CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2014

10th Annual Report

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Prepared for
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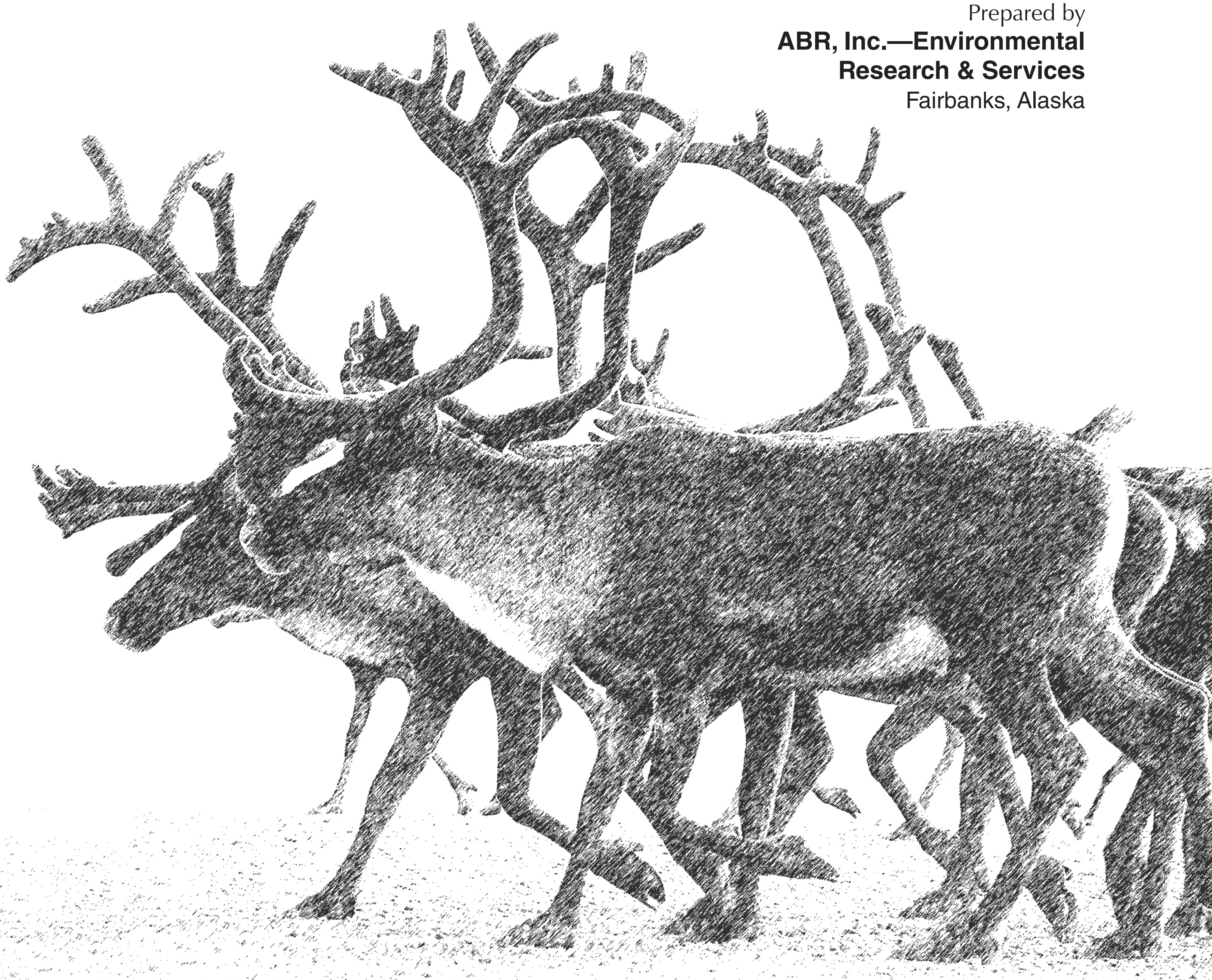

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Prepared for

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EXECUTIVE SUMMARY

- Discoveries of additional oil reserves on the Colville River delta and in the northeastern National Petroleum Reserve–Alaska (NPRA) in the 1990s led to a proposal by ConocoPhillips Alaska, Inc. (CPAI)—the Alpine Satellite Development Program (ASDP)—to expand development from the original Alpine Project facilities on the Colville River delta and into NPRA. The first ASDP facility to be constructed (winter 2004–2005) was the CD4 drill site and access road. The North Slope Borough (NSB) development permit for CD4 stipulated that a 10-year study of the effects of development on caribou distribution and movements be conducted within a 48-km (30-mi) radius of CD4. Although the 48-km radius later was dropped from the permit stipulation, the caribou monitoring study was designed using that distance to delineate the primary study area. The study area also encompasses the CD3 drill site (constructed in winter 2004–2005), the CD5 drill site and access road (constructed in winter 2013–2014), and the proposed GMT1 and GMT2 pads and associated infrastructure.
- This report presents results from the tenth 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 3 adjacent survey areas (NPRA, Colville River Delta, and Colville East) from April to October 2005–2014, 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 1990–2014 for the TH and during 1986–1990 and 2001–2009 for the CAH. GPS-collar data were collected during 2004–2014 for the TH, including 37 collars deployed specifically for this study, and during 2003–2006 and 2008–2014 for the CAH, including 46 collars deployed specifically for this study.
- The Normalized Difference Vegetation Index (NDVI), derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite imagery for the period 2000–2014, 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 vegetative 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). Snow cover (subpixel-scale snow fraction) in spring 2000–2014 also was calculated for the ASDP study area from MODIS satellite imagery.
- Distribution and abundance of caribou in the 3 aerial survey areas varied substantially by season. West of the Colville River, the highest densities of caribou typically occurred in fall; large groups of caribou were present occasionally during the mosquito and oestrid fly seasons, but the occurrence of caribou was highly variable during these seasons. East of the Colville River, the highest densities occurred during the calving and postcalving seasons. The mean proportion of collared TH caribou in the ASDP study area during each month ranged from 6% to 39% for satellite collars during 1990–2014, and from 2% to 45% for GPS collars during 2004–2014. The mean proportion of collared CAH caribou in the study area during each month varied between 12% and 64% for satellite collars during 1986–1990 and 2001–2009, and between 0% and 41% for GPS collars during 2003–2006 and 2008–2014.
- High-density calving occurred east of the Colville River by the CAH (in the southeastern portion of the ASDP study area) and around Teshekpuk Lake by the TH (west of the ASDP study area). In recent years, portions of the TH have calved farther west between Atqasuk and

the Ikpikpuk River. Although some calving occurs in the western half of the ASDP study area, it is not an important calving area for the TH. In 2014, 41 adult caribou (none of which had calves) were observed in the NPRA survey area during the calving survey.

- Analysis of VHF, satellite, and GPS telemetry data demonstrated clearly that the ASDP study area (which includes the Colville River delta) is located at the interface of the annual ranges of the TH and CAH. Although caribou from both herds move onto the delta occasionally (usually during the summer insect season), large movements across the delta are unusual. Movements by collared TH and CAH caribou through the CD4 vicinity have occurred infrequently and sporadically. Two collared caribou (one from each herd) moved through the vicinity of CD4 (within 4 km) in July 2014.

- Spatial analysis of caribou distribution among different geographic sections of the NPRA survey area during 2002–2014 showed that the coastal section received significantly more use by caribou during the mosquito season than would be expected if caribou distribution were uniform throughout the survey area, consistent with use of coastal areas as mosquito-relief habitat. The coastal section received significantly less use by caribou groups during winter, calving, postcalving, late summer, and fall seasons. Riparian areas along Fish and Judy creeks received significantly more use by caribou groups during the postcalving season, oestrid fly season, and late summer. The southeastern section, in which the proposed ASDP pipeline/road corridor would be constructed, received significantly less use by caribou groups in all seasons except winter.

- Although radio-collared TH caribou do cross the proposed ASDP road/pipeline alignment from the new CD5 pad and road to the proposed GMT2 pad location in NPRA occasionally (primarily in July and during fall migration), the data collected thus far demonstrate that the proposed alignment is located in an area of low-density use by caribou. CAH caribou have crossed the proposed alignment only rarely and it is not likely that the proposed pipeline/road corridor would have a large effect on the CAH, judging from their recent movement patterns. 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. Very little evidence was found for selection or avoidance of specific distance zones by TH caribou (only one zone in one season) within 6 km of the proposed ASDP road alignment.

- For the years 2002–2014 combined, caribou in the NPRA survey area avoided flooded tundra (use was significantly less than availability) during calving, postcalving, and fall. Riverine habitats were preferred (use was significantly greater than availability) from postcalving through late summer, but were avoided during winter, spring migration, and calving. Tussock tundra was preferred during calving, but was avoided during mosquito season, oestrid fly season, and late summer. Sedge/grass habitat was preferred during spring migration, calving, and postcalving, but was avoided during the oestrid fly season and late summer.

- Caribou groups in the NPRA survey area tended to select areas with high vegetative biomass (indicated by high NDVI values) during most seasons in 2014. Persistent cloud cover during calving prevented estimation of NDVI_Calving and NDVI_Rate over a large proportion of the survey area. Areas with high NDVI_621 were selected during winter and calving, and areas with high NDVI_Peak were selected during winter.

- 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 best model describing the density of CAH caribou calving in the Colville East survey area in 2014 contained variables for a west-to-east gradient, the proportion of water, the distance to the coast, and the proportion of wet habitat. Based on model-averaged parameter estimates, the density of calving caribou during the calving survey in 2014 increased with distance to the coast and from west to east.

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ACKNOWLEDGMENTS

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ACRONYMS

ABR	ABR, Inc.—Environmental Research & Services
ADFG	Alaska Department of Fish and Game
agl	above ground level
AICc	Akaike's Information Criterion, corrected for small sample sizes
ANWR	Arctic National Wildlife Refuge
ASDP	Alpine Satellite 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
GLM	Generalized Linear Models
GPS	Global Positioning System
IAP	Integrated Activity Plan
IMAPP	International MODIS/AIRS Processing Package
LAADS	Level-1 and Atmospheres Archive and Distribution System
LSCV	least-squares cross-validation
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NDVI_Calving	NDVI value measured during June 1–10
NDVI_Peak	NDVI value measured at peak summer biomass
NDVI_Rate	daily change in NDVI value during June (NDVI_Calving to NDVI_621)
NDVI_621	NDVI value interpolated to June 21 (peak lactation)
NIR	near-infrared reflectance
NPRA	National Petroleum Reserve–Alaska
NQ	Argos System location quality score
NSB	North Slope Borough
QICc	Quasi-likelihood Information Criterion, corrected for small sample sizes
SCF	sightability correction factor
SE	standard error
TAPS	Trans-Alaska Pipeline System
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

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 (refer to Study Area section below for maps), an area that is used at various times of the year by 2 neighboring herds of barren-ground caribou (*Rangifer tarandus granti*)—the Teshekpuk Herd (TH) and the Central Arctic Herd (CAH). The TH generally ranges to the west and the CAH to the east of the Colville River delta (Person et al. 2007; Arthur and Del Vecchio 2009; Parrett 2007, 2011; Wilson et al. 2012; Lawhead et al. 2014a).

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving has typically been located 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 (Kelleyhouse 2001; Carroll et al. 2005; Person et al. 2007; Parrett 2007, 2011, Yokel et al. 2009; Wilson et al. 2012). In 2010, many TH females calved farther west, between Atqasuk and the Itkillik River, outside the area used in most recent years; in the years since 2010, the TH has continued to calve over a larger area than was observed before 2010 (Parrett 2011).

Most TH caribou winter on the coastal plain, generally west of the Colville River, although some caribou occasionally overwinter south of the Brooks Range with the Western Arctic Herd (WAH; Carroll et al. 2005, Person et al. 2007). In recent years, substantial portions of the TH have wintered in areas outside the previous range of the herd, both southeast in the winter range of the CAH since 2004–2005 (Lenart 2009, 2011; Parrett 2011; Lawhead et al. 2014a) and, in a highly unusual movement, far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004, Parrett 2009).

Concentrated calving activity by the CAH tends to occur in 2 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, Lenart 2011, Lawhead et al. 2015). The western segment of the CAH has exhibited localized avoidance of the area within 2–4 km of active roads during and for 2–3 weeks immediately after calving by maternal caribou (Dau and Cameron 1986; Cameron et al. 1992; Lawhead et al. 2004), until the seasonal onset of mosquito harassment. The CAH typically moves to the Beaufort Sea coast during periods of mosquito harassment (White et al. 1975, Dau 1986, Lawhead 1988). In recent years, the majority of the CAH has wintered south of the Brooks Range, generally east of the Trans-Alaska Pipeline/Dalton Highway corridor (Arthur and Del Vecchio 2009, Lenart 2011, Lawhead et al. 2014a).

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. (2014) for the most current listing of other CPAI wildlife studies on the Colville delta. In addition to wildlife surveys, an ecological land survey (ELS) was conducted on the Colville 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 delta and NPRA studies augmented long-term wildlife studies supported by CPAI and its predecessors since the 1980s in the North Slope oilfields on the central Arctic Coastal Plain.

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 radio collars outfitted with very high frequency (VHF) and satellite transmitters and, since 2004, satellite-linked Global Positioning System (GPS) receivers (Philo et al. 1993, Carroll et al. 2005, Person et al. 2007, Parrett 2011, Wilson et al. 2012, Lawhead et al. 2014a). Consultants working for BP Exploration (Alaska), Inc., also conducted aerial transect surveys over much of the TH calving grounds during 1998–2001 (Noel 1999, 2000; Jensen and Noel 2002; Noel and George 2003).

East of the Colville River, ADFG has conducted annual studies of the CAH since the late 1970s using a combination of VHF, satellite, and GPS telemetry, as well as periodic aerial transect surveys (Cameron et al. 1995, 2005; Arthur and Del Vecchio 2009; Lenart 2011). Consultants working for BP Exploration (Alaska), Inc., conducted calving surveys of the CAH in the Milne Point oilfield and part of the Kuparuk oilfield in 1991, 1994, and 1996–2001 (Noel et al. 2004).

The current period of oil and gas leasing and exploration in NPRA closely followed the issuance of the original Integrated Activity Plan and Environmental Impact Statement (IAP/EIS) for the Northeast NPRA Planning Area (BLM and MMS 1998). 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, 2008b). A new planning effort for the entire area of NPRA (Northeast, Northwest, and South planning areas) began in summer 2010 and BLM released the final area-wide IAP/EIS in October 2012 (BLM 2012).

Beginning in winter 2004–2005, the CD4 drill site and access road on the inner Colville River delta were the first of the proposed facilities to be built for the ASDP expansion, followed closely that winter by the CD3 pad and airstrip on the outer delta. The NSB issued development permit NSB 04-117 for the CD4 Project on 30 September 2004, stipulating that a 10-year study of the effects of development on caribou be conducted by a third-party contractor hired by CPAI and approved by the NSB Department of Wildlife Management (ABR, Inc., subsequently was hired and approved). The study area was specified as the area within a 48-km (30-mi) 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 CD5 pad and access road, which were constructed during the winter of 2013–2014; the proposed pads for GMT1 (formerly called CD6) and GMT2 (formerly called CD7); and all associated roads, pipelines, and other infrastructure and activities proposed by CPAI and evaluated in the ASDP EIS (BLM 2004). Other infrastructure added recently within the study area are the Nuiqsut Spur Road, a 9.5-km (5.8-mi) gravel road built by the Kuukpik Corporation in winter 2013–2014 to connect Nuiqsut to the CD5 access road, and the Mustang Project gravel mine, pad, and access road, constructed by Brooks Range Petroleum Corporation just north of the Alpine pipeline corridor in the southwestern Kuparuk oilfield during the winters of 2012–2013 and 2013–2014. Although the Nuiqsut Spur Road and Mustang facilities were not constructed by CPAI, their presence may influence caribou distribution in the ASDP study area, so they were included here for completeness. Another facility recently added by CPAI in the eastern portion of the ASDP study area is the Kuparuk DS-2S pad (formerly called Shark Tooth) and access road, which were constructed during winter 2013–2014 in the southwestern Kuparuk oilfield.

PROGRAM GOALS AND STUDY OBJECTIVES

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

To begin implementing the permit stipulation, representatives of CPAI and ABR 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 the 9 preceding years of study (2005–2013) have been presented and discussed in annual review meetings with the NSB Department of Wildlife Management (9 March 2006, 5 April 2007, 17 March 2008, 14 April 2009, 16 March 2010, 24 March 2011, 9 April 2012, 16 April 2013, 13 March 2014), as well as in Nuiqsut (1 August 2006, 1 May 2007, 20 March 2008, 13 October 2009, 27 February 2013, and 5 November 2014).

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 extensive knowledge of local residents has been, and will continue to be, important for formulating research questions and ensuring that appropriate study methods are used. In addition to discussions between biologists and local residents at meetings in Nuiqsut, local observers (Mark Ahmakak, James Taalak, Doreen Nukapigak, and Gordon Brown) have participated in some aerial surveys over the years.

The CD4 permit stipulation recognizes impacts as falling into 2 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 between them. Information on the potential effects of development on caribou distribution can be collected using a variety of methods, including aerial transect surveys, radio telemetry, and observations by local subsistence users. Information about the potential effects on caribou movements, however, cannot be addressed adequately without employing methods such as radio telemetry that allow regular tracking of individually identifiable animals.

Several broad study tasks were identified in the scope of work:

1) Evaluate the seasonal distribution and movements of caribou in the study area in relation to existing and proposed infrastructure and activities in the study area, using a combination of historical and current data sets from aerial transect and telemetry surveys. Specific questions included the following:
    a. Which herds use the study area and the vicinity of the proposed pipeline/road corridor that will interconnect the ASDP facilities?
    b. How do patterns of seasonal use differ between the 2 herds?
    c. How often do caribou cross the existing CD4 pipeline/road corridor and the proposed ASDP pipeline/road corridor in NPRA, and does this differ between the herds?
2) Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snow melt, seasonal flooding (if possible), and estimated biomass of new vegetative growth in the study area, by applying remote-sensing techniques, for comparison with data on caribou distribution.
3) Evaluate forage availability (above- ground vegetative biomass) and indices of habitat use by caribou in relation to proposed infrastructure, to allow temporal comparisons among years (before and after construction) and spatial comparisons within years. Specific questions included the following:
    a. Do plant biomass and composition vary by habitat type and distance to the proposed road, and how well does remote sensing describe the available biomass?
    b. Can caribou distribution be explained in terms of broad geographic areas, habitat

availability, snow cover, or plant biomass?

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

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

Field sampling of plant biomass (Task 3) was scheduled to occur at least 3 times during the 10-year study; one year of sampling was conducted 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 (use of remote sensing to detect and map caribou trails) 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 satellite 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 8 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 3 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 occurs more commonly at the coast and on the delta than it does farther inland.

Based on the original stipulation of the CD4 permit from the NSB, the study area was specified as the area within a 48-km (30-mi) radius around the CD4 drill site (Figure 1, bottom); that specific radius was later dropped by the NSB, but the study area has been retained for comparative purposes for the monitoring program. Aerial transect surveys were conducted in 3 survey areas, most of which were encompassed by the 48-km radius: the Colville East survey area (1,432–1,938 km², depending on the survey and year); the Colville River Delta survey area (494 km²); and the NPRA survey area (988 km² in 2001, then expanded to 1,310 km² in 2002 and to 1,720 km² in 2005).

The Colville East survey area encompasses the western and southwestern margins of the Kuparuk River Unit, including parts of the existing Kuparuk oilfield infrastructure. The Colville East survey area was expanded 240 km² in 2008 to include 2 transects in the area of the Itkillik River, south of the Colville River Delta survey area. In 2010, however, those 2 transects were dropped after the June surveys because of local concerns about potential disturbance of subsistence hunters and because of the low density of caribou observed in the area.

The Colville River Delta survey area encompasses the original Alpine Development

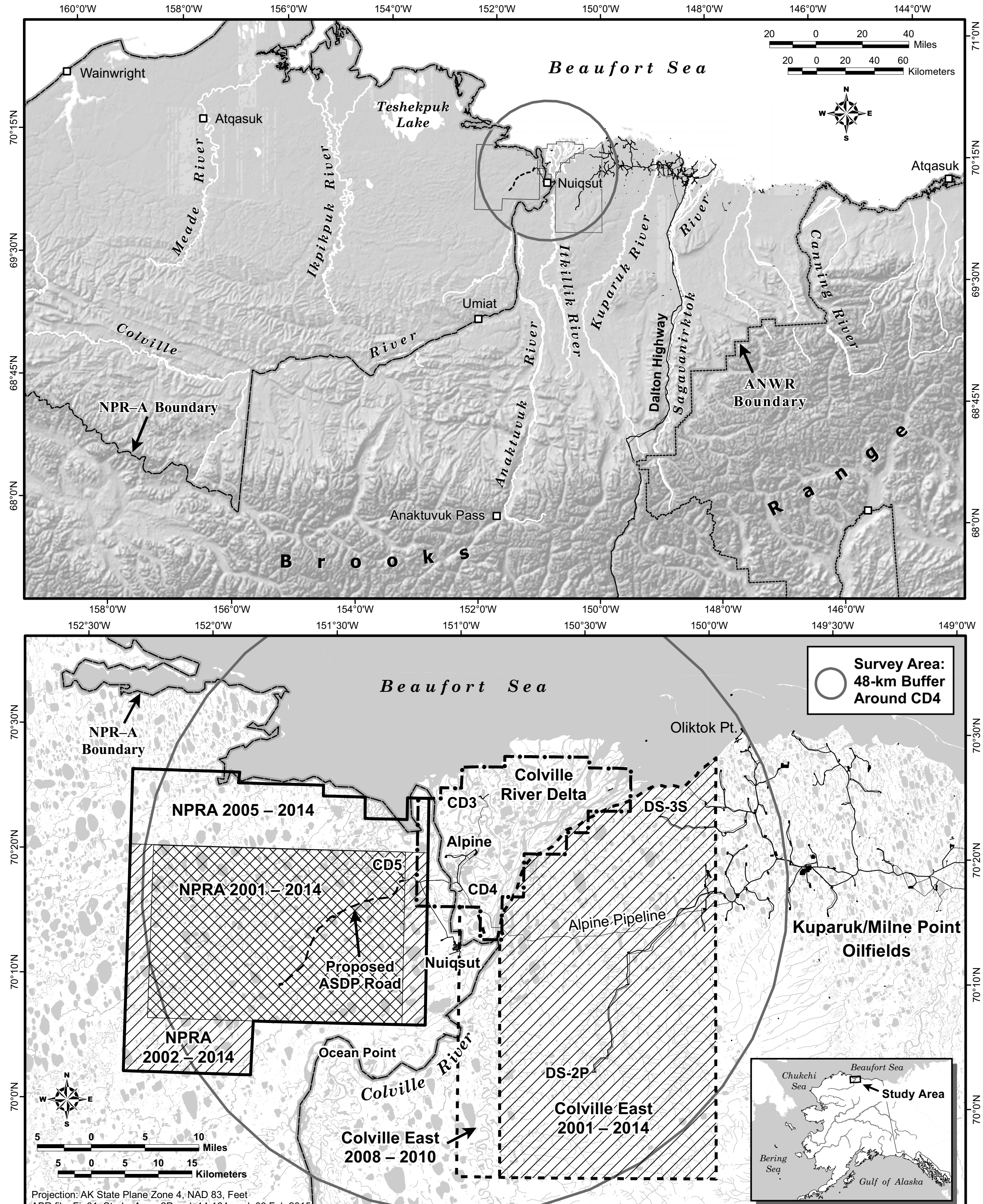

Figure 1. Location of the ASDP caribou monitoring study area on the central North Slope of Alaska (top) and detailed view showing locations of the NPRA, Colville River Delta, and Colville East aerial survey areas, 2001–2014 (bottom).

Project facilities (CD1 and CD2), constructed during 1998–2001, and the newer ASDP drill sites, CD3 (previously called Fiord or CD North) and CD4 (previously called Nanuq or CD South), constructed during 2004–2006. CD3 and CD4 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 one newly constructed drill site (CD5), 2 proposed drill sites (GMT1 and GMT2), and their connecting access roads and pipelines, as well as a potential gravel mine site (called Clover). The CD5 pad (formerly called Alpine West) was constructed during the winter of 2013–2014, whereas the GMT1 (formerly CD6 or Lookout) and GMT2 (formerly CD7 or Spark) drill sites are proposed for future development (BLM 2004, 2014). A new access road was constructed during winter 2013–2014 to connect CD5 to the Alpine Project facilities, requiring the construction of new bridges across the Niġliq (Nechelik) Channel of the Colville River and a nearby distributary channel. Future extensions of the road have been proposed to connect proposed drill sites GMT1 and GMT2 to the CD5 access road. The Nuiqsut Spur Road was constructed by the Kuukpik Corporation in winter 2013–2014 to connect the village of Nuiqsut to the CD5 access road. Although that road is not part of CPAI's ASDP infrastructure, its presence in the ASDP study area warrants its inclusion in this analysis.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, ABR biologists conducted aerial transect surveys in 2014 and analyzed existing radio-telemetry datasets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and from GPS collars deployed specifically for this study annually in 2006–2010 and 2013–2014. Transect surveys were added to the transect database that ABR has compiled for the Colville River Delta and Colville East survey areas since the early 1990s and for the NPRA survey area since 2001. Transect surveys provided broad information on the seasonal distribution and density of caribou in the study area. The radio collars provided detailed location and movement data for a small number of known individuals wherever they moved throughout the year. The telemetry data also provided valuable insight into herd affiliation, which was not available from the transect survey data. Caribou distribution and density were analyzed in relation to an existing habitat map (BLM and Ducks Unlimited 2002) and to estimated values of plant biomass and snow cover from imagery obtained by satellite remote-sensing.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Surveys of the NPRA, Colville River Delta, and Colville East survey areas (Figure 1, bottom) were conducted periodically from April to August 2014 in a Cessna 206 airplane, following the same procedures used since 2001 (Burgess et al. 2002, 2003; Johnson et al. 2004, 2005; Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2014a). The NPRA survey area was expanded westward and southward in 2002 and northward in 2005, and the Colville East survey area was expanded westward from 2008–2010. Additional surveys of Colville East were conducted during the calving season in 2001–2014 (Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012; Lawhead et al. 2013b, 2014b, 2015). Two observers looked out opposite sides of the airplane during all surveys and a third observer 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 in the Colville East survey area during the calving surveys to increase detection of caribou in areas of patchy snow cover in that season, and occasionally in other seasons and areas 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 airplane 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. Therefore, the number of caribou observed in the transect strips was doubled 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 4 100-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. Confidence intervals for estimates of total caribou and calves were calculated with a standard error formula modified from Gasaway et al. (1986), using transects as the sample units except that 3.2-km transect segments were used as the sample unit for Colville East calving surveys (Lawhead et al. 2015).

Observations of other large mammals were recorded during field surveys (both aerial and ground-based) for this and other wildlife studies conducted in 2014 for CPAI. These observations are summarized in this report but are described in more detail by Lawhead et al. (2015).

RADIO TELEMETRY

VHF Collars

Location data were provided by ADFG for all VHF collars in the CAH and TH during the years 1980–2005. Sample sizes varied between herds and among years (Table 1). Radio-tracking surveys for collared caribou ranged over much of northern Alaska, but data on the specific areas covered on each flight were not available except in summer 2005, when CPAI contracted with 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

Table 1. Number of radio-collars deployed on TH and CAH caribou that provided movement data for the ASDP caribou study. Some individuals were recollared in subsequent years.

Herd and Telemetry Sample	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd [a]				
VHF collars [b]	1980–2005	n/a	n/a	212
Satellite collars	1990–2014	94	65	159
GPS collars	2004–2014	145	1	146
Central Arctic Herd [a]				
VHF collars [b]	1980–2005	n/a	n/a	412
Satellite collars, early	1986–1990	16	1	17
Satellite collars, later	2001–2003	10	3	13
GPS collars [c]	2003–2006	45	0	45
GPS collars	2008–2014	51	0	51

[a] Herd affiliation at time of capture.
[b] n/a = not available, but most collared animals were females.
[c] Number of different collared animals located within 48 km (30 mi) of CD4 at least once during the period.

observed. On some surveys, however, visual confirmation was impossible because the aircraft was forced to remain above cloud cover, resulting in much lower location accuracy. The sex, age, and reproductive status of collared animals were not available for this analysis, but most were adult females (Cameron et al. 1995, Arthur and Del Vecchio 2009). Location error was estimated to be 0.5–1 km (S. Arthur, ADFG, pers. comm.), although the error appeared to be greater for some locations.

Satellite Collars

Satellite telemetry used the Argos system (operated by CLS America, Inc.; CLS 2008), in which location data from satellite-collar transmitters were received by polar-orbiting satellites and transmitted through command and acquisition stations to data-processing centers, operated originally by Service Argos and later by CLS. TH collar locations were transferred monthly to the NSB for data archiving. In 1990–1991, the TH satellite transmitters were programmed to transmit 6 h/day for a month after deployment, then 6 h every 2 days for 11 months. During 1991–2002, most collars were programmed to transmit every other day throughout the year. After 2002, many collars were programmed to transmit once every 6 days in winter and every other day during summer. Most of the TH collars deployed in 2000 malfunctioned and transmitted data only sporadically. The CAH satellite collars deployed during 1986–1990 were programmed to operate 6 h/day or 6 h every 2 days, providing 3–4 locations per day for most collars with a mean location error of 0.48–0.76 km (Fancy et al. 1992).

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–November 2014 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2014a, this study; Person et al. 2007) 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 (based on herd affiliation at capture), 159 collars deployed on 141 different caribou (83 females, 58 males) transmitted signals for a mean duration of 564 days per caribou (16 of these caribou were outfitted sequentially with 2 different satellite collars and one had 3 different satellite collars). For the CAH, the 1986–1990 sample included 17 caribou (16 females, 1 male) and the 2001–2003 deployment sample included 13 collars deployed on 12 caribou (10 females, 2 males), transmitting for a mean duration of 623 days.

Although satellite telemetry locations are considered accurate to within 0.5–1 km of the true locations (CLS 2008), the data also require screening to remove spurious locations. Using the method of Person et al. (2007), data were screened to remove duplicate locations, locations obtained before and after collaring or after mortality occurred, and locations for which the Argos system location-quality score (NQ) was zero or “B,” indicating unreliability (CLS 2008). NQ scores of “A” tend to be more accurate than scores of zero (Hays et al. 2001, Vincent et al. 2002), so they were retained. Spurious locations were removed if they were far offshore or far outside the herd range. A distance–rate–angle (DRA) filter, based on the distance and rate of travel between subsequent points and the angle formed by 3 consecutive points, was used to remove other inaccurate locations. Any 3 locations with an intervening angle of <20 degrees and both “legs” with speeds greater than 95% of caribou movements, based on an equation relating maximum speed of travel to the duration between locations developed from TH caribou outfitted with GPS collars (Prichard et al. 2014), were assumed to be inaccurate and were removed, unless the distance of either leg was less than 1 km (Person et al. 2007). If the distance of any leg was <1 km, then the location was not removed because it was close to a previous or subsequent location and therefore more likely to be accurate.

In analysis of animal movements, autocorrelation of locations that are collected close together in time may introduce bias due to lack of independence among location fixes (Schoener 1981, Swihart and Slade 1985, Solow 1989). Due to the highly directional movements of caribou during much of the year, movement data often do not meet the requirement of statistical independence for home-range analysis without removal of large numbers of data points (McNay et al. 1994). If too many data points are removed, however, biologically important information can be lost (Reynolds and Laundré 1990, McNay et al.

1994). To achieve operational independence of data points, it has been suggested that the time between successive samples should approximate the time necessary to travel anywhere else in a home range or seasonal range (Lair 1987, McNay et al. 1994). In addition, systematic sampling of locations over a given time period can remove bias due to autocorrelated data (White and Garrott 1990). Hence, for synoptic analyses of satellite-telemetry data, a subset of locations was selected, using one location from each day. Because caribou are capable of rapid movement, one location per day was considered to be infrequent enough to provide adequate independence between locations, while still maintaining biologically important information. The CAH data set for October 1986–July 1990 (provided by D. B. Griffith, USGS) was screened to select the first location each day with the highest NQ score.

GPS Collars

A total of 89 different TH caribou (88 females, 1 male) were outfitted with GPS collars (purchased by BLM, NSB, or CPAI and deployed by ADFG) during 2004 and 2006–2014. Some animals were collared more than once, for a total of 146 different collar deployments (Table 1). Ten caribou were collared in 2004, 12 were collared in 2006, 12 were collared in 2007, 27 were collared in 2008, 21 were collared in 2009, 14 were collared in 2010 (including one male), 9 were collared in 2011, 17 were collared in 2012, 13 were collared in 2013, and 11 were collared in 2014.

The TH collars deployed in 2004 were programmed to record GPS fixes every 3 h (8 locations daily) throughout the entire year. The GPS collars deployed on TH animals in 2006–2009 and on CAH animals in 2008–2010 were programmed to record fixes at 2-h intervals (12 locations daily) throughout the year. The duty cycle was reduced during the winter for GPS collars deployed in 2009 and 2010 and on CAH animals in 2013–2014 to allow a 2-year deployment period, rather than single-year deployments used previously for this study. These collars still recorded locations at 2-h intervals during the summer, but were programmed to record just 3 locations per day in the winter (15 November–15 April). Additional details on collar deployment are given in Lawhead et al. (2013a).

A total of 43 different female CAH caribou were successfully outfitted with GPS collars (purchased by CPAI) during 2008–2014. Some animals were collared more than once, for a total of 46 different collar deployments: 4 in July 2008, 5 in June 2009 (an additional caribou died soon after capture and an additional transmitter failed), 12 in June 2010, 12 in March 2013, 12 in April 2014, and one in June 2014 (Table 1). Another 45 GPS collars had been deployed on CAH females by ADFG during 2003–2006, using an interval of 5 h between location fixes (Arthur and Del Vecchio 2009). Data from 4 GPS collars deployed on CAH caribou in March 2012 and a TH caribou collared in 2013 that switched to the CAH also were available for analysis.

GPS collars were deployed on female caribou, with the exception of one collar deployed on a TH male by mistake. Females are preferred for GPS collar deployment because the models used (TGW-3680 GEN-III or TGW-4680 GEN-IV store-on-board configurations with Argos satellite uplink, manufactured by Telonics, Inc., Mesa, AZ) are subject to antenna problems when mounted on the expandable collars that are required for male caribou, due to increased neck size during the rutting season (Dick et al. 2013; C. Reindel, Telonics, pers. comm.). Caribou were captured by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter. In keeping with ADFG procedures for the region, no immobilizing drugs were used.

Data reports from Argos satellite uplinks were downloaded weekly from CLS America, Inc. (Largo, MD). All location data were also stored in the collars for downloading after the collars were retrieved. Those downloaded data replaced the location data obtained via the Argos satellite uplinks 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.

All location data within the 48-km study area radius of CD4 were provided by ADFG for the CAH caribou outfitted by ADFG with GPS collars during 2003–2006. The annual GPS-collar sample size (which included some of the same individuals among years) were 24, 24, 33, and 29 females in 2003, 2004, 2005, and 2006, respectively, of which 19, 18, 19, and 20 animals respectively, were recorded at least once within the 48-km radius. Forty-five different individuals were located in the study area at least once during those 4 years (Table 1). Most of those locations were obtained at 5-h intervals, but occasionally 2 locations were recorded over shorter time periods. In such cases, one of the locations obviously appeared to be wrong, so each of the cases was plotted individually for removal of the location that appeared to be inaccurate based on previous and subsequent locations. The duration between consecutive locations was calculated for every point.

Kernel Density Analysis

Eight seasons were used for kernel density analysis of telemetry data locations (and other seasonal analyses), based on mean movement rates and observed timing of caribou life-history events (adapted from Russell et al. 1993 and Person et al. 2007). The 8 seasons were winter (1 December–30 April); spring migration (1 April–29 May); calving (30 May–15 June); postcalving (16–24 June); mosquito harassment (25 June–15 July); oestrid fly harassment (16 July–7 August; this period also includes some mosquito harassment); late summer (8 August–15 September); and fall migration and rut (16 September–30 November).

