SIXTH ANNUAL REPORT

CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2010

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EXECUTIVE SUMMARY

- Recent discoveries of oil in the northeastern National Petroleum Reserve–Alaska (NPRA) led to a proposal by ConocoPhillips Alaska (CPAI)—the Alpine Satellite Development Program (ASDP)—to expand development from the Alpine facilities on the Colville River delta and into NPRA. The first ASDP facility to be constructed (winter 2004–2005) was the CD4 drill site and access road. The North Slope Borough (NSB) development permit for CD4 stipulated that a 10-year study of the effects of development on caribou distribution and movements be conducted within a 48-km (30-mile) radius of CD4, which encompasses CD3 (also constructed in winter 2004–2005) and the planned CD5, GMT1 (formerly CD6), and GMT2 (formerly CD7) pads and associated infrastructure and activities proposed by CPAI.
- This report presents results from the sixth 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 2005–2010, 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 1990–2010 for the TH and 1986–1990 and 2001–2005 for the CAH; and GPS-collar data were collected during 2004–2010 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 2000–2010, 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 2000–2010 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 (2001–2010), 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 37% for satellite collars during 1990–2010 and 3% to 35% for GPS collars during 2004–2010. The mean proportion of collared CAH caribou within the study area during each month varied between 12 and 64% for satellite collars during

1986–1990 and 2001–2009 and between 0 and 52% for GPS collars during 2003–2006 and 2008–2009.

- 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 2010, only 26 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. No movements by satellite- or GPS-collared caribou through the CD4 vicinity (between Nuiqsut and the Alpine facilities) were recorded in 2010. 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 2002–2010 showed that the section near the Beaufort Sea coast contained significantly more caribou groups during the mosquito season than would be expected if caribou distribution were uniform, consistent with use of coastal areas as mosquito-relief habitat, but less groups than expected during winter, calving, postcalving, and fall. Riparian areas along Fish and Judy creeks contained significantly more caribou groups than would be expected if caribou distribution were uniform during the postcalving season, oestrid fly season, and late summer. The southeastern section of the NPRA survey area, in which the proposed ASDP pipeline/road corridor would be constructed, contained significantly fewer groups in all seasons.
- For the years 2002–2010 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 calving, late summer, and fall 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.
- The density of calving caribou in the Colville East Survey Area in 2010 increased with distance to the coast, from east to west, and in areas with more rapid snowmelt. Density decreased in areas with more water bodies, and within 2 km of existing roads.
- 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 (if caribou were uniformly distributed) occurred around the corridor during the oestrid-fly season, probably due to increased use of riparian habitats along Fish and Judy creeks by fly-harassed caribou.

- Radio-collared TH caribou have occasionally crossed the proposed ASDP road alignment in past years, primarily during fall migration, but the data collected thus far indicate that the proposed road/pipeline corridor is in an area of low-density use by caribou.

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ACRONYMS

ADFG	Alaska Department of Fish and Game
agl	above ground level
ANWR	Arctic National Wildlife Refuge
ASDP	Alpine Satellites Development Program
BLM	Bureau of Land Management
CAH	Central Arctic Herd
CPAI	ConocoPhillips Alaska, Inc.
CREFL	MODIS-corrected reflectance
DRA	distance–rate–angle
DRL	Direct Readout Laboratory
EIS	environmental impact statement
ELS	ecological land survey
EOS	Earth-Observing System
ETM+	Enhanced Thematic Mapper+
GEE	generalized estimating equation
GPS	Global Positioning System
IAP	Integrated Activity Plan
IMAPP	International MODIS/AIRS Processing Package
LAADS	Level-1 and Atmospheres Archive and Distribution System
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NDVI_calving	Normalized Difference Vegetation Index during June 1–10
NDVI_peak	Normalized Difference Vegetation Index at peak summer biomass
NDVI_rate	daily change in Normalized Difference Vegetation Index during June
NDVI_621	Normalized Difference Vegetation Index on June 21
NIR	near-infrared reflectance
NPRA	National Petroleum Reserve–Alaska
NQ	Argos system location-quality score
NSB	North Slope Borough
QICc	Quasi-likelihood Information Criteria, corrected for small sample sizes
ROD	Record of Decision
SCF	sightability correction factor
SE	standard error
TDD	thawing degree-days
TH	Teshekpuk Herd
TM	Thematic Mapper
USGS	U.S. Geological Survey
VHF	very high frequency
VIS	visible light reflectance
WAH	Western Arctic Herd
WGS-84	World Geodetic System of 1984

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, Lawhead et al. 2010, Parrett 2009).

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving is located consistently around Teshekpuk Lake and the primary area of insect-relief habitat in midsummer is the swath of land between Teshekpuk Lake and the Beaufort Sea coast (Carroll et al. 2005, Kelleyhouse 2001, Parrett 2007, 2009, Person et al. 2007). 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, Parrett 2009). In recent years, a substantial portion of the TH has wintered in areas outside the previous range of the herd, both far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004, Parrett 2009) and southeast in the winter range of the CAH since 2004–2005 (Lawhead et al. 2007, 2008, 2009, 2010; 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 2011). 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. (2011) 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, Lawhead et al. 2010, Parrett 2009). Consultants working for BP Exploration (Alaska) Inc. also conducted aerial transect surveys over much of the TH calving grounds during 1998–2001 (Noel 1999, 2000; Jensen and Noel 2002; Noel and George 2003).

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

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

The current period of oil and gas leasing and exploration in NPRA closely followed the issuance of the 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 planned pads for CD5, GMT1 (formerly CD6), and GMT2 (formerly CD7); and all associated infrastructure and activities proposed by CPAI and evaluated in the ASDP EIS (BLM 2004).

PROGRAM GOALS AND STUDY OBJECTIVES

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

To begin implementing the permit stipulation, representatives of CPAI and ABR met with NSB staff in Barrow on 2 December 2004. The study options discussed at that meeting were developed into a preliminary study design and scope of work that were circulated in early February 2005 for further review. The revised study design and scope of work were approved in late March 2005 and were amended in early July 2005 to accommodate telemetry surveys by ADFG, which were added under the terms of a cooperative agreement among ADFG, CPAI, and ABR that addressed sharing of telemetry data for use in this monitoring study. The results of each of the five preceding years of study (2005–2009) 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, and 16 March 2010) and in the village of Nuiqsut (1 August 2006, 1 May 2007, 20 March 2008, and 13 October 2009).

This study addresses specific issues concerning the potential impacts of petroleum development on caribou in the ASDP study area, with the intent of drawing on both scientific knowledge and local/traditional knowledge. The accumulated body of scientific knowledge on the TH and CAH provides a starting point and framework for structuring the study to address the issues identified since North Slope oil development began about 40 years ago. The extensive knowledge of local residents has been, and will continue to be, important for formulating research questions and ensuring that appropriate study methods are used. In addition to discussions between biologists and local residents at meetings in Nuiqsut, local observers have participated in some aerial surveys; most recently, James Taalak was part of the survey crew in August 2009.

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:

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

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

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

2) Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snow melt, seasonal flooding (if possible), and estimated biomass of new vegetative growth in the study area, by applying remote-sensing techniques, for comparison with data on caribou distribution.
3) Evaluate forage availability (above-ground vegetative biomass) and indices of habitat use by caribou in relation to proposed infrastructure, to allow temporal comparisons among years (before and after construction) and spatial comparisons within years. Specific questions included the following:

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

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

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

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

Field sampling of plant biomass (Task 3) was scheduled to occur at least three times during the 10-year study; 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.

The study area was specified by the NSB permit as the area within a 48-km (30-mi) radius around the CD4 drill site (Figure 1, bottom). Aerial transect surveys were conducted in three survey areas, most of which were encompassed by the 48-km radius: Colville East (1,432–1,938 km^2, depending on the survey and year), Colville River Delta (494 km^2), and NPRA (988 km^2 in 2001, expanded to 1,310 km^2 in 2002 and to 1,720 km^2 in 2005). The Colville East survey area was expanded 240 km^2 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 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),

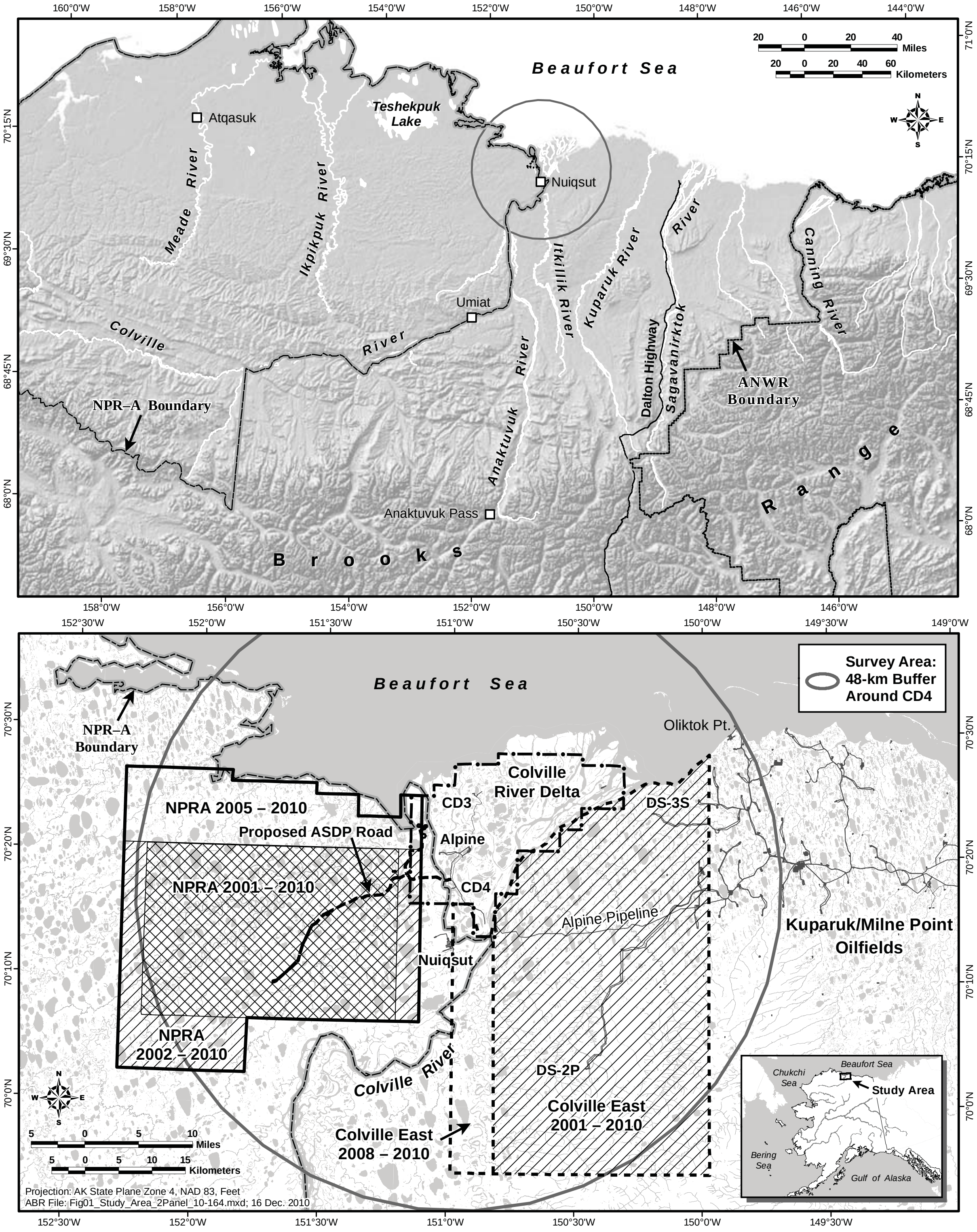

Figure 1. Location of the ASDP caribou monitoring study area (48-km [30-mi] radius around Drill Site CD4) on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2010 (bottom).

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 four more potential drill sites—CD5 (formerly called Alpine West), GMT1 (formerly CD6 or Lookout), GMT2 (formerly CD7 or Spark), and Fiord West—and a potential gravel mine site (also called Clover) that are planned for NPRA (BLM 2004). A new access road is proposed by CPAI to connect these potential sites to the Alpine project facilities, which would require a bridge across the Niġliq (Nechelik) Channel of the Colville River.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, we conducted aerial transect surveys in 2010, 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 in 2006, 2007, 2008, 2009, and 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 September 2010 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, 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 2001–2010 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010, 2011). 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. The number of active collars varied between herds (Table 1). Radio-tracking surveys for collared caribou ranged over much of northern Alaska, but data on the specific areas covered on each flight were not available except in summer 2005, when CPAI contracted ADFG to track VHF-collared caribou in the ASDP study area and surrounding area (Lawhead et al. 2006). Radio-collared caribou were tracked from fixed-wing aircraft using strut-mounted antennas and a scanning radio receiver. Although VHF telemetry does not provide movement data that are 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 originally operated by Service Argos and later by CLS. TH collar locations were transferred monthly to the NSB for

Table 1. Numbers of radio-collared caribou from the Teshekpuk and Central Arctic herds that provided data for analysis of movements in the ASDP caribou study.

Caribou Herd and Telemetry Sample	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd				
VHF collars [a]	1980–2005	n/a	n/a	212
Satellite collars	1990–2010	82	38	120
GPS collars [b]	2004–2010	64	0	64
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	15	3	18
GPS collars [c]	2003–2006	45	0	45
GPS collars [d]	2008–2010	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 and not yet retrieved.

[c] Number of different collared caribou that came within 48 km (30 mi) of CD4 at least once during the period.

[d] Does not include 10 collars deployed by ADFG in 2008 for retrieval in 2011.

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–October 2010 (Prichard and Murphy 2004; Lawhead et al. 2006, 2007, 2008, 2009, 2010, 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, 119 collared caribou (81 females, 38 males) transmitted signals for a mean duration of 555 days (13 of these caribou were outfitted with two or more different 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 41 different female TH caribou were outfitted with GPS collars (purchased by NSB and CPAI) during 2004 and 2006–2010. Some animals were collared more than once for a total of 64 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.

GPS collars were deployed only on females because the model used (TGW-3680 GEN-III store-on-board configuration with Argos satellite uplink, manufactured by Telonics, Inc., Mesa, AZ) is subject to antenna problems when mounted on the expandable collars that are required for male caribou due to increased neck size during the rutting season (C. Reindel, Telonics, pers. comm.). Data reports from satellite uplinks were received by e-mail from CLS America, Inc. (Largo, MD). All location data also were stored in the collars for downloading after the collars were retrieved, however, and those downloaded data replaced the location data that had been obtained via the Argos satellites throughout the year. The "stored-on-board" data provided the complete data set with a higher degree of accuracy and thus were preferred for analysis and archiving. Data were screened to remove any locations obtained prior to collaring or after the collars were removed, as well as any locations that obviously were incorrect because they were far from previous and subsequent locations or were located offshore.

The 2004 TH collars were programmed to record GPS fixes every 3 h (8 locations daily) throughout the entire year. The GPS collars deployed on TH animals in 2006–2008 and on the four CAH animals in 2008 were programmed to record fixes at 2-h intervals (12 locations daily) throughout the year, but battery-life constraints dictated that only 25–50% (depending on the seasonal uplink schedule) of the data collected each day could be transmitted to the Argos satellite. Satellite uplinks were programmed to occur once daily between 16 April and 15 November and once every other day between 16 November and 15 April. The GPS collars deployed on six TH and six CAH females in 2009 and 12 CAH females in 2010 were programmed to record fixes every 2 h from 16 April to 15 November and every 8 hours during the remainder of the year. The duty cycle was reduced in 2009 and 2010 to allow a 2-year deployment period, rather the single-year deployments used previously for this study. 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.

The collars on the 10 remaining animals from the 2006 deployment were retrieved during 24–25 June 2007 and 12 more GPS collars (purchased by CPAI) were deployed. The sample collared in 2007 comprised 10 adults, one 2-yr-old, and one yearling. All caribou in the 2007 sample except the yearling were collared previously: six were outfitted with GPS collars in 2006, three were outfitted with satellite collars in 2004 and recollared with satellite collars in 2005, and two were outfitted with satellite collars in 2003 and recollared with satellite collars in 2005. Of the 12 caribou in the 2007 sample, one died in November 2007 and one died in April 2008. Nine of the remaining caribou were recaptured in late June and early July 2008, but the tenth animal (caribou 0624) spent the spring and summer of 2008 with WAH caribou at the western end of the North Slope, too far away to be recaptured until March 2009, while it was wintering near the Dalton Highway.

Twenty TH females were outfitted during 29 June–1 July 2008 with GPS collars purchased by the NSB. 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. All were adults and three had been collared previously. One collar on a CAH animal stopped transmitting in mid-July 2009 and another CAH animal died in October 2009. Due to the differences between collaring and reporting schedules and the reduced schedule of satellite uplinks this year, fewer than half of the GPS locations from the 2009 collars were available for analysis in this report. The full data set for 2009–2010 will be available after the collars are retrieved in early summer 2011 and the data stored on board are downloaded. In addition to the CPAI-funded collars in 2009, another 15 GPS collars were purchased by BLM for deployment on female TH caribou. Those data are not yet available for inclusion in this report.

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.

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 snowmelt and vegetation green-up over the ASDP study area and a large portion of the surrounding region, due to the wide swath covered on each satellite pass. At least one satellite image over the study area was acquired daily during 20:00–24:00 UT (12:00–16:00 local time) starting in February 2000. 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 climatalogical 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:

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

The binary SnowMap algorithm 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 snowmelt, 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 2000–2010 using the algorithm of Salomonson and Appel (2004). NDSI was calculated and then the subpixel-scale snow fraction was calculated as follows:

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

Values less than zero were set to zero, and values greater than one were set to one. The two additional tests from the SnowMap algorithm then were applied (i.e., MODIS Band-4 reflectance >0.10 and MODIS Band-2 reflectance >0.11). If the 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. The 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 2000–2010, 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 2000–2010 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 >50% snow cover was identified for each pixel. The duration between the last observed snow date and the first observed melted date provided information on the quality of the snowmelt date estimate. For example, if snow was present in a pixel on May 20, followed by several weeks with persistent cloud cover, followed by an observation that snow was absent on June 17, it is unlikely that the snow actually melted on June 17. 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 as

$$\text{NDVI} = (\text{NIR} - \text{VIS}) \div (\text{NIR} + \text{VIS})$$

where:

NIR = near-infrared reflectance (wavelength 0.841–0.876 µm for MODIS), and

VIS = visible light reflectance (wavelength 0.62–0.67 µm for MODIS) (Rouse et al. 1973; http://modis.gsfc.nasa.gov/about/specs.html).

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 2000–2010 were calculated using constrained view-angle 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 2000–2010. 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 2000–2010.

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 2005–2010 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 2005–2009 NPRA survey area, we overlaid the caribou group locations from transect surveys on the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 3). A different land-cover map product created for CPAI studies—the ELS habitat map (Jorgenson et al. 1997, 2003, 2004)—did not cover our entire NPRA survey area and was developed to classify habitats for birds as well as mammals. We chose the NPRA earth-cover classification (30-m pixel size) over the ELS map for this habitat analysis because it covered our entire NPRA survey area, had fewer habitat classes than did the ELS classification, and the classification system appeared to better reflect habitat characteristics important to caribou.

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

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

To test whether the observed proportions of habitat use differed significantly from availability, 30,000 random locations were created within the 2005–2009 NPRA survey area using *ArcGIS 9.3* software (ESRI, Redlands, CA). A 100-m-radius

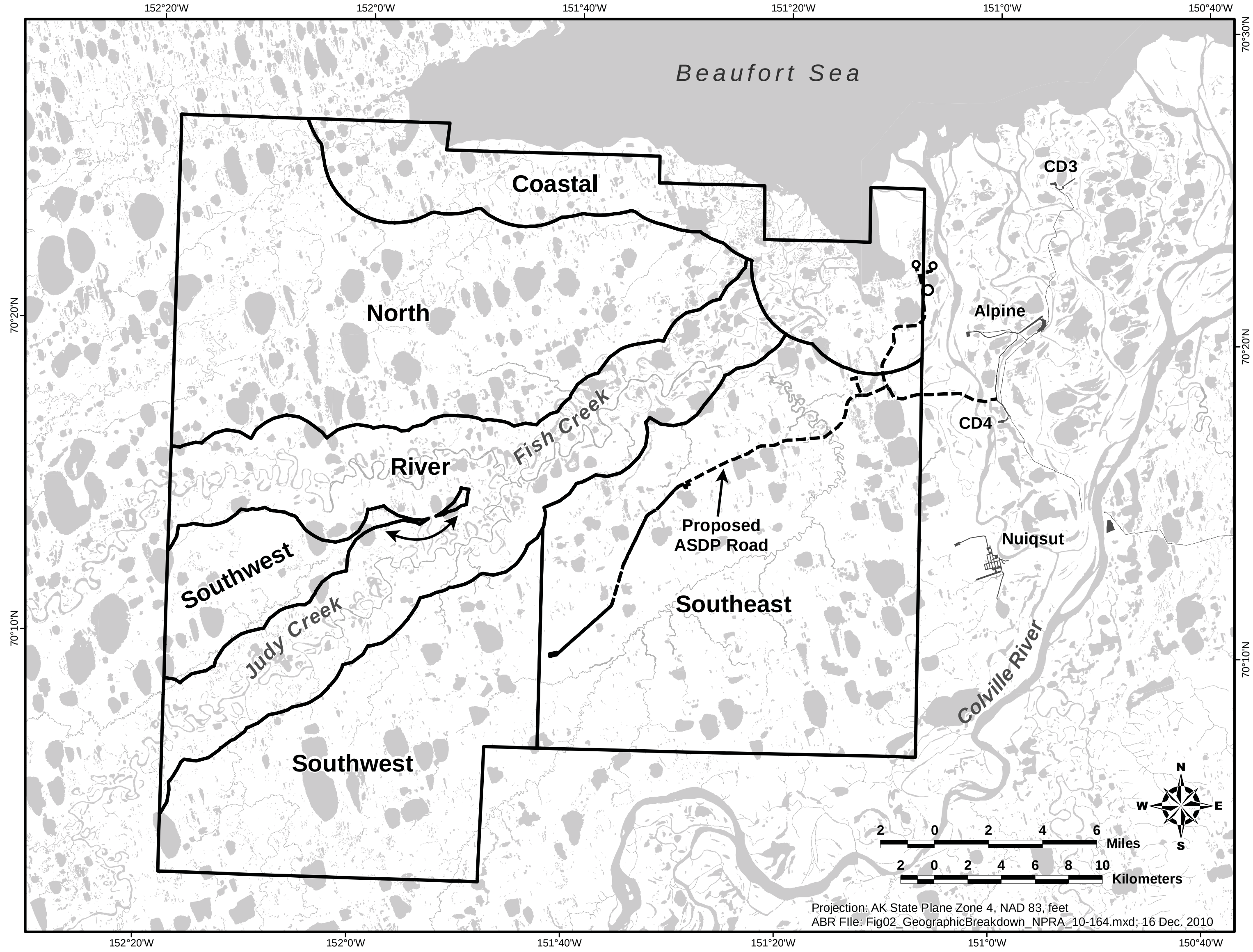

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2010.

