at the end of May. Patchy snow cover was evident in the NPRA portion of the study area by 3 June while the Kuparuk uplands had more extensive snow cover. The study area was largely obscured by clouds from 4 June until 11 June. Based on observations during aerial surveys, substantial amounts of snow still remained in portions of the study area during June 8–10, but it was melting rapidly, and little snow remained on 11 June.

The date of snow melt (defined as the midpoint between the last date when >50% snow cover was observed and first observed date with ≤50% snow cover) was calculated for the years 2000–2012. When the duration between the prior observation and the first observed date of snow melt exceeded a week, the pixel was assigned to the "unknown" category, because extensive cloud cover or satellite sensor malfunction prevented the determination of snow melt to within one week.

The median date of snow melt, computed from 2000–2011 data where the date of melt was known to within one week (Lawhead et al. 2012), indicates that nearly all of the land on the coastal plain typically melts over a period of three weeks (25 May–11 June; Figure 13, Appendix F). Snow melt progresses from the northern foothills of the Brooks Range north to the outer coastal plain, occurring earlier in the "dust shadows" of river bars and human infrastructure, and snow cover persists in the uplands and the many small drainage gullies southwest of the Kuparuk oilfield. The southern coastal plain, wind-scoured areas, and dust shadows typically melt during the last week of May. The central coastal plain and most of the Colville River delta usually melt in the first week of June, leaving snow on the northernmost coastal plain, in uplands, and in terrain features that trap snow, such as gullies. During the second week in June, most of the remaining snow melts, although some snow drift remnants, lake ice, and *aufeis* persist into July.

Within the NPRA survey area, snow melt occurs earliest near stream channels and there is a south-to-north gradient, with snow melt typically occurring several days later towards the coast. On the Colville River delta, there is an east-to-west gradient, with snow melt delayed by about a week in the northeastern portion of the delta compared to the western delta. Snow melt in the Colville East survey area occurs earliest along roads. Snow melt is delayed both in the higher elevations to the south and for the coastal region to the north. Snow melt occurs several days earlier in the central portion of Colville East.

While cloud cover prevented direct observation of the snowmelt date to within a week over most of the survey areas in 2012 (Figure 14), most of the visible portion of the survey area and nearby areas had a snowmelt date within three days of the 2000–2011 median. In the foothills south of the survey areas there was a slightly early snowmelt to the southeast (east of TAPS) while snowmelt was slightly later than normal directly south of the survey areas in the Colville River watershed.

Previous comparisons of the performance of the MODIS subpixel-scale snow-cover algorithm with aggregated Landsat imagery suggest 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 and will be evaluated for use in future analyses.

VEGETATIVE BIOMASS

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 areas that have melted recently. 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.

Due to persistent cloud cover in early June, we were unable to calculate NDVI_Calving and NDVI_Rate over a portion of the study area (mostly in the northwest corner of the NPRA survey area; Figure 15). Where observed, NDVI_Calving was zero over much of the area due to the large amount of snow cover in the area. Even in areas without snow, NDVI_Calving was quite low compared to the median of 2000–2011 observations (Figure 16, Appendix G). NDVI_Rate was high in portions of the study area with data, most likely due to the fact that a substantial portion of snow melt occurred between calving and June 21. NDVI_621 and NDVI_Peak both showed the typical pattern of higher values inland and lower values along rivers and creeks (Figure 15). Based on comparisons of the 2012 values with the 2000–2011 medians, the NDVI_621 in 2012 was slightly above normal in NPRA and the Colville Delta survey areas but lower than normal in most of the Kuparuk West survey area (Figure 16; Appendix H). NDVI_Peak values were close to normal in 2012 (Figure 16; Appendix I).

In this year's analysis we used zero-baseline estimation to calculate NDVI_Calving (i.e., negative NDVI values were set to zero); hence, the values of NDVI_Calving are determined largely by the timing of snow melt. Snow melt typically occurs over a short time period during the calving period. As a result of changing snow cover, the levels of NDVI_Calving vary substantially based on the timing of satellite imagery in relation to melt and the amount of snow and ice remaining to mask the effect of new vegetation. In some past years (Lawhead et al. 2009, 2010), we attempted to address this issue by using the value of NDVI in late September (late fall baseline estimation) as the minimum value of NDVI_Calving. Those baseline estimates, which were obtained after plant senescence but before snow began to accumulate in the fall, were used to estimate the NDVI value of standing dead biomass. However, further examination indicated that the fall NDVI values were higher than those observed early in the season immediately after spring snow melt. We are reviewing the 13-year time series further to evaluate the typical value of NDVI in the study area immediately after snow melt, to determine if better estimates of the NDVI value of early spring standing dead vegetation can be generated for future analyses.

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). Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix J) influenced the seasonal differences in caribou distribution. This analysis focuses on the pooled 11-year data set for aerial transect surveys (2002–2012; 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 and high spatial variability during individual surveys (Appendix K).

For the pooled 2002–2012 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, postcalving, and the mosquito season. The River section contained more groups during postcalving, oestrid-fly season, and late summer. The Southwest section contained more groups during winter, calving, and fall migration, but fewer during the mosquito and oestrid-fly seasons.

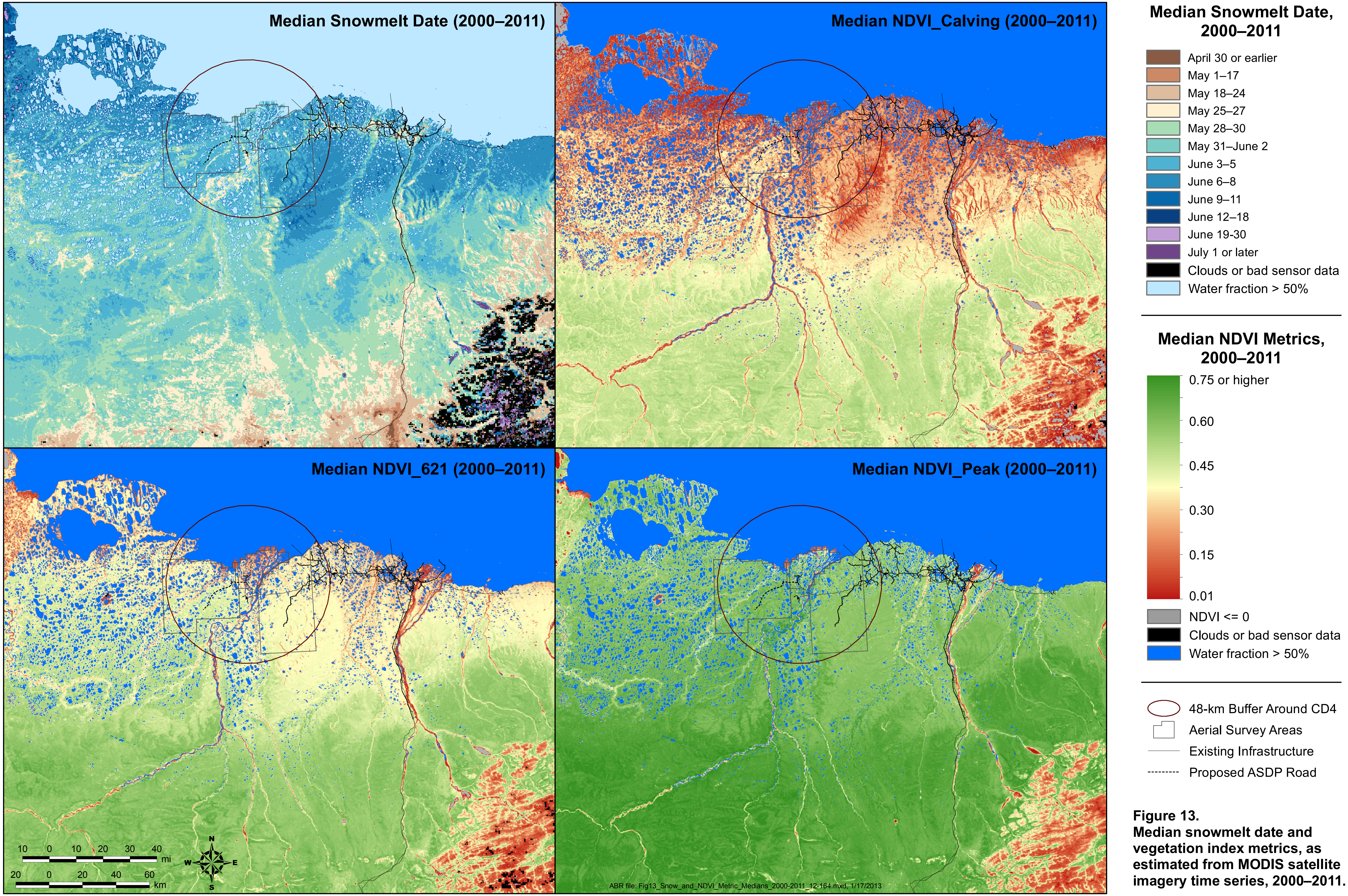
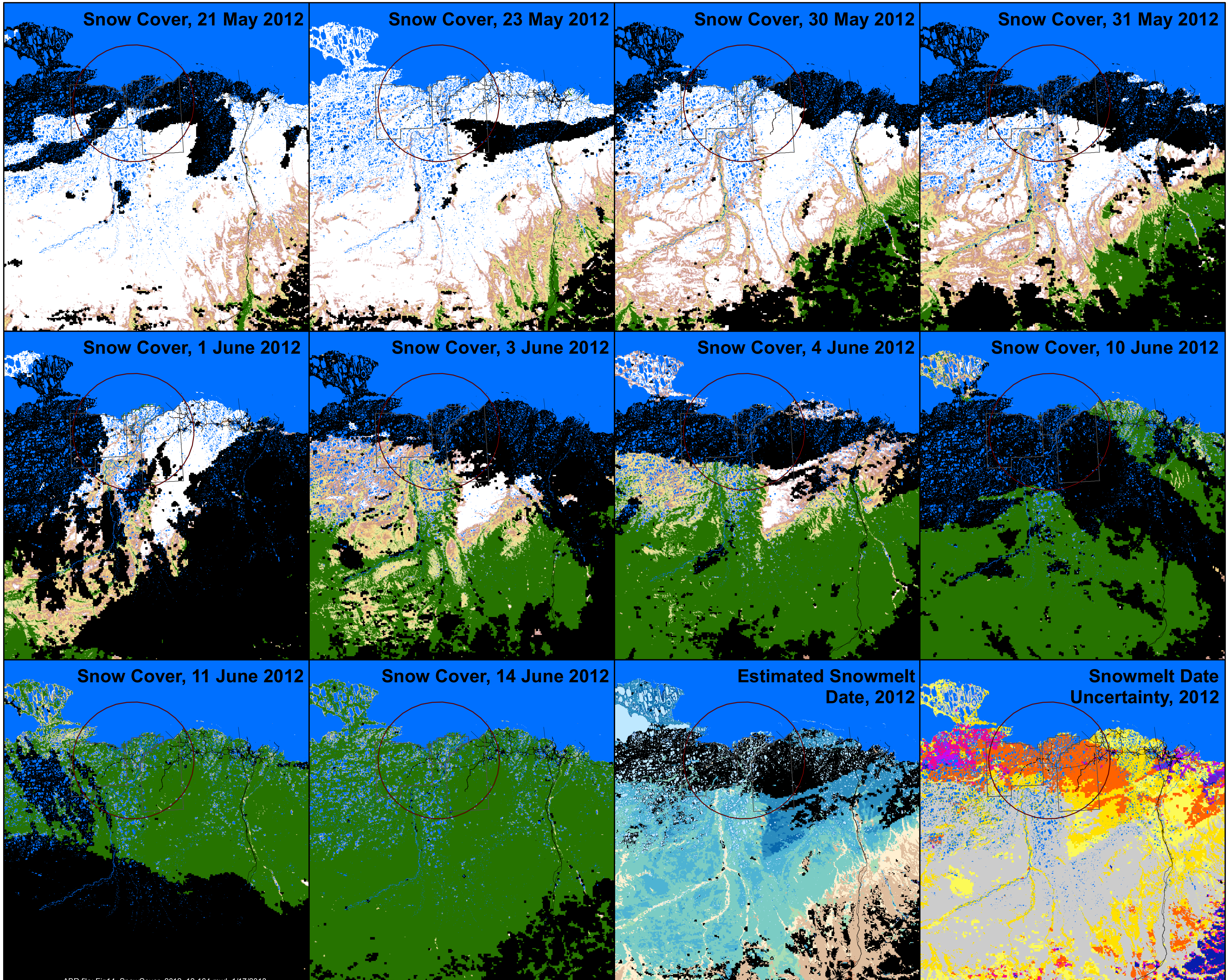


Figure 13.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2011.