To calculate seasonal kernels for 7 of the 8 seasons, a subset of locations was selected, consisting of one location per week for each collared animal; the locations in this subset were infrequent enough to provide adequate independence between locations while still maintaining biologically important information on seasonal distribution. For the eighth season (winter), one location per month was selected because caribou exhibit low movement rates in that season (Person et al. 2007, Prichard et al. 2014). This smaller dataset minimized the impact of pseudoreplication and variable impact of collars with more frequent fixes, while still retaining information on changes in distribution during the season.

For each season and time period, fixed-kernel density estimation was employed to create utilization distribution contours of caribou distribution. Least-squares cross-validation (LSCV) was used to calculate the bandwidth of the smoothing parameter. Because caribou are sexually segregated during some seasons, kernels were analyzed separately for females and males, although the sample size for male CAH caribou was insufficient to allow kernel density analysis. Analyses were conducted with Geospatial Modelling Environment (Beyer 2012), which uses Program *R* (*R* Core Team 2013) for some commands.

Seasonal Occurrence in the Study Area

Seasonal use of the ASDP study area was evaluated using 3 methods. The first method was to calculate the percentages of active caribou collars from each herd that were present at least once each month during the period 2004–2014 for the TH and 2003–2006 and 2008–2014 for the CAH. Active collars were defined as satellite-collared animals with at least 5 active duty-cycles per month and GPS-collared animals with at least 10 days of locations in each month. Males and females were lumped together for this analysis. The second method was to evaluate the proportion of each seasonal utilization distribution from kernel density estimation within the ASDP study area, by sex and herd, after first removing the portion of each seasonal utilization distribution contour that overlapped the ocean. The third method was to examine screened GPS and satellite collar data for caribou movements in the immediate vicinity of CD4 (within a 4-km radius) and for crossings of the proposed ASDP road alignment.

REMOTE SENSING

At least one satellite image over the study area was acquired daily during 20:00–24:00 UT (12:00–16:00 local time) starting in February 2000 (except for some brief outages due to satellite malfunction, the longest of which was 15 June–2 July 2001). For dates between 1 April and 30 September in each year, 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);
- MYD02QKM (MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 250 m);
- MOD02HKM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath 500 m);
- MYD02HKM (MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 500 m);
- MOD021KM (MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1 km);
- MYD021KM (MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 1 km);
- MOD03 (MODIS/Terra Geolocation Fields 5-Min L1A Swath 1 km);
- MYD03 (MODIS/Aqua Geolocation Fields 5-Min L1A Swath 1 km);
- MOD35_L2 (MODIS/Terra L2 Cloud Mask and Spectral Test Results); and
- MYD35_L2 (MODIS/Aqua L2 Cloud Mask and Spectral Test Results).

ATMOSPHERIC CORRECTION

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

CREFL performs a simple atmospheric correction of visible, near-infrared, and short-wave infrared bands (MODIS bands 1–16), correcting for Rayleigh scattering and gaseous absorption by water vapor and ozone using climatological values. The CREFL "corrected reflectance" algorithm does not use real-time atmospheric inputs and does not correct for atmospheric aerosols. MODIS Land Surface Reflectance (MOD09_L2 and MYD09_L2) granules are available that incorporate real-time climatological inputs, correct for aerosol absorption, and clarify ("destripe") data from some noisy detectors. While the surface reflectance algorithms may provide slightly more robust results for vegetation-index calculations, the CREFL product was used to provide continuity with the complete 2000–2014 record compiled over the course of this study.

CLOUD MASKING

Clouds are common in the ASDP study area. Thick clouds prevent the observation of ground conditions by optical remote-sensing instruments such as MODIS. Thin clouds and cloud shadows may allow visual interpretation of the ground conditions, but can cause spectral algorithms to produce spurious results. Therefore, exclusion of areas obscured by clouds is a requirement for efficient analysis of satellite-derived time-series data. Because the standard (MOD35_L2/MYD35_L2) cloud mask frequently misidentified areas with patchy snow and ice as cloud, a refined cloud mask for the MODIS Terra data was used (Lawhead et al. 2014a). The improved mask incorporated snow cover history to reduce false cloud detection during the active snowmelt season.

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]). These effects were minimized 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 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 cover for late spring and early summer was estimated using the fractional snow algorithm of Salomonson and Appel (2004). Only MODIS Terra data were used for snow mapping because MODIS Band 6, used in the estimation of snow cover, is not functional on the MODIS Aqua sensor. Details of the daily snow fraction calculation were described by Lawhead et al. (2014a).

A time-series of images covering April–September was analyzed for each year during 2000–2014 to identify the first date with 50% or lower snow cover for each pixel in each year. The closest prior date with >50% snow cover was then identified for each pixel. An unbiased estimate of the snow-melt date (the first date with <50% snow cover) was calculated as the midpoint between the last observed date with >50% snow cover and the first observed date with <50% snow cover. The duration between the dates of the 2 satellite images with the last observed "snow" date and the first observed "melted" date provided information on the uncertainty in the estimate of snow-melt date. For example, if snow was present in a pixel on 20 May, followed by several weeks with persistent cloud cover, followed by an observation that snow was absent on 17 June, the estimated snow-melt date was 3 June and the uncertainty in the snow-melt date estimate was 28 days. Pixels with >50% water (or ice) cover were excluded from the analysis (see next section for details).

VEGETATIVE BIOMASS

The Normalized Difference Vegetation Index (NDVI; Rouse et al. 1973) is used to estimate the biomass of green vegetation within a pixel of satellite imagery at the time of image acquisition. The rate of increase in NDVI between 2 images acquired on different days during green-up has been hypothesized to represent the amount of new growth occurring during that time interval (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index. html):

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

where:

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

VIS = visible light reflectance (wavelength 0.62–0.67 µm for MODIS).

Occasionally, spurious high values of NDVI were observed in deep cloud shadows over vegetated land surfaces; therefore, NDVI was set to zero for very dark pixels (MODIS Band-1 reflectance <0.025). Such dark pixels occurred only in shadows and clear water. NDVI values for each year during 2000–2014 were calculated using constrained view-angle (sensor zenith angle ≤40°) maximum-value composites derived from corrected reflectance MODIS imagery acquired from the calving period (1–10 June; NDVI_Calving), at the presumed peak of lactation for parturient females (21 June; NDVI_621; Griffith et al. 2002), and at the peak of the growing season (generally late July or early August; NDVI_Peak). For each composite period, the maximum NDVI with no clouds and a sensor view-angle of 40 degrees or lower was selected.

Starting in 2013, data from both the Terra and Aqua satellites were used to generate NDVI composites. The satellites acquire data at slightly different times and viewing angles, so combining the data improves the ability to capture the ground surface with an appropriate sensor view-angle. The Aqua data were not used to characterize snow cover because one of the bands used for snow-cover mapping is not functional on the Aqua MODIS sensor.

NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) for each year 2000–2014 (adequate cloud-free data were not available to calculate NDVI_Calving over the entire study area in some years). NDVI values near peak lactation (NDVI_621) were interpolated based on the linear change from 2 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 2000–2014.

The presence of snow, ice, and waterbodies depress NDVI values and decouple them from their relationship to vegetation properties (Macander 2005). Therefore, pixels with 50% or more water cover were excluded to remove the effect of large waterbodies. The water mask, at 240-m resolution, was based on an analysis of 3 Landsat images from 2008; details were described by Lawhead et al. (2014a).

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. Group locations and density were compared among different distance zones around the proposed ASDP road alignment, extending west from the Colville River delta into NPRA, to characterize the preconstruction baseline level of use of the area by caribou. Because the distribution of caribou is influenced by different factors during different seasons, the aerial-transect survey data were grouped into the same 8 seasons that were used in the kernel density analysis.

GEOGRAPHIC LOCATION

Visual inspection of the distribution of caribou observed during aerial surveys in previous years suggested differing levels of caribou use across the NPRA survey area, so tests were conducted to evaluate distributional differences among geographic sections of the area. The 2002–2004 and 2005–2014 survey areas, which differed in size, were divided into 5 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 section); (3) the area north of Fish and Judy creeks (North section); (4) the western half of the area south and west of Fish and Judy creeks (Southwest section); and (5) the eastern half of the area south of Fish and Judy creeks (Southeast section), in which nearly the entire proposed ASDP road would be constructed.

A chi-square goodness-of-fit test was used to evaluate whether the number of caribou groups in each section differed significantly among seasons and years from "expected" values calculated from use–availability analysis (Neu et al. 1974, Byers et al. 1984), which tests for departures from a uniform distribution among sections. If significant differences were found, individual sections then were compared using Bonferroni multiple-comparison tests.

DISTANCE TO PROPOSED ROAD

The locations of caribou groups recorded on aerial transect surveys in the NPRA survey area since 2001 constitute the baseline data set on caribou density for the area in which the proposed ASDP road may be constructed. Thus, these data are a primary source of information regarding caribou distribution in relation to natural factors in the road corridor. The current version of the proposed road alignment was provided to ABR in 2009 (Lawhead et al. 2010), so the analytical results since then differ somewhat from those reported before 2009, which were based on an earlier proposed alignment. The analysis in this report used the most current version of the road alignment but, because of the construction of the CD5 access road and the Nuiqsut Spur Road during the winter of 2013–2014, the areas of the distance-to-road zones changed after 2013. The area within 4 km of these two new roads was excluded from further characterization of baseline caribou density because both roads were subject to construction and some other traffic activity in 2014. Comparison of caribou densities in this area before and after construction will be possible in the future after additional surveys are flown, but the 2014 sample size was too small to permit analysis this year.

The number of groups and the density of caribou by year and by season were calculated within 5 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 pads (Alpine pads CD1, CD2, CD3, CD4, CD5, and Nuiqsut) and connecting access roads were removed to minimize the potential influence of current traffic on the baseline characterization. The number of groups and the caribou density in each zone were calculated for each combination of year and season, and a chi-square goodness-of-fit test was used to determine if the observed number of groups in

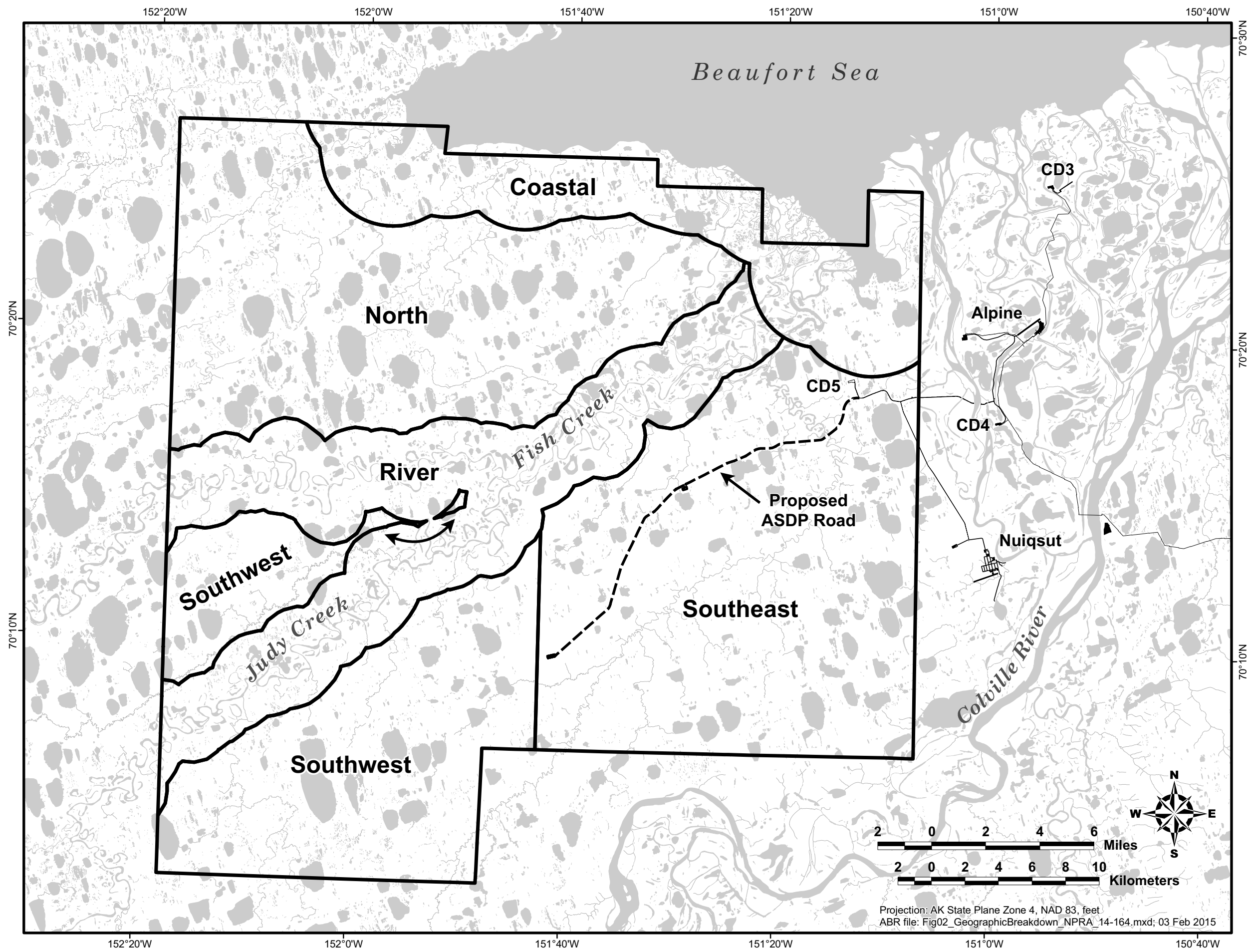

Figure 2. Location of geographic sections used for spatial analysis of caribou distribution in the NPRA survey area, 2002–2014.

each category differed significantly from expected values, which were calculated assuming a uniform distribution (Neu et al. 1974, Byers et al. 1984). If significant differences were found, individual distance categories were compared using Bonferroni multiple-comparison tests.

A Generalized Estimating Equation (GEE) analysis (SPSS version 18.0 software, SPSS, Inc., Chicago, IL), employing a negative binomial distribution and a log link, was used to test for annual differences in the numbers of caribou among the different distance zones, with each survey as an independent subject, distance zone as a within-subject effect, season as a between-subject effect, and the natural logarithm of the area surveyed as the offset term. This offset term adjusts for differences in area among zones. The natural-log transformation of area was used to match the log link in the analysis.

An autoregressive-1 working correlation matrix was used to model dependencies among distance zones during surveys. Simple contrasts with a Sidak correction for multiple comparisons were used to evaluate whether density in any of the 2–4-km or 4–6-km zones differed significantly from the 0–2-km zone containing the proposed road alignment and to test for significant differences among seasons. The single survey in the 2005 oestrid fly season was removed from this analysis to eliminate the undue influence on the test results that would have resulted from the large groups observed on that single survey. The mosquito and oestrid fly seasons were combined because the model failed to converge when the mosquito season was included separately, probably because of the low numbers of caribou observed in that season. No aerial surveys have been flown in the mosquito season since 2007 because of the inefficiency of that survey method when large numbers of caribou aggregate and move rapidly in response to varying weather conditions and insect activity levels.

HABITAT USE

To compare habitat use with availability in the NPRA survey area, the caribou group locations from transect surveys were overlaid 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)—was developed to classify habitats for birds as well as mammals and did not cover the entire NPRA aerial survey area. Hence, the NPRA earth-cover classification (30-m pixel size) was selected over the ELS map for this habitat analysis because it covered the entire NPRA survey area, had fewer cover classes than did the ELS classification, and the classification system appeared to better reflect habitat characteristics important to caribou.

The NPRA survey area contained 15 cover classes from the NPRA earth-cover classification (Appendix A), which were lumped further into 10 types to analyze habitat use. The barren ground/other, dunes/dry sand, and sparsely vegetated classes, which mostly occurred along Fish and Judy creeks, were combined into a single riverine habitat type. The 2 flooded-tundra classes were combined as flooded tundra and the clear-water, turbid-water, and *Arctophila fulva* classes were combined into a single water type; these largely aquatic types are used very little by caribou, so the water type was excluded from the analysis of habitat preference.

Use of habitat types by caribou was calculated by selecting all map pixels within a 100-m radius of the location coordinates for each caribou group, which adjusted the percentage to reflect the estimated accuracy of the coordinates. Caribou groups located in waterbodies were moved to the nearest shoreline. The percentage of each habitat type (excluding water) within the selected pixels was calculated; 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 2005–2014 NPRA survey area using *ArcGIS* 9.3 software (Environmental Systems Research Institute, Inc. [ESRI], Redlands, CA). A 100-m-radius buffer was created around each random location and the proportion of each habitat type was calculated. Random locations for which more than 50% of the buffer area was water were removed from the analysis, leaving totals of 25,339 random locations in the 2005–2014 survey area (12,475 in the winter 2008 survey area because it could not be surveyed completely) and 19,470 locations in the 2002–2004 survey area. For each period of interest, a number of locations equal to the number of caribou groups observed was selected from the appropriate survey area (randomly and with replacement). From that subset of random locations, the mean proportion of each habitat type was calculated. 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 the observed proportion was considered to be significantly different from random at $P = 0.05$ or $P = 0.01$, respectively. Habitat preference was defined as significantly greater use than availability and habitat avoidance was defined as significantly less use than availability.

SNOW COVER

Snow cover at the beginning of the calving season was estimated from 2 MODIS scenes, acquired on 4 June and 3 June 2014. The 4 June data were used to estimate snow cover, except that when cloud cover was present on the 4 June image, data from 3 June were used. The value of snow cover (%) for 3–4 June was estimated for each caribou group location (excluding caribou groups located in pixels with >50% water). The estimated snow-cover percentages for 3–4 June at caribou group locations were compared to all locations available within the study area by comparing the

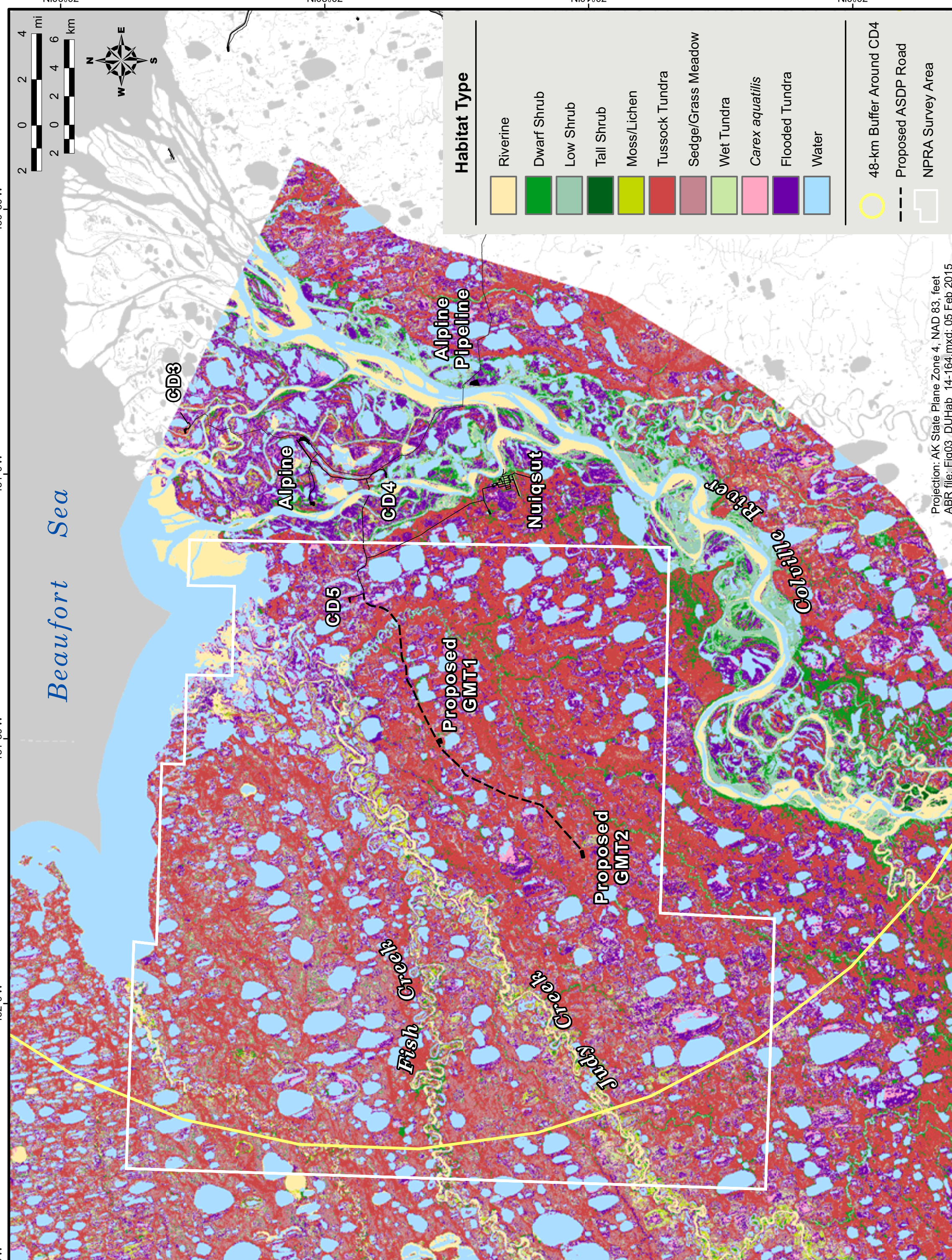

Figure 3. Habitat types used for caribou habitat-selection analyses in the NPRA survey area, 2002–2014.

snow cover used by caribou to the snow cover at random locations. For each simulation, random locations were selected within the survey area (excluding pixels with >50% water) equal to the number of locations used by caribou groups for a given season. The mean snow cover of the random locations was calculated and recorded and a new sample was generated in the same manner. This process was repeated 5,000 times to generate values of mean snow cover. These 5,000 mean values were compared with the actual locations used by caribou. If the mean snow-cover value of all pixels used by caribou 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. Preference was defined as significantly greater use than availability and habitat avoidance was defined as significantly less use than availability.

VEGETATIVE BIOMASS

Caribou group locations in the NPRA survey area in 2014 were compared with estimated vegetative biomass (NDVI values). Two of the variables (NDVI_Calving and NDVI_Rate) could not be estimated for portions of the study area in 2014 due to persistent cloud cover during 1–10 June 2014. The values of the variables NDVI_Calving, NDVI_Rate, NDVI_621, and NDVI_Peak were determined for each caribou group location (excluding pixels with >50% water and missing values) and those values were compared with availability using comparisons with random locations. For each season, a number of NDVI values equal to the number of caribou groups observed in a given season were selected (randomly and with replacement) from all pixels at random locations within the study area. The mean of the random locations was calculated and a new sample was generated in the same manner; this process was repeated 5,000 times to generate mean values. The resulting 5,000 mean values were compared with the availability of NDVI values in the survey area. If the mean NDVI value of pixels used by caribou groups 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. Preference was defined as significantly greater use than availability and habitat avoidance was defined as significantly less use than availability.

CARIBOU DENSITY ANALYSIS

NPRA Survey Area

Density analysis was focused on the NPRA survey area to better understand the factors affecting baseline levels of use by caribou before the potential construction of the proposed ASDP road. 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 2005–2014 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).

To summarize caribou distribution and abundance data in the NPRA survey area, the inverse distance-weighted (IDW) interpolation technique of the *3D Analyst* extension of *ArcMap* software (ESRI, Redlands, CA) was used on a geographical information system (GIS) platform to map caribou densities over all years (2002–2014). This analysis used the total numbers of caribou in each of the 164 grid cells in the transect strips; mean values were calculated for each grid cell over all years and were assigned to the grid-cell centroids. Densities were calculated by dividing the total number of caribou observed on each survey by the land area in the grid cell. The IDW interpolation technique calculated a density surface as the distance-weighted density of the 14 nearest centroids for each 200-m grid cell in the study area (power = 1). This analysis produced color maps showing surface models of the estimated density of all caribou (large caribou plus calves) observed over the entire survey area.

Statistical evaluation of factors potentially related to caribou density within each cell incorporated the caribou numbers from each survey, mean NDVI values from 2014, the proportion of tussock-tundra habitat (as a proportion of land area), the 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 3–4 June 2014, transect number (as a measure of a west-to-east density gradient; Lawhead et al. 2006), presence or absence of Fish or Judy creeks, and presence or absence of the proposed ASDP road corridor. In

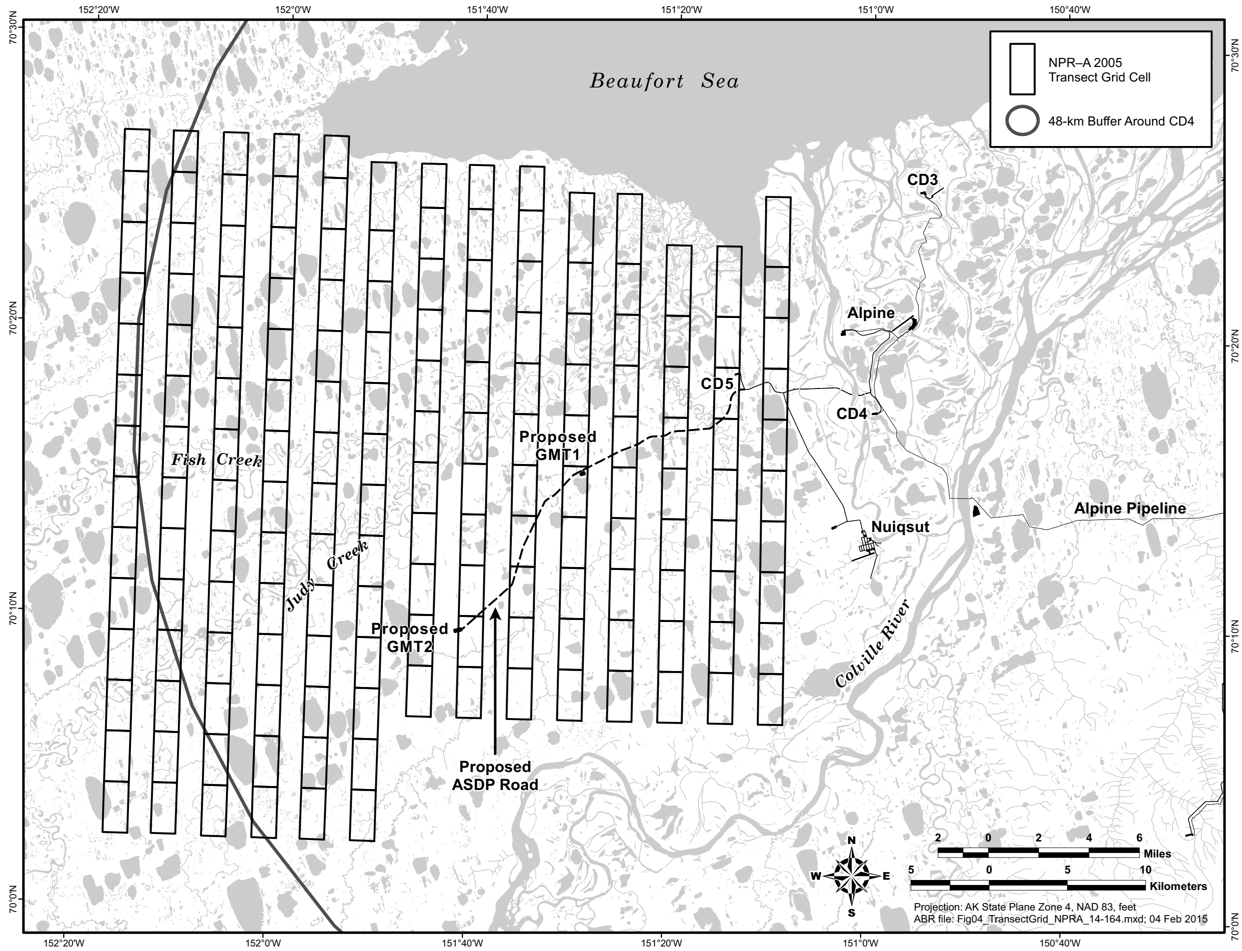

Figure 4. Locations of transect grid-cells used to analyze caribou density in the NPRA survey area, 2005–2014.

the 2013 and 2014 analyses, a model with the 5 geographic sections (Coastal, North, River, Southwest, and Southeast) used in previous analyses was added as an independent variable.

The spatial pattern of NDVI_Peak is highly correlated across years so the value of NDVI_Peak from 2014 was used in multi-year analyses. Various models for density in each season were tested for the combined data for the years 2002–2014; data from 2001 were not included in this analysis because the NPRA survey area that year was smaller than in subsequent years. A GEE analysis (SPSS version 18.0 software, SPSS Inc., Chicago, IL) using a negative binomial distribution and a log link, was used to test for differences in the number of caribou among the different grid cells. In this analysis, each survey was treated as independent; various combinations of NDVI_Peak, 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 a Maximum Likelihood Estimate of the negative binomial ancillary parameter and used the mean estimate in all models to facilitate model selection. Independent variables with Pearson correlation coefficients >0.5 were not included in the same model. One grid cell located on the outer Colville River delta was removed because it was mostly barren ground and thus was an outlier in most analyses, leaving a total of 163 grid cells in the analysis.

An information–theoretic approach (Anderson et al. 2000, Burnham and Anderson 2002) was used to compare a predetermined set of candidate models with different combinations of independent variables. Quasi-likelihood Information Criteria (with the adjustment for small sample size; QICc) were calculated and the Akaike weights were used to estimate the relative probability of each model being the most parsimonious model in the candidate set. The model-averaged parameter estimates and standard errors (SE) then were computed by calculating the mean of the estimated parameter values for each model containing the variable of interest, while weighting the average by the Akaike weight (Burnham and Anderson 2002). These model-averaged parameter estimates and standard errors are preferred over model-specific parameters because they incorporate estimates from all possible models and take into account the uncertainty in choosing the best model. Therefore, it is not necessary to base results on a single "best" model (Burnham and Anderson 2002).

Seventeen candidate models were used for seasonal tests over all years (2002–2014) combined. All models contained survey ID (categorical variable accounting for different survey densities), presence or absence of Fish or Judy creeks, and the presence or absence of the proposed road. The models also contained all combinations of the variables distance to coast, NDVI_Peak, proportion of tussock tundra, proportion of wet habitat, and transect number (west-to-east gradient). An additional model included the 5 geographic sections as a potential alternative explanation of caribou distribution. Surveys on which fewer than 10 caribou were observed were dropped from the analysis because they provided little information of statistical value regarding caribou distribution. Two grid cells containing large groups of caribou during the oestrid fly season (one in 2002 and one in 2009) were dropped for that season because they were outliers that prevented some models from converging. In addition, one survey during the oestrid fly season in 2005 was dropped because nearly all caribou seen on that survey were in large groups (1,670–2,400 animals) in only 4 grid cells, and the road variable was dropped from the oestrid fly season analysis because the standard errors of some parameters could not be accurately estimated with road in the model.

Colville East Survey Area during Calving

Because of the high levels of use of the Colville East survey area by CAH caribou during the calving season in the last 2 decades (Lawhead et al. 2015), a similar analysis to that described above was used to model factors related to calving distribution in this survey area during the aerial survey on 9–10 June 2014. Survey transects were divided into 552 1.6-km-long segments (3 other segments were completely covered by water, so were eliminated from the analysis). Calculations for each segment included the total number of caribou observed, proportion of area covered by waterbodies, minimum distance to the coast, presence of an existing road within 2 km, mean NDVI_Peak in 2014, proportion of wet graminoid tundra (Muller et al. 1999) in the area, and snow cover on 4 June 2014. This analysis employed Generalized Linear Models (GLM) using a Poisson distribution with a log link, testing 31 candidate models containing all possible combinations of 5 variables (within 2 km of roads, NDVI_Peak, distance to coast, snow cover, and proportion of wet graminoid tundra). The proportions of the grid cells covered by waterbodies and transect number (west-to-east gradient) were included in all models. The waterbody variable was included to adjust for large differences in the amount of land area among transect segments and the transect number was included to account for the expected gradient in calving density across the study area (Person et al. 2007). Candidate models were compared using Akaike's Information Criterion corrected for small sample sizes (AICc) and model-averaged parameter estimates were calculated in the same manner as for the NPRA surveys.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

Weather conditions can exert strong effects on caribou population dynamics. Deep winter snow and icing events increase the difficulty of travel, decrease forage availability, and increase susceptibility to predation (Fancy and White 1985, Griffith et al. 2002). Severe cold and wind events also can cause direct mortality of caribou (Dau 2005). Late snow melt can delay spring migration, cause lower calf survival, and decrease future reproductive success (Finstad and Prichard 2000, Griffith et al. 2002, Carroll et al. 2005). 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).

The timing of snow melt in spring and the severity of insect harassment in midsummer varied considerably during the last 14 years in which aerial surveys were conducted in the ASDP study area. The timing of snow melt was delayed in 2001, early in 2002, about average in 2003–2008 and 2014, early in 2009, and generally delayed in 2010–2013 (Lawhead et al. 2015). At the Kuparuk airstrip, snow depth was above average in early April 2014, but was reported as 0 cm on 15 and 31 May (Appendix B). Nearby weather stations reported snow until 31 May, however, and patchy snow was present in the study area during the calving surveys in June. Therefore, if accurate, the snow levels reported at the airstrip were not representative of the entire study area. Patchy snow cover remained in all survey areas during the early calving survey (4–5 June) and in portions of the Colville East survey area during the late calving survey (9–10 June) (Lawhead et al. 2015). Snow cover was low (5–20%) during the NPRA survey conducted on 8 June and snow was essentially gone from all survey areas by the time of the postcalving survey on 23–24 June. Although spring phenology was close to average in 2014, the calving distribution of the CAH was farther south than in most years.

Variability in weather conditions results in large fluctuations in caribou density during the insect season as caribou aggregate and move rapidly through the study area in response to fluctuating insect activity. Caribou typically move toward the coast in response to mosquito harassment and then disperse inland when mosquito activity abates in response to colder temperatures or high winds (Murphy and Lawhead 2000, Yokel et al. 2009, Wilson et al. 2012). Hence, temperature patterns can be used to predict the occurrence of harassment by mosquitoes (*Aedes* spp.) and oestrid flies (warble fly *Hypoderma tarandi* and nose bot fly *Cephenemyia trompe*) (Russell et al. 1993). Compilation of summer weather data was used to assess insect-season conditions and to predict the probability of insect harassment between late June and mid-August. The occurrence of air temperatures conducive to insect activity in 2014 (as indicated by the sum of thawing degree-days [TDD]) was below average in June, average in early July, and below average in late July and early August (Appendix B). Based on the available weather data and the observed distribution and movements of radio-collared caribou, it appeared that insect harassment was low during the summer of 2014. The combination of average spring temperatures and cool summer temperatures in 2014, with correspondingly low activity of insect pests, should have resulted in favorable conditions for caribou and a resulting improvement in body condition by fall.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

Six aerial strip-transect surveys of the NPRA survey area were flown between 19 April and 22 August 2014 (Figure 5, Table 2). Surveys planned for mid-September and early and late October could not be flown due to persistent poor weather. In contrast to some previous years, caribou density in the NPRA survey area was low during the 6 surveys that were flown in 2014. The estimated density of caribou ranged from a high of 0.16 caribou/km² on 24 June to zero on 12 May (Table 2, Figure 6). The density of caribou observed during calving in 2014 (0.05 caribou/km² on 8 June) was higher than in 2013 (0.01 caribou/km²), but was slightly below the range of densities observed during calving surveys in 2001–2012 (0.06–0.87 caribou/km² for 6–9 June).