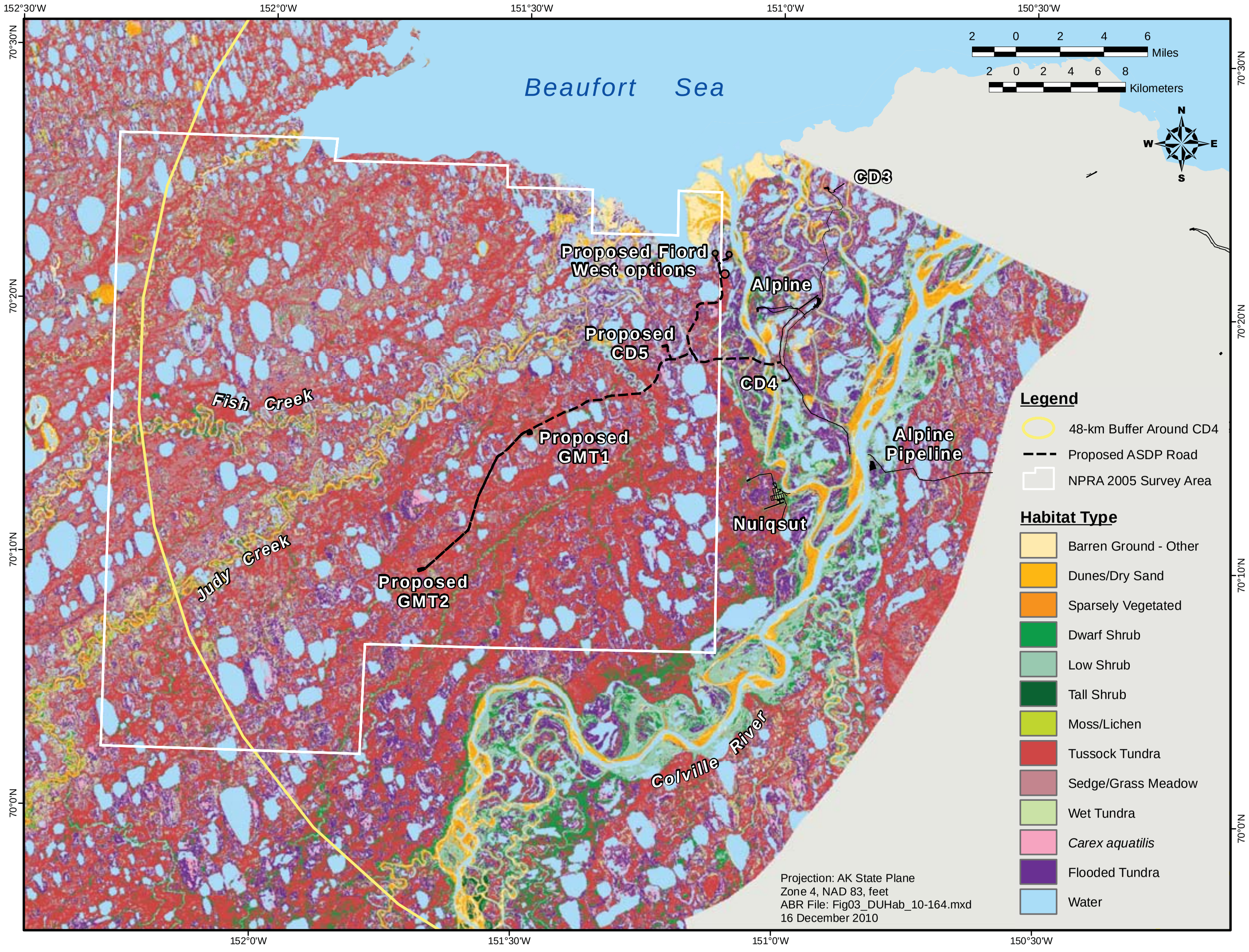

Figure 3. Habitat classification (BLM and Ducks Unlimited 2002) used for caribou habitat-selection analyses in the NPRA survey area, 2002–2010.

buffer was created around each random location and the proportion of each habitat type was calculated. Random locations for which more than 50% of the buffer area was water were removed from the analysis, leaving a total of 25,339 random locations in the 2005–2009 survey area (12,475 in the winter 2008 survey area because it could not be surveyed completely) and 19,470 in the 2002–2004 survey area. 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 7 June were estimated for each caribou group location (excluding pixels with >50% water). The snow-cover percentages for 7 June 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 2010 with estimated vegetative biomass (NDVI values). The values of the variables NDVI_calving, NDVI_621, NDVI_rate, and NDVI_peak were determined for each caribou group location (excluding pixels with >50% water) and those values were compared with availability using estimates derived by bootstrapping (Manly 1997). For each season, we selected (randomly and with replacement) a number of samples of NDVI values equal to the number of caribou groups observed 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 the following 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), using a negative binomial distribution and a log link, was used to test for annual differences in the numbers of caribou among the different distance zones, with each survey as an independent subject, distance zone as a within-subject effect, season as a between-subject effect, and the natural logarithm of the area surveyed as the offset term. To adjust for differences in area among zones, we used a natural-log transformation of area to match the log link in the analysis.

An autoregressive-1 working correlation matrix was used to model dependencies among distance zones during surveys. Simple contrasts with a Sidak correction for multiple comparisons were used to evaluate whether density in any of the 2–4-km or 4–6-km zones differed significantly from the 0–2-km zone containing the proposed road alignment. Tukey's *post hoc* multiple-comparison test was used to look for significant differences among seasons. The single survey in the 2005 oestrid-fly season was removed from this analysis to eliminate the undue influence on the test results that would have resulted from the large groups observed on that single survey. The mosquito and oestrid-fly seasons were combined because the model failed to converge when the mosquito season was included separately, probably 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 aggregated and moved 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 2005–2010 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 2010, 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 7 June 2010, 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 on the Colville River delta composed mostly of barren ground), so we used the value of NDVI_peak from 2010 in multi-year analyses. NDVI_rate from 2010 was used only for analysis of 2010 calving density.

We tested various models for calving density in 2010 and the density in each season for the combined years 2002–2010. Data from 2001 were not included in this analysis because the NPRA transect-survey area that year was smaller than in subsequent years. A generalized estimating equation (GEE) analysis (*SPSS* version 16.0 software, SPSS Inc., Chicago, IL) using a negative binomial distribution and a log link was used to test for differences in the number of caribou among the different grid cells. In this analysis, each survey was treated as independent; various combinations of NDVI_peak, NDVI_rate, snow cover, distance to coast, proportion of tussock tundra, proportion of wet habitats, transect number, presence of Fish or Judy Creeks, and presence of the proposed road were within-subject effects; survey date was a between-subject effect; and the natural logarithm of the area of each grid cell was the offset term. An exchangeable working correlation matrix was used to model dependencies among grid cells during surveys.

We used an information–theoretic approach (Anderson et al. 2000, Burnham and Anderson 2002) to compare a predetermined set of candidate models with different combinations of independent variables. We calculated Quasi-likelihood Information Criteria with the adjustment for small sample size (QIC_c) and used the Akaike weights to estimate the relative probability of each model

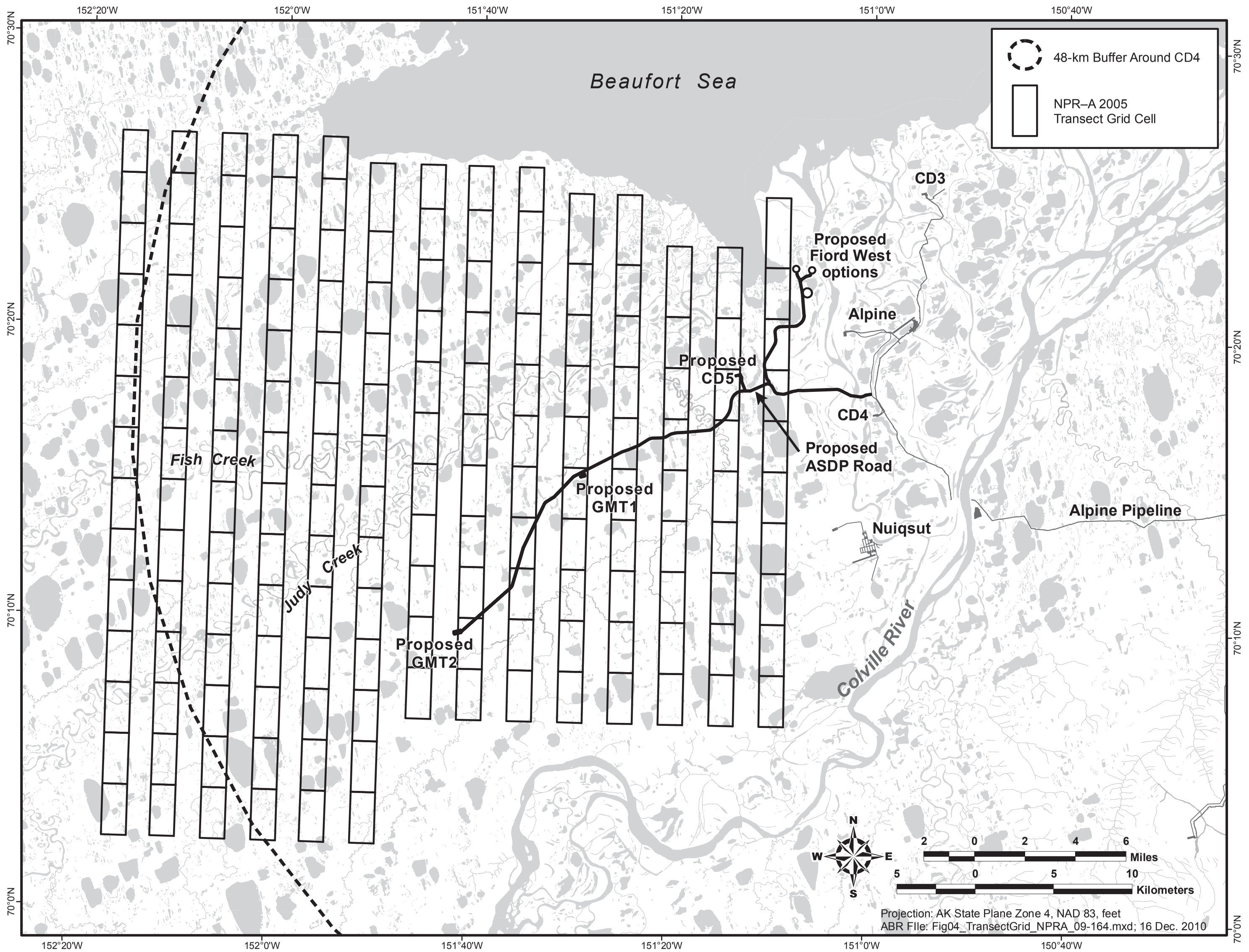

Figure 4. Locations of transect grid-cells ($n = 164$) used to analyze caribou density in the NPRA survey area, 2005–2010.

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

The presence of Fish and Judy creeks was included in all 20 candidate models for calving density in NPRA in 2010, but the different models had various combinations of NDVI_peak, NDVI_rate, snow cover on 7 June 2010, 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 2010 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 2010. NDVI_621 was excluded because it was highly correlated with NDVI_peak, so the latter variable was used instead. One grid cell located on the Colville River delta was removed because it contained little suitable habitat and was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

Sixteen candidate models were used for seasonal tests over all years (2002–2010) combined. For these models, the year-specific variables (snow-cover fraction and NDVI_rate) were dropped and the distance-to-coast variable and the survey date (to account for large inter-survey differences in density) were added. Surveys on which <10 caribou were observed were dropped from the analysis because they provided little information on caribou distribution. Two grid cells containing large groups of caribou during the oestrid-fly season were dropped because they were outliers that prevented some models from converging. In addition, one survey during the oestrid-fly season in 2005 was dropped because nearly all caribou seen on that survey were in large groups (1,670–2,400 animals) in only four grid cells.

We used a similar analysis to model factors related to the calving distribution of CAH caribou in Colville East during the aerial survey on 9 June 2010. We divided the survey transects into 553 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 2010, and the proportion of wet graminoid tundra (Muller et al. 1999) in the area. We also calculated the rate of snowmelt during June 6–9 by running separate linear regressions of the mean snow cover on those days for each grid cell and recording the inverse of the resulting slope. We used the rate of snowmelt instead of snow cover because that variable explained more of the variation in caribou numbers when included in the global model. The same generalized estimating equation (GEE) analysis as was used for the NPRA calving density analysis was used for Colville East, producing 31 candidate models composed of all possible combination of five variables (within 2 km of roads, NDVI_peak, distance to coast, rate of snowmelt, and proportion of wet graminoid tundra). The proportion covered by water bodies and transect number (a measure of west-to-east distance) 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 2011). Candidate models were compared and model-averaged parameter estimates were calculated in the same manner as for the NPRA surveys.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

The timing of snow melt in spring and the severity of insect harassment in midsummer varied considerably during the years in which aerial surveys were conducted in the ASDP study area. The timing of snow melt was delayed in 2001, advanced in 2002, about average in 2003–2008, and early in 2009 (Lawhead and Prichard 2011). In 2010, the timing of snowmelt was later than average. Snow depth was near the long-term average for Kuparuk at the end of May (Appendix B). Temperatures were below the long-term average in May but were above average for a week (6–12 June) immediately after the normal peak of calving, during which time most of the remaining snow patches melted (Lawhead and Prichard 2011). Snow cover was patchy in the southern portion of the survey areas during the calving surveys on 7–9 June, lowering the sightability of caribou. The complex visual background created by snowmelt required adjustment of the counts for low detectability by applying a sightability correction factor (SCF) for large caribou (Lawhead et al. 1994). Snow was essentially gone from all survey areas by the time of the postcalving survey on 21–22 June. The little snow remaining at that time was in linear drift remnants 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 occurrence of air temperatures conducive to insect activity (as indicated by TDD sums) in late June 2010 was the second lowest on record for the Kuparuk Airstrip (Appendix B). The temperatures in early July were close to the average, 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 the Kuparuk airstrip were below average in late June and were at or above average in July and early August (Lawhead and Prichard 2011). Thus, the available weather data indicate that the levels of insect activity and resulting harassment of caribou in 2010 would have been low in late June and at or above average in July and 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

Six surveys of the NPRA survey area were flown between 20 April and 15 September 2010 (Table 2, Figure 5). Two surveys were planned for October but could not be flown due to persistent poor weather. Caribou density in the NPRA survey area was low in the spring and during calving, relatively high during late June, decreased during August, and was highest in mid-September. The estimated density of caribou ranged from a high of 0.62 caribou/km² on 15 September to a low of 0.02 on 20 April (Table 2). The density of caribou during calving (0.06 caribou/km² on 7 June) was lower than the middle of the range of 0.15–0.87 caribou/km² (6–9 June) observed during 2001–2009 (no calving survey was conducted in 2004). Only 1 calf (3.8% of the total number of caribou) were observed in the survey area on 7 June, underscoring the low use of the area for calving compared with other parts of the study area, most notably the Colville East survey area.

Table 2. Number and density of caribou in the NPRA, Colville River Delta, Colville East, and Itkillik River survey areas, April–September 2010.

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								
20 April [h]	1,466	12	0	12	24	9.0	0.02	4.0
7 June [g]	1,720	25	1	26	98	21.4	0.06	2.9
22 June	1,720	189	24	213	426	83.9	0.25	3.5
4 August	1,720	20	0	20	40	9.0	0.02	1.3
19 August	1,720	54	2	56	112	15.9	0.07	1.4
15 September	1,720	528	6	534	1,066	147.2	0.62	2.6
COLVILLE RIVER DELTA								
18–20 April	494	2	0	2	4	2.8	0.01	2
7 June	494	0	0	0	0	–	0	–
21 June	494	4	0	4	8	3.1	0.02	1.3
4 August	494	409	nr	409	818	565.9	1.66	45.4
19 August	494	1	nr	1	2	1.4	0.004	1.0
15 September	494	5	nr	5	10	7.1	0.02	5
COLVILLE EAST								
18–20 April [h]	608	17	0	17	34	19.6	0.06	2.8
9 June [i j]	1,432	1,257	614	1,871	6,570	1,369.0	4.59	4.8
21–22 June	1,696	1,572	766	2,338	4,676	557.4	2.76	12.8
5 August	1,696	33	2	35	70	14.8	0.04	2.7
18–20 August	1,696	52	nr	52	104	22.8	0.06	1.6
16 September	1,696	222	nr	222	444	69.7	0.26	4.2
ITKILLIK RIVER								
18–20 April	240	0	0	0	0	–	0	–
9–10 June	240	11	1	12	24	11.3	0.10	2.4
21–22 June	240	50	1	51	102	21.2	0.43	4.3

[a] Survey coverage was 50% of this area (860 km² in NPRA, 247 km² on the Colville R. Delta, 848–969 km² in Colville East) for complete surveys.
[b] Adults + yearlings.
[c] nr = not recorded; calves not reliably differentiated due to larger size.
[d] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage).
[e] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), using transects as sample units.
[f] Density = Estimated Total / Survey Area Size.
[g] Applied Sightability Correction Factor of 1.88 due to patchy snow cover during survey.
[h] Survey not completed due to inclement weather.
[i] Survey of calving-season transects (1.6-km spacing) at 90-m altitude for 50% coverage; SE calculated based on 3.2 km-long transect segments (Lawhead and Prichard 2009).
[j] Applied Sightability Correction Factor of 1.88 due to patchy snow cover during survey to area south of Alpine pipelines.

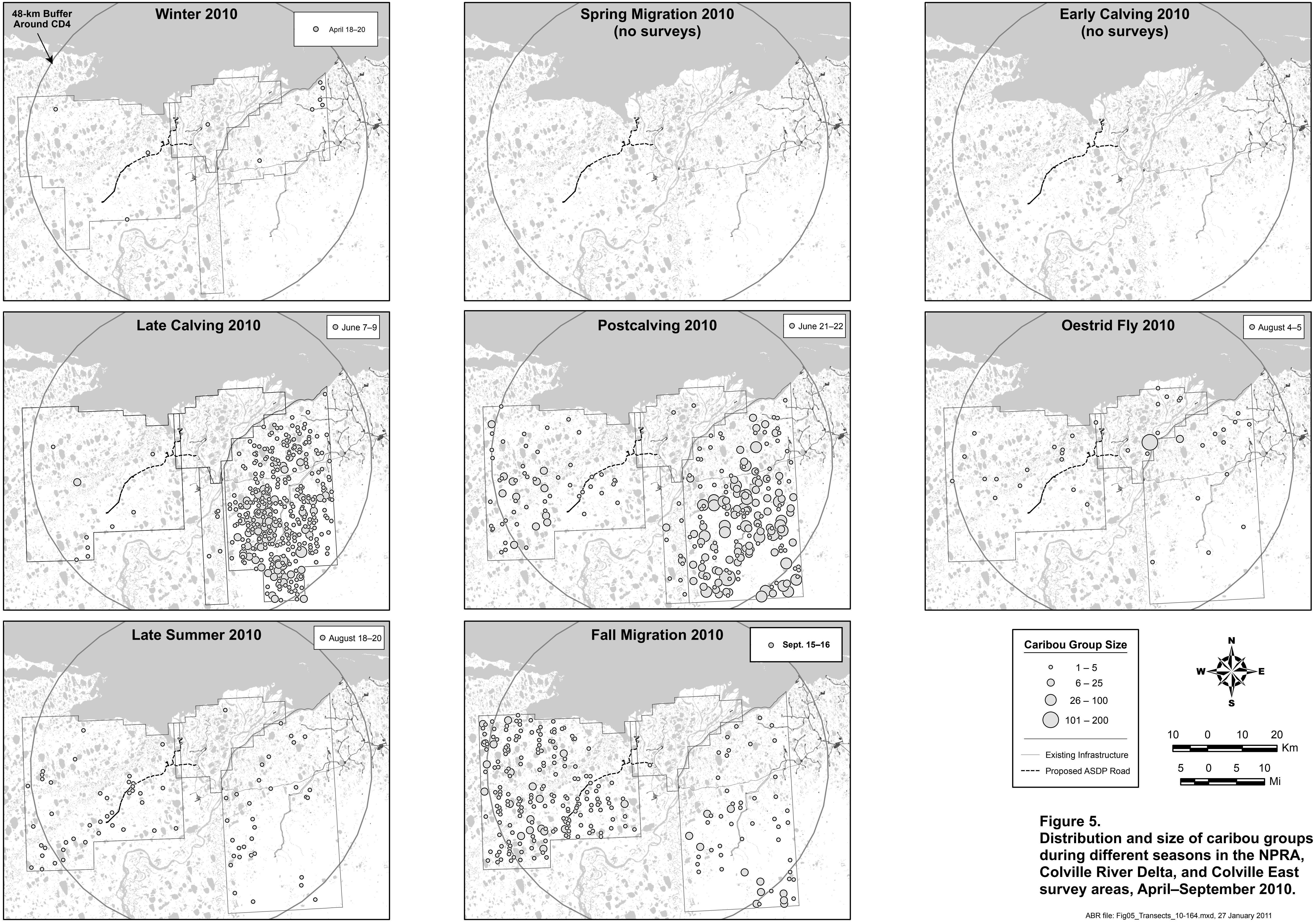

Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–September 2010.

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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 2011). This conclusion is supported by analyses of telemetry data (Prichard and Murphy 2004, Carroll et al. 2005, Person et al. 2007), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area. Although a few collared CAH caribou have calved west of the Colville River in isolated years (principally 2001), it is a rare occurrence (Arthur and Del Vecchio 2009, Lenart 2009).

Large mosquito-harassed groups of caribou were not observed during aerial surveys in late June or August 2010, 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 all surveys in 2010 (Table 2). Since our surveys began in 2001, the highest densities in the NPRA survey area typically have occurred in late September or October (annual maxima of 1.2–3.5 caribou/km² during 2001–2008, except in 2006 when only one survey was conducted after August and the density was only 0.01 caribou/km²) (Figure 6). High densities also have been recorded occasionally in late winter (2.4 caribou/km² in April 2003) and postcalving (1.5 caribou/km² in late June 2001) (Burgess et al. 2002, Johnson et al. 2004, Lawhead et al. 2010).

Colville River Delta Survey Area

Six surveys of the Colville River Delta survey area were flown between 18 April and 15 September 2010 (Table 2, Figure 5). Similar to most years, the estimated density of caribou was

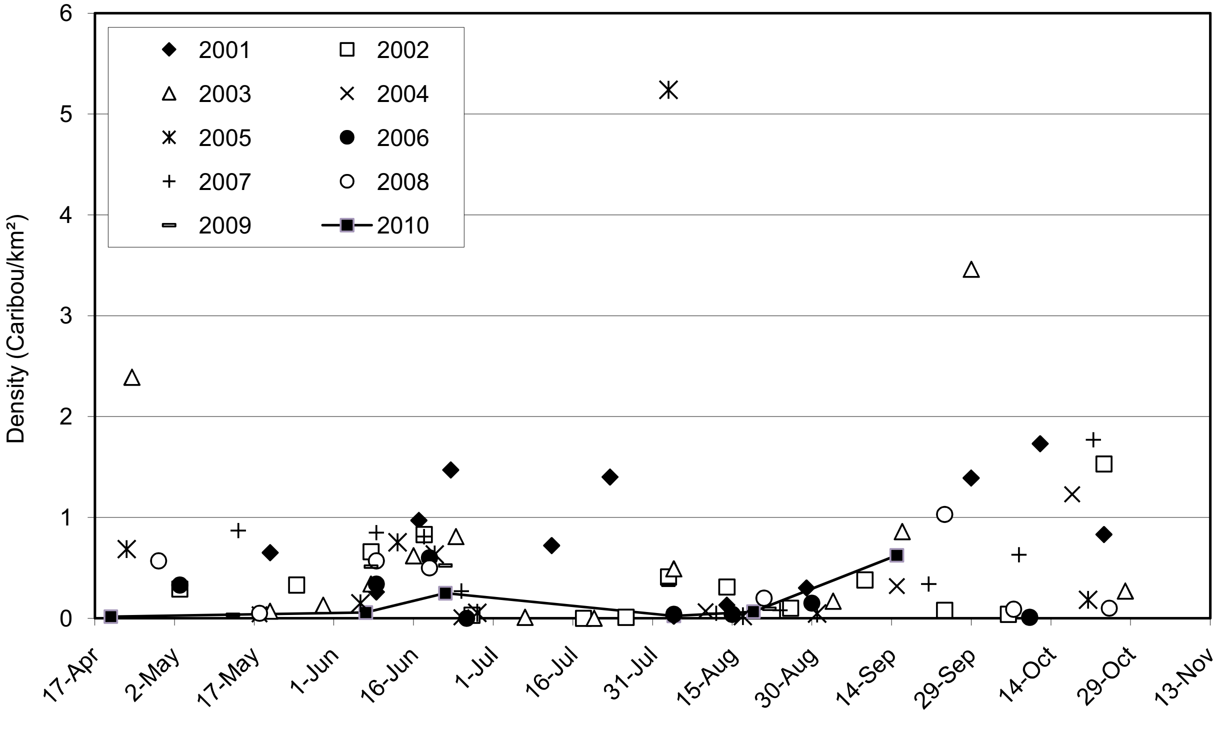

Figure 6. Caribou density observed on 89 surveys of the NPRA survey area, April–October 2001–2010 (line connects 2010 survey values).

very low during most surveys (0–0.02 caribou/km²). A group of 400 caribou was observed on the eastern Colville River delta on 4 August, producing an estimated density of 1.66 caribou/km², the maximal estimate recorded in 2010. Two large groups of caribou (>1,000 animals) were recorded on time-lapse cameras monitoring loon nests north of Alpine on the Colville River delta (J. Parrett, ABR, pers. comm.). Both groups moved west on the afternoon and evening of 15 July. Those animals probably were from the CAH, judging from the proximity of several CAH collars just east of the Colville delta at the time, while all TH collars were located far west of the delta.

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).

It is difficult to record the dynamic movements of insect-harassed caribou with periodic transect surveys. The highest number recorded on transect surveys during 2001–2010 (Table 2, Lawhead et al. 2010) occurred 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.

Colville East Survey Area

Six surveys of the Colville East survey area were flown between 18 April and 15 September 2010. The estimated density of caribou on complete surveys ranged from the peak of 4.59 caribou/km² during calving on 9 June to a low of 0.04 caribou/km² on 5 August (Table 2). The highest densities among all three ASDP survey areas in 2010 were recorded in Colville East during calving and postcalving (2.76–4.59 caribou/km²), as is usually the case in that area. No caribou were seen on a survey in the Itkillik River area on 18–20 April, 12 caribou were observed during calving, and 51 caribou were observed during postcalving (Table 2). The Itkillik River area was not surveyed after June 2010 because of concerns about potential conflicts with subsistence hunters, as well as the low density of animals observed there on past surveys.

During the late calving season (mid-June) in 2010, caribou were concentrated in the western portion of the survey area to a greater degree than has been observed in previous years. The 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 2011).

The Colville East survey area typically has high densities of caribou during postcalving as CAH caribou move northward prior to mosquito emergence (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007, 2008, 2009). Inland portions of the survey area often are used during the insect season when cooler weather depresses insect activity and caribou move south away from the coast. Since 2003, CAH caribou have tended to move farther east in midsummer than in earlier years, with many moving into the Arctic National Wildlife Refuge and even approaching the Alaska–Yukon border.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area in 2010, although groups totaling 22 muskoxen were observed on August 17–18 east of the Colville River delta. 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 2010 (Appendix C). 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) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Grizzly bears (*Ursus arctos*) were recorded on six occasions in the NPRA survey area between June and August 2010 (Appendix C). One of the observations was of a female with two cubs, one was of two adults, and the rest were of single adults. Six sightings, totaling 12 bears and including three observations of a female with two cubs, were recorded on the Colville River delta. The number of repeated observations of the same individuals among surveys was unknown, however. We recorded no observations of moose, wolves, wolverines, or polar bears in the ASDP study area in 2010.

