7TH ANNUAL REPORT

CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2011

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May 2012

Printed on recycled paper.

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 (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 seventh 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 2005–2011, 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 1990–2011 for the TH and 1986–1990 and 2001–2005 for the CAH; and GPS-collar data were collected during 2004–2011 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 2008–2010 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 2000–2011, 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 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 2000–2011 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 (2001–2011), although distribution and abundance fluctuated substantially. West of the Colville River, the highest densities of caribou typically occurred in fall; large groups of caribou were present occasionally during mosquito and oestrid-fly seasons, but the occurrence of caribou was highly variable among seasons. East of the Colville River, the highest densities occurred during the calving and postcalving seasons. The mean proportion of collared TH caribou within the ASDP study area during each month ranged from 8% to

39% for satellite collars during 1990–2011 and 3% to 41% for GPS collars during 2004–2011. 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 2001–2011 and between 0 and 48% for GPS collars during 2003–2006 and 2008–2011.

- High-density calving occurred east of the Colville River for the CAH (in the southeastern part of the ASDP study area) and around Teshekpuk Lake for the TH (west of the ASDP study area). Although some calving occurs in the western half of the NPRA survey area, it is not an area of concentrated calving for the TH. During 2011, only 84 caribou were observed in the NPRA survey area during the calving survey.
- 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. Two satellite-collared male TH caribou and two GPS-collared female CAH caribou were in the CD4 vicinity (between Nuiqsut and the Alpine facilities) in midsummer 2011. 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 2002–2011 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 2002–2011 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 late summer 2011 but areas with lower levels of vegetative biomass were used more than expected during the oestrid-fly season.
- 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 2011 contained a west-to-east gradient and NDVI_621, but none of the model-weighted parameter estimates differed significantly from zero.
- In the Colville East survey area, the density of calving caribou during the early calving survey in 2011 increased with distance to the coast, from west to east, and in areas that had greater snow cover on 30 May 2011. Density decreased in areas with more waterbodies and within 2 km of existing roads. During the late calving survey, the density of calving caribou increased in areas that had greater snow cover on 30 May 2011 and decreased in areas with more waterbodies and 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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This study was funded by ConocoPhillips Alaska, Inc. (CPAI) and was administered by Robyn McGhee, CPAI Environmental Scientist, for whose support we are grateful. Assistance with field logistics was provided by CPAI environmental personnel Kelly Brown, Justin Blank, Cory Runa, and Erik Burney. CPAI senior environmental coordinators at Kuparuk—Jim Short, Shannon Donnelly, Wendy Mahan, and Kristy McCullogh—also provided assistance and support.

Alaska Department of Fish and Game (ADFG) biologists in Barrow and Fairbanks played crucial roles in this study by capturing caribou, deploying radio-collars, and providing telemetry data under a cooperative agreement among ADFG, CPAI, and ABR. We thank Lincoln Parrett, Geoff Carroll, Beth Lenart, Jason Caikoski, Steve Arthur, and Patty Del Vecchio of ADFG for their professional cooperation and assistance. Brian Person of the North Slope Borough (NSB) Department of Wildlife Management provided valuable information and advice on GPS- and satellite-telemetry databases.

Pilots Sandy Hamilton, Morgan Stanton, and Bob Eubank (Arctic Air Alaska) provided safe and efficient piloting of survey airplanes under flying conditions that often were less than optimal. The hard work and dedication of ABR staff were key to the success of this study. Assistance in the field was provided by Jennifer Boisvert, Joel Gottschalk, Alyson McHugh, Julie Parrett, John Rose, and Tim Obritschkewitsch and support during data analysis and report preparation was provided by Chris Swingley, Dorte Dissing, Allison Zusi–Cobb, Will Lentz, Pam Odom, Tony LaCortiglia, and Davya Flaharty. Reviews by Robyn McGhee (CPAI) and Brian Person (NSB) improved this report.

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, Lawhead et al. 2011).

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, 2009). 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; Lenart 2009; Parrett 2009).

Concentrated calving activity by the CAH tends to occur in two areas of the coastal plain, one located south and southwest of the Kuparuk oilfield and the other east of the Sagavanirktok River, away from current oilfield development (Wolfe 2000, Arthur and Del Vecchio 2009, Lawhead and Prichard 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 2009).

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. 2011). Consultants working for BP Exploration (Alaska) Inc. also conducted aerial transect surveys over much of the TH calving grounds during 1998–2001 (Noel 1999, 2000; Jensen and Noel 2002; Noel and George 2003).

East of the Colville River, ADFG has conducted annual studies of the CAH since the late 1970s using a combination of VHF, satellite, and GPS telemetry, as well as periodic aerial transect surveys (Cameron et al. 1995, 2005; Arthur and Del Vecchio 2009; Lenart 2009). Consultants working for BP Exploration (Alaska) Inc. conducted calving surveys of the CAH in the Milne

Point oilfield and part of the Kuparuk oilfield in 1991, 1994, and 1996–2001 (Noel et al. 2004).

The current period of oil and gas leasing and exploration in NPRA closely followed the issuance of the 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 and is currently underway.

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 infrastructure and activities proposed by CPAI and evaluated in the ASDP EIS (BLM 2004).

PROGRAM GOALS AND STUDY OBJECTIVES

The goal of the 10-year study was specified by the CD4 permit stipulation: “The purpose of the study will be to evaluate the short- and long-term impacts of CD4 and other CPAI satellite developments on the movements and distribution of caribou.” The study is intended to be cooperative and collaborative in nature and communication of results with NSB stakeholders is a key component: “The study design will be reviewed by the NSB Department of Wildlife Management for review and approval. Additionally, a draft annual report shall be submitted to the North Slope Borough, City of Nuiqsut, Native Village of Nuiqsut, and Kuukpik Corporation for review and comments.”

To begin implementing the permit stipulation, representatives of CPAI and ABR met with NSB staff in Barrow on 2 December 2004. The study options discussed at that meeting were developed into a preliminary study design and scope of work that were circulated in early February 2005 for further review. The revised study design and scope of work were approved in late March 2005 and were amended in early July 2005 to accommodate telemetry surveys by ADFG, which were added under the terms of a cooperative agreement among ADFG, CPAI, and ABR that addressed sharing of telemetry data for use in this monitoring study. The results of each of the six preceding years of study (2005–2010) 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 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, 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 issues 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 pipeline/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

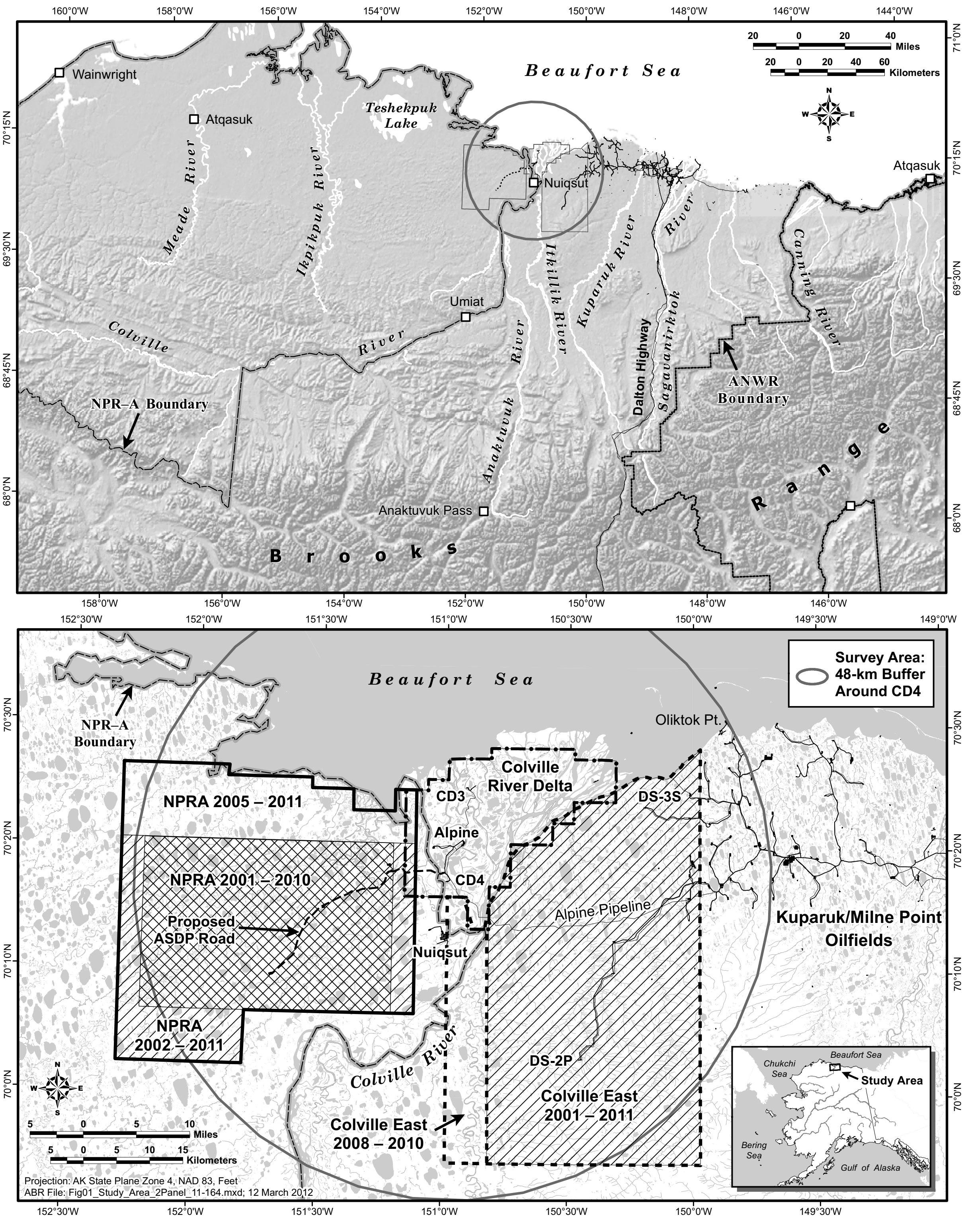


Figure 1. Location of the ASDP caribou monitoring study area (48-km radius around Drill Site CD4) on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2011 (bottom).

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 aerial transect surveys in 2011, adding to the transect database compiled for the Colville River Delta and Colville East survey areas since the early 1990s and for the NPRA survey area since 2001. We also analyzed several radio-telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and from GPS collars deployed specifically for this study annually in 2006–2010. The transect surveys provided broad information on the seasonal distribution and density of caribou in the study area. The radio-collars provided detailed location and movement data for a small number of known individuals wherever they moved throughout the year. The 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 August 2011 in a Cessna 206 or 185 airplane, following the same procedures used since 2001 (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, this study). The NPRA survey area was expanded westward and southward in 2002 and northward in 2005, and the Colville East survey was expanded westward in 2008. Additional surveys of Colville East were conducted during the calving season in 2001–2011 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012). 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.

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 (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

Table 1. Number of radio-collared caribou (collaring events) from the Teshekpuk and Central Arctic herds that provided movement data for the ASDP caribou study.

Caribou Herd and Telemetry Sample	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd				
VHF collars [a]	1980–2005	n/a	n/a	212
Satellite collars	1990–2011	95	46	141
GPS collars [b]	2004–2011	71	0	71
Central Arctic Herd				
VHF collars [a]	1980–2005	n/a	n/a	412
Satellite collars, early	1986–1990	16	1	17
Satellite collars, recent	2001–2005	14	4	18
GPS collars [c]	2003–2006	45	0	45
GPS collars	2008–2011	22	0	22

[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.

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–August 2011 (Prichard and Murphy 2004; Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 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, 141 collaring events of 126 different caribou (84 females, 42 males) transmitted signals for a mean duration of 546 days per caribou (14 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 17 caribou (14 females, 3 males), transmitting for a mean duration of 546 days. A few caribou moved between herds after collaring: four female TH animals switched to the CAH and five TH animals (4 females, 1 male) switched to the WAH. One male caribou collared with the CAH in September 2002 showed movements typical of the WAH. A caribou was assumed to have switched herds if it was in the calving area of another herd during a subsequent calving season. None of these satellite-collared caribou returned to their original herd during the time they were collared.

Although satellite-telemetry locations are considered accurate to within 0.5–1 km of the true locations (CLS 2008), the data also require screening to remove spurious locations. Using the method of Prichard and Murphy (2004), data were screened to remove duplicate locations, locations obtained before and after collaring or after mortality occurred, and locations for which the Argos system location-quality score (NQ) was zero or "B," indicating unreliability (CLS 2008). NQ scores of "A" tend to be more accurate than scores of zero (Hays et al. 2001, Vincent et al. 2002), so they were retained. Locations were removed that obviously were inaccurate because they were offshore or far from other locations. We applied a distance/rate/angle (DRA) filter, based on the distance and rate of travel between subsequent points and the angle formed by three consecutive points, and removed locations that appeared to be incorrect. Any three locations with an intervening angle of <20 degrees and both "legs" with speeds greater than 10 km/h were assumed to be inaccurate and were removed, unless the distance of either leg was less than 1 km (Prichard and Murphy 2004). If the distance of any leg was <1 km, then the location was not removed because it was close to a previous or subsequent location and therefore more likely to be accurate. We removed any locations that clearly were inaccurate based on previous and subsequent locations.

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

For the TH and recent CAH 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 42 different female TH caribou were outfitted with GPS collars (purchased by NSB and CPAI) during 2004 and 2006–2011. Some animals were collared more than once for a total of 79 different collaring events (Table 1). GPS collars were deployed by ADFG on 45 CAH females during 2003–2006, using an interval of 5 h between location fixes (Arthur and Del Vecchio 2009). Four additional GPS collars (purchased by CPAI) were deployed on CAH females in July 2008, six were deployed in June 2009, and 12 were deployed in June 2010. Ten CAH collars (deployed in 2010) were still actively transmitting in December 2011.

GPS collars were deployed only on females 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.). Data reports from satellite uplinks were received by e-mail from CLS America, Inc. (Largo, MD). All location data also were stored in the collars for downloading after the collars were retrieved, however, and those downloaded data replaced the location data that had been obtained via the Argos satellites throughout the year. The “stored-on-board” data provided the complete data set with a higher degree of accuracy and thus were preferred for analysis and archiving. Data were screened to remove any locations obtained prior to collaring or after the collars were removed, as well as any locations that obviously were incorrect because they were far from previous and subsequent locations or were located offshore.

The 2004 TH collars were programmed to record GPS fixes every 3 h (8 locations daily) throughout the entire year. The GPS collars deployed on TH animals in 2006–2009 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 the 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). Battery-life constraints dictated that only 25–50% (depending on the seasonal uplink schedule) of the data collected each day could be transmitted to the Argos satellite. Satellite uplinks were programmed to occur once daily between 16 April and 15 November and once every other day between 16 November and 15 April. Caribou were captured by firing a handheld net-gun from a Robinson R-44 piston-powered helicopter. In keeping with ADFG procedures for the region, no immobilizing drugs were used.

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

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

In June 2007, 12 more GPS collars (purchased by CPAI) were deployed. The sample collared in 2007 comprised 10 adults, one 2-yr-old, and one yearling. All caribou in the 2007 sample except the yearling were collared previously. Of the 12 caribou in the 2007 sample, one died in November 2007 and one died in April 2008. Nine of the remaining caribou were recaptured in late June and early July 2008, but the tenth animal (caribou 0624) spent the spring and summer of 2008 with WAH caribou at the western end of the North Slope, too far away to be recaptured until March 2009, while it was wintering near the Dalton Highway.

Twenty TH females were outfitted during 29 June–1 July 2008 with GPS collars purchased by the NSB. Eight collars were retrieved in late June 2009, and the collars of all surviving caribou were retrieved in June 2010. Seven TH and four CAH caribou were outfitted with factory-refurbished GPS collars purchased by CPAI in 2008. All of the CAH animals and all but two of the TH animals were new captures; two of the TH animals were recaptures from 2007. Three of the CAH collars also were equipped with Animal Pathfinder™ units (University of Calgary, Alberta), experimental devices that used triaxial accelerometer and magnetometer sensors to estimate the distance and directions of movement between consecutive GPS fixes, thereby providing a continuous movement trace for the collared animals; the devices also took digital photographs periodically for characterization of habitat use. Those devices were retrieved in 2009 but, to date, the data have not been processed successfully. ADFG also deployed 10 refurbished GPS collars on CAH females in July 2008, but data from those collars are not included in this report.

Twelve female caribou (six each from the TH and CAH) were outfitted with CPAI-purchased GPS collars in 2009; an additional CAH animal was collared but died soon after capture. One collar on a CAH animal stopped transmitting in mid-July 2009 and another CAH animal died in October 2009. All were adults and three had been collared previously. In addition to the CPAI-funded collars in 2009, another 15 GPS collars were purchased by BLM for deployment on female TH caribou.

In 2010, 12 GPS collars funded by CPAI were deployed on female CAH caribou in mid-June. Five caribou were captured west of the Sagavanirktok River and the other seven were captured east of it. One of these caribou died in July 2010 and a second caribou died in September 2010. The collars are providing occasional uplinks of locations and will be retrieved in 2012. Another 14 GPS collars were purchased by BLM for deployment on female TH caribou. In June 2011, nine female TH were outfitted with GPS collars purchased by BLM.

For the CAH caribou outfitted by ADFG with GPS collars during 2003–2006, all location data within the 48-km study area radius of CD4 were provided by ADFG. The annual GPS-collar samples (which included some of the same individuals among years) numbered 24, 24, 33, and 29 females in 2003, 2004, 2005, and 2006, respectively, of which 19, 18, 19, and 20 animals were recorded at least once within the 48-km radius; 45 different individuals were located in the study area at least 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* 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 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:

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

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 2000–2011 using the algorithm of Salomonson and Appel (2004). NDSI was calculated and then the subpixel-scale snow fraction was calculated as follows:

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

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 2000–2011, 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 2000–2011 was processed in this manner and a composite was compiled to identify the first date with 50% or lower snow cover for each pixel. 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 in that time interval (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated (Rouse et al. 1973; http://modis.gsfc.nasa.gov/about/specs.html) as follows:

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

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 2000–2011 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 2000–2011 (though there were not adequate cloud-free days to calculate NDVI_Calving over much of the study area in some years, including 2011). NDVI values near peak lactation (NDVI_621) were interpolated 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 2000–2011.

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. The alignment of the proposed ASDP road was changed in 2009, requiring recalculation of the distance buffers previously delineated around the alignment, as described below.

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

GEOGRAPHIC LOCATION

Visual inspection of caribou distribution 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 2005–2011 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.

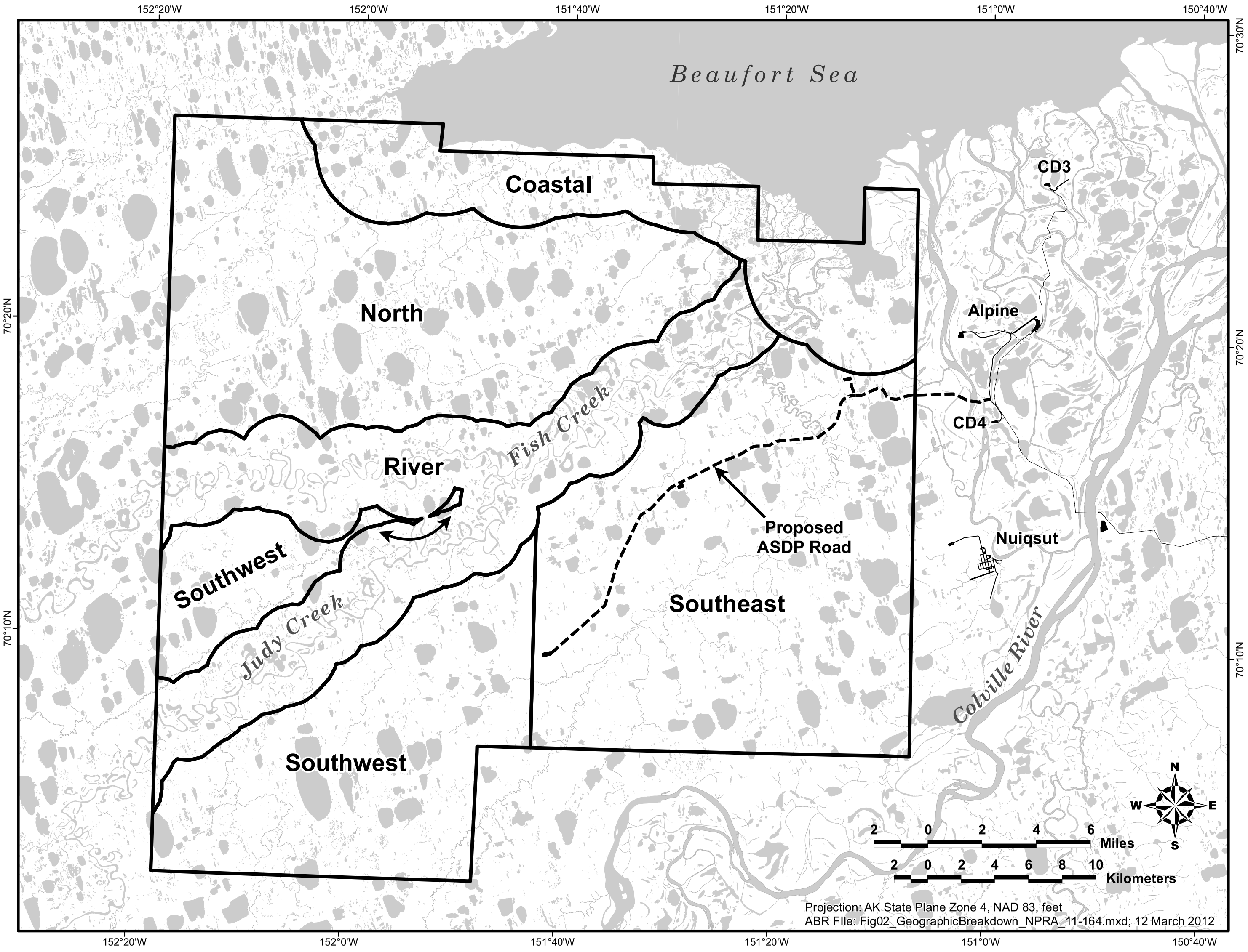
HABITAT USE

To compare habitat use with availability in the expanded 2005–2011 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 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 2005–2011 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



Projection: AK State Plane Zone 4, NAD 83, feet
ABR FIle: Fig02_GeographicBreakdown_NPRA_11-164.mxd; 12 March 2012

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2011.