No calves were observed during the calving survey on 8 June 2014. 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

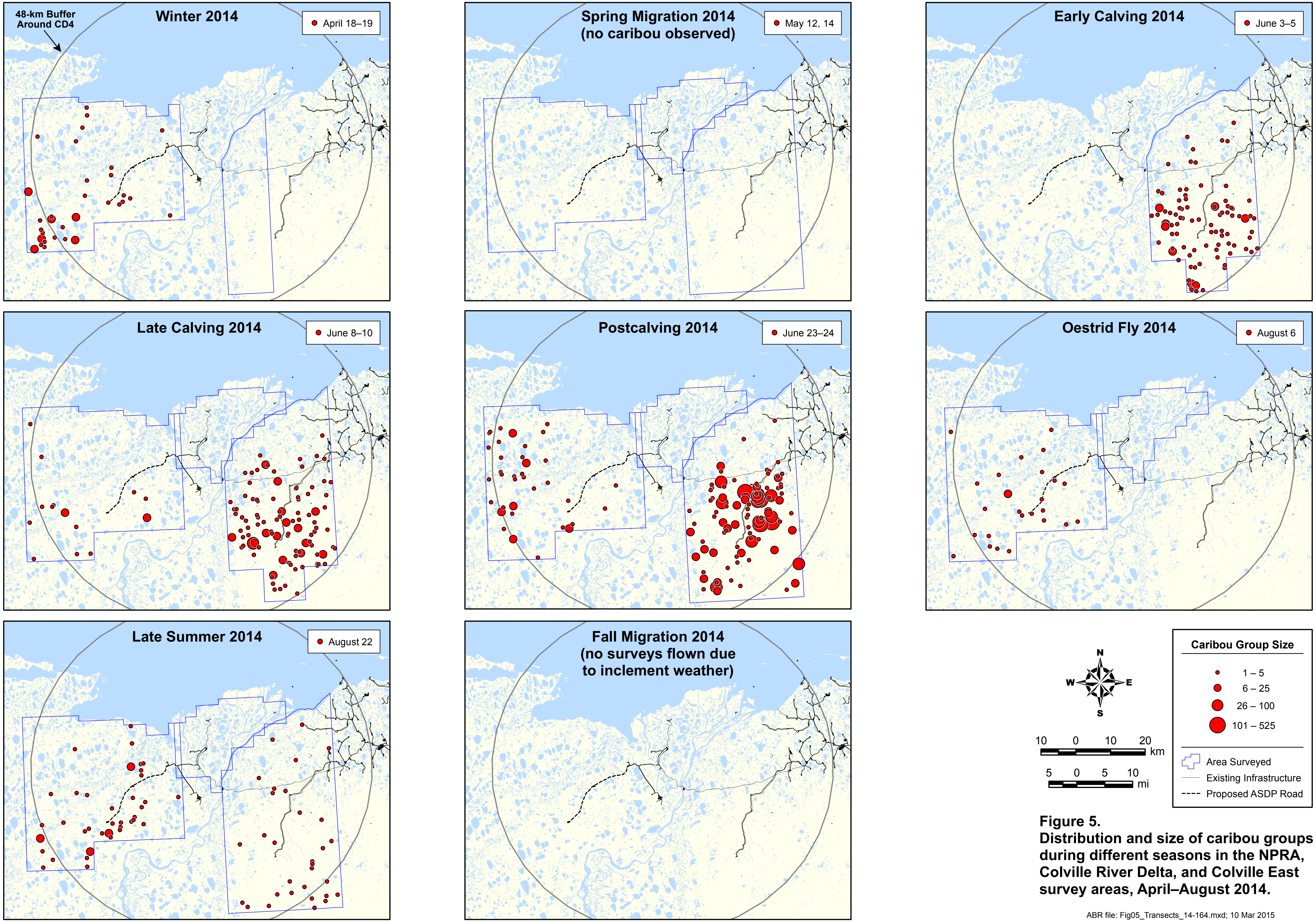

Figure 5.
Distribution and size of caribou groups during different seasons in the NPRA, Colville River Delta, and Colville East survey areas, April–August 2014.

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Table 2. Number and density of caribou in the NPRA, Colville River Delta, and Colville East survey areas, April–August 2014.

Survey Area and Date	Area [a]	Observed Large Caribou [b]	Observed Calves [c]	Observed Total Caribou	Mean Group Size [d]	Estimated Total [e]	SE [f]	Density (caribou/km²) [g]
NPRA								
April 19	1,720	112	0	112	3.4	224	45.1	0.13
May 12	1,720	0	0	0	–	0	–	0
June 8	1,720	41	0	41	2.9	82	19.8	0.05
June 24	1,720	130	5	135	3.8	270	56.8	0.16
August 6	1,720	46	nr	46	1.8	92	15.2	0.05
August 22	1,720	105	nr	105	2.8	210	39.1	0.12
COLVILLE DELTA								
May 12	494	0	0	0	–	0	–	0
June 8	494	0	0	0	–	0	–	0
June 23	494	0	0	0	–	0	–	0
August 6	494	5	nr	5	2.5	10	4.8	0.02
August 22	494	0	nr	0	–	0	–	0
COLVILLE EAST								
April 18 [h]	606	0	0	0	–	0	–	0
May 12, 14	1,696	0	0	0	–	0	–	0
June 4–5 [i]	1,432	200	37	237	2.7	889 [j]	202.6 [j]	0.62 [j]
June 9–10 [i]	1,432	293	71	364	3.6	753 [j]	105.2 [j]	0.53 [j]
June 23	1,696	1,231	371	1,602	16.5	3,204	808.7	1.89
August 22	1,696	39	nr	39	1.3	78	12.0	0.05

[a] Survey coverage was 50% of this area (860 km² in NPRA, 247 km² on the Colville River Delta, 848–969 km² in Colville East) for complete surveys.
[b] Adults + yearlings.
[c] nr = not recorded; calves not reliably differentiated due to larger size.
[d] Mean Group Size = Observed Total ÷ number of caribou groups observed.
[e] Estimated Total = Total Caribou × 2 (to adjust for 50% sampling coverage).
[f] SE = Standard Error of Total Caribou, calculated according to Gasaway et al. (1986), using transects as sample units.
[g] Density = Estimated Total ÷ Area.
[h] Partial survey 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 et al. 2015).
[j] Applied Sightability Correction Factor of 1.88 (Lawhead et al. 1994) to some portions of survey area with patchy snow cover.

area, which is used mainly by CAH caribou (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2014a). This conclusion is supported by analyses of telemetry data (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Parrett 2011, Wilson et al. 2012), which show that most TH females calve around Teshekpuk Lake, west of the ASDP study area.

Since 2010, the calving distribution of the TH has expanded, with some calving occurring as far west as the Ikpikpuk River and Atqasuk and a few females calving east of the Colville River with the CAH (Parrett 2011; L. Parrett, ADFG, pers. comm.). The amount of emigration of collared animals from the TH also appears to have increased in the last decade. Since 2004, 4–24% of collared TH caribou have been located with adjacent herds during the calving period and, since 2008, many of the females calving with other herds have remained with those herds during the summer (Parrett 2011). A few collared CAH caribou have calved west of the Colville River in isolated years

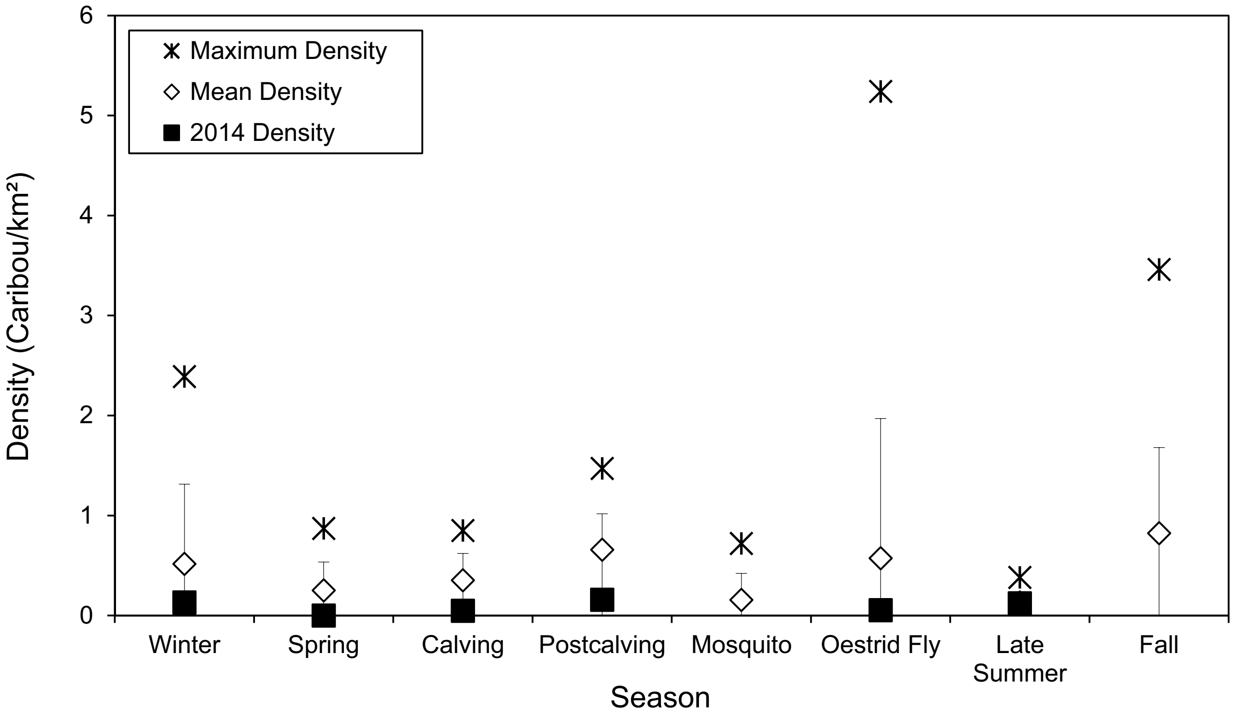


Figure 6. Seasonal density of caribou observed on 100 surveys of the NPRA survey area, April–October 2001–2014.

(notably 2001), although it is a rare occurrence (Arthur and Del Vecchio 2009, Lenart 2009).

Caribou densities increased slightly on the NPRA transects in late June (Table 2, Figures 5 and 6), a time when caribou usually move toward the coast as weather warms inland and becomes conducive to mosquito activity. No aerial surveys were conducted in July because telemetry data provide better information on the extensive movements that occur during the insect season (see Radio Telemetry section, below). Transect surveys during mosquito season generally are inefficient for locating caribou aggregations. Since 2001, the only transect survey during which large groups of insect-harassed caribou (numbering between 200 and 2,400 animals) were found in the NPRA survey area was on 3 August 2005 (Lawhead et al. 2006).

Since ABR began these transect surveys in 2001, the highest densities in the NPRA survey area have tended to occur in the oestrid fly season and fall migration (Figure 6). Poor flying conditions caused by persistent inclement weather have limited the ability of the study team to conduct surveys during fall; only 3 surveys could be conducted in September and October during the years 2009–2014. High densities also have been recorded occasionally in late winter (2.4 caribou/km² in April 2003) and postcalving (1.5 caribou/km² in late June 2001) (Burgess et al. 2002, Johnson et al. 2004, Lawhead et al. 2010).

Colville River Delta Survey Area

Five surveys of the Colville River Delta survey area were flown between 12 May and 22 August 2014 (Table 2; Figure 5). Surveys planned for mid-April, mid-September, and early and late October were precluded by poor weather. Similar to most surveys in previous years, the estimated density of caribou was low on all surveys (0–0.02 caribou/km²).

Use of the Colville delta by large numbers of caribou does not occur annually. Large numbers have been recorded sporadically during past summers (e.g., 1992, 1996, 2001, 2005, 2007, 2010) 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 an unusually large movement westward onto the delta by at least 10,700 CAH caribou in the third week of July 2001, ~6,000 of which continued across the delta into northeastern NPRA (Lawhead and Prichard 2002, Arthur and Del Vecchio 2009) and moved west through the area of the proposed ASDP road. At least 3,241 TH caribou were photographed on the outer delta on 18 July 2007 and up to several thousand more may have moved onto the delta by the end of July that year (Lawhead et al. 2008). Two large groups of caribou (>1,000 each) were recorded on the Colville delta in July 2010 by time-lapse cameras set up to observe bird nests (Lawhead et al. 2011). The highest number of caribou seen on Colville delta transect surveys during 2001–2014 was recorded on 2 August 2005, when 994 caribou were found in the Colville River Delta survey area (2.01 caribou/km²; Lawhead et al. 2006). Because such movements by large numbers of insect-harassed caribou often occur quickly, radio-telemetry data are more useful for describing caribou distribution and movements during the insect season than are periodic aerial transect surveys.

Colville East Survey Area

Six aerial transect surveys of the Colville East survey area were flown between 18 April and 22 August 2014 (Table 2, Figure 5). Due to inclement weather, only a partial survey could be flown in mid-April and the surveys planned for early August, mid-September, and early and late October could not be flown. The estimated density of caribou on complete surveys ranged from zero on 12–14 May to 1.89 caribou/km² on the postcalving survey on 23 June (Table 2); the latter was the highest density recorded among all 3 ASDP survey areas in 2014. The density of calving caribou in Colville East was low compared with previous years, however (Lawhead et al. 2004, 2013b, 2014b; Lawhead and Prichard 2006, 2007, 2008, 2009, 2010, 2011, 2012). During the late calving survey on 9–10 June 2014, many collared CAH caribou still were south of the Colville East survey area (E. Lenart, ADFG, pers. comm.).

The Colville East survey area typically hosts high densities of caribou during postcalving as CAH caribou move northward in advance of emerging mosquitoes (Lawhead et al. 2004; Lawhead and Prichard 2006, 2007, 2008, 2009, 2010, 2011, 2012; Lawhead et al. 2013b, 2014b, 2015). The estimated total caribou count increased from 889–753 caribou/km² during the calving season to 3,204 caribou/km² during the postcalving survey. However, by the 22 August survey, caribou densities were very low (0.05 caribou/km²) in the Colville East survey area as caribou moved out of the region.

During typical years, the 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 July 2004, collared CAH caribou have tended to move farther east in midsummer than in earlier years, with many caribou moving into ANWR and some even crossing the Alaska–Yukon border. Based on telemetry collar information, a sizeable portion of the CAH remained in or near the GKA through July 2014, however.

Other Mammals

No muskoxen (*Ovibos moschatus*) were observed in the NPRA survey area during surveys for caribou or other wildlife species by ABR biologists in 2014. As in previous years, muskoxen were seen in the region along the Colville, Kuparuk, and Sagavanirktok rivers, and along the coast near Milne Point (Lawhead et al. 2015). In 2012, a large mixed-sex group of muskoxen moved west from the Colville River delta and apparently drowned after falling through thin lake ice near Pik Dunes in NPRA (E. Lenart, ADFG, pers. comm.). In 2013, only one muskox was observed near the Colville delta (Lawhead et al. 2013b). In 2014, however, a group of 10–11 animals was observed consistently along the east side of the main channel of the Colville, just southeast of the delta (Appendix C). Before 2005, muskoxen were observed during aerial surveys in northeastern NPRA only in June 2001 (Burgess et al. 2002), even though the species occurs regularly on the Colville delta and adjacent coastal plain to the east (Johnson et al. 1998, 2004; Lawhead and Prichard 2002, 2003a, 2003b, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, Lawhead et al. 2013b, 2014b, 2015) and historical records of the species exist for northeastern NPRA (Bee and Hall 1956, Danks 2000).

Grizzly bears (*Ursus arctos*) were recorded on seven occasions in the NPRA survey area from 8

June to 6 August 2014, including two sightings on 19 June (Appendix C; Lawhead et al. 2015). Two observations were of 2 adults without cubs, 2 sightings were of females with single cubs, and 3 sightings were of females with 2 cubs. Twenty-five sightings of grizzly bears, including 5 sightings of a female with 2 cubs, were recorded on the Colville delta from 3 June to 21 August 2014 (Appendix C; Lawhead et al. 2015). Ten other sightings of grizzly bears were recorded in other areas east of the Colville delta in summer 2014 (Appendix C; Lawhead et al. 2015). The number of repeated observations of the same individuals among surveys was unknown, but the likelihood of multiple resightings was high.

One wolverine (*Gulo gulo*) was photographed near Fish Creek in NPRA on 4 July by a time-lapse camera directed at a loon nest. One adult polar bear (*Ursus maritimus*) was seen on 23 August on the Fish Creek delta. Thirty spotted seals (*Phoca larga*) were observed on 19 August and 23 August at a previously described haulout location in the Colville River delta, and one ringed seal (*Pusa hispida*) was seen hauled out on sea ice near Oliktok Point on 7 June (Appendix C; Lawhead et al. 2015).

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 from ADFG's GPS-collar sample during 2003–2006 are not depicted because, under the terms of a data-sharing agreement with ADFG, those data were not available outside 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 proportion of the collared sample from each herd detected each month inside the ASDP study area was used to characterize the patterns of occurrence by each herd (Figure 8, Appendices D and E). Although it generally is not warranted to consider each collared caribou as representing a specific number of unmarked caribou in a herd, these monthly percentages provide reasonable estimates of the relative abundance of each herd in the study area throughout the year.

VHF Collars

Interpretation of VHF telemetry data is limited by the fact that the locations of collared individuals are restricted by the number, extent, and timing of radio-tracking flights. Therefore, the distribution of collars on each flight was a snapshot that allows only general conclusions to be drawn regarding caribou in the area surveyed and movements between successive flights. No new VHF data has been available since 2005; VHF collar locations from previous years were discussed by Lawhead et al. (2006).

Satellite Collars

Combining observations over all years of data, the percentage of satellite-collared TH animals in the ASDP study area ranged from 6% to 39% of the total collared samples during each month (Figure 8, Appendix D). The greatest use by TH caribou occurred in the western half of the study area (Figure 9). The highest overall percentages occurred in July–October (21–39%) and the lowest percentages (6–12%) occurred in November–June (Figure 8, Appendix D). The monthly percentages varied substantially within and among years, largely due to small samples of collared animals in most years. At least 50% of satellite-collared TH animals were within the ASDP study area during July in 7 of the last 9 years (Appendix D).

Satellite-telemetry data show substantially more use of the eastern half of the ASDP study area (east of the Colville River) by CAH caribou than by TH caribou (Figure 9). Combining observations over all 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 (Figure 8, Appendix D). 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%; Figures 8 and 9, Appendix D). As with the TH sample, the monthly percentages varied substantially (0–100%) within years, at least in part due to the small sample sizes of collared animals.

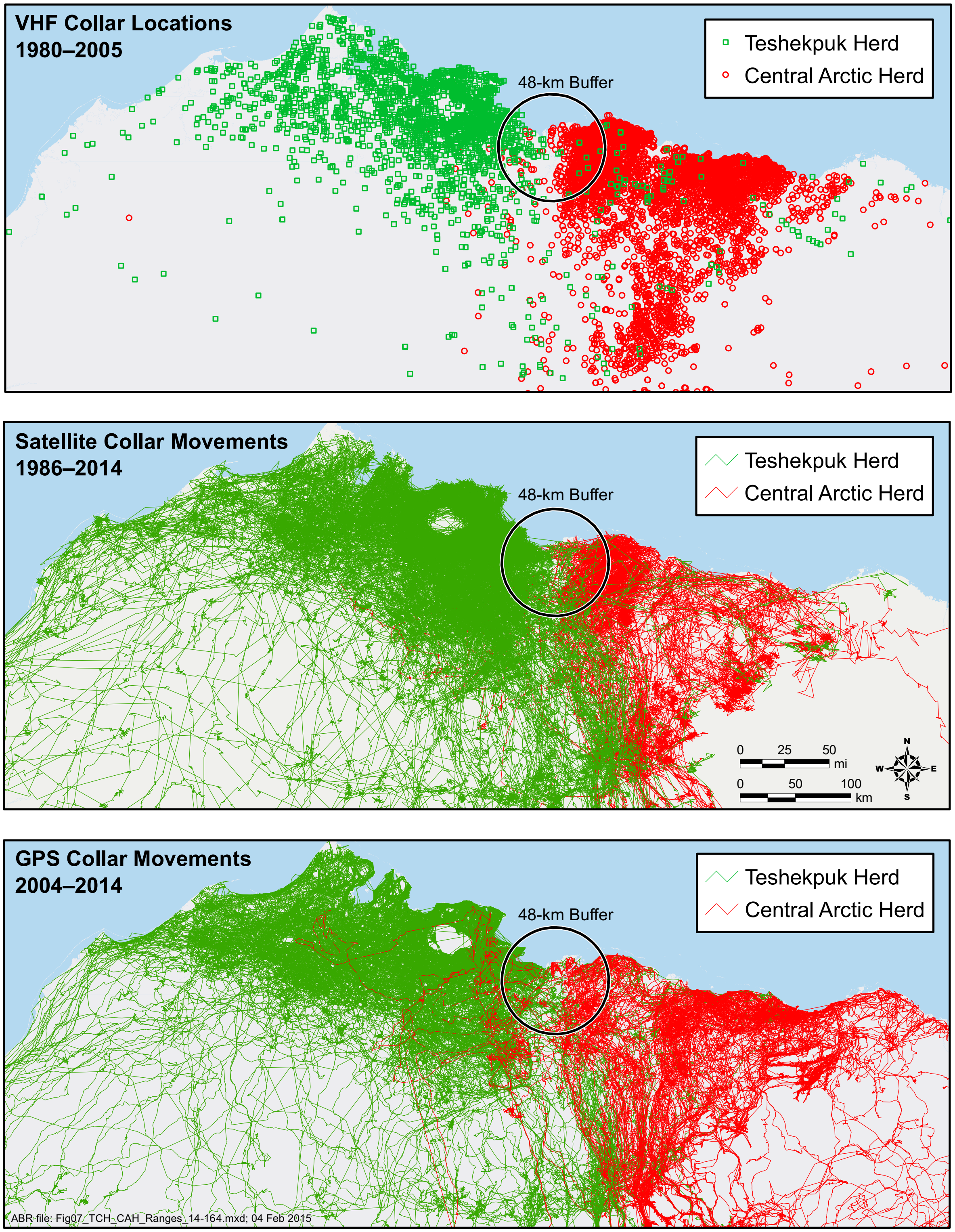


Figure 7. Ranges of TH and CAH caribou in northern Alaska in relation to the ASDP study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2014.

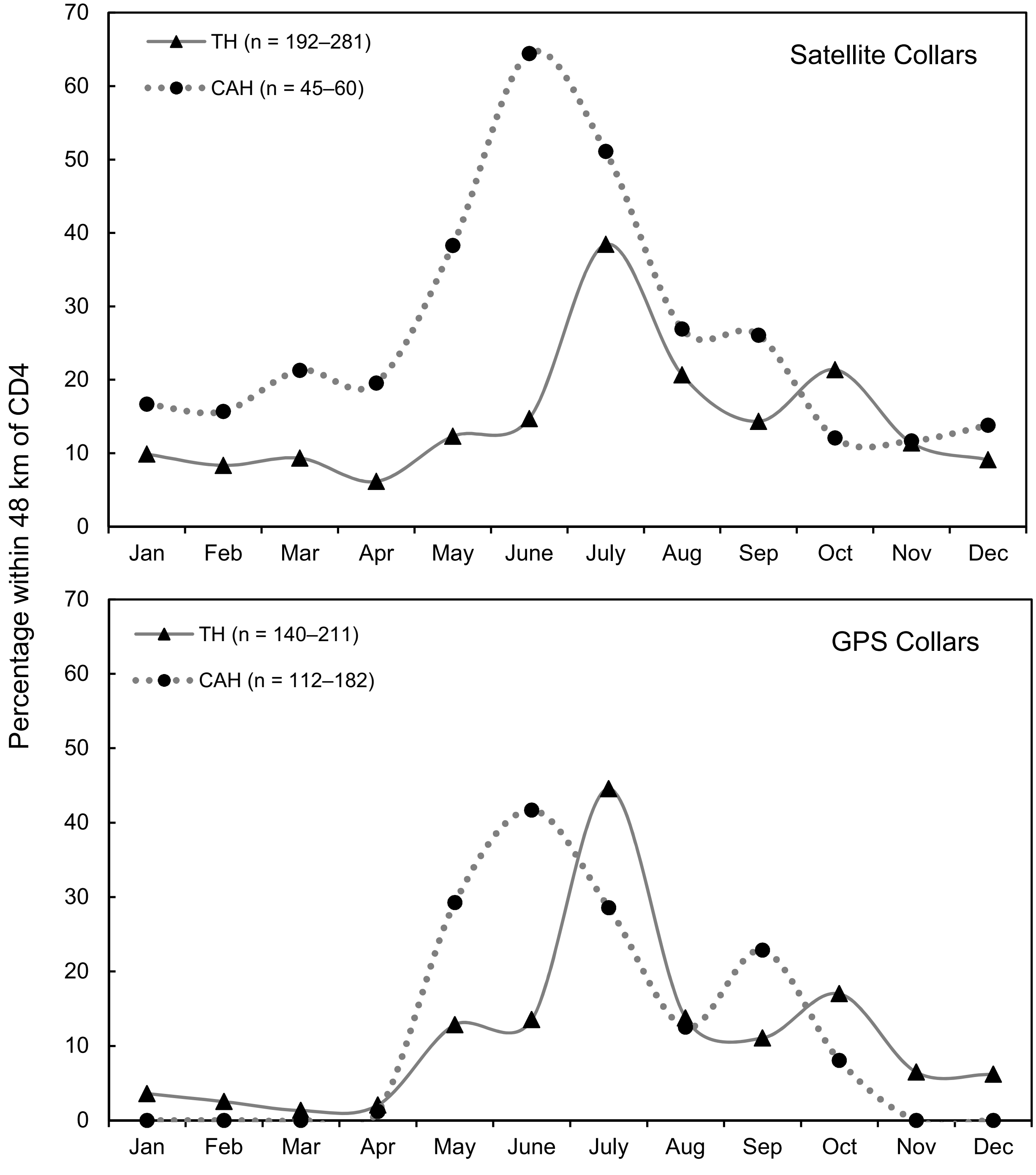


Figure 8. Percentage of satellite- and GPS-collared caribou samples from the TH and CAH that were located within 48 km of CD4 at least once in each month. See Appendices D and E for sample sizes by collar type, herd, and year.

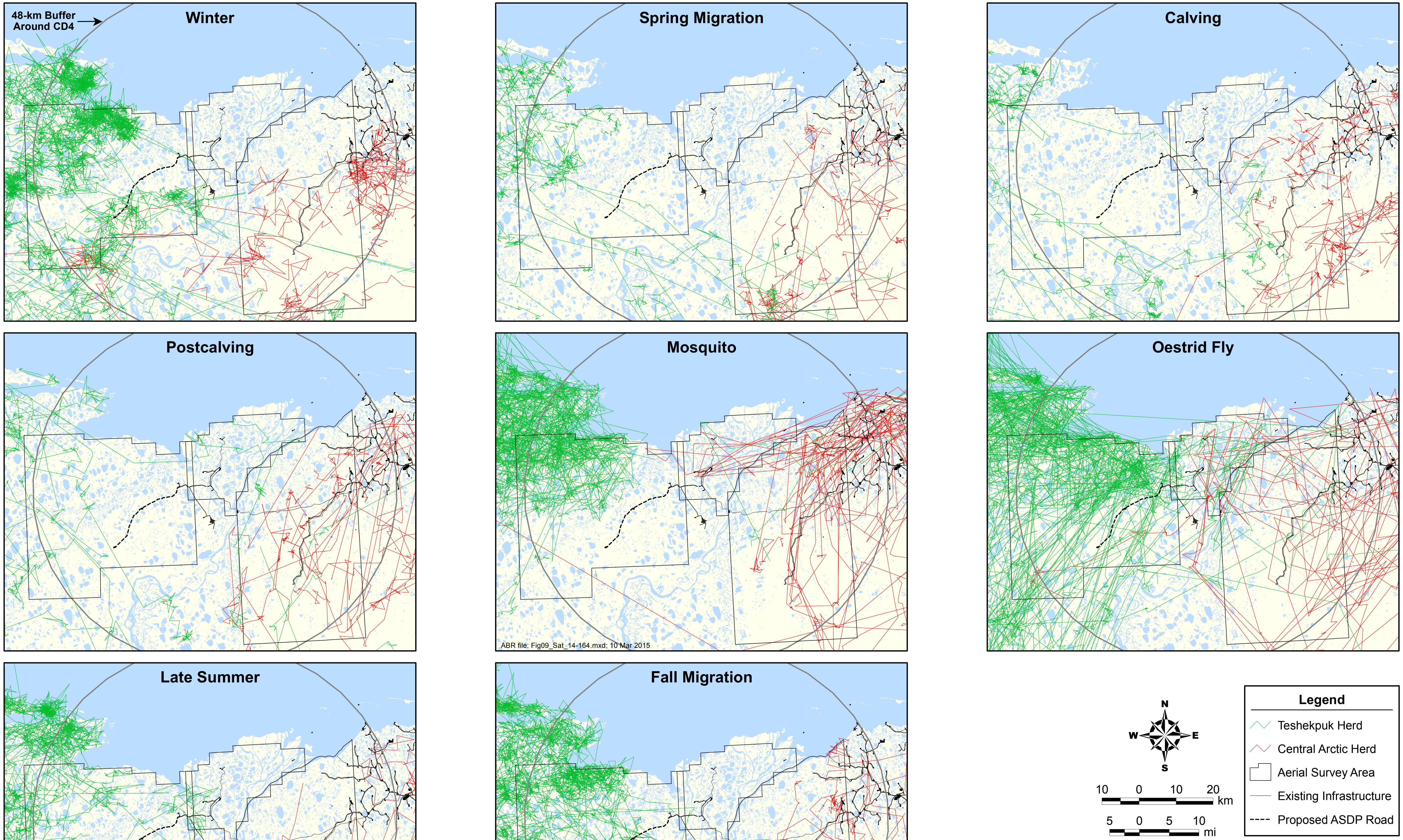


Figure 9.
Movements of satellite-collared caribou from the TH (1990–2014: 159 collar deployments) and CAH (1986–1990: 17 collar deployments; 2001–2009: 13 collar deployments) in the ASDP study area during 8 different seasons.

The number of collared CAH animals using the ASDP study area during the winter months was higher during 1986–1990 than during 2001–2009 (Appendix D). The difference in winter use between these 2 periods resulted from some collared animals remaining on the coastal plain during winter in the late 1980s rather than migrating south to the Brooks Range and associated foothills. The bulk of telemetry data accumulated since the 1970s 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.

GPS Collars

The percentages of the GPS-collared sample from the TH that were present at least once each month in the ASDP study area during 2004–2014 were similar to those of satellite-collared caribou. Only 2–7% of GPS-collared TH caribou were in the study area in winter (November–April; Figures 8 and 10, Appendix E). The monthly percentage increased to 13–14% in May and June, peaked at 45% during July, then declined again to 11–17% during August–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 2008–2014 was extremely low (0–1%) during the months of November–April (Figures 8 and 10, Appendix E). The monthly percentage increased sharply to 30% in May, peaked at 41% in June due to heavy use of the Colville East area during calving, then decreased to 29% in July and 8–23% during August–October.

The detailed movement tracks of 21 female CAH caribou collared in 2013 (one of which spent 2014 with the TH) and 2014 were mapped in relation to the ASDP study area for the period extending from December 2013 through November 2014 (Figures 11–14). These animals were outfitted by ADFG biologists in 2013 and 2014 with GPS collars purchased by CPAI for the ASDP study. All but one were collared in April on winter range in the Brooks Range east of the Dalton Highway; the one exception (Caribou C1444) was collared in late June 2014 on the coastal plain ~50 km east of the Sagavanirktok River. One animal (Caribou C1312) died in April 2014, a year after being collared, and the collar was retrieved by ADFG in fall 2014.

The seasonal movement patterns of the CAH caribou from December 2013 through November 2014 were broadly similar to the movement patterns of GPS-collared CAH caribou from July 2007 to December 2013 (Lawhead et al. 2014a). During calving in 2014, GPS-collared CAH females were distributed over a wide geographic area, ranging from Teshekpuk Lake on the west (Caribou C0910; Figure 11) to east of the Canning River in ANWR (Caribou C1325 and C1418; Figures 11 and 13); Caribou C0810 was a notable exception as she wintered on the Seward Peninsula with WAH animals and then moved with TH animals on the coastal plain during the calving and insect seasons, far to the southwest and west of the ASDP study area, and during fall migration into the Brooks Range (Figure 14). Except for those 4 individuals, all of the other GPS-collared females calved in the traditional calving grounds of the CAH between the Colville and Canning rivers (Figures 11–14).

After the calving season, GPS-collared CAH females ranged widely in summer from Teshekpuk Lake and farther west (Caribou C0810, C0910, and C1107) all the way east into Canada (Caribou C1108) (Figures 11–14). Most of the GPS-collared animals used traditional CAH summer range between the Colville and Canning rivers after calving, but 4 moved westward into NPRA during the insect season and late summer (Caribou C1330, C02120, C1001, C1107; Figures 12–13) and 4 others (Caribou C1325, C1108, C1418, and C1437) behaved more like Porcupine Herd (PH) animals after calving, moving east and south near or into Canada and then returning southwest to winter in the southern Brooks Range (Figures 11 and 13). Their movement patterns may be an artifact of their collaring location on winter range where CAH and PH animals have mixed in recent years, but also may reflect an increasing degree of herd interchange between those 2 herds (E. Lenart, ADFG, pers. comm.), as has occurred between the TH and CAH farther west.

Kernel Density Analysis

After quality screening, location data from satellite and GPS collars deployed on 61 CAH females, 2 CAH males, 152 TH females, and 58 TH males during the years 1990–2014 for the TH and 2001–2014 for the CAH were used to estimate seasonal density kernels. These numbers differ from those in Table 1 because they represent individual animals rather than collar deployments; some individuals were collared multiple times and some caribou switched herds after collaring. Kernels were used to produce 50%, 75%, and 95% isopleths (utilization distribution contours), which depict gradations in caribou density for both sexes of TH caribou and for female CAH caribou (Figures 15–17); the sample size of CAH males was too small for this analysis.

Female CAH caribou generally wintered between the Dalton Highway/TAPS corridor and Arctic Village, migrated north in the spring to calve on both sides of the Dalton Highway/TAPS corridor, spent the mosquito season near the coast (mostly east of Deadhorse), and spent the oestrid fly and late summer seasons distributed across the Arctic Coastal Plain on either side of the Dalton Highway/TAPS corridor (Figure 15).

TH caribou generally wintered between Nuiqsut and Wainwright or near Anaktuvuk Pass, migrated to their calving grounds centered on Teshekpuk Lake, and spent the rest of the summer on the coastal plain, primarily between Nuiqsut and Atqasuk (Figures 16–17). Males wintered in the area around Anaktuvuk Pass more than did females, lagged behind females during the spring migration, calving, and postcalving seasons, and were not distributed as far west as females during the summer (Figures 16–17).

CAH females used the ASDP study area most during the calving and postcalving seasons (19–23% of total utilization; Figure 18). TH females used the area at consistently low levels (5–8% of total utilization) throughout the year (Figure 18). Very few TH males used the ASDP study area in winter, but use gradually increased during the spring migration, calving, postcalving, and mosquito seasons, peaking during the oestrid fly season (18%), and then decreased again in late summer and fall (4%) (Figure 18) as males migrated into the foothills and mountains of the Brooks Range or toward Atqasuk (Figure 17). These patterns of use were generally similar to those previously discussed (Figure 8, Appendices D and E), although the peak values were lower in this analysis.

Movements Near CD4

Movements by satellite-collared TH and CAH caribou near CD4 (within 4 km of the pad, covering the area between Nuiqsut and the Alpine processing facility) have occurred infrequently and sporadically—during calving (early June), the oestrid fly season (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 9, 10, and 19).

TH Collars

One satellite-collared TH female was recorded 1.5 km west of the future location of CD4 in August 1992, one female was 4 km west of CD4 on 28 September 2004, and one female traveled north moving 2 km southwest of CD4 on 11 June 2007. In late July 2007, 3 satellite-collared TH males and one satellite-collared TH female moved east past Alpine and CD4 (judging from straight-line distances between successive locations) as they moved to the eastern Colville delta. One TH satellite-collared male passed within 4 km west of CD4 in late July 2010 before briefly moving north and then turning south. In late July 2011, a satellite-collared TH male was recorded within 300 m of CD4 before moving away to the southwest. In early August 2012, a satellite-collared TH female passed ~3.5 km west of CD4 before moving southwest. No satellite-collared TH caribou were recorded within 4 km of CD4 in 2013 or 2014.