On 17 August 2009, a group of 20 spotted seals (*Phoca largha*) was hauled out on a mud bar off the main channel of the Colville River in the northeastern delta (Appendix C). The haulout location was used consistently in late summer during more intensive surveys of the delta in the 1990s (Johnson et al. 1999) and during caribou surveys in 2008 and 2009 (Lawhead and Prichard 2009, 2010).

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 2010 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 37% of the total collared samples during each month (Table 3). The greatest use by TH caribou occurred in the western half of the study area. The highest overall percentages occurred in July–August and October and the lowest percentages (8–15%) 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 2010, 12 of the 13 transmitting TH satellite collars were present in the ASDP study area in July (Table 3).

Judging from the straight-line connections between successive locations, 11 of 13 satellite-collared male TH caribou crossed the alignment of the proposed ASDP road in the NPRA survey area during the period September 2009–October 2010 (the cutoff for inclusion of satellite-collar data in this report). All of the crossings occurred during 21–28 July 2010. Many of the collared animals were west of the Colville River delta in mid-July until a major, rapid movement of caribou occurred to the southwest across the proposed road corridor and continued southward out of the study area.

Satellite-telemetry data show substantially more use of the eastern half of the ASDP study

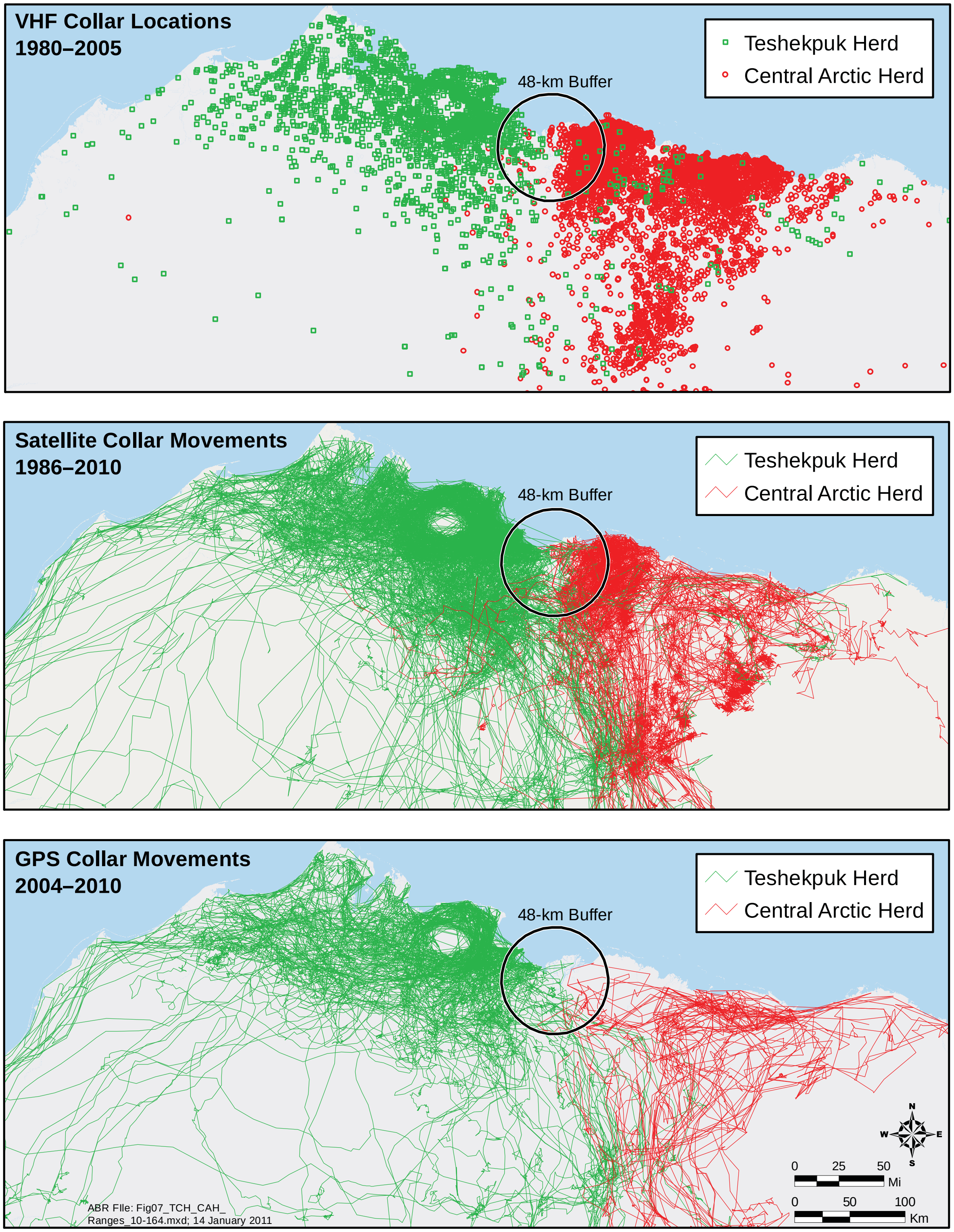

Figure 7. Ranges of the Teshekpuk and Central Arctic caribou herds in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2010.

Table 3. Percentage of satellite-collared caribou samples (*n*) from the Teshekpuk (TH) and Central Arctic (CAH) herds that were within 48 km of CD4 at least once in each month. Caribou with <5 active duty-cycles per month were excluded.

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
TH	1990	–	–	–	–	–	–	50 (6)	17 (6)	33 (6)	0 (6)	0 (6)	0 (6)
	1991	0 (6)	0 (5)	0 (5)	0 (5)	20 (5)	33 (3)	67 (3)	67 (3)	33 (3)	50 (4)	50 (4)	0 (3)
	1992	0 (3)	0 (2)	33 (3)	50 (2)	50 (2)	33 (3)	25 (8)	33 (6)	33 (6)	33 (6)	67 (6)	67 (6)
	1993	80 (5)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	0 (6)	0 (5)	0 (5)	25 (4)	0 (3)	0 (3)
	1994	0 (3)	0 (3)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)	50 (2)	0 (2)	0 (1)	0 (1)	0 (1)
	1995	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	13 (8)	38 (8)	25 (8)	25 (8)	14 (7)	14 (7)
	1996	14 (7)	14 (7)	14 (7)	14 (7)	14 (7)	0 (7)	14 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (6)
	1997	0 (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)	–	–
	Total	13 (166)	11 (149)	12 (149)	8 (148)	14 (149)	10 (147)	37 (216)	25 (206)	17 (210)	24 (202)	15 (176)	12 (169)
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 within 48 km of CD4 at least once in each month. Only data downloaded from retrieved collars are included (current deployed collars are excluded).

Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
TH	2004	–	–	–	–	–	–	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)
	2005	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	–	–	–	–	–	–
	2006	–	–	–	–	–	–	50 (12)	8 (12)	0 (12)	67 (12)	0 (12)	0 (12)
	2007	0 (12)	0 (12)	0 (12)	0 (11)	18 (11)	40 (10)	55 (11)	73 (11)	27 (11)	36 (11)	27 (11)	20 (10)
	2008	20 (10)	20 (10)	20 (10)	33 (9)	33 (9)	11 (9)	29 (28)	7 (28)	7 (28)	4 (28)	0 (28)	0 (27)
	2009	0 (27)	0 (25)	0 (24)	0 (21)	5 (21)	10 (21)	40 (10)	40 (10)	40 (10)	0 (9)	0 (9)	0 (9)
	2010	0 (9)	0 (8)	0 (8)	0 (8)	0 (8)	0 (7)	–	–	–	–	–	–
	Total	4 (68)	3 (65)	3 (64)	5 (59)	14 (59)	16(57)	35 (71)	24 (71)	15 (71)	29 (70)	9 (70)	7 (68)
CAH	2003	–	–	–	4 (24)	54 (24)	75 (24)	8 (24)	13 (24)	21 (24)	8 (24)	0 (24)	0 (24)
	2004	0 (24)	0 (24)	0 (24)	4 (24)	33 (24)	58 (24)	13 (24)	4 (24)	42 (24)	0 (24)	0 (24)	0 (24)
	2005	0 (33)	0 (33)	0 (33)	0 (33)	24 (33)	45 (33)	33 (33)	27 (33)	21 (33)	9 (33)	–	–
	2006	0 (29)	0 (29)	0 (29)	0 (29)	38 (29)	38 (29)	55 (29)	0 (29)	34 (29)	14 (29)	–	–
	2008	–	–	–	–	–	–	0 (4)	25 (4)	25 (4)	0 (4)	0 (4)	0 (4)
	2009	0 (4)	0 (4)	0 (4)	0 (4)	25 (4)	25 (4)	–	–	–	–	–	–
	Total	0 (90)	0 (90)	0 (90)	2 (114)	36 (114)	52 (114)	28 (114)	12 (114)	29 (114)	8 (114)	0 (52)	0 (52)

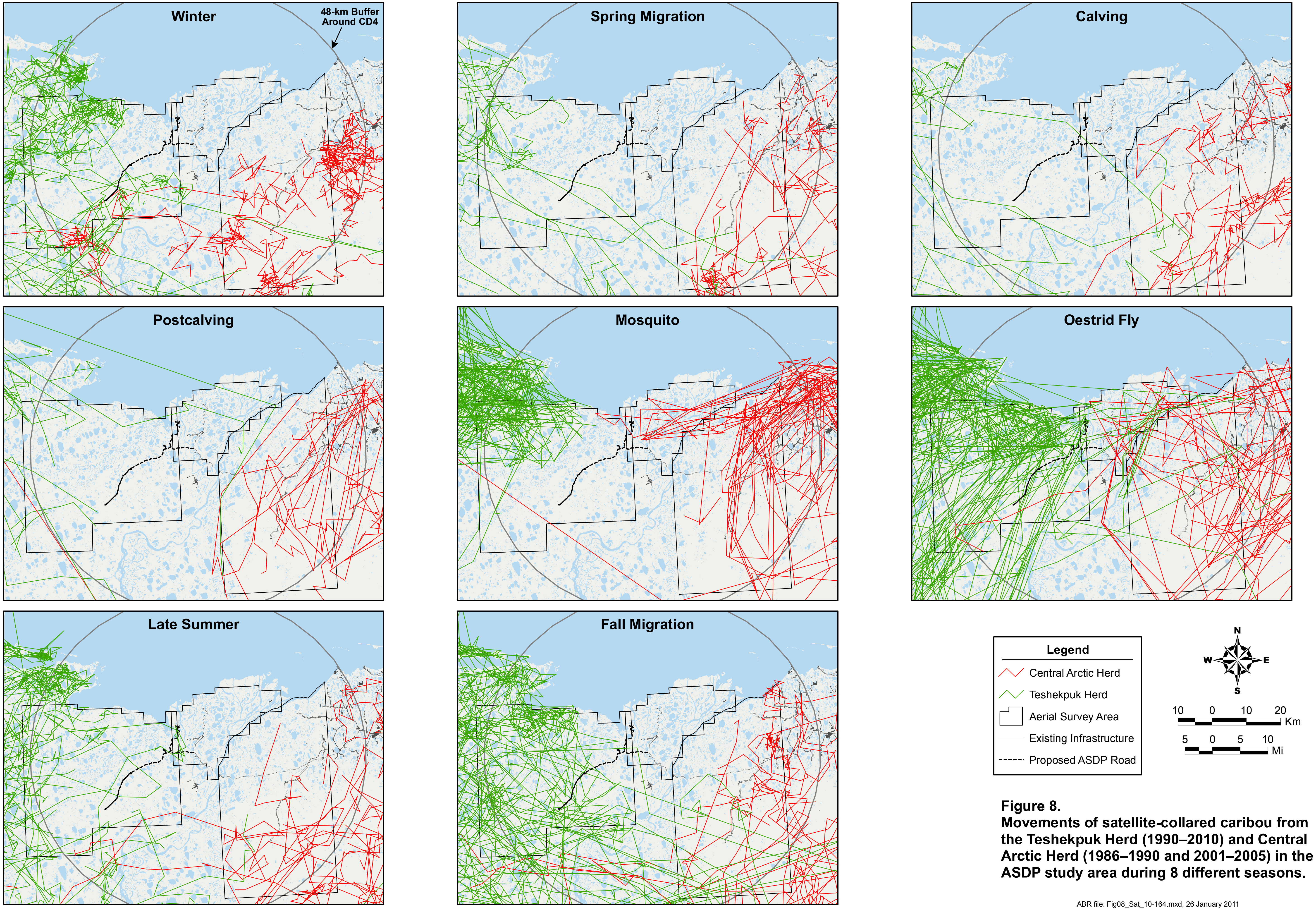

Figure 8.
Movements of satellite-collared caribou from the Teshekpuk Herd (1990–2010) and Central Arctic Herd (1986–1990 and 2001–2005) in the ASDP study area during 8 different seasons.

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area (east of the Colville River) by CAH caribou than by TH animals (Figure 8). No satellite-collared CAH animals crossed the proposed ASDP road alignment in the NPRA survey area in any year for which data are available (1986–1990, 2001–2005, and 2007–2010). 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 2001–2010 (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. One movement of moderate numbers of CAH caribou onto the Colville delta (see next section) occurred in July 2010, evidently for the first time in several 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 2004–2010 were similar to those of satellite-collared caribou. Only 3–9% of GPS-collared TH caribou were in the study area in winter (November–April) (Table 4, Figure 9). The monthly percentages increased to 14–35% during May–August, declined to 15% in September, and rose again to 29% 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 2008–2010 varied between 0 and 8% during the months of October–April (Table 4, Figure 9). The monthly percentage increased to 36% in May, peaked at 52% in June due to heavy use of the Colville East area during calving, and decreased to 12–29% in July–September.

The detailed movement tracks of the six TH and 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 December 2010 (Figures 10–11; the 2009 movements of these caribou were mapped in the previous report [Lawhead et al. 2010]). The detailed movement tracks of 12 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

June through December 2010 (Figures 12–13). Complete movement data from these 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 2009 (Appendices D–I).

In 2010, GPS-collared TH caribou were near Teshekpuk Lake in late June and early July, and moved north of the lake, presumably for relief from insect harassment. In late July, two of the five GPS-collared caribou moved into the ASDP study area and then moved abruptly southward. The caribou spread out across the northern coastal plain in late summer and two caribou then moved into the Brooks Range southwest of Anaktuvuk Pass, while three remained on the coastal plain in October.

Five of the 12 CAH caribou that were outfitted with CPAI GPS collars in June 2010 were captured west of Prudhoe Bay and seven were captured east of the Prudhoe Bay (Figures 12–13). All but one of the collared CAH caribou moved east in early July and one caribou remained near the Prudhoe Bay oil facilities. In mid-July, three collared CAH caribou moved to the east of the Colville River delta. Those three crossed to the south of the Alpine pipelines on about 18 July and gradually moved back to the east. By early August, all collared CAH caribou except one were again east of the Sagavanirktok River. The remaining caribou was near the Colville River south of Ocean Point. The collared animals spread out along the southern portion of the coastal plain for the remainder of August and September, and then moved into the Brooks Range in early October.

The following accounts detail the movements of the three CAH GPS-collared caribou that moved through the Colville East area survey in mid-July 2010. Caribou C04189 was south of Prudhoe Bay in late June, then moved through the Prudhoe Bay oilfield to the coast in the first week of July. She moved west along the coast, crossing both the Milne Point and Oliktok Point roads by 9 July, and was on the eastern Colville River delta on 13 July. Between 15 and 17 July, this caribou crossed the eastern portion of the Alpine pipelines and moved inland until 25 July, then she moved eastward south of Prudhoe Bay and continued farther east into the western portion of the Arctic National Wildlife Refuge (ANWR) by the end of July. She crossed the Dalton Highway in mid-August and again in late September and was in the Brooks Range east of the highway in November.

CAH caribou C04219 was collared east of the Sagavanirktok River in late June, then moved east near Kaktovik by 3 July before moving back to the west. She moved west along the southern edge of the Prudhoe Bay oilfield during 9–11 July, crossed the Spine Road east of CPF-2 on 13 July, and continued west near the Colville River delta. Between 15 and 17 July, this caribou crossed the eastern portion of the Alpine pipelines and continued inland until 25 July, then moved south of the Prudhoe Bay field and farther east. She moved to the Point Thomson area by the end of July and later moved south, and was in the Brooks Range east of the Dalton Highway in November.

CAH caribou C0819 was in the southern portion of the Prudhoe Bay oilfield on 10 July, then moved west, remaining south of the oilfields. Between 12 and 14 July, she crossed the eastern portion of the Alpine pipeline corridor from south to north. Between 16 and 18 July, she moved south again across the Alpine pipelines. This caribou was located near CPF-2 on July 24, near the Prudhoe Bay oilfield on July 26, and then moved southeast. In September, she moved south along the Sagavanirktok River and was in the Brooks Range east of the Dalton Highway in November.

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 5–6).

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

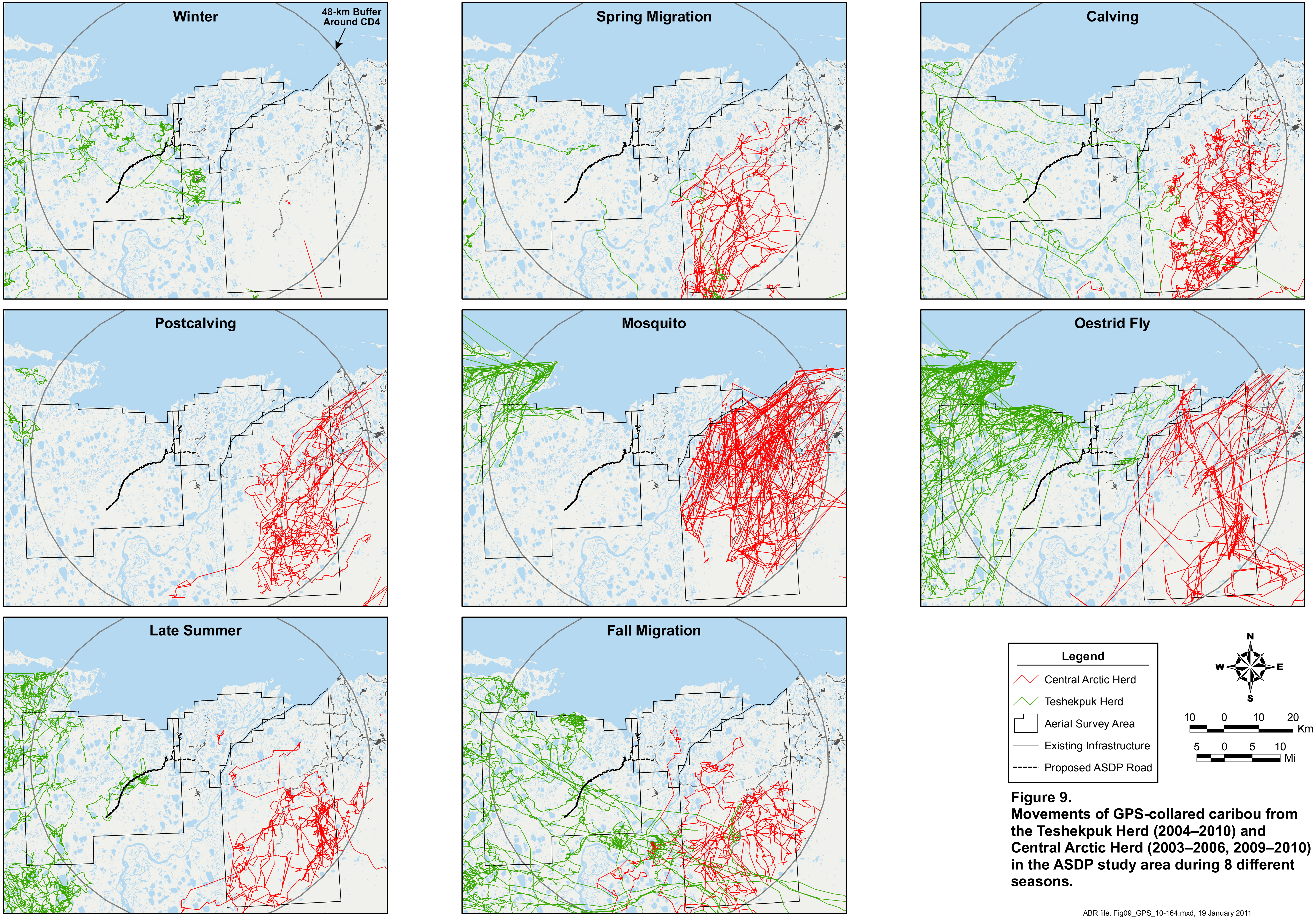

Figure 9.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2010) and Central Arctic Herd (2003–2006, 2009–2010) in the ASDP study area during 8 different seasons.

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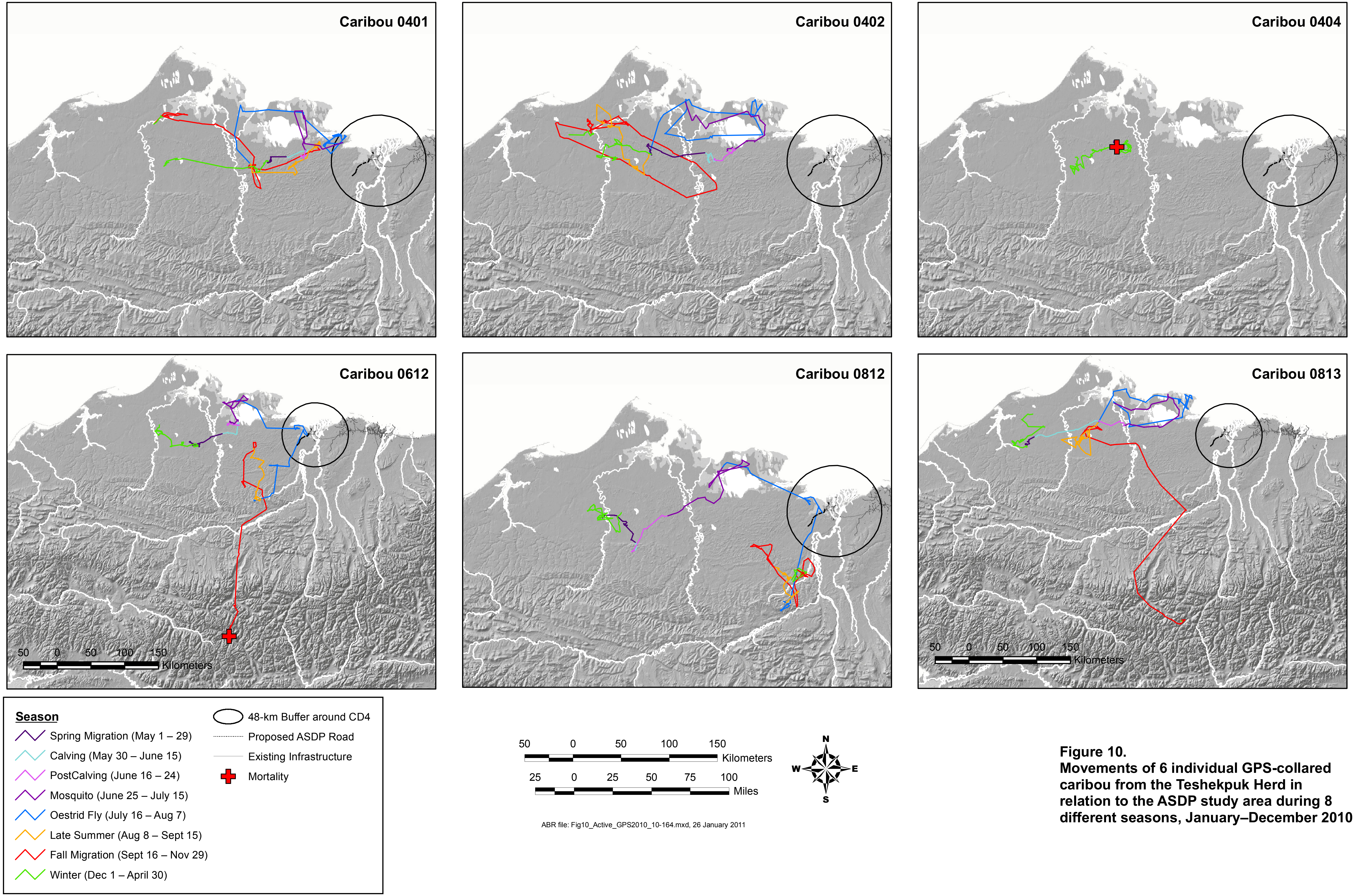
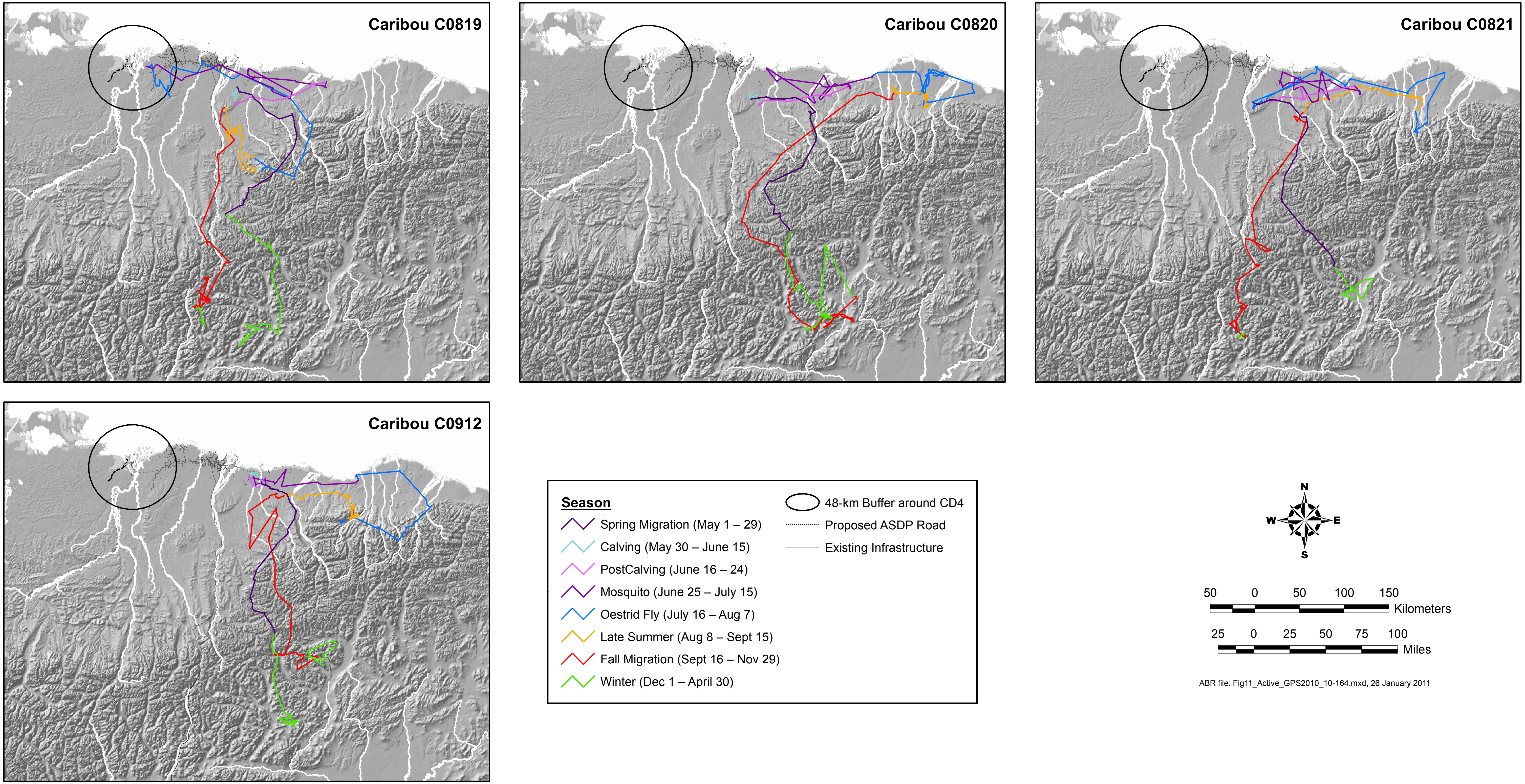


