CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2015 AND 2016

12th Annual Report

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Prepared for
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Anchorage, Alaska

Prepared by
ABR, Inc.—Environmental Research & Services
Fairbanks, Alaska

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June 2017

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGMENTS

This study was funded by ConocoPhillips Alaska, Inc. (CPAI), and was administered by Robyn McGhee, CPAI Environmental Scientist, for whose support we are grateful. Valuable assistance with field logistics was provided by Mary Hrynyk, Candy Fitzpatrick, and Patrick Weeks. Alaska Department of Fish and Game (ADFG) biologists played crucial roles in this study by capturing caribou, deploying radio-collars, and providing telemetry data under a cooperative agreement among ADFG, CPAI, and ABR. We thank ADFG biologists Lincoln Parrett, Beth Lenart, and Jason Caikoski for their professional cooperation and assistance. Brian Person of the North Slope Borough (NSB) Department of Wildlife Management and Dave Yokel of the Bureau of Land Management (BLM) provided GPS and satellite telemetry data, valuable information, and advice. Pilots Bob Gill and Bud Roberts of 70 North and Jesse Cummings of Golden Eagle Outiftters provided safe and efficient piloting of survey airplanes under flying conditions that often were less than optimal. Assistance in the field was provided by ABR employees James Smith and Tim Obritschkewitsch, and support during data collection, analysis, and report preparation was provided by Chris Swingley, Dorte Dissing, Allison Zusi, Tawna Morgan, Will Lentz, Pam Odom, and Tony LaCortiglia. Reviews by Robyn McGhee and Lisa Pekich of CPAI improved this report.

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
EIS	environmental impact statement
GLM	Generalized Linear Models
GMT	Greater Moose's Tooth
GPS	Global Positioning System
IAP	Integrated Activity Plan
LAADS	Level-1 and Atmospheres Archive and Distribution System
LSCV	least-squares cross-validation
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NDVI_Calving	NDVI during June 1–10
NDVI_621	NDVI interpolated to June 21
NDVI_Rate	daily change in NDVI during June (NDVI_Calving to NDVI_621)
NDVI_Peak	NDVI at peak summer biomass
NIR	near-infrared reflectance
NPRA	National Petroleum Reserve–Alaska
NSB	North Slope Borough
PH	Porcupine Herd
PTT	Platform Transmitter Terminal
RSF	Resource Selection Function
SCF	sightability correction factor
SE	standard error
TAPS	Trans-Alaska Pipeline System
TDD	thawing degree-days
TH	Teshekpuk Herd
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 in the northeastern portion of the National Petroleum Reserve–Alaska (NPRA) and the adjacent Colville River delta, an area that is used at various times of the year by two 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, Wilson et al. 2012, Lawhead et al. 2015, Parrett 2015, Lenart 2015, Nicholson et al. 2016).

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving typically has 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; Parrett 2007, 2015; Person et al. 2007; Yokel et al. 2009; Wilson et al. 2012). 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 2015; L. Parrett, ADFG, pers. comm.).

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 near the winter range of the CAH since 2004–2005 (Lawhead et al. 2015, Lenart 2015, Parrett 2015) and, in a highly unusual movement, far east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 (Carroll et al. 2004, Parrett 2009).

The TH increased substantially in size from the mid-1970s to the early 1990s (Parrett 2015). The TH experienced a dip in numbers in the early to mid-1990s, but increased steadily from 1995 to its peak estimated population size of 68,932 animals in July 2008 (Parrett 2015). The herd subsequently declined. A photocensus in July 2011 produced an estimated population size of 55,704 animals (Parrett 2015), a decline of at least 19% from the 2008 estimate. A photocensus conducted in July 2013 produced an estimate of 39,172 animals (including ~7,000 animals that were mixed with the WAH at the time of the census; Parrett 2015), a further decrease of at least 30% since 2011. The latest photocensus in July 2015 produced a minimum count of 35,181 caribou and an accompanying estimate, using a homogeneity model for missing radio-collars, of 41,542 animals (SE = 3,486) (L. Parrett, ADFG, pers. comm.) indicating the population decline had slowed.

Concentrated calving activity by the CAH tends to occur in two areas of the coastal plain, one located south and southwest of the Kuparuk oilfield and the other east of the Sagavanirktok River (Wolfe 2000, Arthur and Del Vecchio 2009, Lenart 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). The majority of the CAH generally winters south of the Brooks Range, generally east of the Dalton Highway/Trans-Alaska Pipeline (TAPS) corridor (Arthur and Del Vecchio 2009, Lawhead et al. 2015, Lenart 2015, Nicholson et al. 2016), although many animals have remained north of the Brooks Range on the coastal plain in the last two winters (E. Lenart, ADFG, pers. comm.).

From the early 1970s to 2002, the CAH grew at an overall rate of 7% per year (Lenart 2009). The herd grew rapidly from ~5,000 animals in the mid-1970s to the early 1990s, reaching a minimum count of 23,444 caribou in July 1992 before declining 23% to a minimum count of 18,100 caribou in July 1995, similar to the decline observed in the TH during that period. By July 1997, the herd was estimated at 18,824 animals. The herd continued increasing, reaching an estimated population size of 66,666 animals in July

2009 (Lenart 2015), representing a mean annual increase of 13% since 2002. A photocensus in July 2010 produced an estimate of 68,442 animals, indicating that herd growth had slowed (Lenart 2015). The herd subsequently declined to an estimated 50,753 animals by July 2013 (Lenart 2015) and ~22,000 animals by July 2016 (ADFG press release, 16 November 2016, http://www.adfg.alaska.gov/index.cfm?adfg=press releases.pr11162016_caribou). The magnitude of the recent decline may have been affected by emigration of some CAH animals to the Porcupine Herd (PH) and TH, with which the CAH often intermixes on shared winter ranges (E. Lenart, ADFG, pers. comm., ADFG 2017).

This monitoring study builds on prior research funded by ConocoPhillips Alaska, Inc., (CPAI, and its heritage companies 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 NPRA since 1999 (Johnson et al. 2015; Jorgenson et al. 1997, 2003, 2004). Since 1990, contemporaneous, collaborative telemetry studies of caribou distribution and movements have been conducted 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) (Philo et al. 1993, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Lawhead et al. 2015, Parrett 2015). 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).

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).

Since 2004, the CD4 drill site and access road and CD3 pad and airstrip have been constructed on the Colville River delta and the CD5 drill site and access road have been constructed in northeastern NPRA just west of the delta. Other infrastructure added recently within the study area was the Nuiqsut Spur Road built by the Kuukpik Corporation in winter 2013–2014.

STUDY OBJECTIVES

This study seeks to understand caribou movements and distribution in and around the ASDP area and infrastructure 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.

Evaluation of the natural and anthropogenic factors affecting caribou in the study area fall into two broad categories: those affecting movements and those affecting 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 tasks were identified for study:

1. Evaluate the seasonal distribution and movements of caribou 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 connect current and proposed facilities?*

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

2) Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snowmelt, 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 indices of habitat use by caribou in the study area. Specific questions included the following:

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

STUDY AREA

The study area is located on the central Arctic Coastal Plain of northern Alaska (Figure 1, top). The climate in the region is arctic maritime (Walker and Morgan 1964). Winter lasts about eight months and is cold and windy. The summer thaw period lasts about 90 days (June–August) and the mean summer air temperature is 5°C (Kuparuk oilfield records: National Oceanic and Atmospheric Administration, unpublished data). Monthly mean air temperatures on the Colville River delta range from about –10°C in May to 15°C in July and August (North 1986), with a strong regional gradient of summer temperatures increasing with distance inland from the coast (Brown et al. 1975). Mean summer precipitation is <8 cm, most of which falls as rain in August. The soils are underlain by permafrost and the temperature of the active layer of thawed soil above permafrost ranges from 0° to 10°C during the growing season.

Spring is brief, lasting about three weeks from late May to mid-June, and is characterized by the flooding and break-up of rivers and smaller tundra streams. In late May, water from melting snow flows both over and under the ice on the Colville River, resulting in flooding on the Colville River delta that typically peaks during late May or the first week of June (Walker 1983; annual hydrology 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 hydrology 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 earlier permit stipulations, the study area was specified as the area within a 48-km (30-mi) radius around the CD4 drill site (Lawhead et al. 2015). During 2004–2014, aerial transect surveys were conducted in three survey areas, which encompassed most of that 48-km radius (Lawhead et al. 2015): 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 River Delta survey area (494 km²); and the Colville East survey area (1,432–1,938 km², depending on the survey and year). In 2016, however, the study area was redefined to focus on the NPRA and Colville River Delta survey areas (Figure 1, bottom); aerial survey results for the Colville East survey area are reported elsewhere (Prichard et al. 2017).

The Colville River Delta survey area encompasses Alpine drill sites CD1 through CD4. The NPRA survey area encompasses one newly constructed drill site (CD5), two proposed Greater Moose's Tooth (GMT) drill sites (GMT1 and GMT2), and their connecting access roads and pipelines. It also includes the Nuiqsut Spur Road that 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 infrastructure, its presence in the study area warrants its inclusion in this analysis.