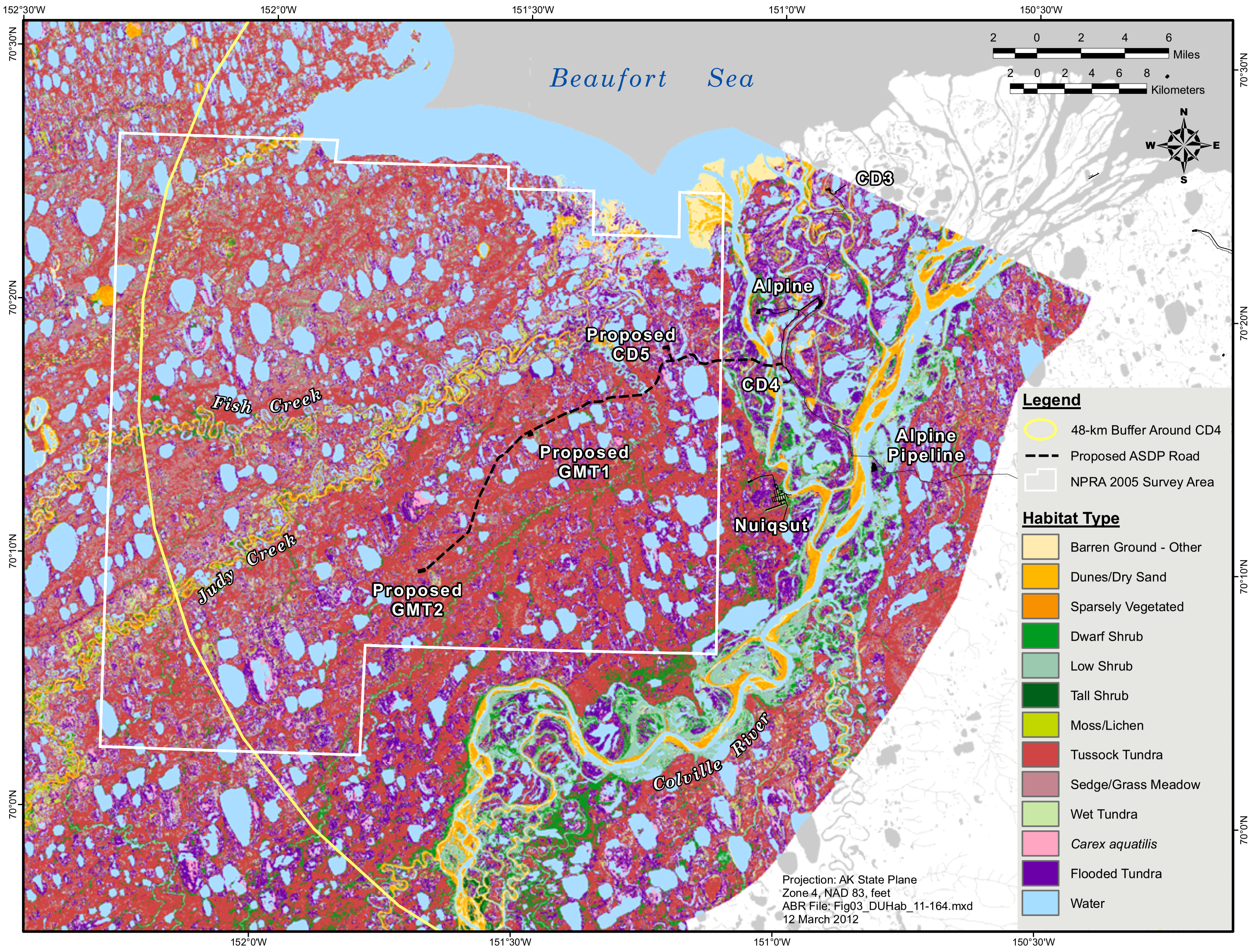


Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2011.

locations in the 2005–2009 survey area (12,475 in the winter 2008 survey area because it could not be surveyed completely) and 19,470 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

The values of snow cover (%) on 30 May 2011 were estimated for each caribou group location (excluding pixels with >50% water). The snow-cover percentages for 30 May at all locations where caribou were seen were compared with availability using the statistical technique of bootstrapping (Manly 1997), calculated in the following way. From all pixels used by caribou in a season, we selected (randomly and with replacement) a number of samples of snow-cover fractions equal to the number of caribou observed. The mean of the new data set was calculated and a new sample was generated in the same manner; this process was repeated 20,000 times to generate mean values. The resulting 20,000 mean values were compared with the availability of snow-cover values in the survey area. If the mean snow-cover value of all pixels within the survey area was more extreme than 95% or 99% of the randomly generated means, then use was considered to differ significantly from availability at $P = 0.05$ or $P = 0.01$, respectively.

VEGETATIVE BIOMASS

We compared caribou group locations in the NPRA aerial-survey area in 2011 with estimated vegetative biomass (NDVI values). Two of the variables (NDVI_Calving and NDVI_Rate) could not be estimated for most of the study area in 2011 due to persistent cloud cover that obscured the ground near much of the coast from 1–14 June 2011. The values of variables NDVI_621 and NDVI_Peak were determined for each caribou group location (excluding pixels with >50% water) and those values were compared with availability using estimates derived by bootstrapping (Manly 1997). For each season, we selected (randomly and with replacement) a number of samples of NDVI values equal to the number of caribou groups observed 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. We received an updated alignment for the proposed road in 2009 and recalculated the distance zone buffers accordingly (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 were flown in the mosquito season 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 2005–2011 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 2011, 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 30 May 2011, 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 ($r > 0.828$ for 2005–2010 within the 163 grid cells in the NPRA survey area, after removing one outlier cell on the Colville River delta composed mostly of barren ground), so we used the value of NDVI_Peak from 2011 in multi-year analyses. NDVI_621 from 2011 was used only for analysis of 2011 calving density.

We tested various models for calving density in 2011 and the density in each season for the combined years 2002–2011. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than in subsequent years. A GEE analysis (*SPSS* version 16.0 software, SPSS Inc., Chicago, IL) using a negative binomial distribution and a log link, was used to test for differences in the number of caribou among the different grid cells. In this analysis, each survey was treated as independent; various combinations of NDVI_Peak, NDVI_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.

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

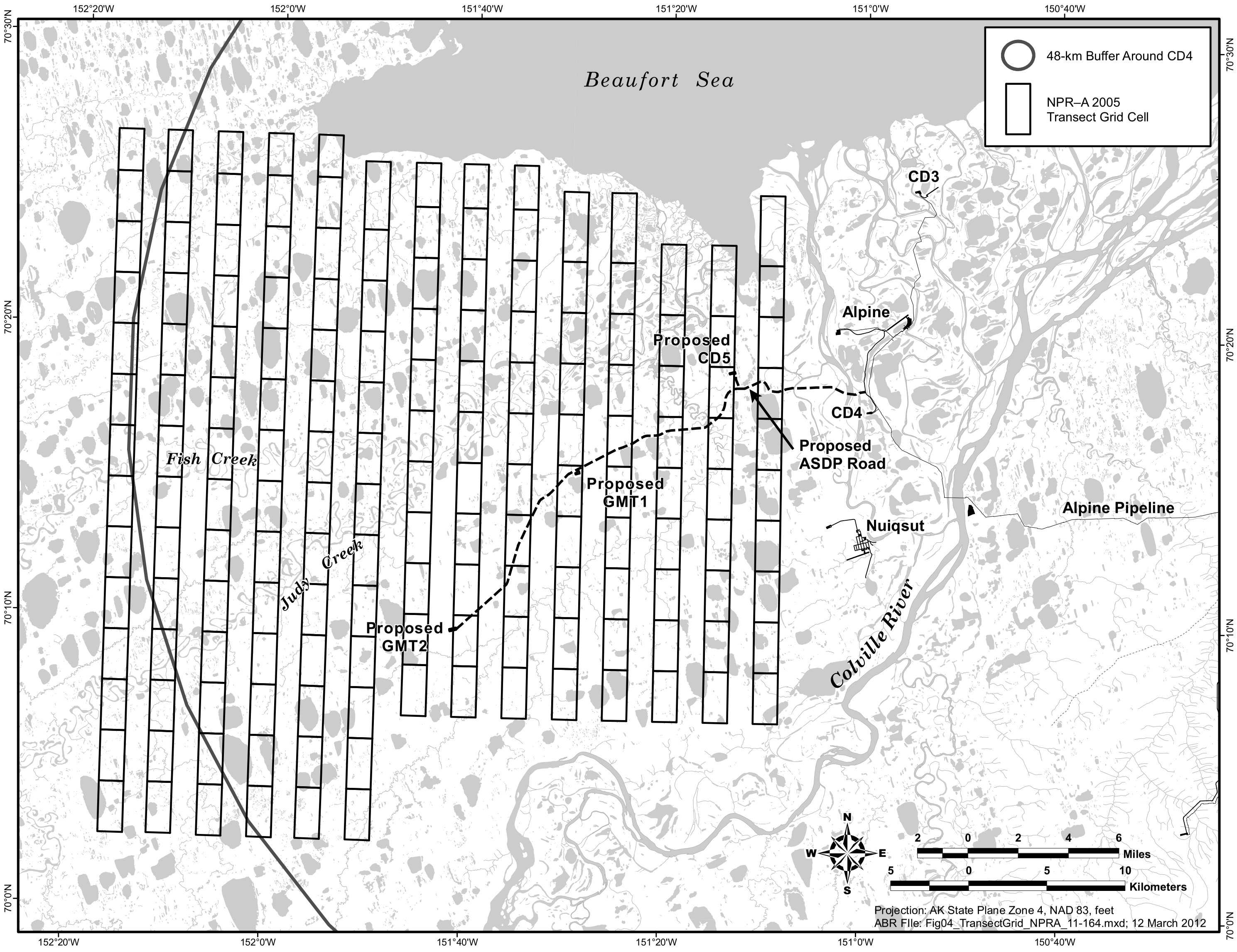


Figure 4. Locations of transect grid-cells ($n = 164$) used to analyze caribou density in the NPRA survey area, 2005–2011.

estimated parameter values for each model containing the variable of interest, while weighting the average by the Akaike weight (Burnham and Anderson 2002). These model-averaged parameter estimates and standard errors are preferred over model-specific parameters because they incorporate estimates from all possible models and take into account the uncertainty in choosing the best model. Therefore, it is not necessary to base results on a single "best" model.

The presence of Fish and Judy creeks was included in all 20 candidate models for calving density in NPRA in 2011, but the different models had various combinations of NDVI_Peak, NDVI_621, snow cover on 30 May 2011, 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. The presence of the proposed road was dropped from the analysis in 2011 because the model failed to converge when it was included; this may have resulted from the low number of caribou observed during the single calving survey in 2011. NDVI_Rate was not included in the analysis because it could not be measured over much of the survey area in 2011. One grid cell located on the Colville River delta was removed because it contained little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

Sixteen candidate models were used for seasonal tests over all years (2002–2011) 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 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.

We used a similar analysis to model factors related to the calving distribution of CAH caribou in Colville East during the aerial surveys on 2–3 June and 10 June 2011. 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 2011, the proportion of wet graminoid tundra (Muller et al. 1999) in the area, and snow cover on 30 May 2011. 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 covered by waterbodies and transect number (west-to-east gradient) was 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 2012). Candidate models were compared and model-averaged parameter estimates were calculated in the same manner as for the NPRA surveys. Separate analyses were conducted for each of the two surveys ("early" and "late").

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 and 2011 (Lawhead and Prichard 2012). Snow depth was slightly above the long-term average for Kuparuk in mid-May 2011 but had melted at the Kuparuk airstrip by the end of May (Appendix B). Patchy snow cover remained over much of the study area, however, and temperatures largely remained below freezing during early June. Snow cover was therefore still patchy during both calving surveys conducted on 2–4 June and 8–10 June 2011 (Lawhead and Prichard 2012) 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 (Lawhead et al. 1994). Snow was essentially gone from all survey areas by the time of the postcalving survey on 22–23 June 2011. 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. The Kuparuk airstrip was closed for most of the summer in 2011 during the initial phase of a project to pave the runway. Consequently, the daily recording of weather data at the airstrip ended on 17 June and we were unable to obtain summer temperature data for comparison with the long-term weather record for this location. To estimate summer weather conditions in the GKA after mid-June in 2011, we acquired daily temperature data from the National Weather Service for the weather stations at Nuiqsut and Deadhorse. In comparisons of temperature data from previous years, Deadhorse summer temperatures tended to be lower than Kuparuk temperatures and Nuiqsut summer temperatures tended to be higher than Kuparuk temperatures. We therefore used the average of the Nuiqsut and Deadhorse temperatures as an estimate of Kuparuk summer temperatures in 2011. 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 TDD sums) was about average in late June and early July, but late July and early August were both 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 based on daily maximum temperatures (but ignoring wind speed; Russell et al. 1993) at Nuiqsut and Deadhorse were below average in late June and early July and were above average in late July and early August (Lawhead and Prichard 2012). Thus, the available weather data indicate that the levels of insect activity and resulting harassment of caribou in 2011 were low in June and early July and above average in late July and early August.

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

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

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

Five surveys of the NPRA survey area were flown between 28 April and 19 August 2011 (Table 2, Figure 5). One survey in September and two surveys in October were planned but could not be flown due to persistent poor weather. Caribou density in the NPRA survey area was moderately high in the spring and during calving, then increased in late June; it was very low in early August and increased slightly by mid-August. The estimated density of caribou ranged from a high of 0.67 caribou/km² on 22 June to a low of 0.01 caribou/km²on 1 August (Table 2). The density of caribou during calving (0.18 caribou/km² on 8 June) was in the low end of the range of densities observed during 2001–2010 (0.06–0.87 caribou/km² for 6–9 June). Only eight calves (10.5% of the total number of caribou) were observed in the survey area on 8 June 2011, underscoring the low use of the area for calving

Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–August 2011.

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 28	1,720	198	0	198	396	61.5	0.23	3.6
June 8[g]	1,720	76	8	84	315	67.1	0.18	2.5
June 22	1,720	553	27	580	1,160	154.9	0.67	4.7
August 1	1,720	5	1	6	12	3.4	0.01	1.2
August 19	1,720	55	nr	55	110	15.5	0.06	1.2
COLVILLE RIVER DELTA								
April 28–29	494	0	0	0	0	–	0	–
June 8[g]	494	0	0	0	0	–	0	–
June 22	494	12	0	12	24	15.5	0.05	6.0
August 1	494	73	21	91	292[h]	122.4	0.59	26.3
August 18–20	494	3	0	3	6	2.2	0.01	1.0
COLVILLE EAST								
April 29	1,696	14	0	14	28	8.7	0.02	2.3
June 2–3[g, i]	1,432	382	40	422	1,584	441.2	1.11	2.2
June 10[g, i]	1,432	462	132	594	2,229	488.4	1.56	3.4
June 22–23	1,696	672	106	778	1,556	94.9	0.92	6.1
August 2	1,696	594	140	734	1,468	550.9	0.87	11.0
August 18–20	1,696	32	nr	32	64	12.6	0.04	1.2

[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) due to patchy snow cover during survey.

[h] An additional 201 caribou were observed off-transect during the survey; therefore, the observed total was greater than the estimated total and was used in the density calculation.

[i] Survey of calving-season transects (1.6-km spacing) at 90-m altitude for 50% coverage; SE calculated based on 3.2 km-long transect segments (Lawhead and Prichard 2012).

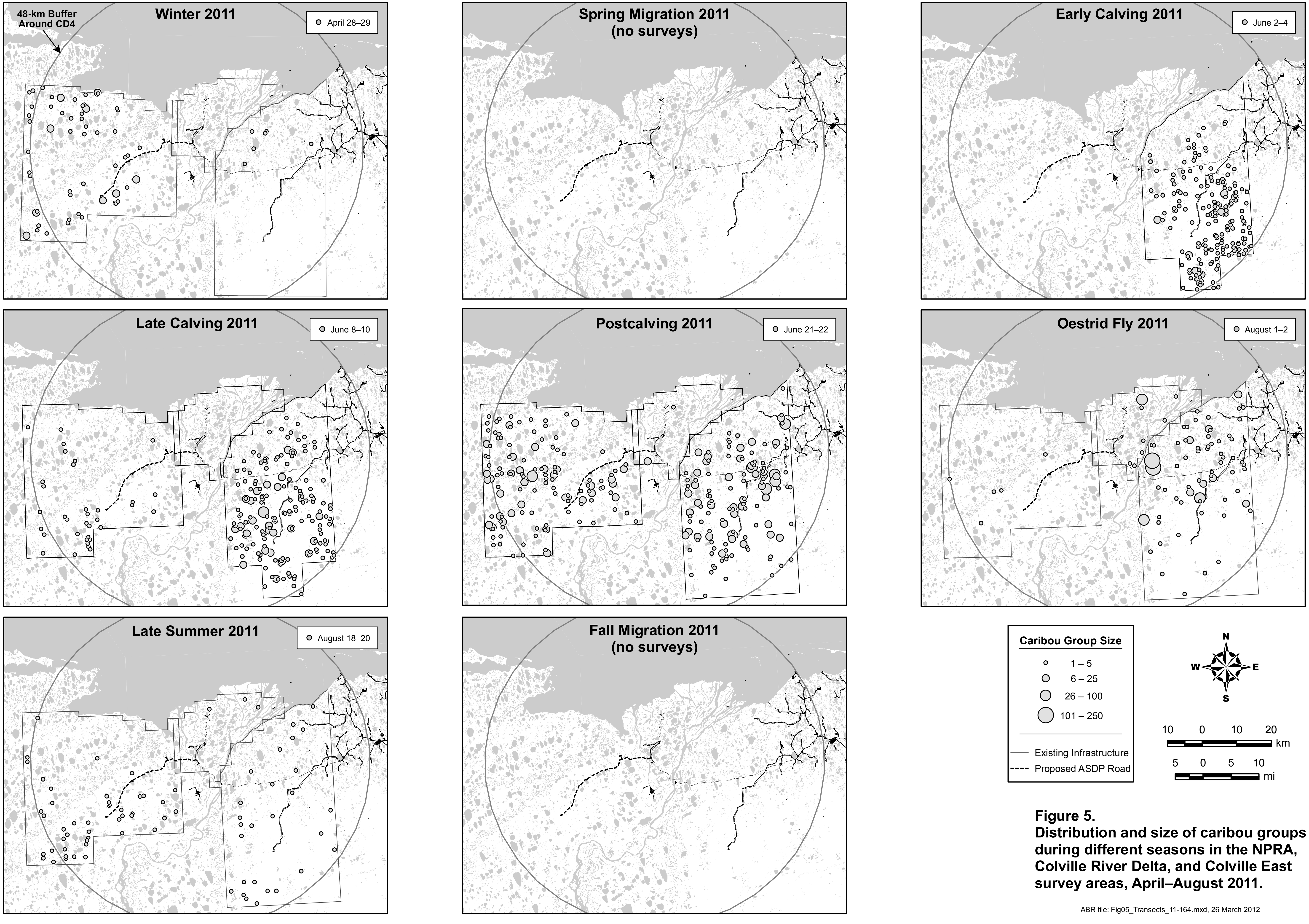


Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–August 2011.

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compared with other parts of the study area, most notably the Colville East survey area.

Annual surveys since 2001 have shown that the NPRA survey area, which is used mainly by TH caribou, is not a high-density calving area, in contrast to the Colville East survey area, which is used mainly by CAH caribou (Lawhead et al. 2006, 2007, 2008, 2009, 2010; Lawhead and Prichard 2012). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005, Person et al. 2007), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area. Although a few collared CAH caribou have calved west of the Colville River in isolated years (notably 2001), it is a rare occurrence (Arthur and Del Vecchio 2009, Lenart 2009).