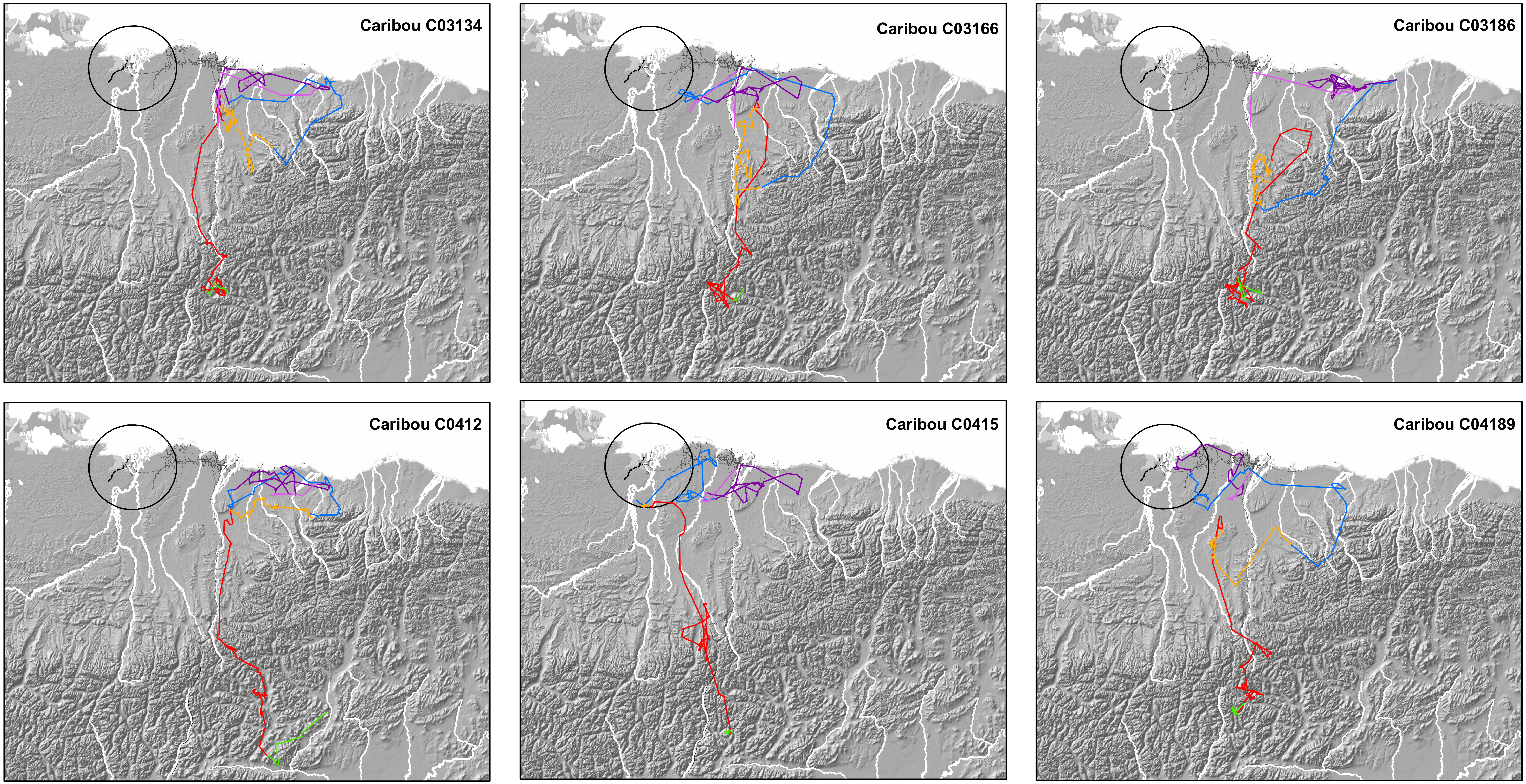
ABR file: Fig10_Active_GPS2010_10-164.mxd, 26 January 2011

Figure 10.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, January–December 2010.



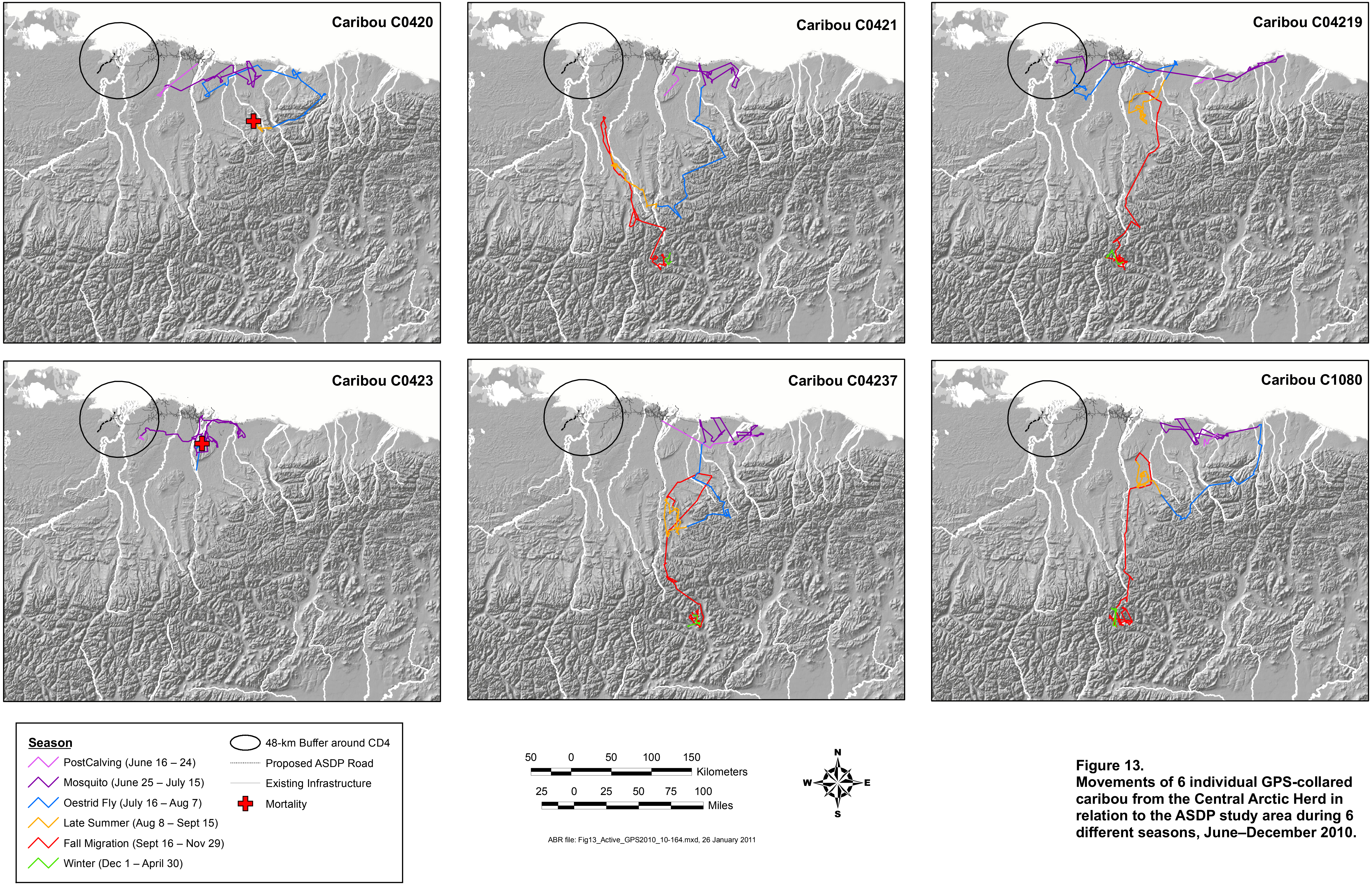
ABR file: Fig11_Active_GPS2010_10-164.mxd, 26 January 2011

Figure 11.
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 2010.



ABR file: Fig12_Active_GPS2010_10-164.mxd, 26 January 2011

Figure 12.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 6 different seasons, June–December 2010.



ABR file: Fig13_Active_GPS2010_10-164.mxd, 26 January 2011

Figure 13.
Movements of 6 individual GPS-collared caribou from the Central Arctic Herd in relation to the ASDP study area during 6 different seasons, June–December 2010.

2000, Arthur and Del Vecchio 2009). Use of the eastern half of the ASDP study area by CAH caribou was sporadic during the mosquito and oestrid-fly seasons, consistent with previous research that documented a strong relationship between local CAH movements on summer range in relation to temperature and prevailing wind conditions (White et al. 1975, Dau 1986, Lawhead 1988, Cameron et al. 1995). During mosquito harassment, CAH caribou typically head north to the coast and then move into the wind, which usually blows from the east–northeast. During less common periods of westerly winds, however, large numbers of CAH caribou occasionally moved onto the Colville River delta in the past. In recent years, most CAH caribou have moved east of the Sagavanirktok River during the insect season and have remained far east or south of the study area until the following spring migration and calving season.

For all three types of transmitters combined, the telemetry data demonstrate that the Colville River delta is the only area where the summer ranges of the TH and CAH overlap, and use of the delta by large numbers of animals from either herd is infrequent. Most CAH caribou remain east of the delta, most TH caribou stay west of it, and the existing Alpine facilities (including CD4) are located on the delta at the interface of the herd ranges (Figures 7–9). Exceptional movements by both herds have been documented, however. The most notable instance occurred in July 2001, when at least 10,700 CAH caribou moved west onto the Colville River delta and at least 6,000 of those animals continued across the delta into NPRA, with many remaining there into September (Lawhead and Prichard 2002, Arthur and Del Vecchio 2009).

The ranges of the two herds overlap more in fall and winter, primarily because of the recent expansion of TH caribou into the CAH winter range. Although most TH animals typically overwinter on the coastal plain, large numbers have wintered south of the Brooks Range in areas used by the CAH or WAH in some years (Prichard and Murphy 2004, Carroll 2007, Person et al. 2007, Lawhead et al. 2009, Lenart 2009, Parrett 2009). In a highly unusual movement in 2003–2004, a large proportion (perhaps up to a third) of the TH moved east across the Colville and Sagavanirktok rivers during fall migration and wintered in and near ANWR (Carroll et al. 2004, Carroll 2007). In subsequent winters, some TH animals have continued to spend the winter in the traditional range of the CAH south of the Brooks Range. 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.

Of 41 different TH animals equipped with GPS collars during 2004–2010, 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 2010, no GPS-collared TH caribou moved onto the Colville River delta.

Of the sample of 17 CAH satellite collars during 1986–1990, one moved into the CD4 vicinity briefly during 21–23 July 1988 and four moved nearby during 11–13 July 1989. Of the sample of 17 CAH satellite collars during 2001–2005, four moved through the vicinity while heading inland on 28–30 July 2001, evidently after having been collared on the outer Colville delta. The single CAH caribou outfitted with a satellite collar during 2007–2010 did not move into the vicinity of CD4. Only one of the 45 CAH GPS collars in the ASDP study area during 2003–2006 moved onto the Colville delta, east of CD4 on 27 September 2004. None of the 22 CAH caribou outfitted with GPS collars in 2008–2010 moved into the vicinity of CD4 (Figure 14, Appendices G and I).

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 were by TH caribou (Figure 14). Of the TH sample of 120 satellite collars (1990–2010), 40 animals (33%) crossed the proposed alignment at least 87 times between September 1990 and July 2010. Crossings occurred in every month except January. Of the TH sample of 55 GPS-collared caribou (2004–2010), 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), the only satellite- or GPS-collared caribou from that herd to do so. Some VHF-collared CAH caribou probably crossed the proposed ASDP road alignments (including the CD4 alignment before construction) with the aggregation of at least 6,000 CAH caribou that moved west across the Colville River delta and into the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2009), but they were not tracked frequently enough to document their route of travel.

REMOTE SENSING

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

The date of snow melt (defined as the first observed date when the snow fraction dropped below 50% coverage) was calculated for the years 2000–2010 (Figure 15). In many cases, this observed date of snow melt was the first cloud-free observation following a period of persistent cloud cover; the actual date of melt could have occurred during any of the days during the cloudy period when the snow fraction could not be observed. The date of the last noncloudy observation before the observed date of snow melt also was determined. When the duration between the prior observation and the first observed date of snow melt exceeded a week, the pixel was depicted in gray in Figure 15, because extensive cloud cover or satellite sensor malfunction prevented the determination of snow melt to within one week. Consistent patterns among years include the progression of melt from the foothills to the outer coastal plain, earlier snow melt in the “dust shadows” of river bars and human infrastructure, and persistent snow cover in the uplands and many gullies southwest of the Kuparuk Oilfield.

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. The southern coastal plain,

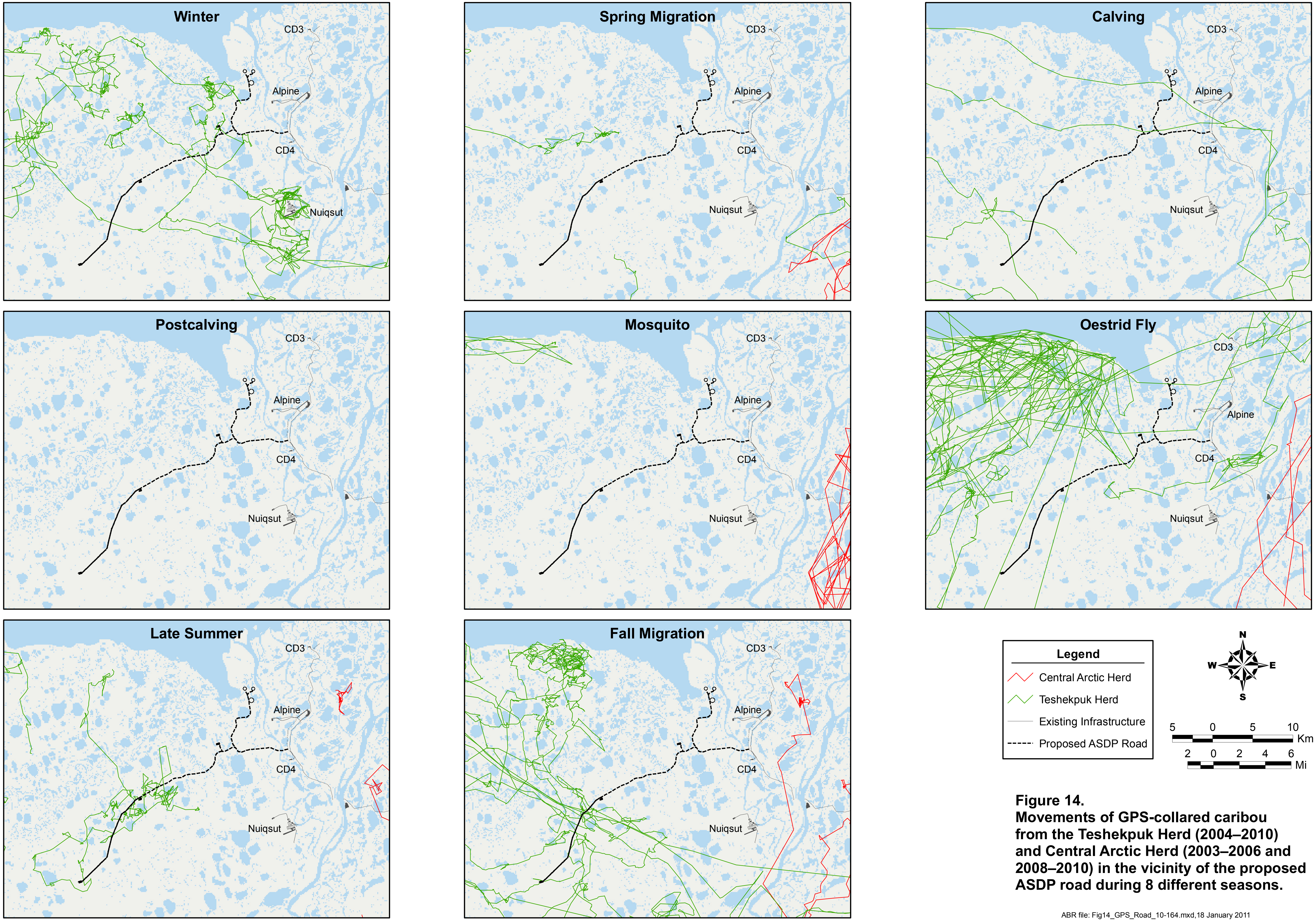


Figure 14.
Movements of GPS-collared caribou from the Teshekpuk Herd (2004–2010) and Central Arctic Herd (2003–2006 and 2008–2010) in the vicinity of the proposed ASDP road during 8 different seasons.

ABR file: Fig14_GPS_Road_10-164.mxd,18 January 2011

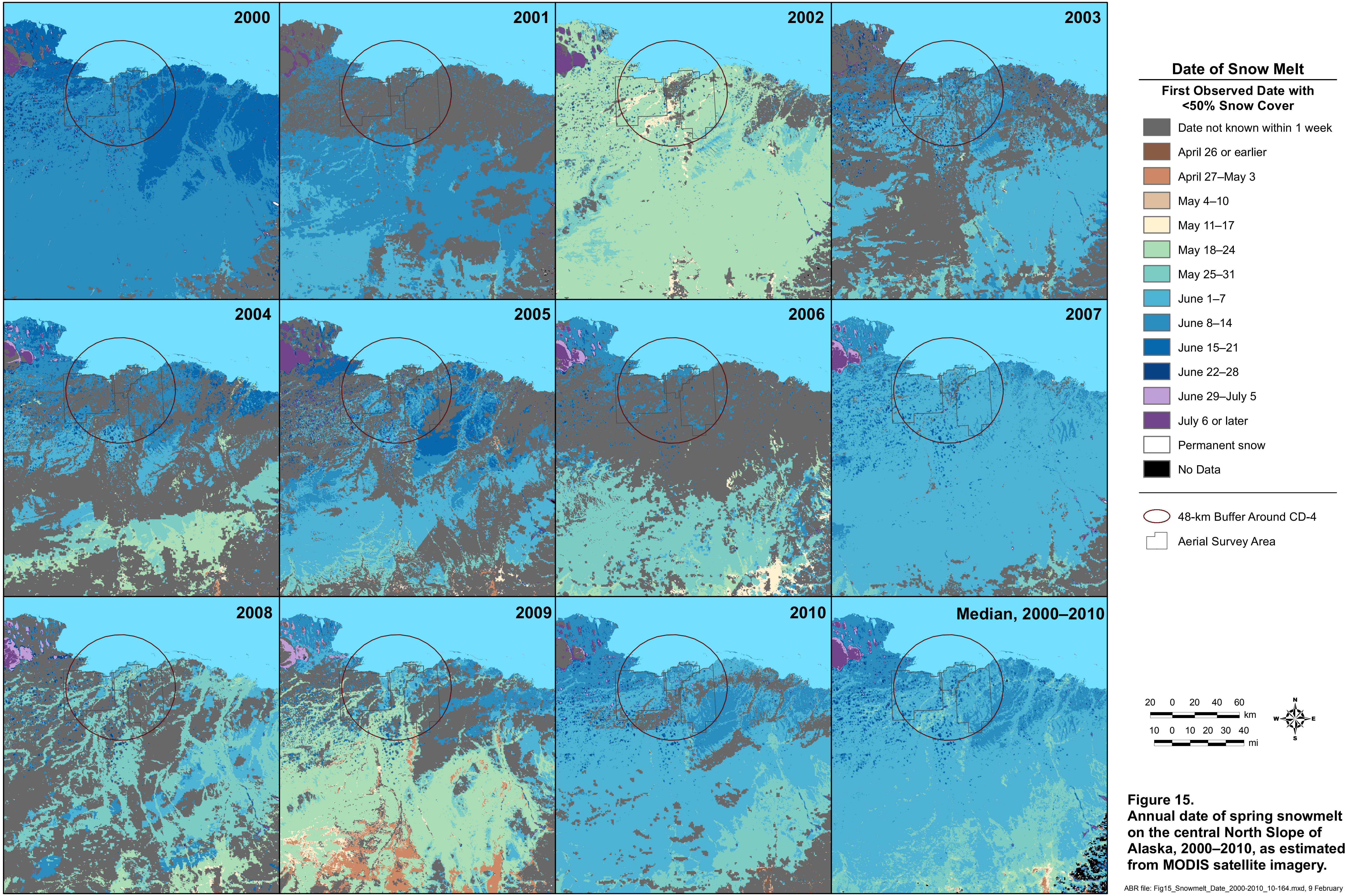


Figure 15.
Annual date of spring snowmelt on the central North Slope of Alaska, 2000–2010, as estimated from MODIS satellite imagery.

ABR file: Fig15_Snowmelt_Date_2000-2010_10-164.mxd, 9 February 2011 wind-scoured areas, and dust shadows typically melt during the last week of May. The central coastal plain and Colville River delta usually melt in the first week of June, leaving snow on the northernmost coastal plain, uplands, and in terrain features, such as gullies, that trap snow. During the second week in June, most of that remaining snow melts, although snow drift remnants, lake ice, and *aufeis* persist into July.

Based on data from the 11-year time series, the timing of snow melt was near average in 2010. Large patches of snow covered much of the southern half of the survey area on 7 June (Figure 16). Temperatures were above average during 6–12 June (Lawhead and Prichard 2011) and much of the remaining snow melted during this period (Figure 16).

A qualitative comparison of snow melt across years (Figure 15) suggests that, although the annual timing of melt varies substantially, the spatial pattern is fairly uniform across years, with some areas tending to melt first each year and other areas consistently retaining snow longer. It may be possible to use these spatial patterns to infer snow cover under cloudy portions of satellite scenes in the future; such an approach could provide a method to improve snow-cover estimates even with the patchy cloud coverage that complicates remote sensing in most years.

Previous comparisons of the performance of the MODIS subpixel-scale snow-cover algorithm with aggregated Landsat imagery 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

To examine the chronological dynamics of vegetation green-up, we examined the 11-year time series of MODIS imagery for the variables NDVI_calving, NDVI_621, and NDVI_peak. 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.