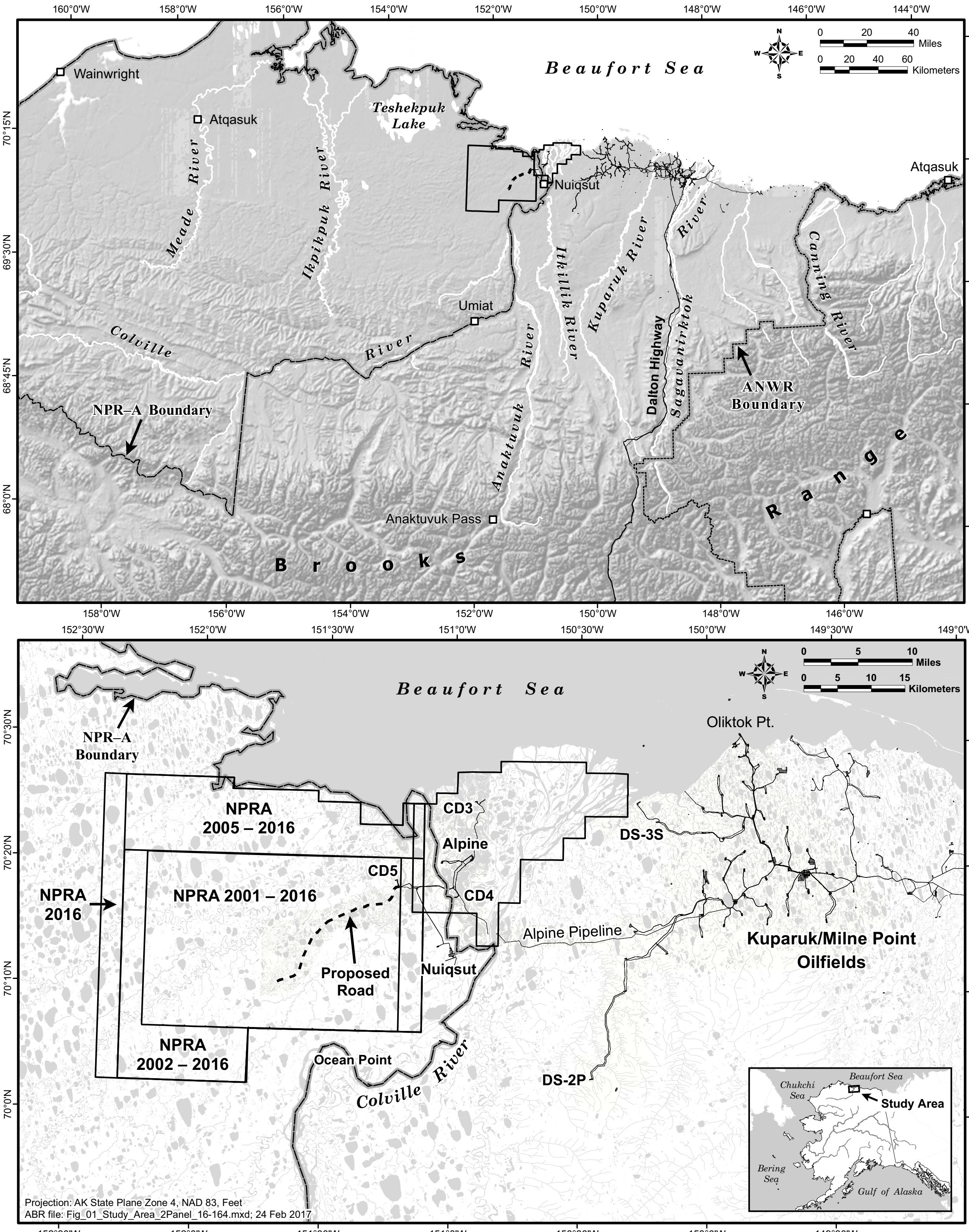


Figure 1. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the NPRA and Colville River Delta survey areas, 2001–2016.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, ABR biologists conducted aerial transect surveys in 2015 and 2016 and analyzed existing radio-telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and from GPS collars deployed specifically for this study annually in 2006–2010,2013–2014, and 2016.

Eight seasons were used for analysis of telemetry and aerial survey data, 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 eight 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, a period that also includes some mosquito harassment); late summer (8 August–15 September); and fall migration and rut (16 September–30 November).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Transect surveys provided information on the seasonal distribution and density of caribou in the study area. Surveys of the NPRA and Colville River Delta survey areas (Figure 1, bottom) were conducted periodically from April to October 2015 and 2016 in a fixed-wing airplane (Cessna 206, Cessna 207, or Helio Courier), following the same procedures used since 2001 (Lawhead et al. 2015 and references therein). The NPRA survey area was expanded westward and southward in 2002 and northward in 2005, and an additional transect was added to the western edge of the NPRA survey area in 2016.

In 2015, aerial transect surveys in the NPRA and Colville River Delta survey areas were flown in mid-April (late winter), early June (calving), late June (postcalving), and early October (fall). Surveys planned for May and early August and late October were cancelled due to budgetary constraints, and surveys planned for late August and September could not be completed due to persistent inclement weather. In 2016, aerial transect surveys in the NPRA and Colville River Delta survey areas were flown in mid-May (spring migration), early June (calving), late June (postcalving), early August (oestrid fly season), late August (late summer), mid-September (fall), and early October (fall); the Colville Delta area could not be surveyed in October due to poor weather.

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. The lower altitude was used only in the NPRA calving survey in 2001 to increase detection of caribou.

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 NPRA calving season survey 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 GPS receivers.

When caribou were observed within the transect strip, the perpendicular location on the transect centerline was recorded using a GPS receiver, the numbers of “large” caribou (adults and yearlings) and calves were recorded, and the perpendicular distance from the transect centerline was estimated in four 100-m or 200-m intervals, depending on the strip width. For plotting on maps, the midpoint of the distance interval was used (e.g., 300 m for the 200–400-m interval). Thus, the maximal mapping error was estimated to be ~100 m. Confidence intervals for estimates of total caribou and calves were calculated with a standard error formula modified from Gasaway et al. (1986), using 2-mile segments of the transects as the sample units.

Observations of other large mammals were recorded during field surveys (both aerial and ground-based) for this and other wildlife studies conducted for CPAI. These observations were summarized by Prichard et al. (2017).

DENSITY MAPPING

To summarize aerial survey data in the NPRA survey area for the period 2002–2016, we used the inverse distance-weighted (IDW) interpolation technique of the *gstat* package in *R* (Pebesma 2004) to map seasonal densities of caribou. Transect strips in the 2002–2004 and 2005–2015 NPRA survey areas were subdivided into 124 and 164 grid cells, respectively (the westernmost transect added in 2016 was not included due to limited sample size). Each grid cell was 1.6 km wide by 3.2 or 4.8 km long, depending on the transect length. The IDW technique used total numbers of caribou in each of the grid cells; 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 best power (between 1 and 1.2) and the best number of adjacent centroids (between 10 and 24) to use in the calculations were selected based on the values that minimized the residual mean square error. 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.

RADIO TELEMETRY

VHF Collars

Location data were provided by ADFG for all VHF collars in the CAH and TH during the years 1980–2005 (Table 1). Radio-collared caribou (primarily adult females) were tracked from fixed-wing aircraft using strut-mounted antennas and a scanning radio receiver. Although VHF telemetry does not provide detailed movement data, this method provided data on group size and behavior when the collared caribou could be observed (Cameron et al. 1995, Arthur and Del Vecchio 2009).

Satellite Collars

Satellite (platform transmitter terminal; PTT) telemetry used the Argos system (operated by CLS America, Inc.; CLS 2008) and locations were transferred monthly to the NSB for data archiving. Locations were transmitted either at 6 h/day for a month after deployment and then 6 h every other day throughout the year, or once every 6 days in winter and every other day during summer (Lawhead et al. 2015). The CAH satellite collars were programmed to operate 6 h/day or 6 h every 2 days (Fancy et al. 1992, Lawhead et al. 2015).

Table 1. Number of radio collars deployed on TH and CAH caribou that provided movement data for the ASDP caribou study.

Herd [a] / Collar Type	Years	Number of Females	Number of Males	Total Number
Teshekpuk Herd				
VHF collars [b]	1980–2005	n/a	n/a	212
Satellite collars	1990–2016	95	80	175
GPS collars	2004–2016	195	1	196
Central Arctic Herd				
VHF collars [b]	1980–2005	n/a	n/a	412
Satellite collars	1986–1990	16	1	17
Satellite collars	2001–2004	10	3	14
Satellite collars	2012–2016	6	6	12
GPS collars	2003–2016	160	0	160

[a] Herd affiliation at time of capture.
[b] n/a = not available, but most collared animals were females.

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–November 2016 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, this study; Person et al. 2007) and for CAH caribou during the periods October 1986–July 1990, July 2001–September 2004, and April 2012–September 2015 (Cameron et al. 1989, Fancy et al. 1992, Lawhead et al. 2006, Lenart 2015; Table 1). In the TH sample (based on herd affiliation at capture), 175 collars deployed on 156 different caribou (84 females, 72 males) transmitted signals for a mean duration of 525 days per collar. The CAH 1986–1990 sample included 17 caribou (16 females, 1 male). The 2001–4 and 2012–2016 deployment sample included 26 collars deployed on 25 caribou (16 females, 9 males; one male was outfitted sequentially with two different collars), transmitting for a mean duration of 572 days per collar.

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. Spurious locations were removed following the methods described in Lawhead et al (2015).

GPS Collars

A total of 195 GPS collars purchased by BLM, NSB, ADFG, and CPAI (TGW-3680 GEN-III or TGW-4680 GEN-IV store-on-board configurations with Argos satellite uplink, manufactured by Telonics, Inc., Mesa, AZ) were deployed by ADFG biologists on 130 different TH caribou (129 females, 1 male) during 2004 and 2006–2016, with a mean deployment duration of 454 days (Table 1). A total of 160 GPS collars (purchased by CPAI and ADFG) were deployed on 109 different female CAH caribou during 2003–2016, with a mean duration of 572 days. Collars were programmed to record locations at 2-, 3-, 5-, or 8-h intervals, depending on the desired longevity of the collar (Arthur and Del Vecchio 2009; Lawhead et al. 2015).

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 collar models used 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 daily from CLS America, Inc. (Largo, MD) and the full dataset was downloaded after the collars were retrieved. Data were screened to remove spurious locations following the methods described in Lawhead et al (2015).

SEASONAL OCCURRENCE IN THE STUDY AREA

Seasonal use of the NPRA and Colville River Delta survey areas was evaluated using two methods. The first method was to evaluate the proportion of each seasonal utilization distribution from kernel density estimation within the survey areas, by sex and herd, after first removing the portion of each seasonal utilization distribution contour that overlapped the ocean. The second method was to examine screened GPS and satellite collar data to describe caribou movements in the immediate vicinity of existing and proposed ASDP infrastructure.

To calculate seasonal kernels for seven of the eight seasons, a subset of collar 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 potential impact of pseudoreplication and the 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 2016), which uses Program *R* (*R* Core Team 2015) for some commands.

REMOTE SENSING

We downloaded calibrated radiance, geolocation, and cloud-mask swaths from MODIS Terra and Aqua sensors from the Level-1 and Atmospheres Archive and Distribution System (LAADS, Goddard Space Flight Center, Greenbelt, MD). Images collected over the study area at 12:00–16:00 local time for dates between 1 April and 31 August were obtained for 2015 and 2016, adding to the data compiled for 2000–2014 (see Lawhead et al. 2015 for detailed description of methods).

We applied the MODIS Corrected Reflectance (CREFL) Science Processing Algorithm (Version 1.7.1) 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). For data through 2015, we applied a revised cloud mask that incorporated snow cover history to reduce false cloud detection during the active snowmelt season. However, the revised cloud mask did not work with 2016 imagery, probably due to changes in the data from the aging MODIS sensors. For 2016, we applied manual cloud masks for the snowmelt season, while the standard cloud mask was applied for images in June and later.

We applied the MODIS Reprojection Tool Swath (MRTSwath Version 2.2) to grid the swath data to the Alaska Albers coordinate system (WGS-84 horizontal datum). We resampled to 60-m resolution initially, then aggregated to 240-m resolution (reflectance) and 960-m resolution (sensor view angle and cloud mask) to minimize systematic geolocation errors (see Lawhead et al. 2015 for details).

SNOW COVER

Snow cover 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. (2014).

A time series of images covering the April–June period was analyzed for each year during 2000–2016. Pixels with >50% water (or ice) cover were excluded from the analysis. For each pixel in each year, we identified:

- The first date with 50% or lower snow cover;
- The closest prior date with >50% snow cover was then identified;
- The midpoint between the last observed date with >50% snow cover and the first observed date with <50% snow cover, which is an unbiased estimate of the actual snowmelt date (the first date with <50% snow cover);
- The duration between the dates of the two satellite images with the last observed “snow” date and the first observed “melted” date, providing information on the uncertainty in the estimate of snowmelt date. When the time elapsed between those two dates exceeded a week because of extensive cloud cover or satellite sensor malfunction, the pixel was assigned to the “unknown” category.