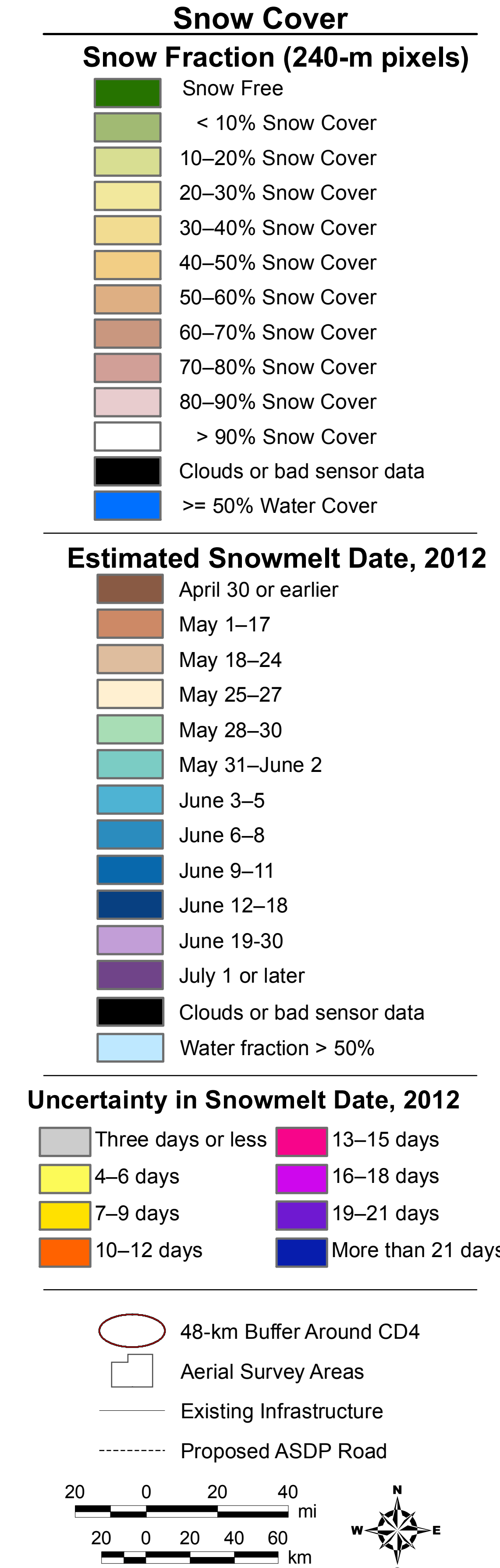


Figure 14. Extent of snow cover between mid-May and mid-June on the central North Slope of Alaska in 2012, as estimated from MODIS satellite imagery.

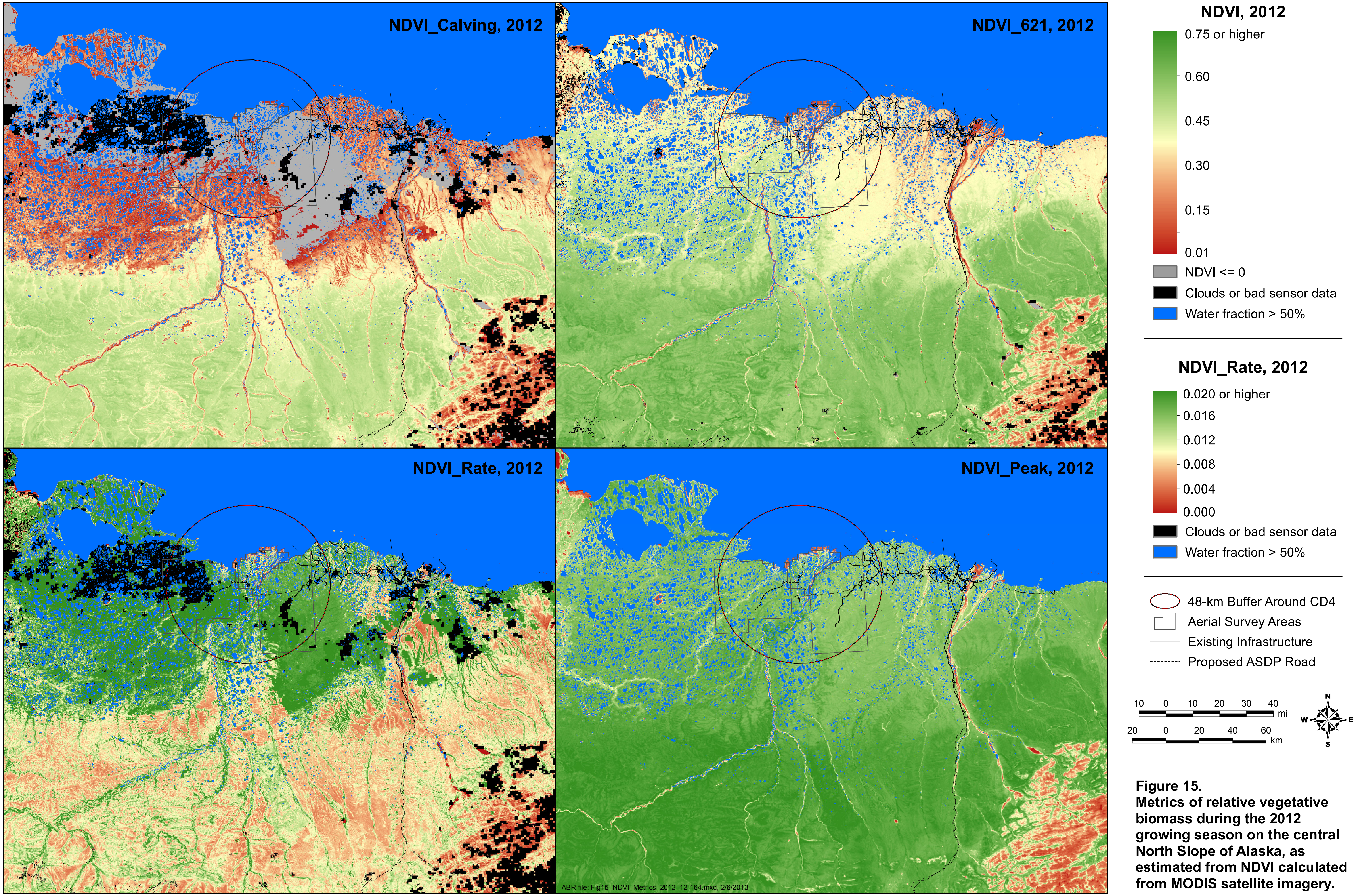
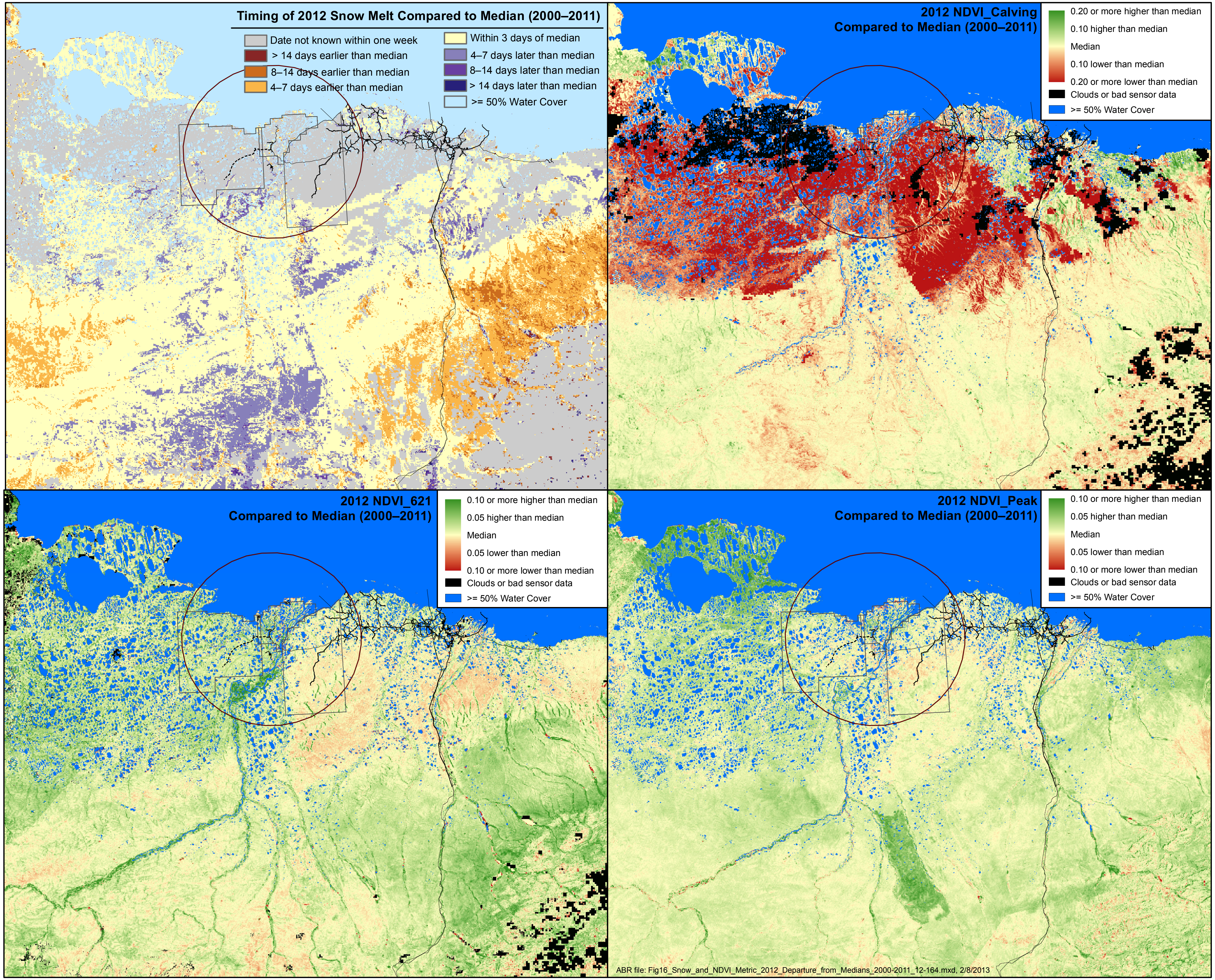


Figure 15.
Metrics of relative vegetative biomass during the 2012 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.



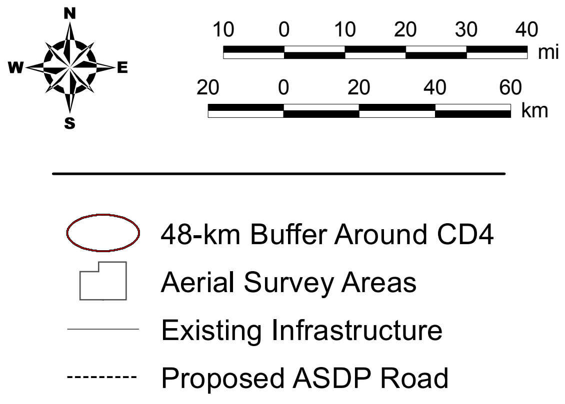


Figure 16.
Departure of 2012 values from median snowmelt date and vegetation index metrics (2000–2011), as estimated from MODIS satellite imagery time series.

Table 5. Use divided by availability (proportion of groups over proportion of area) 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
2012	Winter	1	20	0.50	1.54	0.26	0.93	1.43	4.73	0.316
	Spring	1	23	0.87	1.15	1.58	0.80	0.62	2.58	0.631
	Calving	1	93	0--	0.43^{--}	0.61	1.27	2.10^{++}	44.48	<0.001
	Postcalving	1	110	1.09	1.80^{++}	1.51	0.27^{--}	0.56-	41.83	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	17	0	0.26	1.53	1.31	1.40	5.75	0.219
	Fall Migration	1	37	0.27-	1.90	0^{--}	1.00	1.29	16.55	0.002
	Total	6	300	0.53--	1.23	0.97	0.81	1.24	16.58	0.002
2002–2012	Winter [a]	6	549	0.48--	0.79^{-}	1.01	0.91	1.58^{++}	56.63	<0.001
	Spring	9	421	1.08	1.56^{++}	0.91	0.69^{--}	1.02	37.74	<0.001
	Calving	12	1,061	0.36--	1.04	0.91	0.72^{--}	1.64^{++}	157.65	<0.001
	Postcalving	11	1,188	0.36--	1.34^{++}	1.62^{++}	0.61^{--}	0.87	216.82	<0.001
	Mosquito	6	102	2.78+	2.34^{++}	1.09	0.35^{--}	0.25^{--}	80.35	<0.001
	Oestrid Fly	10	235	0.74	0.73	2.31^{++}	0.53^{--}	0.68^{--}	112.71	<0.001
	Late Summer	17	794	0.64--	1.10	1.51^{++}	0.71^{--}	0.94	73.82	<0.001
	Fall Migration	17	1,531	0.59--	1.07	1.07	0.80^{--}	1.27^{++}	64.65	<0.001
	Total	88	5,881	0.58--	1.16^{++}	1.24^{++}	0.72^{--}	1.16^{++}	350.17	<0.001
Available land area (km²), 2002–2004				8.9	64.8	133.7	191.0	148.2		
Available land area (km²), 2005–2012				70.7	160.9	136.0	191.0	148.4		

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

During all seasons except winter, 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, late summer, and fall migration. During the few surveys flown in 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 (Murphy and Lawhead 2000, Yokel et al. 2009, Wilson et al. 2012). 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 2012 were generally similar to the results from pooled data from all years, but some differences existed due to the small sample sizes associated with a single year (Table 5).