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 17). Values of this variable were relatively high throughout the study area in 2002 and 2006–2009, when snow melt occurred later. Intermediate values of NDVI_calving occurred in 2003, 2004 and 2010, and large patches of very low values were obvious where snow remained. 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.

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, such as happened in 2010. 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 11-year time series further to evaluate the typical value of NDVI in the study area immediately after snowmelt, for application to future analyses.

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 18). NDVI_621 values were lowest in 2003 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). 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 average during 2000, 2003 and 2004, and was lower than average in 2001 and 2009 (Figure 19).

Potential anomalies in the metrics for snow melt and NDVI in 2010 were examined by subtracting the median values for all years (2000–2010) from the 2010 values (Figure 20). Where it was known within a week, the 2010 melt date was very close to the median value throughout the region—generally within three days, and almost always within one week. Therefore, it is likely that the timing of snow melt was close to the median date for those areas of the coastal plain where cloud cover prevented direct observation of snow melt. NDVI_calving exhibited strong variability within the region. Some areas near the coast had higher-than-average values of NDVI_calving in 2010, whereas other areas on the Colville delta and farther inland had average or lower-than-average values. Values of NDVI_621 were lower than average in 2010 within the study area, particularly on the floodplains of the Colville River and Fish Creek, indicating that plant biomass near peak lactation lagged in comparison with other years. The lower values on floodplains suggest that the willow shrubs, which usually leaf out fully by 21 June, had not done so in 2010 by that date. This possibility is supported by the cooler-than-average temperatures that prevailed in the second half of June 2010 (Appendix B; Lawhead and Prichard 2011). In contrast to the study area, however, NDVI_621 in 2010 was above average farther inland. The anomaly in NDVI_peak in 2010 was just the opposite: vegetation greenness was greater than average in the study area, but was below average in most of the foothills. Over the entire growing season in 2010, plant growth appeared to be more favorable near the coast, despite the fact that growth started more slowly there in 2010.

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 2005–2010 survey areas. Variation in NDVI values and in the distribution and abundance of habitat types among geographic sections (Appendix J) influenced the seasonal differences in caribou distribution. This analysis focuses on the pooled 9-year data set for aerial transect surveys (2002–2010; 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 K).

For the pooled 2002–2010 sample, significantly more groups of caribou occurred in the North, River, and Southwest sections than would be expected if caribou were distributed uniformly among sections (Table 5). The North section contained fewer groups during winter and more groups during spring migration, postcalving, and the mosquito season. The River section contained more groups during postcalving, oestrid-fly season, and late summer. The Southwest section contained more groups during winter, calving, and fall migration, but fewer during the mosquito and oestrid-fly seasons.

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

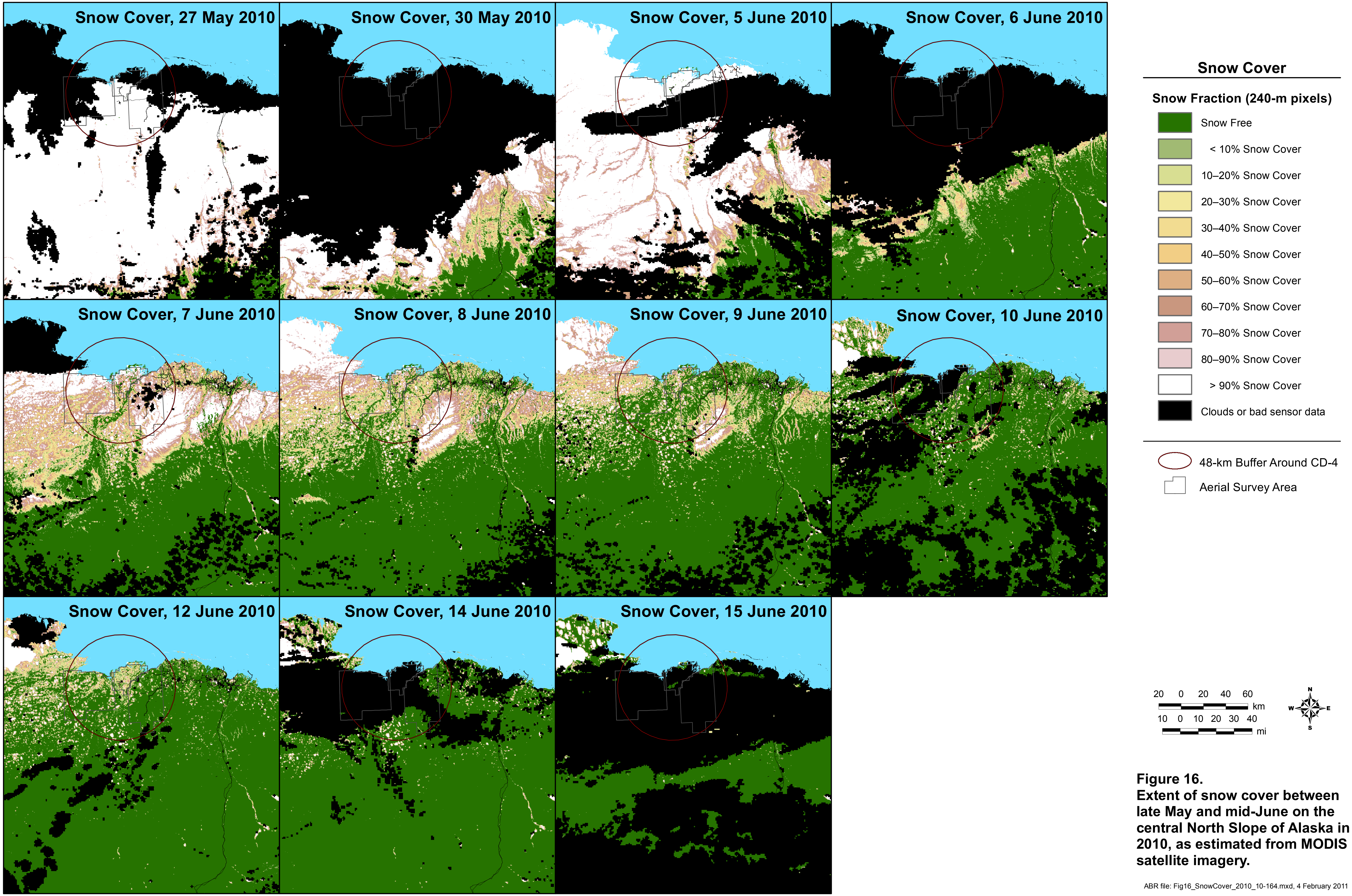


Figure 16.
Extent of snow cover between late May and mid-June on the central North Slope of Alaska in 2010, as estimated from MODIS satellite imagery.

ABR file: Fig16_SnowCover_2010_10-164.mxd, 4 February 2011

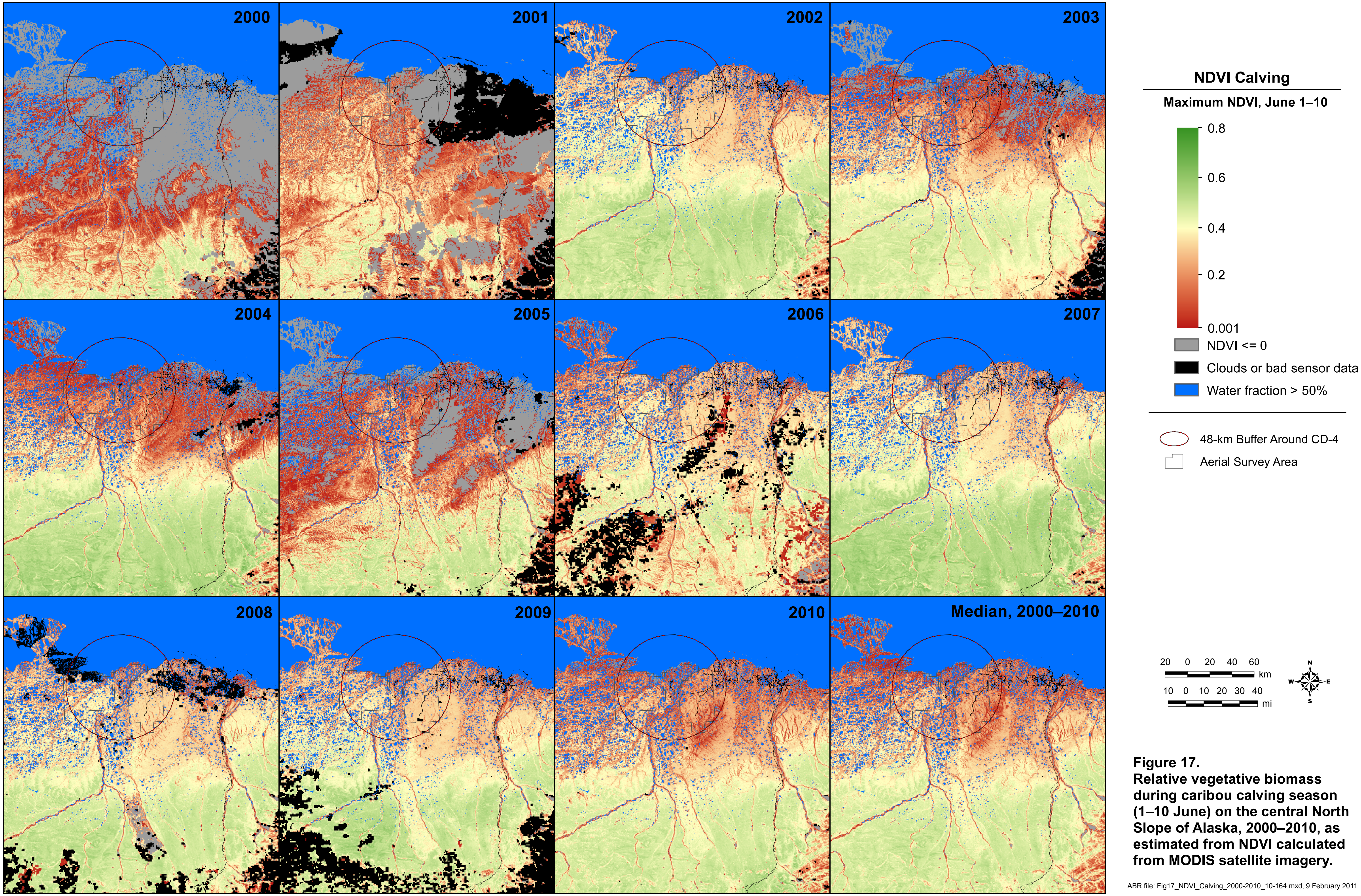
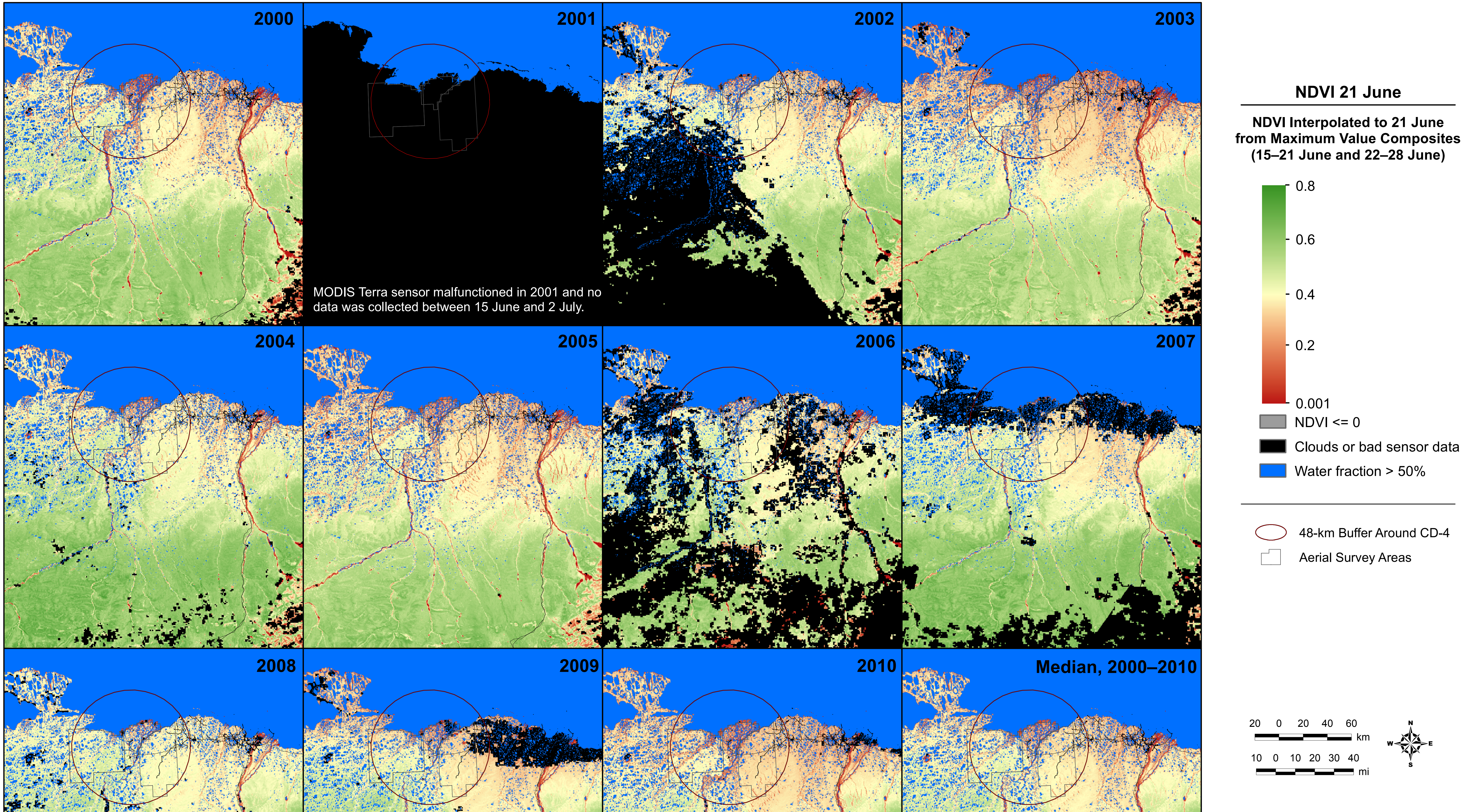


Figure 17.
Relative vegetative biomass during caribou calving season (1–10 June) on the central North Slope of Alaska, 2000–2010, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig17_NDVI_Calving_2000-2010_10-164.mxd, 9 February 2011



MODIS Terra sensor malfunctioned in 2001 and no data was collected between 15 June and 2 July.

Figure 18.
Relative vegetative biomass during peak lactation (21 June) on the central North Slope of Alaska, 2000–2010, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig18_NDVI_0621_2000-2010_10-164.mxd, 8 February 2011

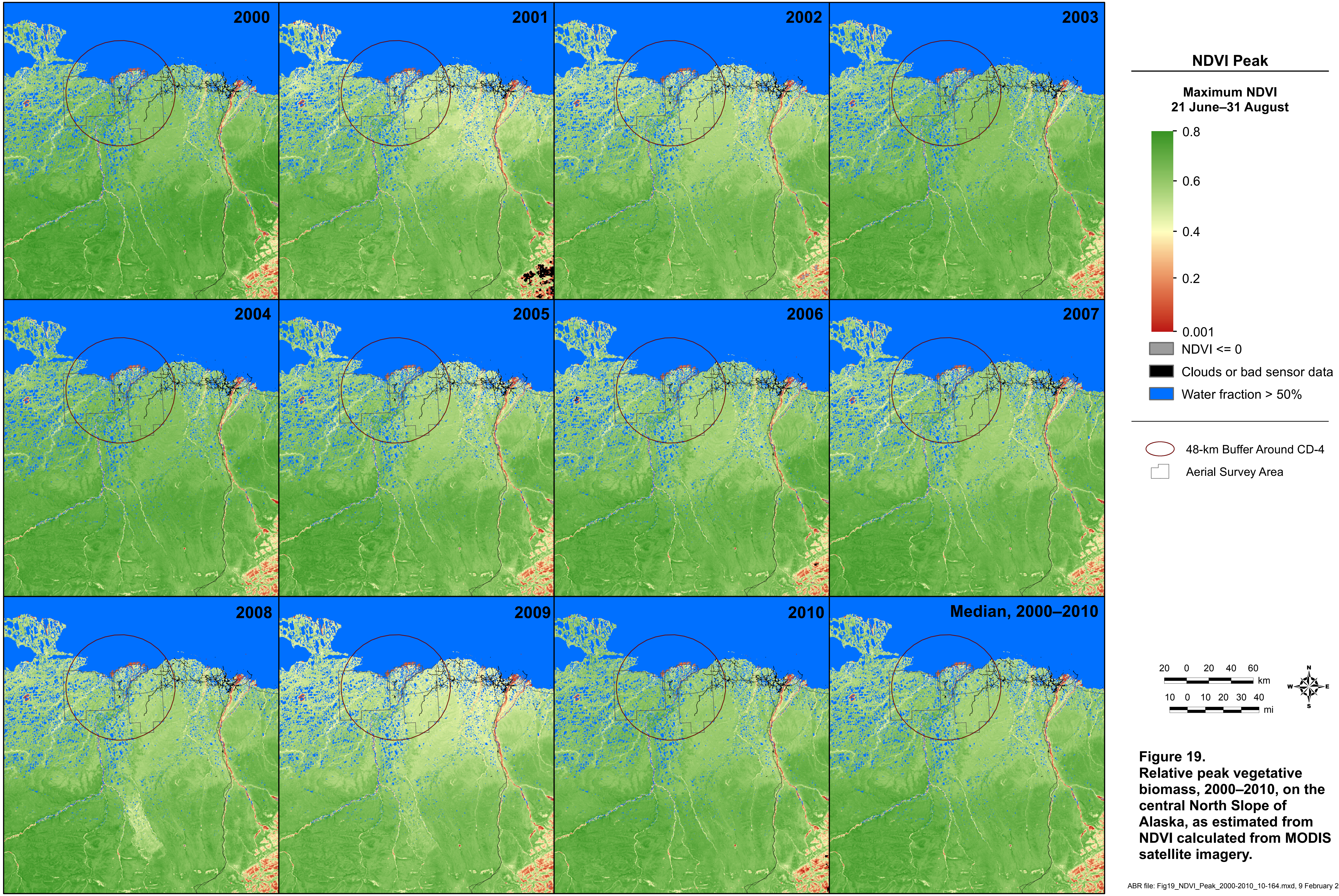


Figure 19.
Relative peak vegetative biomass, 2000–2010, on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file: Fig19_NDVI_Peak_2000-2010_10-164.mxd, 9 February 2011

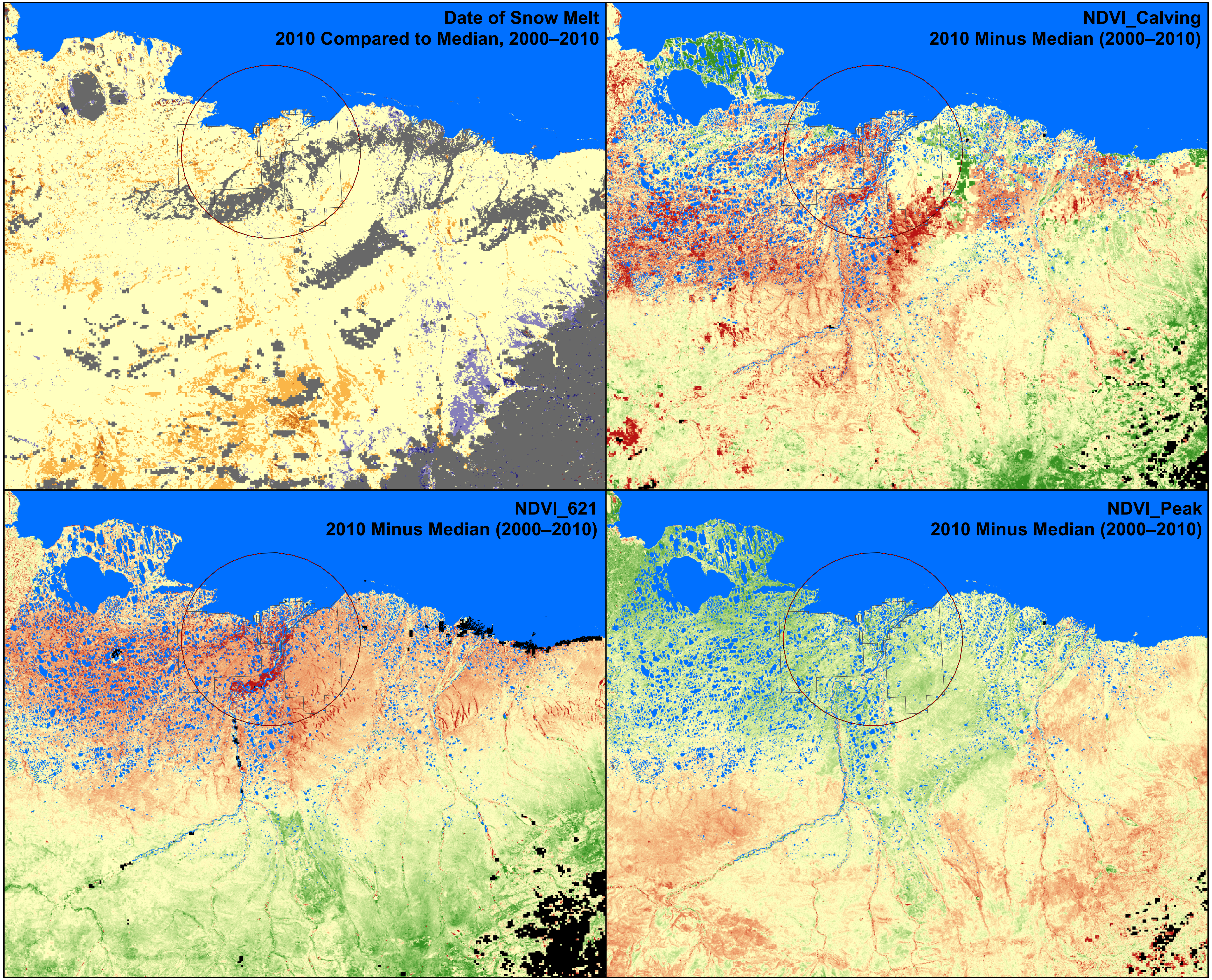


Figure 20.
Comparison of 2010 snow and vegetation index metrics to median values, 2000–2010, as estimated from MODIS satellite imagery.

ABR file: Fig20_Metrics_2010_vs_Median_10-164.mxd, 9 February 2011

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
2010	Winter [a]	1	3	1	0	0	2	0	3.91	0.418
	Spring	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
2002–2010	Winter [b]	4	474	19--	57--	105	140-	153^{++}	104.73	<0.001
	Spring	8	398	29	116^{++}	74	82--	97	42.34	<0.001
	Calving	10	934	31--	211	183	183--	326^{++}	120.39	<0.001
	Postcalving	9	955	21--	246^{++}	323^{++}	168--	197	180.39	<0.001
	Mosquito	6	102	18^{+}	43^{++}	24	11--	6--	80.35	<0.001
	Oestrid Fly	9	230	11	31	113^{++}	38--	37--	102.69	<0.001
	Late Summer	15	731	38	166	242^{++}	141--	144	90.19	<0.001
	Fall Migration	16	1,494	63--	294	344	354--	439^{++}	61.81	<0.001
	Total	77	5,318	230--	$1{,}164^{++}$	$1{,}408^{++}$	1,117--	$1{,}399^{++}$	332.51	<0.001
Available land area (2002–2004)				8.9	64.8	133.7	191.0	148.2		
Available land area (2005–2010)				70.7	160.9	136.0	191.0	148.4		

[a] Only part of the area surveyed.
[b] 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 Coast section on 2 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. Results for 2010 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.

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 (Prichard and Murphy 2004, Carroll et al. 2005). 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, Prichard and Murphy 2004). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3, Appendix J) that provide good fly-relief habitat near foraging areas.

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

HABITAT USE

Caribou group locations during transect surveys were significantly related to the distribution of habitat types in the NPRA earth-cover classification (BLM and Ducks Unlimited 2002). The numerous combinations of seasons, years, and habitat classes resulted in a complex matrix of test results (Table 6, Appendix L) among years. As in the geographic analysis above, the pooled-year samples provided larger sample sizes, so this section focuses primarily on those results than on individual years with smaller sample sizes.

Several strong patterns of habitat selection were evident in the test results. Across all seasons and years (2002–2010), 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 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 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 L). 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) reported that TH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid classes; both of those studies used the vegetation classification by Muller et al. (1998, 1999). Using a classification similar to the ELS scheme developed by Jorgenson et al. (2003), Lawhead et al. (2004) found that CAH caribou in the Meltwater study area in the southwestern Kuparuk Oilfield and the adjacent area of concentrated calving selected moist sedge–shrub tundra, the most abundant type, during calving. Using the NPRA earth-cover classification (BLM and Ducks Unlimited 2002) in our NPRA survey area (which is not an important calving area), we found that caribou used areas with sedge/grass and tussock tundra more than expected and used wet, flooded, and riverine areas less than expected.