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):

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

where:

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

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

We derived constrained view-angle (sensor zenith angle ≤40°) maximum-value composites from corrected reflectance MODIS imagery acquired over targeted portions of the growing season in 2000–2016. NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) for each year during 2000–2016 (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 two composite periods (15–21 June and 22–28 June) in each year. NDVI_Rate was calculated as the linear change in NDVI from NDVI_Calving to NDVI_621 for each year. Finally, NDVI_Peak was calculated from all imagery obtained between 21 June and 31 August for each year during 2000–2016. Details of the processing to minimize the impact of clouds, cloud shadows, snow, ice and water on the NDVI metrics are described in Lawhead et al. (2015).

HABITAT CLASSIFICATION

We used the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 2) for habitat classification and analysis. The NPRA survey area contained 15 cover classes from the NPRA earth-cover classification (Appendix A), which were lumped further into nine types to analyze habitat use. The Barren Ground/Other, Dunes/Dry Sand, Low Shrub, and Sparsely Vegetated classes, which mostly occurred along Fish and Judy creeks, were combined into a single Riverine habitat type. The two flooded-tundra classes were combined as Flooded Tundra and the Clear-water, Turbid-water, and *Arctophila fulv*a 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.

Previous reports (e.g., Lawhead et al 2015) used a land-cover map created by Ducks Unlimited for the North Slope Science Initiative (NSSI 2013); however, discontinuities in classification methodology and imagery bisected our NPRA survey area and potentially resulted in land-cover classification differences in different portions of the survey area, so we used the BLM and Ducks Unlimited (2002) classification instead.

RESOURCE SELECTION ANALYSIS

In previous years of this study (Lawhead et al. 2015 and prior ASDP citations therein), we conducted multiple separate analyses to characterize preconstruction conditions in the NPRA survey area. Caribou group locations from aerial transects were analyzed with respect to multiples factors including geographic zones, habitat, snow-cover classes, and estimated values of vegetative biomass (NDVI) to evaluate the relationship of those factors to caribou distribution. For the 2015 and 2016 efforts, we replaced those separate analyses with a single analytical approach by using resource selection function (RSF) models (Boyce and McDonald 1999, Manley et al. 2002). RSF models allow simultaneous comparison of selection for multiple variables and incorporation of caribou locations from both aerial surveys and radio telemetry. RSF models compare actual locations with random locations within a logistic regression framework and can be a useful tool for quantifying important factors influencing habitat selection during different seasons and for assessing relative importance of different areas based on the spatial pattern of those factors.

We used group locations from aerial surveys and locations from GPS-collared individuals but not from satellite-collared animals, due to the lower accuracy of the latter collar type. We used caribou locations from transect surveys conducted during 2002–2016 in the NPRA survey area; the seasonal sample sizes for the Colville River Delta survey area were too small to support RSF analysis. The telemetry data spanned the period 11 May 2003–31 December 2016 and were filtered to include only locations falling within the aerial survey areas. To standardize the time between GPS-collar locations, maintain a good sample size, and reduce the effect of autocorrelation on results, we subsampled locations at 48-h intervals in all seasons. We assumed that 48 h was enough time for a caribou to move across the entire study area, so autocorrelation would be minimal (Lair 1987,

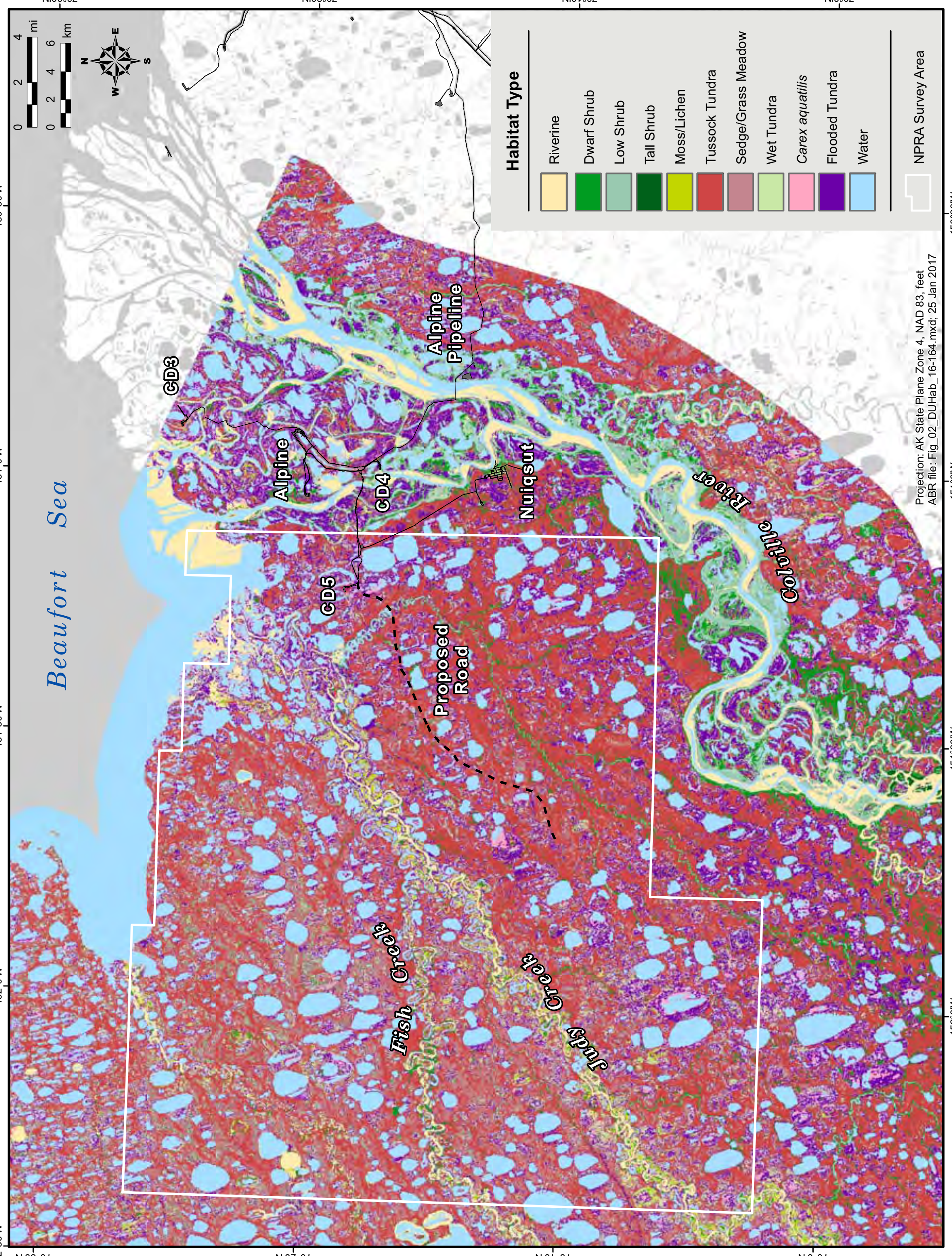


Figure 2. Habitat types used for caribou habitat-selection analysis in the NPRA survey area (adapted from BLM and Ducks Unlimited 2002).

McNay et al. 1994). We excluded caribou locations in waterbodies on the habitat map and in areas that were excluded from the NDVI calculations because they were predominantly water-covered.

To estimate resource selection, we used logistic regression (Manley et al. 2002). For each actual caribou or caribou group location, we generated 100 random locations in non-water habitats within the same survey area as the actual location. We were therefore testing for selection at the level of specific areas or attributes for animals that were within the survey area. For this analysis we use the terms "selection" and "avoidance" to refer to attributes that are used more or less than expected by caribou, when compared with random points.

We used the 'glm' function from the 'stats' package in Program *R* (*R* Core Team 2015) to create logistic regression models that maximized the probability of differentiating actual caribou locations from random locations. The other variables included in the models were habitat type (merged into the eight non-water categories; Figure 2); median NDVI for 2000–2016 (the NDVI metric used varied according to the season analyzed: median NDVI_Calving during the calving season, median NDVI_621 during the postcalving season, and NDVI_Peak during all other seasons); landscape ruggedness (Sappington et al. 2007) calculated over a 150-m by 150-m box centered at each 30-m pixel; the median snow-free date (date at which the pixel is typically snow-free [Macander et al. 2015], used only for the winter, spring migration, and calving seasons); distance to coast; west to east distribution We used the natural logarithm of landscape ruggedness to account for a skewed distribution (most values close to one) in that variable.

All locations were tested for collinearity between explanatory variables by calculating variance inflation factors (VIF) with the 'corvif' function found in the AED library in *R* (Zuur et al. 2009). Landscape ruggedness was log-transformed to meet normality assumptions. In addition, continuous variables were scaled (subtracted the mean and divided by the standard deviation) to aid in model convergence and parameter interpretation (Zuur et al. 2009). Because aerial survey data had low spatial precision (estimated error of 100–200 m), we calculated the most common habitat in a 210-m by 210-m area (7 × 7 pixels) centered on the estimated group location.

For each season, we tested all combinations of all variables (no interactions were included) using the 'glmulti' packing in *R* (Calcagno and de Mazancourt 2010) using Akaike's Information Criterion adjusted for small sample sizes (AICc) to compare models. We calculated the unconditional (model-weighted) coefficients and standard error (SE) of each parameter by calculating a weighted average of different models that was weighted by the probability that each model was the best model in the candidate set (Akaike's weight; Burnham and Anderson 2002).

We tested the fit of the best models for each season using k-fold cross-validation (Boyce et al. 2002). At each step, we withheld one fifth of the caribou locations and calculated relative probabilities of use for locations used by those caribou (testing data) based on the remaining data (training data). We repeated this process five times; i.e., for each fifth of the caribou locations. We used the mean Pearson's rank correlation coefficient for the five testing data sets as a measure of model fit.

For each season, we created a map of the relative probability of use of the survey area. We calculated the relative probability of use based on the equation for the logistic regression. We used the model-weighted parameter estimates from all independent variables that had a 50% or greater probability of being in the best model (e.g., the sum of all Akaike weights for all models that included the variable was >0.5).

RESULTS

WEATHER CONDITIONS

Snow depth was above average at the Kuparuk airstrip in early April 2015, but melted quickly in the third week of May, much earlier than normal (Appendix B). Although some small patches of snow were still present in survey areas during the calving survey that year, sightability of caribou was high and no sightability correction factor (SCF) was required during calving (Lawhead et al. 2016). In 2016, snow depth was above average in early April, but melted quickly by mid-May, about a month earlier than average, creating patchy snow conditions for the May survey in the NPRA. Brief snowfall events occurred during the calving season in June, but no SCF was required to adjust the calving survey results.

Between late June and mid-August 2015, the occurrence of air temperatures conducive to insect activity (as indicated by the sum of thawing degree-days [TDD]) was above average in June, average in early July, and below average in late July and early August (Appendix B). Based on the available weather data, observations by ABR biologists conducting ground surveys for other studies in the study area, and the distribution and movements of radio-collared caribou, the onset of mosquito harassment on 16 June 2015 was very early (the earliest date observed since ABR began caribou surveys in the region in 1981; ABR, Inc., unpublished data), but the occurrence and severity of insect harassment was generally low after early July 2015 (Lawhead et al. 2016).