Several of the 90 different GPS-collared TH animals (147 deployments, including some caribou that switched herds) during 2004–2014 moved through the area within 4 km of CD4. One female crossed the Colville delta westward between CD4 and Alpine on 6 June 2005 en route to Teshekpuk Lake. One female crossed ~2 km north of CD4 during calving in 2007, one spent 1–6 August 2007 ~2 km south of CD4 before heading west, and one moved within 4 km of CD4 from the west on 26 July 2007 before turning north. One female caribou was recorded ~2.5 km west of CD4 on 24–25 July before moving southwest. In 2014, one female

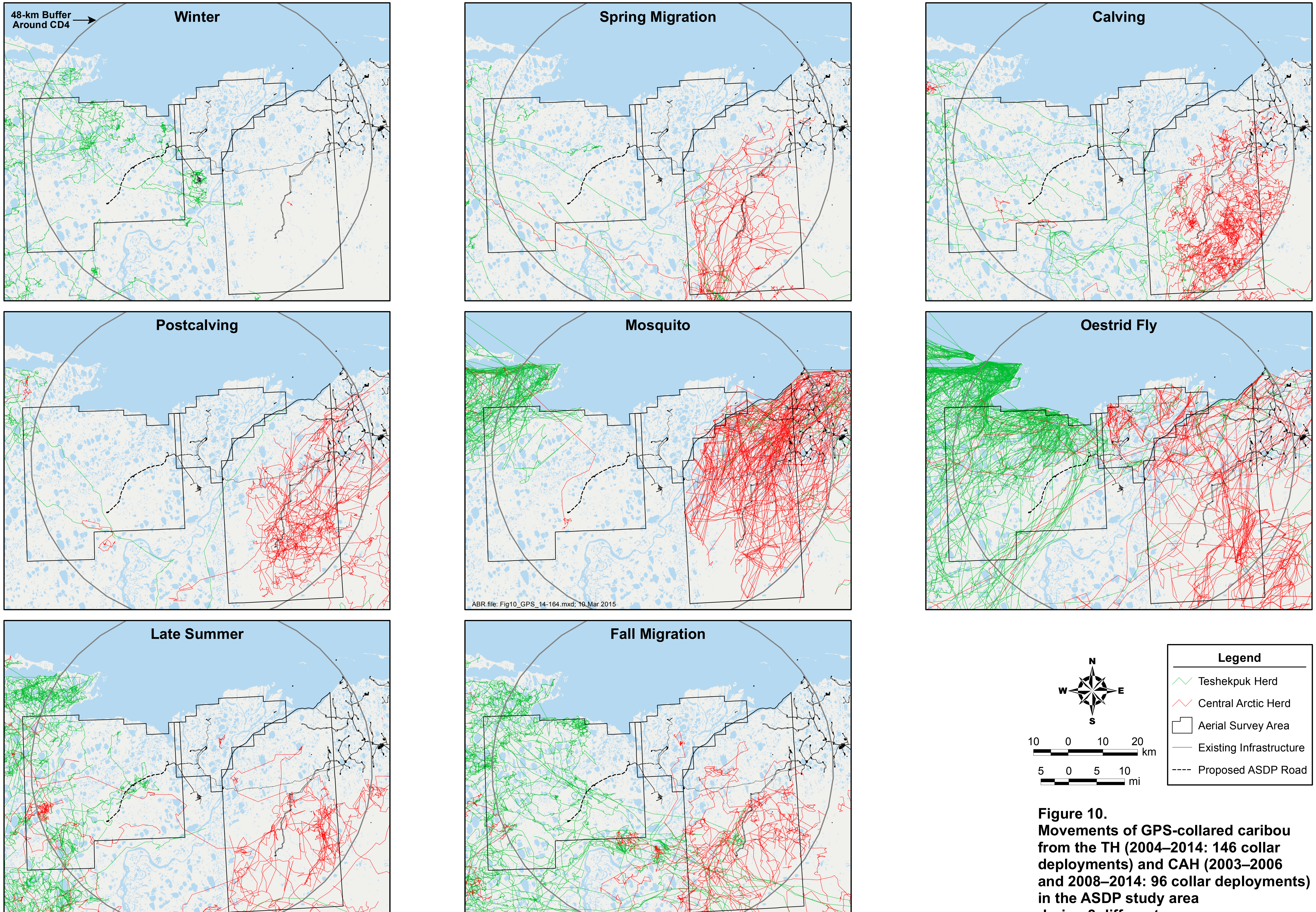


Figure 10.
Movements of GPS-collared caribou from the TH (2004–2014: 146 collar deployments) and CAH (2003–2006 and 2008–2014: 96 collar deployments) in the ASDP study area during 8 different seasons.

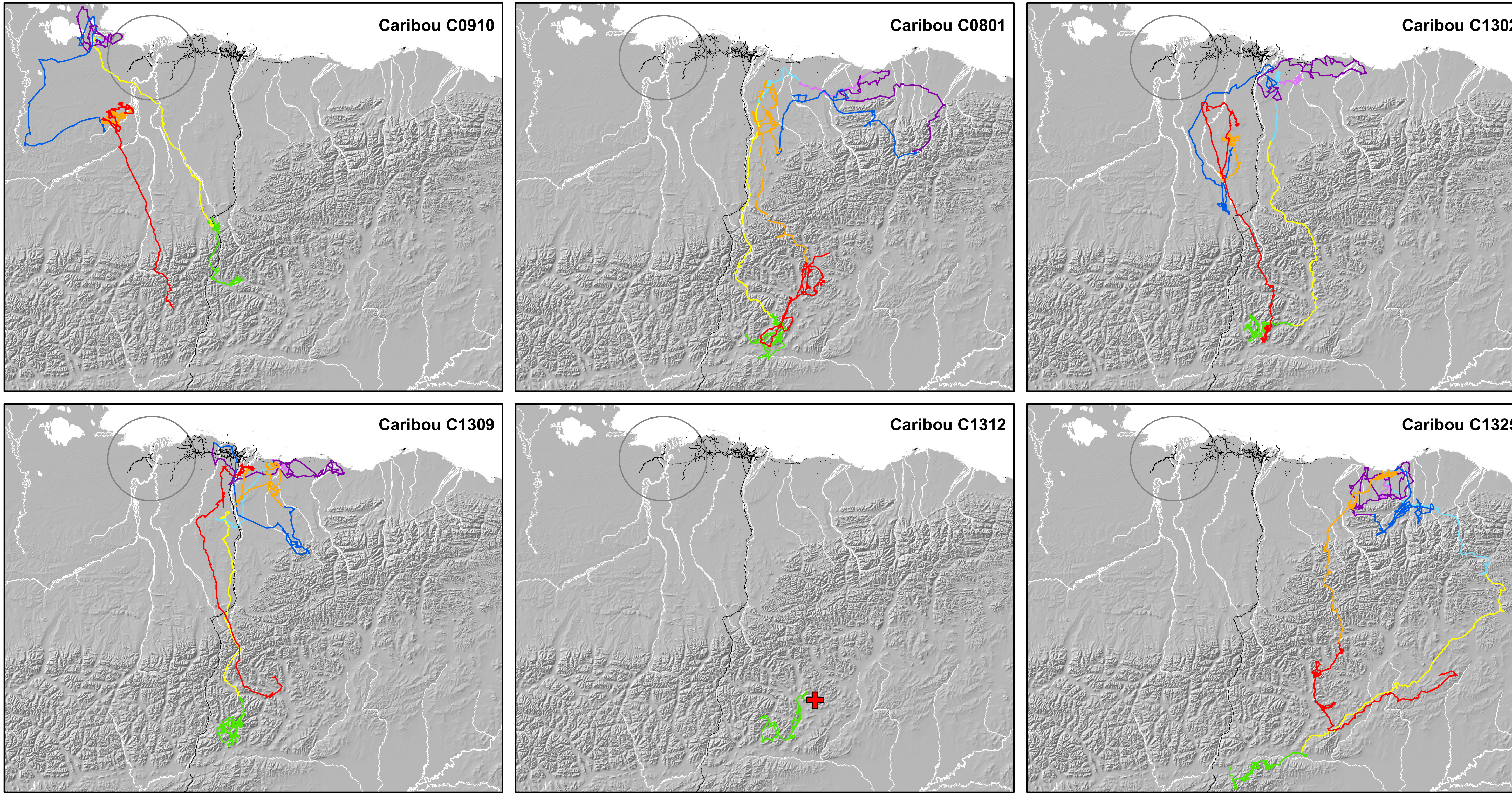


Figure 11.
Movements of 6 individual GPS-collared caribou from the CAH in relation to the ASDP study area during 8 seasons, December 2013–November 2014.

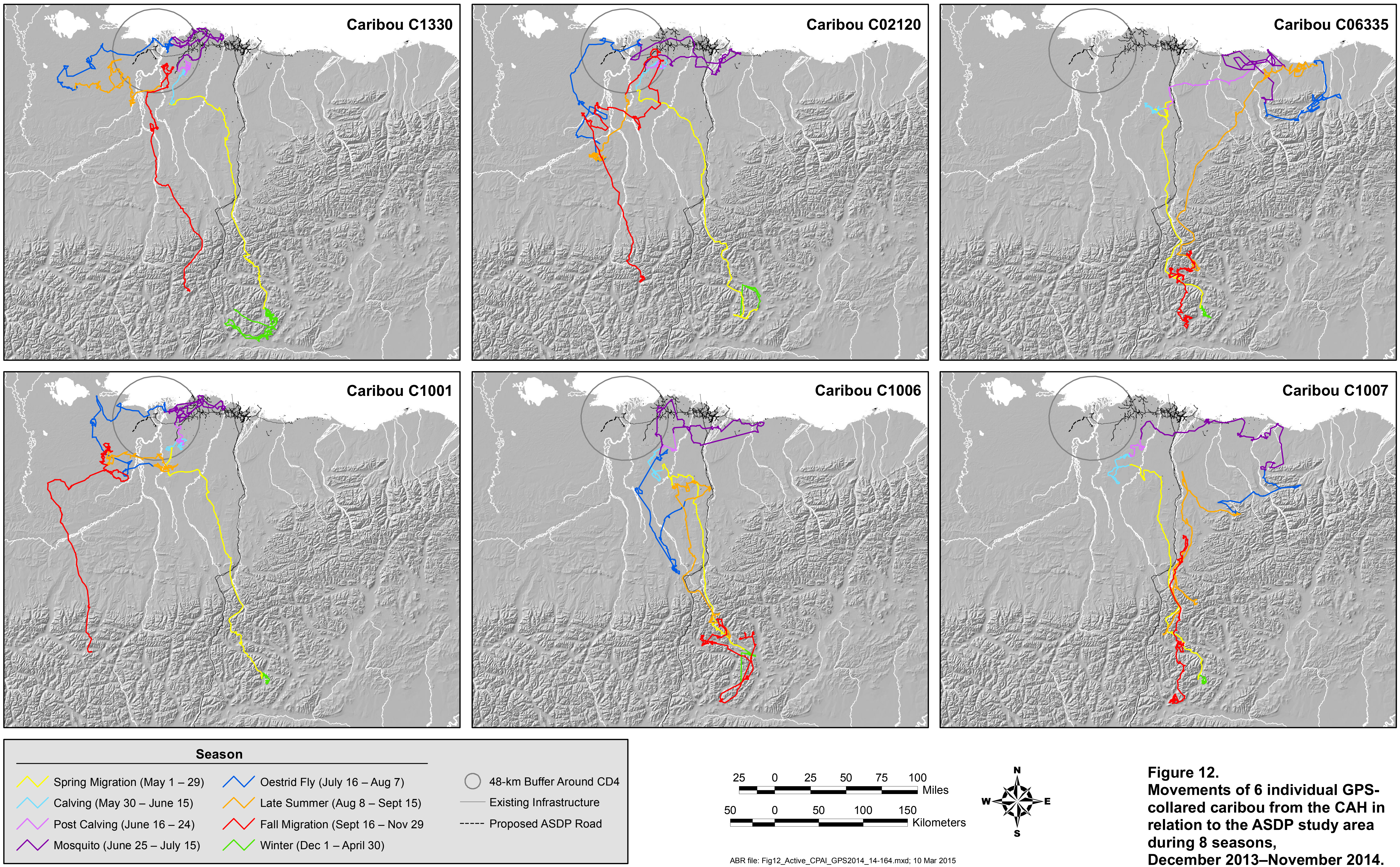


Figure 12.
Movements of 6 individual GPS-collared caribou from the CAH in relation to the ASDP study area during 8 seasons, December 2013–November 2014.

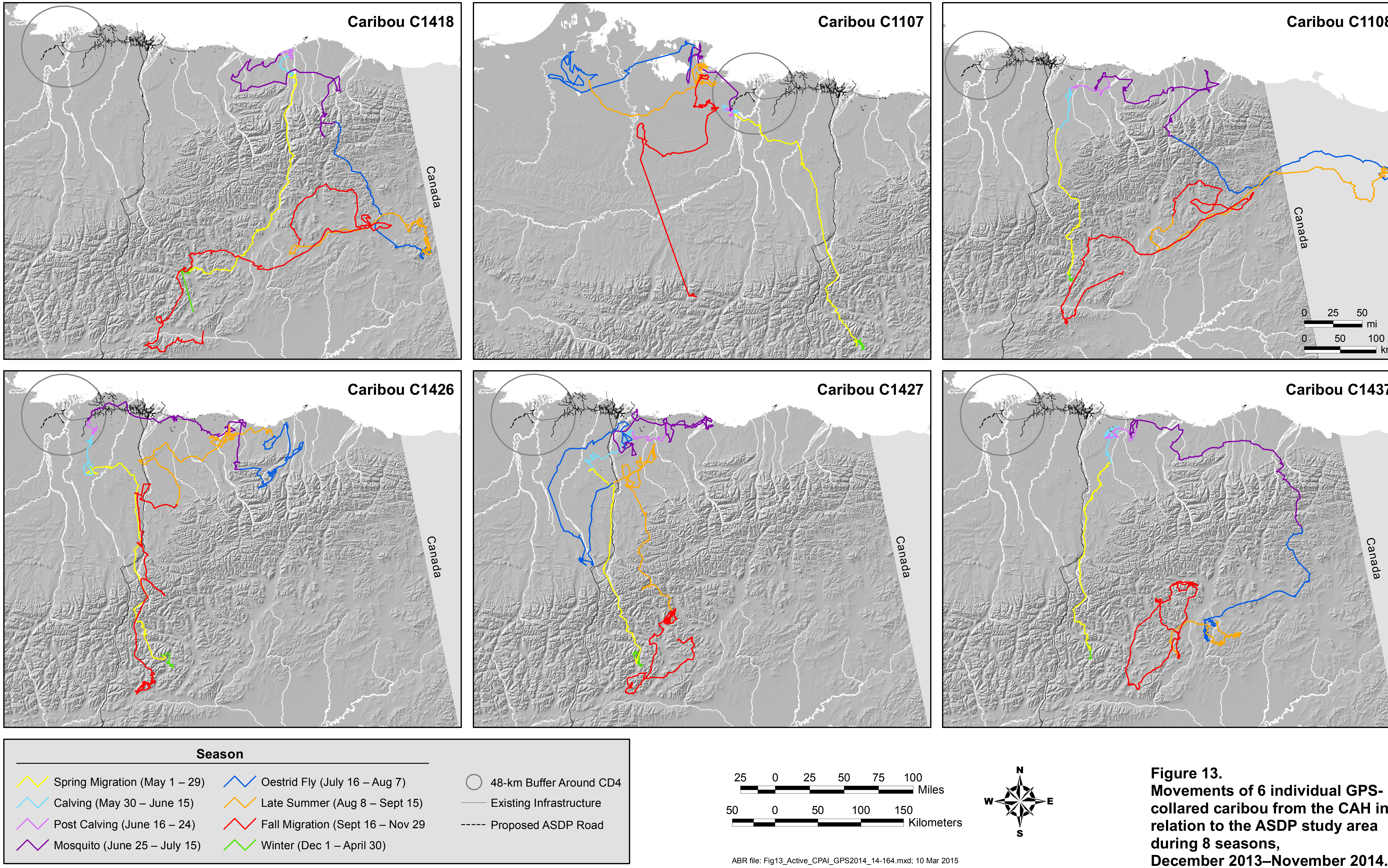


Figure 13.
Movements of 6 individual GPS-collared caribou from the CAH in relation to the ASDP study area during 8 seasons, December 2013–November 2014.

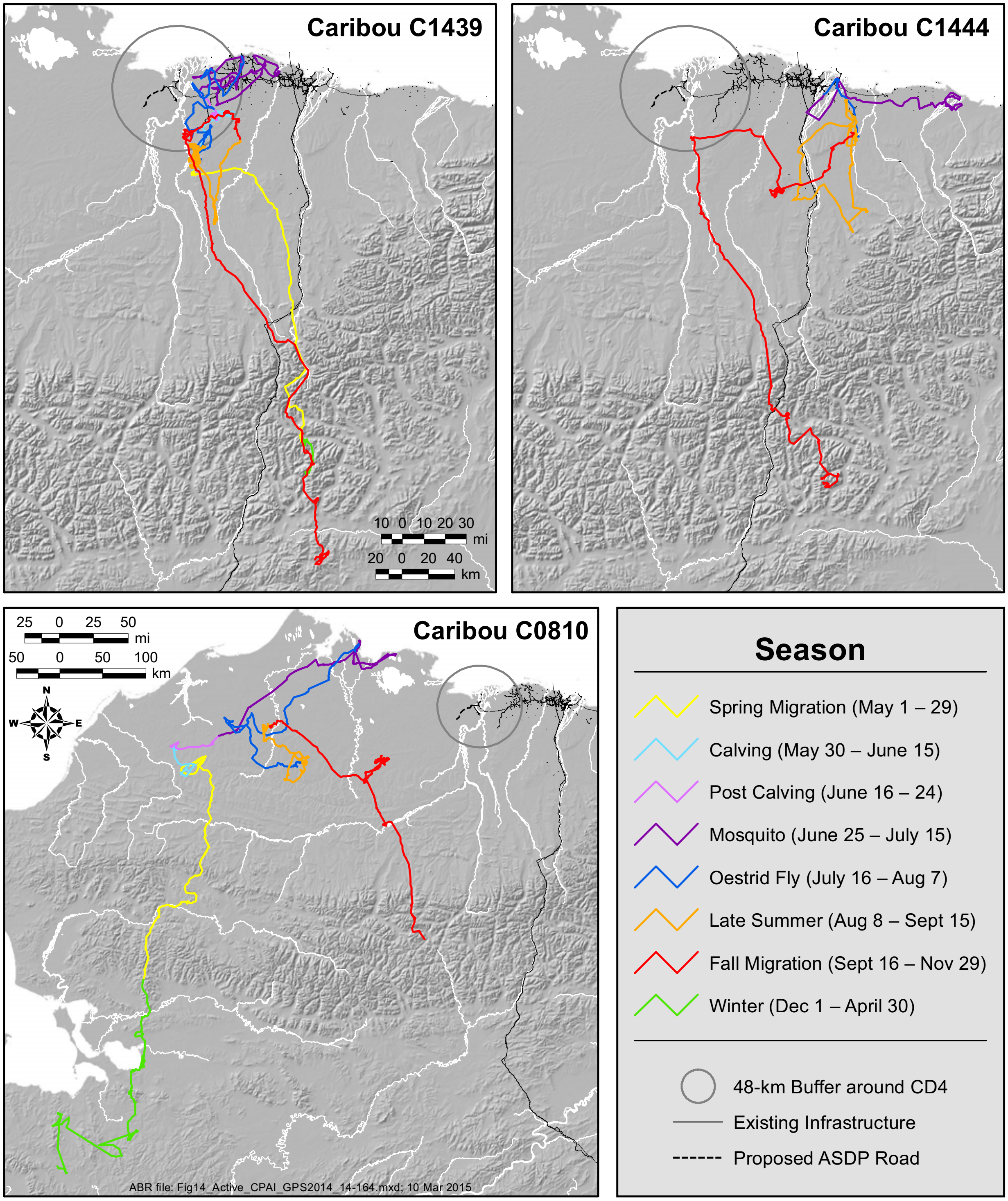


Figure 14. Movements of 3 individual GPS-collared caribou from the CAH in relation to the ASDP study area during 8 seasons, December 2013–November 2014.

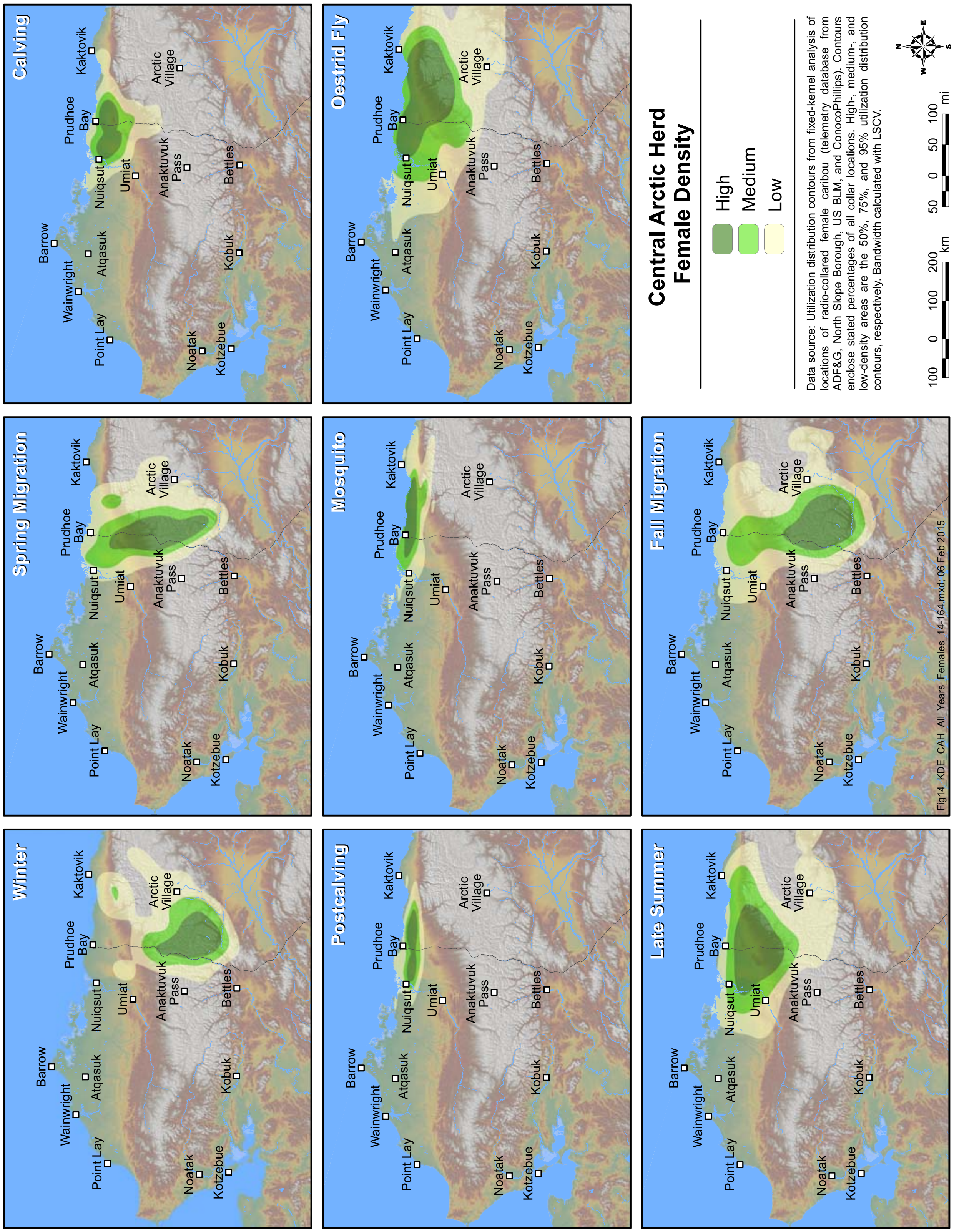


Figure 15. Seasonal distribution of CAH females based on fixed kernel density estimation of telemetry locations, 2001–2014.

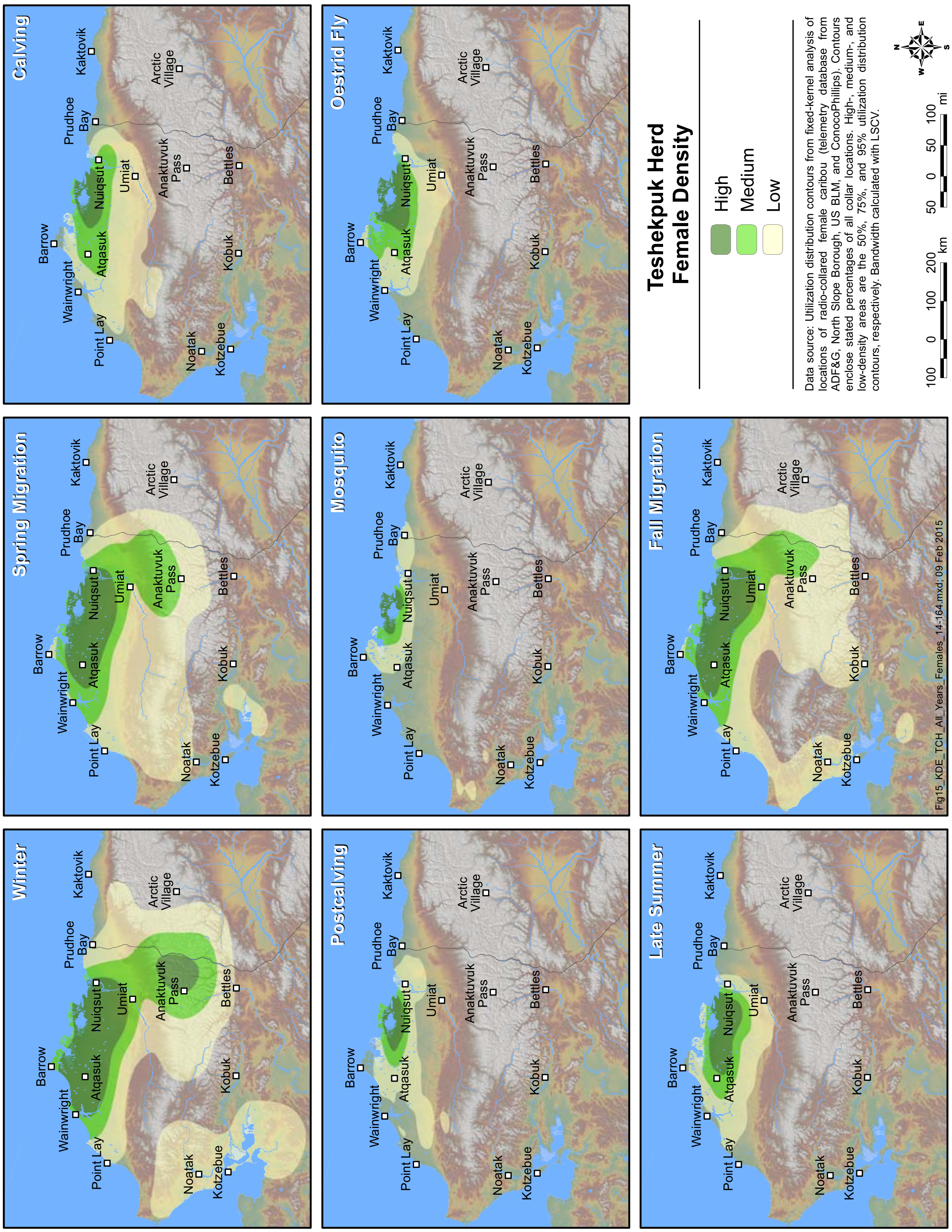


Figure 16. Seasonal distribution of TH females based on fixed kernel density estimation of telemetry locations, 1990–2014.

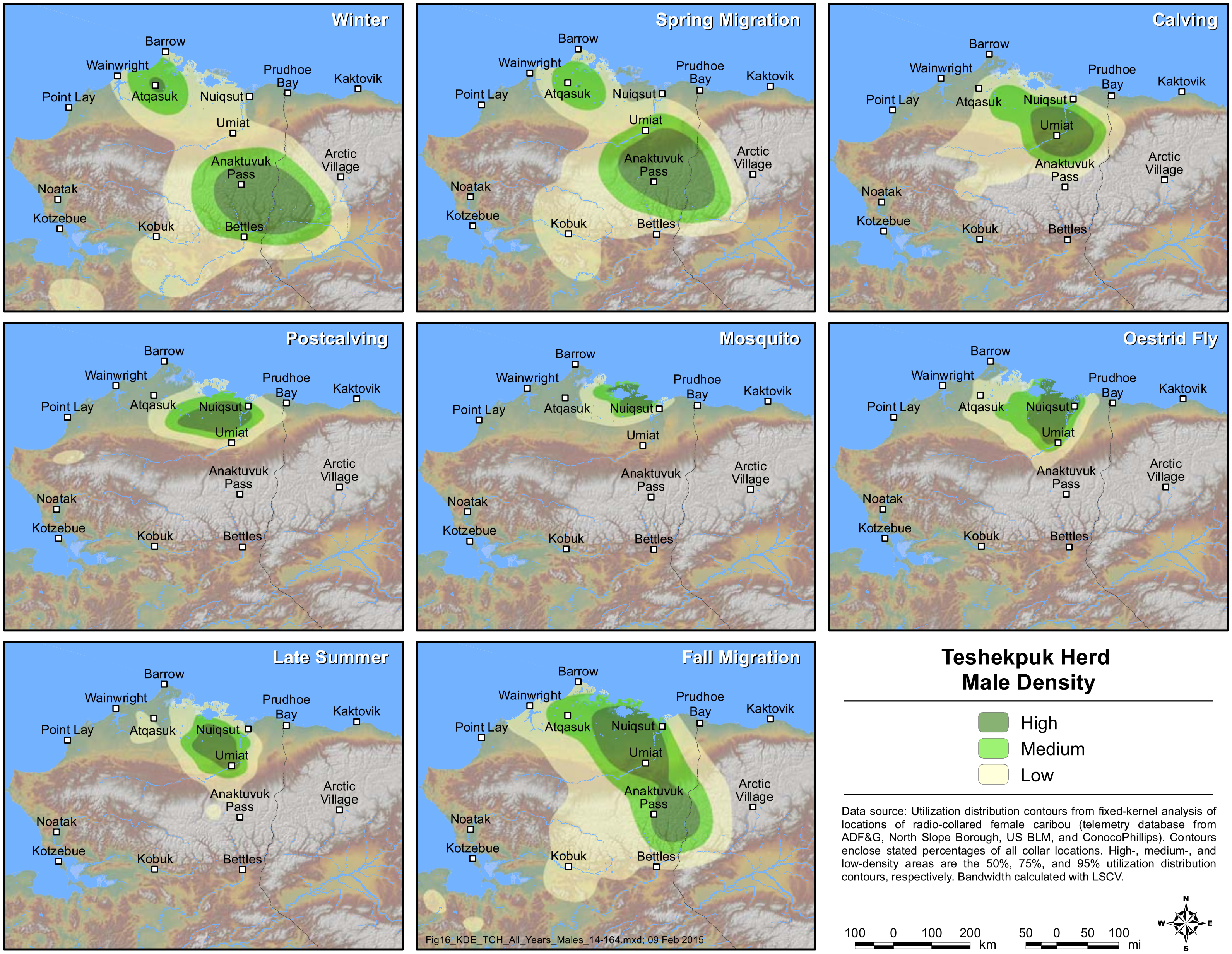


Figure 17. Seasonal distribution of TH males based on fixed kernel density estimation of telemetry locations, 1997–2014.

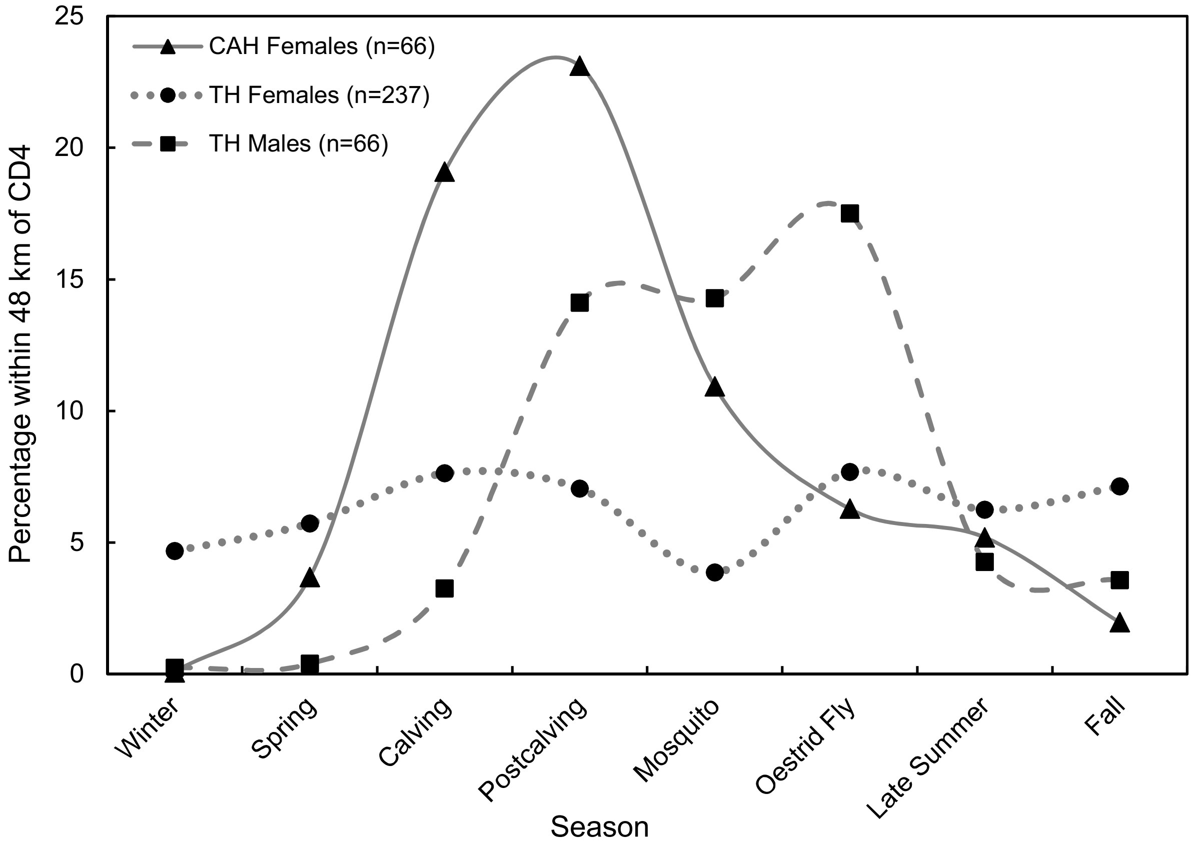


Figure 18. Percentage of CAH and TH caribou within 48 km of CD4, based on kernel density estimation, 1990–2014.

moved rapidly (~6.5 km in 2 h) from east to west on 17 July, crossing the delta 4 km north of CD4 (Figure 19).

CAH Collars

Of the sample of 17 satellite-collared CAH animals during 1986–1990, one moved into the delta ~3 km east of the future location of CD4 briefly during 21–23 July 1988 and 3 others passed approximately 4 km north of the future location on CD4 during 11–13 July 1989. Of the sample of 16 satellite-collared CAH animals (17 deployments) during 2001–2006, 4 animals moved 3–4 km east of the future location of CD4 while heading inland off the Colville delta on 28–30 July 2001.