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 typically calve near Teshekpuk Lake, so densities decrease with increasing distance away from the lake (Person et al. 2007, Parrett 2009, Wilson et al. 2012). Hence, more caribou would be likely to occur in the western portion of the NPRA survey area in that season than in the eastern portion. The TH appears to be expanding its calving range in recent years, including some calving occurring further to the southeast. There is also some evidence that there is increased use of the Southeastern area near Ocean Point on the Colville River by the TH after calving and before mosquito harassment begins (L. Parrett, ADFG, pers. comm.). We did observe increased use of the Southeast section of the NPRA survey area during the late calving survey in 2012 than was typical in previous years (Table 5, Figure 5).

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, Person et al. 2007, Wilson et al. 2012). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3, Appendix J) that provide good fly-relief habitat near foraging areas.

The Southwest section consistently contained higher densities of caribou than did the Southeast section. The reasons 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 possible 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 L) 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.

Several strong patterns of habitat selection were evident in the test results. Across all seasons and years (2002–2012), the proportions of caribou groups using riverine habitats, sedge/grass meadow, moss/lichen, and dwarf-shrub types were significantly greater than expected based on the relative availability of those habitats, whereas the proportions of groups using flooded tundra was significantly less than expected (Table 6). Riverine habitats were used more than expected during the postcalving, mosquito, and oestrid-fly seasons and in late summer, consistent with the geographic analysis described above, but use was less than expected during winter and spring migration. Dwarf shrub was used more than expected during

Table 6. Seasonal use of different habitat types by caribou in the NPRA survey area in 2012 alone and 2002–2012 combined, expressed as use (% of the area within 100 m of each group excluding water) divided by availability (% of area excluding water).

				Habitat Type [a]								
Year	Season	No. of Survey	No. of Groups	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2012	Winter	1	20	0.95	0.89	0.77	0.95	1.25	0.52	1.16	0.82	0.08
	Spring Migration	1	23	0.84	1.02	1.50+	0.98	0.84	2.24	0.47	0.00	1.54
	Calving	1	93	0.77	0.83	0.88	1.51++	0.93	1.64	0.97	1.13	0.97
	Postcalving	1	110	0.91	0.94	1.04	0.97	1.07	0.72	1.31	3.21	0.50
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	1	17	0.40	0.58	0.75	0.53	1.70++	0.00	1.67	0.00	0.09
	Fall Migration	1	37	0.85	1.00	0.80	0.33--	1.20	0.98	0.91	0.00	2.98+
	Total	6	300	0.83-	0.90-	0.96	1.04	1.07	1.10	1.10	1.58	0.98
2002–2011	Winter [b]	6	549	1.06	0.99	1.00	0.95	1.05	0.75	1.26+	0.95	0.44--
	Spring Migration	9	421	1.07	1.02	0.99	1.23++	0.94	1.02	0.79	0.82	0.52--
	Calving	12	1,061	0.93	0.87--	0.93-	1.19++	1.05+	0.91	0.96	0.85	0.79
	Postcalving	11	1,188	0.86--	0.86--	1.04	1.06+	0.99	1.27+	1.16+	1.88++	1.54++
	Mosquito	6	102	1.52++	0.95	0.93	1.17	0.70--	1.88+	1.06	0.67	2.52+
	Oestrid Fly	10	235	1.26+	1.11	1.08	0.60--	0.62--	2.61++	1.35+	1.90	4.87++
	Late Summer	17	794	1.02	0.97	1.03	0.80--	0.84--	1.90++	1.43++	1.59	2.93++
	Fall Migration	17	1,531	0.99	0.93--	0.99	1.00	1.01	1.37++	1.14+	1.04	1.01
	Total	88	5,881	0.99	0.93--	0.99	1.02++	0.97	1.31++	1.15++	1.25+	1.43++
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–2012				8.4%	18.7%	10.5%	16.5%	37.3%	1.5%	3.2%	0.2%	3.7%

[a] NPRA earth-cover classification (BLM and Ducks Unlimited 2002).
[b] Riverine type comprises Dry Dunes, Sparsely Vegetated, and Barren Ground subtypes.
[c] Partial survey.
[d] Two partial surveys.
+ 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 ($P < 0.01$).

winter, postcalving, oestrid-fly season, 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 during calving occurred despite the fact that the Southeast section, which contained fewer caribou groups during calving than expected (Table 5), had the highest proportion of tussock tundra in the study area (Appendix J). 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 values during any other season. Use of sedge/grass meadow was greater than expected during spring migration, calving, and postcalving, but less during oestrid-fly season and late summer. The moss/lichen class occurred in higher proportions in riverine areas and was used more than expected during the postcalving, mosquito season, oestrid-fly season, late summer, and fall migration.

During calving, caribou in the NPRA survey area appear to seek dry, snow-free areas and avoid wet and flooded tundra. Comparison across studies is complicated by the fact that different investigators have used different habitat classifications. Kelleyhouse (2001) and Parrett (2007) reported that TH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid classes; these 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 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. Wilson et al. (2012) used the same habitat classification to examine summer habitat selection for telemetry data from the TH at two different spatial scales. They found that TH caribou consistently avoided patches of flooded vegetation and selected areas of sedge–grass meadow.

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 potentially having greater forage availability.

The distribution of habitats differs among the various distance zones were delineated 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 proposed 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 in NPRA during calving indicated that the caribou groups observed on 10–11 June 2012 were not using areas with snow cover on June 1 that differed from availability ($P > 0.05$; Table 8). The average snow cover in the NPRA survey area on 1 June was 95.8% and the 86 caribou groups observed on the calving survey on 10–11 June were using areas that had a mean snow cover of 97.0% (95% C.I. = 94.4–99.0%). Caribou selection for snow cover during calving has been variable among years, possibly because the timing of snow melt was variable among years (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012). The area around Fish and Judy creeks had lower snow cover on 1 June and the northern, southwest, and coastal areas had more snow cover (Appendix J). Because the snow cover was still nearly

Table 7. Area (percentage) of habitat types (water and other types calculated separately) within distance-to-road zones north and south of the proposed ASDP road alignment 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	4–6	17.8	9.2	23.2	12.7	10.2	33.2	3.1	2.2	0.2	1.9	1.9	2.2
	2–4	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	<0.1	<0.1	0.1
South	0–2	21.3	6.9	18.3	9.8	9.6	51.4	0.6	2.9	0.3	<0.1	<0.1	0.1
	2–4	15.5	7.0	18.2	8.9	6.9	53.1	0.3	4.8	0.7	<0.1	<0.1	0.1
	4–6	10.0	7.0	20.2	7.7	5.7	55.9	0.2	3.0	0.3	<0.1	<0.1	<0.1

[a] NPRA earth-cover classification (BLM and Ducks Unlimited 2002); percentages calculated for habitats excluding water.

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) and snow cover at locations used by caribou groups in the NPRA survey area during different seasons in 2012, compared with availability using a bootstrap analysis.

Season	NDVI Calving	*n*	NDVI 621	*n*	NDVI Rate	*n*	NDVI Peak	*n*	Snow Cover (%)[b]	*n*
Winter	0.0530	(10)	0.4209++	(17)	0.0204	(10)	0.5899+	(17)	98.5++	(17)
Spring	0.0084	(15)	0.4118+	(20)	0.0225++	(15)	0.5794	(20)	96.6	(20)
Calving	0.0120	(76)	0.4376++	(87)	0.0231++	(76)	0.6012++	(87)	97.0	(86)
Post Calving	0.0181	(34)	0.3822	(98)	0.0214	(34)	0.5673	(98)	96.0	(93)
Late Summer	0.0500	(11)	0.3893	(13)	0.0192	(11)	0.5439	(13)	86.2-	(13)
Fall	0.0018-	(22)	0.4122+	(35)	0.0231++	(22)	0.5853+	(35)	99.7++	(32)
Total Use	0.0165	(168)	0.4089++	(270)	0.0223++	(168)	0.5818++	(270)	96.5	(261)
Available	0.0179		0.3927		0.0207		0.5727		95.8	

[a] Caribou groups in pixels with >50% water fraction were excluded from the analysis.
[b] Snow cover on 1 June 2012.
\+ 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 ($P < 0.01$).

complete on 1 June, the 2012 analysis did not provide a strong test of caribou selection for areas of intermediate rates of snowmelt.

Previous studies have not produced consistent results concerning the calving distribution of northern Alaska caribou 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 et al. 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 accurately detect melt dates on satellite imagery because of cloud cover.

VEGETATIVE BIOMASS

Among seasons in 2012, caribou in NPRA selected areas with high values of estimated biomass (NDVI_Peak and NDVI_621) during winter, spring (NDVI_621 only), calving, and fall (Table 8). In general, inland areas (Southeast and Southwest sections of the NPRA survey area) had higher estimated biomass than did the Coast, North, and River sections (Appendix J). In 2005, and 2007–2011, caribou also 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. (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 (2001) 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 (i.e., 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 for the effects of snow melt, so, unless snowmelt always occurred before calving, 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 M). For 2012, however, fewer caribou groups than expected (based on a uniform distribution) occurred within 2 km of the road alignment during the fall season. For all years combined (2001–2012), fewer caribou groups than expected (based on a uniform distribution) occurred within 2 km of the road alignment during the oestrid-fly season.

Caribou density among the distance-to-road zones (Figure 17) 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 $P < 0.003$; the 2005 oestrid-fly season survey with large groups 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 ($P = 0.004$). No other seasons differed significantly ($P > 0.05$).

Table 9. Number of caribou groups in distance-to-proposed road zones by year (2012 only and 2001–2012 combined) 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
2012	Winter	1	4	0	2	2	0	0	5.26	0.261
	Spring Migration	1	7	2	1	4	0	0	3.82	0.430
	Calving	1	25	3	4	7	3	8	4.98	0.289
	Postcalving	1	12	3	0-	6	2	1	3.65	0.455
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	5	1	1	2	0	1	0.97	0.915
	Fall Migration	1	11	0	3	1-	2	5	10.78	0.029
	Total	6	64	9	11	22	7	15	3.99	0.407
2001–2012	Winter	6	139	22	21	43	29	24	2.58	0.630
	Spring Migration	10	89	17	9	29	16	18	2.68	0.613
	Calving	13	246	59	33	73	37	44	6.35	0.174
	Postcalving	13	338	67	55	110	49	57	1.02	0.907
	Mosquito	7	17	4	4	5	1	3	2.07	0.722
	Oestrid Fly	12	50	18+	9	8--	5	10	14.59	0.006
	Late Summer	19	201	45	39	62	23	32	6.59	0.159
	Fall Migration	20	438	76	66	147	67	82	2.03	0.730
	Total	100	1,518	308	236	477	227	270	7.66	0.105
Area (km²) surveyed in 2002[a]				31.4	27.9	52.8	26.7	27.0		
Area (km²) surveyed in 2002–2004				35.0	29.4	67.5	33.1	33.5		
Area (km²) surveyed in 2005–2012				39.4	33.4	69.1	33.2	33.6		

[a] Average of two different-sized 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 ($P < 0.01$).