In 2016, air temperatures were at or above average from early May through mid-July, but were below average from mid-July through mid-August. Warm weather in early June resulted in midges emerging by 12 June, which usually signals that mosquito emergence will begin soon. Caribou showed some indications of northward movement that day, but did not reach the coast, suggesting that mosquito harassment was mild or abated closer to the coast. Mosquitos usually emerge within a few days of midge emergence, but cold temperatures and strong winds on and after 13 June likely suppressed mosquito emergence. ABR biologists conducting ground-based surveys for other projects near the Colville River Delta reported little mosquito harassment until 22 June, with moderate to severe harassment following on 23 and 24 June.

Kuparuk weather data indicated that temperatures in 2016 were above the long-term average in late June and early July and were below the long-term average in late July and early August (Appendix B). These weather data suggest that severe insect harassment conditions may have occurred multiple times in early summer when calves were young, but less frequently later in the summer when oestrid flies tend to be more active.

Table 2. Number and density of caribou in the NPRA and Colville River Delta survey areas, April–October 2015.

Survey Area and Date	Area [a]	Observed Large Caribou [b]	Observed Calves [c]	Observed Total Caribou	Mean Group Size [d]	Estimated Total Caribou [e]	SE [f]	Density (caribou/km²) [g]
NPRA								
April 20	1,720	289	0	289	4.5	578	96.3	0.34
June 8	1,720	173	3	176	2.7	352	72.1	0.20
June 18	1,720	2	0	2	1.0	4	1.9	<0.01
October 6	1,720	842	nr	842	14.0	1,648	353.6	0.96
Colville River Delta								
April 22	494	0	0	0	-	0	-	0
June 8	494	0	0	0	-	0	-	0
June 18	494	20	0	20	20	40	28.3	0.08
October 7	494	0	nr	0	-	0	-	0

[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 differentiated reliably due to larger size.
[d] Mean Group Size = Observed Total Caribou ÷ number of caribou groups observed.
[e] Estimated Total Caribou = Observed Total Caribou × 2 (to adjust for 50% sampling coverage).
[f] SE = Standard Error of Estimated Total Caribou, calculated following Gasaway et al. (1986), using transects as sample units.
[g] Density = Estimated Total Caribou ÷ Area.

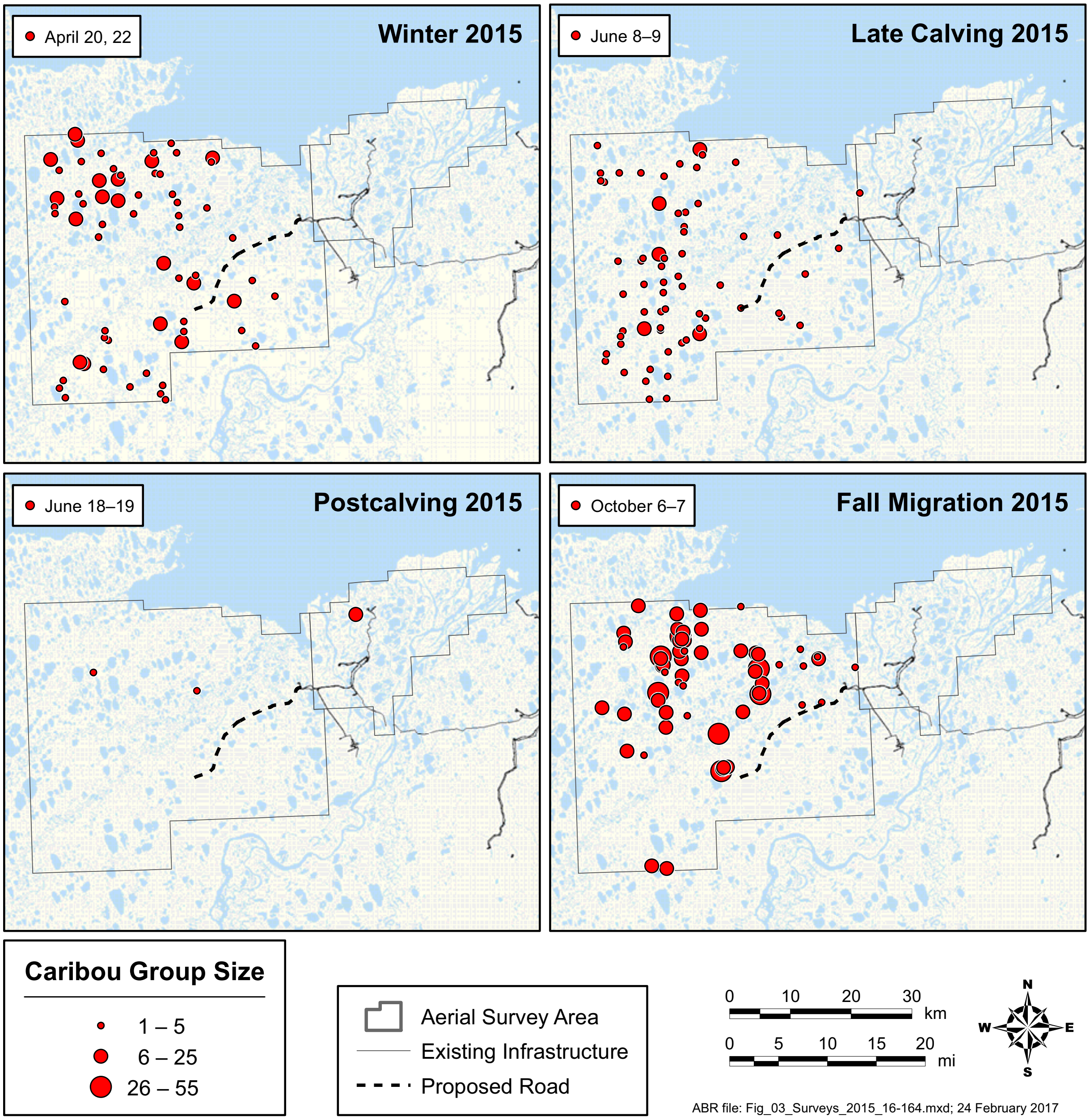


Figure 3. Distribution and size of caribou groups during different seasons in the NPRA and Colville River Delta survey areas, April–October 2015.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

In 2015, four aerial surveys of the NPRA survey area were flown between 19 April and 6 October (Table 2, Figure 3), the estimated density of caribou ranged from a high of 0.96 caribou/km² on 6 October to <0.01 caribou/km² on 18 June (Table 2, Figure 3). A total of 289 caribou and a density of caribou of 0.34 caribou/km² were observed during the late winter survey on 20 April. The density of caribou observed during the calving survey on 8 June (0.20 caribou/km²) was lower than the density observed during the late winter survey and was near the low end of the range of densities observed during calving surveys in

2001–2014 (0.01–0.87 caribou/km² for 6–9 June); only three calves were observed. Only two large caribou and no calves were observed during the postcalving survey on 18 June (Table 2, Figure 3), due to the early emergence of mosquitoes, which caused movement of caribou out of the survey area toward mosquito-relief habitat along the Beaufort Sea coast by the time of the survey. 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). A total of 842 caribou were observed during the fall migration survey on 6 October, resulting in an estimated density of 0.96 caribou/km².

In 2016, seven aerial surveys of the NPRA survey area were flown between 17 May and 10 October. The estimated density ranged from a high of 1.08 caribou/km² on October 10 to 0.03 caribou/km² on August 2 (Table 3, Figure 4). The late winter survey in April could not be flown due to inclement weather. A total of 23 caribou (<0.01 caribou/km²) were observed on the spring migration survey on 17 May (Table 3, Figure 4). The density of caribou increased to 0.18 and 0.15 caribou/km² for the calving and postcalving surveys, but only 14 and 16 calves were seen on each of those surveys, respectively. Density decreased on the 2 August survey (0.03 caribou/km²) during the oestrid fly season. Caribou density subsequently increased to 0.20 caribou/km² on the late summer survey (August 29), 0.46 caribou/km² on the first fall survey (September 19), and 1.08 caribou/km² on the second fall survey (October 10).

These results are generally consistent with the seasonal patterns of caribou density observed in the NPRA survey area since 2001 (Figure 5). Caribou densities on the winter, calving, and fall surveys in 2015 and 2016 were close to the long-term means

Table 3. Number and density of caribou in the NPRA and Colville River Delta survey areas, May–October 2016.

Survey Area and Date	Area [a]	Observed Large Caribou [b]	Observed Calves [c]	Observed Total Caribou	Mean Group Size [d]	Estimated Total Caribou [e]	SE [f]	Density (caribou/km²) [g]
NPRA								
May 17 [h]	1,818	23	0	23	4.6	88	19.3	0.05
June 6–7	1,818	150	14	164	3.3	328	59.4	0.18
June 17	1,818	158	16	174	4.0	348	46.7	0.14
August 2	1,818	25	nr	25	1.5	50	7.8	0.03
August 29	1,818	181	nr	181	2.4	362	43.5	0.20
September 19	1,818	420	nr	420	5.0	840	129.1	0.46
October 10	1,818	980	nr	980	6.2	1960	308.3	1.08
Colville River Delta								
May 16	494	0	0	0	–	0	–	0
June 6	494	0	0	0	–	0	–	0
June 16	494	1	0	1	4.6	56	1.4	<0.01
August 3	494	5	nr	5	1.7	10	5.7	0.02
August 29	494	3	nr	3	1.5	6	3.0	0.01
September 19	494	2	nr	2	1.0	4	1.9	0.01

[a] Survey coverage was 50% of this area (909 km² in NPRA, 247 km² on the Colville River Delta) for complete surveys.
[b] Adults + yearlings.
[c] nr = not recorded; calves not differentiated reliably due to larger size.
[d] Mean Group Size = Observed Total Caribou ÷ number of caribou groups observed.
[e] Estimated Total Caribou = Observed Total Caribou × 2 (to adjust for 50% sampling coverage).
[f] SE = Standard Error of Estimated Total Caribou, calculated following Gasaway et al. (1986), using transects as sample units.
[g] Density = Estimated Total Caribou ÷ Area.
[h] Applied Sightability Correction Factor (SCF) of 1.88 (Lawhead et al. 1994) to areas with patchy snow cover.