Only one of the 45 GPS-collared CAH caribou in the ASDP study area during 2003–2006 moved onto the central Colville delta, passing ~3 km east of CD4 on 27 September 2004. None of the 19 CAH females (22 deployments) outfitted with GPS collars in 2008–2011 moved into the vicinity of CD4 during 2008–2010, but 2 of those animals were located near CD4 in late July 2011 (one ~1 km east and the other ~3 km north). The timing of those movements corresponded with the incidental observation (during bird surveys) of 2 groups of caribou, totaling ~600 animals, on the delta on 25 July 2011, plus a group of ~140 animals on 1 August (Lawhead et al. 2012). In 2013, 2 GPS-collared CAH female came near CD4, when Caribou C0810 passed ~2.5 km south of CD4 as it moved from east to west during 22–23 July (Lawhead et al. 2014a) and Caribou 0924 (originally collared with the TH) crossed the Colville delta rapidly from east to west on 22 July. Although the exact route is unknown and the locations were over 24 h apart, based on a straight-line distance between subsequent locations, Caribou 0924 may have passed within 300 m of CD4 (a more precise route may be available after the collar is retrieved and the data stored on board are downloaded). In 2014, only one female (Caribou C02120) was located near CD4, passing from east to west ~4 km away on 17–18 July (Figure 19).

Movements Near the Proposed Road Alignment

A greater proportion of all radio-collared TH and CAH caribou movements since 1990 have occurred across the proposed ASDP road alignment in NPRA than occurred near CD4, although such movements were not frequent (Figures 9, 10, and 19).

TH Collars

As expected on the basis of herd distribution, most crossings of the proposed road alignment were by TH caribou (Figures 9 and 10). Of the sample of 141 different satellite-collared TH caribou during 1990–2014 (159 deployments, including caribou that switched herds), 41 animals (29%) crossed the proposed alignment at least 125 times (including multiple crossings by some individuals on the same days) between September 1990 and December 2014. Crossings occurred in every month except January. Crossing events occurred most frequently in July, when 37 (30%) were recorded. Smaller proportions occurred in other months: 22 crossings (18%) in October, 18 crossings (14%) in March, 13 crossings (10%) in August, 11 crossings (9%) each in September and November; 5 or fewer crossings were recorded in the other months. In 2014, only one satellite-collared TH caribou crossed the proposed alignment: a male was recorded 13 km southwest of Nuiqsut on 19 July, moved northwest to within 5 km of the south side of the proposed road, and was next located ~23 km farther west, presumably having crossed the proposed road between the proposed locations of GMT1 and GMT2.

Of the sample of 90 different GPS-collared TH caribou during 2004–2014 (147 deployments, including caribou that switched herds), a total of 25 (28%) crossed the alignment 81 times. Crossings occurred in all months except February and March, including 22 crossings by 14 caribou in July (12 in 2010 and 10 in 2011); 12 crossings by 4 caribou in August (9 in 2007, 1 in 2009, and 2 in 2010); 12 crossings by one caribou in September (2007); 10 crossings by 6 caribou in October (5 in 2004 and 5 in 2007); 7 crossings by 3 caribou in November (6 in 2004, 1 in 2013); and 8 crossings by one individual in January (2008). Fewer crossings were recorded in other months: one in April, 2 in May, 5 in June, and 2 in November. The most crossings in any single month occurred in July 2010, when 12 crossings by 9 different caribou were recorded. No GPS-collared TH caribou crossed the road alignment in 2014.

CAH Collars

Only one satellite-collared CAH animal (a female) crossed the western end of the proposed alignment on 1 April 1987 while moving from west to east. Some VHF-collared CAH caribou probably crossed the alignments of the future ASDP roads (including the CD4 alignment before construction) with the aggregation of at least 6,000 CAH caribou that moved west across the Colville delta and into the NPRA survey area in late July 2001 (Lawhead and Prichard 2002, Arthur and Del Vecchio 2009), but they were not tracked frequently enough to document their route of travel.

Of 47 GPS-collared CAH females during 2008–2014 (52 deployments, including caribou that switched herds), only 2 animals (4%) crossed the road alignment: one in August 2013 and the other (C02120) in July 2014 (Figures 12 and 19).

REMOTE SENSING

Because MODIS imagery covers large areas at a relatively coarse resolution (250–500-m pixels), it was possible to evaluate snow cover and vegetation indices over a much larger region than the ASDP study area with no additional effort or cost. The region evaluated extends from the western edge of Teshekpuk Lake east to the Alaska–Yukon border and from the Beaufort Sea inland to the northern foothills of the Brooks Range. The ability to examine this large region allowed us to place the ASDP study area into a larger geographic context in terms of the chronology of snow melt and vegetation green-up, which are environmental variables that have been reported to be important factors affecting caribou distribution.

SNOW COVER

In 2014, snow melt was underway along some floodplains in the ASDP study area on 14 May

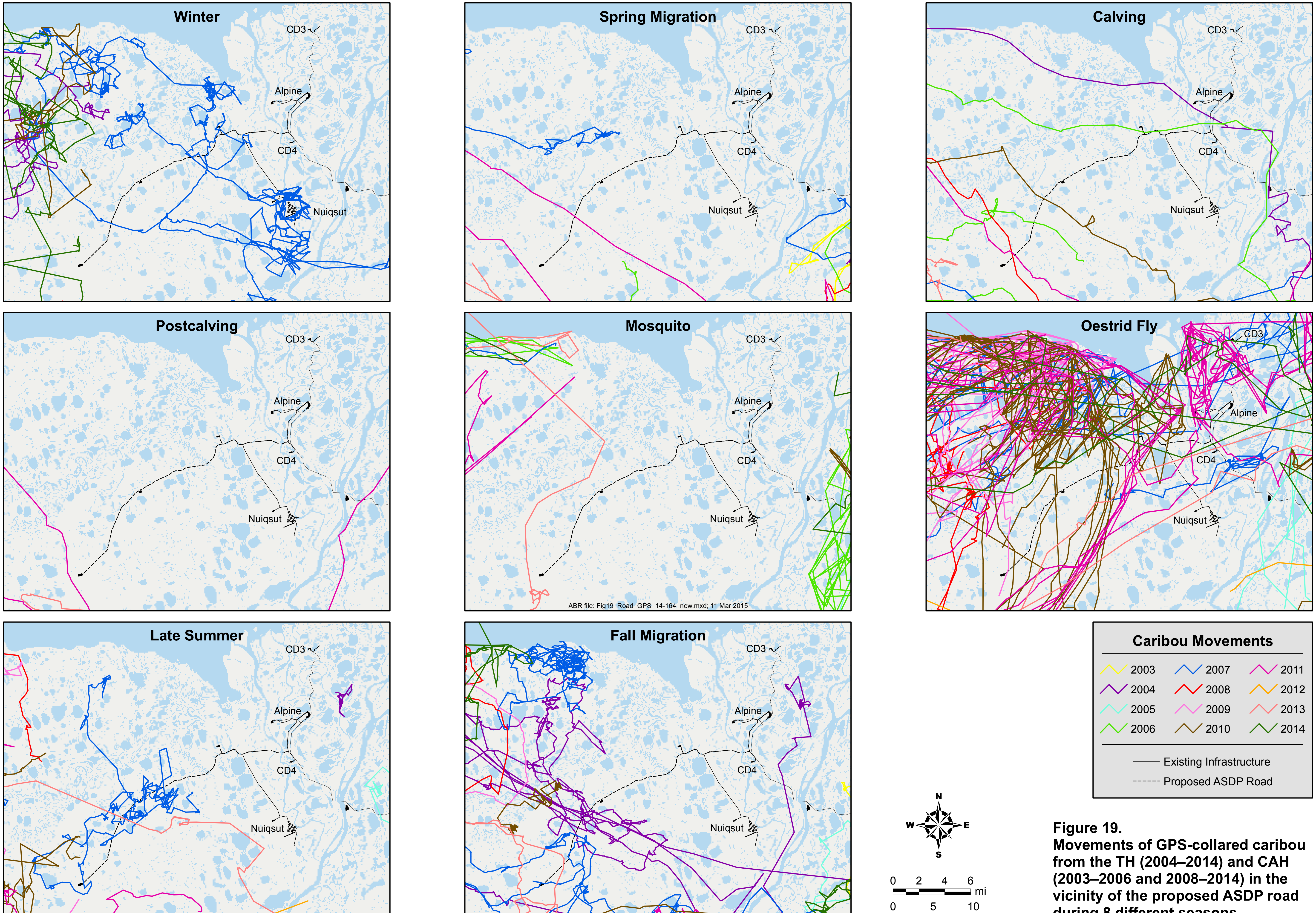


Figure 19.
Movements of GPS-collared caribou from the TH (2004–2014) and CAH (2003–2006 and 2008–2014) in the vicinity of the proposed ASDP road during 8 different seasons.

2014 (Figure 20). Persistent cloud cover then obscured the study area until 3–4 June, at which time snow was patchy to absent in most of the study area, with the exception of the snow-covered uplands between the Kuparuk and Colville rivers. By the time the next cloud-free view was obtained on 13 June, most snow had melted in the study area.

For each pixel, the date of snow melt (defined as the midpoint between the last date when >50% snow cover was observed and first observed date with ≤50% snow cover) was calculated for the years 2000–2014. When the time elapsed between these two dates exceeded a week, the pixel was assigned to the "unknown" category, because extensive cloud cover or satellite sensor malfunction prevented an evaluation of snow melt to within 1 week.

The median dates of snow melt, computed from 2000–2014 data (where the date of melt was known to within 1 week), indicate that nearly all of the land on the coastal plain typically melts over a period of 3 weeks between 25 May and 11 June (Figure 21; Appendix F). Snow melt progresses from the northern foothills of the Brooks Range north to the outer coastal plain, occurring earlier in the "dust shadows" of river bars and human infrastructure, and later in the uplands and numerous small drainage gullies southwest of the Kuparuk oilfield. The southern coastal plain, wind-scoured areas, and dust shadows typically melt during the last week of May (Figure 21). The central coastal plain and most of the Colville delta usually melt in the first week of June, leaving snow on the northernmost coastal plain, in uplands, and in terrain features that trap snow, such as gullies. During the second week in June, most of the remaining snow melts, although some deep snow drift remnants, lake ice, and aufeis persist into July (Figure 21).

Within the NPRA survey area, snow melt occurs earliest near stream channels and a south-to-north gradient is apparent, with snow melt typically occurring several days later near the coast. On the Colville delta, an east-to-west gradient is visible, with snow melt delayed by about a week in the northeastern portion of the delta compared to the western delta. Snow melt in the Colville East survey area occurs earliest along roads. Snow melt is delayed both in the higher elevations to the south and for the coastal region to the north. Snow melt tends to occur several days earlier in the central portion of the Colville East survey area than it does in the northern and southern portions (Figure 21).

Because of persistent cloud cover in 2014, snowmelt date was not known to within 1 week for much of the study area (Figure 20). The snowmelt date was known only for small patches in the study area, where snowmelt was mostly within 3 days of the long-term median date or 4–7 days earlier than the median data (Figure 22). In larger patches on the coastal plain where the 2014 snowmelt date was known to within 1 week, the date of melt was generally within 3 days of the median date (Figure 22).

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 the period 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 provided that the code for that algorithm is published so it can be evaluated for use in future analyses.

VEGETATIVE BIOMASS

The first flush of new vegetative growth that occurs in spring among melting patches of snow is valuable to foraging caribou (Kuropat 1984, Klein 1990, Johnstone et al. 2002), but the spectral signal of snow, ice, and 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 (NDVI_Calving, NDVI_Rate, NDVI_621) 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 the initial flush of new growth begins to appear.

Although persistent cloud cover prevented measurement of NDVI over much of the NPRA and Colville East survey areas in the 2014 calving season, the estimated vegetative biomass during calving (NDVI_Calving) appeared to be low over most of the ASDP study area and was zero (indicating solid snow cover) in some of the coastal and upland portions of the Colville East survey area (Figure 23). Compared to the 2000–2014 median, NDVI_Calving in 2014 was near the average over the parts of the survey areas where it could be measured (Figure 22; Appendix G). NDVI_Rate was low in the NPRA and Colville River Delta survey areas and in the coastal portion of the Colville East survey area (Figure 23). NDVI_Rate was high in the southern, upland portion of Colville East, which was snow-covered at the start of the measurement period. NDVI_621 and NDVI_Peak both showed the typical pattern of higher values inland and lower values along small rivers and creeks; some tall shrub areas along the Colville River were brown in NDVI_621 but very green in NDVI_Peak (Figure 23; Appendices H and I). Based on comparisons with 2000–2014 median values, the NDVI_621 and NDVI_Peak values in 2014 were mixed in the NPRA and the Colville River Delta survey areas and were slightly higher than average in the Colville East survey area (Figure 22).

For the 2014 analysis, we continued to use zero-baseline estimation to calculate NDVI_Calving (i.e., negative NDVI values were set to zero); hence, the values of NDVI_Calving are determined largely by the timing of snow melt. Snow melt typically occurs over a short time period during the calving period. As a result of changing snow cover, the levels of NDVI_Calving vary substantially based on the timing of satellite imagery in relation to melt and the amount of snow and ice remaining to mask the effect of new vegetation. In some past years (Lawhead et al. 2009, 2010), we attempted to address this issue by using the value of NDVI in late September (late fall baseline estimation) as the minimum value of NDVI_Calving. Those baseline estimates, which were obtained after plant senescence but before snow began to accumulate in the fall, were used to estimate the NDVI value of standing dead biomass. Further examination indicated, however, that the fall NDVI values were higher than those observed early in the season immediately after spring snow melt, so we reverted to using zero-baseline estimation instead.

CARIBOU DISTRIBUTION ANALYSES

The following analyses are restricted mostly to the NPRA survey area to characterize pre-construction patterns of use in the area where additional ASDP infrastructure has been proposed. However, we did also examine caribou density in the Colville East survey area during the calving season because of the importance of that area for CAH calving.

GEOGRAPHIC LOCATION

The distribution of caribou groups during aerial transect surveys was highly variable among the 5 geographic sections analyzed in the NPRA survey area (Figure 2) in most seasons and years. This analysis focuses on the pooled 13-year data set for aerial transect surveys (2002–2014, excluding the smaller area surveyed in 2001; Table 3) rather than individual years; the differences observed in the pooled data set generally were similar within individual years, but often were not significant due to smaller sample sizes and high spatial variability during individual surveys (Appendix J).

For the pooled 2002–2014 sample, significantly more groups of caribou occurred in the Southwest section and significantly fewer occurred in the Coast and Southeast sections (Table 3). In the fall migration, winter, spring migration, and calving seasons, caribou used the Southwest and North sections significantly more than other sections. The North and River sections were used more during the postcalving, mosquito, oestrid fly, and late summer seasons. During the few surveys flown in the mosquito season, caribou groups were significantly more numerous in the Coast section, which is consistent with the well-documented use of coastal mosquito-relief habitat by caribou (Murphy and Lawhead 2000, Parrett 2007, Yokel et al. 2009, Wilson et al. 2012). During the oestrid fly season, the number of groups in the Coast section was not significantly greater, but this group-based analysis does not reflect the large numbers of caribou found in 5 large groups in the Coast section on 3 August 2005, a date on which mosquitoes also were active and affecting caribou distribution. Outside of the mosquito and oestrid fly seasons, caribou generally used the Coast and North sections significantly less than other sections. During all seasons except winter, the Southeast

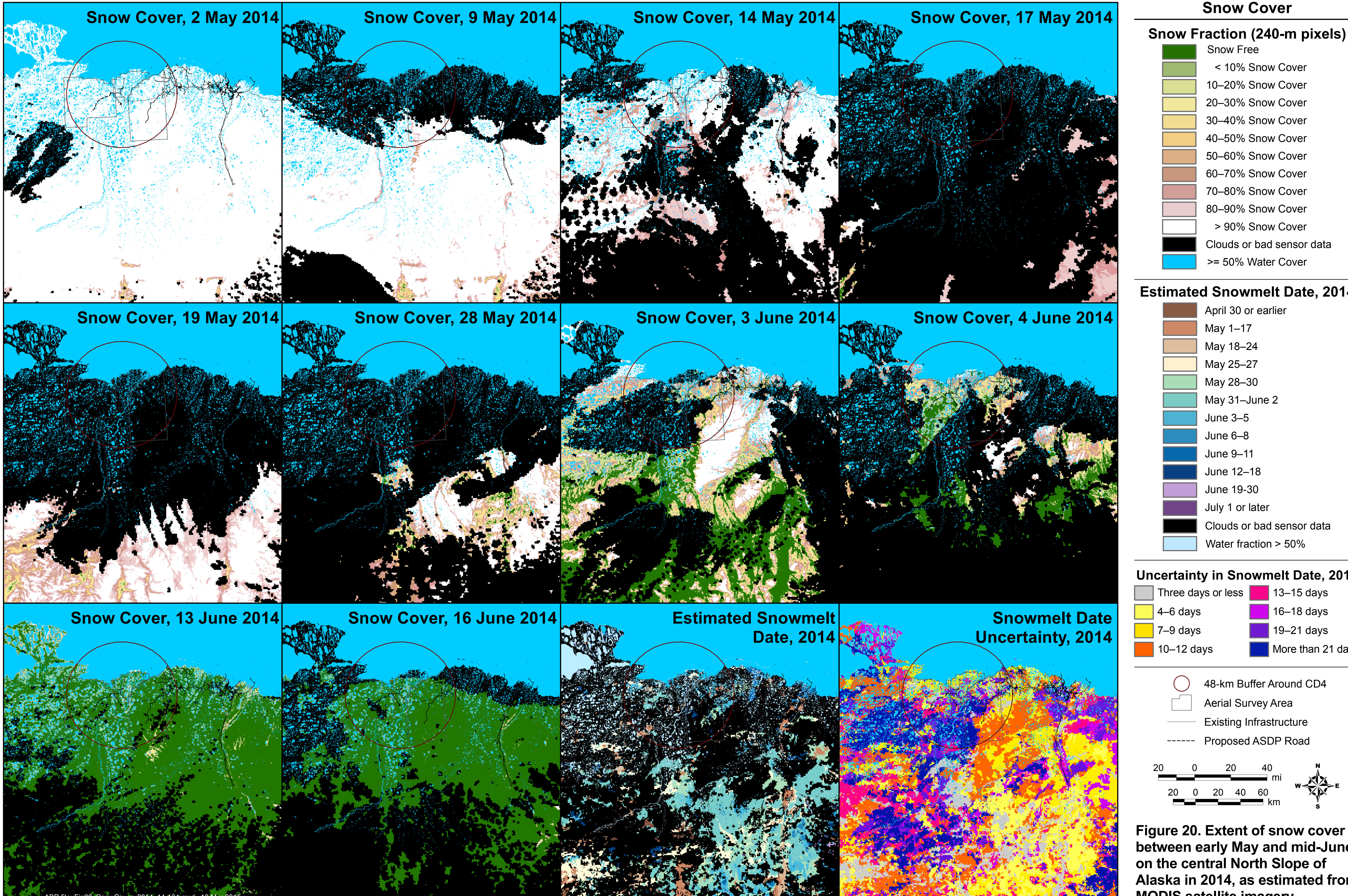


Figure 20. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2014, as estimated from MODIS satellite imagery.

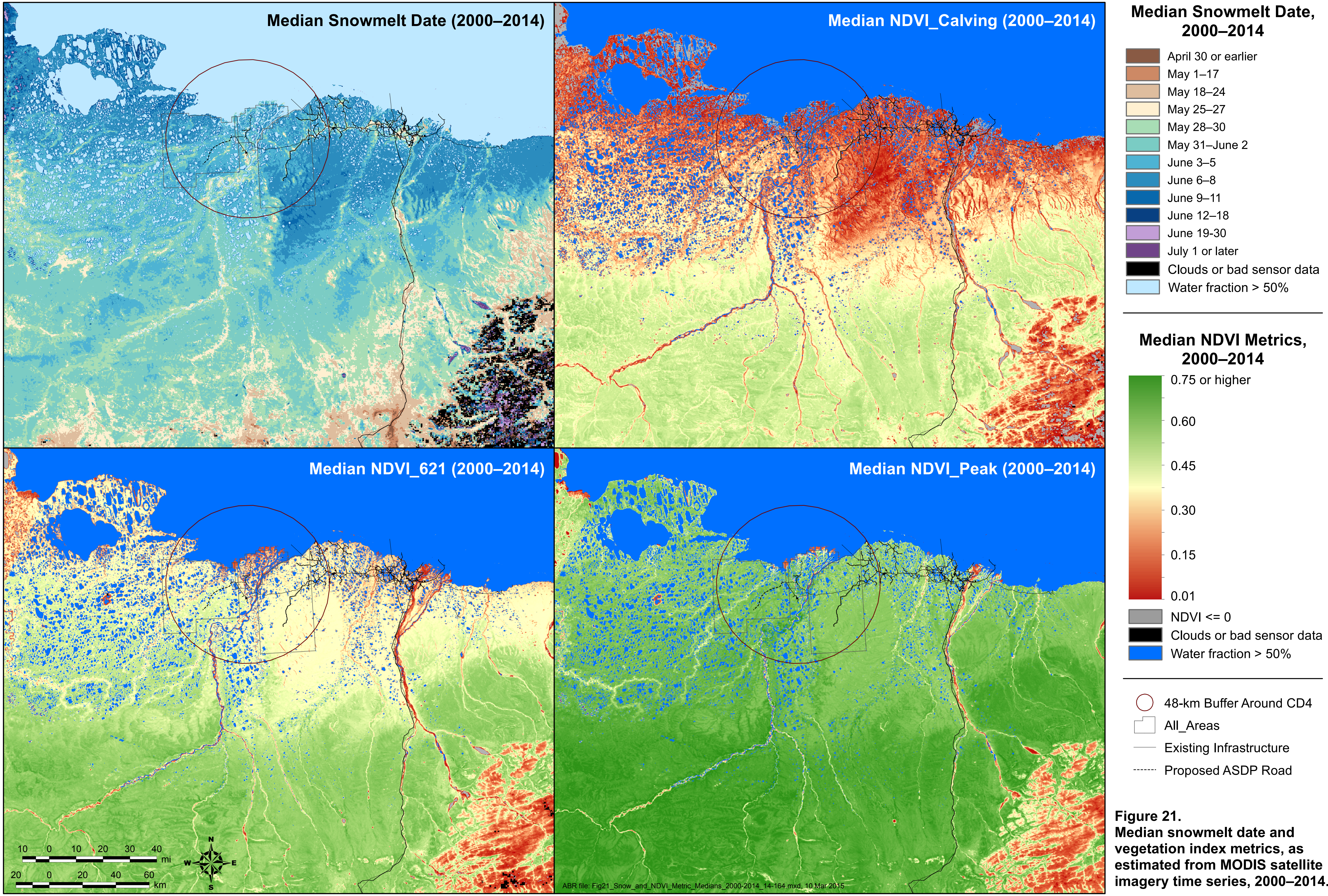
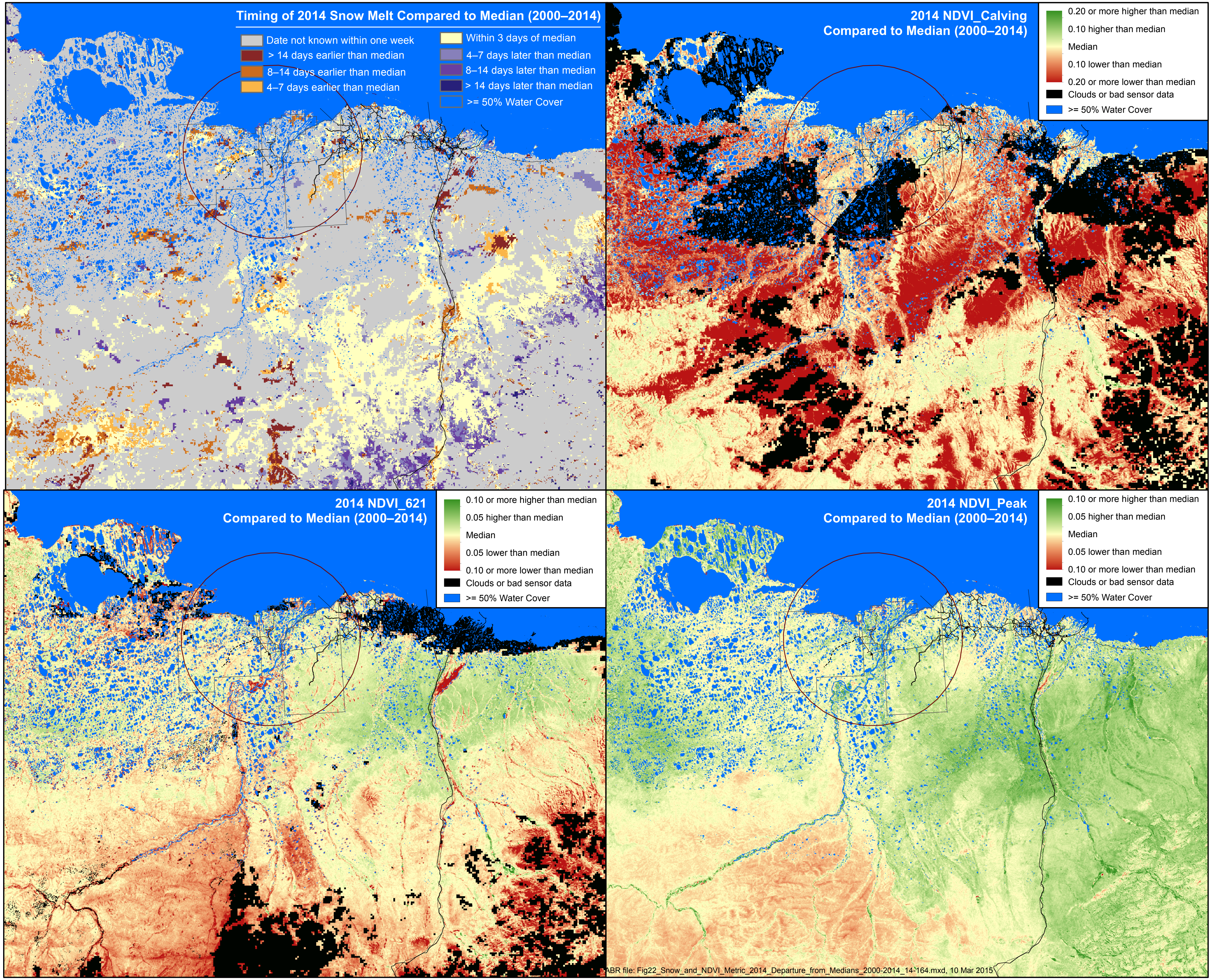


Figure 21.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2014.



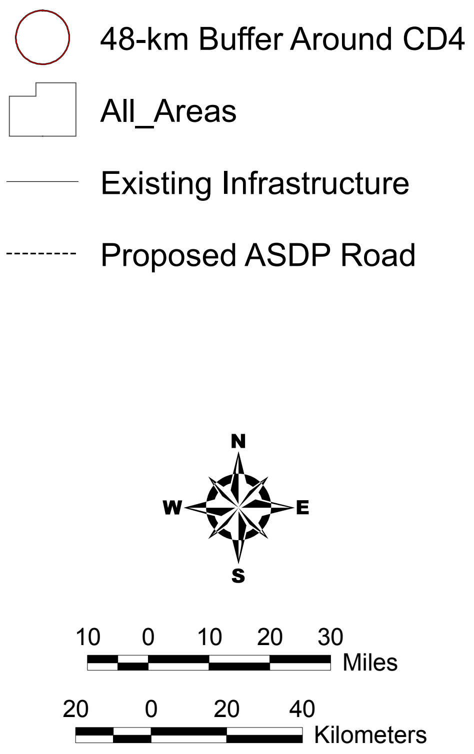


Figure 22. Departure of 2014 values from median snowmelt date and vegetation index metrics (2000–2014), as estimated from MODIS satellite imagery time series.

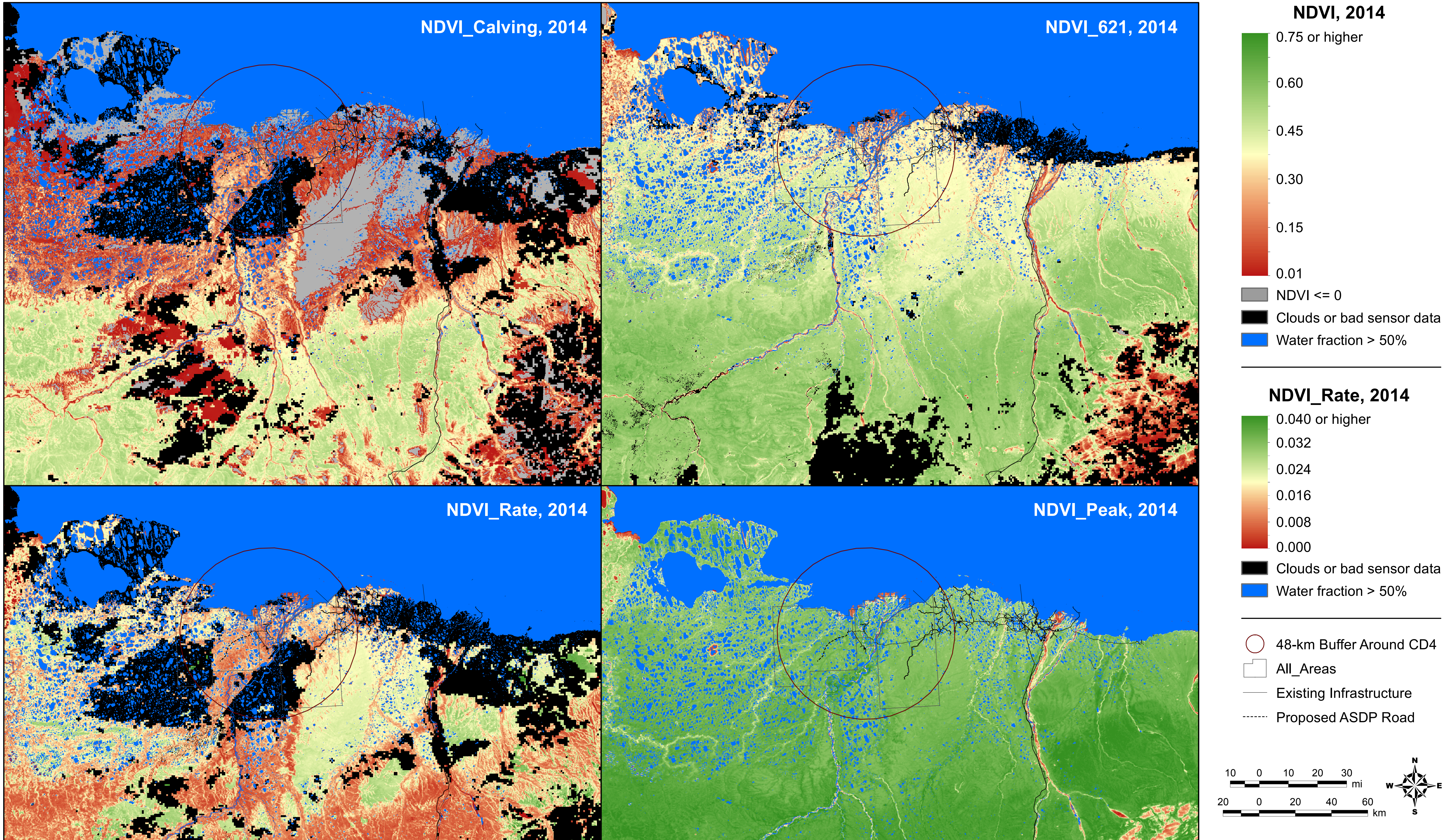


Figure 23.
Metrics of relative vegetative biomass during the 2014 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

Table 3. Caribou use of different geographic sections of the NPRA survey area, by year and season, as measured by preference–avoidance analysis (use divided by availability) and chi-square goodness-of-fit tests (assuming a uniform distribution).

				Geographic Section						
Year(s)	Season	No. of Surveys	Total Groups	Coast	North	River	Southeast	Southwest	Chi-square Value	*P*-value
2014	Winter	1	33	0.61	0.53	0.63	0.79	2.31^{++}	15.32	0.004
	Spring Migration	1	0	–	–	–	–	–	–	–
	Calving	1	14	0	0.63	0.74	0.79	2.38	7.80	0.099
	Postcalving	1	36	0--	1.59	1.73	0.51	0.79	12.75	0.013
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	25	0	0.53	1.25	1.18	1.52	5.74	0.219
	Late Summer	1	38	0.26-	0.23--	0.96	1.85^{+}	1.13	14.75	0.005
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	6	146	0.21--	0.72	1.10	1.06	1.50^{+}	19.95	0.001
2002–2014	Winter [a]	8	594	0.49--	0.78--	1.01	0.90	1.61^{++}	81.50	<0.001
	Spring Migration	10	421	1.08	1.56^{++}	0.91	0.69--	1.02	34.09	<0.001
	Calving	14	1,078	0.35--	1.02	0.92	0.73--	1.65^{++}	167.09	<0.001
	Postcalving	13	1,230	0.37--	1.33^{++}	1.62^{++}	0.60--	0.87	225.41	<0.001
	Mosquito	6	102	2.78^{+}	2.34^{++}	1.09	0.35--	0.25--	80.35	<0.001
	Oestrid Fly	12	260	0.63	0.71-	2.22^{++}	0.59--	0.76	108.41	<0.001
	Late Summer	20	893	0.57--	1.01	1.46^{++}	0.77--	1.02	65.82	<0.001
	Fall Migration	17	1,531	0.59--	1.07	1.07	0.80--	1.27^{++}	64.65	<0.001
	Total	100	6,109	0.56--	1.13	1.23	0.73--	1.18^{++}	368.05	<0.001
Available land area (km²), 2002–2004				8.9	64.8	133.7	191.0	148.2		
Available land area (km²), 2005–2014				70.7	160.9	136.0	191.0	148.4		

[a] Only part of the area could be surveyed on 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 ($P < 0.01$).

section, which includes nearly the entire length of the proposed ASDP road alignment, contained significantly fewer groups than did other sections (Table 3).

Most results were not statistically significant for the 2014 sample due to small sample sizes (Table 3). Caribou showed more use of the Southwest section during winter and the Southeast section during late summer, whereas the Coast section was used significantly less during postcalving, as were the Coast and North sections during late summer.

These results are interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain. During calving, the highest densities of TH females typically calve near Teshekpuk Lake, so densities decrease with increasing distance away from the lake (Person et al. 2007, Parrett 2009, Wilson et al. 2012). Hence, more caribou are likely to occur in the western portion of the NPRA survey area in that season than in the eastern portion. The TH calving range has expanded in recent years, however, including more calving activity southeast of Teshekpuk Lake, and use of the area near Ocean Point on the Colville River has increased somewhat during postcalving (L. Parrett, ADFG, pers. comm.).

When mosquito harassment begins in late June or early July, caribou move toward the coast where lower temperatures and higher wind speeds prevail. When oestrid flies emerge, typically by mid-July, the large groups that formed in response to mosquito harassment begin to break up and caribou disperse, seeking elevated or barren habitats such as sand dunes, mudflats, and river bars (Lawhead 1988, Person et al. 2007, Wilson et al. 2012). The riverine habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3; Appendix J) that provide good fly-relief habitat near foraging areas.

The Southwest section consistently contained higher densities of caribou than did the Southeast section. The reasons underlying this difference are not known for certain, but examination of telemetry data suggests that it may be related to the greater distance of the latter section from Teshekpuk Lake and its location on the fringe of the TH range. Whatever the reason(s), it is important to recognize that this pattern of distribution exists before construction of the proposed ASDP pipeline/road corridor.

DISTANCE TO PROPOSED ROAD

Caribou groups were observed within 6 km of the proposed ASDP alignment on 5 out of 6 surveys in 2014, with only one group observed in that area during the calving survey. In 2014, the number of caribou groups observed in each distance-to-road zone around the proposed ASDP alignment did not differ significantly in any season from expected values based on a uniform distribution among zones (Table 4). For all years combined (2001–2014), the number of caribou groups observed in each distance-to-road zone around the proposed ASDP road alignment did not differ significantly from a uniform distribution in any season, with one exception: significantly fewer groups occurred within 2–4 km south of the road alignment during the mosquito season (Table 4; Appendix K).