Large mosquito-harassed groups of caribou were not observed during aerial surveys in late June or August 2011, although no surveys were conducted in July when mosquito and oestrid-fly harassment typically peak. During the insect (mosquito and oestrid-fly) season, transect surveys produce unpredictable results due to the rapid movements by caribou across broad areas in response to fluctuating insect activity levels. 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 2011 (Table 2). Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (annual maxima of 1.2–3.5 caribou/km² during 2001–2008, except in 2006 when only one survey was conducted after August and the density was only 0.01 caribou/km²) (Figure 6). Only one survey was conducted in September or October 2009–2011 due to poor weather conditions. High densities also have been recorded occasionally in

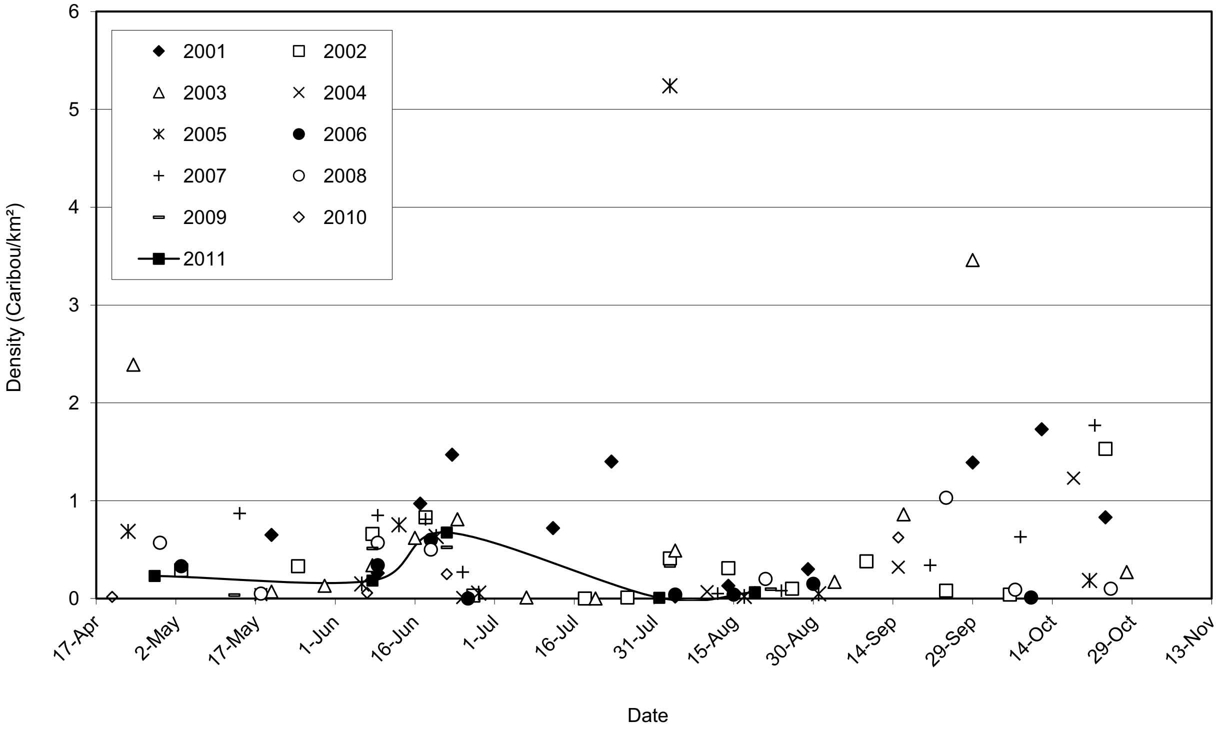

Figure 6. Caribou density observed on 94 surveys of the NPRA survey area, April–October 2001–2011 (line connects 2011 survey values).

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 28 April and 20 August 2011 (Table 2, Figure 5). Similar to most previous years, the estimated density of caribou was low on most surveys (0–0.05 caribou/km²), but the density in the area was moderate on 1 August (0.59 caribou/km²), including a group of 200 caribou. At least 600 caribou were observed in two large groups on the Colville delta during a loon survey on 25 July and ~140 caribou were seen near CD3 on 1 August (J. Parrett, ABR, pers. comm.).

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

It is difficult to record the dynamic movements of insect-harassed caribou with periodic transect surveys. The highest number recorded on transect surveys during 2001–2011 (Table 2, Lawhead et al. 2010) 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 29 April and 20 August 2011 (Figure 5). The estimated density of caribou on complete surveys ranged from 1.56 caribou/km² during the late calving survey on 10 June to a low of 0.02 caribou/km² on 29 April (Table 2). The highest densities among all three ASDP survey areas in 2011 were recorded in Colville East during calving and postcalving (0.92–1.56 caribou/km²), which is typical for that part of the ASDP study area. During the late calving survey (mid-June) in 2011, caribou were concentrated in the western portion of the Colville East survey area, similar to the distribution in 2010 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 Arctic National Wildlife Refuge and some even crossing the Alaska–Yukon border. In 2011, a portion of the herd did return to the area near Kuparuk in July, as is described in more detail later in this report.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area in 2011, although groups totaling 10–11 muskoxen were seen repeatedly east of the Colville River delta between 29 April and 18 August. Most of the muskoxen seen in the region extending from the NPRA survey area east to the Prudhoe Bay oilfield were located between the Milne Point Road and the Kuparuk River in 2011 (Appendix C; Lawhead and Prichard 2012). 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) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Grizzly bears (*Ursus arctos*) were recorded on three occasions in the NPRA survey area in June 2011 (Appendix C; Lawhead and Prichard 2012). One of the observations was of a female with two cubs and the other two were of single adults. Three sightings of single adult bears were recorded on the Colville River delta (Appendix C; Lawhead and Prichard 2012). The number of repeated observations of the same individuals among surveys was unknown, however.

Spotted seals (*Phoca largha*) were observed at a haulout on the eastern Colville delta on four different occasions in August 2011: approximately 30 seals on 8 August, 40 seals on 15 August, 38 seals on 24 August, and 50–60 seals on 29 August (Appendix C; Lawhead and Prichard 2012). Approximately 20 seals were estimated at the same haulout site on 12 September, but the observer was too far away to obtain a good count. The haulout was located on a river bar on the west side of the main channel of the Colville River. According to helicopter pilot reports, seals hauled out consistently in that location during most of August 2011. This haulout was a previously undescribed site that was located approximately 1.6 km upstream from a previously reported haulout. The latter haulout was one of two sites that received repeated use during surveys of spotted seals on the Colville delta in the late 1990s (Johnson et al. 1999) and in incidental observations recorded since then.

No observations of moose, wolves, wolverines, or polar bears were recorded in the ASDP study area on our surveys in 2011.

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. Previous VHF collar locations were discussed by Lawhead et al. (2006); no new VHF data were available for the 2011 season.

Satellite Collars

Combining observations over all years of data, the percentage of satellite-collared TH animals (with at least five active duty cycles per month) in the ASDP study area ranged from 8% to 39% 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 (17–39%) and the lowest percentages (8–14%) 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. In 2011, 9 of the 12 transmitting TH satellite collars were present in the ASDP study area in July. Over 50% of collared animals were in the ASDP study area in 5 of the last 6 years (Table 3).

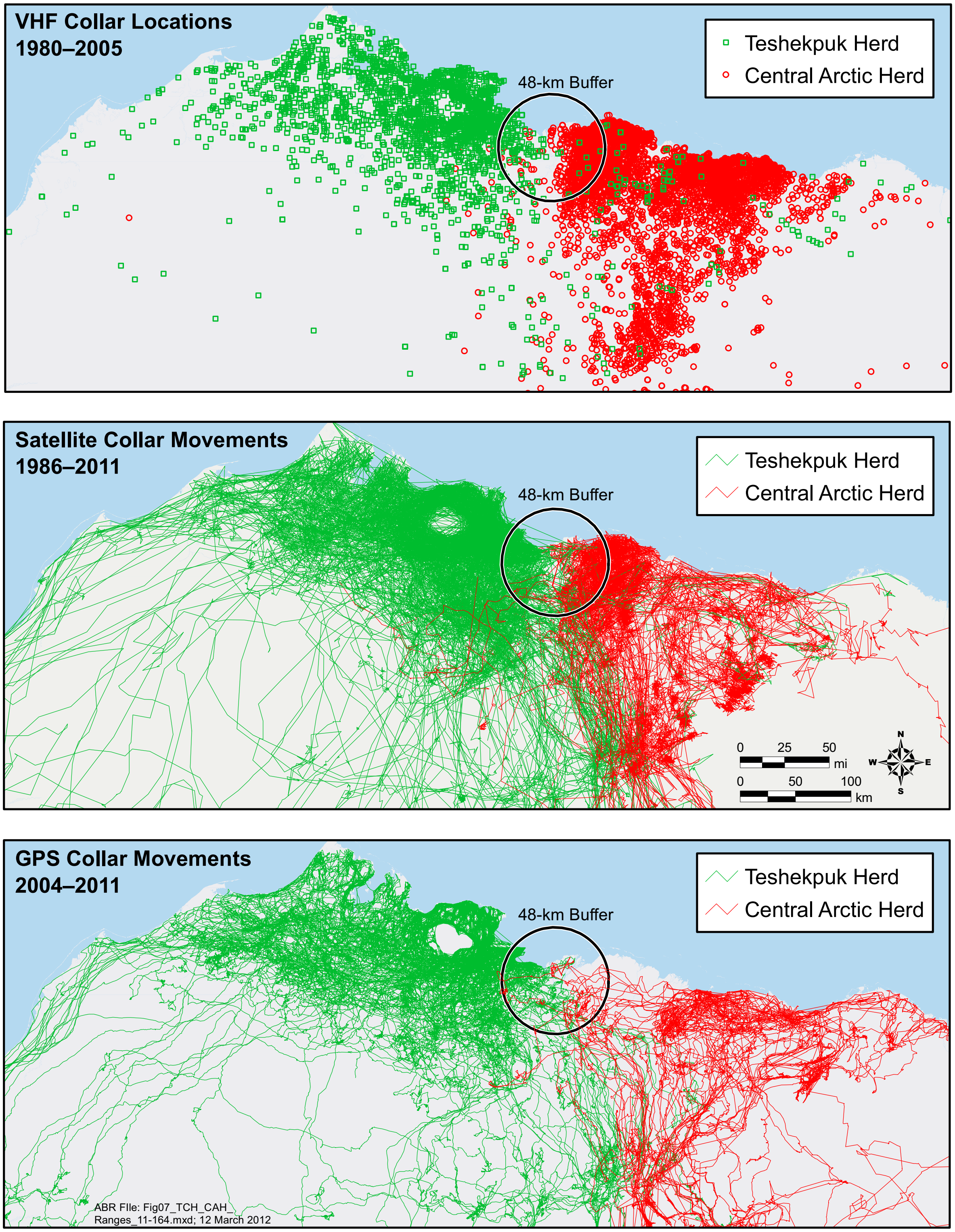

Figure 7. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2011.

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)	25 (4)	0 (3)	0 (3)
	1994	0 (3)	0 (3)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)	50 (2)	0 (2)	0 (1)	0 (1)	0 (1)
	1995	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	13 (8)	38 (8)	25 (8)	25 (8)	14 (7)	14 (7)
	1996	14 (7)	14 (7)	14 (7)	14 (7)	14 (7)	0 (7)	14 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (6)
	1997	0 (5)	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 (1)	0 (2)
	2001	0 (3)	0 (3)	0 (1)	0 (3)	0 (4)	25 (4)	0 (1)	10 (10)	0 (10)	10 (10)	10 (10)	10 (10)
	2002	10 (10)	10 (10)	10 (10)	10 (10)	17 (12)	9 (11)	10 (10)	11 (9)	12 (17)	13 (16)	8 (13)	0 (11)
	2003	8 (13)	18 (11)	40 (10)	20 (10)	18 (11)	9 (11)	0 (25)	32 (22)	27 (22)	18 (22)	11 (18)	6 (17)
	2004	6 (17)	8 (13)	7 (15)	7 (14)	13 (15)	0 (15)	0 (13)	8 (13)	17 (12)	73 (11)	45 (11)	40 (10)
	2005	38 (8)	25 (8)	29 (7)	25 (8)	38 (8)	0 (8)	35 (26)	64 (25)	29 (24)	35 (23)	23 (22)	18 (22)
	2006	18 (22)	18 (22)	14 (22)	9 (22)	29 (21)	14 (21)	58 (36)	6 (34)	13 (32)	34 (29)	0 (27)	0 (27)
	2007	4 (25)	8 (25)	8 (24)	0 (23)	4 (23)	14 (22)	58 (19)	61 (18)	35 (17)	59 (17)	31 (16)	31 (16)
	2008	33 (15)	21 (14)	21 (14)	14 (14)	17 (12)	8 (12)	14 (7)	14 (7)	0 (7)	0 (7)	0 (7)	0 (7)
	2009	0 (7)	0 (5)	0 (7)	0 (7)	0 (7)	0 (7)	86 (14)	7 (14)	8 (12)	0 (11)	0 (10)	0 (9)
	2010	0 (9)	0 (9)	0 (9)	0 (9)	0 (9)	20 (10)	92 (13)	8 (12)	9 (11)	0 (11)	0 (8)	0(6)
	2011	0 (6)	0 (6)	0 (6)	0 (7)	0 (6)	33 (12)	75 (12)	0 (12)	–	–	–	–
	Total	12 (172)	10 (155)	12 (155)	8 (155)	14 (155)	12 (159)	39 (228)	23 (218)	17 (210)	24 (202)	14 (184)	11 (175)
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)	38 (8)	13 (8)	33 (27)	7 (28)	7 (28)	4 (28)	0 (28)	0 (27)
	2009	0 (27)	0 (25)	0 (24)	0 (21)	5 (21)	14 (21)	50 (16)	50 (16)	25 (16)	0 (15)	0 (15)	0 (15)
	2010	0 (15)	0 (14)	0 (14)	0 (14)	0 (14)	0 (12)	60 (5)	0 (5)	0 (5)	0 (5)	0 (4)	0 (4)
	2011	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	–	–	–	–	–	–
	Total	4 (78)	3 (75)	3 (74)	4 (69)	12 (68)	15 (65)	41 (81)	26 (82)	13 (82)	25 (81)	8 (80)	6 (78)
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)	17 (6)	17 (6)	0 (5)	0 (5)	0 (4)	0 (4)	0 (4)
	2011	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	–	–	–	–	–	–
	Total	0 (98)	0 (98)	0 (98)	2 (122)	34 (122)	48 (124)	27 (124)	11 (123)	27 (123)	7 (122)	0 (60)	0 (60)

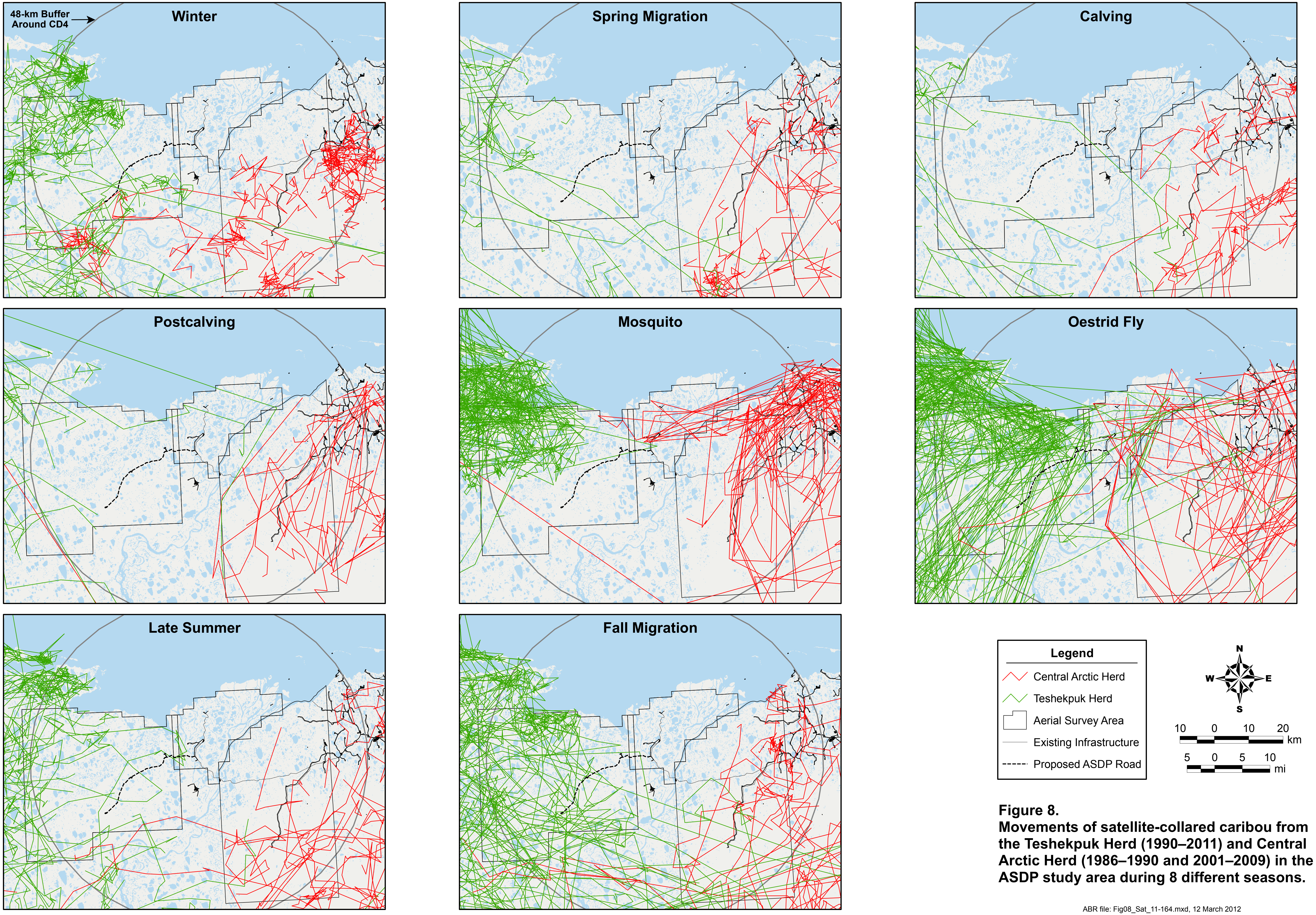

Figure 8.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2011) and Central Arctic Herd (1986–1990 and 2001–2009) in the ASDP study area during 8 different seasons.

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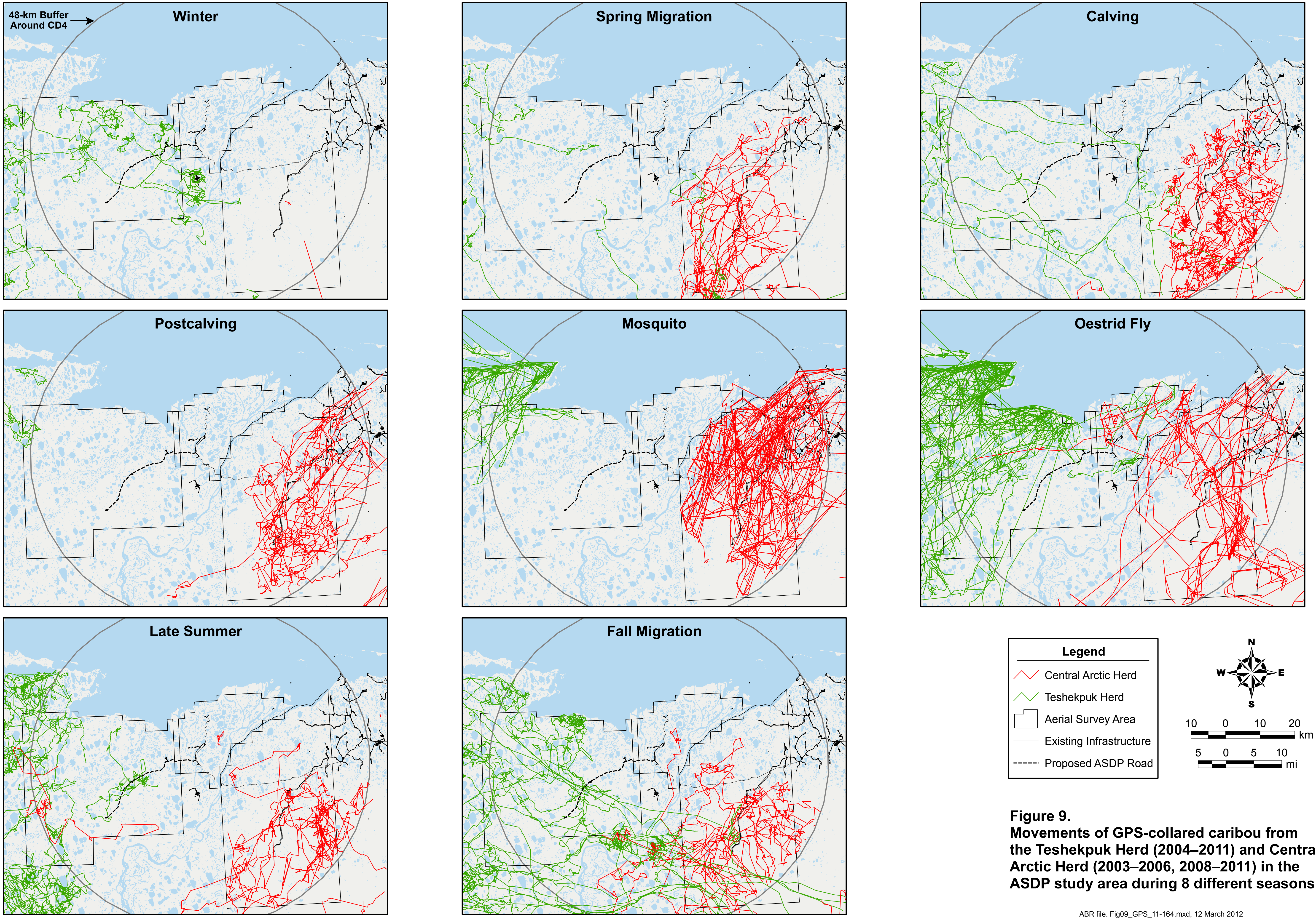

Figure 9.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2011) and Central Arctic Herd (2003–2006, 2008–2011) in the ASDP study area during 8 different seasons.

ABR file: Fig09_GPS_11-164.mxd, 12 March 2012

Four of the 12 satellite-collared male TH caribou were located repeatedly in the ASDP study area from 25 June until late July 2011. Five other collared caribou were in the study area from approximately 15 July to 26 July 2011. Two of the caribou were within 3 km of CD4 in late June. All other collared caribou remained west of the Colville River delta, primarily in the northern half of the NPRA survey area.

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). No satellite-collared CAH animals crossed the proposed ASDP road alignment in the NPRA survey area in any year for which data are available (1986–1990, 2001–2005, and 2007–2009). Several collared CAH individuals moved through the vicinity of the Alpine project facilities in July 1989, nine years before construction began. Combining observations for each month over all eight years of data, the percentage of the total sample of satellite-collared CAH caribou in the study area ranged from 12% to 64% each month (Table 3). The highest occurrence of collared CAH caribou was in May, June, and July (38%, 64%, and 51% of the total sample, respectively) and the lowest was during October–February (12–19%) (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, however, 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 2004–2011 were similar to those of satellite-collared caribou. Only 3–8% of GPS-collared TH caribou were in the study area in winter (November–April) (Table 4, Figure 9). The monthly percentages increased to 12–41% during May–August, declined to 13% in September, and rose again to 25% 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 2008–2011 varied between 0 and 7% during the months of October–April (Table 4, Figure 9). The monthly percentage increased to 34% in May, peaked at 48% in June due to heavy use of the Colville East area during calving, and decreased to 11–27% in July–September.