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

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

Table 6. Seasonal use of different habitat types by caribou in the NPRA survey area in 2010 alone and 2002–2010 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]
2010	Winter	1[c]	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+
2002–2010	Winter	4[d]	474	1.02	1.02	1.01	0.92	1.05	0.80	1.29+	0.88	0.50-
	Spring Migration	8	398	1.09	1.02	0.96	1.25^{++}	0.94	0.95	0.81	0.85	0.45^{--}
	Calving	10	934	0.95	0.87--	0.93-	1.17++	1.05++	0.86	0.95	0.74	0.78
	Postcalving	9	955	0.86--	0.86--	1.03	1.07+	0.98	1.29+	1.10	1.81+	1.67++
	Mosquito	6	102	1.52^{++}	0.95	0.93	1.17	0.70--	1.88^{+}	1.06	0.67	2.52++
	Oestrid Fly	9	230	1.26+	1.12	1.06	0.60--	0.62--	2.54++	1.34	1.70	4.88++
	Late Summer	15	731	1.01	0.97	1.05	0.81--	0.80--	2.04++	1.45++	1.60	3.24++
	Fall Migration	16	1,494	0.99	0.93--	0.99	1.02	1.01	1.38++	1.15+	1.06	0.96
	Total	77	5,318	1.00	0.93--	0.99	1.02+	0.96-	1.34++	1.14++	1.20	1.49++
Availability (2002–2004)				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability (2005–2010)				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 ($P < 0.01$).

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 in the NPRA survey area.

Zone	Distance Zone (km)	Water	Habitat Type [a]									
			Carex aquatilis	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Dry Dunes	Sparsely Vegetated
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	0.0	0.0
South	0–2	21.3	6.9	18.3	9.8	9.6	51.4	0.6	2.9	0.3	0.0	0.0
	2–4	15.5	7.0	18.2	8.9	6.9	53.1	0.3	4.8	0.7	0.0	0.0
	4–6	10.0	7.0	20.2	7.7	5.7	55.9	0.2	3.0	0.3	0.0	0.0

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

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 7 June 2010 used areas that had significantly less snow than the average snow cover estimated over the entire NPRA survey area on that date ($P < 0.05$; Table 8). The average snow cover in the NPRA survey area on 7 June was 38.7%, whereas the eight caribou groups observed on the calving survey were using areas that had a mean snow cover of 12.1% (99% C.I. = 1–28.6%). Caribou selected areas that had more snow cover earlier in 2009 (Lawhead et al. 2010), but showed the opposite pattern in 2008, selecting areas with more recent snow melt during calving (Lawhead et al. 2009). Snow melt was largely complete prior to our calving surveys in both of those years, however.

Previous studies have not provided consistent results concerning the calving distribution of northern Alaska herds in relation to snow cover. Kelleyhouse (2001) concluded that TH females selected areas of low snow cover during calving and Carroll et al. (2005) reported that TH caribou calved farther north in years of early snow melt. Wolfe (2000) did not find any consistent selection for snow-cover classes during calving by the CAH, whereas Eastland et al. (1989) and Griffith et al. (2002) reported that calving caribou of the Porcupine Herd preferentially used areas with 25–75% snow cover. The presence of patchy snow in calving areas is associated with the emergence of highly nutritious new growth of forage species such as the tussock cottongrass *Eriophorum vaginatum* (Kuropat 1984, Griffith et al. 2002, Johnstone et al. 2002) and it also may increase dispersion of caribou and create a complex visual pattern that reduces predation (Bergerud and Page 1987, Eastland 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 2010, caribou in NPRA selected areas with low values of estimated biomass (all NDVI variables) only during the oestrid-fly season (Table 8), probably as a result of higher use of the northern and riverine areas (Table 5) and a preference for unvegetated areas for relief from fly harassment. Caribou selected areas with high values of estimated biomass during calving, late summer, and fall. In general, the more inland areas (Southeast and Southwest sections of the

Table 8. Estimated vegetative biomass (expressed as mean NDVI values) and snow cover at locations used by caribou groups in the NPRA survey area in 2010, compared with availability using a bootstrap analysis.

Season	n^a	NDVI_calving	NDVI_621	NDVI_rate	NDVI_peak	Snow Cover (%)[b]
Winter	3	0.1778	0.3378	0.0133 +	0.5869	48.0
Calving	8	0.2725	0.3800 +	0.0090	0.6181 +	12.1 -
Postcalving	57	0.1907	0.3215	0.0111	0.5832	27.9 -
Oestrid Fly	13	0.1100 --	0.2212 -	0.0094 -	0.5101 -	25.1
Late Summer	38	0.2454 +	0.3649 +	0.0121	0.6153 +	30.8
Fall	187	0.1998	0.3431 +	0.0121	0.5947 +	36.5
Total Use	306	0.2017	0.3375 +	0.0115	0.5910 +	33.2 -
Available		0.1920	0.3289	0.0116	0.5855	38.7

[a] Caribou groups in pixels with >50% water fraction were not included in analysis.
[b] Snow cover on June 7, 2010.
\+ 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 ($P < 0.01$).

NPRA survey area) had higher estimated biomass than did the Coast, North, and River sections (Appendix J). In 2005, 2007–2009, 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 snowmelt, 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 M). For all years combined (2001–2010), 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 21) 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 ($P = 0.008$). No other seasons differed significantly ($P > 0.05$).

Over all seasons combined, there were no significant differences among zones ($P = 0.132$). Significant differences in density were found among calving ($P = 0.040$), postcalving ($P = 0.022$), and late summer ($P = 0.044$). There were no significant differences among zones during any season after applying multiple-comparison tests. During calving, the higher density in the north 4–6 km zone than in the north 2–4 km zone was near the level of significance ($P = 0.055$).

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

CARIBOU DENSITY ANALYSIS

Grid-cell analysis of the NPRA aerial-transect data examined the influence of geographic location, snow cover, vegetative biomass, habitat type, and distance to the proposed ASDP road alignment on caribou density during the calving season in 2010 and among all seasons for the years 2002–2010. A number of variables used in the grid-cell analyses were correlated; therefore, we examined the relationships among vegetation, snow, and habitat variables calculated for the 164 grid-cells before conducting the density analyses.

After removing one outlier, the estimated peak vegetative biomass (NDVI_peak) was highly correlated with NDVI_621 ($r = 0.873$; $P < 0.001$) and NDVI_calving ($r = 0.846$; $P < 0.001$), but was less correlated with NDVI_rate ($r = 0.518$; $P < 0.001$). These results indicate that the spatial pattern of NDVI values after snowmelt is consistent throughout all phenological stages. NDVI_peak in 2010 was highly correlated with the NDVI_peak in 2009 ($r = 0.917$; $P < 0.001$) 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 ($r = 0.773$; $P < 0.001$) but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $r = -0.498$; $P < 0.001$) and in riverine habitats ($r = -0.662$; $P < 0.001$). 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

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

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
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
2001–2010	Winter	4	123	21	19	37	27	19	2.99	0.559
	Spring Migration	9	82	15	8	25	16	18	3.99	0.407
	Calving	11	213	53	29	65	33	33	6.06	0.195
	Postcalving	11	301	62	54	96	37	52	4.72	0.317
	Mosquito	7	17	4	4	5	1	3	2.07	0.722
	Oestrid Fly	11	49	17	9	8 --	5	10	13.06	0.011
	Late Summer	17	183	44	36	56	21	26	8.44	0.077
	Fall Migration	19	427	76	63	146	65	77	1.34	0.854
	Total	89	1,395	292	222	438	205	238	8.70	0.069
Area surveyed in 2001 (km^2)[a]				31.4	27.9	52.8	26.7	27.0		
Area surveyed in 2002–2004 (km^2)				35.0	29.4	67.5	33.1	33.5		
Area surveyed in 2005–2010 (km^2)				39.4	33.4	69.1	33.2	33.6		

[a] Average of different survey areas.
[+] Use greater than expected ($P < 0.05$).
[++] Use greater than expected ($P < 0.01$).
\- Use less than expected ($P < 0.05$).
-- Use less than expected ($P < 0.01$).

significant ($r = –0.544$; $P < 0.001$), suggesting that even small waterbodies artificially depressed NDVI values.

The snow-cover fraction in the NPRA survey area on 7 June 2010 was highly correlated with NDVI_rate ($r = –0.861$, $P < 0.001$) and NDVI_calving ($r = –0.795$, $P < 0.001$), but was less correlated with NDVI_621 ($r = –0.562$, $P < 0.001$) and NDVI_peak ($r = –0.578$, $P < 0.001$). These results suggest that the NDVI values measured in early June were largely a function of snow cover, but that other factors (such as habitat type and standing water) became more important influences on NDVI values after snow melt.

Caribou Density During the 2010 Calving Season

The best model describing caribou density in the western half of the study area (NPRA survey area) during the 2010 calving season included just two independent variables: presence of Fish or Judy creeks (included in all models), and snow cover on 7 June. This model had an estimated 23.8 % probability of being the best model ($w_i = 0.238$; Appendix N). The second-best model included those two variables plus the proportion of wet habitat and had a 13.2% probability of being the best model ($w_i = 0.13.2$; Appendix N). The model-weighted parameter estimates indicated that none of the variables were significantly different from zero ($P > 0.10$; Table 10). Very few caribou

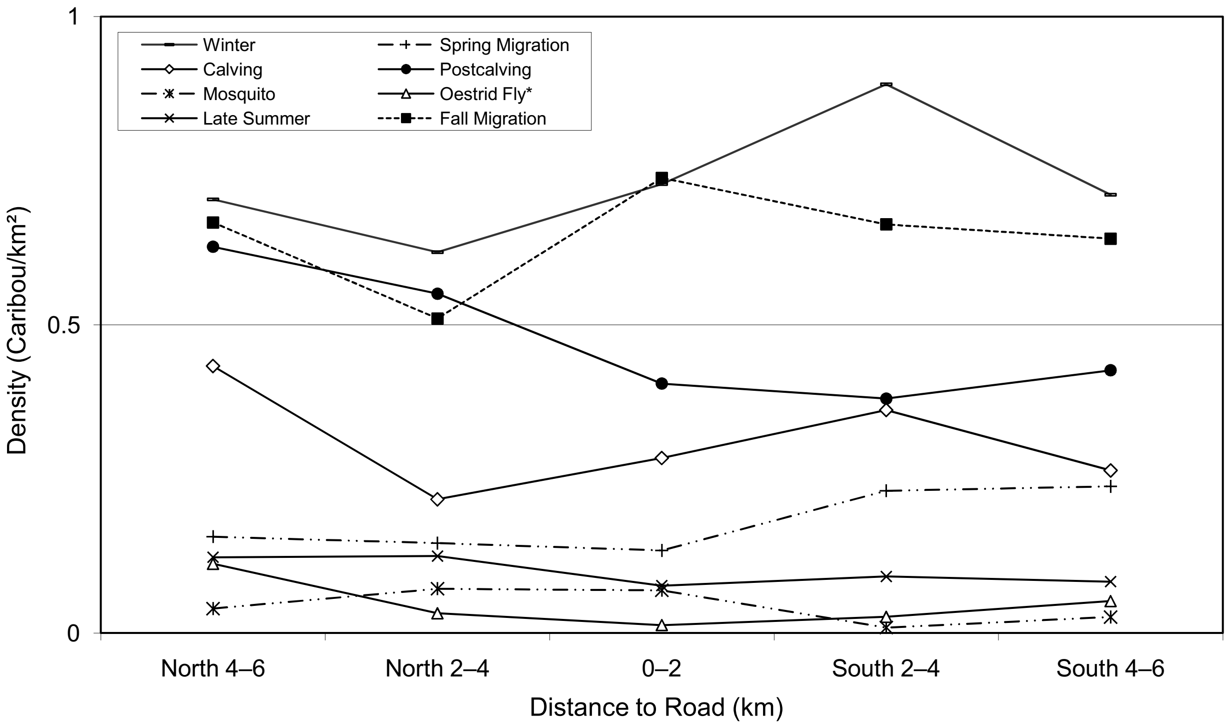


Figure 21. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during eight different seasons in 2001–2010.

Table 10. Model-weighted parameter estimates for caribou density in the NPRA survey area during calving, 7 June 2010.

Variable	Coefficient	SE	*P*-value
Intercept	–1.016	3.498	0.771
Presence of creeks	–0.820	0.980	0.403
NDVI_peak	–0.030	26.094	0.999
NDVI_rate	–124.011	294.214	0.673
Snow cover on June 8 (%)	–0.046	0.031	0.137
Tussock tundra (%)	1.558	3.919	0.691
Wet habitat (%)	–2.413	3.944	0.541
Transect number (W to E)	–0.035	0.120	0.769

were observed in the NPRA survey area on the calving survey in 2010, however, so the tests we used had low power to detect significant factors affecting caribou distribution at that time.

Caribou density in the eastern half of the study area (Colville East survey area) was the highest recorded among the various areas surveyed in the Colville–Kuparuk area during the 2010 calving season (Lawhead and Prichard 2011). Caribou density in Colville East appeared to be influenced by a variety of factors. The best model was the global model containing all seven variables (Appendix O). This model had an estimated 41.8% probability of being the best model in the candidate set (w_i = 0.418; Appendix O). The second-best model contained all of the variables except the proportion of wet graminoid tundra and had a 34.9% probability of being the best model (w_i = 0.349; Appendix O). The model without the proportion of wet graminoid tundra and NDVI_peak had a 16.0% probability of being the best model (w_i = 0.160; Appendix O).

Based on the model-weighted parameter estimates, caribou density in the Colville East survey area in the 2010 calving season declined where increasing proportions of land were covered by waterbodies (P = 0.001; Table 11), decreased from west to east (P = 0.011), was lower within 2 km of existing roads (P = 0.002), increased with distance to the coast (P = 0.009), and was higher in areas with rapid snowmelt (P = 0.009). The model-weighted parameter estimates for NDVI_peak (P = 0.132) and the proportion of wet graminoid tundra (P = 0.355) were not significant (Table 11).

These results are consistent with previous findings that maternal females with young calves tend to avoid areas within 2–4 km of active roads and gravel pads for 2–3 weeks during and immediately after calving (Dau and Cameron 1986, Lawhead 1988, Cameron et al. 1992, Nellemann and Cameron 1996, Lawhead et al. 2004). The fact that caribou appear to select areas of recent snowmelt 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).

Caribou Density Among Seasons

In the combined sample across all years and seasons, different variables were significantly related to caribou density in the NPRA survey area among seasons (Table 12, Appendix P). During winter, caribou density was lower in the eastern portion than in the western portion of the survey area. During spring migration, caribou density decreased with increasing distance from the coast and was lower in the eastern portion of the survey area.

The best model for calving included survey number, the presence of creeks, and the presence of the proposed road alignment (these first three variables were in all models, so were included in the best model by default), transect number (west to east), and proportion of tussock tundra (Appendix P). The model-weighted parameter estimates indicated that caribou density during calving was greater near the creeks (P = 0.014), in areas of higher NDVI_peak values (P < 0.001), and higher proportion of tussock tundra (P < 0.001). Calving density was lower in areas with greater proportions of wet habitat (P = 0.007) and in the eastern transects (P 0.016). The distance to the coast (P = 0.248) and the presence of the proposed road (P = 0.242) were not significant (Table 12, Appendix Q).

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 between-year correlations of caribou density during calving were low for 2005–2010 (Spearman's rho = –0.072–0.407), suggesting that different factors influenced caribou distribution among years at the scale of our analysis.

Table 11. Model-weighted parameter estimates for caribou density in the Colville East survey area during calving, 8 June 2010.

Variable	Coefficient	SE	*P*-value
Intercept	3.891	3.772	0.302
Proportion covered by waterbodies	–2.847	0.864	0.001
Transect number (W to E)	–0.045	0.018	0.011
Within 2 km of roads	–0.764	0.244	0.002
NDVI_peak	–8.880	5.900	0.132
Distance to coast	0.022	0.008	0.009
Rate of snow melt (% per day)	0.024	0.009	0.009
Proportion of wet graminoid tundra (%)	–0.634	0.686	0.355

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, 2002–2010.

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

ns	Not significant.
+	Greater than zero ($P < 0.05$).
++	Greater than zero ($P < 0.01$).
-	Less than zero ($P < 0.05$).
--	Less than zero ($P < 0.01$).
**	Significantly different among surveys ($P < 0.01$).

During postcalving, density was higher near the creeks and in areas with higher NDVI_peak values and decreased inland from the coast and from west to east. During the mosquito season, caribou density was higher near creeks, near the coast, and in the western portion of the survey area. During the oestrid-fly season, density was higher near the creeks and lower in areas with high NDVI_peak. In late summer, density was higher near the creeks and in the west and was lower in areas with higher NDVI_peak values and a higher proportions of tussock tundra. During fall migration, caribou density was higher in the western portions than in the eastern portions of the survey area (Table 12; Appendix Q).

Overall, strong seasonal patterns in caribou density were evident. A west-to-east gradient of decreasing density was evident throughout the entire year, most likely because the NPRA survey area is located on the eastern edge of the TH range. The riverine area of Fish and Judy creeks had higher densities from the postcalving season through late summer. The riverine area is characterized by a mosaic of habitats, including abundant willows and forbs that provide forage, as well as barrens, dunes, and river bars that provide some relief from oestrid-fly harassment. Caribou densities near the coast were higher during spring migration, the postcalving and mosquito seasons, and late summer, which are generally consistent with increased use of coastal areas during mosquito harassment. Caribou densities in areas with high proportions of tussock tundra were greater during calving and lower during late summer than in other areas. 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 most of the year, there was no evidence that the area around the proposed ASDP road alignment in NPRA was used by caribou to a different degree than adjacent areas.

CONCLUSIONS

Analysis of the VHF, satellite, and GPS telemetry data sets clearly demonstrates that the Colville River delta and ASDP study area (48-km radius circle centered on CD4) are at the interface of the annual ranges of the TH and CAH. The CD4 drill site is located in an area that is used relatively little by caribou from either herd. The TH consistently uses the western half of the ASDP study area to some extent during all seasons of the year; caribou numbers generally are low in the NPRA survey area during calving, highly variable during the insect season, and then tend to increase in the fall. In contrast, the CAH uses the eastern half of the ASDP study area primarily during calving (including concentrated calving in the southeastern part of the Colville East survey area), postcalving, and the insect season. Although caribou from both herds occur on the Colville delta occasionally, large movements onto or across the delta are uncommon for either herd. 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. One movement of CAH caribou onto the Colville delta from the east was recorded during the insect-harassment season in July 2010.

Movements by satellite- and GPS-collared TH and CAH caribou into the vicinity of CD4 (between Nuiqsut and the Alpine processing facilities) have occurred sporadically and infrequently during the calving, mosquito, and oestrid-fly seasons and fall migration since monitoring began, years before the CD4 infrastructure was built. None of the satellite collars in the TH were recorded in the immediate vicinity of CD4 during 1990–2006 or 2008–2010. 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 GPS-collared TH females during 2004–2010, one crossed the delta between CD4 and Alpine in June 2005, one crossed the delta between CD4 and Alpine in June 2007, one crossed just west of Alpine in July 2007, and another spent several days in August 2007 about 2 km south of CD4. One satellite-collared CAH caribou moved into the CD4 vicinity briefly in July 1988 and four others were nearby briefly in July 1989, more than a decade before construction.

Four CAH satellite collars moved through the CD4 vicinity while heading inland in late July 2001 and one CAH GPS collar moved onto the Colville delta east of CD4 in late September 2004.

Radio-collared TH caribou occasionally crossed the proposed ASDP pipeline/road-corridor alignment extending from CD4 to the proposed GMT2 drill site in NPRA, primarily during fall migration, but the proposed alignment is located in a geographic area that currently receives low-density use by caribou from that herd. In July 2010, 13 of 18 radio-collared TH caribou crossed the proposed road corridor, indicating that a large proportion of the herd was in the area at that time.

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 2010 appeared to select areas away from the coast, and with more rapid recent snowmelt 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, mosquito, oestrid-fly, and late summer seasons. The complex mosaic of riverine habitats provides opportunities both for foraging and for relief from oestrid-fly harassment. The presence of these streams was a significant variable explaining the distribution and density of caribou in the NPRA survey area, affecting both geographic 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-water areas are typically 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 are spectrally different from clear water. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. The turbid-water class may contain small amounts of *Arctophila fulva* or *Carex aquatilis*, but generally has <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-pattern	Continuously flooded areas composed of 25–50% water. *Carex aquatilis* is the dominant species. Other species may include *Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris*. Non-pattern is distinguished from low-centered polygons by the lack of polygon features and associated shrub species that grow on dry ridges of low-centered polygons.
Wet Tundra	Associated with areas of super-saturated soils and standing water. Wet tundra often floods in early summer and generally drains of excess water during dry periods, but remains saturated throughout the summer. It is composed of 10–25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum angustifolium*, 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 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. 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.

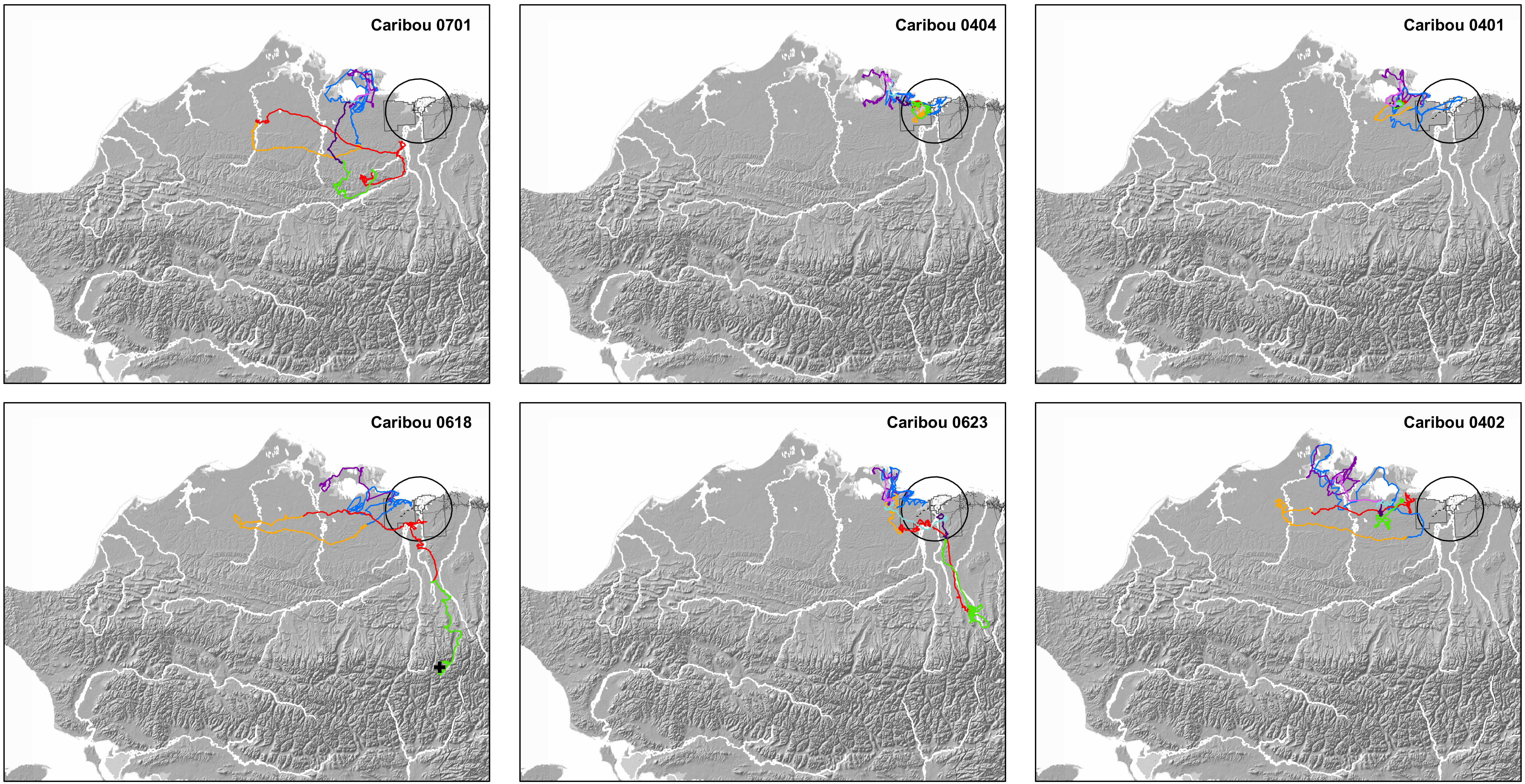
Cover Class	Description
Low Shrub	Associated with small streams and rivers, but also occurs on hillsides in the southern portion of the NPRA. This class is dominated by shrubs 0.3–1.5 m in height. Major species included *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre.*
Dunes/Dry Sand	Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with <10% vegetation. Plant species may include *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Sparsely Vegetated	Occurs primarily along the coast in areas affected by high 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% vegetation. The vegetation in these areas may include rare plants, but the more commonly found species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes.*
Barren Ground/ Other	Associated with river and stream gravel bars, mountainous areas, and human development. Includes <10% vegetation. May incorporate dead vegetation associated with salt burn from ocean water.

Appendix B. Snow depth (cm; 1 April–31 May) and cumulative thawing degree-days (° C above freezing; 1 May–15 August) at the Kuparuk airstrip, 1983–2010. Some values changed from previous reports due to different rounding error in average temperature calculations.