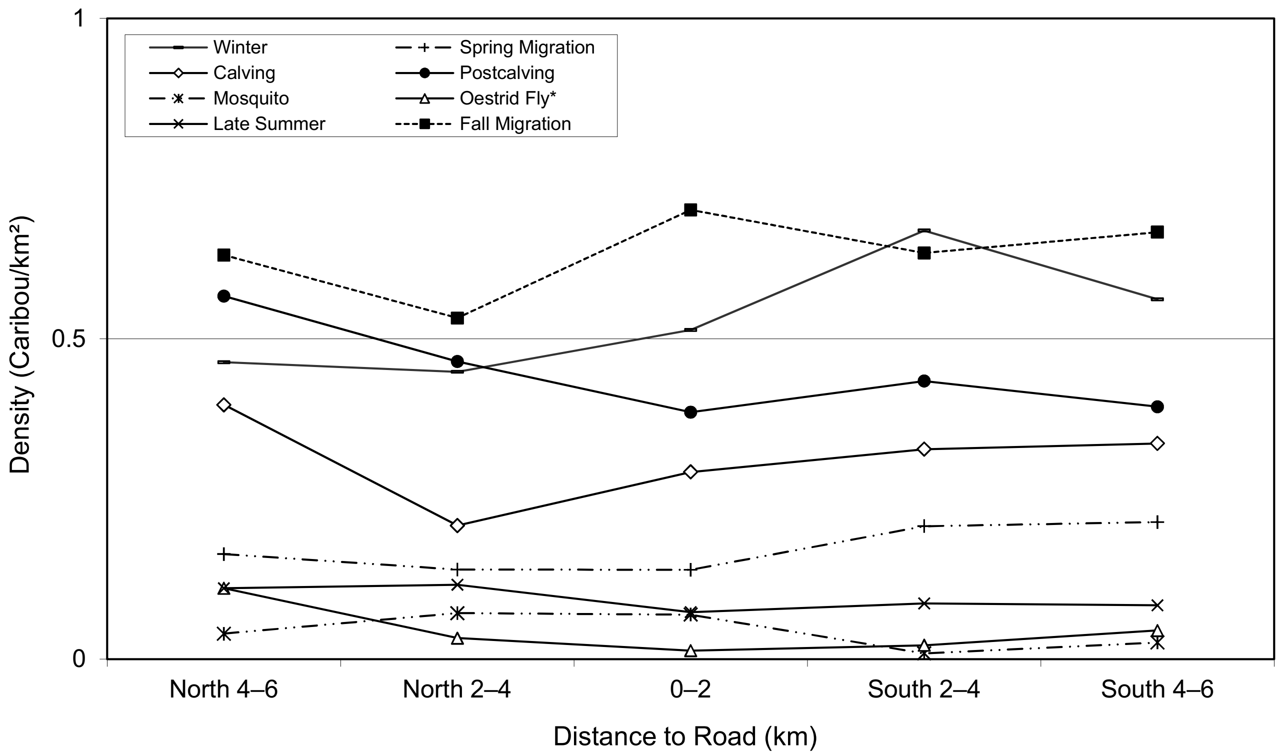


Figure 17. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2012.

Over all seasons combined, there were no significant differences among zones ($P = 0.106$). Significant differences in density among zones were found during calving ($P = 0.012$), postcalving ($P = 0.020$), and winter ($P = 0.011$). But, after applying multiple-comparison tests, there were no significant difference among zones and no differences were found when comparing the area within 2 km of the road with the other zones ($P > 0.10$).

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 do occur in the NPRA survey area occasionally, as was 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 of adequately sampling the highly variable occurrence of caribou at that time of year with that survey method. 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 2012 and among all seasons for the years 2002–2012. 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 that was largely unvegetated, the 2012 estimated peak vegetative biomass (NDVI_Peak) was highly correlated with NDVI_621 ($r = 0.869$; $P < 0.001$). These results indicate that the spatial pattern of NDVI values after snow melt is consistent throughout the snow-free period. NDVI_Peak in 2012 was highly correlated with the NDVI_Peak in 2011 (r = 0.962; P < 0.001), 2010 (r = 0.928; P < 0.001), 2009 (r = 0.920; P < 0.001), and 2008 (r = 0.929; P < 0.001). This consistent spatial pattern of NDVI_Peak can be explained largely by differences among habitat types. NDVI_Peak in 2012 increased with an increasing proportion of tussock tundra (r = 0.762; P < 0.001), but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; r = –0.483; P < 0.001) and in riverine habitats (r = –0.655; P < 0.001). Despite the masking we 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 = –0.481; P < 0.001), suggesting that even small waterbodies artificially depressed NDVI values.

The snow-cover fraction in the NPRA survey area on 1 June 2012 was weakly correlated with NDVI_621 (r = –0.222, P = 0.004) and with NDVI_Peak (r = –0.188, P = 0.016). In general, the NDVI values measured in early June are largely a function of snow cover, but other factors (such as habitat type and standing water) became more important influences on NDVI values after snow melt. Early in spring, much of the first snow melt occurs along Fish and Judy creeks, an area that also has low vegetative biomass.

Caribou Density During the 2012 Calving Season

The best model describing caribou density in the western half of the study area (NPRA survey area) during the 2012 calving season included four independent variables: the presence of the road and the presence of the creeks (both included in all models), the west to east variable and NDVI_621. This model had an estimated 63.5 % probability of being the best model (w_i = 0.635; Appendix N). The second-best model included the same variables plus snowcover on 1 June and had a 23.4% probability of being the best model (w_i = 0.234; Appendix N). The next two best models were the same as the first two models but without the west to east variable. Based on the model-weighted parameter estimates snow cover appeared to have little explanatory power (Table 10) and was just an uninformative parameter (Arnold 2010). Therefore, models with NDVI_621 and the west to east variable had a combined 86.9% probability of being the best model. The model-weighted parameter estimates indicated that NDVI_621, NDVI_Peak, percent of tussock tundra, percent wet habitat, and the west to east variable were all significantly different from zero (all P > 0.01; Table 10).

Caribou densities in the NPRA survey area during calving indicate a preference for areas with higher NDVI_Peak values in most years. The two NDVI variables, and the tussock tundra, and wet habitat variables are all correlated to some degree. Because of the high correlation between NDVI values and habitat types, it is difficult to distinguish

Table 10. Model-weighted parameter estimates for caribou density in the NPRA survey area during the calving survey on 10–11 June 2012.

Variable	Coefficient	SE	*P*-value
Intercept	–11.846	3.196	<0.001
Fish or Judy Creek	–0.512	0.606	0.398
Proposed Road	–0.043	0.745	0.954
NDVI_Peak	35.929	7.928	<0.001
NDVI_621	27.976	5.469	<0.001
Snow cover on 1 June (%)	0.003	0.034	0.925
Tussock tundra (%)	5.103	1.490	<0.001
Wet habitat (%)	–4.196	1.532	0.006
W to E (transect number)	–0.138	0.051	0.007

whether caribou select specific habitat types and areas with greater vegetative biomass or simply avoid 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 (Lawhead et al. 2006). Tussock tundra does contain higher biomass of plant species that are preferred by caribou, such as *Eriophorum vaginatum*, forbs, and lichens, however. The between-year correlations of caribou density during calving were low for 2005–2012 (Spearman's rho = –0.062–0.417), suggesting that different factors influenced caribou distribution among years at the scale of our analysis. Caribou appear to select drier areas with lots of tussock tundra during calving and these areas tend to have high NDVI values in both late June and mid-summer.

Caribou density in Colville East was best described by the model that contained a west to east gradient and the proportion of water in the area, (contained in all models), the presence of a road within 2 km, snow cover on 1 June, and distance to the coast (Appendix O). This model had an estimated 25.2% probability of being the best model in the candidate set. The second best model had the same variables plus NDVI_Peak and had an estimated 18.7% chance of being the best model. Other models with various combinations of these variables also had some level of support (Appendix O). Based on the model-weighted parameter estimates, caribou density in the Colville East survey area in the 2012 calving season declined in areas within 2 km of roads ($P = 0.037$), was higher in areas with more snow cover on 1 June ($P = 0.005$), and increased with distance to the coast ($P < 0.001$; Table 11).

These results are consistent with previous findings that maternal females with young calves tend to avoid areas within 2–4 km of active roads and gravel pads for 2–3 weeks during and immediately after calving (Dau and Cameron 1986, Lawhead 1988, Cameron et al. 1992, Nellemann and Cameron 1996, Lawhead et al. 2004). The fact that caribou appear to select areas of recent snow melt is consistent with research indicating that caribou select high-quality, newly emergent vegetation when it is available (Klein 1990, Kuropat 1994, Johnstone et al. 2002).

Snow melt occurs earlier near roads due to the dust shadow effect, so, although most areas were still snow covered on 1 June, areas near the road tended to have less snow cover than areas more than 2 km from the road (96.9% vs. 98.2%; $P = 0.060$), but this analysis suggests that even after accounting for snow cover, calving caribou were less dense within 2 km of roads.

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 12, Appendix P). During all seasons, caribou density was lower in the eastern portion than in the western portion of the survey area, the presence of the proposed road was not significantly related to density (road was not included in oestrid season models due to failures of the models to converge), and density varied significantly among surveys. During winter, caribou density was also higher in areas with tussock tundra and lower near creeks. During calving the model-weighted parameter estimates indicated that caribou density was greater in areas of higher NDVI_Peak values, at greater distances from the coast, and in areas with a higher proportion of tussock tundra. Calving density was lower in areas with greater proportions of wet habitat (Table 12, Appendix Q).

During postcalving, density was higher near the creeks and in areas with more tussock tundra and decreased inland from the coast and in wet habitats. During the mosquito season, caribou density was higher near the coast. During the oestrid-fly season, density was higher near the creeks and was lower in areas with higher NDVI_Peak. In late summer, density was higher near the creeks and was lower in areas with higher NDVI_Peak values and areas with more tussock tundra. During fall migration and spring, there were no other significant variables (Table 12; Appendix Q).

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.

Table 11. Model-weighted parameter estimates for caribou density in the Colville East survey area during the late calving (9–10 June) survey in 2012.

Variable	Coefficient	SE	*P*-value
Intercept	–3.330	3.857	0.388
Proportion covered by waterbodies	–1.453	0.848	0.086
W to E (transect number)	–0.030	0.022	0.187
Within 2 km of roads	–0.599	0.287	0.037
NDVI_Peak	–8.325	6.084	0.171
Distance to coast	0.049	0.010	<0.001
Snow cover on 1 June	0.050	0.018	0.005
Proportion of wet graminoid tundra (%)	–0.279	0.859	0.746

Table 12. 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, 2002–2012.

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

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 ($P < 0.05$)
** Significantly different among surveys ($P < 0.01$).
a. Road not included in the model for oestrid-fly season.

The riverine area of Fish and Judy creeks had higher densities for much of the 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 the postcalving, and mosquito seasons which are generally consistent with increased use of coastal areas during mosquito harassment periods. Caribou densities in areas with high proportions of tussock tundra were greater during calving, post calving, and winter. During calving, tussock tundra provides abundant forage, such as *Eriophorum vaginatum*, as well as drier microsites during the seasonal flooding that accompanies snow melt. Throughout 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.

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) and postcalving with variable use in the insect season. 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.

Although large groups of caribou from both herds occur on the Colville delta occasionally, these large movements onto or across the delta are relatively uncommon for either herd. CAH caribou are somewhat 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. In recent years, the distribution of the CAH during the mosquito and oestrid-fly seasons has shifted farther eastward, so fewer caribou from that herd are using the Colville River delta than did so in earlier years. Movements of CAH caribou onto the Colville delta from the east were recorded during the insect-harassment season during July in 2010 and 2011. In 2012, large groups of caribou were observed to the east of the Colville delta during the postcalving survey as CAH caribou moved to the coast as the onset of mosquito harassment occurred.

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. No caribou outfitted with telemetry collars were located near CD4 during 2012 but one caribou was near CD3 in Late July. We did not have any data from radio-collared CAH after April 2012.

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 July and fall migration, but the proposed alignment is located in a geographic area that currently receives low-density use by caribou from that herd. Only one radio-collared caribou crossed the proposed road corridor in 2012. This caribou moved with the CAH during June and July but then moved west and rejoined the TH in early August, 2012. Over all years, CAH caribou have rarely crossed the proposed alignment 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.

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 the timing of snow melt and plant phenology, and may vary between the two adjacent herds. CAH calving in the Colville East survey area in 2012 appeared to select areas away from the coast, with more recent snow melt, and avoided areas within 2 km of roads. They did not appear to select areas with high NDVI_Peak or avoid areas with high proportions of wet graminoid tundra.

The riverine habitats along Fish and Judy creeks were selected by caribou in the postcalving, oestrid-fly, and late summer seasons. The complex mosaic of riverine habitats provides opportunities both for foraging and for relief from oestrid-fly harassment. The presence of these streams was a significant variable explaining the distribution and density of caribou in the NPRA survey area, affecting both geographic and habitat 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 typically is lowest in the southeastern section of the NPRA survey area, in which the proposed road alignment would be 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 currently 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. The TH may be in the midst of a change in long-term patterns of distribution and demography. In recent years, the TH calving distribution has expanded to the west and southeast and the winter distribution has varied widely each year. There is also some evidence that there are increasing levels of emigration to other herds, lower parturition rates, and a declining population (Parrett 2011, Parrett ADFG, pers. comm.). These studies and continued monitoring will be useful for interpreting the impact of current and future changes in the context of new development and a changing climate.