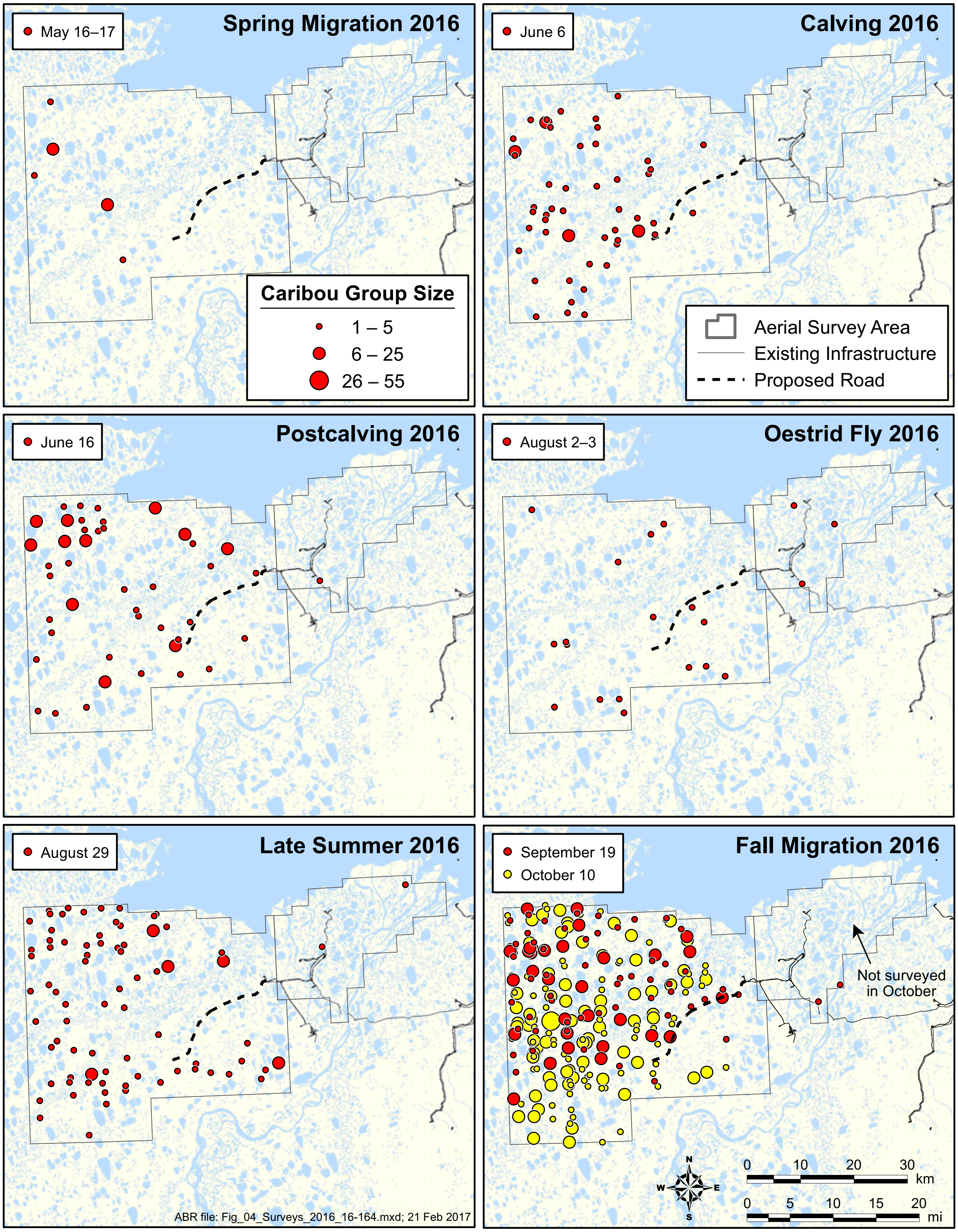


Figure 4. Distribution and size of caribou groups during different seasons in the NPRA and Colville River Delta survey areas, May–October 2016.

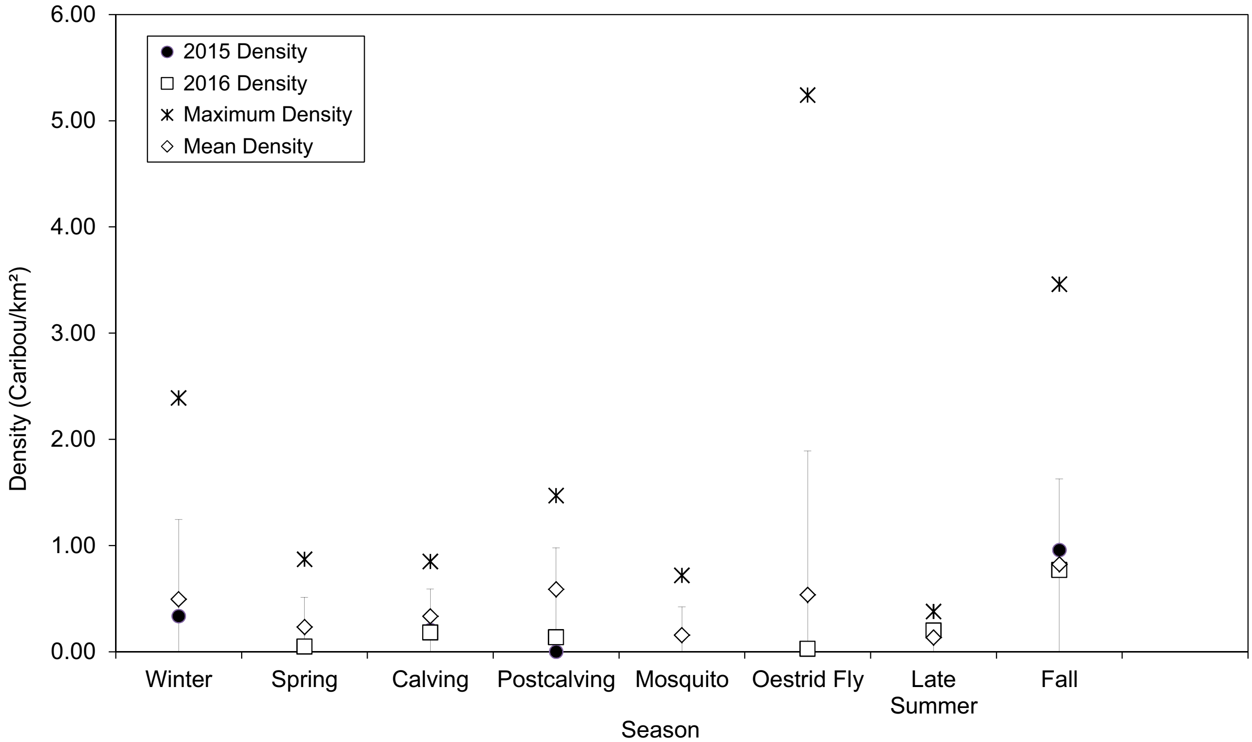


Figure 5. Seasonal density of caribou observed on 111 surveys of the NPRA survey area, April–October 2001–2016.

for those seasons, but caribou density during the 2015 postcalving survey was much lower than the long-term mean, due to the early emergence of mosquitoes in 2015. Results from the seasonal density mapping of caribou recorded on aerial surveys of the NPRA survey area during 2002–2016 also showed large differences among seasons (Figure 6). The highest mean density was observed during the oestrid fly season, but that density was strongly affected by several large groups that were observed in only one year (2005). During most seasons, a decreasing gradient in caribou density from west to east was apparent.

Colville River Delta Survey Area

In 2015, four surveys of the Colville River Delta survey area were flown between 22 April and 7 October 2015 and six surveys were flown between 16 May and 19 September 2016 (Tables 2–3). Similar to most surveys outside of the mosquito and oestrid fly seasons in previous years, the estimated density of caribou was very low on all surveys in 2015 and 2016 (0–0.08 caribou/km²); no caribou were recorded during three of the four surveys in 2015 and two of the six surveys in 2016 (Tables 2–3; Figures 3–4).

RADIO TELEMETRY

Radio collars provided detailed location and movement data throughout the year for a small number of individual caribou. The telemetry data also provided valuable insight into herd affiliation, which is not available from transect surveys. Mapping of the telemetry data from VHF, satellite (PTT), and GPS collars clearly shows that the study area is located at the interface of the annual ranges of the TH and CAH (Figures 7–9). The majority of collar locations for the TH and CAH occurred west and east, respectively, of the Colville River. The composite satellite and GPS telemetry data demonstrate that, although collared TH caribou use the study area to some extent in all seasons, their use peaks during the summer insect season (primarily oestrid fly season) and fall

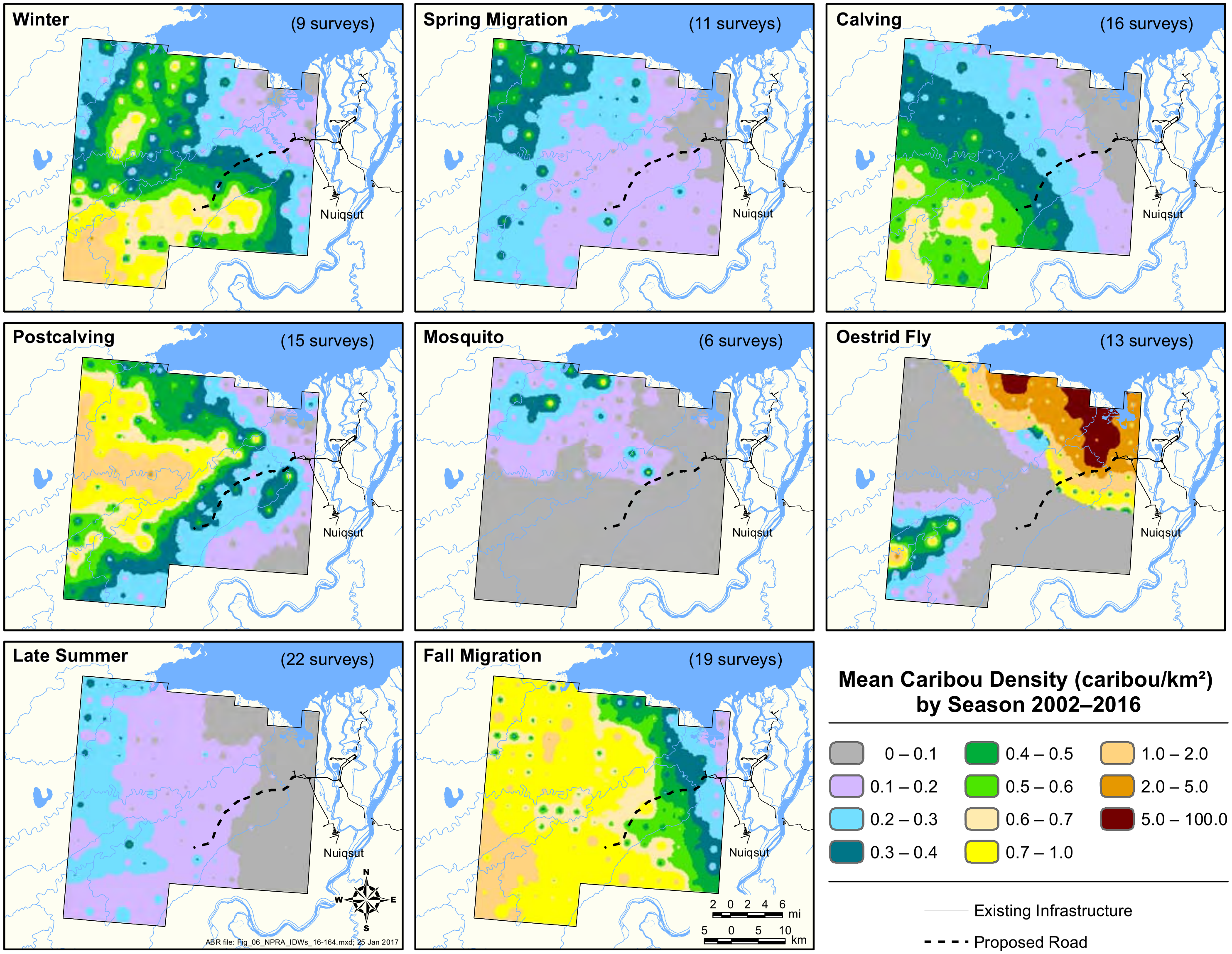


Figure 6. Seasonal density of caribou within the NPRA survey area based on IDW interpolation of aerial survey results, 2002–2016.