The detailed movement tracks of the four CAH females outfitted with GPS collars purchased by CPAI for the ASDP study in 2009 were examined in relation to the ASDP study area from January through June 2011 (Figures 10 and 11; the previous movements of these caribou are depicted in Appendices D and E). The detailed movement tracks of 10 other 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 January through December 2011 (Figures 12–13). The movements of these caribou during June–December 2010 were mapped in a previous report (Lawhead et al. 2011). Complete movement data from the latter collars will not become available until they are retrieved in 2012. The seasonal movement patterns of the TH and CAH caribou were generally similar to the previous movement patterns of the caribou outfitted with GPS collars from July 2007 to December 2010 (Lawhead et al. 2011; Appendices D and E).

In 2011, two GPS-collared TH caribou wintered west of the study area and two wintered south of the study area. All four female TH caribou moved toward Teshekpuk Lake during calving and were recaptured south of Teshekpuk Lake in late June (Figure 10). The four GPS-collared CAH caribou that were captured initially in 2009 wintered in the Brooks Range east of the Dalton Highway and calved with the eastern segment of the CAH and were recaptured east of the Sagavanirktok River in late June (Figure 11). The other 10 CAH GPS-collared caribou that were collared in 2010 also wintered in the Brooks Range east of the Dalton Highway. Four of the 10 caribou were west of the Sagavanirktok River during calving and the other six were east of the Sagavanirktok River during calving (Figures 12 and 13). All moved east toward ANWR during the mosquito season, with two caribou moving as far east as Kaktovik and an additional one moving inland south of Kaktovik. Two caribou moved back into the ASDP study area in mid-July and remained west of the Dalton Highway for the rest of the summer; both moved into NPRA in August. All of the collared caribou moved south in early October and were in the Brooks Range east of the Dalton Highway in December 2011 (Figures 12 and 13).

The following accounts detail the movements of the two CAH GPS-collared caribou that moved through the Colville East area survey in mid-July 2011. CAH Caribou C0412 moved onto the Colville River delta from the east on 17 July 2011. She moved just west of CD2 on 25 July and remained on the delta until 4 August, when she moved west into NPRA. This caribou remained in NPRA until 27 September, when she crossed the Colville River and moved southeast toward the Brooks Range.

CAH Caribou C04189 crossed the eastern end of the Alpine sales oil pipelines on 17 July 2011 and then moved northwest onto the Colville River delta on the same day. She remained on the delta until 25 July, when she crossed the pipeline/road corridor between CD1 and CD2 and then crossed the Alpine infield flowlines about 3 km south of CD1. She moved off the delta and crossed the Alpine sales oil pipelines again northwest of DS-2L on July 27 before crossing and recrossing the Meltwater (DS-2P) pipeline/road corridor and moving off to the southwest.

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

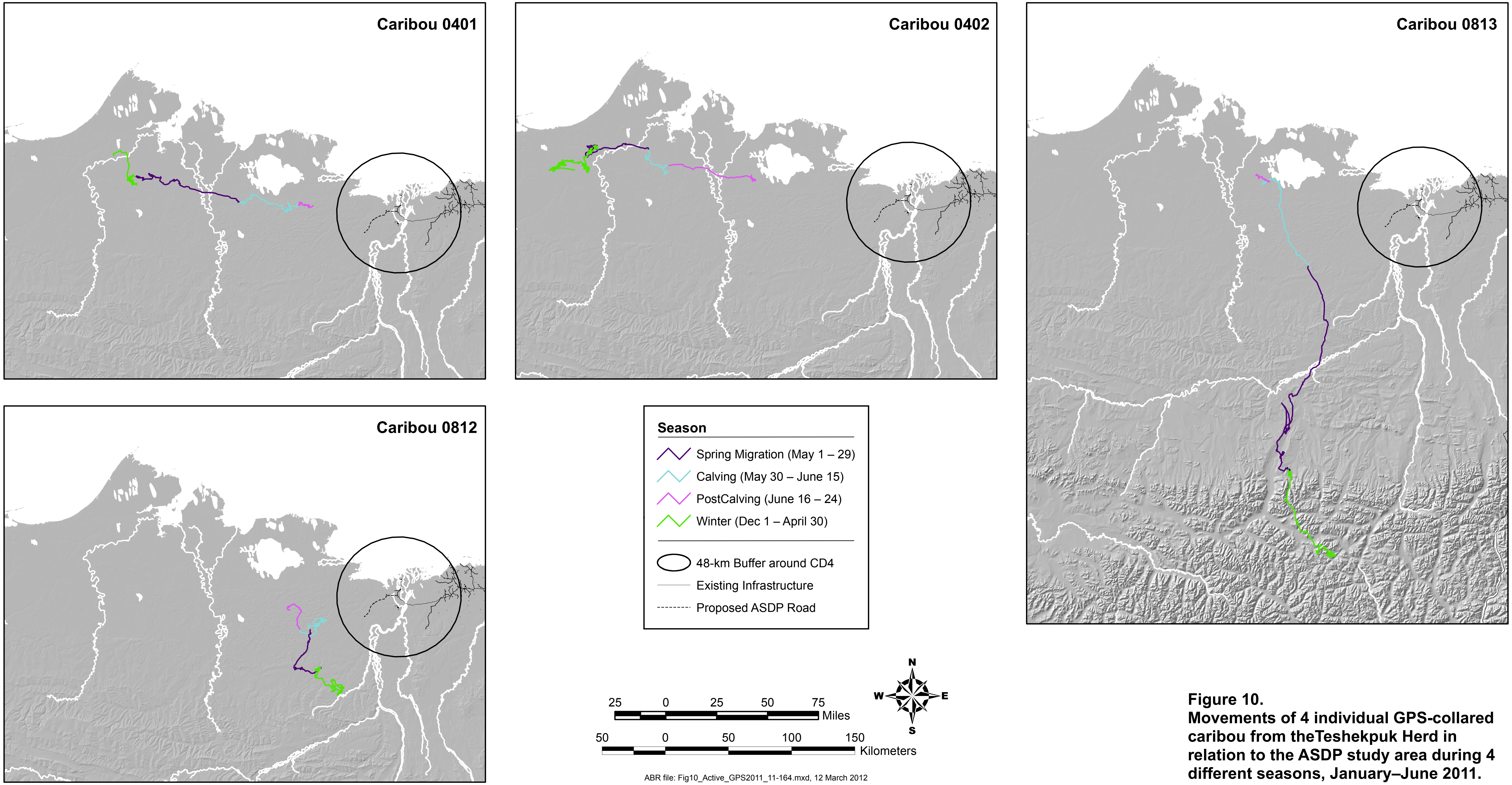

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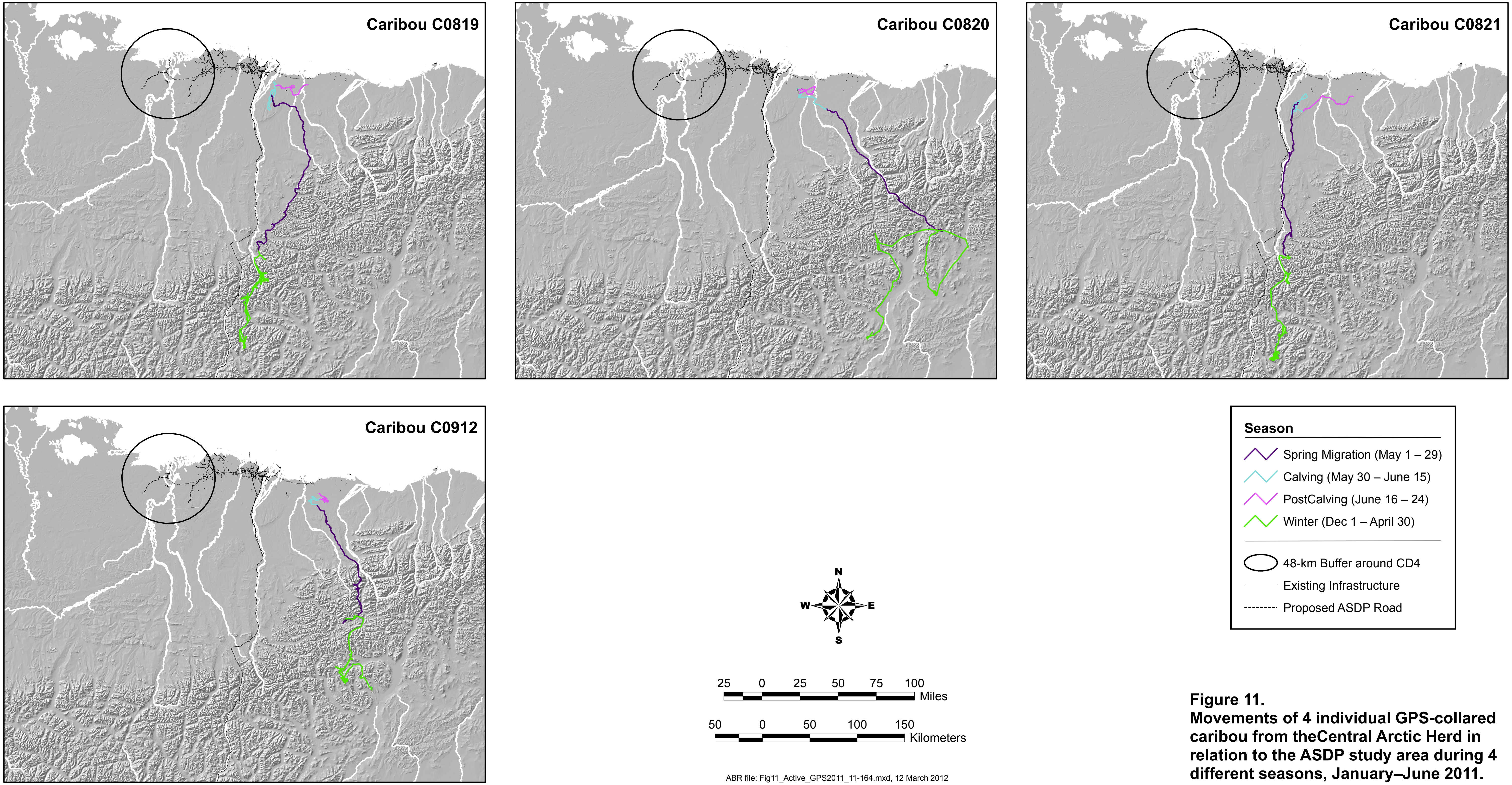
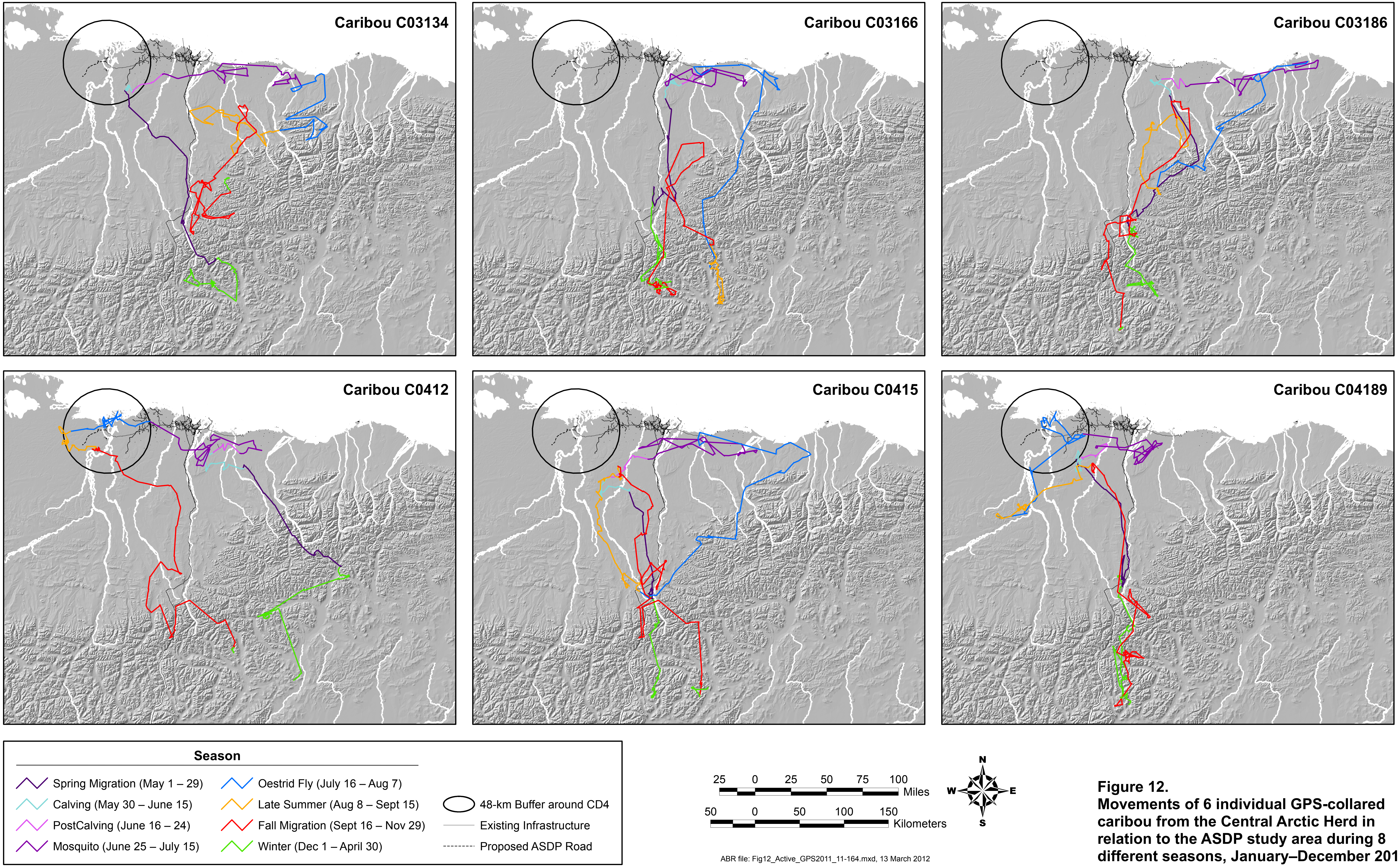
Figure 10.
Movements of 4 individual GPS-collared caribou from theTeshekpuk Herd in relation to the ASDP study area during 4 different seasons, January–June 2011.



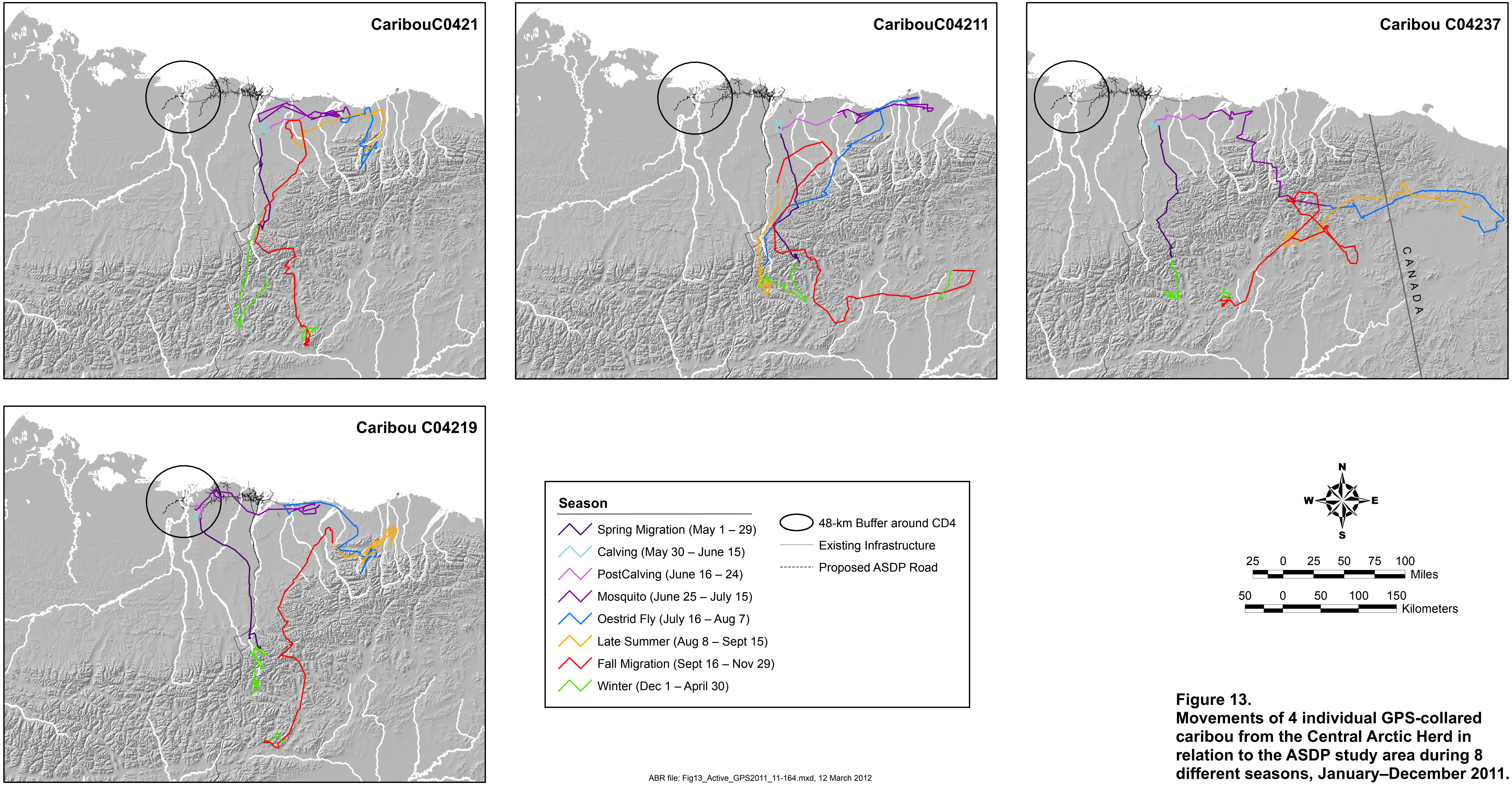
ABR file: Fig11_Active_GPS2011_11-164.mxd, 12 March 2012

Figure 11.
Movements of 4 individual GPS-collared caribou from theCentral Arctic Herd in relation to the ASDP study area during 4 different seasons, January–June 2011.



ABR file: Fig12_Active_GPS2011_11-164.mxd, 13 March 2012

Figure 12.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 8 different seasons, January–December 2011.



ABR file: Fig13_Active_GPS2011_11-164.mxd, 12 March 2012

Figure 13.
Movements of 4 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 8 different seasons, January–December 2011.

conditions (White et al. 1975, Dau 1986, Lawhead 1988, Cameron et al. 1995). During mosquito harassment, CAH caribou typically head north to the coast and then move into the wind, which usually blows from the east–northeast. During less common periods of westerly winds, however, large numbers of CAH caribou occasionally moved onto the Colville River delta in the past. In recent years, most CAH caribou have moved east of the Sagavanirktok River during the insect season and have remained far to the east or south of the study area until the following spring migration and calving season. In 2011, two collared CAH caribou made an unusual move west of the Colville delta into NPRA.

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). Two collared CAH caribou moved into NPRA in 2011, but it is unknown how many caribou moved into NPRA at this time.

The ranges of the two herds overlap more in fall and winter, primarily because of the recent expansion of TH caribou into the CAH winter range. Although most TH animals typically overwinter on the coastal plain, large numbers have wintered south of the Brooks Range in areas used by the CAH or WAH in some years (Prichard and Murphy 2004, Carroll 2007, Person et al. 2007, Lawhead et al. 2009, Lenart 2009, Parrett 2009). In a highly unusual movement in 2003–2004, a large proportion (perhaps up to a third) of the TH moved east across the Colville and Sagavanirktok rivers during fall migration and wintered in and near ANWR (Carroll et al. 2004, Carroll 2007). In subsequent winters, some TH animals have continued to spend the winter in or near the traditional range of the CAH south of the Brooks Range. During the winter of 2011–12, collared animals from all 4 arctic caribou herds are wintering along the Dalton Highway (L. Parrett, ADFG, pers. comm.). 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 120 satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006; the nearest one was a female that moved from northwest of CD4 to south of Nuiqsut on 30 September 2004, remaining west of the Niġliq Channel. In 2007, four satellite-collared TH caribou moved east past Alpine and CD4 (judging from straight-line distances between satellite locations) as they moved to the eastern Colville delta in late July. Another satellite-collared caribou passed between Nuiqsut and CD4 as it moved northwest during calving in 2007. In 2010 (January–October), no satellite-collared TH caribou were in the CD4 vicinity, but 12 of 13 collars were in the ASDP study area and near the western Colville delta in July. 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 was on the western edge of this road on 24–25 July.

Of 43 different TH animals equipped with GPS collars during 2004–2011, one crossed the Colville delta westward between CD4 and Alpine on 6 June 2005 *en route* to Teshekpuk Lake. Caribou 0404 spent 1–6 August 2007 about 2 km south of CD4 before heading west. Caribou 0621 wintered near Nuiqsut during the winter of 2007–2008, but did not move onto the Colville delta. In 2011, no GPS-collared TH caribou for which data are currently available moved onto the Colville River delta.

Of the sample of 17 CAH satellite collars during 1986–1990, one moved into the CD4 vicinity briefly during 21–23 July 1988 and four moved nearby during 11–13 July 1989. Of the sample of 17 CAH satellite collars during 2001–2005, four moved through the vicinity while heading inland on 28–30 July 2001, evidently after having been collared on the outer Colville delta. Only one of the 45 CAH GPS collars in the ASDP study area during 2003–2006 moved onto the Colville delta, east of CD4 on 27 September 2004.