Analysis of caribou density produced similar results. Caribou density within 6 km of the proposed alignment (Figure 24) was significantly lower during the combined mosquito and oestrid fly seasons than during calving, postcalving, and fall migration (all $P < 0.008$; the 2005 oestrid fly season survey with large groups was dropped from the analysis to avoid undue influence on test results). Density was significantly lower in late summer than during calving ($P = 0.03$), postcalving ($P = 0.003$), and fall ($P = 0.007$). No other seasons differed significantly ($P > 0.05$).

Over all seasons combined, no significant differences in caribou density were found among the 5 distance zones ($P = 0.566$). A significant season-by-zone interaction was detected ($P < 0.001$). Within seasons, however, no significant differences were found among zones and no significant differences were found ($P > 0.05$) when comparing the middle zone (within 2 km of the road) with the other distance zones to the north and south.

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

Table 4. Number of caribou groups in distance-to-proposed-road zones by year (2014 only and 2001–2014 combined) and season, with results of a chi-square goodness-of-fit test (assuming a uniform distribution).

				Distance Zone (km)						
Year(s)	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	Middle 0–2	South 2–4	South 4–6	Chi-square Value	*P*-value
2014	Winter	1	8	2	1	2	3	0	3.18	0.529
	Spring Migration	1	–	–	–	–	–	–	–	–
	Calving	1	1	0	0	0	1	0	4.50	0.342
	Postcalving	1	5	0	1	0	1	3	7.39	0.117
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	9	0	2	3	3	1	3.76	0.439
	Late Summer	1	19	3	2	2	4	8	8.63	0.071
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	6	42	5	6	7	12	12	8.58	0.072
2001–2014	Winter [a]	8	140	19	29	40	32	20	6.58	0.160
	Spring Migration	11	84	14	11	27	17	15	0.96	0.916
	Calving	15	235	45	35	62	39	54	6.87	0.146
	Postcalving	15	325	62	52	105	47	59	2.13	0.712
	Mosquito	7	18	5	3	6	0--	4	4.66	0.325
	Oestrid Fly	14	54	17	11	10	8	8	10.30	0.036
	Late Summer	22	230	44	44	71	33	38	2.75	0.600
	Fall Migration	20	405	58	63	142	67	75	3.66	0.453
	Total	112	1,491	264	248	463	243	273	2.69	0.611
Area (km^2) surveyed in 2001for baseline density analysis [b]				29.9	30.5	56.1	30.6	31.3		
Area (km^2) surveyed in 2002–2004 for baseline density analysis				29.7	32.4	64.1	35.0	34.9		
Area (km^2) surveyed in 2005–2013 for baseline density analysis				37.2	33.5	64.1	35.0	34.9		
Area (km^2) surveyed in 2014 for baseline density analysis [c]				37.2	25.9	46.6	31.3	31.1		

[a] Only part of the area could be surveyed on one survey.
[b] Average of different-sized survey areas.
[c] Adjusted to remove area within 4 km of new CD5 access road and Nuiqsut Spur Road.
-- Use less than expected ($P < 0.01$).

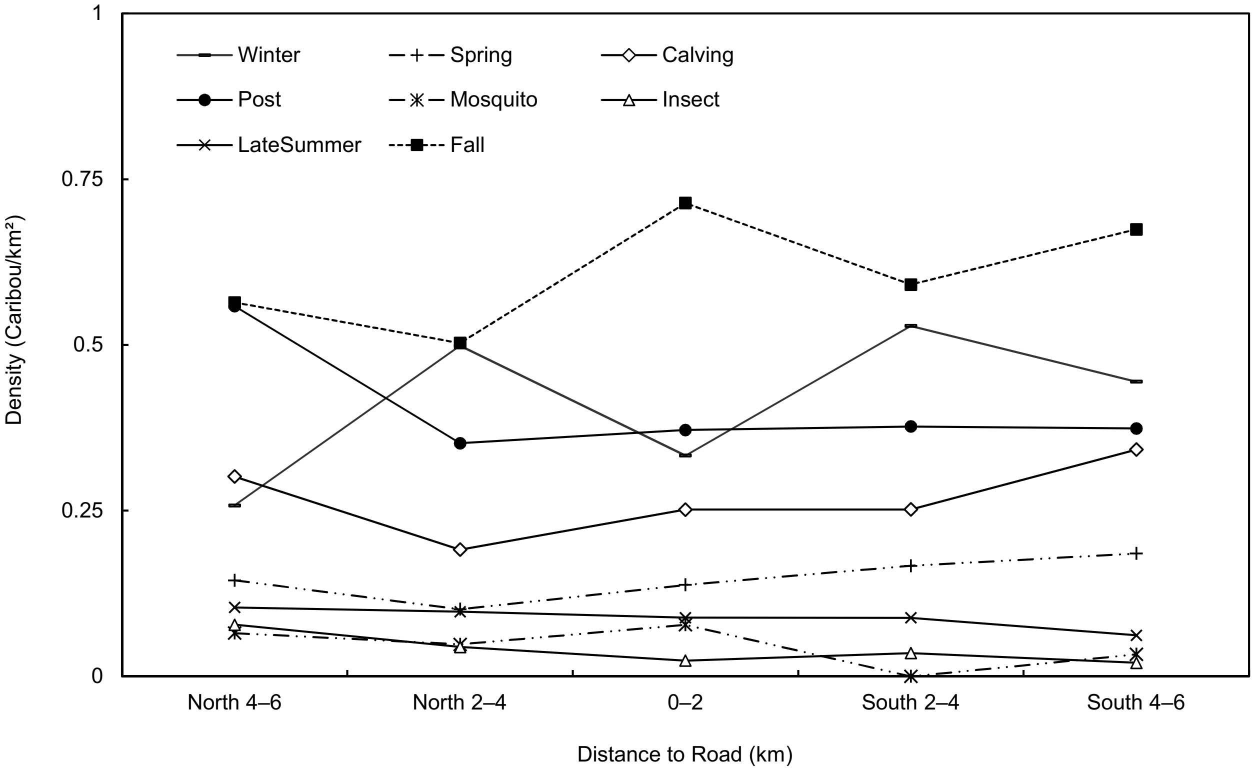


Figure 24. Density of caribou in 2-km-wide zones north and south of the proposed ASDP road, based on aerial transect surveys during 8 different seasons in 2001–2014.

mosquito and oestrid fly seasons, but large groups did occur occasionally in the NPRA survey area during these seasons, as was documented by the aerial survey on 2 August 2005 and the large movement of CAH caribou into the NPRA survey area in July 2001. Aerial-transect survey coverage during the mosquito and oestrid fly seasons has been sparse due to the difficulty of adequately sampling the highly variable occurrence of caribou at that time of year with that survey method. Caribou density in other seasons was fairly consistent and did not exhibit a pattern with regard to distance from the proposed road alignment.

HABITAT USE

Caribou group locations during transect surveys were significantly related to the distribution of habitat types derived from 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 among years (Table 5; Appendix L). As in the geographic analysis above, the pooled-year samples provided larger sample sizes, so this section focuses primarily on those results rather 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 (2002–2014), caribou groups avoided flooded tundra and preferred riverine, low shrub, sedge/grass meadow, moss/lichen, and dwarf shrub habitat types (Table 5). Riverine habitats were preferred during the postcalving, mosquito, and oestrid fly seasons and in late summer, generally consistent with the geographic analysis described above, but were avoided during winter, spring migration, and calving. Dwarf shrub was preferred during winter, postcalving, oestrid fly season, late summer, and fall migration. Tussock tundra was preferred during calving but was avoided during summer (mosquito, oestrid fly, and late summer seasons). The wet sedge (*Carex aquatilis*) type was preferred during the mosquito and oestrid fly

Table 5. Seasonal use of different habitat types by caribou in the NPRA survey area in 2014 alone and 2002–2014 combined, expressed as use (% of the area within 100 m of each group excluding water) divided by availability (% of area excluding water). Significance was determined with a bootstrap analysis of randomly generated locations.

				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]
2014	Winter	1	8	0.69	0.85	1.03	1.07	1.17	0.51	1.59	1.77	0.10
	Spring Migration	1	0	–	–	–	–	–	–	–	–	–
	Calving	1	1	1.11	0.91	0.73	1.16	1.13	0.04	0.91	9.26^{+}	0.02
	Postcalving	1	5	0.66	0.65	0.98	1.21	1.23	2.17	0.86	1.50	1.00
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	9	1.01	0.97	1.22	1.11	0.95	0.69	1.81	0.00	1.38
	Late Summer	1	19	0.84	1.12	1.26	0.74	1.14	1.30	0.57	1.14	0.46
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	6	42	0.81	0.90	1.08	1.03	1.14	1.11	1.12	1.97	0.62
2002–2014	Winter [c]	8	569	1.06	1.00	1.00	0.94	1.05	0.75-	1.28^{+}	1.04	0.48--
	Spring Migration	10	421	1.07	1.03	0.99	1.22^{++}	0.94	1.02	0.80	0.82	0.51--
	Calving	14	1,065	0.93	0.87--	0.92^{-}	1.19^{++}	1.05^{++}	0.90	0.96	0.86	0.78-
	Postcalving	13	1,199	0.85--	0.86--	1.04	1.05^{+}	0.99	1.27^{+}	1.16^{+}	1.89^{++}	1.51^{++}
	Mosquito	6	102	1.52^{++}	0.95	0.93	1.17	0.70--	1.88^{+}	1.06	0.67	2.52^{+}
	Oestrid Fly	12	244	1.25^{+}	1.11	1.08	0.61--	0.63--	2.53^{++}	1.37^{+}	1.87	4.59^{++}
	Late Summer	20	874	1.02	0.99	1.02	0.80--	0.86--	1.81^{++}	1.35^{++}	1.49	2.67^{++}
	Fall Migration	17	1,531	0.99	0.93--	0.99	1.00	1.01	1.37^{++}	1.14^{+}	1.04	1.01
	Total	90	6,005	0.99	0.93--	0.99	1.02^{++}	0.97	1.30^{++}	1.14^{++}	1.25^{+}	1.39^{++}
Availability, 2002–2004				8.3%	20.1%	11.0%	14.2%	39.2%	1.4%	3.3%	0.2%	2.4%
Availability, 2005–2014				8.4%	18.7%	10.5%	16.5%	37.3%	1.5%	3.2%	0.2%	3.7%

[a] Derived from NPRA earth-cover classification (BLM and Ducks Unlimited 2002); tall shrub type (Figure 3) did not occur in the NPRA aerial survey area.
[b] Riverine type comprises dunes/dry sand, sparsely vegetated, and barren ground/other cover classes.
[c] Only part of the area could be surveyed on 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 ($P < 0.01$).

seasons but was avoided during postcalving. Flooded tundra was avoided during calving, postcalving, and fall migration. Wet tundra was avoided during calving but use of that type did not differ from expected values during any other season. Sedge/grass meadow was preferred during spring migration, calving, and postcalving, but was avoided during the oestrid fly season and late summer. The moss/lichen type, which occurred in higher proportions in riverine areas, was preferred during the postcalving, mosquito, oestrid fly, late summer, and fall migration seasons, and was avoided in winter.

The few caribou found in the NPRA survey area during the calving season appear to seek dry, snow-free areas and avoid wet and flooded tundra. Comparison across studies is complicated by the fact that different investigators have used different habitat classifications. Kelleyhouse (2001) and Parrett (2007) reported that TH caribou selected wet graminoid vegetation during calving and Wolfe (2000) reported that CAH caribou selected wet graminoid or moist graminoid classes; those studies used the vegetation classification by Muller et al. (1998, 1999). Using a habitat classification similar to the one 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 habitats based on the NPRA earth-cover classification (BLM and Ducks Unlimited 2002), we found that caribou in the NPRA survey area (which is not an important calving area) preferred sedge/grass meadow and tussock tundra and avoided wet tundra, flooded tundra, and riverine areas. Wilson et al. (2012) used the same habitat classification and TH telemetry data to investigate summer habitat selection at 2 different spatial scales, concluding that TH caribou consistently avoided patches of flooded vegetation and selected areas of sedge/grass meadow.

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

The proportion of various habitats differs among the distance zones around the proposed ASDP road alignment (Table 6), due mainly to the presence of Fish and Judy creeks to the north of the proposed alignment and the corresponding increase in riverine habitats there. The proportion of sedge/grass, wet tundra, flooded tundra, and *Carex aquatilis* habitats are higher in the north and the proportion of tussock tundra generally is higher in the southern portion of the survey area. Future evaluations of caribou distribution after construction of the proposed GMT1 and GMT2 infrastructure will need to incorporate these differences in habitat availability and use by caribou.

SNOW COVER

Comparison of snow cover (3–4 June) with the locations of caribou groups in NPRA during calving on 8 June 2014 indicated that the use of areas with snow cover did not differ from the availability of those areas ($P > 0.05$; Table 7). However, the sample size was low because snow-cover estimates could not be obtained for large areas that were under cloud cover during the snow-melt period. For areas where snow cover was estimated, the average snow cover in the NPRA survey area on 3–4 June was only 31.5% and varied between 10% and 53% among different geographic sections of the NPRA survey area (Appendix M). Snow cover averaged 14% at the locations of the 4 caribou groups seen on the calving survey in areas where snow cover was estimated, but this sample was too small for meaningful statistical analysis. Caribou selection for snow cover during calving has been variable among years, possibly because the variable timing of snow melt among years (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2014a).

Previous studies have not produced consistent results concerning the calving distribution of northern Alaska caribou herds in relation to snow cover. Kelleyhouse (2001) concluded that TH females selected areas of low snow cover during

Table 6. Area (percentage) of habitat types (water and other types calculated separately) within distance-to-road zones north and south of the proposed ASDP road alignment in the NPRA survey area. Distance-to-road zones for 2014 exclude areas within 4 km of the newly constructed CD5 access road and Nuiqsut spur road.

			Habitat Type[a]								
Year(s)	Distance Zone (km)	Water	*Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine[b]
Pre-2014	North 4–6	19.1	8.8	26.1	12.3	8.8	33.2	3.3	1.9	0.2	5.6
	North 2–4	15.1	9.0	26.1	11.6	10.0	38.3	0.8	3.0	0.6	0.6
	Middle 0–2	15.0	8.0	21.5	11.4	10.0	45.7	0.6	2.4	0.3	0.1
	South 2–4	15.1	7.1	18.4	8.3	6.4	54.6	0.2	4.3	0.6	0.1
	South 4–6	14.9	7.1	20.3	8.0	6.4	54.2	0.2	3.3	0.3	<0.1
2014	North 4–6	19.1	8.8	26.1	12.3	8.8	33.2	3.3	1.9	0.2	5.6
	North 2–4	14.5	8.6	23.7	11.0	10.5	40.6	0.6	3.5	0.7	0.7
	Middle 0–2	12.4	6.4	18.3	10.9	11.3	49.5	0.6	2.7	0.2	0.1
	South 2–4	8.6	6.8	17.0	8.4	6.7	55.9	0.2	4.4	0.6	0.1
	South 4–6	7.3	6.1	18.5	8.2	7.0	56.1	0.2	3.5	0.4	<0.1

[a] Derived from NPRA earth-cover classification (BLM and Ducks Unlimited 2002); percentages calculated for terrestrial habitats (excluding water); tall shrub type (Figure 3) did not occur in the NPRA aerial survey area.
[b] Riverine type comprises dunes/dry sand, sparsely vegetated, and barren ground/other cover classes.

Table 7. Estimated vegetative biomass (expressed as mean NDVI values) and snow cover at locations used by caribou groups in the NPRA survey area during different seasons in 2014, compared with availability using a bootstrap analysis. Sample sizes (n) are in parentheses.

Season	NDVI Calving [a]		NDVI 621 [a]		NDVI Rate [a]		NDVI Peak [a]		Snow Cover (%) [b]	
Winter	0.1463	(19)	0.4078^{+}	(29)	0.0154	(17)	0.5990^{++}	(31)	22.5	(15)
Spring Migration										
Calving	0.1698	(5)	0.4283^{++}	(11)	0.0172	(5)	0.5963	(11)	14.0	(4)
Postcalving	0.1053	(21)	0.3821	(33)	0.0153	(21)	0.5840	(33)	34.0	(20)
Mosquito										
Oestrid Fly	0.1383	(16)	0.3789	(21)	0.0143	(16)	0.5743	(21)	23.7	(16)
Late Summer	0.179^{++}	(25)	0.3905	(37)	0.0124--	(25)	0.5855	(37)	11.3--	(25)
Fall Migration										
Total Use	0.145^{++}	(86)	0.3935^{+}	(131)	0.0144	(84)	0.5874^{+}	(133)	21.7--	(80)
Available	0.1162		0.3784		0.0147		0.5774		31.5	

[a] Caribou groups in pixels with >50% water fraction were excluded from the analysis.
[b] Snow cover on 3–4 June 2014.
$^{+}$ Use greater than expected ($P < 0.05$).
$^{++}$ Use greater than expected ($P < 0.01$).
-- Use less than expected ($P < 0.01$).

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 PH caribou 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 variability in detection of snowmelt dates on satellite imagery because of cloud cover.

VEGETATIVE BIOMASS

In 2014, caribou in NPRA selected areas with high values of NDVI_621 and NDVI_Peak during winter, high NDVI_621 during calving, and high NDVI_Calving and low NDVI_Rate in late summer (Table 7). Due to persistent cloud cover during early June, however, the biomass variables NDVI_Calving and NDVI_Rate were not available for many caribou group locations, so this analysis is not a strong test of caribou selection for those metrics. Most caribou groups observed during the late summer survey in 2014 were in the Southeast and Southwest sections of the NPRA survey area (Figure 5). In general, those inland areas had higher estimated biomass and lower values of NDVI_Rate than did the Coast, North, and River sections (Figure 23; Appendix M).

We used NDVI to estimate biomass in this study because other researchers have reported significant relationships between caribou distribution and the biomass variables NDVI_Calving, NDVI_621, and NDVI_Rate during the calving period. Griffith et al. (2002) reported that the annual calving grounds used by the PH 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 PH was strongly positive, as was the relationship between NDVI_Calving and the percentage of marked females calving on the coastal plain of ANWR (Griffith et al. 2002).

Female caribou of both the CAH and TH have been reported to select areas of high NDVI_Rate (Wolfe 2000, Kelleyhouse 2001). In contrast, female caribou of the WAH selected areas with high NDVI_Calving and NDVI_621 (Kelleyhouse 2001). Kelleyhouse (2001) suggested that geographical differences in phenology may account for the differences among herds. The calving grounds of the CAH and TH typically are colder and covered with snow later than are those of the WAH, so the chronology of forage development and selection in early June likely differs accordingly. Caribou select areas of patchy snow cover and high NDVI_Rate during the period of snow melt but select high biomass (NDVI_621) after tussock cottongrass (*E. vaginatum*) flowers are no longer available (Kelleyhouse 2001, Johnstone et al. 2002).

In the eastern portion of the ASDP study area (i.e., the Meltwater study area of Lawhead et al. 2004), caribou use of areas with 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 snow 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 above analyses adjusted NDVI_Calving or NDVI_Rate for the effects of snow melt. Hence, unless snow melt always occurred before calving, the analytical results probably are more strongly related to temporal and spatial differences in snow melt than to differences in vegetative biomass.

CARIBOU DENSITY ANALYSIS

NPRA Survey Area

Spatial density mapping of caribou recorded during aerial surveys in the NPRA survey area showed large differences among seasons (Figure 25). During most seasons, a decreasing gradient in caribou density from west to east was apparent. The highest mean density levels were observed during the oestrid fly season, but those densities were strongly affected by just a few large groups that were observed in 2005.

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 2014 and among all seasons for the years 2002–2014. A number of variables used in the grid-cell analyses were correlated, so we examined the relationships among vegetation, snow, and habitat variables calculated for the 164 grid cells before conducting the density analyses.

After removing one grid-cell outlier on the outer Colville delta that was largely unvegetated, the 2014 estimated peak vegetative biomass (NDVI_Peak) was highly correlated with NDVI_621 ($r = 0.819$; $P < 0.001$). These results indicate that the spatial pattern of NDVI values after snow melt is consistent throughout the snow-free period. NDVI_Peak in 2014 was highly correlated with the NDVI_Peak in 2013 ($r = 0.951$; $P < 0.001$), 2012 ($r = 0.912$; $P < 0.001$), 2011 ($r = 0.932$; $P < 0.001$), and 2010 ($r = 0.938$; $P < 0.001$). This consistent spatial pattern of NDVI_Peak can be explained largely by differences among habitat types. NDVI_Peak in 2014 increased with an increasing proportion of tussock tundra ($r = 0.747$; $P < 0.001$), but decreased in wetter habitats (*Carex aquatilis*, wet tundra, flooded tundra, and sedge/grass meadow classes combined; $r = –0.469$; $P < 0.001$) and in riverine habitats ($r = –0.659$; $P < 0.001$). 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

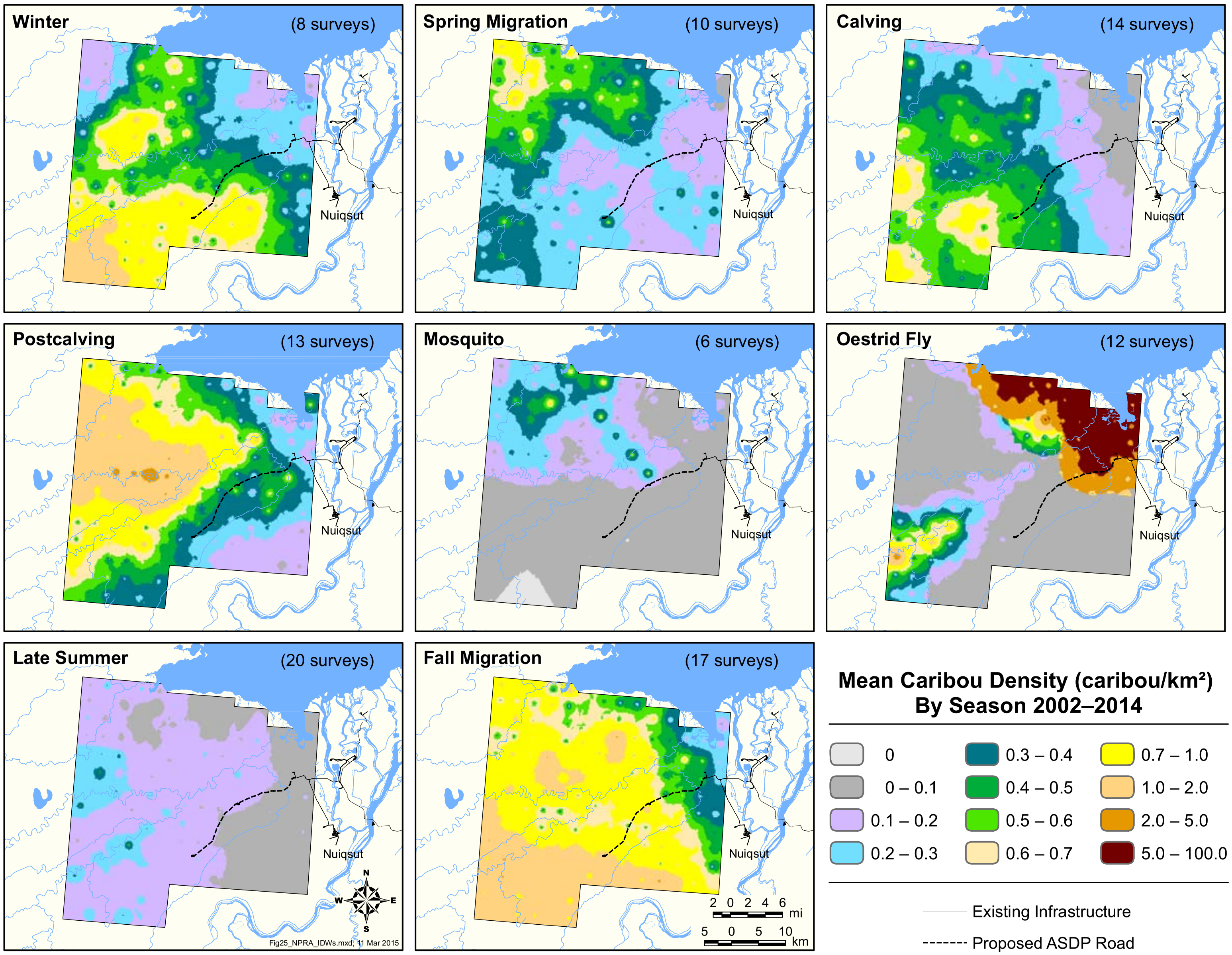


Figure 25. Mean caribou density in the NPRA survey area during 8 different seasons in 2002–2014.

significant ($r = -0.426$; $P < 0.001$), suggesting that even small waterbodies depressed NDVI values.

The snow-cover fraction in the NPRA survey area on 3–4 June 2014 was negatively correlated with NDVI_Calving ($r = -0.892$, $P = 0.001$), NDVI_621 ($r = -0.571$, $P = 0.001$), NDVI_Peak ($r = -0.512$, $P < 0.001$), and positively correlated with NDVI_Rate ($r = 0.680$, $P = 0.001$). In general, the NDVI values measured in early June are a function of snow cover, so that NDVI_Calving and NDVI_Rate may reflect snow cover and snow melt more than vegetative biomass. Other factors (such as temperature, habitat type, and standing water) become more important influences on NDVI values after snow melt. Early in spring, much of the first snow melt occurs along Fish and Judy creeks, an area that also has low vegetative biomass. The snow melt results in 2014 may have been influenced by the large area that was covered by cloud cover in early June and thus unavailable for biomass estimation.

Calving Season

Only 14 groups of caribou were observed in the NPRA survey area on the 2014 calving survey and no estimates of NDVI_Calving, NDVI_Rate, or snow cover could be obtained over a large portion of the area, so a meaningful density analysis could not be performed. Caribou densities in the NPRA survey area during past calving surveys indicated a preference for areas with higher NDVI_Peak values in most years. The variables for NDVI, tussock tundra, and wet habitats are correlated to some degree. 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 during calving in this area. 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 *E. vaginatum*, forbs, and lichens, however. The between-year correlations of caribou density during calving were low for 2005–2012 (Spearman's rho = –0.062–0.417), suggesting that different factors influenced caribou distribution among years at the scale of this analysis. Caribou appear to select slightly drier areas with abundant tussock tundra during calving and those areas tend to have high NDVI values in both late June and midsummer.

All Seasons

Using the combined sample across all years and seasons, different variables were significantly related to caribou density in the NPRA survey area among seasons (Table 8; Appendices N and O). During all seasons except the oestrid fly season, caribou density was lower in the eastern portion of the survey area than in the western portion, the presence of the proposed road was not significantly related to density (road was not included in oestrid season models because the models failed to converge), and density varied significantly among surveys.

During winter, caribou density was higher in areas with more tussock tundra and high NDVI_Peak values and was lower in the River, Northern, and Southeast sections than in the Southwest section (Table 8; Appendix O).

During calving, the model-weighted parameter estimates indicated that caribou density was greater in areas of higher NDVI_Peak values, at greater distances from the coast, and in areas with a higher proportion of tussock tundra, and was higher in the Southwest section than in the other 4 geographic sections. Calving density was lower in areas with greater proportions of wet habitat (Table 8; Appendix O).

During postcalving, caribou density was higher near the creeks and in areas with more tussock tundra and higher peak biomass, and was lower in wet habitats and with increasing distance from the coast. Caribou density was higher in the Northern and River sections and lower in the Coast and Southeast sections (Table 8; Appendix O).

During the mosquito season, caribou density was higher with decreasing distance from the coast and was higher in the Coast, River, and Northern sections than in the Southwest section. During the oestrid fly season, density was higher near the creeks and with increasing distance from the coast and was lower in areas with higher peak biomass and in the Coast section (Table 8; Appendix O).

Table 8. 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, 2002–2014.

Variable	Winter	Spring Migration	Calving	Post calving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
Presence of creeks	-	ns	ns	++	ns	++	++	ns
Presence of proposed road [a]	ns	ns	ns	ns	ns		ns	ns
Survey	**	**	**	**	**	**	**	**
NDVI_Peak	++	ns	++	++	ns	-	-	ns
Distance to coast	ns	ns	++	--	--	++	ns	ns
Tussock tundra (%)	+	ns	++	++	ns	ns	ns	ns
Wet habitats (%)	ns	ns	--	-	ns	ns	ns	ns
West to East (transect number)	--	--	--	--	--	ns	--	--
Section (Coastal) [b]	ns	ns	--	-	++	-	-	-
Section (Northern) [b]	--	ns	--	++	++	ns	ns	ns
Section (River) [b]	--	ns	--	++	++	ns	ns	ns
Section (Southeast) [b]	--	ns	--	--	ns	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 ($P < 0.05$)
** Significantly different among surveys ($P < 0.01$).
[a] Road not included in the model for oestrid fly season.
[b] Compared to Southwest section.

In late summer, density was higher near the creeks and was lower in areas with higher peak biomass values and in the Southeast and Coast sections. During fall migration, the Coast and Southeast sections had lower densities than did the Southwest section (Table 8; Appendix O).

Overall, strong seasonal patterns in caribou density were evident. A west-to-east gradient of decreasing density was evident throughout the entire year, presumably 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 for much of the summer. The riverine area is characterized by a mosaic of habitats, including abundant willows and forbs that provide forage, as well as barrens, dunes, and river bars that provide some relief from oestrid fly harassment. Caribou densities near the coast were higher during the postcalving and mosquito seasons, which is 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, postcalving, and winter. During calving, tussock tundra provides abundant forage, such as *E. vaginatum*, as well as drier microsites during the seasonal flooding that accompanies snow melt. Throughout the year, no evidence was found to indicate that the area around the proposed ASDP road alignment in NPRA was used by caribou to a different degree than adjacent areas, which is consistent with the results of the distance-to-road zone analysis.

Colville East Survey Area during Calving

Caribou density in Colville East was best described by the model that contained a west-to-east gradient, the proportion of water-bodies in the area, distance to coast, and presence of wet habitat (Appendix P). This model had an estimated 13.7% probability of being the best model in the candidate set. The second-best model, which had the same variables except for the proportion of wet habitat, had an estimated 13.2% probability of being the best model. Other models with various combinations of these variables also had some level of support (Appendix P). The variables west-to-east gradient, proportion of waterbodies, and distance to coast were included in all models. Based on the model-weighted parameter estimates, caribou density in the Colville East survey area in the 2014 calving season increased with distance from the coast ($P < 0.001$) and from west to east ($P < 0.001$). No other model-weighted parameters were significant (Table 9).

CONCLUSIONS

Analysis of VHF, satellite, and GPS telemetry data sets covering nearly 3 decades clearly demonstrates that the ASDP study area (a 48-km-radius circle centered on CD4 and including the Colville River delta) is at the interface of the annual ranges of the TH and CAH. The CD4 drill site is located in an area that is used sporadically by caribou from both herds. 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 during fall migration. Because TH caribou use the western half of the ASDP study area year-round, detailed analyses of caribou distribution and density for this report focused primarily on the NPRA survey area, which encompasses the proposed ASDP road alignment. In contrast, the CAH uses the eastern half of the ASDP study area primarily during the calving season (including high-density calving in the southern part of the Colville East survey area) and the postcalving season; CAH use of the study area is more variable during the mosquito and oestrid fly seasons.

In most years, use of the Colville delta by satellite- and GPS-collared caribou peaked during the summer insect season (mosquito and oestrid fly periods, from late June to early August), primarily involving CAH animals during the mosquito season and both herds during the oestrid fly season. The annual harvest of caribou by Nuiqsut hunters peaks sharply during the months of July and August, with lower percentages 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, 2011, 2012, 2013, 2014). By far, the greatest proportion of the Nuiqsut caribou harvest is taken by boat-based hunters during midsummer (SRBA 2014). The timing of hunting activity in relation to seasonal use of the study area by caribou suggests that caribou harvested on the Colville delta by hunters in July and August primarily were from the CAH in most years, although large groups of TH caribou occasionally occurred on the delta in those months. In contrast, caribou harvested in the study area in October are much more likely to be TH animals migrating to winter range. An exception to this general pattern occurred in summer 2007 when TH caribou used the delta more during the insect season than did CAH caribou (Lawhead et al. 2008). The tendency of many CAH caribou to move east of the

Table 9. Model-weighted parameter estimates for caribou density in the Colville East survey area during the late calving survey, 9–10 June 2014.

Variable	Coefficient	SE	*P*-value
Intercept	–7.598	2.434	0.002
Proportion covered by waterbodies	1.947	1.363	0.153
West to East (transect number)	0.168	0.032	<0.001
Within 2 km of roads	0.458	0.418	0.274
NDVI_Peak	2.870	10.199	0.778
Distance to coast	0.080	0.015	<0.001
Snow cover on 3–4 June	0.005	0.006	0.427
Proportion of wet graminoid tundra (%)	1.396	0.924	0.131

Sagavanirktok River during much of the insect season in the last decade has resulted in fewer caribou from that herd using the delta in midsummer. The movements of collared caribou in the last 2 years, however, suggest that moderate numbers of CAH caribou have moved onto the Colville delta in July.

Although large groups of caribou from both herds occasionally occur on the Colville delta, large movements onto or across the delta are relatively uncommon for either herd and do not occur annually. CAH caribou are somewhat more likely to occur on the delta in summer and TH caribou are more likely to occur in the area during fall or spring migration. Movements by large numbers of TH caribou onto the Colville delta in July 2007 were a notable exception to this generalization. In the last decade, the distribution of the CAH during the mosquito and oestrid fly seasons has shifted farther eastward, so fewer caribou from that herd used the Colville River delta than did so in earlier years. In 2014, however, more CAH caribou remained in the eastern portion of the ASDP study area in midsummer than in other years since about 2004.

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 during fall migration since monitoring began in the 1980s, well before any ASDP infrastructure was built. Two caribou outfitted with radio collars (one from the TH and the other from the CAH) passed within 4 km of CD4 during 2014.

Radio-collared TH caribou in recent years have occasionally crossed the proposed ASDP pipeline/road-corridor alignment extending from CD5 to the proposed GMT2 drill site in NPRA, primarily during July and fall migration, but the proposed alignment is located in a geographic area that currently receives low-density use by caribou from that herd. Only 2 radio-collared caribou (one CAH and one TH) crossed the proposed road corridor in 2014. Over all years, CAH caribou have crossed the proposed alignment only rarely and it is not likely that the proposed pipeline/road corridor would have a large effect on the CAH, judging from their recent movement patterns.

Use of the NPRA survey area by TH caribou varies widely among seasons. These differences are related to snow cover, vegetative biomass, habitat distribution, and distance to the coast. During calving, caribou generally use areas of higher plant biomass (as estimated by NDVI values) and higher proportions of tussock tundra and sedge/grass habitats. 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 2 herds. The density of CAH caribou calving in the Colville East survey area in 2014 was highest in the southeast portion of the Colville East survey area, and CAH caribou did not appear to select areas with high peak biomass or to avoid areas having a high proportion of wet graminoid tundra.

Riverine habitats along Fish and Judy creeks in the western half of the ASDP study area were selected by caribou in the postcalving, oestrid fly, and late summer seasons. The complex mosaic of riverine habitats provides opportunities both for foraging and for relief from oestrid fly harassment. The presence of those 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 Southeast section of the NPRA survey area (in which the proposed road alignment would be located). Very little evidence (restricted to one distance zone during one season) was found 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 or proposed. Detailed analyses of the existing patterns of seasonal distribution, density, and movements are providing a useful record of the ways in which caribou currently use the study area. Both the TH and CAH have recently undergone sharp declines in population due to decreased survival of both adults and calves, particularly after the prolonged winter of 2012–2013, and both herds may be exhibiting changes in long-term patterns of distribution and demography. In recent years, the TH calving distribution has expanded to the west and southeast, the winter distribution has varied widely each year, and some evidence suggests decreasing parturition rates and increasing rates of emigration to other herds (Parrett 2011; L. Parrett, ADFG, pers. comm.). Hence, continued monitoring of caribou distribution and movements in the ASDP study area will provide valuable information for comparison with historical data.