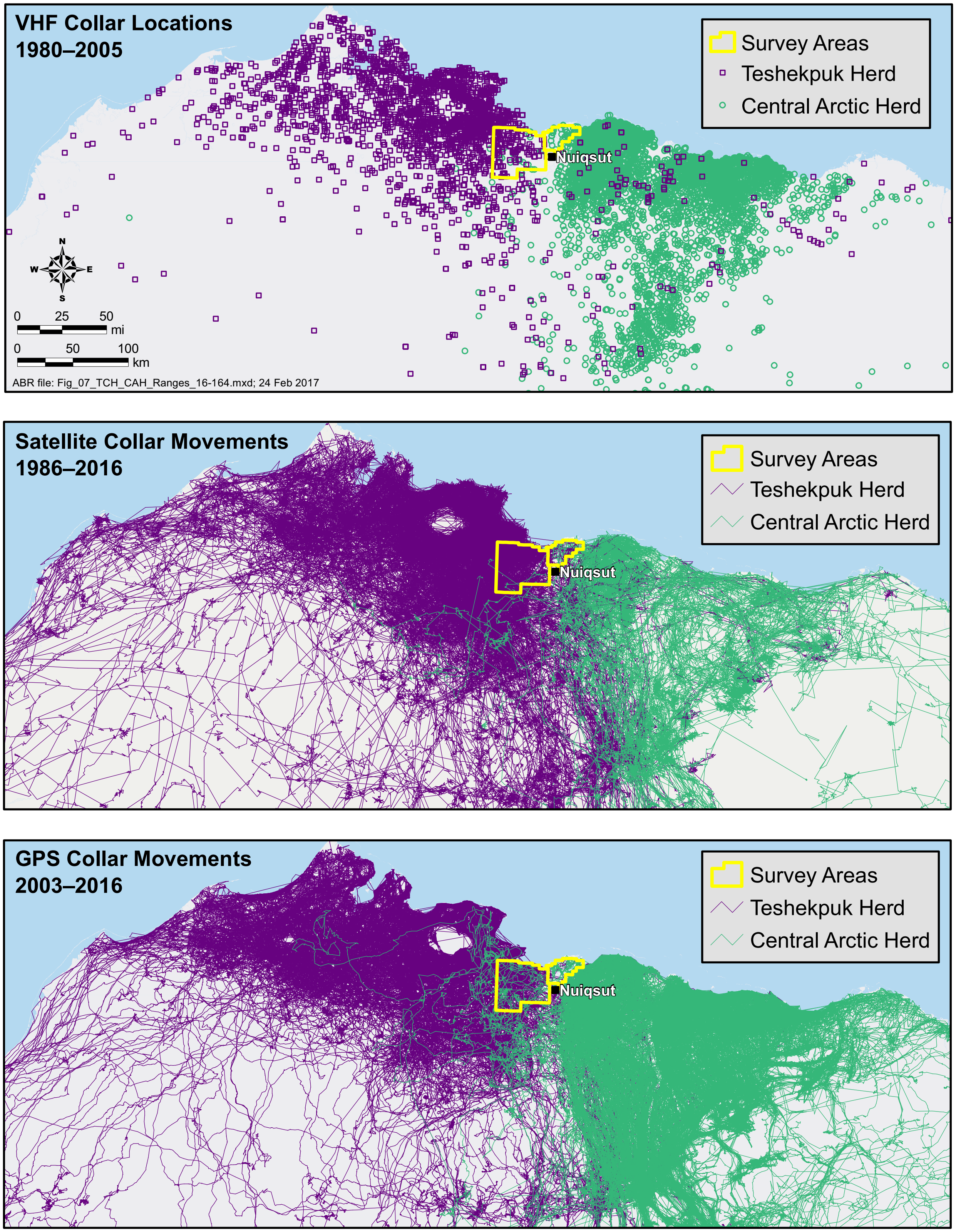


Figure 7. Ranges of TH and CAH caribou in northern Alaska in relation to the study area, based on VHF, satellite, and GPS radio-telemetry, 1980–2016.

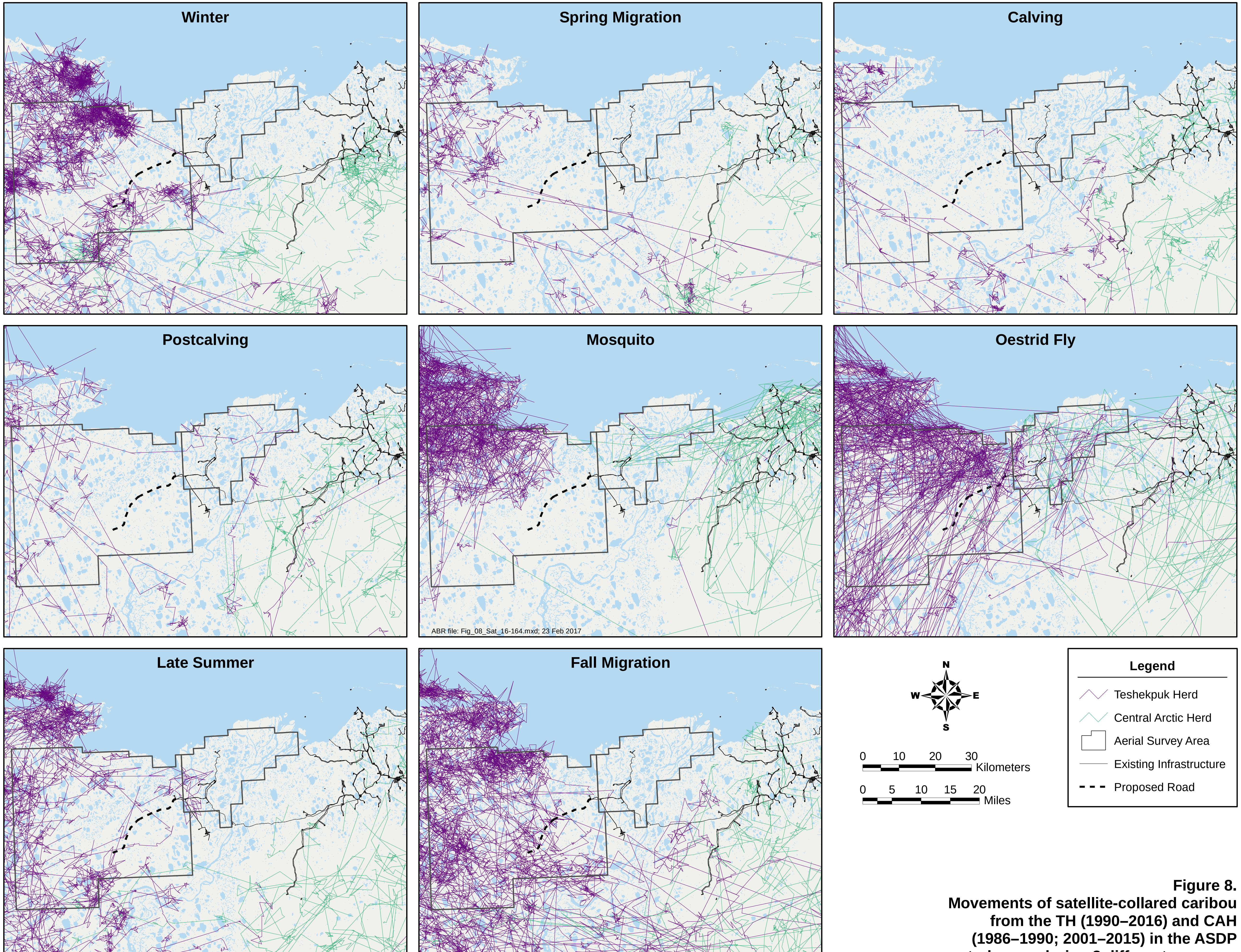


Figure 8.
Movements of satellite-collared caribou from the TH (1990–2016) and CAH (1986–1990; 2001–2015) in the ASDP study area during 8 different seasons.

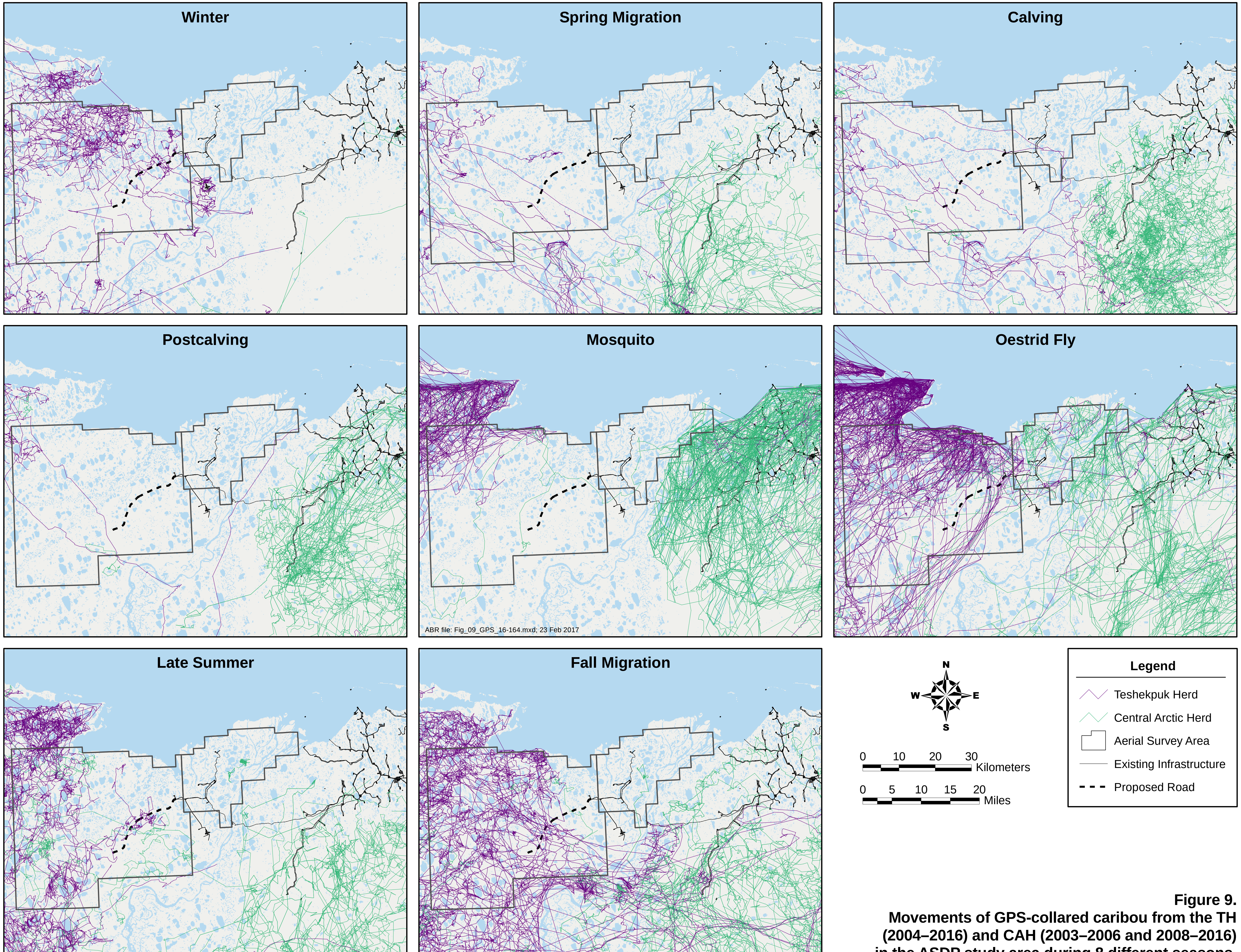


Figure 9.
Movements of GPS-collared caribou from the TH (2004–2016) and CAH (2003–2006 and 2008–2016) in the ASDP study area during 8 different seasons.

migration, followed closely by winter and late summer (Figures 8–9). The least use of the area by collared TH caribou occurred during spring migration, calving, and postcalving. Use by collared CAH caribou occurs mainly during the mosquito and oestrid fly seasons, with much lower levels of use occurring in other seasons.