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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 waters typically are deep (>1 m). This class may contain small amounts of *Arctophila fulva* or *Carex aquatilis*, but generally has <15% surface coverage by these species.
Turbid Water	Waters that contain particulate matter or shallow (<1 m), clear waterbodies that differ spectrally from Clear Water class. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. Turbid waters may contain small amounts of *Arctophila fulva* or *Carex aquatilis*, but generally have <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*. Small percentages 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*. Small percentages of *Carex aquatilis, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may 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, E. vaginatum, Sphagnum* spp., *Salix* spp., *Betula nana, Arctostaphylos* spp., and *Ledum palustre*.
Flooded Tundra–Non-patterned	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-patterned class 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*, 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, E. 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 north of the Brooks Range 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 <30 cm in height. Because of the relative dryness of the sites on which this cover type occurs, it is the most species-diverse class. 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 0.3–1.5 m in height. Major species include *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 <10% vegetative cover. 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 tides or storm tides, in recently drained lake or pond basins, and in areas where bare mineral soil is being recolonized by vegetation. Dominated by non-vegetated material with 10–30% vegetative cover. The vegetation may include rare plants, but the most common species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Barren Ground/ Other	Associated with river and stream gravel bars, mountainous areas, and human development. Includes <10% vegetative cover. 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, 1983–2012.

	Snow Depth (cm)			Cumulative Thawing Degree-days (º C)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	66.2	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	127.6	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
2010	41	43	13	0	1.4	53.3	51.1	126.7	168.9	149.2
2011[a]	25	18	0	0	27.8	12.5	101.2	122.4	171.6	143.2
2012[a]	48	53	2	0	1.7	26.8	137.3	140.2	195.2	143.5
Mean	23.9	15.1	3.3	0.5	11.5	41.4	98.6	125.5	144.3	127.8

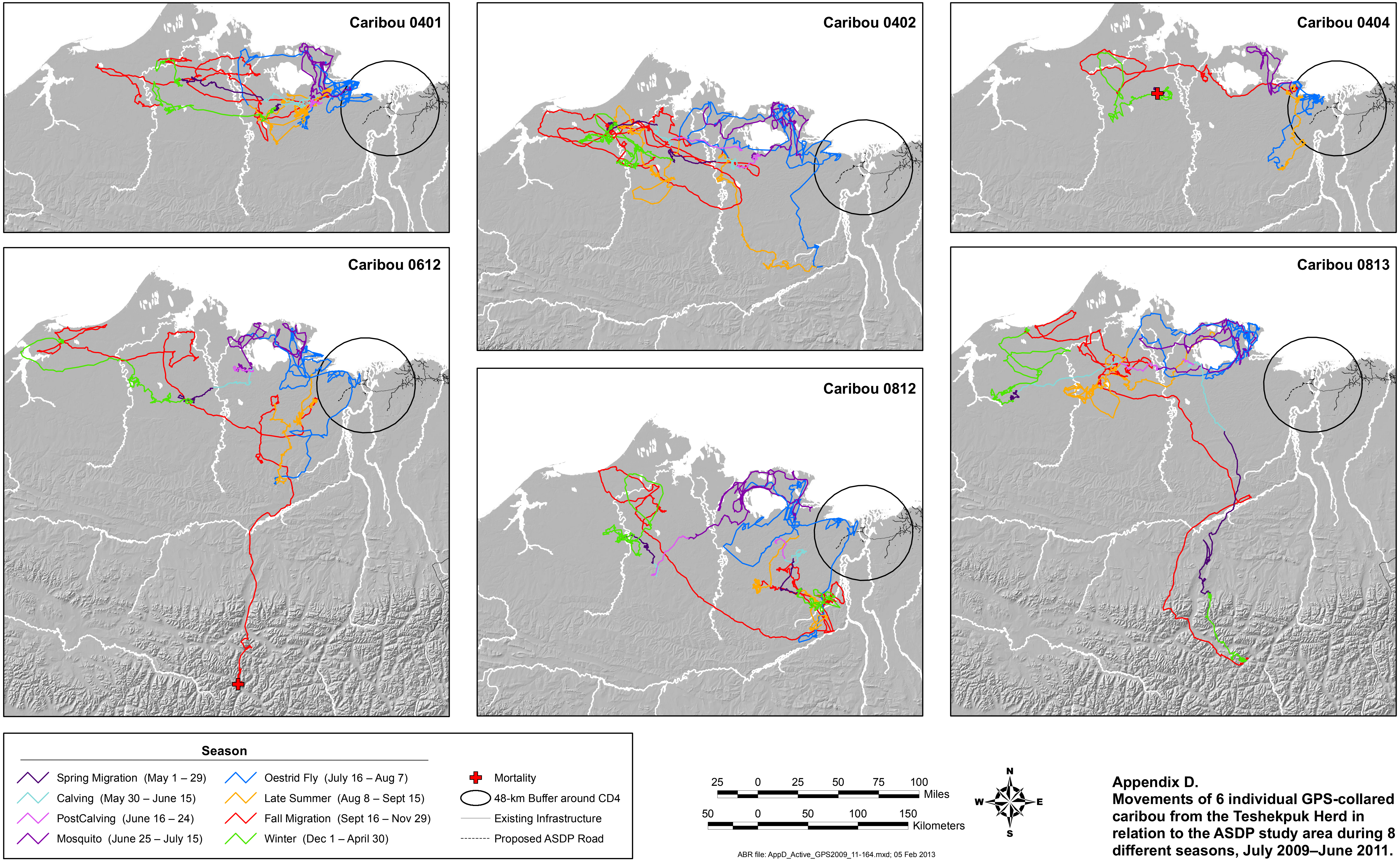
[a] Kuparuk weather data were not available from 17 June 2011 – 9 December 2011, 4–14 August 2012, and 30–31 August 2012, so cumulative TDD was estimated by averaging Deadhorse and Nuiqsut temperatures (Lawhead and Prichard 2012).

Appendix C. Location and number of other mammals observed during aerial surveys for caribou in and near the ASDP study area, April–October 2012.

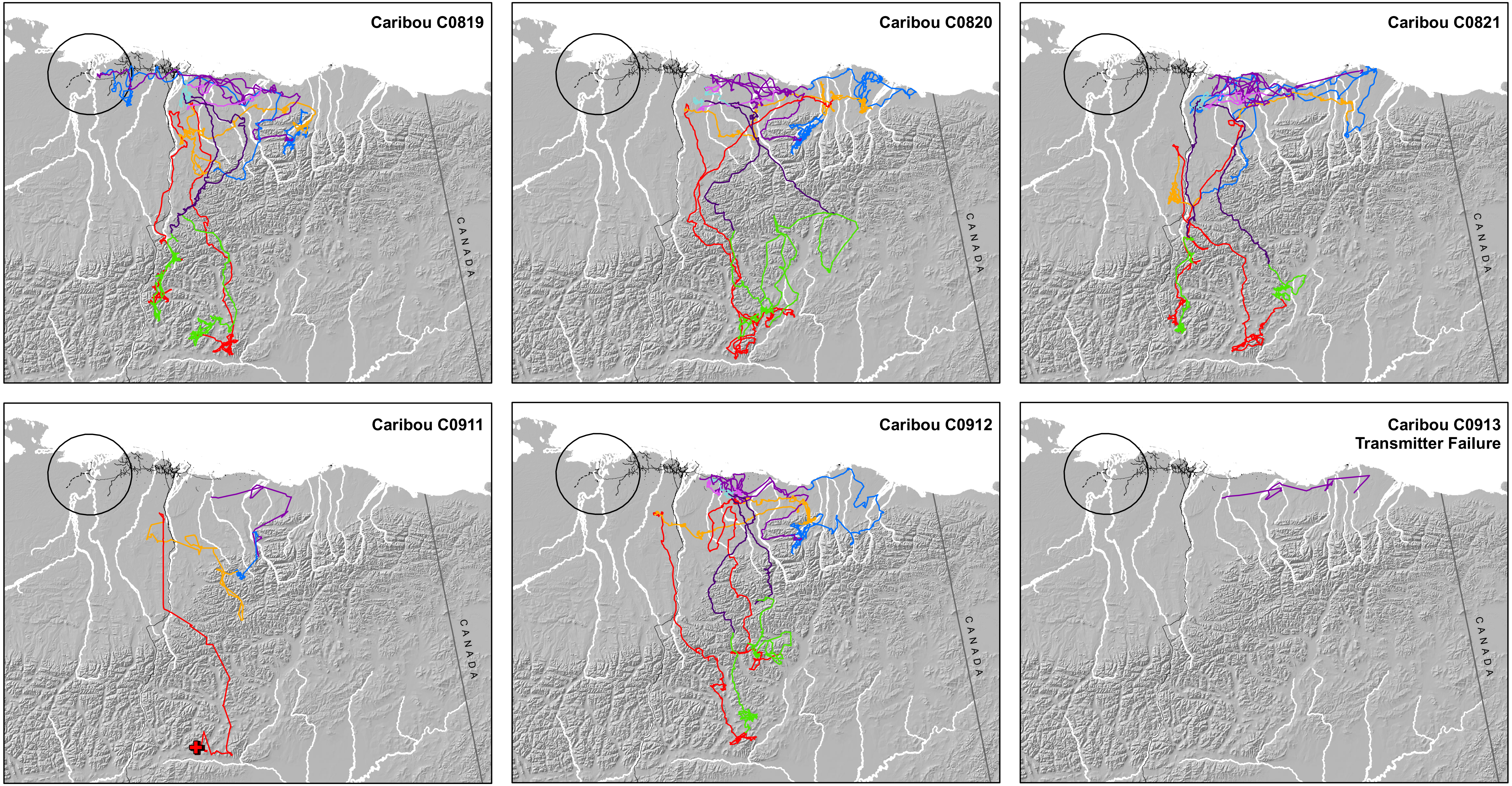
Species	General Location	Date	Adults	Young	Total	Specific Location
Grizzly Bear	NPRA	April 26	1	2	3	W of Nuiqsut
		May 10	1	0	1	SW of Nuiqsut
		May 10	1	2	3	W of Nuiqsut
		May 10	1	0	1	SW of Nuiqsut
		May 10	1	0	1	Near coast
		June 19	1	0	1	W of Nuiqsut
		June 19	1	2	3	Fish Creek delta
		June 21	1	0	1	Near Coast
		October 4	1	0	1	SW of Nuiqsut
	Colville River Delta	June 13	1	2	3	E of Alpine
	Alpine Pipelines	May 11	1	1	2	N of Alpine pipelines
		June 9	1	3	4	N of Alpine pipelines
		June 16	1	0	1	Near DS-2N
		October 4	1	3	4	Near DS-2L
	Upper Miluveach River	May 11	1	2	3	SW of DS-2P
		May 12	1	0	1	E of DS-2P
		June 16	1	0	1	E of DS-2P
		June 16	1	0	1	E of DS-2P
		June 22	2	0	2	E of DS-2P
		June 25	1	0	1	E of DS-2P
		June 25	1	0	1	E of DS-2P
		June 25	1	1	2	E of DS-2P
		October 4	1	0	1	E of DS-2P
	CPF-3 Area	June 6	1	0	1	W of CPF-3
		June 7	1	0	1	W of CPF-3
		June 8	1	0	1	W of CPF-3
		June 9	1	0	1	W of CPF-3
		June 10	1	0	1	W of CPF-3
		June 12	1	0	1	W of CPF-3
		June 14	1	0	1	Near DS-3S
	Kuparuk River	June 23	1	0	1	N of Spine Road
	Prudhoe Bay	June 22	1	0	1	W of Deadhorse airport
Muskoxen	Alpine Pipelines	May 11	11	0	11	S of Alpine pipelines
	Colville River Delta	April 27	21	0	21	NW Colville Delta
		May 10	21	2	23	NW Colville Delta
		June 9	11	2	13	NE of Nuiqsut
		June 11	11	3	14	NE of Nuiqsut

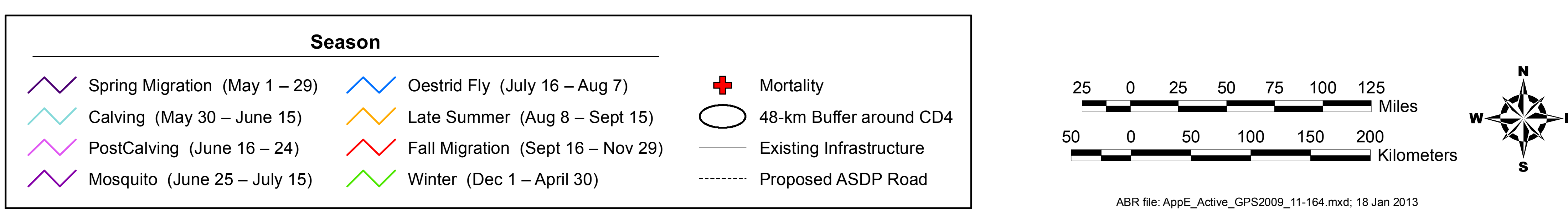
Appendix C. Continued.