	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
Mean	23.0	13.6	3.5	0.6	11.3	42.9	97.3	125.1	141.5	126.7

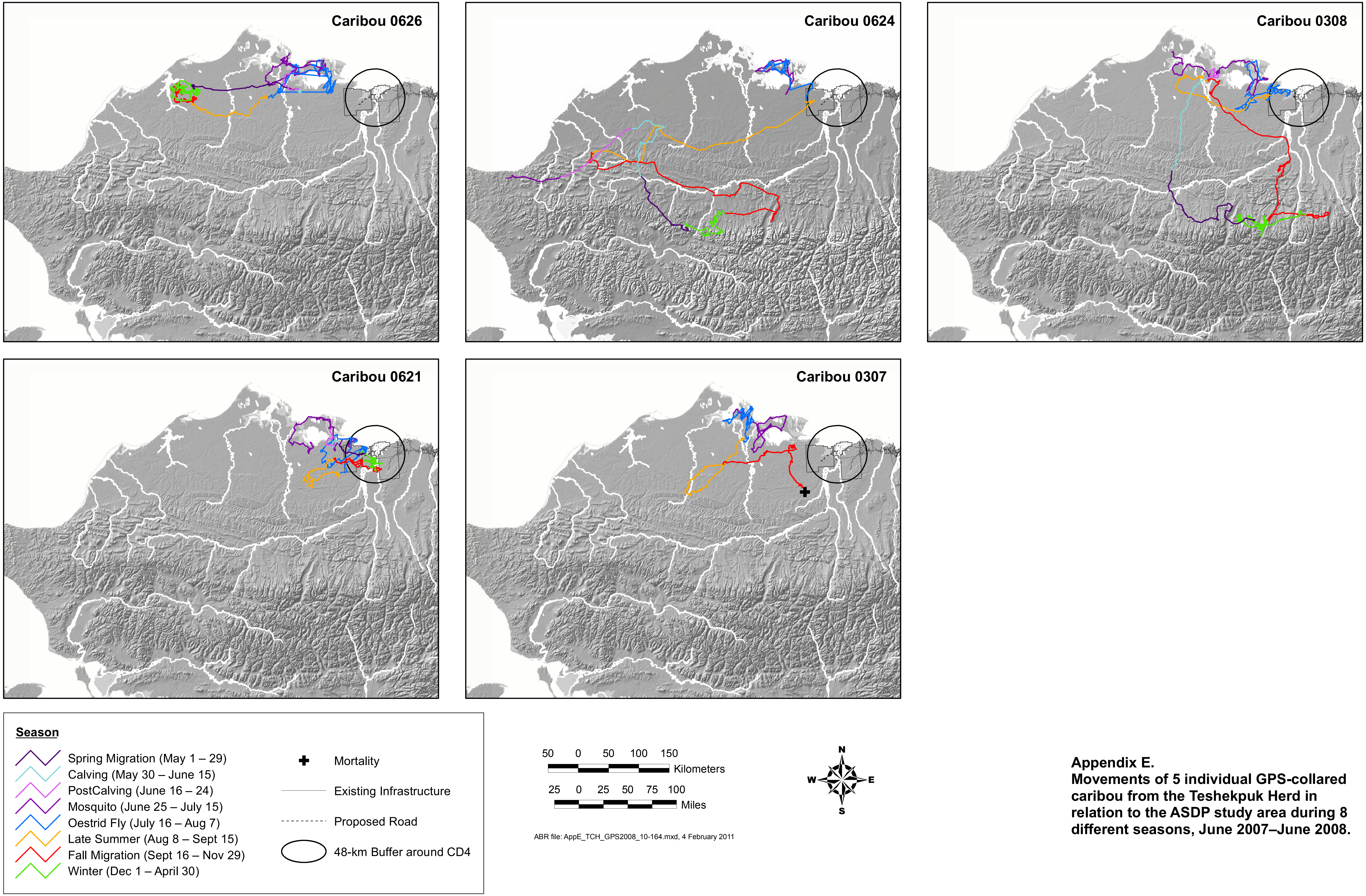
Appendix C. Locations and number of other mammals observed during aerial surveys in and near the ASDP study area, April–September 2010.

Species	General Location	Date	Adults	Young	Total	Specific Location
Muskox	Colville River delta	June 9	5	1	6	Miluveach R. mouth
		June 10	1	0	1	NE Colville delta
		June 13	5	1	6	SE Colville delta
		June 13	1	0	1	SE Colville delta
		August 5	1	0	1	SE Colville delta
		August 5	1	0	1	SE Colville delta
		August 5	6	1	7	SE Colville delta
		August 7	1	1	2	NE Colville delta
		August 17	10	3	13	E of Nuiqsut
		August 18	6	1	7	SE Colville delta
		August 18	1	1	2	N Colville delta
	Kuparuk oilfield	April 18	5	0	5	S of Alpine pipelines
		June 9	7	4	11	S of DS-2M
		June 12	7	4	11	DS-2M
		June 15	7	4	11	E of DS-3S
	Kuparuk River	June 8	9	4	13	Beechey Pt.
		June 8	9	3	12	Kuparuk R. mouth
		June 20	3	0	3	Near Spine Rd.
		June 22	6	0	6	S of Spine Rd.
		June 22	3	0	3	Near Spine Rd.
		June 22	9	0	9	Near Spine Rd.
		August 16	7	3	10	Kuparuk R. mouth
		August 17	10	1	11	S of Spine Rd.
		August 18	5	2	7	Near Spine Rd.
Grizzly bear	NPRA	June 11	1	0	1	W of Fish Creek
		June 12	1	2	3	S of Fish Creek
		June 13	2	0	2	SW of Fish Creek
		June 22	1	0	1	W of Fish Creek
		July 14	1	0	1	Fish Creek
		August 4	1	0	1	W of Fish Creek
	Colville River delta	June 13	1	2	3	SE of Alpine
		June 26	1	2	3	NW Colville delta
		July 13	1	0	1	E Colville delta
		August 3	1	0	1	SW of Alpine
		August 19	1	0	1	E Colville delta
		August 19	1	2	3	N of Nuiqsut
	Oilfield area	June 9	1	2	3	E of DS-2P
		June 9	1	0	1	E of DS-2P
		June 9	1	3	4	E of DS-2P
		June 21	1	3	4	SW of DS-2P
		August 18	1	2	3	N of DS-2L
	Kuparuk River	June 8	1	0	1	S of Spine Rd.
		June 8	1	0	1	W of Kuparuk R.
		June 8	1	0	1	W of upper Kuparuk R.
Spotted seal	Colville River delta	August 17	20	0	20	NE Colville delta



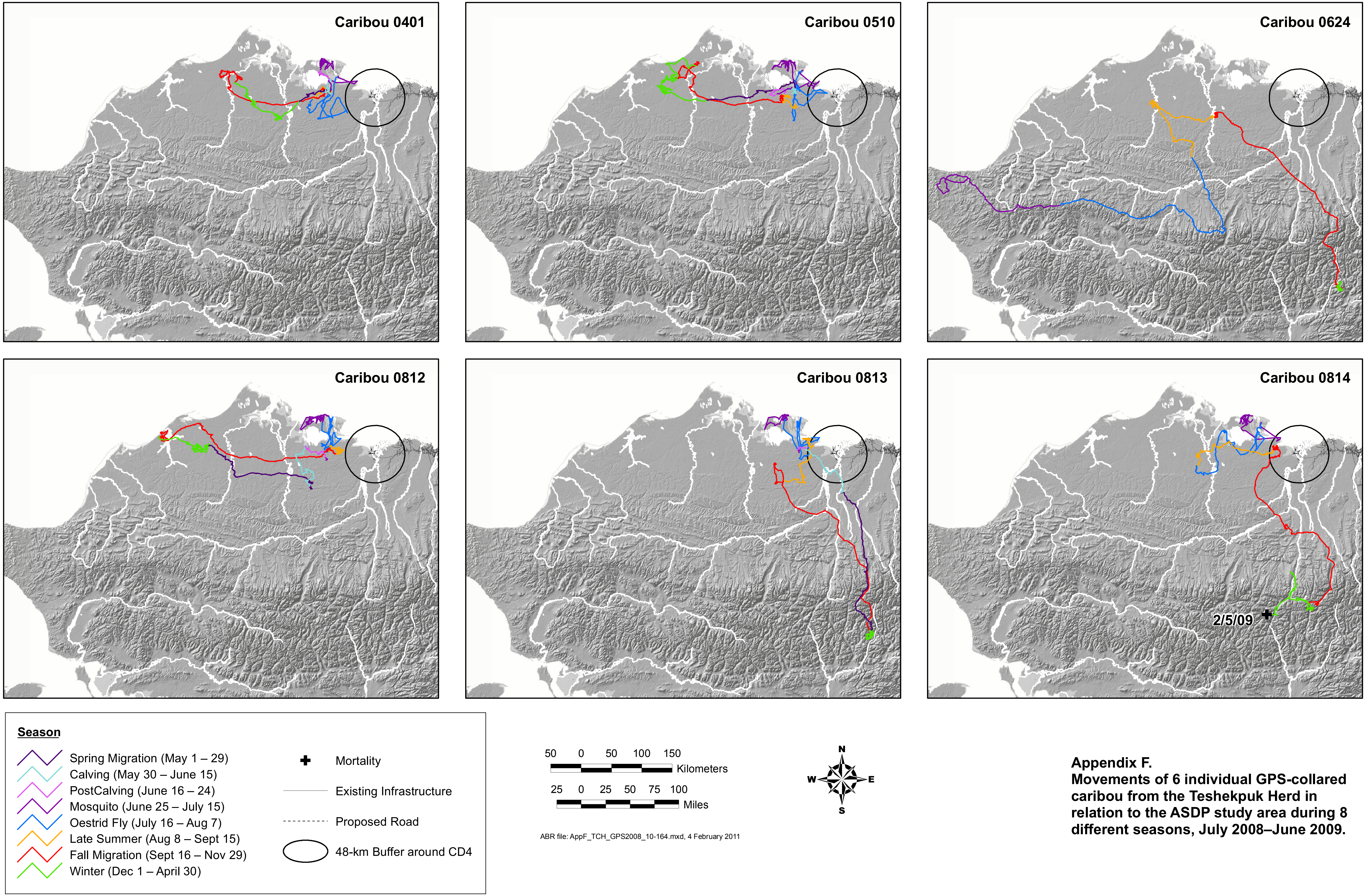
ABR file: AppL_TCH_GPS2008_10-164.mxd, 27 January 2011

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



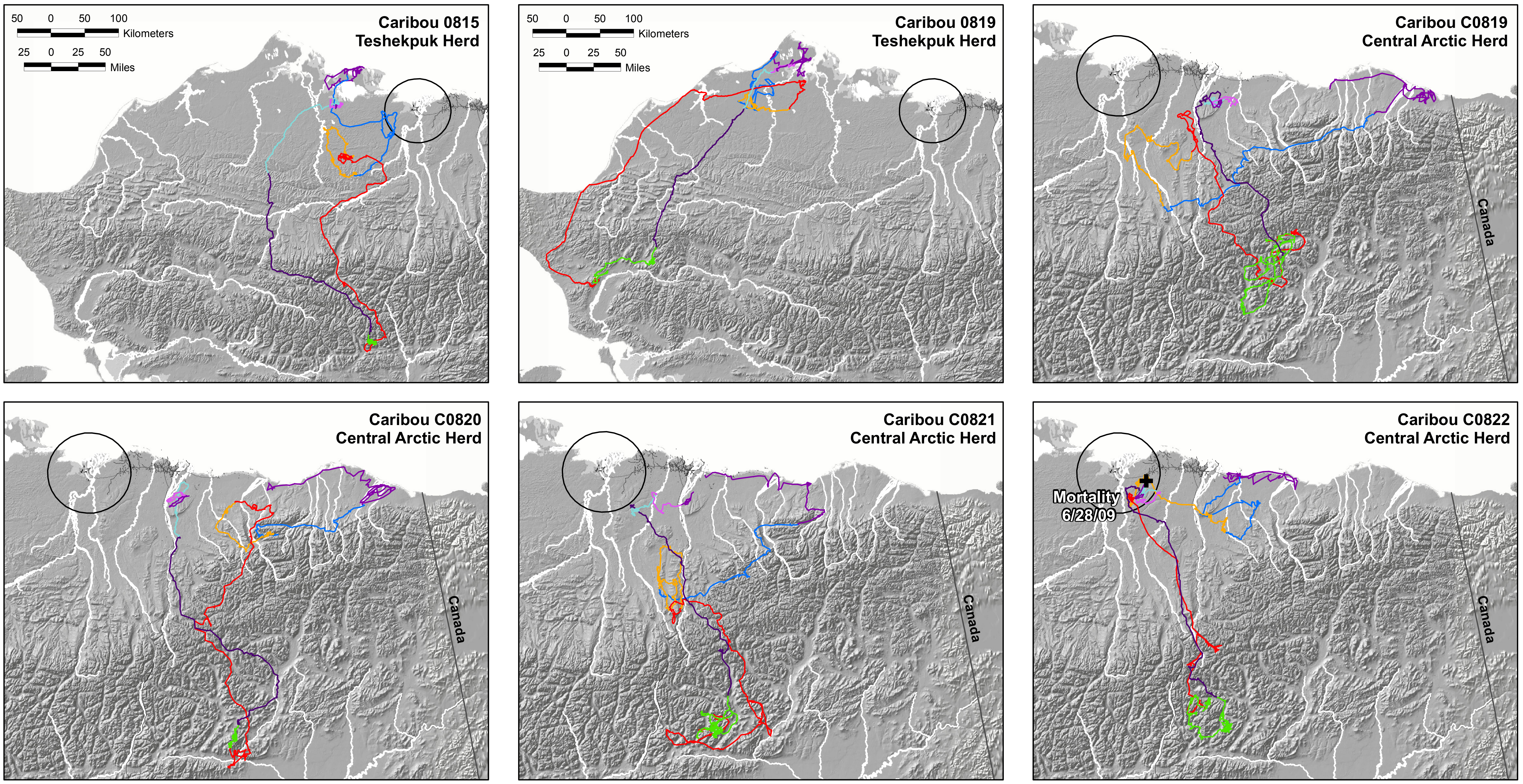
ABR file: AppE_TCH_GPS2008_10-164.mxd, 4 February 2011

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



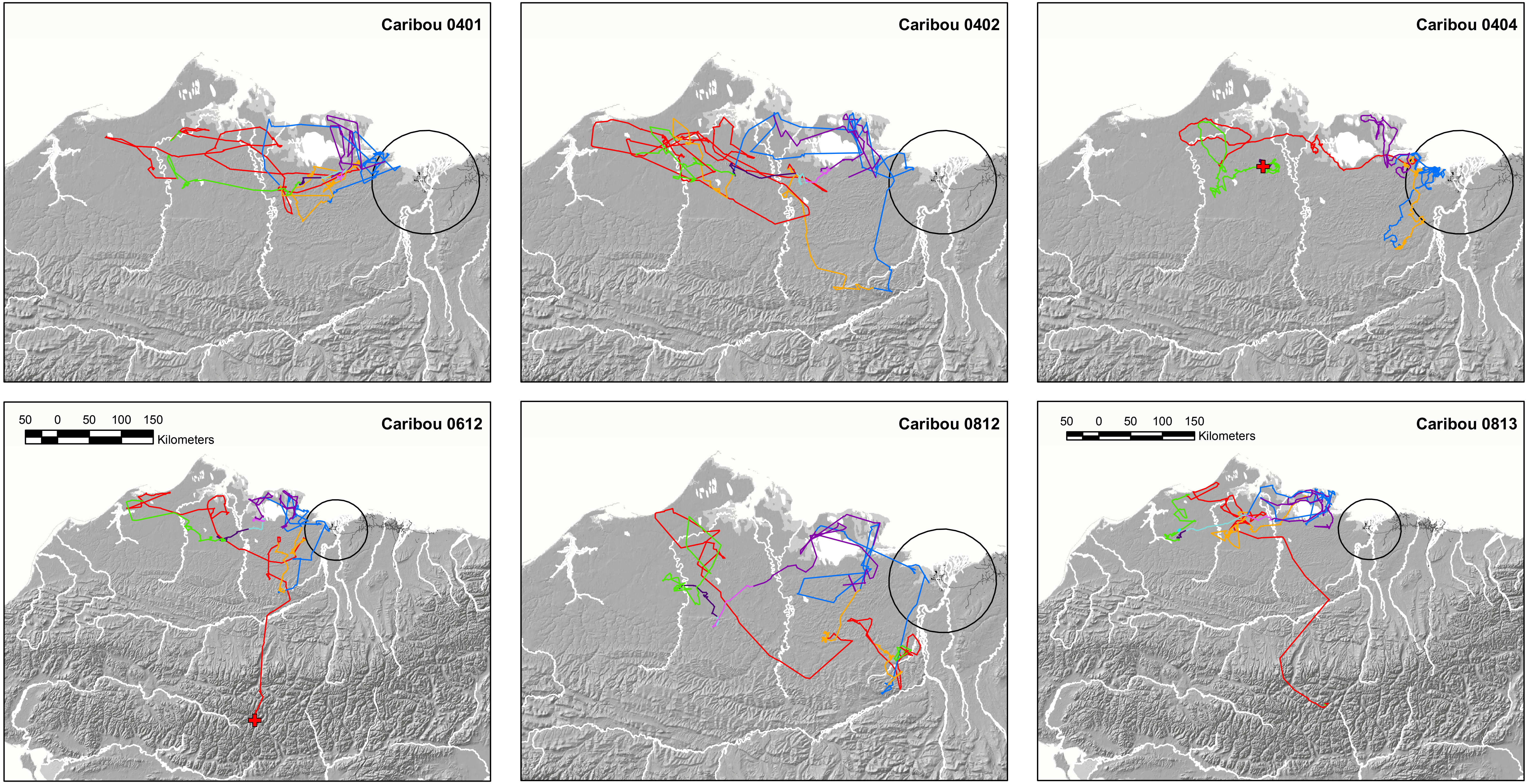
ABR file: AppF_TCH_GPS2008_10-164.mxd, 4 February 2011

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



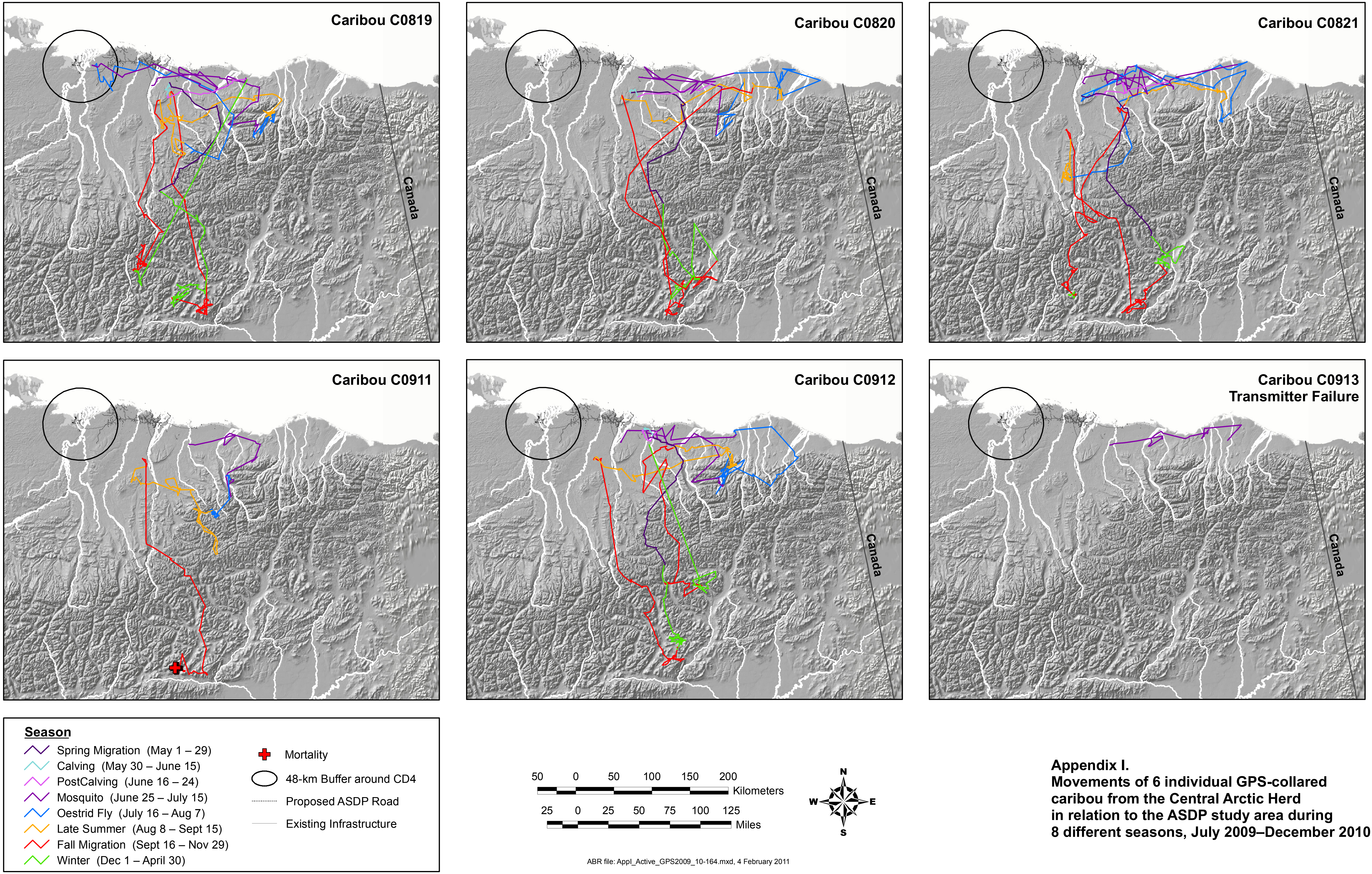
ABR file: AppG_TCH_GPS2008_10-164.mxd, 4 February 2011

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



ABR file: AppH_Active_GPS2009_10-164.mxd, 4 February 2011

Appendix H.
Movements of 6 individual GPS-collared caribou from the Teshekpuk Herd in relation to the ASDP study area during 8 different seasons, July 2009–December 2010.



ABR file: Appl_Active_GPS2009_10-164.mxd, 4 February 2011

Appendix I.
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–December 2010.

Appendix J. Descriptive statistics for snow cover and vegetative biomass (NDVI) in 2010 and for habitat types (BLM and Ducks Unlimited 2002) within different geographic sections of the 2002–2004 and 2005–2010 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	0.1673	0.1526	0.1777	0.2361	0.2613
		NDVI_621	0.3101	0.3188	0.3020	0.3536	0.3764
		NDVI_rate	0.0119	0.0144	0.0106	0.0099	0.0097
		NDVI_peak	0.5778	0.5821	0.5763	0.6060	0.6066
	Snow Cover 6 June	Mean %	68.2	89.5	54.7	65.2	61.5
	Snow Cover 7 June	Mean %	35.1	65.0	26.3	26.0	23.6
	Snow Cover 8 June	Mean %	15.5	40.1	11.6	8.2	7.3
	Snow Cover 9 June	Mean %	8.4	19.4	7.5	4.9	4.4
	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
2005–2010	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_calving	0.0857	0.1405	0.1752	0.2360	0.2611
		NDVI_621	0.2633	0.3117	0.2995	0.3536	0.3764
		NDVI_rate	0.0148	0.0146	0.0106	0.0099	0.0097
		NDVI_peak	0.5240	0.5782	0.5757	0.6060	0.6066
	Snow Cover 6 June	Mean %	87.2	90.2	55.2	65.2	61.5
	Snow Cover 7 June	Mean %	64.9	65.3	27.0	26.0	23.7
	Snow Cover 8 June	Mean %	40.8	39.7	12.2	8.2	7.3
	Snow Cover 9 June	Mean %	22.1	17.9	8.2	4.9	4.4
	Habitat Type (% area)	Water	24.2	22.1	15.3	17.7	11.4
		Carex aquatilis	8.3	6.3	6.4	6.2	8.4
		Flooded Tundra	15.0	10.1	14.9	18.3	18.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.3
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	13.5
		Tussock Tundra	19.7	25.5	24.8	41.3	34.3
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1
		Low Shrub	<0.1	<0.1	0.1	0.3	0.2
		Dry Dunes	3.2	0.3	2.0	0.1	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1
		Barren Ground	8.0	0.8	2.1	0.1	0.1

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

				Geographic Section						
Year(s)	Season	No. of Surveys	Total Groups	Coast	North	River	South East	South West	Chi-square	*P*-value
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0	26	13--	40	47	25.70	<0.001
	Calving	1	116	1	23	42^{+}	22--	28	22.02	<0.001
	Postcalving	1	82	0	13	45^{++}	12--	12--	47.85	<0.001
	Mosquito	1	5	0	4^{++}	1	0	0	22.81	<0.001
	Oestrid Fly	3	24	0	0-	18^{++}	2--	4	34.13	<0.001
	Late Summer	3	201	1	32	82^{++}	42--	44	39.67	<0.001
	Fall Migration	3	148	0	7--	33	23--	85^{++}	75.01	<0.001
	Total	14	702	2--	105	234^{++}	141--	220	84.88	<0.001
2003	Winter	1	313	1--	28	75	97	112^{++}	15.55	0.004
	Spring Migration	1	13	0	3	4	1--	5	5.18	0.269
	Calving	2	101	0	12	26	22--	41^{+}	13.44	0.009
	Postcalving	2	273	1--	37	90+	64--	81	22.35	<0.001
	Mosquito	1	1	0	1	0	0	0	7.44	0.115
	Oestrid Fly	2	116	1	6--	61^{++}	24--	24	50.81	<0.001
	Late Summer	1	37	0	10	15	7	5	16.94	0.002
	Fall Migration	3	431	2--	46	140^{++}	64--	179^{++}	98.07	<0.001
	Total	13	1,285	5--	143	411^{++}	279--	447^{++}	134.33	<0.001
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0	1	1	3	0	2.66	0.617
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	2	0	0	2	0	0	6.18	0.186
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	75	0	14	34^{++}	9--	18	29.07	<0.001
	Fall Migration	1	66	2	9	10	41^{++}	4--	28.10	<0.001
	Total	5	148	2	24	47	53	22--	13.91	0.008
2005	Winter	1	98	11	19	15	14--	39^{++}	23.82	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	98	3--	15	10-	21	49^{++}	51.71	<0.001
	Postcalving	1	112	7	29	27	16--	33	13.99	0.007
	Mosquito	1	32	10+	7	6	4	5	17.40	0.002
	Oestrid Fly	1	25	8	3	8	5	1--	19.38	0.001
	Late Summer	2	29	2	11	3	6	7	4.97	0.291
	Fall Migration	1	46	2	11	8	13	12	2.17	0.704
	Total	9	440	43	95	77	79--	146^{++}	45.53	<0.001
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	79	14	40^{++}	8-	9--	8--	46.65	<0.001
	Calving	1	118	3--	32	13-	23	47^{++}	34.13	<0.001
	Postcalving	1	88	3--	22	40^{++}	11--	12	44.58	<0.001
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	32	0-	14	11	3--	4	17.99	0.001
	Late Summer	2	94	7	26	31^{+}	12--	18	18.04	0.001
	Fall Migration	1	5	0	0	1	4^{+}	0	7.89	0.096
	Total	8	416	27-	134^{++}	104^{+}	62--	89	51.22	<0.001
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	159	13	44	44	26--	32	14.84	0.005
	Calving	1	198	4--	44	22--	40	88^{++}	74.75	<0.001
	Postcalving	1	178	3--	60^{+}	49	37	29	32.45	<0.001
	Mosquito	1	62	8	31^{++}	15	7--	1--	38.28	<0.001
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	83	8	19	31^{++}	14	11	19.69	0.001
	Fall Migration	3	347	20--	94	63	112	58	15.86	0.003
	Total	9	1,027	56--	292^{++}	224	236-	219	45.50	<0.001

Appendix K. Continued.