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

Cover Class	Description
Clear Water	Fresh or saline waters with little or no particulate matter. Clear waters typically are deep (>1 m). This class may contain small amounts of *Arctophila fulva* or *Carex aquatilis*, but generally has <15% surface coverage by these species.
Turbid Water	Waters that contain particulate matter or shallow (<1 m), clear waterbodies that differ spectrally from Clear Water class. This class typically occurs in shallow lake shelves, deltaic plumes, and rivers and lakes with high sediment loads. Turbid waters may contain small amounts of *Arctophila fulva* or *Carex aquatilis*, but generally have <15% surface coverage by these species.
Carex aquatilis	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Carex aquatilis*. Small percentages of *Arctophila fulva, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may be present.
Arctophila fulva	Associated with lake or pond shorelines and composed of 50–80% clear or turbid water >10 cm deep. The dominant species is *Arctophila fulva*. Small percentages of *Carex aquatilis, Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris* may be present.
Flooded Tundra–Low-centered Polygons	Polygon features that retain water throughout the summer. This class is composed of 25–50% water; *Carex aquatilis* is the dominant species in permanently flooded areas. The drier ridges of polygons are composed mostly of *Eriophorum russeolum, E. vaginatum, Sphagnum* spp., *Salix* spp., *Betula nana, Arctostaphylos* spp., and *Ledum palustre*.
Flooded Tundra–Non-patterned	Continuously flooded areas composed of 25–50% water. *Carex aquatilis* is the dominant species. Other species may include *Hippuris vulgaris, Potentilla palustris,* and *Caltha palustris*. Non-patterned class is distinguished from low-centered polygons by the lack of polygon features and associated shrub species that grow on dry ridges of low-centered polygons.
Wet Tundra	Associated with areas of super-saturated soils and standing water. Wet tundra often floods in early summer and generally drains of excess water during dry periods, but remains saturated throughout the summer. It is composed of 10–25% water; *Carex aquatilis* is the dominant species. Other species may include *Eriophorum angustifolium*, other sedges, grasses, and forbs.
Sedge/Grass Meadow	Dominated by the sedge family, this class commonly consists of a continuous mat of sedges and grasses with a moss and lichen understory. The dominant species are *Carex aquatilis, Eriophorum angustifolium, E. russeolum, Arctagrostis latifolia,* and *Poa arctica*. Associated genera include *Cassiope* spp., *Ledum* spp., and *Vaccinium* spp.
Tussock Tundra	Dominated by the tussock-forming sedge *Eriophorum vaginatum*. Tussock tundra is common throughout the arctic foothills north of the Brooks Range and may be found on well-drained sites in all areas of the NPRA. Cottongrass tussocks are the dominant landscape elements and moss is the common understory. Lichen, forbs, and shrubs are also present in varying densities. Associated genera include *Salix* spp., *Betula nana*, *Ledum palustre*, and *Carex* spp.
Moss/Lichen	Associated with low-lying lakeshores and dry sandy ridges dominated by moss and lichen species. As this type grades into a sedge type, graminoids such as *Carex aquatilis* may increase in cover, forming an intermediate zone.
Dwarf Shrub	Associated with ridges and well-drained soils and dominated by shrubs <30 cm in height. Because of the relative dryness of the sites on which this cover type occurs, it is the most species-diverse class. Major species include *Salix* spp., *Betula nana*, *Ledum palustre, Dryas* spp., *Vaccinium* spp., *Arctostaphylos* spp., *Eriophorum vaginatum,* and *Carex aquatilis.* This class frequently occurs over a substrate of tussocks.

Appendix A. Continued.

Cover Class	Description
Low Shrub	Associated with small streams and rivers, but also occurs on hillsides in the southern portion of the NPRA. This class is dominated by shrubs 0.3–1.5 m in height. Major species include *Salix* spp., *Betula nana*, *Alnus crispa*, and *Ledum palustre.*
Dunes/Dry Sand	Associated with streams, rivers, lakes and coastal beaches. Dominated by dry sand with <10% vegetative cover. Plant species may include *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Stellaria* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Sparsely Vegetated	Occurs primarily along the coast in areas affected by high tides or storm tides, in recently drained lake or pond basins, and in areas where bare mineral soil is being recolonized by vegetation. Dominated by non-vegetated material with 10–30% vegetative cover. The vegetation may include rare plants, but the most common species include *Stellaria* spp., *Poa* spp., *Salix* spp., *Astragulus* spp., *Carex* spp., *Arctostaphylos* spp., and *Puccinellia phryganodes*.
Barren Ground/ Other	Associated with river and stream gravel bars, mountainous areas, and human development. Includes <10% vegetative cover. May incorporate dead vegetation associated with salt burn from ocean water.

Appendix B. Snow depth (cm) and cumulative thawing degree-days (° C above freezing) at the Kuparuk airstrip, 1983–2014.

	Snow Depth (cm)			Cumulative Thawing Degree-days (° C)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	66.2	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	20	10	0	0	5.0	100.8	112.2	124.7	109.4
1987	15	8	3	0	0.6	6.7	61.4	112.2	127.8	93.1
1988	10	5	5	0	0	16.7	78.1	108.3	143.1	137.5
1989	33	–	10[a]	0	5.6	20.6	109.4	214.7	168.1	215.8
1990	8	3	0	0	16.1	39.7	132.2	145.0	150.0	82.5
1991	23	8	3	0	7.8	14.4	127.6	73.3	115.0	70.6
1992	13	8	0	0.3	20.3	55.0	85.3	113.9	166.1	104.2
1993	13	5	0	0	8.6	33.6	94.4	175.8	149.7	96.1
1994	20	18	8	0	4.4	49.2	51.7	149.7	175.8	222.2
1995	18	5	0	0	1.1	59.4	87.5	162.8	106.9	83.3
1996	23	5	0	8.1	41.7	86.1	121.1	138.9	168.1	95.8
1997	28	18	8	0	20.8	36.1	109.7	101.7	177.8	194.2
1998	25	8	0	3.6	45.8	74.2	135.0	158.9	184.4	174.4
1999	28	15	10	0	1.4	30.3	67.8	173.3	81.1	177.5
2000	30	23	13	0	0	36.7	169.7	113.3	127.5	118.6
2001	23	30	5	0	0.8	51.9	72.2	80.0	183.9	131.7
2002	30	trace	0	4.2	30.3	57.8	70.3	92.2	134.4	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	8.9	26.4	185.6	148.1	151.4	153.3
2005	23	13	0	0	2.5	14.2	78.1	67.5	79.4	176.7
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
2007	25	46	5	0	0	46.4	81.7	115.0	138.9	134.4
2008	20	18	0	0	32.8	71.7	138.9	172.2	132.5	86.1
2009	36	13	0	0	16.7	71.7	44.4	142.8	126.4	133.6
2010	41	43	13	0	1.4	53.3	51.1	126.7	168.9	149.2
2011[a]	25	18	0	0	27.8	12.5	101.2	122.4	171.6	143.2
2012[a]	48	53	2	0	1.7	26.8	137.3	140.2	195.2	143.5

Appendix B. Continued.

Year	Snow Depth (cm)			Cumulative Thawing Degree-days (º C)						
	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
2013	33	18	2	0	4.2	79.2	131.7	112.8	188.0	185.4
2014	33	0[b]	0[b]	11.1	4.2	28.6	82.0	127.2	102.3	67.9
Mean	24.4	15.2	3.1	0.9	11.0	42.2	99.1	125.2	144.4	127.7

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

[b] Kuparuk airport station reported no snow after 8 May 2014, whereas other weather stations nearby reported snow until 31 May and patchy snow was present in the GKA survey areas into early June. Therefore, if accurate, the airport information was not representative of the study area.

Appendix C. Location and number of other mammals observed during aerial surveys for caribou and other wildlife in and near the ASDP study area, April–August 2014.

Species	General Location	Date	Adults	Young	Total	Specific Location
Grizzly Bear	NPRA	June 8	2	0	2	Southwest of Nuiqsut
		June 13	1	2	3	Fish Creek delta
		June 14	2	0	2	West of Nuiqsut
		June 19	1	2	3	North of Nuiqsut
		June 19	1	2	3	North of Nuiqsut
		June 24	1	1	2	North of Fish Creek
		August 6	1	1	2	Fish Creek
	Colville River Delta	June 3	1	0	1	Central delta
		June 8	1	0	1	Eastern delta
		June 12	1	0	1	Southern delta
		June 12	2	0	2	Outer delta
		June 12	1	0	1	Central delta
		June 12	1	0	1	Central delta
		June 23	1	2	3	Southern delta
		June 23	1	2	3	Central delta
		June 23	1	0	1	Outer delta
		June 25	1	2	3	Central delta
		June 25	1	2	3	Central delta
		June 27	1	0	1	Central delta
		June 29	1	0	1	Central delta
		July 1	2	0	2	Central delta
		July 1	1	0	1	Central delta
		July 1	1	0	1	Central delta
		July 2	1	0	1	Central delta
		July 2	1	0	1	Central delta
		July 2	1	0	1	Central delta
		July 2	1	0	1	Central delta
		July 3	1	2	3	Southern delta
		July 5	1	0	1	Central delta
		July 6	1	0	1	Central delta
		July 7	1	0	1	Near Alpine
		August 21	1	0	1	Outer delta
	Kuparuk Oilfield	June 12	1	0	1	South of Spine Road
		June 12	1	0	1	Southeast of Milne Pt.
		June 23	1	0	1	East of Milne Pt.
		June 25	1	0	1	West of CPF-3
		August 20	1	0	1	Northwest of CPF-3
	Upper Miluveach River	June 10	2	0	2	East of DS-2L
		June 12	1	0	1	Southeast of DS-2N
		June 12	1	2	3	Southeast of DS-2P
		June 23	1	0	1	South of DS-2P
		August 22	1	0	1	East of DS-2N

Appendix C. Continued.

Species	General Location	Date	Adults	Young	Total	Specific Location
Muskox	Colville River Delta	June 12	10	0	10	Southeast of delta
		June 14	11	0	11	Southeast of delta
		June 25	10	0	10	Southeast of delta
		August 6	10	0	10	Southeast of delta
		August 22	10	0	10	Southeast of delta
		August 23	10	0	10	Southeast of delta
	Itkillik River	April 18	10	0	10	Southeast of Nuiqsut
	Kuparuk River	June 23	12	2	14	Coast
		June 25	16	6	22	Spine Road
		June 25	10	1	11	South of Spine Road
		August 23	7	0	7	South of Spine Road
		August 24	8	2	10	South of Spine Road
	Beechey Point	June 3	14	3	17	Near coast
		June 9	3	0	3	Near coast
		June 9	22	7	29	East of Beechey Pt.
		June 12	14	2	16	South of Beechey Pt.
Ringed Seal	Oliktok Point	June 7	1	0	1	Oliktok Point
Spotted Seal	Colville River Delta	August 19	30	0	30	East of Alpine
		August 23	13	0	13	East of Alpine
Polar Bear	Harrison Bay	August 23	1	0	1	Fish Creek delta
Wolverine	NPRA	July 4	1	0	1	Fish Creek

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

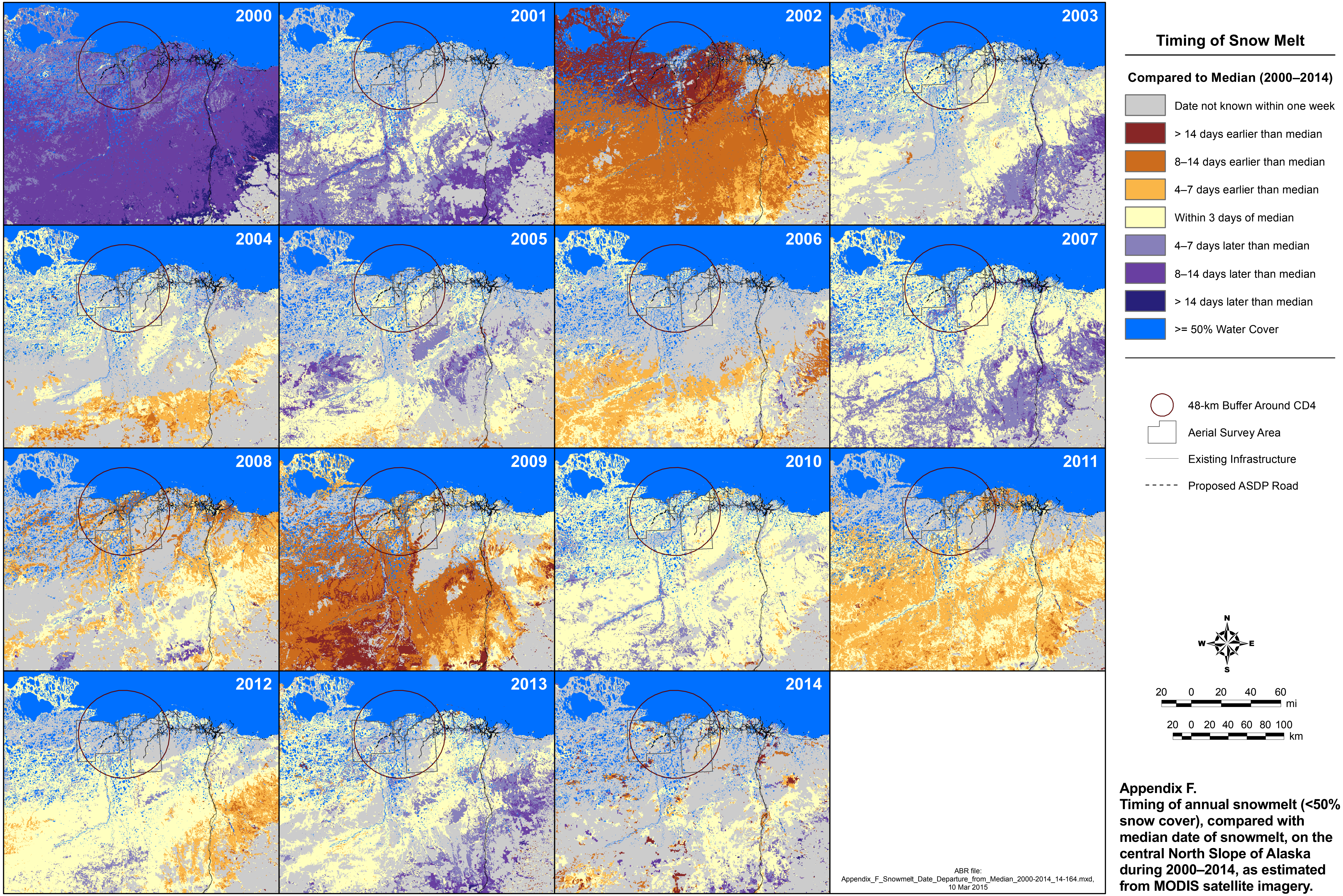
Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
TH	1990	–	–	–	–	–	–	50 (6)	17 (6)	33 (6)	0 (6)	0 (6)	0 (6)
	1991	0 (6)	0 (5)	0 (5)	0 (5)	20 (5)	33 (3)	67 (3)	67 (3)	33 (3)	50 (4)	50 (4)	0 (3)
	1992	0 (3)	0 (2)	33 (3)	50 (2)	50 (2)	33 (3)	25 (8)	33 (6)	33 (6)	33 (6)	67 (6)	67 (6)
	1993	80 (5)	0 (1)	0 (1)	0 (1)	0 (1)	100 (1)	0 (6)	0 (5)	0 (5)	20 (5)	0 (4)	0 (4)
	1994	0 (4)	0 (4)	0 (4)	0 (3)	0 (3)	0 (3)	0 (3)	33 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	1995	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	11 (9)	33 (9)	22 (9)	22 (9)	11 (9)	11 (9)
	1996	11 (9)	11 (9)	11 (9)	11 (9)	13 (8)	0 (8)	13 (8)	0 (8)	0 (7)	0 (7)	0 (7)	0 (6)
	1997	0 (6)	0 (4)	0 (4)	0 (4)	0 (3)	0 (3)	0 (3)	–	0 (2)	0 (2)	0 (2)	0 (2)
	1998	0 (2)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	33 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	1999	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	33 (3)	–	0 (2)	0 (2)	0 (2)	0 (1)
	2000	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	67 (3)	0 (2)	0 (2)	0 (2)	–	0 (2)
	2001	0 (3)	0 (3)	0 (1)	0 (3)	0 (4)	20 (5)	0 (2)	9 (11)	0 (10)	9 (11)	9 (11)	10 (10)
	2002	10 (10)	10 (10)	10 (10)	10 (10)	17 (12)	8 (12)	10 (10)	10 (10)	11 (18)	11 (18)	7 (15)	0 (13)
	2003	7 (14)	15 (13)	33 (12)	17 (12)	14 (14)	7 (14)	0 (28)	27 (26)	23 (26)	28 (25)	8 (25)	4 (24)
	2004	4 (23)	5 (19)	5 (21)	5 (20)	14 (22)	5 (22)	0 (19)	6 (17)	13 (16)	50 (14)	36 (14)	33 (12)
	2005	33 (9)	20 (10)	22 (9)	20 (10)	30 (10)	0 (10)	32 (28)	59 (27)	27 (26)	35 (23)	22 (23)	17 (23)
	2006	17 (23)	18 (22)	14 (22)	9 (23)	27 (22)	14 (21)	58 (36)	6 (34)	13 (32)	34 (29)	0 (27)	0 (26)
	2007	4 (25)	8 (25)	8 (24)	0 (24)	4 (24)	17 (23)	60 (20)	58 (19)	28 (18)	56 (18)	29 (17)	29 (17)
	2008	31 (16)	20 (15)	20 (15)	13 (15)	17 (12)	15 (13)	13 (8)	13 (8)	0 (8)	0 (8)	0 (8)	0 (8)
	2009	0 (8)	0 (6)	0 (8)	0 (8)	0 (8)	13 (8)	86 (14)	21 (14)	8 (12)	0 (11)	0 (10)	0 (9)
	2010	0 (9)	0 (8)	0 (9)	0 (9)	0 (9)	20 (10)	92 (13)	8 (12)	8 (12)	0 (12)	0 (6)	0(6)
	2011	0 (6)	0 (6)	0 (6)	0 (7)	0 (6)	27 (11)	75 (12)	0 (12)	8 (12)	8 (12)	0 (7)	0 (9)
	2012	0 (8)	0 (8)	0 (9)	0 (8)	22 (9)	56 (9)	50 (14)	7 (14)	7 (14)	0 (14)	0 (10)	0 (11)
	2013	0 (8)	0 (8)	0 (5)	0 (5)	0 (4)	0 (9)	78 (9)	0 (9)	13 (8)	0 (7)	0 (7)	0 (7)
	2014	0 (8)	0 (5)	0 (7)	0 (8)	0 (8)	43 (7)	31 (13)	15 (13)	8 (12)	27 (11)	9 (11)	9 (11)
	Total	10 (213)	8 (192)	10 (193)	6 (195)	12 (195)	15 (204)	39 (281)	21 (271)	15 (272)	21 (262)	12 (237)	9 (224)
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)

Appendix D. Continued.

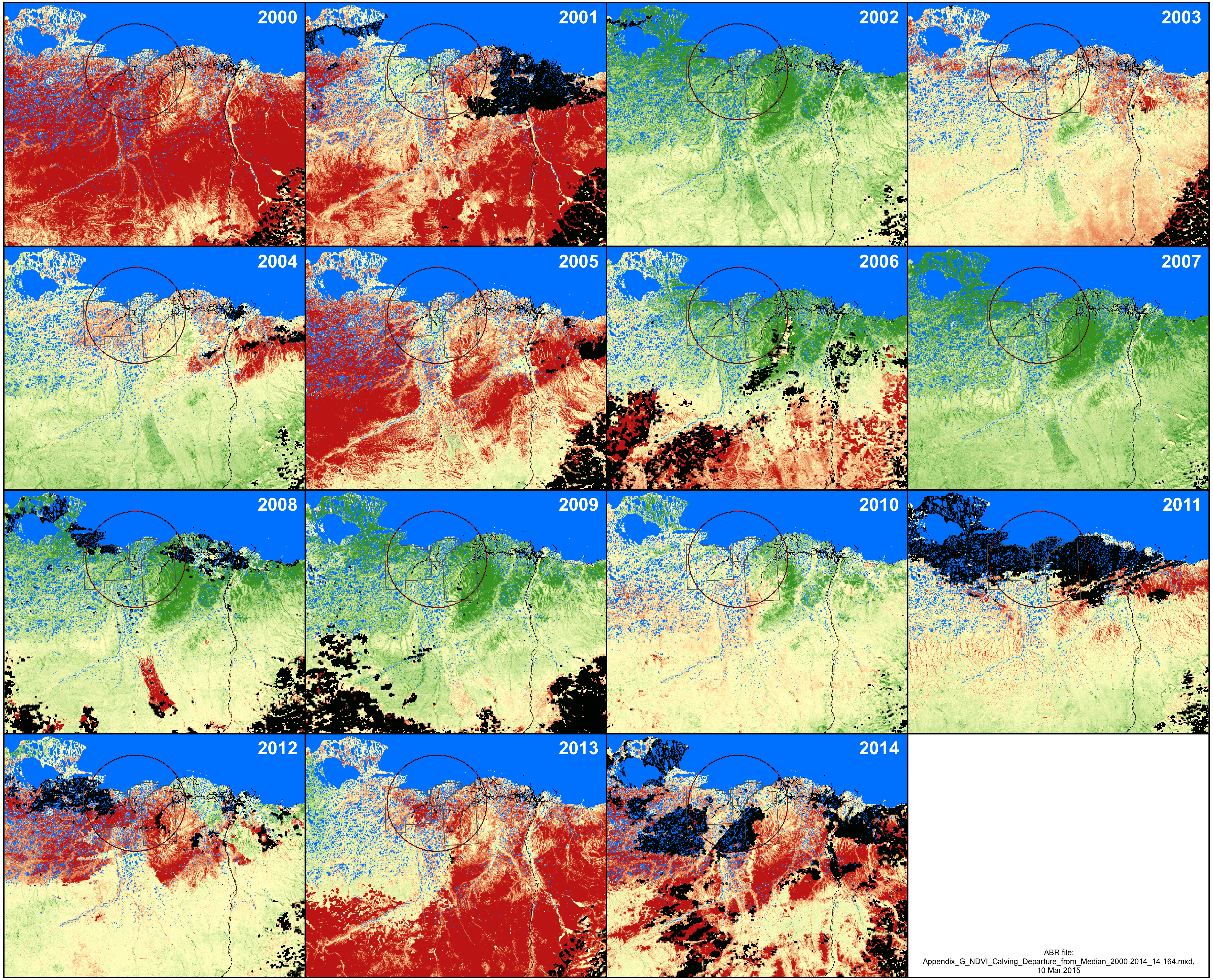
Herd	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
CAH	2002	0 (11)	0 (10)	0 (10)	0 (10)	56 (9)	89 (9)	78 (9)	22 (9)	18 (11)	0 (11)	0 (11)	0 (11)
	2003	0 (11)	0 (9)	17 (6)	0 (6)	20 (5)	75 (4)	0 (4)	0 (3)	0 (3)	33 (6)	0 (6)	0 (6)
	2004	0 (5)	0 (6)	0 (6)	0 (6)	33 (6)	67 (6)	17 (6)	0 (5)	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)

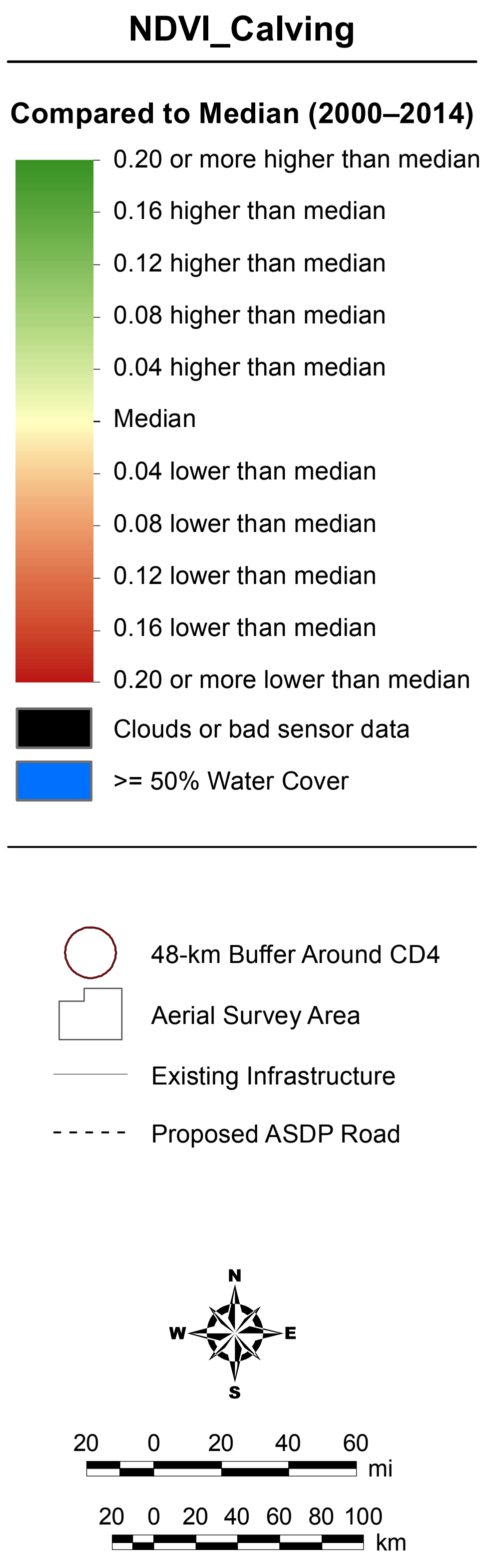
Appendix E. Percentage of GPS-collared caribou samples (*n*) from the TH and CAH that were located within 48 km of CD4 at least once in each month. Only caribou with at least 10 locations per month were included.

Herd	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
TH	2004	–	–	–	–	–	–	10 (10)	20 (10)	20 (10)	70 (10)	30 (10)	30 (10)
	2005	10 (10)	0 (10)	0 (10)	0 (10)	20 (10)	20 (10)	–	–	–	–	–	–
	2006	–	–	–	–	–	–	50 (12)	8 (12)	0 (12)	67 (12)	0 (12)	0 (12)
	2007	0 (12)	0 (12)	0 (12)	0 (11)	18 (11)	40 (10)	55 (11)	73 (11)	27 (11)	36 (11)	27 (11)	20 (10)
	2008	20 (10)	20 (10)	20 (10)	33 (9)	38 (8)	13 (8)	33 (27)	7 (27)	7 (27)	4 (27)	0 (27)	0 (26)
	2009	0 (26)	0 (24)	0 (23)	0 (21)	5 (21)	14 (21)	42 (26)	35 (26)	15 (26)	0 (25)	0 (25)	0 (25)
	2010	0 (25)	0 (24)	0 (24)	0 (24)	0 (23)	5 (21)	74 (23)	17 (23)	18 (22)	10 (21)	8 (26)	4 (26)
	2011	8 (25)	4 (23)	0 (19)	0 (18)	12 (17)	11 (18)	48 (21)	0 (21)	10 (20)	25 (20)	0 (20)	0 (19)
	2012	0 (19)	0 (18)	0 (16)	0 (18)	31 (16)	28 (18)	30 (27)	4 (27)	11 (28)	0 (24)	0 (23)	0 (22)
	2013	0 (20)	0 (18)	0 (19)	0 (18)	0 (17)	0 (16)	67 (27)	0 (28)	7 (27)	8 (25)	9 (22)	10 (21)
	2014	5 (20)	5 (20)	0 (19)	0 (17)	18 (17)	8 (26)	30 (27)	8 (26)	4 (25)	20 (25)	12 (25)	17 (23)
	Total	3 (167)	2 (159)	2 (152)	2 (146)	13 (140)	14 (148)	45 (211)	14 (211)	11 (208)	17 (200)	7 (201)	6 (193)
CAH	2003	–	–	–	4 (24)	54 (24)	75 (24)	8 (24)	13 (24)	21 (24)	8 (24)	0 (24)	0 (24)
	2004	0 (24)	0 (24)	0 (24)	4 (24)	33 (24)	58 (24)	13 (24)	4 (24)	42 (24)	0 (24)	0 (24)	0 (24)
	2005	0 (33)	0 (33)	0 (33)	0 (33)	24 (33)	45 (33)	33 (33)	27 (33)	21 (33)	9 (33)	–	–
	2006	0 (29)	0 (29)	0 (29)	0 (29)	38 (29)	38 (29)	55 (29)	0 (29)	34 (29)	14 (29)	–	–
	2008	–	–	–	–	–	–	0 (4)	25 (4)	25 (4)	0 (4)	0 (4)	0 (4)
	2009	0 (4)	0 (4)	0 (4)	0 (4)	25 (4)	25 (4)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)
	2010	0 (4)	0 (4)	0 (4)	0 (4)	0 (5)	13 (16)	35 (17)	6 (16)	6 (16)	0 (15)	0 (15)	0 (15)
	2011	0 (15)	0 (15)	0 (15)	0 (15)	20 (15)	20 (15)	27 (11)	18 (11)	9 (11)	9 (11)	0 (11)	0 (11)
	2012	0 (11)	0 (11)	0 (11)	0 (12)	20 (5)	20 (5)	20 (5)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
	2013	0 (2)	0 (2)	0 (2)	0 (4)	0 (13)	27 (11)	27 (11)	11 (9)	25 (8)	0 (8)	0 (8)	0 (8)
	2014	0 (8)	0 (8)	0 (8)	0 (20)	26 (19)	37 (19)	35 (20)	20 (20)	15 (20)	20 (20)	0 (20)	0 (20)
	Total	0 (130)	0 (130)	0 (130)	1 (169)	30 (171)	41 (180)	29 (182)	13 (176)	23 (175)	8 (174)	0 (112)	0 (112)

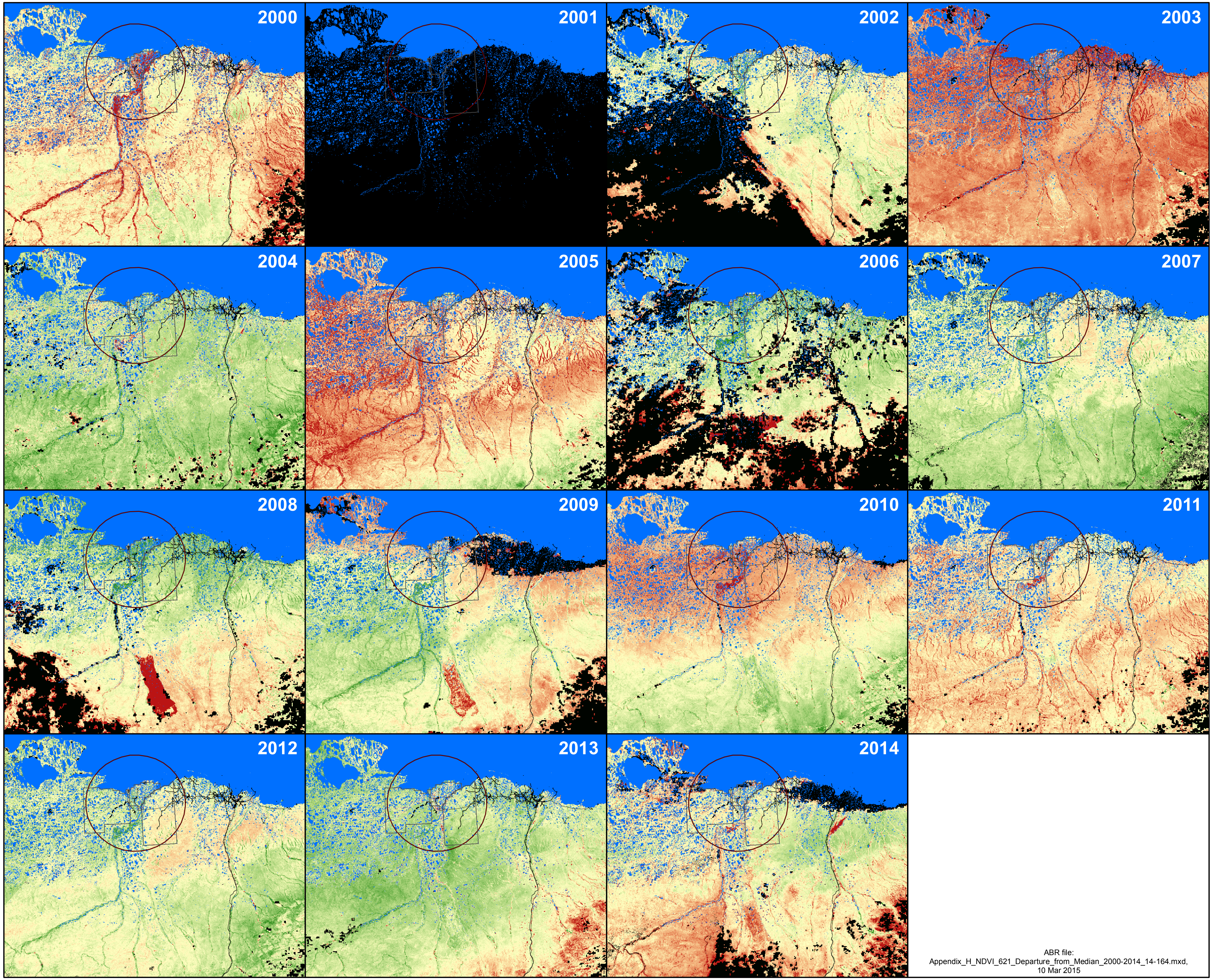


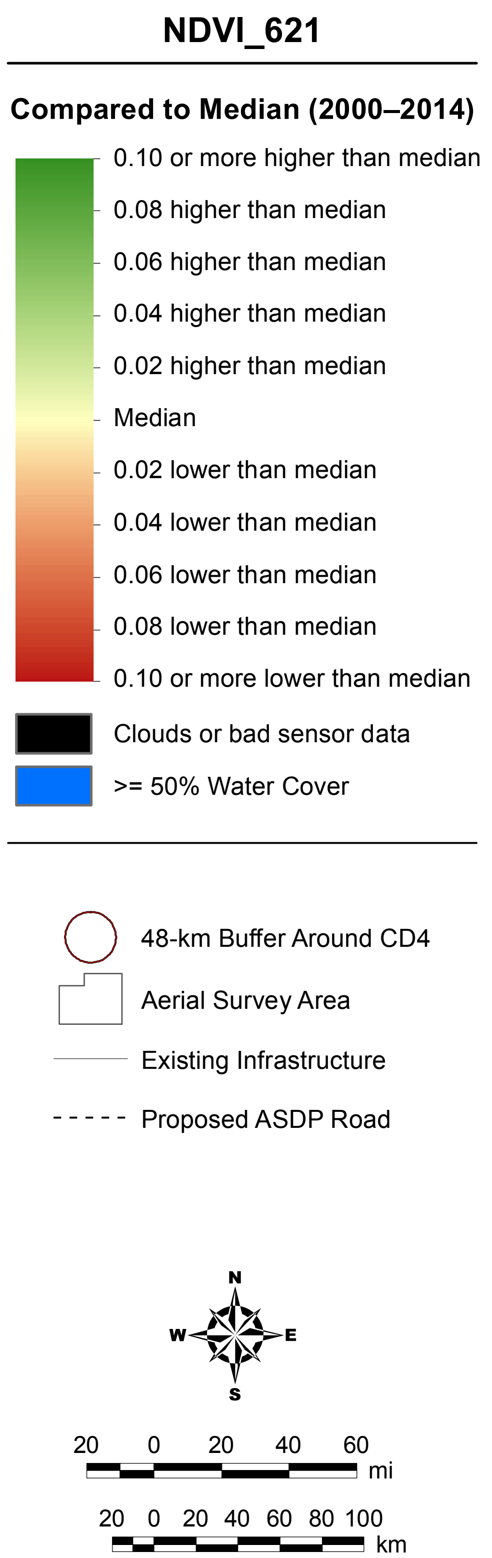
Appendix F.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2014, as estimated from MODIS satellite imagery.