VHF Collars

Interpretation of VHF telemetry data is limited by the fact that the locations of collared individuals are limited 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 distribution and movements between successive tracking flights. No new VHF data have been available for this study since 2005; VHF collar locations from previous years were discussed in more detail by Lawhead et al. (2006).

Satellite and GPS Collars

The detailed movement tracks of 22 different female CAH caribou that were fitted with GPS collars in 2013, 2014, and 2016 were mapped in relation to the study area for the period from December 2014 through November 2016 (Figures 10–13). All but one of the caribou collared in 2013 and 2014 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. The six caribou collared in 2016 were captured in early July near the coast. Two animals (Caribou C0910 and C1444; Figure 10) died in April 2015 and their collars were retrieved by ADFG biologists in summer 2015. Caribou C1107 died in October 2015 and that collar was retrieved in summer 2016.

The seasonal movements of GPS-collared female CAH caribou from December 2014 through November 2016 were broadly similar to patterns described previously (July 2007 to December 2014; Lawhead et al. 2015 and references therein). Collared CAH females were distributed over a wide geographic area during calving in 2015, with the extremes ranging from ~100 km east of Point Lay on the west (Caribou C0810; Figure 13) to east of the Canning River in ANWR (Caribou C0801, C1325, and C1108; Figure 12). Most of these females calved in the traditional calving grounds of the CAH between the Colville and Canning rivers (Figures 10–13), with the exception of C1001, which calved in the traditional TH calving area near Teshekpuk Lake (Figure 13) and Caribou C0810. Caribou C0810 was notable because her movements were not typical of CAH animals; she spent the winter of 2013–2014 on the Seward Peninsula with WAH animals (Lawhead et al. 2015) and the winter of 2014–2015 in the Brooks Range with TH animals. In 2015, she calved and spent the summer with the WAH and then moved northeast toward Umiat before migrating south to the Brooks Range with TH animals (Figure 13).

After the calving season in 2015, GPS-collared CAH females ranged widely, from Teshekpuk Lake and farther west (Caribou C0810 and C1001; Figure 13) to as far east as Canada (Caribou C1108, C1418, C1437, C1325; Figure 12). Most of the GPS-collared animals used traditional CAH summer range between the Colville and Canning rivers after calving, but one moved west into NPRA during the insect season and late summer (Caribou C1330; Figure 13) and four others (Caribou C1325, C1108, C1418, and C1437) displayed movement patterns typical of the PH after calving, moving east and south near or into Canada (Figure 12). Only one of these caribou (Caribou C1437) returned to Alaska to winter in the Brooks Range during the winter of 2015–2016.

During calving 2016, three collared caribou (C1330, C0810, and C1001) were with the TH near Teshekpuk Lake (Figure 13), four collared caribou (C1426, C02120, C1439, and C1006; Figures 10–11) were with the western segment of the CAH, and three collared caribou (C1309, C1007, and C1427; Figures 10–11) were with the eastern segment of the CAH, and four collared caribou (Figure 12) were in ANWR or just west of the Canning River during calving. Two of those four collared caribou (C0801 and C06335) migrated from the west, one collared caribou (C1437) migrated from the south and one collared caribou (C1108) migrated from the east.

In late June 2016, CPAI collars that were deployed on caribou in 2013 (C0801, C1309, C1330, and C0810) were retrieved by ADFG and new GPS collars were deployed on two of these caribou (C0801 and C1309) plus three other CAH females (C1102, C1329, and C1620). Two of the retrieved collars (C1330, C0810) were on caribou moving with the TH in 2016, so those caribou were not recollared. After that collaring operation, one female (C1001) remained with the TH, moving north and west of Teshekpuk Lake during the mosquito season and remained on the coastal plain for the rest of 2016 (Figure 13). Two collared caribou (C1427 and C1620) remained largely between the Sagavanirktok and Canning rivers during the summer (Figure 11), an area usually occupied by the eastern segment of the CAH. Eight collared caribou (C1426, C1007, C02120, C1439, C1006, C1309, C1329, and C1102) were in the oilfields west of the Sagavanirktok River during part or all of the mosquito season, typical of the traditional movement pattern of the CAH western segment. Four caribou (C0801, C1108, C06335, and C1437) moved into the eastern Brooks Range during the mosquito season, apparently with PH animals (Figure 12).

Caribou C1329 moved west of the Colville River in September and was near caribou C1001 with the TH during early winter (Figure 11). Caribou C1309 remained near the oilfields during most of the remainder of 2016. Six collared caribou (C1426, C02120, C1439, C1006, C1427, and C1620) were on the Coastal Plain south of the oilfields during early winter (Figures 10–11). Two collared caribou (C0801 and C1102) were in the Brooks Range east of the Dalton Highway during early winter (Figures 11–12). Three collared caribou (C1108, C06335, and C1437) were in the Brooks Range near the Canadian Border during early winter, apparently with the PH animals (Figure 12). Based on the radio-collar data, the movements of CAH animals in 2016 were unusual in that most of the CAH herd apparently remained on the Coastal Plain rather than migrating south in to the Brooks Range bin early winter.

A number of collared caribou exhibited movements that were more typical of the PH or TH herds than the CAH. Some of these animals may have been PH animals that were inadvertently collared while on winter range where CAH and PH animals have mixed in recent years, but some of the changes in herd association appear to represent real interchange of individuals among herds, as described by Person et al. (2007).

Kernel Density Analysis

Seasonal concentration areas were estimated using fixed-kernel density analysis, based on locations from satellite and GPS collars deployed on 195 TH females and 72 TH males during 1990–2016 and on 131 CAH females and 8 CAH males during 2001–2016. These numbers differ from the number of collar deployments listed earlier (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% utilization distribution contours (isopleths), which depict gradations in caribou density for female CAH caribou and for both sexes of TH caribou (Figures 14–16); 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 in two areas on either side of the Dalton Highway/TAPS corridor, spent the mosquito season near the coast (mostly east of Deadhorse), and dispersed across the across the coastal plain on both sides of the Dalton Highway/TAPS corridor during the oestrid fly and late summer seasons (Figure 14).

TH caribou generally wintered between on the Arctic Coastal Plain between Nuiqsut and Wainwright or in the central Brooks Range near Anaktuvuk Pass, migrated to their calving grounds near Teshekpuk Lake, and spent the rest of the summer on the coastal plain, primarily between Nuiqsut and Atqasuk (Figures 15–16). Compared with females, males tended to overwinter in the central Brooks Range instead of the coastal plain , migrated to summer range later, and were not distributed as far west during the summer (Figures 15–16).

Examination of the percentage of kernel densities by month showed that collared CAH females used the NPRA survey area at low levels (<2% of the total female CAH utilization distribution) from May through October, with almost no use the rest of the year (Figure 17). Use of the survey area by TH males increased sharply from May to a peak in July (15.3% of the utilization distribution) during the oestrid fly