				Geographic Section						
Year(s)	Season	No. of Surveys	Total Groups	Coast	North	River	South East	South West	Chi-square	*P*-value
2008	Winter	1[a]	60	6	10	15	27	2	10.15	0.038
	Spring Migration	1	10	1	0	2	2	5	6.47	0.167
	Calving	1	145	5--	33	26	36	45[+]	13.58	0.009
	Postcalving	1	82	5	43[++]	18	6--	10	48.08	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	112	13	37	35[+]	21	6--	29.75	<0.001
	Fall Migration	3	245	21	70	57	43--	54	14.44	0.006
	Total	8	654	51	193[++]	153[+]	135--	122	48.97	<0.001
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

[a] Partial survey.

[+] Use greater than expected ($P < 0.05$).

[++] Use greater than expected ($P < 0.01$).

- Use less than expected ($P < 0.05$).

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

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

				Habitat Type [a]								
Year	Season	No. of Surveys	No. of Groups	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2002	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	2	126	0.99	0.91	0.89	1.42^{++}	1.03	0.14--	0.83	1.17	0.06--
	Calving	1	116	1.01	0.90	1.04	1.05	0.91	1.31	1.55^{+}	0.29	1.92
	Postcalving	1	82	0.91	0.70--	1.01	1.07	1.03	1.87	0.78	0.29	2.70^{+}
	Mosquito	1	5	0.69	0.98	1.49	1.14	0.75	0.42	1.47	0	2.98
	Oestrid Fly	3	24	1.13	0.79	1.05	0.64	0.69	1.08	1.96	1.00	7.97^{++}
	Late Summer	3	201	1.02	1.02	0.99	0.80-	0.74--	2.18^{++}	1.44^{+}	2.14	4.89^{++}
	Fall Migration	3	148	1.24	1.01	1.15	0.98	0.86	1.34	1.32	0.34	1.25
	Total	14	702	1.05	0.93-	1.02	1.02	0.88--	1.41^{+}	1.26^{+}	1.01	2.60^{++}
2003	Winter	1	313	1.01	0.89-	0.93	0.93	1.07+	0.76	1.35^{+}	0.77	1.06
	Spring Migration	1	13	0.85	1.02	0.83	1.46	0.91	1.68	1.14	0.00	0.46
	Calving	2	101	1.12	0.75--	1.01	0.99	1.00	1.60	1.01	0.62	2.49^{+}
	Postcalving	2	273	0.93	0.91	0.96	1.05	0.95	1.19	1.01	1.05	2.69^{++}
	Mosquito	1	1	2.77	1.57	1.04	2.22	0.07	0	0	0	0
	Oestrid Fly	2	116	1.02	1.05	1.08	0.57--	0.69--	3.34^{++}	1.39	2.56	5.66^{++}
	Late Summer	1	37	0.90	1.00	0.95	1.59^{+}	0.82	1.39	0.77	0.00	1.15
	Fall Migration	3	431	1.08	0.90-	1.00	0.94	0.97	1.66^{++}	1.30+	1.92+	1.49
	Total	13	1,285	1.02	0.91--	0.98	0.96	0.96	1.48^{++}	1.22^{++}	1.33	2.08^{++}
2004	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	5	0.80	1.56	0.87	0.58	0.41	14.20^{++}	0.35	8.29	2.03
	Calving	0	–	–	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–	–	–
	Mosquito	1	2	3.68	2.10	0.61	1.24	0.04	0	0	0	0.70
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	75	1.03	0.93	1.14	0.85	0.72--	2.45^{++}	1.45	0.76	4.80^{++}
	Fall Migration	1	66	1.20	0.98	0.86	0.69-	1.08	1.01	1.19	1.39	1.28
	Total	5	148	1.14	0.99	1.00	0.78-	0.86	2.17^{++}	1.28	1.28	3.08^{++}
2005	Winter	1	98	1.20	1.12	0.90	1.00	1.04	0.42-	0.93	0.32	0.14--
	Spring Migration	0	–	–	–	–	–	–	–	–	–	–
	Calving	2	98	0.64-	0.77-	0.86	1.17	1.23^{++}	0.55	0.99	1.76	0.47
	Postcalving	1	112	0.80	0.73--	0.97	1.24^{+}	1.11	1.08	1.19	2.13	0.49
	Mosquito	1	32	2.18^{++}	0.95	0.78	0.96	0.51--	2.88^{+}	1.29	2.39	3.33^{++}
	Oestrid Fly	1	25	3.33^{++}	1.47^{+}	0.72	0.29--	0.25--	2.51	0.30	0	4.86^{++}
	Late Summer	2	29	1.75^{+}	1.00	0.91	0.70	0.93	1.56	1.74	0	0.78
	Fall Migration	1	46	0.97	0.97	0.98	1.20	0.99	0.61	0.72	0	0.98
	Total	9	440	1.18^{+}	0.93	0.90-	1.06	1.00	1.01	1.03	1.18	0.93
2006	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	79	1.00	0.89	1.10	1.23	0.97	0.94	0.81	0	0.75
	Calving	1	118	0.96	0.89	0.87	1.33^{++}	1.08	0.64	0.71	0.77	0.08--
	Postcalving	1	88	0.60--	0.93	1.27^{+}	1.00	0.85	1.67	1.24	4.40^{+}	2.35^{++}
	Mosquito	1	0	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	32	1.10	1.15	1.18	1.19	0.73	0.51	1.17	0	1.46
	Late Summer	2	94	0.80	0.79-	1.12	1.08	0.87	2.69^{++}	1.47	0.65	2.06^{+}
	Fall Migration	1	5	0.84	0.32	0.51	0.14	1.39	0.57	3.04	9.56	4.06
	Total	8	416	0.86-	0.89-	1.08	1.16^{++}	0.94	1.37	1.07	1.41	1.29
2007	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	159	1.21	1.18	0.99	1.19+	0.85-	1.14	0.74	0.68	0.49
	Calving	1	198	0.97	0.92	0.96	1.13	1.12+	0.37--	0.77	0.61	0.27--
	Postcalving	1	178	0.86	0.86-	1.00	0.99	1.04	1.19	1.10	0.57	1.53
	Mosquito	1	62	1.15	0.94	1.00	1.16	0.85	1.55	0.99	0.00	1.60
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	2	83	1.18	0.98	1.08	0.51--	0.66--	1.17	1.76^{+}	4.14^{+}	5.21^{++}
	Fall Migration	3	347	0.93	0.91-	0.97	1.06	1.09^{+}	1.11	0.91	0.44	0.59-
	Total	9	1,027	1.00	0.95	0.99	1.04	1.00	1.02	0.96	0.81	1.11

Appendix L. Continued.

				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

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

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

[c] Partial survey

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

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

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

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

Appendix M. Number of caribou groups in distance-to-proposed-road zones by year (2001–2009) and season, with results of a chi-square goodness-of-fit test (assuming a uniform distribution).

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	0–2	South 2–4	South 4–6	Chi-square	*P*-value
2001	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	10	1	1	2	1	1	8.32	0.080
	Calving	1	14	2	1	8	3	2	6.58	0.160
	Postcalving	2	104	17	23	32	14	17	3.42	0.489
	Mosquito	1	4	0	1	1	1	0	1.14	0.888
	Oestrid Fly	2	2	0	0	2	0	0	4.25	0.373
	Late Summer	2	38	13	6	10	3	13	6.46	0.167
	Fall Migration	3	79	14	12	32	10	14	2.82	0.589
	Total	12	251	47	44	87	32	47	2.44	0.655
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	26	4	3	7	4	8	3.63	0.458
	Calving	1	28	9	6	8	3	2	6.59	0.159
	Postcalving	1	18	4	4	7	1	2	2.70	0.609
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	3	3	1	0	0	1	1	2.86	0.581
	Late Summer	3	37	5	10	13	6	3	5.78	0.216
	Fall Migration	3	24	6	1-	8	6	3	3.86	0.426
	Total	14	136	29	24	43	21	19	2.83	0.587
2003	Winter	1	71	11	9	21	19	11	5.23	0.265
	Spring Migration	1	1	1	0	0	0	0	4.67	0.322
	Calving	2	22	3	5	9	1-	4	3.40	0.494
	Postcalving	2	72	13	7	26	11	15	2.11	0.715
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	2	29	11	4	3--	3	8	14.24	0.007
	Late Summer	1	8	3	0	3	0	2	4.65	0.325
	Fall Migration	3	101	21	19	30	16	15	2.50	0.645
	Total	13	304	63	44	92	50	55	3.19	0.526
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	2	1	0	1	0	0	2.31	0.679
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	11	4	1	5	1	0	5.10	0.277
	Fall Migration	1	35	5	6	14	5	5	0.98	0.913
	Total	5	48	10	7	20	6	5	2.81	0.591
2005	Winter	1	21	4	5	6	3	3	1.01	0.909
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	21	6	2	4	3	6	4.91	0.296
	Postcalving	1	14	3	5	4	1	1	4.90	0.298
	Mosquito	1	3	1	0	1	0	1	1.84	0.765
	Oestrid Fly	1	7	2	3	2	0	0	5.78	0.216
	Late Summer	2	5	0	1	3	1	0	2.94	0.567
	Fall Migration	1	13	1	1	5	1	5	6.12	0.190
	Total	9	84	17	17	25	9	16	3.20	0.525
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	11	2	0	5	3	1	3.50	0.478
	Calving	1	26	9	0-	6	3	8	12.15	0.016
	Postcalving	1	16	6	3	3	1	3	5.02	0.285
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	4	1	1	0	1	1	2.01	0.734
	Late Summer	2	14	3	5	1--	2	3	6.56	0.161
	Fall Migration	1	2	0	0	1	0	1	2.61	0.624
	Total	8	73	21	9	16	10	17	9.73	0.045

Appendix M. Continued.

				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
2010	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

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

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

$-$ Use less than expected ($P < 0.05$).

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

Appendix N. Model-selection results (General Estimating Equations) for analyses of caribou density during calving 2010 in the NPRA survey area (163 grid cells). The best model (bold type) contained the variables indicating the presence or absence of Fish or Judy creeks (Creek; included in all models) and the percent snow cover on June 7 (Snow Cover).

Model [a]	*n* [b]	K [c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
Creek, Snow Cover	**163**	**5**	**133.15**	**0.00**	**0.238**
Creek, Snow Cover, Wet Habitat	163	6	134.33	1.19	0.132
Creek, Snow Cover, Tussock	163	6	134.82	1.67	0.103
Creek, W to E, Snow Cover	163	6	135.03	1.88	0.093
Creek, Snow Cover, NDVI_rate	163	6	135.08	1.93	0.091
Creek, Snow Cover, NDVI_peak	163	6	135.14	2.00	0.088
Creek, W to E, Snow Cover, Wet Habitat	163	7	135.77	2.63	0.064
Creek, W to E, Snow Cover, Tussock	163	7	136.40	3.25	0.047
Creek, NDVI_rate	163	5	136.91	3.76	0.036
Creek, W to E, Snow Cover, NDVI_rate	163	7	136.95	3.80	0.036
Creek, W to E, Snow Cover, NDVI_peak	163	7	137.02	3.88	0.034
Creek, W to E, NDVI_rate	163	6	138.59	5.44	0.016
Creek, Wet Habitat	163	5	140.23	7.09	0.007
Creek, W to E, Wet Habitat	163	6	140.98	7.83	0.005
Creek, Tussock	163	5	141.75	8.61	0.003
Creek, NDVI_peak	163	5	142.05	8.90	0.003
Creek, W to E, Tussock	163	6	142.43	9.29	0.002
Creek, W to E, NDVI_peak	163	6	143.87	10.73	0.001
Creek	163	4	146.66	13.52	0.000
Creek, W to E	163	5	148.51	15.36	0.000

[a] Coast = distance from coast; 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 O. Model-selection results (General Estimating Equations) for analyses of caribou density during calving 2010 in the Colville East survey area (553 grid cells). The best model (bold type) contained the variables transect number and proportion of waterbodies (both included in all models), proportion of wet habitat, rate of snowmelt (% per day), distance to coast (km), and NDVI_peak.

Model [a]	*n* [b]	K [c]	QIC_c [d]	ΔQIC_c [e]	w_i [f]
W to E, Water, Road, Wet Habitat, Snowmelt, Coast, NDVI_peak	**553**	**10**	**2411.66**	**0.00**	**0.418**
W to E, Water, Road, Snowmelt, Coast, NDVI_peak	553	9	2412.02	0.36	0.349
W to E, Water, Road, Snowmelt, Coast	553	8	2413.58	1.92	0.160
W to E, Water, Road, Wet Habitat, Snowmelt, Coast	553	9	2415.22	3.56	0.070
W to E, Water, Road, Wet Habitat, Snowmelt,NDVI_peak	553	9	2422.10	10.44	0.002
W to E, Water, Road, Wet Habitat, Snowmelt	553	8	2425.68	14.02	0.000
W to E, Water, Road, Coast, NDVI_peak	553	8	2428.49	16.83	0.000
W to E, Water, Road, Wet Habitat, Coast, NDVI_peak	553	9	2428.87	17.21	0.000
W to E, Water, Road, Snowmelt	553	7	2431.84	20.18	0.000
W to E, Water, Road, Coast	553	7	2431.99	20.33	0.000
W to E, Water, Road, Snowmelt, NDVI_peak	553	8	2433.35	21.69	0.000
W to E, Water, Road, Wet Habitat, Coast	553	8	2433.97	22.31	0.000
W to E, Water, Snowmelt, Coast	553	7	2434.55	22.89	0.000
W to E, Water, Snowmelt, Coast, NDVI_peak	553	8	2434.66	23.00	0.000
W to E, Water, Wet Habitat, Snowmelt, Coast, NDVI_peak	553	9	2436.02	24.36	0.000
W to E, Water,Wet Habitat, Snowmelt, Coast	553	8	2436.52	24.86	0.000
W to E, Water, Road, Wet Habitat, NDVI_peak	553	8	2442.83	31.17	0.000
W to E, Water, Road, Wet Habitat	553	7	2447.97	36.31	0.000
W to E, Water, Road	553	6	2452.86	41.20	0.000
W to E, Water, Wet Habitat,Snowmelt, NDVI_peak	553	8	2452.88	41.22	0.000
W to E, Water, Wet Habitat, Snowmelt	553	7	2453.10	41.44	0.000
W to E, Water, Road, NDVI_peak	553	7	2453.78	42.12	0.000
W to E, Water, Coast, NDVI_peak	553	7	2456.03	44.37	0.000
W to E, Water, Coast,	553	6	2457.42	45.76	0.000
W to E, Water, Wet Habitat, Coast,NDVI_peak	553	8	2457.87	46.21	0.000
W to E, Water, Snowmelt	553	6	2458.98	47.32	0.000
W to E, Water, Wet Habitat, Coast	553	7	2459.25	47.59	0.000
W to E, Water, Snowmelt, NDVI_peak	553	7	2460.97	49.31	0.000
W to E, Water,Wet Habitat, NDVI_peak	553	7	2479.91	68.25	0.000
W to E, Water,Wet Habitat	553	6	2480.96	69.30	0.000
W to E, Water, NDVI_peak	553	6	2487.13	75.47	0.000

[a] W to E = transect number from west to east; Water = proportion covered by waterbodies; Road = within 2 km of a road; Wet Habitat = proportion classified as wet graminoid tundra; Snowmelt = rate of snowmelt during June 6–9 (% per day); Coast = distance from coast; NDVI_peak = maximum NDVI during 2010.

[b] Sample size.

[c] Number of estimable parameters in the approximating model.

[d] Quasi-likelihood Information Criterion, corrected for small sample size.

[e] Difference in value between the QIC_c of the current model and that of the best approximating model.

[f] Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix P. Model selection results for Generalized Estimating Equation analyses of caribou density in different seasons during 2002–2010 in the NPRA survey area (163 grid cells). Bold type denotes the best model for each season.

		Model [a]														
Season	Value	S,C,R	S,C,R,DC	S,C,R,NP	S,C,R,TT	S,C,R,WH	S,C,R,TR	S,C,R,TR,NP	S,C,R,TR,TT	S,C,R,DC,NP	S,C,R,DC,TT	S,C,R,DC,WH	S,C,R,TR,DC	S,C,R,TR,WH	S,C,R,TR,DC,NP	S,C,R,TR,DC,TT
All Seasons	*n* [b]	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163
Winter	K [c]	7	8	8	8	8	8	9	**9**	9	9	9	9	9	10	10
	QIC_c [e]	2100	2093	2100	2011	2102	2079	2080	**2077**	2095	2095	2095	2080	2080	2082	2079
	w_i [f]	0.000	0.000	0.000	0.000	0.000	0.107	0.072	**0.393**	0.000	0.000	0.000	0.091	0.085	0.037	0.165
Spring	K	11	12	12	12	12	12	13	13	13	13	13	13	13	14	**14**
	QIC_c	2883	2878	2883	2885	2884	2862	2861	2863	2880	2880	2880	2845	2864	2847	**2842**
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.124	0.000	0.058	**0.713**
Calving	K	13	14	14	14	14	14	15	15	15	15	15	15	15	**16**	16
	QIC_c	5097	5007	5027	5084	5094	4956	4885	4902	4991	5005	5009	4923	4930	**4885**	4891
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.468	0.004	0.000	0.000	0.000	0.000	0.000	**0.511**	0.021
Postcalving	K	12	13	13	13	13	13	14	14	14	14	14	14	14	15	**15**
	QIC_c	5896	5897	5897	5891	5896	5718	5717	5720	5899	5892	5897	5683	5719	5682	**5682**
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.166	0.000	0.273	**0.292**
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11
	QIC_c	916	825	879	906	913	906	861	897	826	826	826	**789**	904	790	791
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.447**	0.000	0.216	0.173
Oestrid Fly	K	8	9	9	9	9	9	10	10	10	10	10	10	10	**11**	11
	QIC_c	1055	1044	1053	1049	1055	1033	1029	1031	1031	1033	1043	1034	1035	**1024**	1029
	w_i	0.000	0.000	0.000	0.000	0.000	0.006	0.056	0.021	0.022	0.006	0.000	0.006	0.002	**0.808**	0.069
Late	K	18	19	19	19	19	19	20	20	20	20	20	20	20	**21**	21
Summer	QIC_c	4452	4449	4419	4424	4447	4393	4352	4378	4420	4425	4446	4366	4393	**4348**	4361
	w_i	0.000	0.000	0.000	0.000	0.000	0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.000	**0.884**	0.000
Fall	K	19	20	20	20	20	20	21	21	21	21	21	21	**21**	22	22
Migration	QIC_c	8995	8995	8994	8986	8981	8959	8957	8957	8989	8984	8978	8960	**8953**	8959	8959
	w_i	0.000	0.000	0.000	0.000	0.000	0.035	0.076	0.068	0.000	0.000	0.000	0.016	**0.547**	0.030	0.025

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[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 tundr
WH = proportion of wet habitat (four types combined; see text), and TR = transect number (west to east).

[b] *n* = sample size.

[c] K = number of estimable parameters in the approximating model.

[d] RSS = Residual Sum of Squares.

[e] QIC_c = Quasi-Likelihood Information Criterion, corrected for small sample size.

[f] w_i = Akaike Weight = Probability that the current model (i) is the best approximating model in the candidate set.

Appendix Q. Model-weighted parameter estimates, standard error (SE), and *P*-value of variables included in the grid-cell analyses of caribou densities in the NPRA survey area, 2002–2010. Asterisks denote significance of *P*-value (* < 0.05, ** <0.01, *** <0.001).

Season	Variable	Mean	SE	*P*-value
Winter	Intercept	–3.990	0.815	<0.001***
	Presence of Creek	–0.228	0.264	0.389
	Includes Proposed Road	–0.280	0.336	0.404
	NDVI_peak	2.462	4.235	0.561
	Distance to Coast (km)	0.005	0.010	0.610
	Tussock Tundra (%)	0.973	0.703	0.167
	Wet Habitat (%)	–0.514	0.716	0.473
	Transect Number (West to East)	–0.086	0.027	<0.001***
Spring Migration	Intercept	–3.989	0.666	<0.001***
	Presence of Creek	–0.448	0.246	0.069
	Includes Proposed Road	–0.533	0.367	0.146
	NDVI_peak	1.721	4.509	0.703
	Distance to Coast (km)	–0.025	0.009	0.009**
	Tussock Tundra (%)	0.940	0.714	0.188
	Wet Habitat (%)	–0.496	0.691	0.472
	Transect Number (West to East)	–0.089	0.026	<0.001***
Calving	Intercept	–11.031	1.792	<0.001***
	Presence of Creek	0.377	0.153	0.014*
	Includes Proposed Road	–0.278	0.237	0.242
	NDVI_peak	14.441	2.912	<0.001***
	Distance to Coast (km)	0.008	0.006	0.248
	Tussock Tundra (%)	1.906	0.450	<0.001***
	Wet Habitat (%)	–1.178	0.436	0.007**
	Transect Number (West to East)	–0.119	0.016	0.016*
Postcalving	Intercept	0.766	1.077	0.477
	Presence of Creek	1.081	0.152	<0.001***
	Includes Proposed Road	0.380	0.234	0.104
	NDVI_peak	3.446	2.948	0.243
	Distance to Coast (km)	–0.025	0.006	<0.001***
	Tussock Tundra (%)	0.516	0.474	0.277
	Wet Habitat (%)	–0.476	0.470	0.311
	Transect Number (West to East)	–0.151	0.017	<0.001***
Mosquito	Intercept	3.262	1.655	0.049*
	Presence of Creek	0.742	0.320	0.020*
	Includes Proposed Road	0.647	0.483	0.181
	NDVI_peak	–4.622	6.191	0.455
	Distance to Coast (km)	–0.114	0.015	<0.001***
	Tussock Tundra (%)	–0.381	1.041	0.714
	Wet Habitat (%)	0.093	1.043	0.929
	Transect Number (West to East)	–0.168	0.035	<0.001***
Oestrid Fly [a]	Intercept	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
	Transect Number (West to East)	–0.093	0.050	0.064

Appendix Q. Continued.

Season	Variable	Mean	SE	*P*-value
Late Summer	Intercept	4.217	1.454	0.004**
	Presence of Creek	0.519	0.131	<0.001***
	Includes Proposed Road	0.060	0.227	0.793
	NDVI_peak	–9.022	2.556	<0.001***
	Distance to Coast (km)	–0.012	0.006	0.053
	Tussock Tundra (%)	–0.871	0.418	0.037*
	Wet Habitat (%)	0.006	0.422	0.989
	Transect Number (West to East)	–0.096	0.015	<0.001***
Fall Migration	Intercept	–0.141	0.582	0.809
	Presence of Creek	0.045	0.139	0.745
	Includes Proposed Road	–0.100	0.204	0.623
	NDVI_peak	–2.452	2.362	0.299
	Distance to Coast (km)	0.001	0.006	0.965
	Tussock Tundra (%)	–0.406	0.400	0.310
	Wet Habitat (%)	0.610	0.402	0.130
	Transect Number (West to East)	–0.047	0.014	0.001***

[a] Two outliers removed prior to analysis.