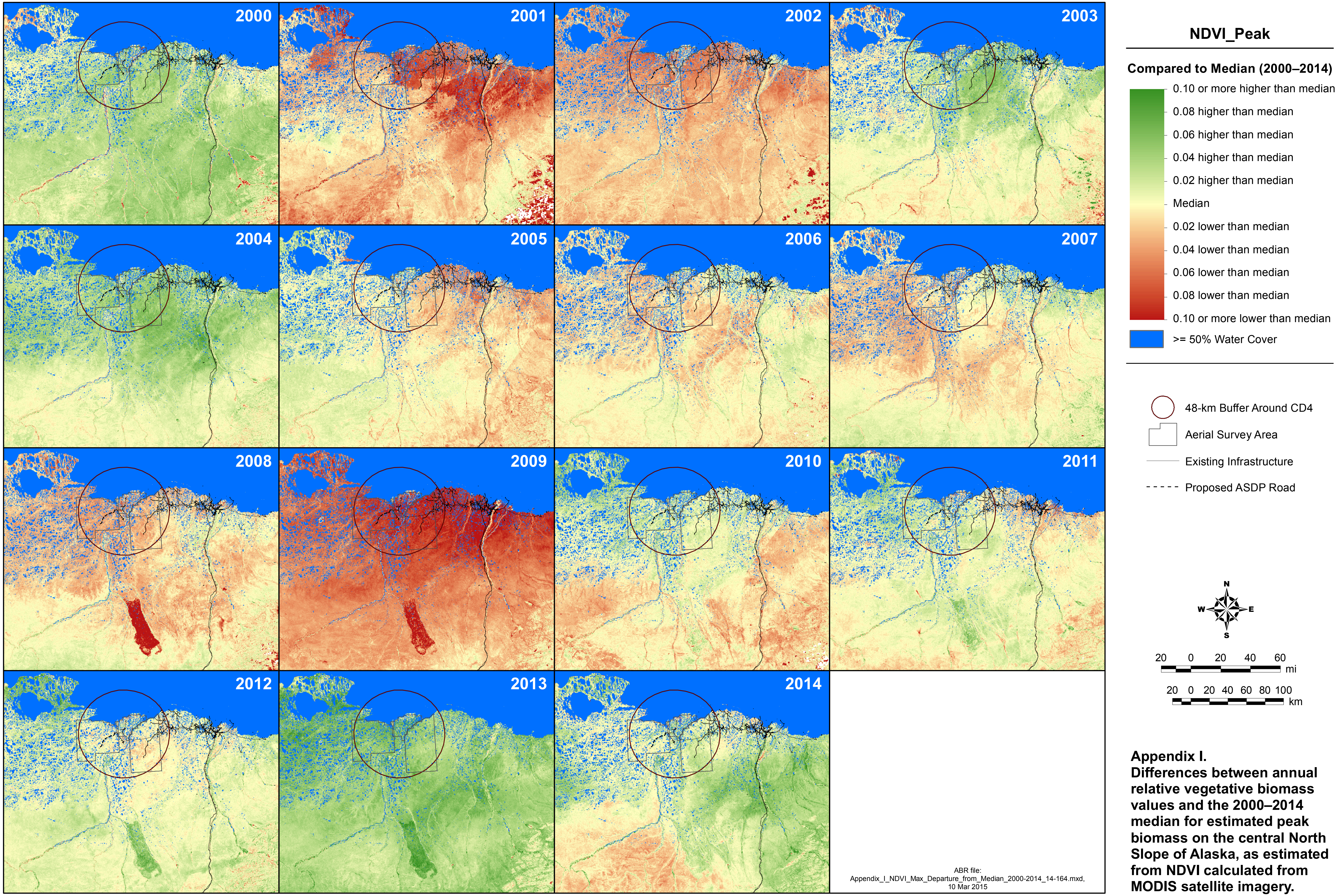


Appendix G.
Differences between annual relative vegetative biomass values and the 2000–2014 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.





Appendix H.
Differences between annual relative vegetative biomass values and the 2000–2014 median at estimated peak lactation for caribou (21 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.



Appendix I.
Differences between annual relative vegetative biomass values and the 2000–2014 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

Appendix J. Number of caribou groups in different geographic sections of the NPRA survey area, by year (2002–2013) and season, with results of chi-square goodness-of-fit tests (assuming a uniform distribution).

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

Appendix J. Continued.

Year	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South east	South west	Chi-square	*P*-value
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	159	13	44	44	26--	32	14.84	0.005
	Calving	1	198	4--	44	22--	40	88^{++}	74.75	<0.001
	Postcalving	1	178	3--	60^{+}	49	37	29	32.45	<0.001
	Mosquito	1	62	8	31^{++}	15	7--	1--	38.28	<0.001
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	83	8	19	31^{++}	14	11	19.69	0.001
	Fall Migration	3	347	20--	94	63	112	58	15.86	0.003
	Total	9	1,027	56--	292^{++}	224	236-	219	45.50	<0.001
2008	Winter	1[a]	60	6	10	15	27	2	10.15	0.038
	Spring Migration	1	10	1	0	2	2	5	6.47	0.167
	Calving	1	145	5--	33	26	36	45^{+}	13.58	0.009
	Postcalving	1	82	5	43^{++}	18	6--	10	48.08	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	112	13	37	35^{+}	21	6--	29.75	<0.001
	Fall Migration	3	245	21	70	57	43--	54	14.44	0.006
	Total	8	654	51	193^{++}	153^{+}	135--	122	48.97	<0.001
2009	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	6	1	2	2	1	0	2.68	0.613
	Calving	1	149	15	51^{+}	43^{+}	16--	24	32.07	<0.001
	Postcalving	1	79	1--	30^{+}	32^{++}	10--	6--	45.41	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	17	0	6	6	1--	4	8.01	0.091
	Late Summer	1	59	5	13	8	14	19	4.91	0.296
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	310	22	102^{++}	91^{++}	42--	53	56.14	<0.001
2010	Winter[a]	1	3	1	0	0	2	0	3.91	0.418
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	9	0	1	1	3	4	4.24	0.375
	Postcalving	1	61	1--	12	22^{+}	12	14	14.83	0.005
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	16	2	2	9+	3	0-	16.00	0.003
	Late Summer	1	41	2	4-	3-	16	16	15.70	0.003
	Fall Migration	1	206	16	57	32	54	47	5.05	0.282
	Total	6	336	22-	76	67	90	81	8.40	0.078
2011	Winter	1	55	5	24^{++}	1--	11	14	20.77	<0.001
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	34	1	6	3	4-	20^{++}	30.12	<0.001
	Postcalving	1	123	2--	32	37^{+}	31	21	17.76	0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	5	0	0	4^{++}	0	1	12.59	0.013
	Late Summer	1	46	0--	4--	3--	18	21^{++}	28.30	<0.001
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	263	8--	66	48	64	77^{+}	22.81	<0.001

Appendix J. Continued.

Year	Season	No. of Surveys	Total Groups	Geographic Section: Coast	North	River	South east	South west	Chi-square	*P*-value
2012	Winter	1	20	0.50	1.54	0.26	0.93	1.43	4.73	0.316
	Spring Migration	1	23	0.87	1.15	1.58	0.80	0.62	2.58	0.631
	Calving	1	93	0--	0.43--	0.61	1.27	2.10++	44.48	<0.001
	Postcalving	1	110	1.09	1.80++	1.51	0.27--	0.56-	41.83	<0.001
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	17	0	0.26	1.53	1.31	1.40	5.75	0.219
	Fall Migration	1	37	0.27-	1.90	0--	1.00	1.29	16.55	0.002
	Total	6	300	0.53--	1.23	0.97	0.81	1.24	16.58	0.002
2013	Winter	1	12	0.83	1.10	1.73	0	1.59	5.41	0.248
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	3	0	1.46	0	1.23	1.59	1.29	0.864
	Postcalving	1	6	5.00	0.73	0.87	0	0.79	11.39	0.022
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	0	–	–	–	–	–	–	–
	Late Summer	2	61	0.16--	0.43--	0.94	0.97	2.11++	24.55	<0.001
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	6	82	0.61--	0.59-	1.01	0.77	1.92++	20.09	<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 K. Number of caribou groups in distance zones around the proposed ASDP road, by year (2001–2013) and season, with results of chi-square goodness-of-fit tests (assuming a uniform distribution).

				Distance to Proposed ASDP Road (km)						
Year	Season	No. of Surveys	Total Groups	North 4–6	North 2–4	Middle 0–2	South 2–4	South 4–6	Chi-square Value	*P*-value
2001	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	10	1	1	2	1	5	7.50	0.112
	Calving	1	13	2	2	7	1	1	3.59	0.465
	Postcalving	2	99	18	18	31	16	16	0.33	0.988
	Mosquito	1	4	0	1	2	0	1	2.01	0.733
	Oestrid Fly	2	2	0	0	2++	0	0	4.39	0.356
	Late Summer	2	36	11	7	9	4	5	5.88	0.208
	Fall Migration	3	73	13	12	30	10	8	4.41	0.354
	Total	12	237	45	41	83	32	36	4.16	0.385
2002	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	2	22	1	3	7	5	6	3.16	0.531
	Calving	1	28	10	5	8	3	2	10.58	0.032
	Postcalving	1	18	4	4	7	1	2	3.13	0.536
	Mosquito	1	0	0	0	0	0	0	-	-
	Oestrid Fly	3	3	1	0	0	2	0	6.67	0.154
	Late Summer	3	38	5	10	14	5	4	4.07	0.396
	Fall Migration	3	19	2	3	6	5	3	1.09	0.896
	Total	14	128	23	25	42	21	17	2.96	0.565
2003	Winter	1	67	6	14	17	19	11	7.77	0.100
	Spring Migration	1	1	1	0	0	0	0	5.60	0.231
	Calving	2	23	2	6	8	1--	6	5.17	0.270
	Postcalving	2	69	10	8	26	9	16	3.61	0.462
	Mosquito	1	0	0	0	0	0	0	-	-
	Oestrid Fly	2	25	10	4	2--	3	6	15.90	0.003
	Late Summer	1	8	3	0	3	1	1	4.28	0.370
	Fall Migration	3	93	15	18	29	18	13	1.43	0.838
	Total	13	286	47	50	85	51	53	3.82	0.431
2004	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	2	1	0	1	0	0	2.83	0.586
	Calving	0	–	–	–	–	–	–	–	–
	Postcalving	0	–	–	–	–	–	–	–	–
	Mosquito	1	0	0	0	0	0	0	-	-
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	10	3	1	5	0	1	4.76	0.313
	Fall Migration	1	34	4	6	13	5	6	0.79	0.940
	Total	5	46	8	7	19	5	7	1.73	0.344
2005	Winter	1	17	3	6	3	3	2	5.01	0.823
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	2	21	4	1	2--	7	7	11.43	0.022
	Postcalving	1	14	4	5	3	1	1	6.08	0.193
	Mosquito	1	4	1	0	1	0	2	4.04	0.401
	Oestrid Fly	1	7	2	3	2	0	0	5.82	0.213
	Late Summer	2	4	0	1	3	0	0	4.71	0.318
	Fall Migration	1	12	0	1	5	1	5	7.87	0.096
	Total	9	79	14	17	19	12	17	4.49	0.344
2006	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	11	2	1	4	3	1	1.52	0.823
	Calving	1	26	8	0--	4	4	10	15.66	0.004
	Postcalving	1	13	6	2	2	0	3	9.15	0.057
	Mosquito	1	0	0	0	0	0	0	–	–
	Oestrid Fly	1	3	1	1	0	0	1	2.82	0.588
	Late Summer	2	12	3	4	1-	2	2	4.44	0.350
	Fall Migration	1	1	0	0	1++	0	0	2.19	0.700
	Total	8	66	20	8	12-	9	17	13.08	0.011

Appendix K. Continued.

Year	Season	No. of Surveys	Total Groups	Distance to Proposed ASDP Road (km) North 4–6	North 2–4	Middle 0–2	South 2–4	South 4–6	Chi-square Value	*P*-value
2007	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	27	5	5	9	5	3	0.70	0.951
	Calving	1	40	6	5	11	10	8	2.44	0.655
	Postcalving	1	40	7	7	13	7	6	0.16	0.997
	Mosquito	1	10	4	2	3	0	1	4.70	0.319
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	2	16	5	4	5	2	0	5.15	0.272
	Fall Migration	3	78	14	8	28	13	15	2.54	0.638
	Total	9	211	41	31	69	37	33	0.95	0.918
2008	Winter	1	29	7	6	9	4	3	1.90	0.754
	Spring Migration	1	3	1	0	0	2	0	6.64	0.156
	Calving	1	27	5	5	8	5	4	0.21	0.995
	Postcalving	1	6	1	0--	3	0--	2	3.62	0.460
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	20	4	4	3	4	5	2.74	0.603
	Fall Migration	3	48	10	8	14	7	9	0.51	0.972
	Total	8	133	28	23	37	22	23	1.21	0.876
2009	Winter	0	–	–	–	–	–	–	–	–
	Spring Migration	1	1	0	0	0	1^{++}	0	4.85	0.303
	Calving	1	19	3	7	6	2	1	6.95	0.139
	Postcalving	1	16	7	4	4	1	0	10.51	0.033
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	1	0	0	1^{++}	0	0	2.19	0.700
	Late Summer	1	10	1	3	4	0	2	3.50	0.477
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	47	11	14	15	4	3-	11.04	0.026
2010	Winter	1	1	0	0	1^{++}	0	0	2.19	0.700
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	3	0	1	0	0	2	6.86	0.144
	Postcalving	1	11	0	1	5	1	4	5.88	0.208
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	3	2	1	0	0	0	6.37	0.173
	Late Summer	1	17	2	1	9	3	2	4.35	0.360
	Fall Migration	1	37	0--	5	15	6	11	11.43	0.022
	Total	6	72	4--	9	30	10	19	13.56	0.009
2011	Winter	1	11	0	0	5	2	4	6.92	0.140
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	8	2	0	0	2	4	9.40	0.052
	Postcalving	1	21	1-	2	5	8	5	9.04	0.060
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	1	1^{++}	0	0	0	0	4.50	0.343
	Late Summer	1	13	0	2	4	2	5	5.89	0.208
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	5	54	4-	4	14	14	18	17.46	0.002
2012	Winter	1	5	1	1	2	1	0	1.05	0.903
	Spring Migration	1	7	2	1	4	0	0	4.32	0.365
	Calving	1	26	3	3	8	3	9	6.18	0.186
	Postcalving	1	13	4	0	6	2	1	4.87	0.301
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–
	Late Summer	1	5	1	1	2	0	1	1.05	0.902
	Fall Migration	1	10	0	2	1	2	5	9.76	0.045
	Total	6	66	11	8	23	8	16	4.03	0.402

Appendix K. Continued.

Year	Season	No. of Surveys	Total Groups	Distance to Proposed ASDP Road (km) North 4–6	North 2–4	Middle 0–2	South 2–4	South 4–6	Chi-square Value	*P*-value
2013	Winter	1	2	0	1	1	0	0	2.65	0.618
	Spring Migration	0	–	–	–	–	–	–	–	–
	Calving	1	0	0	0	0	0	0	–	–
	Postcalving	1	0	0	0	0	0	0	–	–
	Mosquito	0	–	–	–	–	–	–	–	–
	Oestrid Fly	1	0	0	0	0	0	0	–	–
	Late Summer	2	22	3	4	7	6	2	2.45	0.654
	Fall Migration	0	–	–	–	–	–	–	–	–
	Total	6	24	3	5	8	6	2	2.7	0.609

+ 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, 2002–2013.

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

Appendix L. Continued.

Year	Season	No. of Surveys	No. of Groups	Habitat Type [a] *Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2008	Winter	1[c]	60	0.90	1.34	1.50	1.24	0.83	1.46	1.19	1.35	0.09-
	Spring Migration	1	10	1.28	1.08	0.66	0.48	1.28	0.19	1.68	3.10	0.00
	Calving	1	145	0.88	1.01	0.84	1.23^{+}	1.10	0.53-	0.49--	0.42	0.32-
	Postcalving	1	82	1.02	0.91	0.98	1.23	1.01	1.42	0.69	0.70	0.45
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	1	112	0.77	0.93	0.98	0.65--	0.84-	2.31^{++}	1.54^{+}	1.44	4.08^{++}
	Fall Migration	3	245	0.83-	0.89	0.91	1.17^{+}	1.05	1.51^{+}	1.11	0.20	0.66
	Total	8	654	0.88	0.97	0.95	1.07^{+}	1.01	1.40^{++}	1.02	0.74	1.05
2009	Winter	0	–	–	–	–	–	–	–	–	–	–
	Spring Migration	1	6	1.38	0.86	0.48	0.93	1.26	1.46	0.89	0	0
	Calving	1	149	1.03	0.82--	0.95	1.21^{++}	0.93-	1.43^{+}	1.26	0.64	1.40
	Postcalving	1	79	0.89	0.86-	1.18^{+}	1.23^{++}	0.81--	1.64	1.30	6.51^{++}	1.50
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	17	0.68	1.03	1.15	0.59	0.73	3.12^{+}	1.38	0	4.52^{+}
	Late Summer	1	59	1.39	1.08	1.15	0.67	0.86-	2.59^{++}	1.27	0	1.42
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	5	310	1.05	0.89--	1.05^{+}	1.07^{++}	0.88--	1.80^{++}	1.27^{+}	1.97	1.57
2010	Winter	1c	3	0.60	0.84	1.13	1.02	0.90	0.96	4.18	0	0.67
	Spring Migration	0	–		–	–	–	–	–	–	–	–
	Calving	1	9	0.72	0.68	0.79	0.49	1.58^{+}	0	1.43	8.00	0
	Postcalving	1	61	0.81	0.80	1.05	0.94	0.98	0.44	1.80^{+}	2.71	2.18^{+}
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	16	0.93	1.50	1.09	0.17--	0.21--	2.61	1.79	2.32	8.55^{++}
	Late Summer	1	41	0.82	0.94	1.16	1.03	1.11	0.36	1.26	2.19	0.02--
	Fall Migration	1	206	0.89	0.95	1.01	1.10	0.96	1.42	1.14	1.31	1.09
	Total	6	336	0.87	0.94	1.04	1.00	0.96	1.14	1.35^{+}	1.90	1.47^{+}
2011	Winter	1	55	1.29	0.78	1.05	1.39+	0.97	0.54	0.94	1.29	0.05--
	Spring Migration	0	–		–	–	–	–	–	–	–	–
	Calving	1	34	0.87	0.71	0.82	1.09	1.23	0.18-	1.24	3.18	0.57
	Postcalving	1	123	0.79	0.85	1.12	1.05	0.94	1.67	1.53+	1.29	1.54
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	5	1.24	0.53	1.61	0.73	0.17-	5.54	1.51	11.16	7.85^{+}
	Late Summer	1	46	1.34	1.18	0.75	0.82	1.10	0.42	0.92	2.02	0.05-
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	5	263	1.01	0.87-	1.01	1.08	1.00	1.09	1.26	1.85	0.96
2012	Winter	1	20	0.95	0.89	0.77	0.95	1.25	0.52	1.16	0.82	0.08
	Spring Migration	1	23	0.84	1.02	1.50+	0.98	0.84	2.24	0.47	0.00	1.54
	Calving	1	93	0.77	0.83	0.88	1.51^{++}	0.93	1.64	0.97	1.13	0.97
	Postcalving	1	110	0.91	0.94	1.04	0.97	1.07	0.72	1.31	3.21	0.50
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	0	–	–	–	–	–	–	–	–	–	–
	Late Summer	1	17	0.40	0.58	0.75	0.53	1.70^{++}	0.00	1.67	0.00	0.09
	Fall Migration	1	37	0.85	1.00	0.80	0.33--	1.20	0.98	0.91	0.00	2.98^{+}
	Total	6	300	0.83-	0.90-	0.96	1.04	1.07	1.10	1.10	1.58	0.98

Appendix L. Continued.

Year	Season	No. of Surveys	No. of Groups	Habitat Type [a]: *Carex aquatilis*	Flooded Tundra	Wet Tundra	Sedge/ Grass	Tussock Tundra	Moss/ Lichen	Dwarf Shrub	Low Shrub	Riverine [b]
2013	Winter	1	12	0.74	1.26	0.90	1.02	0.77	0.74	1.29	3.84	2.47
	Spring Migration	0	–	–	–	–	–	–	–	–	–	–
	Calving	1	3	0.10	0.17	0.26	1.16	1.96+	0	0.30	0	0
	Postcalving	1	6	0.01-	0.22-	0.53	1.27	1.79+	0.82	0.25	0	0.13
	Mosquito	0	–	–	–	–	–	–	–	–	–	–
	Oestrid Fly	1	0	–	–	–	–	–	–	–	–	–
	Late Summer	2	61	1.05	1.11	0.82	0.91	1.03	0.74	0.58	0	0.59
	Fall Migration	0	–	–	–	–	–	–	–	–	–	–
	Total	6	82	0.89	1.03	0.79	0.96	1.08	0.72	0.65	0.56	0.81

[a] NPRA earth-cover classification (BLM and Ducks Unlimited 2002).
[b] Riverine type comprises dunes/dry sand, sparsely vegetated, and barren ground/other cover classes.
[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. Descriptive statistics for snow cover and vegetative biomass in 2014 and for habitat types among geographic sections of the 2002–2004 and 2005–2014 NPRA survey areas.

			Geographic Section				
Survey Area	Variable	Unit	Coast	North	River	Southeast	Southwest
2002–2004	Area	km²	9.8	88.3	156.1	232.2	167.2
	Vegetative Biomass	NDVI_Calving	0.1167	0.0545	0.1001	0.1891	0.1681
		NDVI_621	0.3536	0.3668	0.3520	0.3973	0.4197
		NDVI_Rate	0.0139	0.0181	0.0149	0.0122	0.0155
		NDVI_Peak	0.5763	0.5712	0.5672	0.5976	0.5956
	Snow Cover (3–4 June)	Mean %	25.2	49.9	26.5	12.7	10.75
	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
		Dunes/Dry Sand	0.1	0.1	2.0	0.1	0
		Sparsely Vegetated	<0.1	0.5	2.9	0.1	<0.1
		Barren Ground/Other	0.4	0.7	2.1	0.1	0.1
2005–2014	Area	km²	93.2	206.6	160.7	232.2	167.3
	Vegetative Biomass	NDVI_Calving	0.0455	0.0488	0.0968	0.1891	0.1680
		NDVI_621	0.2930	0.3549	0.3500	0.3974	0.4196
		NDVI_Rate	0.0144	0.0175	0.0148	0.0122	0.0156
		NDVI_Peak	0.5154	0.5661	0.5667	0.5976	0.5957
	Snow Cover (3–4 June)	Mean %	49.0	53.4	28.2	12.7	10.8
	Habitat Type (% area)	Water	24.2	22.1	15.3	17.7	11.4
		Carex aquatilis	8.3	6.3	6.4	6.2	8.4
		Flooded Tundra	15.0	10.1	14.9	18.3	18.2
		Wet Tundra	6.9	7.6	11.3	7.3	10.3
		Sedge/Grass Meadow	11.8	23.3	13.9	5.4	13.5
		Tussock Tundra	19.7	25.5	24.8	41.3	34.3
		Moss/Lichen	1.0	1.2	3.2	0.3	0.7
		Dwarf Shrub	1.3	2.3	3.1	2.9	3.1
		Low Shrub	<0.1	<0.1	0.1	0.3	0.2
		Dunes/Dry Sand	3.2	0.3	2.0	0.1	0
		Sparsely Vegetated	0.7	0.5	2.8	0.1	<0.1
		Barren Ground/Other	8.0	0.8	2.1	0.1	0.1

Appendix N. GEE model-selection results for analyses of caribou density in different seasons during 2002–2014 in the NPRA survey area (163 grid cells). Bold type denotes the best model for each season.

Season	Value	Model [a] S,C,R	S,C,R,DC	S,C,R,NP	S,C,R,TT	S,C,R,WH	S,C,R,TN	S,C,R,TN,NP	S,C,R,TN,TT	S,C,R,DC,NP	S,C,R,DC,TT	S,C,R,DC,WH	S,C,R,TN,DC	S,C,R,TN,WH	S,C,R,TN,DC,NP	S,C,R,TN,DC,TT	S,C,R,TN,DC,WH	S,C,R,ZN
All Seasons	*n* [b]	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163
Winter	K [c]	11	12	12	12	12	12	**13**	13	13	13	13	13	13	14	14	14	15
	QICc [d]	1,591	1,584	1,588	1,591	1,593	1,563	**1,558**	1,559	1,586	1,586	1,586	1,563	1,562	1,560	1,561	1,564	1,570
	w_i [e]	<0.001	<0.001	<0.001	<0.001	<0.001	0.041	**0.347**	0.273	<0.001	<0.001	<0.001	0.029	0.046	0.132	0.108	0.023	0.001
Spring	K	12	13	13	13	13	13	14	14	14	14	14	**14**	14	15	15	15	16
	QICc	1,238	1,240	1,238	1,239	1,238	1,232	1,233	1,234	1,240	1,241	1,240	**1,231**	1,233	1,233	1,233	1,233	1,237
	w_i	0.007	0.003	0.006	0.005	0.007	0.169	0.116	0.070	0.002	0.002	0.003	**0.238**	0.084	0.093	0.088	0.091	0.015
Calving	K	17	18	18	18	18	18	19	19	19	19	19	19	19	**20**	20	20	21
	QICc	2,957	2,863	2,919	2,945	2,953	2,890	2,838	2,851	2,860	2,863	2,865	2,834	2,868	**2,819**	2,821	2,830	2,884
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**0.692**	0.304	0.003	<0.001
Postcalving	K	16	17	17	17	17	17	18	18	18	18	18	18	18	**19**	19	19	20
	QICc	3,423	3,422	3,424	3,424	3,425	3,329	3,331	3,329	3,424	3,423	3,424	3,305	3,329	**3,297**	3,299	3,301	3,315
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.010	<0.001	**0.623**	0.278	0.089	<0.001
Mosquito	K	8	9	9	9	9	9	10	10	10	10	10	**10**	10	11	11	11	12
	QICc	343	308	324	338	342	338	323	334	307	308	309	**294**	338	296	296	296	315
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	**0.462**	<0.001	0.181	0.186	0.170	<0.001
Oestrid Fly [f]	K	8	9	9	9	9	9	10	10	**10**	10	10	10	10	11	11	11	12
	QICc	647	638	647	647	649	637	639	639	**633**	636	639	635	639	633	635	637	646
	w_i	<0.001	0.029	<0.001	<0.001	<0.001	0.039	0.018	0.016	**0.281**	0.057	0.014	0.124	0.016	0.274	0.086	0.045	<0.001
Late Summer	K	23	24	24	24	24	24	25	25	25	25	25	25	25	**26**	26	26	27
	QICc	3,062	3,057	3,058	3,057	3,063	3,034	3,033	3,034	3,043	3,048	3,057	3,036	3,036	**3,031**	3,034	3,038	3,051
	w_i	<0.001	<0.001	<0.001	<0.001	<0.001	0.076	0.176	0.105	0.001	<0.001	<0.001	0.037	0.029	**0.467**	0.093	0.015	<0.001
Fall Migration	K	20	21	21	21	21	21	22	22	22	22	22	22	22	23	23	23	**24**
	QICc	3,317	3,319	3,316	3,316	3,313	3,308	3,308	3,309	3,317	3,317	3,315	3,309	3,307	3,310	3,311	3,309	**3,307**
	w_i	0.002	0.001	0.003	0.003	0.011	0.128	0.129	0.078	0.002	0.001	0.005	0.065	0.190	0.048	0.032	0.074	**0.228**

[a] S = Survey; C = presence or absence of Fish or Judy creeks; R = presence or absence of proposed road; NP = NDVI_Peak; DC = distance to coast; TT = proportion of tussock tundra; WH = proportion of wet habitat (4 types combined; see text); TN = transect number (west-to-east gradient); and ZN = one of 5 geographic zones.
[b] *n* = sample size.
[c] K = number of estimable parameters in the approximating model.
[d] QIC_c = Quasi-Likelihood Information Criterion, corrected for small sample size.
[e] w_i (Akaike Weight) = Probability that the current model (i) is the best approximating model in the candidate set.
[f] Road not included in models.

Appendix O. Model-weighted parameter estimates, standard error (SE), and *P*-value of variables included in the grid-cell analyses of caribou density in the NPRA survey area, 2002–2014.

Season	Variable	Mean	SE	*P*-value [a]
Winter	Intercept	–4.795	2.693	0.075
	Presence of Creek	–0.548	0.219	0.012*
	Presence of Proposed Road	–0.404	0.290	0.163
	Distance to Coast (km)	0.001	0.008	0.861
	NDVI_Peak	8.661	3.287	0.008**
	Tussock Tundra (%)	1.345	0.558	0.016*
	Wet Habitat (%)	–0.795	0.563	0.158
	W to E (transect number)	–0.119	0.020	<0.001***
	Section (Coastal)	–0.357	0.272	0.189
	Section (Northern)	–0.584	0.206	0.005**
	Section (River)	–1.366	0.332	<0.001***
	Section (Southeast)	–0.973	0.205	<0.001***
Spring Migration	Intercept	–1.922	1.032	0.062
	Presence of Creek	–0.418	0.221	0.059
	Presence of Proposed Road	–0.408	0.325	0.209
	Distance to Coast (km)	–0.013	0.009	0.120
	NDVI_Peak	–2.916	3.924	0.457
	Tussock Tundra (%)	–0.133	0.655	0.840
	Wet Habitat (%)	0.353	0.645	0.584
	W to E (transect number)	–0.067	0.023	0.003**
	Section (Coastal)	0.068	0.350	0.846
	Section (Northern)	0.381	0.231	0.099
	Section (River)	0.317	0.331	0.338
	Section (Southeast)	–0.310	0.223	0.165
Calving	Intercept	–8.219	3.049	0.007**
	Presence of Creek	0.141	0.150	0.348
	Presence of Proposed Road	–0.326	0.225	0.148
	Distance to Coast (km)	0.030	0.006	<0.001***
	NDVI_Peak	12.187	2.743	<0.001***
	Tussock Tundra (%)	1.822	0.434	<0.001***
	Wet Habitat (%)	–1.130	0.423	0.008**
	W to E (transect number)	–0.105	0.015	<0.001***
	Section (Coastal)	–1.839	0.232	<0.001***
	Section (Northern)	–0.786	0.146	<0.001***
	Section (River)	–0.916	0.225	<0.001***
	Section (Southeast)	–0.968	0.145	<0.001***
Postcalving	Intercept	–2.524	2.696	0.349
	Presence of Creek	1.128	0.151	<0.001***
	Presence of Proposed Road	0.195	0.206	0.344
	Distance to Coast (km)	–0.036	0.006	<0.001***
	NDVI_Peak	9.469	2.517	<0.001***
	Tussock Tundra (%)	1.262	0.408	0.002**
	Wet Habitat (%)	–1.017	0.405	0.012*
	W to E (transect number)	–0.178	0.015	<0.001***
	Section (Coastal)	–0.502	0.210	0.017*
	Section (Northern)	0.608	0.144	<0.001***
	Section (River)	0.776	0.211	<0.001***
	Section (Southeast)	–0.876	0.149	<0.001***

Appendix O. Continued.

Season	Variable	Mean	SE	*P*-value [a]
Mosquito	Intercept	2.907	1.803	0.107
	Presence of Creek	0.559	0.419	0.182
	Presence of Proposed Road	0.238	0.644	0.712
	Distance to Coast (km)	–0.122	0.019	<0.001***
	NDVI_Peak	–4.398	8.085	0.587
	Tussock Tundra (%)	–0.849	1.357	0.532
	Wet Habitat (%)	0.306	1.351	0.821
	W to E (transect number)	–0.186	0.046	<0.001***
	Section (Coastal)	2.675	0.661	<0.001***
	Section (Northern)	2.631	0.528	<0.001***
	Section (River)	1.948	0.714	0.006**
	Section (Southeast)	0.713	0.574	0.214
Oestrid Fly [b]	Intercept	2.833	3.821	0.458
	Presence of Creek	1.782	0.293	<0.001***
	Presence of Proposed Road [c]	–	–	–
	Distance to Coast (km)	0.037	0.014	0.007**
	NDVI_Peak	–12.849	5.114	0.012*
	Tussock Tundra (%)	–1.067	0.890	0.230
	Wet Habitat (%)	–0.018	0.890	0.984
	W to E (transect number)	–0.068	0.035	0.054
	Section (Coastal)	–1.811	0.724	0.012*
	Section (Northern)	–0.057	0.320	0.859
	Section (River)	–0.034	0.463	0.941
	Section (Southeast)	–0.341	0.295	0.247
Late Summer	Intercept	1.086	1.786	0.543
	Presence of Creek	0.464	0.131	<0.001***
	Presence of Proposed Road	0.032	0.200	0.873
	Distance to Coast (km)	0.010	0.006	0.092
	NDVI_Peak	–5.703	2.458	0.020*
	Tussock Tundra (%)	–0.695	0.378	0.066
	Wet Habitat (%)	0.087	0.372	0.816
	W to E (transect number)	–0.060	0.014	<0.001***
	Section (Coastal)	–0.499	0.210	0.017*
	Section (Northern)	–0.062	0.137	0.650
	Section (River)	–0.013	0.199	0.948
	Section (Southeast)	–0.510	0.136	<0.001***
Fall Migration	Intercept	–0.379	0.787	0.630
	Presence of Creek	0.069	0.195	0.724
	Presence of Proposed Road	0.059	0.205	0.773
	Distance to Coast (km)	–0.002	0.006	0.686
	NDVI_Peak	–3.350	2.343	0.153
	Tussock Tundra (%)	–0.410	0.403	0.308
	Wet Habitat (%)	0.705	0.405	0.082
	W to E (transect number)	–0.048	0.014	0.001***
	Section (Coastal)	–0.514	0.229	0.024*
	Section (Northern)	0.125	0.152	0.411
	Section (River)	–0.347	0.225	0.123
	Section (Southeast)	–0.426	0.146	0.004**

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

Appendix P. GLM model-selection results for analyses of caribou density during late calving in the Colville East survey area in 2014 (553 grid cells). The best model (bold type) contained the variables W to E (transect number) and proportion of waterbodies (both included in all models), distance to coast (km), and the proportion covered by wet graminoid tundra.

Model [a]	*n* [b]	K [c]	AICc [d]	ΔAICc [e]	w_i [f]
W to E, Water, Coast, Wet Habitat	442	6	467.41	0	0.137
W to E, Water, Coast	442	5	467.49	0.08	0.132
W to E, Water, Coast, Wet Habitat, Road	442	7	468.00	0.59	0.102
W to E, Water, Coast, Road	442	6	468.08	0.67	0.098
W to E, Water, Coast, Wet Habitat, Snow Cover	442	7	468.52	1.11	0.079
W to E, Water, Coast, Snow Cover	442	6	468.74	1.33	0.071
W to E, Water, Coast, Wet Habitat, NDVI_Peak	442	7	469.06	1.64	0.060
W to E, Water, Coast, NDVI_Peak	442	6	469.46	2.05	0.049
W to E, Water, Coast, Wet Habitat, Snow Cover, Road	442	8	469.51	2.10	0.048
W to E, Water, Coast, Wet Habitat, NDVI_Peak, Road	442	8	469.58	2.17	0.046
W to E, Water, Coast, Snow Cover, Road	442	7	469.71	2.30	0.043
W to E, Water, Coast, NDVI_Peak, Road	442	7	470.08	2.67	0.036
W to E, Water, Coast, Snow Cover, NDVI_Peak, Wet	442	8	470.18	2.77	0.034
W to E, Water, Coast, Snow Cover, NDVI_Peak	442	7	470.70	3.29	0.026
W to E, Water, Coast, Snow Cover, NDVI_Peak, Wet	442	8	471.12	3.71	0.021

[a] W to E = west-to-east gradient (transect number); Water = proportion covered by waterbodies; Road = within 2 km of a road; Wet Habitat = proportion classified as wet graminoid tundra; Snow Cover = percent snow cover on 3–4 June 2014; Coast = distance from coast; NDVI_Peak = maximum NDVI value during 2014.

[b] Sample size.

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

[d] Akaike's Information Criterion, corrected for small sample size.

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

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