Species	General Location	Date	Adults	Young	Total	Specific Location
Muskoxen	Colville River Delta	June 24	12	2	14	E of Nuiqsut
		August 17	14	0	14	NE of Nuiqsut
		August 18	11	2	13	NE of Nuiqsut
		October 4	12	1	13	NE of Nuiqsut
	Beechey Point	June 8	9	7	16	E of Milne Point
		June 8	13	1	14	E of Milne Point
		August 16	5	3	8	E of Beechey Point
	Kuparuk River	June 22	10	4	14	N of Spine Rd.
		June 22	11	2	13	S of Spine Rd.
		August 16	3	0	3	N of Spine Rd.
		August 17	3	1	4	S of Spine Rd.
		Sept. 21	5	0	5	S of Spine Rd.
Polar Bear	Beechey point	August 16	1	1	2	Barrier island
Wolverine	NPRA	June 16	1	0	1	Fish Creek delta

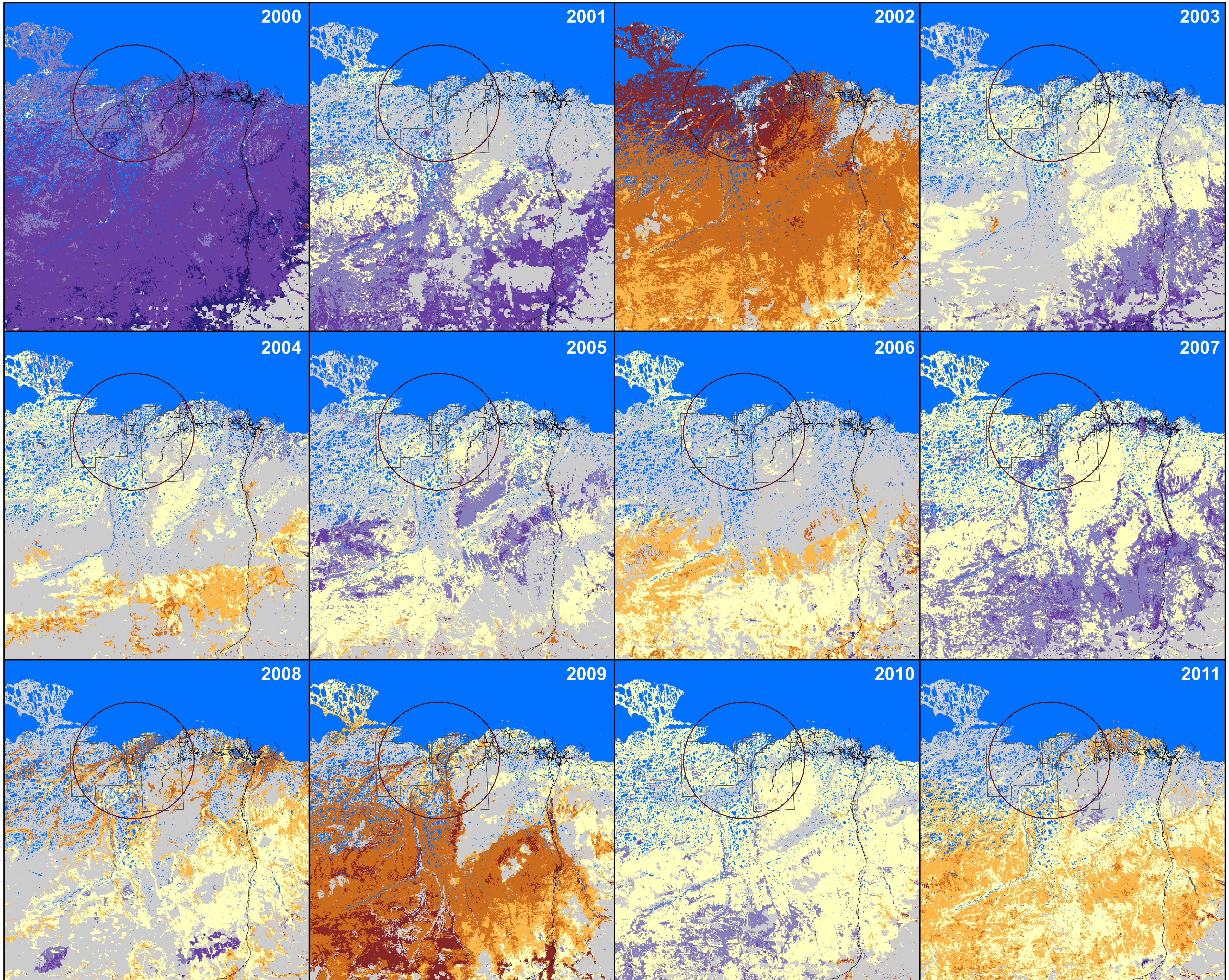


Appendix D.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, July 2009–June 2011.



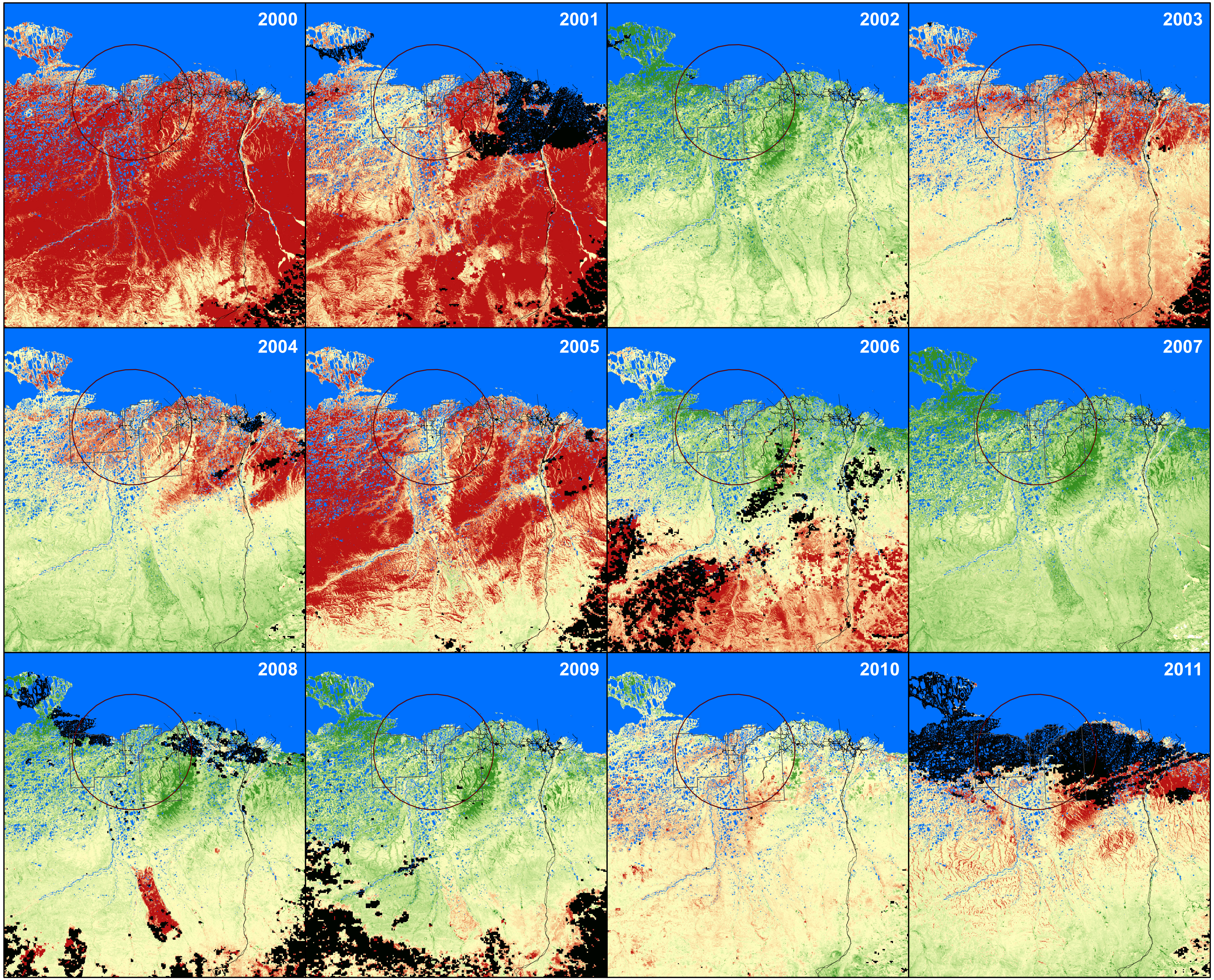


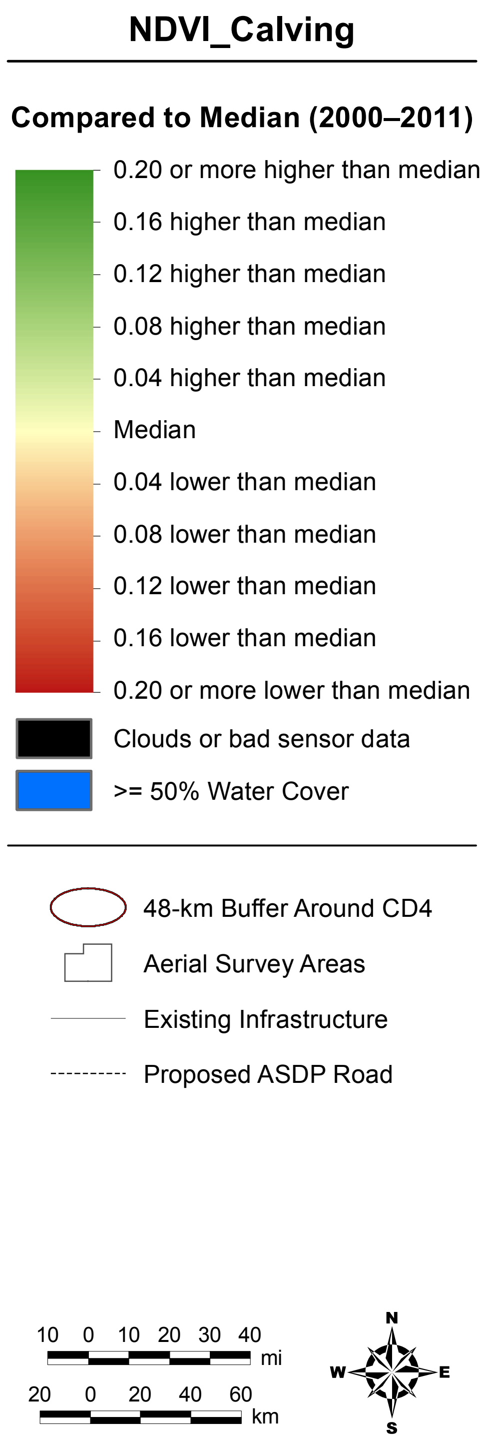
Appendix E.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 8 different seasons, July 2009–June 2011.



Appendix F.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2011, as estimated from MODIS satellite imagery.