None of the 22 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 (Figures 12 and 14). 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, plus a group of about 140 animals on 1 August (J. Parrett, ABR, pers. comm.).

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 14). As expected on the basis of herd distribution (Figures 7–9), all of the crossings of the proposed road alignment except one were by TH caribou (Figure 14). Of the TH sample of 126 different satellite collared caribou (1990–2011), 42 animals (33%) crossed the proposed alignment at least 94 times between September 1990 and July 2011. Crossings occurred in every month except January. Five satellite-collared TH caribou (4 males and one female) crossed the proposed road between 13 July and 28 July 2011.

Of the TH sample of 43 different GPS-collared caribou (2004–2011), five animals crossed the alignment near the western end during fall migration between 2 October and 18 November 2004 and another caribou crossed in early June 2005 near Alpine (the same animal mentioned above that passed between CD4 and Alpine). Caribou 0620 crossed near the western end of the alignment in May 2007; caribou 0624 crossed near the eastern end in June 2007; caribou 0401 crossed near the eastern end in July 2007; caribou 0404 crossed the proposed alignment at least 27 times between late July and early September 2007 and 16 more times in December 2007 and January 2008; caribou 0621 crossed at least three times near the western end in October 2007 and once in April 2008; and caribou 0813 crossed once near the western end in June 2009. Two GPS-collared caribou crossed near the midpoint of the proposed alignment during July 2010 at about the same time that 11 of 13 satellite-collared male caribou crossed.

Two of 16 satellite-collared CAH caribou in the late 1980s crossed the alignment near the present location of the Alpine facilities on 12 July 1989 (nine years before construction). 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. A single CAH caribou outfitted with a GPS collar crossed the northern spur of the proposed road on 4 August 2011 while moving west into NPRA.

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 caribou study area into a larger geographic context in terms of the chronology of snow melt and vegetation green-up.

SNOW COVER

In 2011, snow melt was largely complete in areas inland from the ASDP study area by early June, but substantial snow remained in the study area on 30 May (Figure 15). The study area was largely obscured by clouds from 30 May until 15 June. Based on observations during aerial surveys, substantial amounts of snow still remained in the study area during June 8–10, but it was melting rapidly. Little snow remained on 15 June.

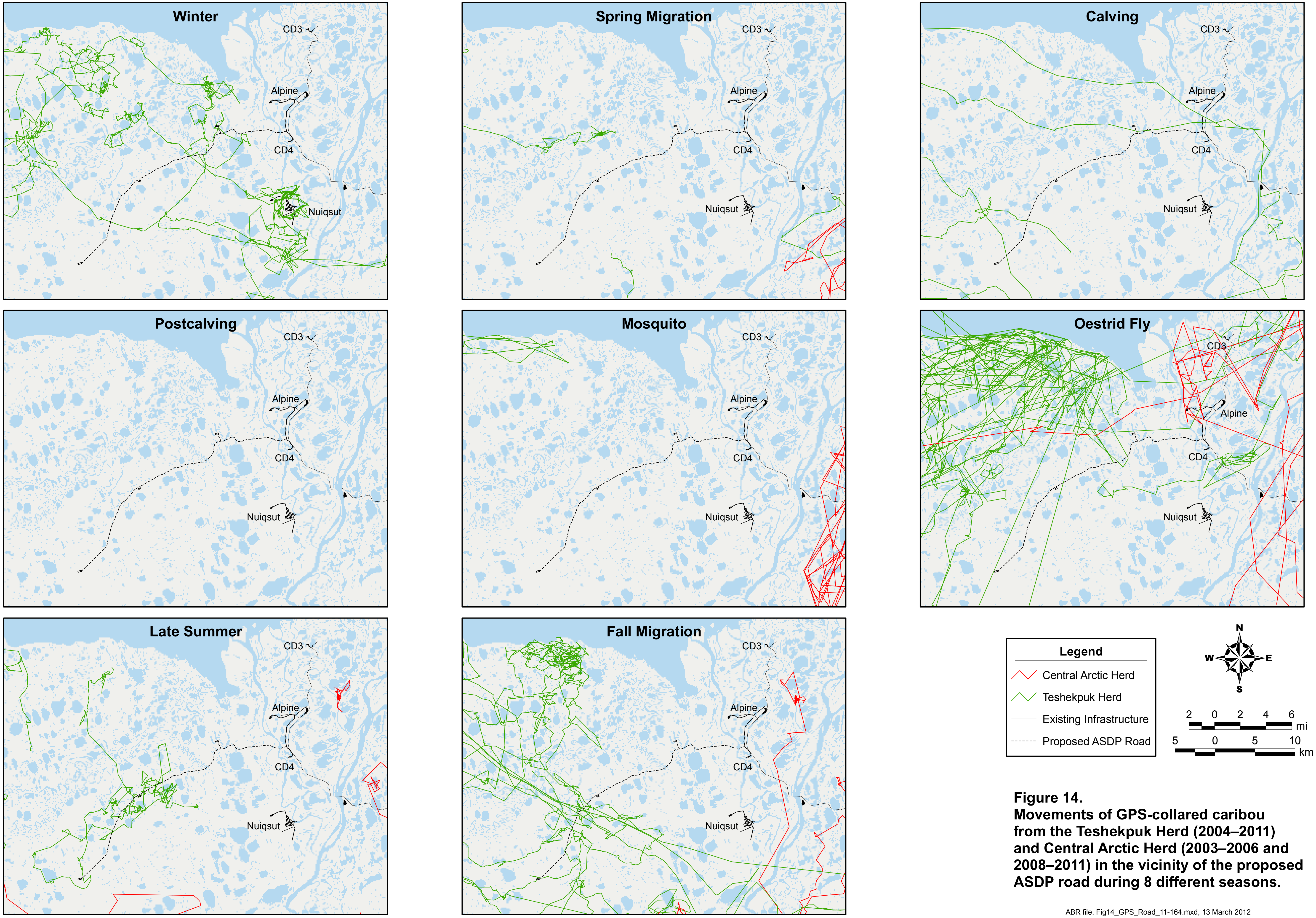


Figure 14.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2011) and Central Arctic Herd (2003–2006 and 2008–2011) in the vicinity of the proposed ASDP road during 8 different seasons.

ABR file: Fig14_GPS_Road_11-164.mxd, 13 March 2012

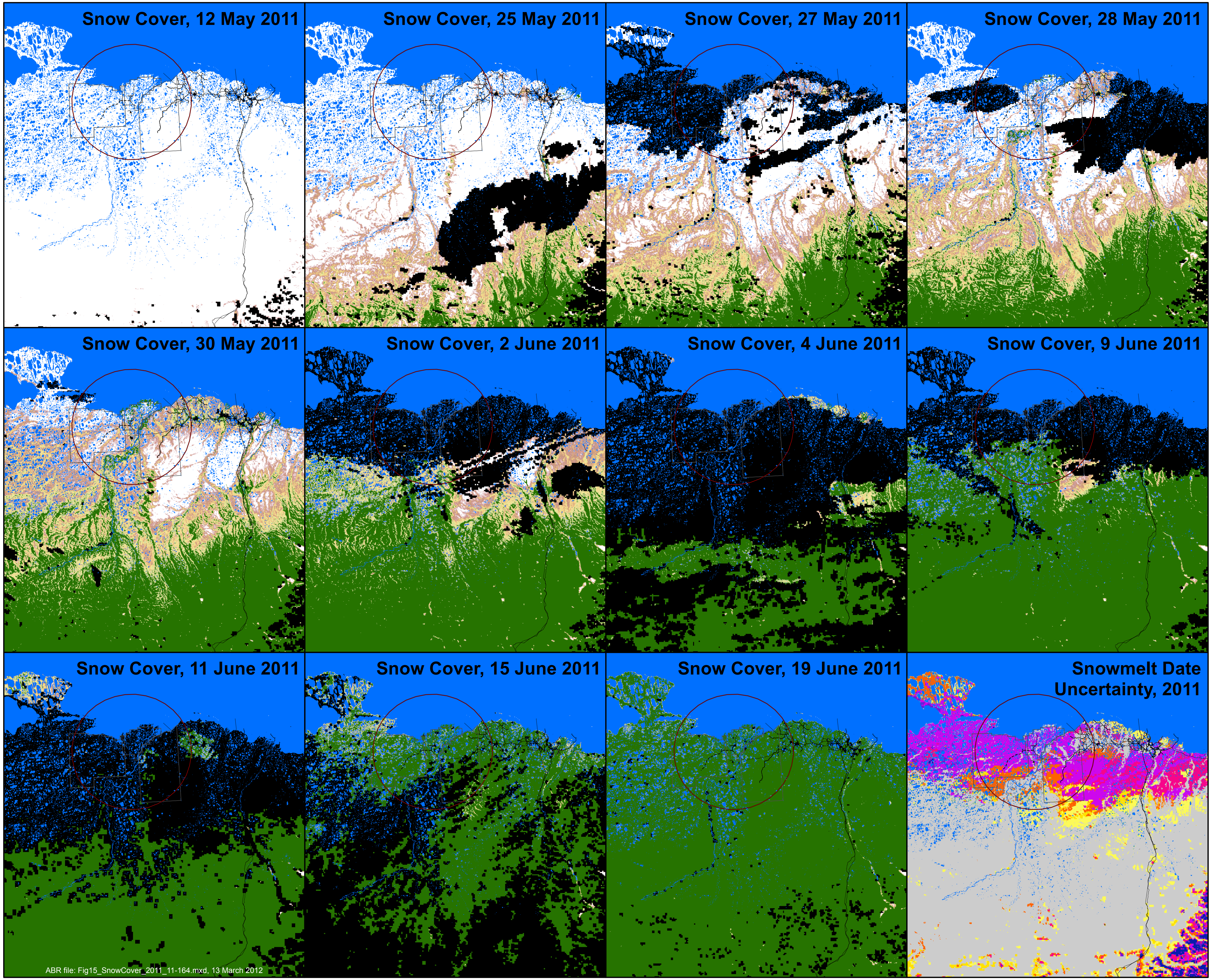


Figure 15.
Extent of snow cover between mid-May and mid-June on the central North Slope of Alaska in 2011, as estimated from MODIS satellite imagery.

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 2000–2011. 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 data where the date of melt was known to within one week, indicates that nearly all of the land on the coastal plain typically melts over a period of three weeks (25 May–11 June; Figure 16). 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 study 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 occurs earliest in the study area along roads in the Colville East study area. In Colville East, 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.

A qualitative comparison of the timing of snow melt across years, compared to the median snow-melt date (Figure 17) suggests that the annual timing of melt varies substantially. Snow melt was more than two weeks early along the coast in 2002, and in the foothills in 2009. Snow melt along the coast was more than a week later than the median in 2000.

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 much of the study area. Based on the available NDVI data and direct observations of snow cover, NDVI_Calving was likely low (Figure 18). NDVI_Rate appeared to be high in portions of the study area with data (particularly the southern end of Colville East), 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 18).

To examine the chronological dynamics of vegetation green-up, we first calculated the median NDVI values for NDVI_Calving, NDVI_621, and NDVI_Peak based on the 12-year time series of MODIS imagery for the variables (Figure 16). For NDVI_Calving, a relationship between median NDVI_Calving and median snow-melt date was apparent, as the highest NDVI values were associated with areas that had been melted the longest, and the lowest values were associated with areas that are most often snow-covered during calving (such as narrow valleys that trap snow in Colville East). The median values of NDVI_621 and NDVI_Peak (Figure 16) have a very similar spatial pattern to the 2011 values (Figure 18), with higher values inland and lower values along rivers and creeks.

Variation among years was assessed by comparing NDVI_Calving, NDVI_621 and NDVI_Peak in each year to the median values for that metric (Figures 19–21). 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 during calving and can change significantly within just a few days. As a result of changing snow cover, the levels of NDVI_Calving vary substantially, based on the timing of satellite imagery in relation to melt and how much snow and ice remains to mask the effect of new vegetation. In the past several 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 occurred but before snow began to accumulate, 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 12-year time series further to evaluate the typical value of NDVI in the study area immediately after snow melt, for application to future analyses.

NDVI_Calving was low in most of the study area during 2000, 2001, and 2005, when extensive areas of snow persisted through 10 June or later (Figure 19). Moderately low values of NDVI_Calving occurred in 2003, 2004 and 2011 (though most of the study areas were cloud-obscured in 2011), and large patches of very low values were obvious where snow remained. Values of this variable were relatively high throughout the study area in 2002 and 2006–2009, when snow melt occurred earlier. The timing of snow melt in the latter three years was near the median date and some of the study area remained snow-covered at the end of the calving period.

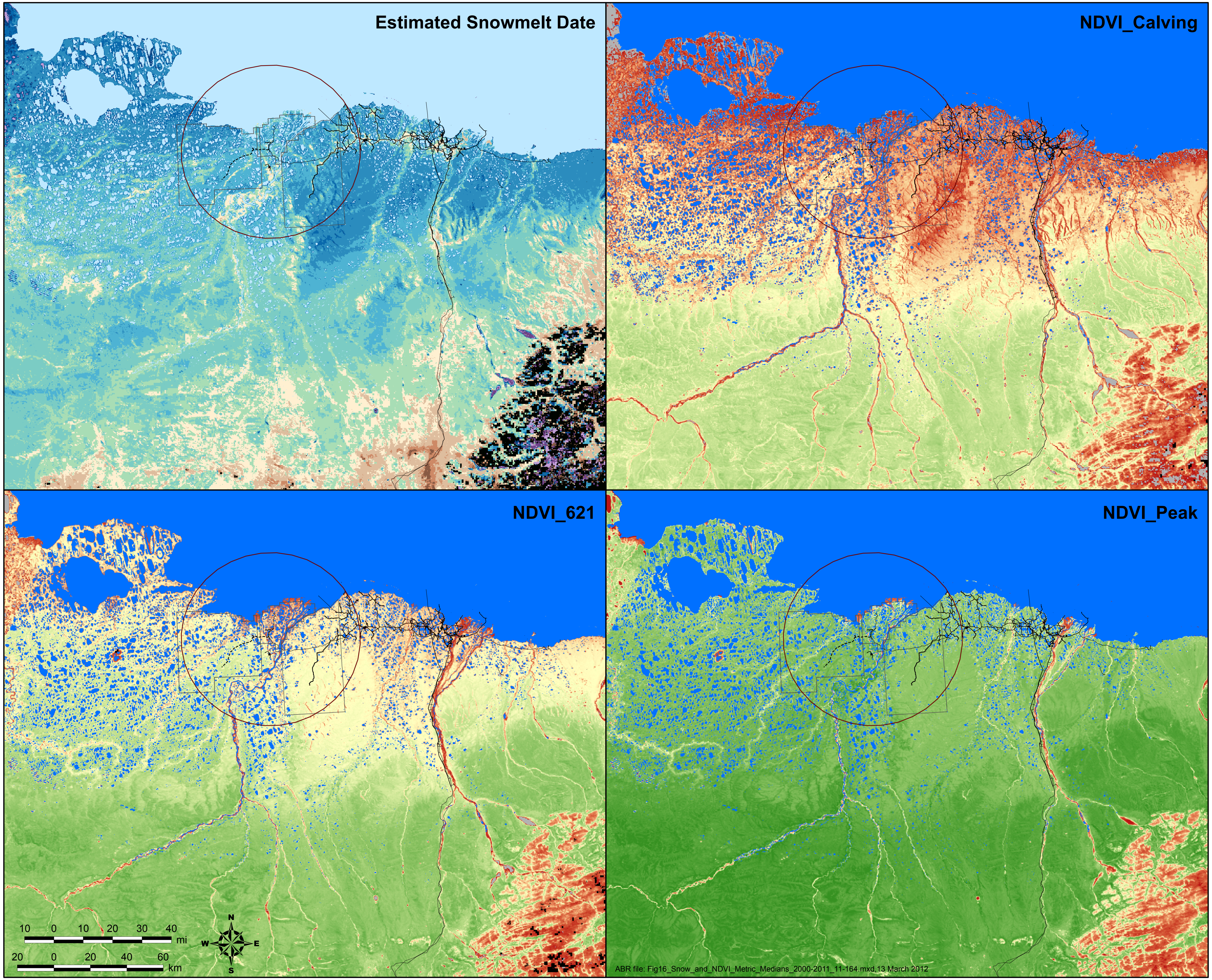
The relative greenness of vegetation during calving (NDVI_Calving) showed large variations among years (Figure 19). We were unable to calculate NDVI_Calving over much of the study area in 2011, but based on calculated areas and the amount of snow remaining in early June, NDVI_Calving was likely below median. The relative greenness of vegetation during peak lactation (21 June, NDVI_621) was higher in 2000, 2002, 2004, 2006, and 2008 than in other years (Figure 20). NDVI_621 values were lowest in 2003, 2005, and 2010 (no data were available between 15 June and 2 July 2001 due to a satellite malfunction, so this metric could not be calculated that year). NDVI_621 was close to the median in the study area in 2011 with lower than median values inland (Figure 20). In general, this metric was less variable among years than is NDVI_Calving, because snow cover was minimal by 21 June in all years. Peak biomass in the study area was higher than the median during 2000, 2003 and 2004, and was lower than the median in 2001, 2002, and 2009. It was slightly above the median in 2011 (Figure 21).

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). For the statistical tests used in this analysis, availability differed between the 2002–2004 and 2005–2011 survey areas. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix F) influenced the seasonal differences in caribou distribution. This analysis focuses on the pooled 10-year data set for aerial transect surveys (2002–2011; Table 5); the differences seen using the pooled data set generally were similar within individual years but often were not significant due to smaller sample sizes (Appendix G).

For the pooled 2002–2011 sample, significantly more groups of caribou occurred in



ABR file: Fig16_Snow_and_NDVI_Metric_Medians_2000-2011_11-164.mxd,13 March 2012

Figure 16.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2011.

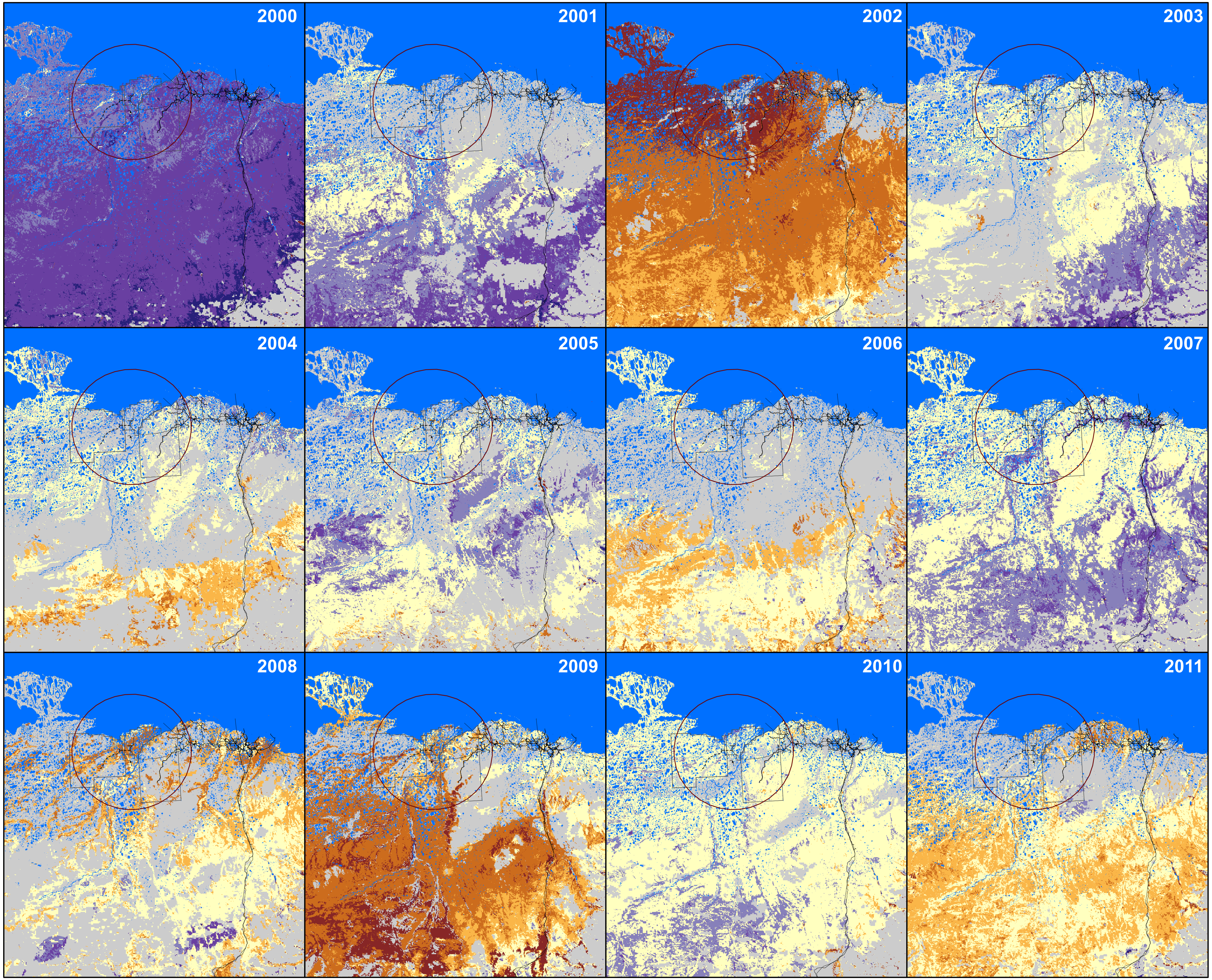


Figure 17.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2011, as estimated from MODIS satellite imagery.