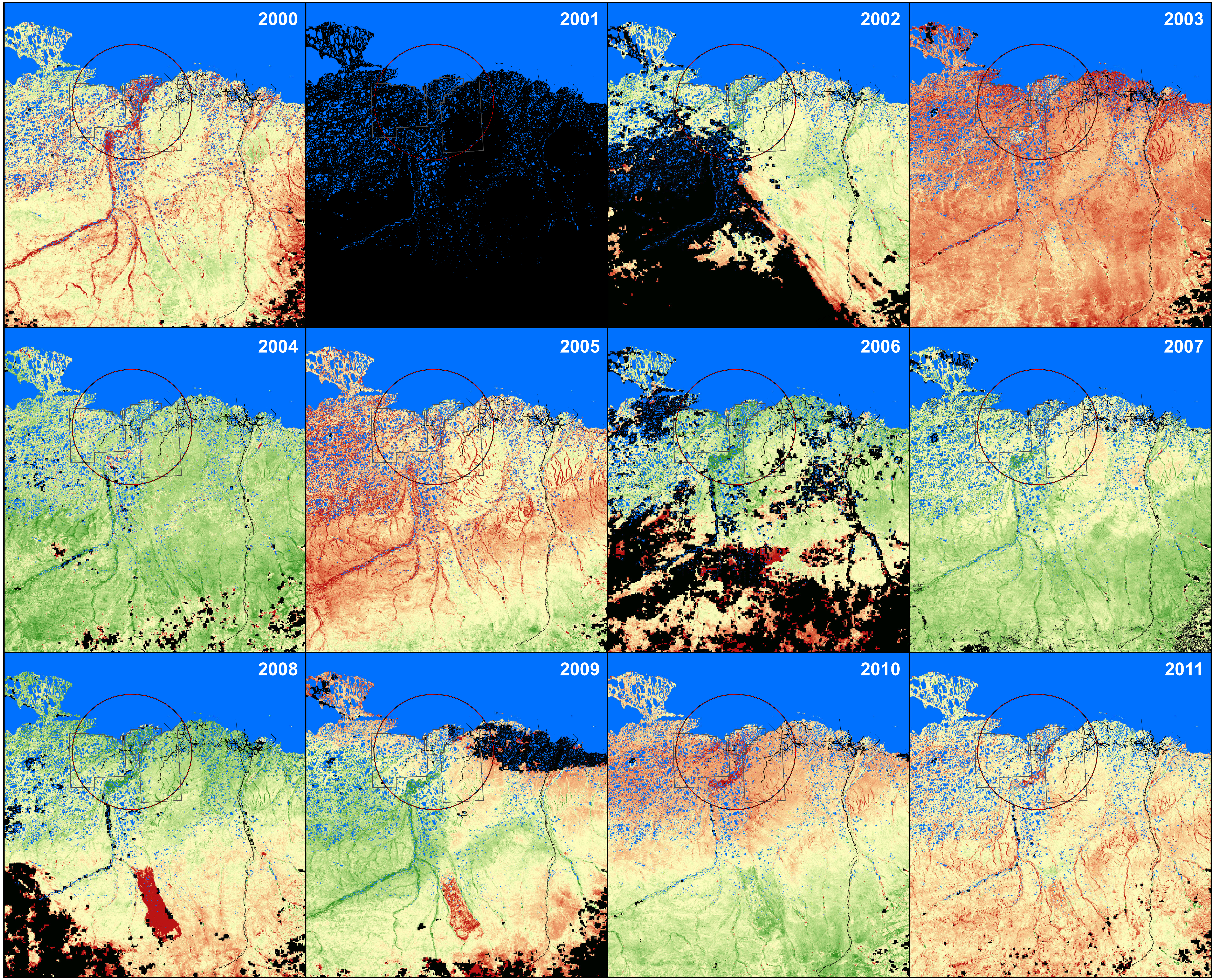
ABR file: Fig17_Snowmelt_Date_Departure_from _Median_2000-2011_11-164.mxd, 13 March 2012

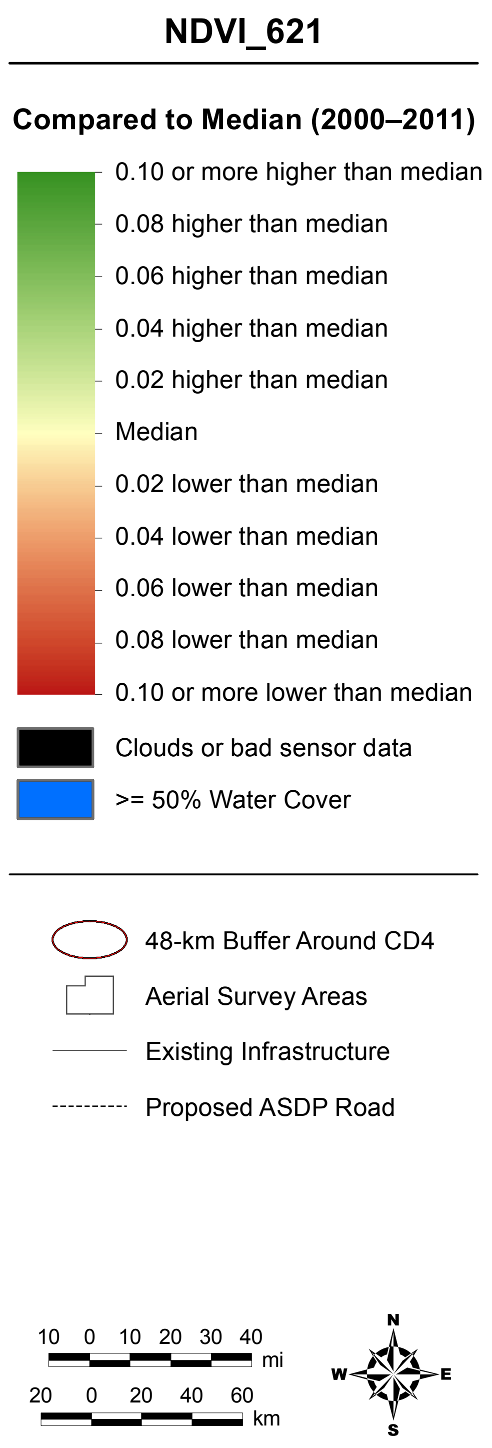




Appendix G.
Differences between annual relative vegetative biomass values and the 2000–2011 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

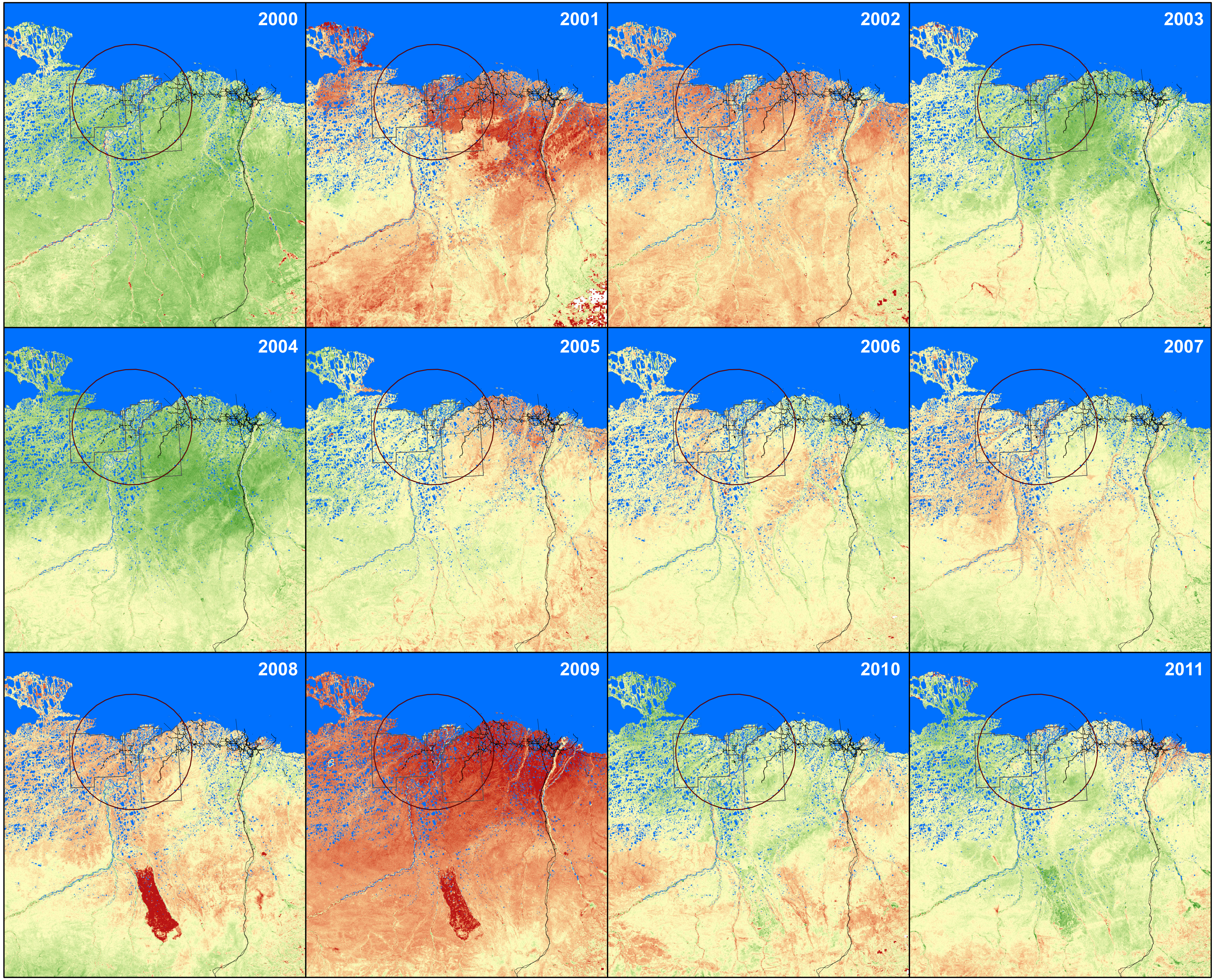
ABR file: Fig19_NDVI_Calving_Departure_from_Median_2000-2011_11-164.mxd, 13 March 2012





Appendix H.
Differences between annual relative vegetative biomass values and the 2000–2011 median at estimated peak lactation for caribou (21 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig20_NDVI_621_Departure_from_Median_2000-2011_11-164.mxd, 13 March 2012



Appendix I.
Differences between annual relative vegetative biomass values and the 2000–2011 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig21_NDVI_Max_Departure_from_
Median_2000-2011_11-164.mxd, 13 March 2012

Appendix J. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2012 and for habitat types (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2012 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	–	0.0036	0.0266	0.0055	0.0388
		NDVI_621	0.3736	0.3809	0.3755	0.4189	0.4315
		NDVI_Rate	0.0187	0.0220	0.0192	0.0212	0.0225
		NDVI_Peak	0.5663	0.5642	0.5591	0.5897	0.6008
	Snow Cover (1 June)	Mean %	97.7	98.4	89.0	95.0	99.2
	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
2005–2011	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_Calving	0.0025	0.0018	0.0254	0.0055	0.0388
		NDVI_621	0.3223	0.3745	0.3736	0.4189	0.4315
		NDVI_Rate	0.0157	0.0203	0.0190	0.0212	0.0225
		NDVI_Peak	0.5159	0.5349	0.5588	0.5897	0.6008
	Snow Cover (1 June)	Mean %	96.2	99.0	89.0	95.0	99.2
	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 K. Number of caribou groups in different geographic sections of the NPRA survey area, by year (2002–2011) and season, with results of chi-square goodness-of-fit tests (assuming a uniform distribution).

				Geographic Section						
Year	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

Appendix K. Continued.

Year	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South East	South West	Chi-square	*P*-value
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
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
2009	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	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
2010	Winter[a]	1	3	1	0	0	2	0	3.91	0.418
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	9	0	1	1	3	4	4.24	0.375
	Postcalving	1	61	1--	12	22^{+}	12	14	14.83	0.005
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	16	2	2	9^{+}	3	0-	16.00	0.003
	Late Summer	1	41	2	4-	3-	16	16	15.70	0.003
	Fall Migration	1	206	16	57	32	54	47	5.05	0.282
	Total	6	336	22-	76	67	90	81	8.40	0.078
2011	Winter	1	55	5	24^{++}	1--	11	14	20.77	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	34	1	6	3	4-	20^{++}	30.12	<0.001
	Postcalving	1	123	2--	32	37^{+}	31	21	17.76	0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	5	0	0	4^{++}	0	1	12.59	0.013
	Late Summer	1	46	0--	4--	3--	18	21^{++}	28.30	<0.001
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	263	8--	66	48	64	77^{+}	22.81	<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 L. 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, 2002–2011.

				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 L. 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
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
2010	Winter	1c	3	0.60	0.84	1.13	1.02	0.90	0.96	4.18	0	0.67
	Spring Migration	0	–		–	–	–	–	–	–	–	–
	Calving	1	9	0.72	0.68	0.79	0.49	1.58+	0	1.43	8.00	0
	Postcalving	1	61	0.81	0.80	1.05	0.94	0.98	0.44	1.80+	2.71	2.18+
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	16	0.93	1.50	1.09	0.17--	0.21--	2.61	1.79	2.32	8.55^{++}
	Late Summer	1	41	0.82	0.94	1.16	1.03	1.11	0.36	1.26	2.19	0.02--
	Fall Migration	1	206	0.89	0.95	1.01	1.10	0.96	1.42	1.14	1.31	1.09
	Total	6	336	0.87	0.94	1.04	1.00	0.96	1.14	1.35+	1.90	1.47+
2011	Winter	1	55	1.29	0.78	1.05	1.39+	0.97	0.54	0.94	1.29	0.05--
	Spring Migration	0	–		–	–	–	–	–	–	–	–
	Calving	1	34	0.87	0.71	0.82	1.09	1.23	0.18-	1.24	3.18	0.57
	Postcalving	1	123	0.79	0.85	1.12	1.05	0.94	1.67	1.53+	1.29	1.54
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	5	1.24	0.53	1.61	0.73	0.17-	5.54	1.51	11.16	7.85+
	Late Summer	1	46	1.34	1.18	0.75	0.82	1.10	0.42	0.92	2.02	0.05-
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	5	263	1.01	0.87-	1.01	1.08	1.00	1.09	1.26	1.85	0.96

[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 M. Number of caribou groups in distance zones around proposed ASDP road, by year (2001–2011) and season, with results of a chi-square goodness-of-fit test (assuming a uniform distribution).

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
2001	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	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 M. 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
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
2010	Winter	1	1	0	0	1	0	0	2.02	0.732
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	3	0	1	0	0	2	7.36	0.118
	Postcalving	1	15	4	1	5	1	4	3.14	0.534
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	3	2	1	0	0	0	6.15	0.188
	Late Summer	1	18	3	1	8	3	3	1.98	0.739
	Fall Migration	1	45	2--	6	14	9	14	11.98	0.017
	Total	6	85	11	10	28	9	14	8.89	0.064
2011	Winter	1	12	1	0	4	2	5	7.50	0.112
	Spring	0	–	–	–	–	–	–	–	–
	Calving	1	8	3	0	1	1	3	6.11	0.191
	Postcalving	1	25	2	1-	8	10	4	12.96	0.011
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	1	1	0	0	0	0	4.30	0.367
	Late Summer	1	13	0	2	4	2	5	6.51	0.164
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	59	7	3--	17	15	17	15.54	0.004

\+ 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 N. Model-selection results (General Estimating Equations) for analyses of caribou density during calving in the NPRA survey area in 2012 (163 grid cells). The best model (bold type) contained the variables presence of proposed road (included in all models), presence of Fish or Judy Creeks (included in all models), W to E (transect number) and NDVI_621.

Model[a]	n[b]	K[c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
Road, Creek, W to E, NDVI_621	163	6	237.75	0.00	0.635
Road, Creek, W to E, Snow Cover, NDVI_621	163	7	239.75	2.00	0.234
Road, Creek, NDVI_621	163	5	242.53	4.78	0.058
Road, Creek, Snow Cover, NDVI_621	163	6	244.17	6.42	0.026
Road, Creek, W to E, NDVI_peak	163	6	244.44	6.69	0.022
Road, Creek, NDVI_peak	163	5	245.85	8.10	0.011
Road, Creek, W to E, Snow Cover, NDVI_peak	163	7	246.38	8.62	0.009
Road, Creek, Snow Cover, NDVI_peak	163	6	247.46	9.71	0.005
Road, Creek, W to E, Tussock	163	6	253.76	16.01	0.000
Road, Creek, W to E, Snow Cover, Tussock	163	7	255.44	17.69	0.000
Road, Creek, W to E, Wet Habitat	163	6	258.80	21.05	0.000
Road, Creek, W to E, Snow Cover, Wet Habitat	163	7	259.02	21.27	0.000
Road, Creek, W to E	163	5	262.49	24.74	0.000
Road, Creek, W to E, Snow Cover	163	6	264.13	26.37	0.000
Road, Creek, Tussock	163	5	264.33	26.58	0.000
Road, Creek, Snow Cover, Tussock	163	6	265.11	27.36	0.000
Road, Creek, Snow Cover, Wet Habitat	163	6	267.31	29.56	0.000
Road, Creek, Wet Habitat	163	5	267.36	29.61	0.000
Road, Creek, Snow Cover	163	5	267.86	30.11	0.000
Intercept	163	2	268.81	31.06	0.000

[a] W to E = west-to-east gradient (transect number); Tussock = proportion of tussock tundra; Wet Habitat = combined proportions of four types (see text); Road = presence of the proposed road; and Creek = presence or absence of Fish or Judy Creeks.
[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 O. Model-selection results (General Estimating Equations) for analyses of caribou density during calving in the Colville East survey area in 2012 (553 grid cells). The best model (bold type) contained the variables W to E (transect number) and proportion of waterbodies (both included in all models), presence of roads, snow cover (%), and distance to coast (km).

Model [a]	n[b]	K[c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
W to E, Water, Road, Snow Cover, Coast	**553**	**8**	**701.04**	**0.00**	**0.252**
W to E, Water, Road, Snow Cover, Coast, NDVI_Peak	553	9	701.63	0.59	0.187
W to E, Water, Snow Cover, Coast	553	7	702.43	1.39	0.126
W to E, Water, Road, Wet Habitat, Snow Cover, Coast, NDVI_Peak	553	10	702.88	1.84	0.100
W to E, Water, Road, Wet Habitat, Snow Cover, Coast	553	9	703.04	2.00	0.093
W to E, Water, Snow Cover, Coast, NDVI_Peak	553	8	703.52	2.48	0.073
W to E, Water, Wet Habitat, Snow Cover, Coast	553	8	704.37	3.33	0.048
W to E, Wet Habitat, Snow Cover, Coast, NDVI_Peak	553	9	705.42	4.38	0.028
W to E, Water, Road, Coast	553	7	705.43	4.39	0.028
W to E, Water, Road, Coast, NDVI_Peak	553	8	705.61	4.57	0.026

[a] W to E = west-to-east gradient (transect number); Water = proportion covered by waterbodies; Road = within 2 km of a road; Wet Habitat = proportion classified as wet graminoid tundra; Snow Cover = percent snow cover on 30 May 2011; Coast = distance from coast; NDVI_Peak = maximum NDVI value during 2012.
[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 P. Model-selection results (Generalized Estimating Equation) for analyses of caribou density in different seasons during 2002–2012 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,TN	S,C,R,TN,NP	S,C,R,TN,TT	S,C,R,DC,NP	S,C,R,DC,TT	S,C,R,DC,WH	S,C,R,TN,DC	S,C,R,TN,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]	9	10	10	10	10	10	11	11	11	11	11	11	11	12	**12**	12
	QIC_c [e]	1,291	1,293	1,291	1,292	1,293	1,281	1,281	1,279	1,293	1,293	1,294	1,283	1,282	1,282	**1,279**	1,283
	w_i [f]	0.001	<0.001	0.001	0.001	<0.001	0.114	0.090	0.344	<0.001	<0.001	<0.001	0.044	0.078	0.066	**0.225**	0.036
Spring	K	12	13	13	13	13	13	14	14	14	14	14	**14**	14	15	15	15
	QIC_c	1,238	1,240	1,239	1,239	1,238	1,232	1,232	1,234	1,241	1,241	1,240	**1,231**	1,233	1,233	1,233	1,233
	w_i	0.007	0.003	0.004	0.005	0.006	0.159	0.170	0.066	0.001	0.002	0.002	**0.223**	0.079	0.106	0.082	0.085
Calving	K	15	16	16	16	16	16	17	17	17	17	17	17	17	18	**18**	18
	QIC_c	2,752	2,676	2,696	2,743	2,749	2,687	2,642	2,653	2,666	2,677	2,678	2,645	2,668	2,632	**2,632**	2,641
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.530	**0.461**	0.006
Postcalving	K	14	15	15	15	15	15	16	16	16	16	16	16	16	17	**17**	17
	QIC_c	3,136	3,137	3,138	3,137	3,138	3,050	3,051	3,051	3,139	3,137	3,138	3,032	3,051	3,032	**3,028**	3,030
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.082	<0.001	0.070	**0.598**	0.250
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11	11
	QIC_c	343	308	330	338	342	338	325	334	309	308	309	**294**	338	296	296	296
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.456**	<0.001	0.192	0.184	0.167
Oestrid Fly[g]	K	9	10	10	10	10	10	11	**11**	11	11	11	11	11	12	12	12
	QIC_c	524	521	525	518	524	510	509	**508**	516	514	521	512	512	508	509	513
	w_i	<0.001	<0.001	<0.001	0.001	<0.001	0.107	0.202	**0.224**	0.004	0.015	<0.001	0.041	0.044	0.215	0.128	0.018
Late Summer	K	20	21	21	21	21	21	22	22	22	22	22	22	22	**23**	23	23
	QIC_c	2,615	2,617	2,606	2,601	2,613	2,587	2,573	2,581	2,605	2,603	2,615	2,585	2,589	**2,575**	2,581	2,587
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.702	0.018	<0.001	<0.001	<0.001	0.002	<0.001	**0.261**	0.016	0.001
Fall Migration	K	20	21	21	21	21	21	22	22	22	22	22	22	**22**	23	23	23
	QIC_c	3,317	3,319	3,318	3,316	3,313	3,308	3,309	3,309	3,320	3,317	3,315	3,309	**3,307**	3,311	3,311	3,309
	w_i	0.003	0.001	0.001	0.004	0.016	0.186	0.101	0.113	<0.001	0.002	0.007	0.095	**0.276**	0.040	0.047	0.108

[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 TN = transect number (west-to-east gradient).

[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.

[g] Road not included in models.

Appendix Q. Model-weighted parameter estimates, standard error (SE), and *P*-value of variables included in the grid-cell analyses of caribou density in the NPRA survey area, 2002–2012.

Season	Variable	Mean	SE	*P*-value[a]
Winter	Intercept	3.237	1.039	<0.002**
	Presence of Creek	-0.494	0.245	0.044
	Includes Proposed Road	0.257	0.305	0.399
	NDVI_Peak	5.475	3.645	0.133
	Distance to Coast (km)	-0.008	0.009	0.370
	Tussock Tundra (%)	1.432	0.638	0.025*
	Wet Habitat (%)	-0.760	0.630	0.228
	W to E (transect number)	-0.093	0.024	<0.001***
Spring Migration	Intercept	1.662	1.253	0.185
	Presence of Creek	-0.434	0.226	0.055
	Includes Proposed Road	0.400	0.325	0.219
	NDVI_Peak	-3.869	3.432	0.260
	Distance to Coast (km)	-0.013	0.009	0.138
	Tussock Tundra (%)	-0.133	0.655	0.840
	Wet Habitat (%)	-0.353	0.645	0.584
	W to E (transect number)	-0.068	0.022	0.002**
Calving	Intercept	-4.426	2.931	0.131
	Presence of Creek	0.172	0.164	0.294
	Includes Proposed Road	-0.235	0.229	0.305
	NDVI_Peak	10.766	2.551	<0.001***
	Distance to Coast (km)	0.026	0.006	<0.001***
	Tussock Tundra (%)	1.881	0.451	<0.001***
	Wet Habitat (%)	-1.186	0.440	0.007**
	W to E (transect number)	-0.106	0.019	<0.001***
Postcalving	Intercept	-2.535	0.556	<0.001***
	Presence of Creek	1.130	0.157	<0.001***
	Includes Proposed Road	-0.357	0.210	0.089
	NDVI_Peak	3.453	2.385	0.148
	Distance to Coast (km)	-0.030	0.006	<0.001***
	Tussock Tundra (%)	1.096	0.429	0.011*
	Wet Habitat (%)	-0.868	0.426	0.041*
	W to E (transect number)	-0.172	0.016	<0.001***
Mosquito	Intercept	-3.112	1.912	0.104
	Presence of Creek	0.538	0.427	0.208
	Includes Proposed Road	0.246	0.645	0.703
	NDVI_Peak	-6.140	7.229	0.396
	Distance to Coast (km)	-0.122	0.019	<0.001***
	Tussock Tundra (%)	-0.849	1.357	0.532
	Wet Habitat (%)	0.306	1.351	0.821
	W to E (transect number)	-0.187	0.046	<0.001***
Oestrid Fly[b]	Intercept	-1.882	3.387	0.579
	Presence of Creek	1.941	0.321	<0.001***
	Includes Proposed Road[c]	–	–	—
	NDVI_Peak	-11.867	5.436	0.029
	Distance to Coast (km)	0.020	0.015	0.202
	Tussock Tundra (%)	-1.829	0.967	0.059
	Wet Habitat (%)	0.402	0.953	0.673
	W to E (transect number)	-0.130	0.035	<0.001***

Appendix Q. Continued.

Season	Variable	Mean	SE	*P*-value[a]
Late Summer	Intercept	1.941	1.291	0.133
	Presence of Creek	0.467	0.140	<0.001***
	Includes Proposed Road	0.122	0.211	0.564
	NDVI_Peak	-8.133	2.043	<0.001***
	Distance to Coast (km)	-0.001	0.006	0.807
	Tussock Tundra (%)	-1.145	0.411	0.005**
	Wet Habitat (%)	0.233	0.415	0.574
	W to E (transect number)	-0.082	0.014	<0.001***
Fall Migration	Intercept	-0.656	0.567	0.248
	Presence of Creek	-0.015	0.143	0.919
	Includes Proposed Road	0.035	0.201	0.863
	NDVI_Peak	-1.699	2.121	0.423
	Distance to Coast (km)	-0.003	0.006	0.622
	Tussock Tundra (%)	-0.410	0.403	0.308
	Wet Habitat (%)	0.705	0.405	0.082
	W to E (transect number)	-0.048	0.014	0.001***

[a] Significance of *P*-value: * <0.05, ** <0.01, *** <0.001.
[b] Two outliers removed prior to analysis.
[c]. Not included in the model.