ABR file: Fig17_Snowmelt_Date_Departure_from_Median_2000-2011_11-164.mxd, 13 March 2012

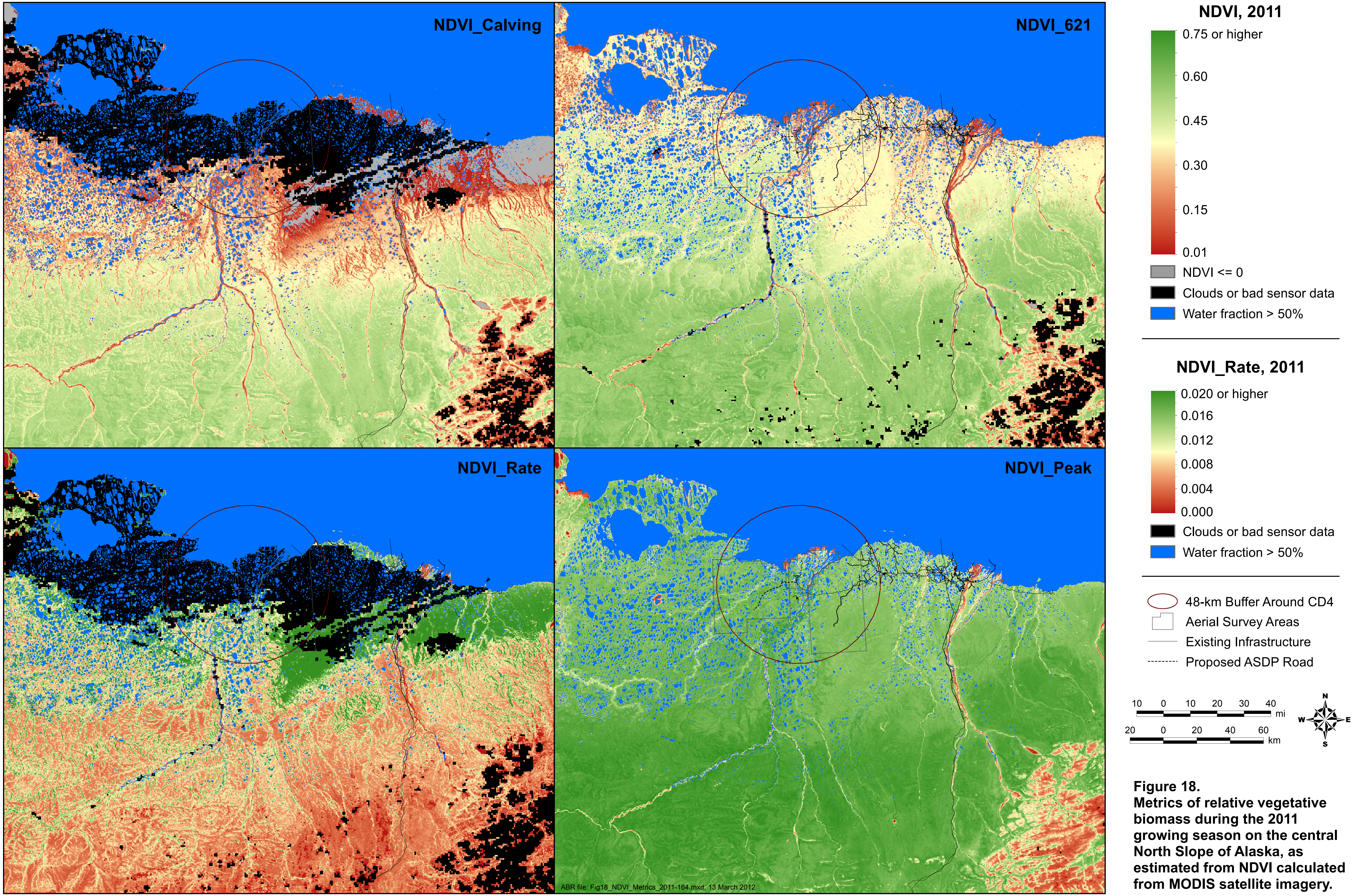


Figure 18.
Metrics of relative vegetative biomass during the 2011 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

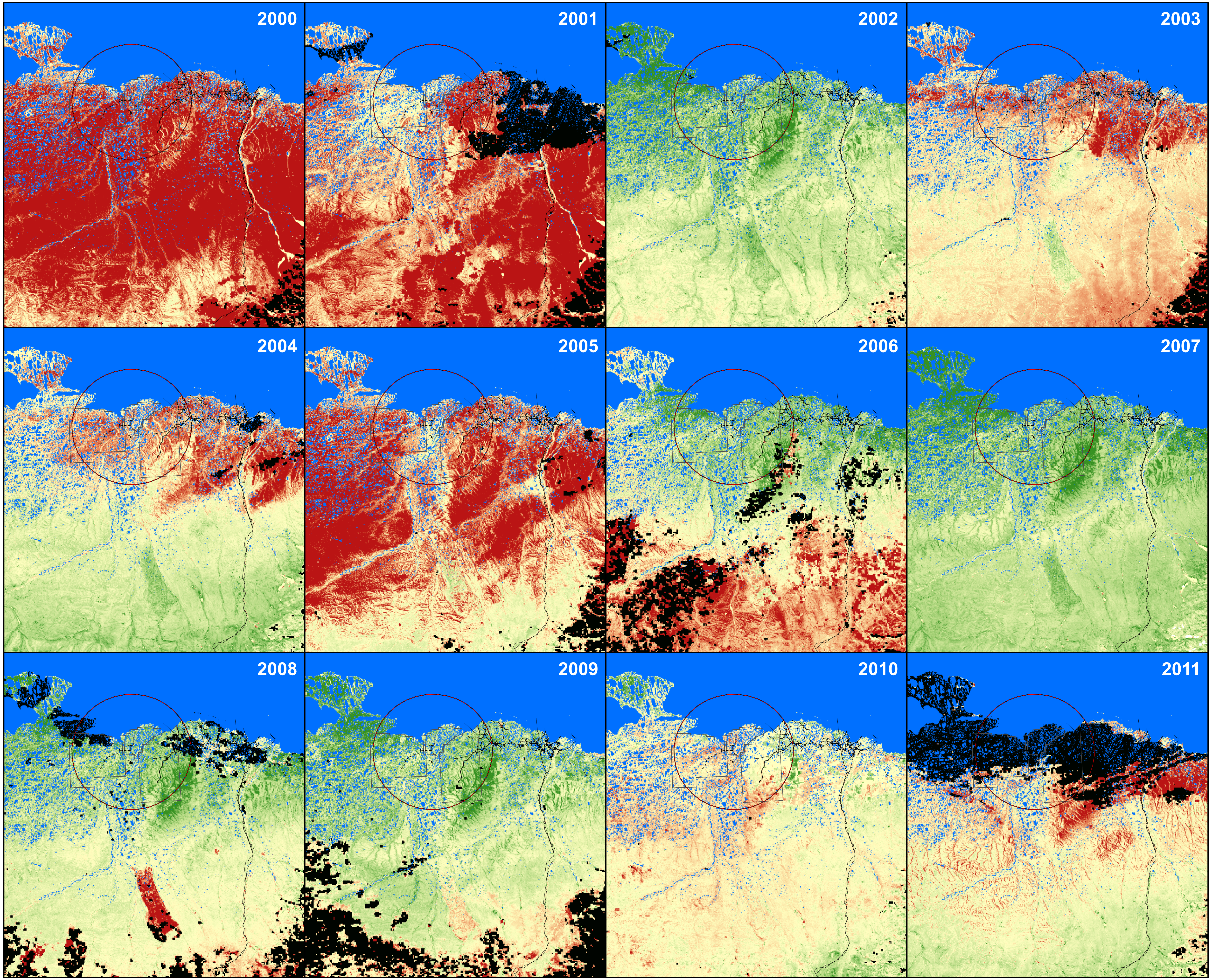
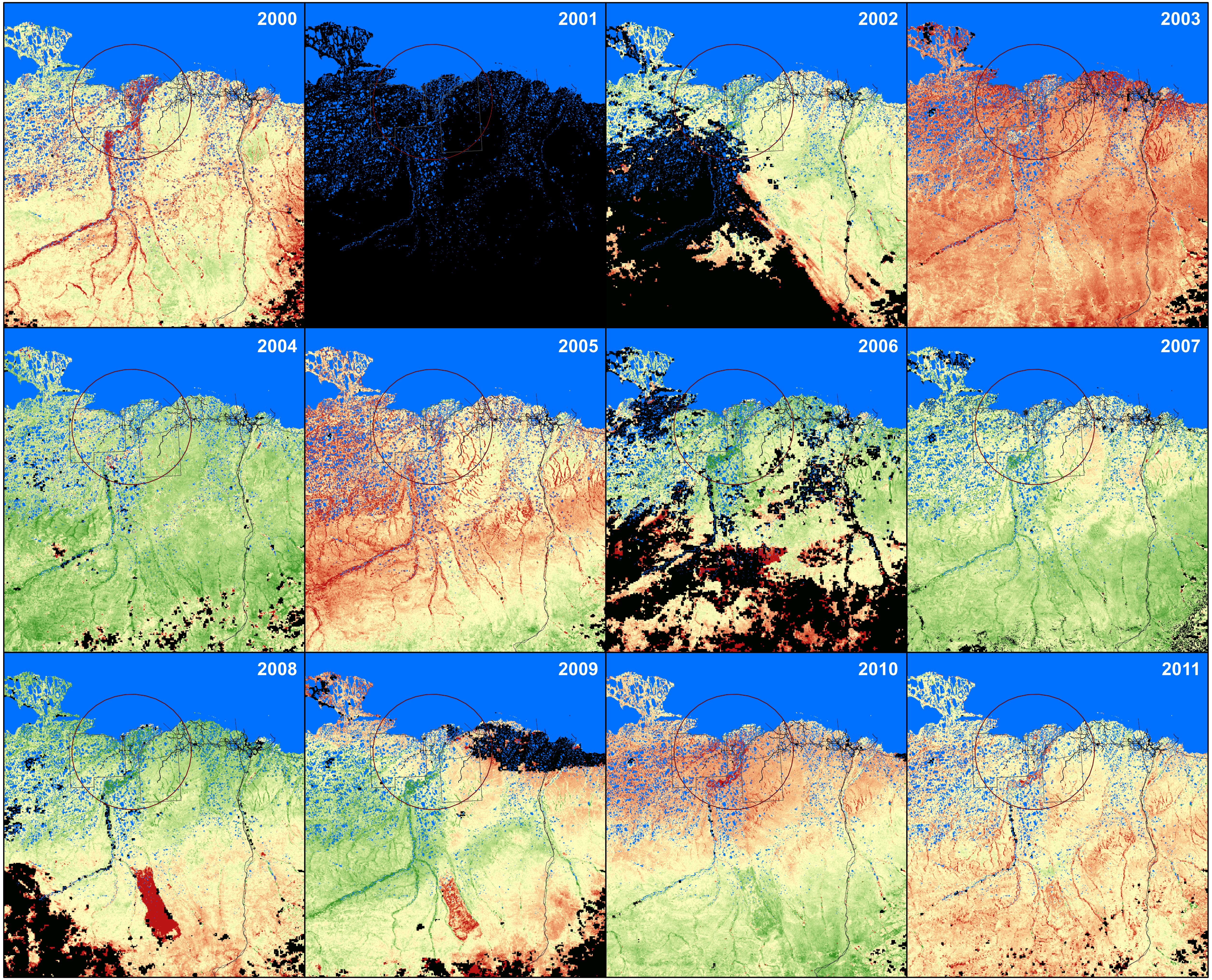


Figure 19.
Differences between annual relative vegetative biomass values and the 2000–2011 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

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



NDVI_621

Compared to Median (2000–2011)

- 🟩 0.10 or more higher than median
- 0.08 higher than median
- 0.06 higher than median
- 0.04 higher than median
- 0.02 higher than median
- Median
- 0.02 lower than median
- 0.04 lower than median
- 0.06 lower than median
- 0.08 lower than median
- 🟥 0.10 or more lower than median
- ■ Clouds or bad sensor data
- 🟦 >= 50% Water Cover

- ○ 48-km Buffer Around CD4
- ☐ Aerial Survey Areas
- Existing Infrastructure
- Proposed ASDP Road

Figure 20.
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

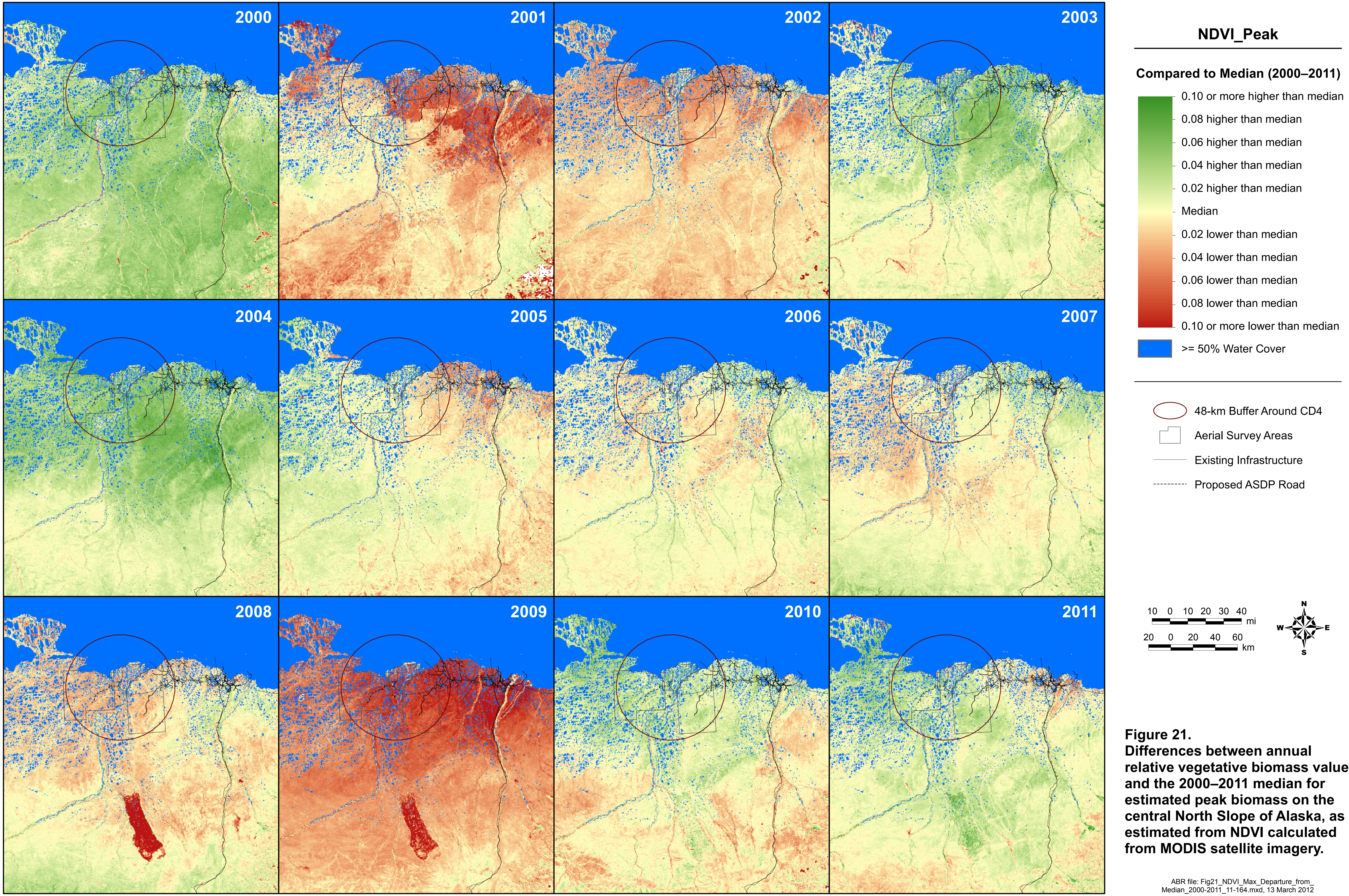


Figure 21.
Differences between annual relative vegetative biomass values and the 2000–2011 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig21_NDVI_Max_Departure_from_Median_2000-2011_11-164.mxd, 13 March 2012

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

				Geographic Section						
Year	Season	No. of Surveys	Total Groups	Coast	North	River	South East	South West	Chi-square	*P*-value
2011	Winter	1	55	5	24^{++}	1--	11	14	20.77	<0.001
	Spring	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
2002–2011	Winter [a]	5	529	24--	81-	106	151	167^{++}	57.80	<0.001
	Spring	8	398	29	116^{++}	74	82--	97	42.34	<0.001
	Calving	11	968	32--	217	186	187--	346^{++}	137.98	<0.001
	Postcalving	10	1,078	23--	278^{++}	360^{++}	199--	218	193.70	<0.001
	Mosquito	6	102	18^{+}	43^{++}	24	11--	6--	80.35	<0.001
	Oestrid Fly	10	235	11	31	117^{++}	38--	38--	112.71	<0.001
	Late Summer	16	777	38--	170	245^{++}	159--	165	73.70	<0.001
	Fall Migration	16	1,494	63--	294	344	354--	439^{++}	61.81	<0.001
	Total	82	5,581	238--	$1{,}230^{++}$	$1{,}456^{++}$	1,181--	$1{,}476^{++}$	338.56	<0.001
Available land area (km²), 2002–2004				8.9	64.8	133.7	191.0	148.2		
Available land area (km²), 2005–2010				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 ($P < 0.01$).

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.

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. 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 2011 were generally consistent with the patterns observed for all years combined, although rivers were used less during late summer than would be expected if distribution were uniform and more caribou were located in the northern section during winter.

These results are interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain. During calving, the highest densities of TH females calve near Teshekpuk Lake, so densities decrease with increasing distance away from the lake (Person et al. 2007, Parrett 2009). 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. 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). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3, Appendix F) 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 H) 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 (2002–2011), the proportions of caribou groups using riverine habitats and the moss/lichen and dwarf-shrub types—three of the four least abundant classes—were significantly greater than expected based on the relative availability of those habitats, whereas the proportions of groups using flooded tundra and tussock tundra—the two most abundant classes—were significantly less than expected. Sedge/grass meadow also was used slightly more than expected (Table 6). Riverine habitats were used more than expected during the postcalving, mosquito, and oestrid-fly seasons and in late summer, consistent with the geographic analysis described above, but use was less than expected during winter and spring migration. Dwarf shrub was used more than expected during 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 F). 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 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,

Table 6. Seasonal use of different habitat types by caribou in the NPRA survey area in 2011 alone and 2002–2011 combined, expressed as use (% of the area within 100 m of each group) divided by availability (% of area, excluding water).

				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]
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
2002–2011	Winter [b]	5	529	1.05	0.99	1.01	0.96	1.04	0.76	1.26^{+}	0.93	0.45--
	Spring Migration	8	398	1.09	1.02	0.96	1.25^{++}	0.94	0.95	0.81	0.85	0.45--
	Calving	11	968	0.94	0.87--	0.93-	1.16^{++}	1.06^{++}	0.84	0.96	0.82	0.77-
	Postcalving	10	1,078	0.86--	0.86--	1.04	1.07^{+}	0.98	1.33^{++}	1.15	1.76^{+}	1.65^{++}
	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	16	777	1.03	0.98	1.03	0.81--	0.82--	1.95^{++}	1.42^{++}	1.62	3.02^{++}
	Fall Migration	16	1,494	0.99	0.93--	0.99	1.02	1.01	1.38^{++}	1.15^{+}	1.06	0.96
	Total	82	5,581	1.00	0.93--	1.00	1.02^{+}	0.96-	1.33^{++}	1.15^{++}	1.23	1.46^{++}
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–2011				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 ($P < 0.01$).

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.

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 we 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 small number of caribou groups observed on 8 June 2011 used areas that had an average snow cover on 30 May ($P > 0.05$; Table 8). The average snow cover in the NPRA survey area on 30 May was 82.4% and the 33 caribou groups observed on the calving survey on 8 June were using areas that had a mean snow cover of 84.9% (95% C.I. = 80.1–88.9%). 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). The area around Fish and Judy creeks had lower snow cover on 30 May and the northern and coastal areas had more snow cover (Appendix F).

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 detect melt dates on satellite imagery because of cloud cover.

VEGETATIVE BIOMASS

Among seasons in 2011, caribou in NPRA selected areas with low values of estimated biomass (NDVI_Peak or NDVI_621) only during the oestrid-fly season (Table 8), probably as a result of higher use of the riverine areas (Table 5) and a preference for unvegetated areas for relief from fly harassment. Caribou selected areas with high values of both estimated biomass measures during calving and late summer and high NDVI_Peak during winter. In general, the more inland areas (Southeast and Southwest sections of the NPRA survey area) had higher estimated

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.

			Habitat Type [a]									
Zone	Distance Zone (km)	Water	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Dry Dunes	Sparsely Vegetated
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
	2–4	17.7	9.4	27.4	11.2	9.7	37.0	0.7	3.0	0.7	0.3	0.2
	0–2	9.4	9.0	25.0	12.0	9.8	41.7	0.5	1.7	0.2	<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
	2–4	15.5	7.0	18.2	8.9	6.9	53.1	0.3	4.8	0.7	<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

[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 2011, compared with availability using a bootstrap analysis.

Season	*n*[a]	NDVI_Calving	NDVI_621	NDVI_Rate	NDVI_Peak	Snow Cover (%)[b]
Winter	50	–	0.3786	–	0.6000++	79.7
Calving	33	–	0.4111++	–	0.6053++	84.9
Postcalving	116	–	0.3649	–	0.5858	72.8--
Oestrid Fly	5	–	0.3417	–	0.5540--	65.2--
Late Summer	41	–	0.4080++	–	0.6038++	80.5
Total Use	245	–	0.3807++	–	0.5937++	77.0--
Available		–	0.3647	–	0.5841	82.4

[a] Caribou groups in pixels with >50% water fraction were excluded from the analysis.
[b] Snow cover on 30 May 2011.
\+ 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 ($P < 0.01$).

biomass than did the Coast, North, and River sections (Appendix F). In 2005, 2007–2010, 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 suggested that geographical differences in phenology may account for the differences among herds. The calving grounds of the CAH and TH typically are colder and covered with snow later than are those of the WAH, so the chronology of forage development and selection in early June likely differs accordingly. Caribou select areas of patchy snow cover and high NDVI_Rate during the period of snow melt but select high biomass (NDVI_621) after tussock cottongrass (*E. vaginatum*) flowers are no longer available.

In the eastern portion of the ASDP study area (the Meltwater study area of Lawhead et al. 2004), caribou use of areas of high NDVI_Rate varied according to the timing of snow melt during 2001–2003. NDVI_Calving and NDVI_Rate are inversely correlated, so the values differ greatly between years of early and late snow melt. In years when melt occurred early, NDVI_Calving was high and NDVI_Rate was low throughout the region. In years when snow cover lingered through calving, NDVI_Calving was low and NDVI_Rate was high.

None of the previous analyses described above adjusted NDVI_Calving and NDVI_Rate for the effects of snow melt, so their results probably are more strongly related to temporal and spatial differences in snow melt than to differences in vegetative biomass.

DISTANCE TO PROPOSED ROAD

In most seasons and years, the number of caribou groups observed in each distance-to-road zone around the proposed ASDP road alignment did not differ significantly from those expected based on a uniform distribution among zones (Table 9, Appendix I). For all years combined (2001–2011), however, 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 22) showed a significant zone-by-season interaction (Wald chi-square P-value < 0.001). Caribou density within 6 km of the proposed alignment was significantly lower during the combined mosquito and oestrid-fly seasons than it was during calving, postcalving, and fall migration (all $P < 0.01$; the 2005 oestrid-fly season survey with large groups was dropped from the analysis to avoid undue influence on test results). Density was significantly lower in late summer than during postcalving ($P < 0.001$), and fall ($P = 0.007$). No other seasons differed significantly ($P > 0.05$).

Over all seasons combined, there were no significant differences among zones ($P = 0.182$). Significant differences in density were found among calving ($P = 0.021$), postcalving ($P = 0.025$), and winter ($P < 0.001$). After applying multiple-comparison tests, the only significant difference among zones was a greater density 4–6 km north of the road than 2–4 km north of the road during calving ($P = 0.027$). No differences were found when comparing the area within 2 km of the road with the other zones ($P > 0.10$).

Table 9. Number of caribou groups in distance-to-proposed road zones by year (2011 only and 2001–2011 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
2011	Winter	1	12	1	0	4	2	5	7.50	0.112
	Spring Migration	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
2001–2011	Winter	5	135	22	19	41	29	24	3.35	0.500
	Spring Migration	9	82	15	8	25	16	18	3.99	0.407
	Calving	12	221	56	29	66	34	36	7.50	0.112
	Postcalving	12	326	64	55	104	47	56	1.40	0.844
	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	18	196	44	38	60	23	31	6.24	0.182
	Fall Migration	19	427	76	63	146	65	77	1.34	0.854
	Total	94	1,454	299	225	455	220	255	7.58	0.108
Area (km^2) surveyed in 2001[a]				31.4	27.9	52.8	26.7	27.0		
Area (km^2) surveyed in 2002–2004				35.0	29.4	67.5	33.1	33.5		
Area (km^2) surveyed in 2005–2011				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 less than expected ($P < 0.05$).

-- Use less than expected ($P < 0.01$).

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 2011 and among all seasons for the years 2002–2011. A number of variables used in the grid-cell analyses were correlated; therefore, we examined the relationships among vegetation, snow, and habitat variables calculated for the 164 grid-cells before conducting the density analyses.

After removing one outlier, the estimated peak vegetative biomass (NDVI_Peak) was highly

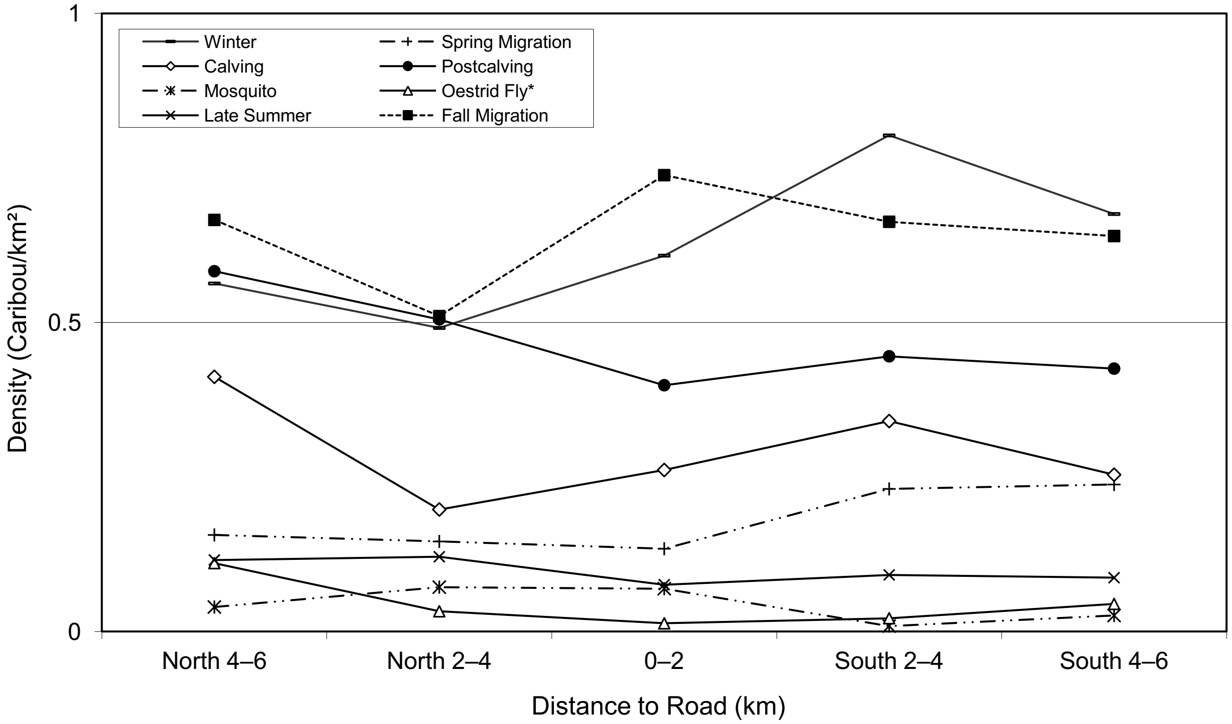


Figure 22. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2011.

correlated with NDVI_621 ($r = 0.839$; $P < 0.001$). These results indicate that the spatial pattern of NDVI values after snow melt is consistent throughout during the snow-free period. NDVI_Peak in 2011 was highly correlated with the NDVI_Peak in 2010 ($r = 0.939$; $P < 0.001$), NDVI_Peak in 2009 ($r = 0.899$; $P < 0.001$), and NDVI_Peak in 2008 ($r = 0.923$; $P < 0.001$). The spatial pattern of NDVI_Peak can be explained largely by differences among habitat types. NDVI_Peak increased with an increasing proportion of tussock tundra ($r = 0.750$; $P < 0.001$) but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $r = –0.466$; $P < 0.001$) and in riverine habitats ($r = –0.653$; $P < 0.001$). 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 ($r = –0.486$; $P < 0.001$), suggesting that even small waterbodies artificially depressed NDVI values.

The snow-cover fraction in the NPRA survey area on 30 May 2011 was not correlated with NDVI_621 ($r = –0.131$, $P = 0.095$) and only weakly correlated with NDVI_Peak ($r = –0.167$, $P = 0.033$). This lack of correlation may have been due to the high proportion of areas with nearly complete snow cover at the time the snow measurement was conducted. Early in spring, much of the snow melt occurs along Fish and Judy Creeks, an area that also has low vegetative biomass. In most previous years, the NDVI values measured in early June were 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.

Caribou Density During the 2011 Calving Season

The best model describing caribou density in the western half of the study area (NPRA survey area) during the 2011 calving season included just two independent variables: west to east variable and NDVI_621. This model had an estimated 25.3 % probability of being the best model ($w_i = 0.253$;

Appendix J). The second-best model included west to east and NDVI_Peak and had a 23.0% probability of being the best model (w_i = 0..230; Appendix J). The next two best models were the same as the first two models but also included snow cover. 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 an NDVI measure and west to east had a combined 92.3% probability of being the best model. The model-weighted parameter estimates indicated that none of the variables were significantly different from zero ($P > 0.10$; Table 10). Few caribou were observed in the NPRA survey area on the calving survey in 2011, however, so the tests we used had low power to detect significant factors affecting caribou distribution at that time.

Caribou density in Colville East was best described by the same model for both the early (June 2–3) and late (June 10) calving survey. The best model for both surveys 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 30 May, and distance to the coast (Appendix K). This model had an estimated 37.3.8% probability of being the best model in the candidate set during the early survey and a 28.5% chance of being the best model during the second survey (Appendix K).

Based on the model-weighted parameter estimates, caribou density in the Colville East survey area in the 2011 calving season declined where increasing proportions of land were covered by waterbodies during both surveys ($P < 0.05$; Table 11), was lower within 2 km of roads during both surveys, and was higher in areas with more snow cover on 30 May during both surveys (Table 11). During the first survey, density also increased from west to east and was significantly higher inland, from the coast.

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 areas near the road had less snow cover than areas more than 2 km from the road (62.2% vs. 76.6%; $P < 0.001$), 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 L). 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, and density varied significantly among surveys. During winter, caribou density was also higher in areas with tussock tundra. During spring migration, caribou density decreased with increasing distance from the coast.

During calving the model-weighted parameter estimates indicated that caribou density during calving was greater near the creeks, in areas of higher NDVI_Peak values, higher at greater distances from the coast and higher proportion of tussock tundra. Calving density was lower in areas with greater proportions of wet habitat (Table 12, Appendix M).

Caribou densities in the NPRA survey area during calving indicate a preference for areas with higher NDVI_Peak values in most years. Because of the high correlation between NDVI values and habitat types, it is difficult to distinguish 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

Table 10. Model-weighted parameter estimates for caribou density in the NPRA survey area during the calving survey on 8 June 2011.

Variable	Coefficient	SE	*P*-value
Intercept	–15.047	11.549	0.193
NDVI_Peak	32.993	20.054	0.100
NDVI_621	17.527	15.165	0.248
Snow cover on 30 May (%)	0.015	0.043	0.721
Tussock tundra (%)	3.508	2.739	0.200
Wet habitat (%)	–2.204	2.486	0.375
W to E (transect number)	–0.112	0.027	0.412

Table 11. Model-weighted parameter estimates for caribou density in the Colville East survey area during early calving (2–3 June) and late calving (10 June) surveys in 2011.

Survey	Variable	Coefficient	SE	*P*-value
Early	Intercept	–3.534	1.739	0.042
	Proportion covered by waterbodies	–2.343	1.194	0.050
	W to E (transect number)	0.069	0.021	0.001
	Within 2 km of roads	–0.692	0.306	0.024
	NDVI_Peak	–1.694	7.560	0.823
	Distance to coast	0.032	0.012	0.008
	Snow cover on 30 May	0.016	0.006	0.014
	Proportion of wet graminoid tundra (%)	–0.895	0.885	0.312
Late	Intercept	–2.258	1.637	0.168
	Proportion covered by waterbodies	–2.963	1.042	0.004
	W to E (transect number)	–0.039	0.022	0.081
	Within 2 km of roads	–0.753	0.340	0.027
	NDVI_Peak	–1.502	6.907	0.828
	Distance to coast	–0.012	0.012	0.306
	Snow cover on 30 May	0.031	0.007	<0.001
	Proportion of wet graminoid tundra (%)	0.001	0.832	0.999

between-year correlations of caribou density during calving were low for 2005–2011 (Spearman's rho = –0.061–0.420), suggesting that different factors influenced caribou distribution among years at the scale of our analysis.

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 creeks and near the coast. During the oestrid-fly season, density was higher near the creeks and lower in areas with high NDVI_Peak. In late summer, density was higher near the creeks and was lower in areas with higher NDVI_Peak values. During fall migration, there were no other significant variables (Table 12; Appendix M).

Overall, strong seasonal patterns in caribou density were evident. A west-to-east gradient of decreasing density was evident throughout the entire year, most likely because the NPRA survey area is located on the eastern edge of the TH range. The riverine area of Fish and Judy creeks had higher densities from the calving season through late summer. The riverine area is characterized by a mosaic of habitats, including abundant willows and forbs that provide forage, as well as barrens, dunes, and river bars that provide some relief from oestrid-fly harassment. Caribou densities near the coast were higher during spring migration, the postcalving, and mosquito seasons which are generally consistent with increased use of coastal areas during mosquito harassment. Caribou densities in areas with high proportions of tussock tundra were greater during calving, 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

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, 2002–2011.

Variable	Winter	Spring Migration	Calving	Post-calving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
Presence of creeks	ns	ns	+	++	+	++	++	ns
Includes proposed road	ns	ns	ns	ns	ns	ns	ns	ns
Survey	**	**	**	**	**	**	**	**
NDVI_Peak	ns	ns	++	ns	ns	-	--	ns
Distance to coast	ns	--	+	--	--	ns	ns	ns
Tussock tundra (%)	+	ns	++	+	ns	ns	ns	ns
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 ($P < 0.01$).

little by caribou from either herd. The TH consistently uses the western half of the ASDP study area to some extent during all seasons of the year; caribou numbers generally are low in the NPRA survey area during calving, highly variable during the insect season, and then tend to increase in the fall. In contrast, the CAH uses the eastern half of the ASDP study area primarily during calving (including concentrated calving in the southeastern part of the Colville East survey area), postcalving, and the insect season. Although caribou from both herds occur on the Colville delta occasionally, large movements onto or across the delta are uncommon for either herd. 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, however. The distribution of the CAH during the insect season has shifted farther eastward in recent years, so fewer caribou from that herd are using the Colville River delta than did 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.

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. Two male satellite-collared caribou were near CD4 in July 2011. None of the satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006 or 2008–2010. In 2007, a satellite-collared TH female passed between Nuiqsut and CD4 during calving and four satellite-collared TH caribou moved east past Alpine and CD4 in late July. Of 43 different TH animals equipped with GPS collars during 2004–2011, one crossed the Colville delta westward between CD4 and Alpine on 6 June 2005 on its way to Teshekpuk Lake. Caribou 0404 spent 1–6 August 2007 about 2 km south of CD4 before heading west. Caribou 0621 wintered near Nuiqsut during the winter of 2007–2008, but did not move onto the Colville delta. In 2011, no GPS-collared TH caribou for which data are currently available moved onto the Colville River delta.

One satellite-collared CAH caribou moved into the CD4 vicinity briefly in July 1988 and four others were nearby briefly in July 1989, more than a decade before construction. Four CAH satellite collars moved through the CD4 vicinity while heading inland in late July 2001 and one CAH GPS collar moved onto the Colville delta east of CD4 in late September 2004. Two CAH GPS-collared caribou were near CD4 in late July 2011 and one returned in early August 2011.

Radio-collared TH caribou occasionally crossed the proposed ASDP pipeline/road-corridor alignment extending from CD4 to the proposed GMT2 drill site in NPRA, primarily during fall migration, but the proposed alignment is located in a geographic area that currently receives low-density use by caribou from that herd. Five satellite-collared TH caribou (4 males and one female) crossed the proposed road between 13 July and 28 July 2011. A single CAH caribou outfitted with a GPS collar crossed the northern spur of the proposed road on 4 August 2011 while moving west into NPRA.

Radio-collared CAH caribou have crossed the proposed alignment very rarely over the years and it is not likely that the proposed pipeline/road corridor would have any effect on the CAH unless movement patterns change substantially in the future. Because TH caribou use the western half of the ASDP study area year-round, detailed analyses of caribou distribution and density focused primarily on the NPRA survey area, which encompasses the proposed ASDP road alignment.

Use of the NPRA survey area by TH caribou varies widely among seasons. These differences can be described in part by snow cover, vegetative biomass, habitat distribution, and distance to the coast. During calving, caribou generally use areas of higher plant biomass (estimated from NDVI values) and higher proportions of tussock tundra. Calving tends to occur in areas of patchy snow cover, although calving habitat selection appears to vary within the study area, depending on 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 2011 appeared to select areas away from the coast, and with more rapid 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 use the study area. The data reported here provide an important record for evaluating and mitigating the potential impacts of ASDP development on caribou distribution and movements, as well as providing ongoing results to refine the study effort in future years of the program.

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

Cover Class	Description
Clear Water	Fresh or saline waters with little or no particulate matter. Clear 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, 1983–2011.

	Snow Depth (cm)			Cumulative Thawing Degree-days (º C)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	73.3	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	20	10	0	0	5.0	100.8	112.2	124.7	109.4
1987	15	8	3	0	0.6	6.7	61.4	112.2	127.8	93.1
1988	10	5	5	0	0	16.7	78.1	108.3	143.1	137.5
1989	33	–	10[a]	0	5.6	20.6	109.4	214.7	168.1	215.8
1990	8	3	0	0	16.1	39.7	132.2	145.0	150.0	82.5
1991	23	8	3	0	7.8	14.4	125.0	73.3	115.0	70.6
1992	13	8	0	0.3	20.3	55.0	85.3	113.9	166.1	104.2
1993	13	5	0	0	8.6	33.6	94.4	175.8	149.7	96.1
1994	20	18	8	0	4.4	49.2	51.7	149.7	175.8	222.2
1995	18	5	0	0	1.1	59.4	87.5	162.8	106.9	83.3
1996	23	5	0	8.1	41.7	86.1	121.1	138.9	168.1	95.8
1997	28	18	8	0	20.8	36.1	109.7	101.7	177.8	194.2
1998	25	8	0	3.6	45.8	74.2	135.0	158.9	184.4	174.4
1999	28	15	10	0	1.4	30.3	67.8	173.3	81.1	177.5
2000	30	23	13	0	0	36.7	169.7	113.3	127.5	118.6
2001	23	30	5	0	0.8	51.9	72.2	80.0	183.9	131.7
2002	30	trace	0	4.2	30.3	57.8	70.3	92.2	134.4	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	8.9	26.4	185.6	148.1	151.4	153.3
2005	23	13	0	0	2.5	14.2	78.1	67.5	79.4	176.7
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
2007	25	46	5	0	0	46.4	81.7	115.0	138.9	134.4
2008	20	18	0	0	32.8	71.7	138.9	172.2	132.5	86.1
2009	36	13	0	0	16.7	71.7	44.4	142.8	126.4	133.6
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
Mean	23.0	13.8	3.4	0.6	11.8	41.9	97.4	125.0	142.5	127.3

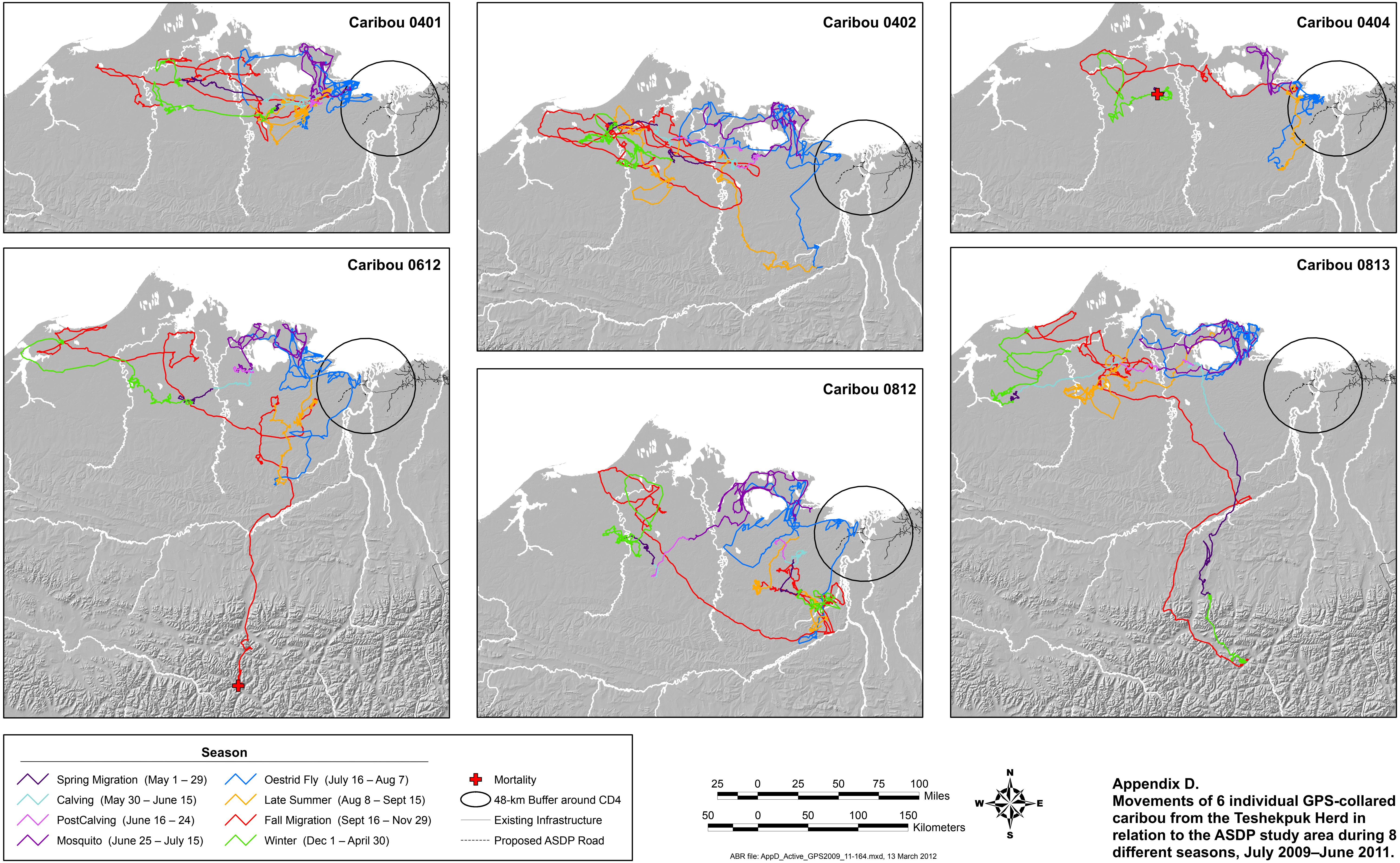
[a] After 15 June, Kuparuk weather data were not available, so cumulative TDD was estimated by averaging Deadhorse and Nuiqsut temperatures (Lawhead and Prichard 2012).

Appendix C. Location and number of other mammals observed during aerial surveys for caribou in and near the ASDP study area, April–September 2011.

Species	General Location	Date	Adults	Young	Total	Specific Location
Muskox	Kuparuk Field	June 3	7	3	10	SW of CPF-2
		June 9	1	0	1	N of CPF-1
		June 10	9	0	9	NW of CPF-2
		June 12	9	0	9	NW of CPF-2
		June 14	1	0	1	W of CPF-2
		June 14	8	0	8	W of CPF-2
		June 16	1	0	1	W of CPF-2
		June 23	7	3	10	N of Alpine Pipeline
	Colville River Delta	April 29	10	1	11	N of DS-3S
		June 10	8	2	10	Miluveach River
		June 14	7	3	10	Kachemach River
		August 1	8	3	11	Miluveach River
		August 2	8	3	11	Miluveach River
		August 17	10	1	11	Kachemach River
		August 18	7	4	11	Kachemach River
	Kuparuk River	June 3	1	0	1	Upper Kuparuk River
		June 4	7	3	10	Upper Kuparuk River
		June 10	7	3	10	Upper Kuparuk River
		June 20	16	1	17	Spine Road
		June 21	15	0	15	Spine Road
		June 21	13	3	16	Upper Kuparuk River
		June 21	13	3	16	Upper Kuparuk River
		June 22	15	0	15	Spine Road
		June 22	4	2	6	Kuparuk River delta
		June 22	6	4	10	Kuparuk River delta
		June 23	15	0	15	Spine Road
		June 23	11	3	14	S of Spine Road
		August 17	2	3	5	S of Spine Road
		August 17	3	2	5	Spine Road
		August 17	15	0	15	Spine Road
	Beechey Point/ Milne Point	June 3	11	4	15	W of Milne Point
		June 4	10	3	13	Milne Point
		June 4	19	1	20	Beechey Point
		June 9	13	3	16	Beechey Point
		June 9	15	0	15	Beechey Point
		June 9	10	4	14	W of Milne Point
		June 9	10	3	13	Milne Point
		June 21	3	0	3	Beechey Point
Grizzly bear	NPRA	June 8	1	2	3	Fish Creek
		June 14	1	0	1	Fish Creek delta
		June 22	1	0	1	Lower Fish Creek
	Colville River Delta	June 14	1	0	1	S of Alpine
		June 14	1	0	1	W of Fish Creek
		June 14	1	0	1	Fish Creek

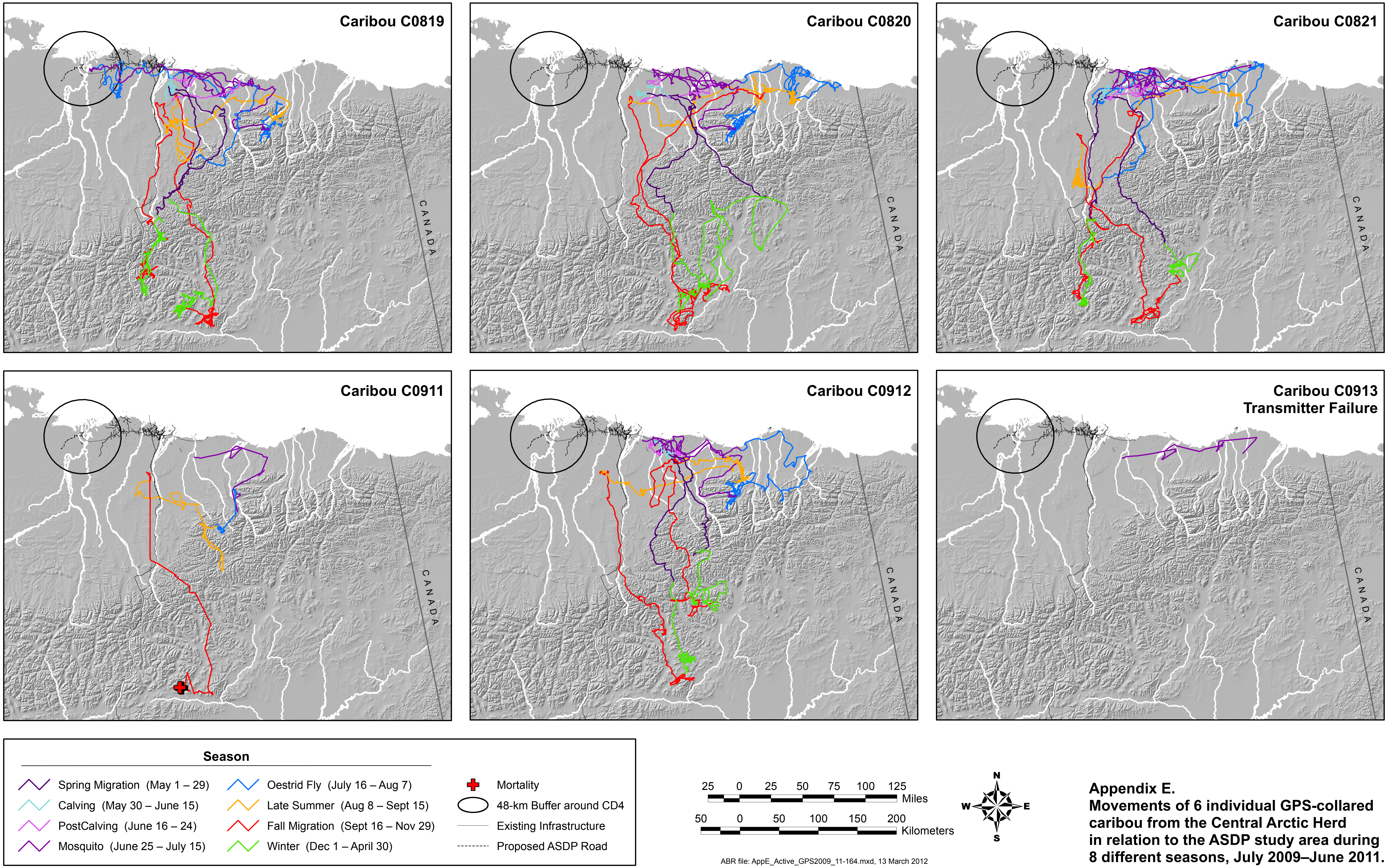
Appendix C. Continued.

Species	General Location	Date	Adults	Young	Total	Specific Location
Grizzly bear	Upper Miluveach River	April 29	1	0	1	S of DS-2P
		June 2	1	0	1	N of DS-2P
		June 3	1	0	1	E of DS-2P
		June 3	1	0	1	Upper Sakonowyak River
		June 10	1	0	1	S of DS-2P
		June 22	1	0	1	S of DS-2P
		June 22	1	0	1	S of DS-2P
		June 23	2	0	2	SE of DS-2P
		June 25	1	0	1	Near DS-2P
		August 2	2	0	2	Upper Miluveach River
		August 2	1	0	1	W of DS-2L
		August 2	1	0	1	W of DS-2L
		August 2	1	0	1	N of DS-2P
		August 2	1	0	1	N of DS-2P
		August 2	1	0	1	Near DS-2P
		August 2	1	0	1	W of DS-2P
		August 2	1	0	1	W of DS-2P
		August 2	1	0	1	W of DS-2L
		August 19	1	0	1	SE of DS-2P
		August 20	1	1	2	NE of DS-2P
		August 20	1	0	1	SE of DS-2P
	Kuparuk Field	June 4	1	0	1	Beechey Point
		June 6	1	2	3	E of CPF-3
		June 12	1	0	1	E of DS-3S
		June 22	2	0	2	S of Beechey Point
	Kuparuk River	August 17	1	0	1	S of Spine Road
Spotted seal	Colville River Delta	August 8	30	0	30	Eastern delta
		August 15	40	0	40	Eastern delta
		August 24	38	0	38	Eastern delta
		August 29	50–60	0	50–60	Eastern delta
		September 12	20	0	20	Eastern delta



ABR file: AppD_Active_GPS2009_11-164.mxd, 13 March 2012

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.



ABR file: AppE_Active_GPS2009_11-164.mxd, 13 March 2012

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. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2011 and for habitat types (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2011 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	–	–	0.1353	0.2262	0.2284
		NDVI_621	0.3478	0.3515	0.3462	0.3938	0.4079
		NDVI_Rate	–	–	0.0155	0.0142	0.0144
		NDVI_Peak	0.5826	0.5810	0.5735	0.5998	0.6087
	Snow Cover (30 May)	Mean %	82.9	88.4	69.8	83.0	84.1
	Habitat Type (% area)	Water	9.9	26.6	14.4	17.7	11.4
		Carex aquatilis	11.5	6.3	6.4	6.2	8.4
		Flooded Tundra	33.0	11.5	14.9	18.3	18.2
		Wet Tundra	12.3	7.5	11.5	7.3	10.3
		Sedge/Grass Meadow	7.4	22.0	14.2	5.3	13.5
		Tussock Tundra	23.7	22.0	25.1	41.3	34.2
		Moss/Lichen	1.4	0.9	3.3	0.3	0.7
		Dwarf Shrub	0.2	1.9	3.2	2.9	2.8
		Low Shrub	0	<0.1	0.1	0.3	0.2
		Dry Dunes	0.1	0.1	2.0	0.1	0
		Sparsely Vegetated	<0.1	0.5	2.9	0.1	<0.1
		Barren Ground	0.4	0.7	2.1	0.1	0.1
2005–2011	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_Calving	–	–	0.1358	0.2266	0.2284
		NDVI_621	0.2922	0.3415	0.3444	0.3938	0.4078
		NDVI_Rate	–	–	0.0155	0.0142	0.0144
		NDVI_Peak	0.5273	0.5785	0.5731	0.5998	0.6087
	Snow Cover (6 June)	Mean %	88.0	88.1	70.3	83.0	84.1
	Habitat Type (% area)	Water	24.2	22.1	15.3	17.7	11.4
		Carex aquatilis	8.3	6.3	6.4	6.2	8.4
		Flooded Tundra	15.0	10.1	14.9	18.3	18.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.3
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	13.5
		Tussock Tundra	19.7	25.5	24.8	41.3	34.3
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1
		Low Shrub	<0.1	<0.1	0.1	0.3	0.2
		Dry Dunes	3.2	0.3	2.0	0.1	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1
		Barren Ground	8.0	0.8	2.1	0.1	0.1

Appendix G. Number of caribou groups in different geographic sections of the NPRA survey area, by year (2002–2010) 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 G. Continued.

				Geographic Section						
Year	Season	No. of Surveys	Total Groups	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

[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 H. 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, 2002–2010.

				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 H. Continued.

				Habitat Type [a]								
Year	Season	No. of Surveys	No. of Groups	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2008	Winter	1[c]	60	0.90	1.34	1.50	1.24	0.83	1.46	1.19	1.35	0.09-
	Spring Migration	1	10	1.28	1.08	0.66	0.48	1.28	0.19	1.68	3.10	0.00
	Calving	1	145	0.88	1.01	0.84	1.23[+]	1.10	0.53-	0.49--	0.42	0.32-
	Postcalving	1	82	1.02	0.91	0.98	1.23	1.01	1.42	0.69	0.70	0.45
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	1	112	0.77	0.93	0.98	0.65--	0.84-	2.31[++]	1.54[+]	1.44	4.08[++]
	Fall Migration	3	245	0.83-	0.89	0.91	1.17[+]	1.05	1.51[+]	1.11	0.20	0.66
	Total	8	654	0.88	0.97	0.95	1.07[+]	1.01	1.40[++]	1.02	0.74	1.05
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+

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[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 I. Number of caribou groups in distance zones around proposed ASDP road, by year (2001–2010) 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 I. Continued.

				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
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

+ 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 J. Model-selection results (General Estimating Equations) for analyses of caribou density during calving in the NPRA survey area in 2011 (163 grid cells). The best model (bold type) contained the variables W to E (transect number) and NDVI_621.

Model[a]	n[b]	K[c]	QIC_c[d]	ΔQIC_c[e]	w_i[f]
W to E, NDVI_621	**163**	**4**	**281.615**	**0.00**	**0.253**
W to E, NDVI_Peak	163	4	281.812	0.20	0.230
W to E, Snow Cover, NDVI_621	163	5	281.857	0.24	0.225
W to E, Snow Cover, NDVI_Peak	163	5	281.946	0.33	0.215
NDVI_Peak	163	3	285.885	4.27	0.030
NDVI_621	163	3	286.749	5.13	0.019
Snow Cover, NDVI_Peak	163	4	286.932	5.32	0.018
Snow Cover, NDVI_621	163	4	288.062	6.45	0.010
W to E, Snow Cover, Tussock	163	5	297.623	16.01	0.000
W to E, Tussock	163	4	297.943	16.33	0.000
W to E, Snow Cover, Wet Habitat	163	5	303.321	21.71	0.000
W to E	163	3	303.718	22.10	0.000
W to E, Wet Habitat	163	4	304.101	22.49	0.000
W to E, Snow Cover	163	4	305.141	23.53	0.000
Tussock	163	3	309.836	28.22	0.000
Intercept	163	2	311.414	29.80	0.000
Snow Cover, Tussock	163	4	311.592	29.98	0.000
Wet Habitat	163	3	313.107	31.49	0.000
Snow Cover	163	3	313.404	31.79	0.000
Snow Cover, Wet Habitat	163	4	314.956	33.34	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).

[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 K. Model-selection results (General Estimating Equations) for analyses of caribou density during calving in the Colville East survey area in 2011 (552 grid cells). The best model (bold type) contained the variables W to E (transect number) and proportion of waterbodies (both included in all models), proportion of wet habitat, snow cover (%), distance to coast (km), and NDVI_Peak.

Survey	Model [a]	n[b]	K[c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
Early	**W to E, Water, Road, Snow Cover, Coast**	**552**	**8**	**1144.97**	**0**	**0.373**
	W to E, Water, Road, Wet Habitat, Snow Cover, Coast	552	9	1145.45	0.48	0.293
	W to E, Water, Road, Snow Cover, Coast, NDVI_Peak	552	9	1146.96	1.98	0.138
	W to E, Water, Road, Wet Habitat, Snow Cover, Coast, NDVI_Peak	552	10	1146.97	2.00	0.137
	W to E, Water, Road, Wet Habitat, Snow Cover	552	8	1151.56	6.59	0.014
Late	**W to E, Water, Road, Snow Cover, Coast**	**552**	**8**	**1437.54**	**0**	**0.285**
	W to E, Water, Road, Snow Cover	552	7	1438.09	0.55	0.217
	W to E, Water, Road, Wet Habitat, Snow Cover, Coast	552	9	1439.43	1.89	0.111
	W to E, Water, Road, NDVI_Peak, Snow Cover, Coast	552	9	1439.54	2.00	0.105
	W to E, Water, Road, NDVI_Peak, Snow Cover	552	8	1439.54	2.00	0.105
	W to E, Water, Road, Wet Habitat, Snow Cover	552	8	1439.74	2.20	0.095
	W to E, Water, Road, NDVI_Peak, Wet Habitat, Snow Cover, Coast	552	10	1441.40	3.86	0.041

[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 2011.

[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 L. Model-selection results (Generalized Estimating Equation) for analyses of caribou density in different seasons during 2002–2011 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]	8	9	9	9	9	9	10	**10**	10	10	10	10	10	11	11	11
	QIC_c[e]	2577	2574	2574	2575	2577	2542	2542	**2532**	2574	2574	2575	2544	2538	2543	2533	2539
	w_i[f]	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.004	**0.532**	<0.001	<0.001	<0.001	0.001	0.031	0.002	0.412	0.014
Spring	K	11	12	12	12	12	12	13	13	13	13	13	13	13	14	**14**	14
	QIC_c	2883	2878	2884	2885	2884	2862	2862	2863	2880	2880	2880	2845	2864	2847	**2842**	2845
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.124	<0.001	0.059	**0.712**	0.104
Calving	K	14	15	15	15	15	15	16	16	16	16	16	16	16	**17**	17	17
	QIC_c	5407	5292	5300	5391	5403	5258	5174	5199	5257	5290	5294	5209	5228	**5165**	5179	5198
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.982**	0.001	<0.001
Postcalving	K	13	14	14	14	14	14	15	15	15	15	15	15	15	16	16	**16**
	QIC_c	6616	6618	6617	6615	6618	6429	6430	6428	6619	6617	6620	6404	6426	6401	6395	**6395**
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	0.020	0.440	**0.536**
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11	11
	QIC_c	916	825	896	906	913	906	881	897	827	826	826	**789**	904	791	791	791
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.471**	<0.001	0.173	0.183	0.172
Oestrid Fly	K	9	10	10	10	10	10	11	11	11	11	11	11	11	**12**	12	12
	QIC_c	1096	1085	1093	1091	1096	1074	1067	1073	1072	1076	1084	1074	1076	**1063**	1071	1076
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.089	0.007	0.009	0.001	<0.001	0.003	0.001	**0.867**	0.019	0.001
Late Summer	K	19	20	20	20	20	20	21	21	21	21	21	21	21	**22**	22	22
	QIC_c	4708	4709	4694	4686	4706	4645	4622	4635	4695	4688	4707	4632	4647	**4621**	4628	4634
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.292	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	**0.688**	0.016	0.001
Fall	K	19	20	20	20	20	20	21	21	21	21	21	21	**21**	22	22	22
Migration	QIC_c	8995	8995	8994	8986	8981	8959	8955	8957	8990	8984	8978	8960	**8953**	8956	8959	8955
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	0.028	0.200	0.055	<0.001	<0.001	<0.001	0.013	**0.440**	0.081	0.020	0.162

[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.

Appendix M. 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, 2002–2011.

Season	Variable	Mean	SE	*P*-value[a]
Winter	Intercept	–1.934	0.508	<0.001***
	Presence of Creek	–0.359	0.246	0.145
	Includes Proposed Road	–0.440	0.322	0.172
	NDVI_Peak	4.229	3.877	0.275
	Distance to Coast (km)	–0.007	0.009	0.451
	Tussock Tundra (%)	1.567	0.665	0.018
	Wet Habitat (%)	–1.087	0.653	0.096
	W to E (transect number)	–0.111	0.025	<0.001***
Spring Migration	Intercept	–3.990	0.662	<0.001***
	Presence of Creek	–0.447	0.246	0.069
	Includes Proposed Road	–0.533	0.367	0.146
	NDVI_Peak	1.703	4.295	0.692
	Distance to Coast (km)	–0.024	0.009	0.009**
	Tussock Tundra (%)	0.940	0.714	0.188
	Wet Habitat (%)	–0.497	0.691	0.472
	W to E (transect number)	–0.089	0.026	0.001***
Calving	Intercept	–9.647	1.583	<0.001***
	Presence of Creek	0.306	0.183	0.046*
	Includes Proposed Road	–0.342	0.240	0.155
	NDVI_Peak	13.103	2.746	<0.001***
	Distance to Coast (km)	0.013	0.006	0.025
	Tussock Tundra (%)	1.814	0.454	<0.001***
	Wet Habitat (%)	–1.122	0.435	0.010**
	W to E (transect number)	–0.101	0.015	<0.001***
Postcalving	Intercept	2.271	0.542	<0.001***
	Presence of Creek	1.115	0.150	<0.001***
	Includes Proposed Road	0.370	0.217	0.088
	NDVI_Peak	3.803	2.601	0.144
	Distance to Coast (km)	–0.021	0.006	<0.001***
	Tussock Tundra (%)	0.909	0.443	0.040
	Wet Habitat (%)	–0.877	0.438	0.045
	W to E (transect number)	–0.148	0.016	<0.001***
Mosquito	Intercept	2.915	1.266	0.026*
	Presence of Creek	0.759	0.316	0.016*
	Includes Proposed Road	0.626	0.479	0.192
	NDVI_Peak	–1.256	5.959	0.833
	Distance to Coast (km)	–0.115	0.015	<0.001***
	Tussock Tundra (%)	–0.381	1.041	0.714
	Wet Habitat (%)	0.093	1.043	0.929
	W to E (transect number)	–0.168	0.035	<0.001***
Oestrid Fly[b]	Intercept	4.220	4.955	0.394
	Presence of Creek	1.764	0.354	<0.001***
	Includes Proposed Road	–1.860	1.873	0.321
	NDVI_Peak	–15.530	7.060	0.028*
	Distance to Coast (km)	0.033	0.019	0.078
	Tussock Tundra (%)	–1.708	1.251	0.172
	Wet Habitat (%)	0.357	1.298	0.783
	W to E (transect number)	–0.093	0.050	0.064

Appendix M. Continued.

Season	Variable	Mean	SE	P-value[a]
Late Summer	Intercept	2.829	1.402	0.044*
	Presence of Creek	0.481	0.130	<0.001***
	Includes Proposed Road	0.077	0.219	0.726
	NDVI_Peak	–7.047	2.375	<0.003**
	Distance to Coast (km)	–0.009	0.006	0.106
	Tussock Tundra (%)	–0.767	0.407	0.060
	Wet Habitat (%)	–0.043	0.407	0.917
	W to E (transect number)	–0.093	0.015	<0.001***
Fall Migration	Intercept	0.271	1.064	0.799
	Presence of Creek	0.024	0.147	0.872
	Includes Proposed Road	–0.096	0.205	0.640
	NDVI_Peak	–3.190	2.343	0.173
	Distance to Coast (km)	<0.001	0.006	0.972
	Tussock Tundra (%)	–0.406	0.400	0.311
	Wet Habitat (%)	0.610	0.402	0.130
	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.