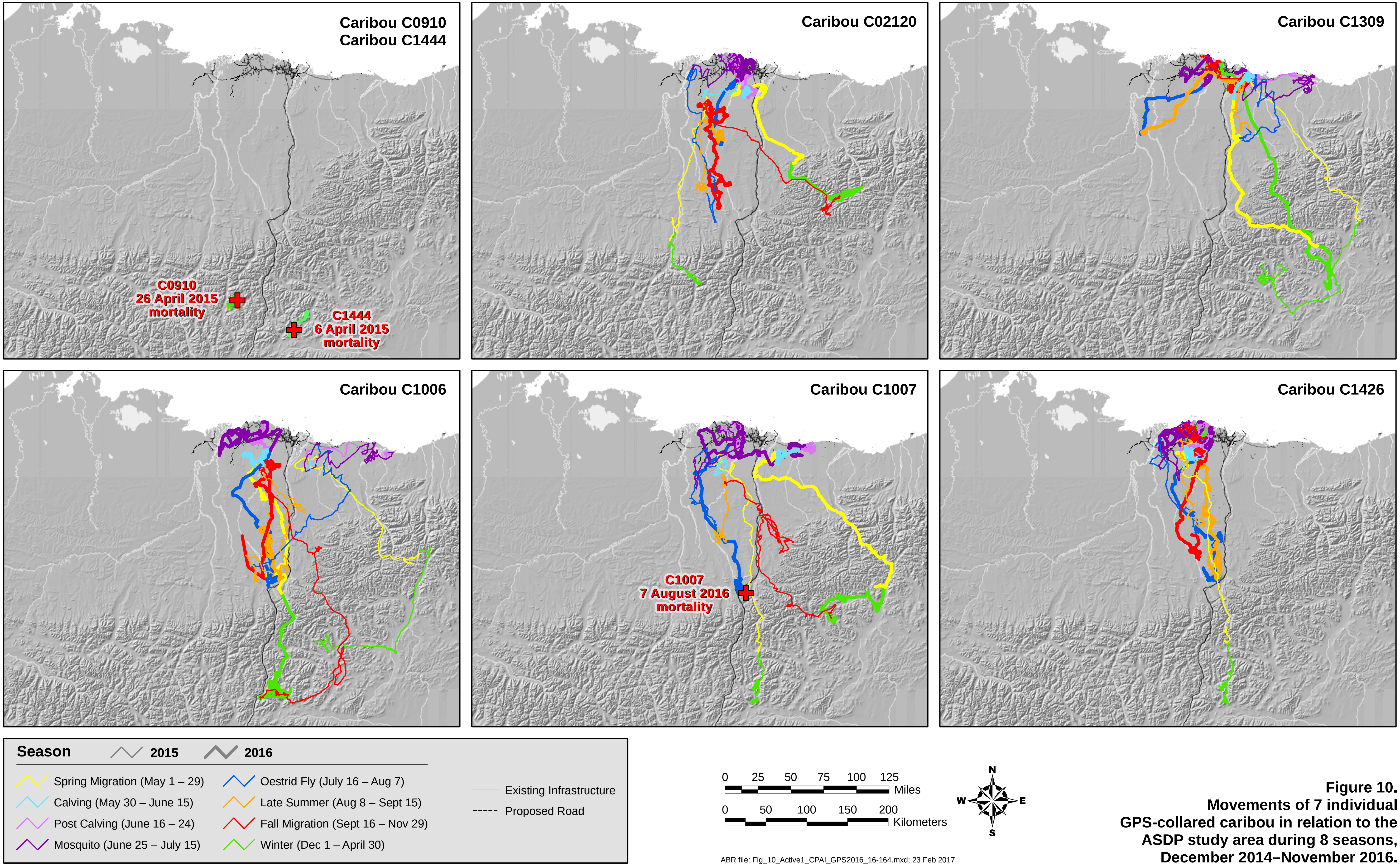
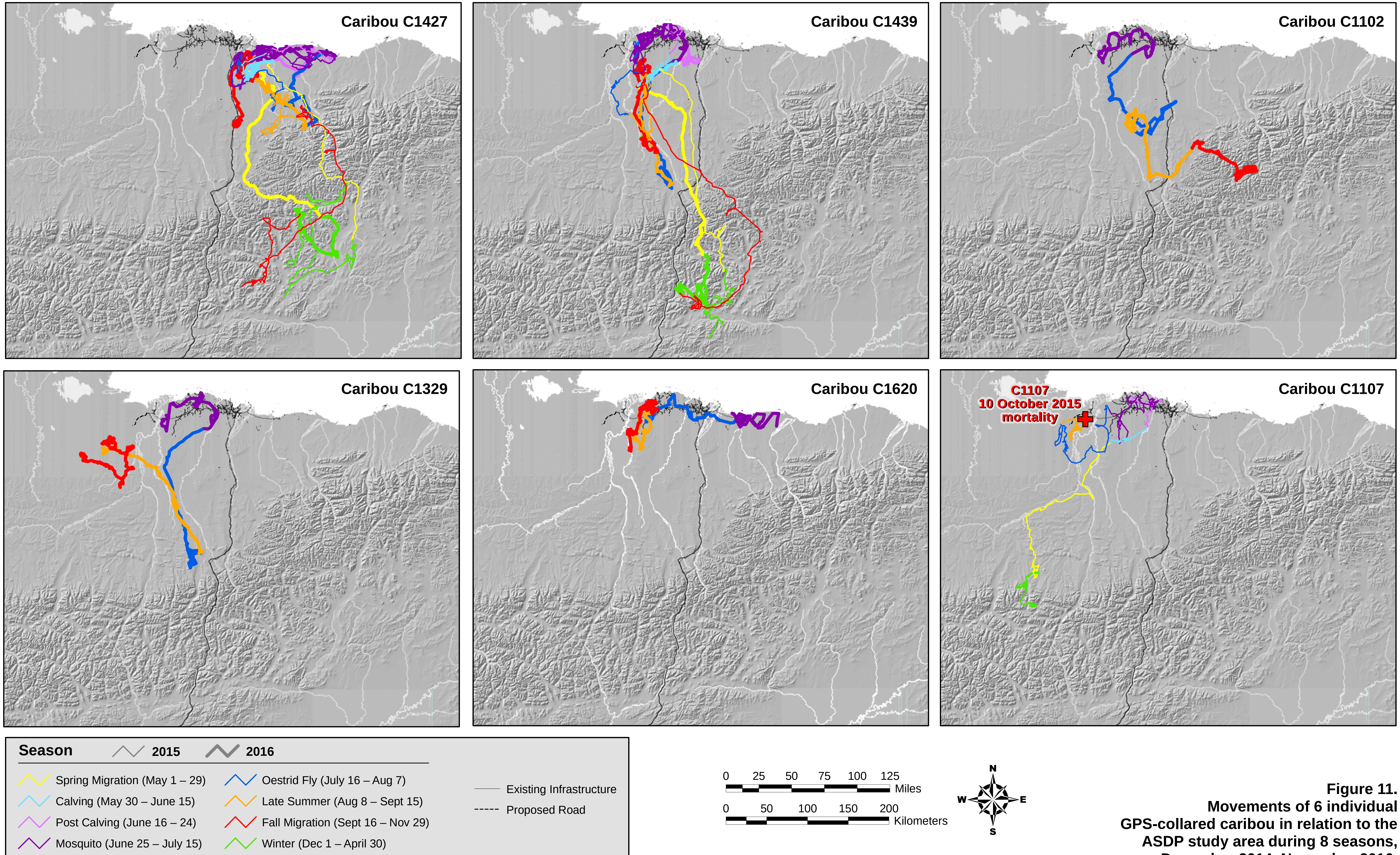


Figure 10.
Movements of 7 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2014–November 2016.



ABR file: Fig_11_Active2_CPAI_GPS2016_16-164.mxd; 23 Feb 2017

Figure 11.
Movements of 6 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2014–November 2016.

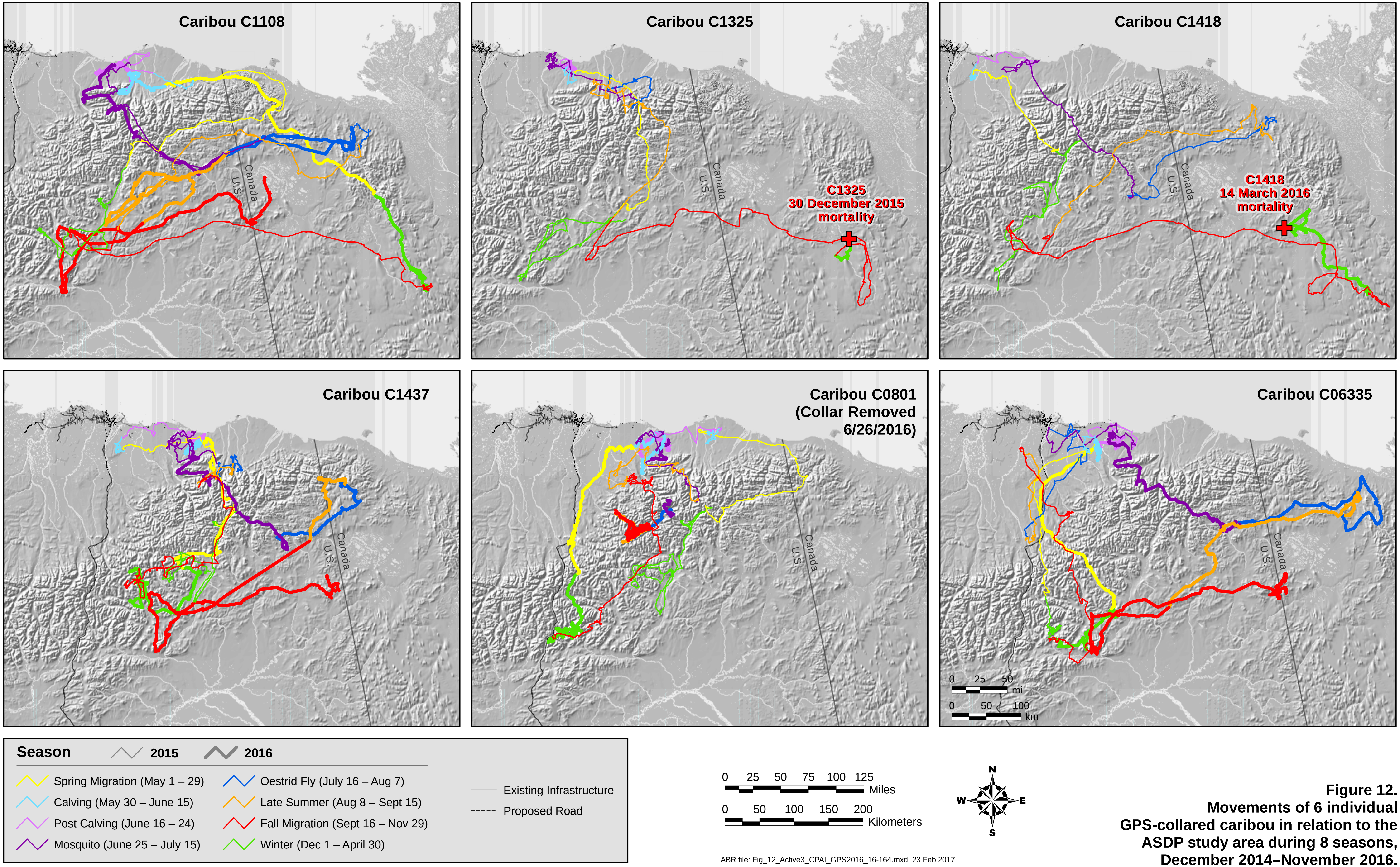


**Figure 12.
Movements of 6 individual
GPS-collared caribou in relation to the
ASDP study area during 8 seasons,
December 2014–November 2016.**

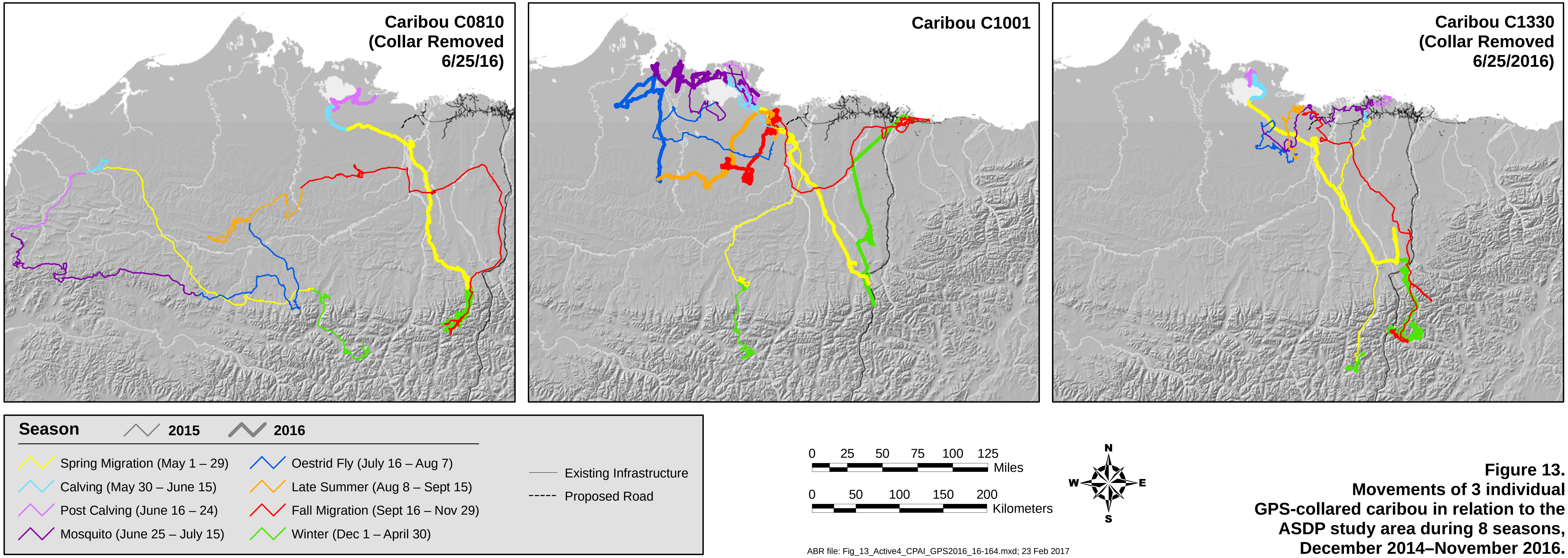


Figure 13.
Movements of 3 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2014–November 2016.

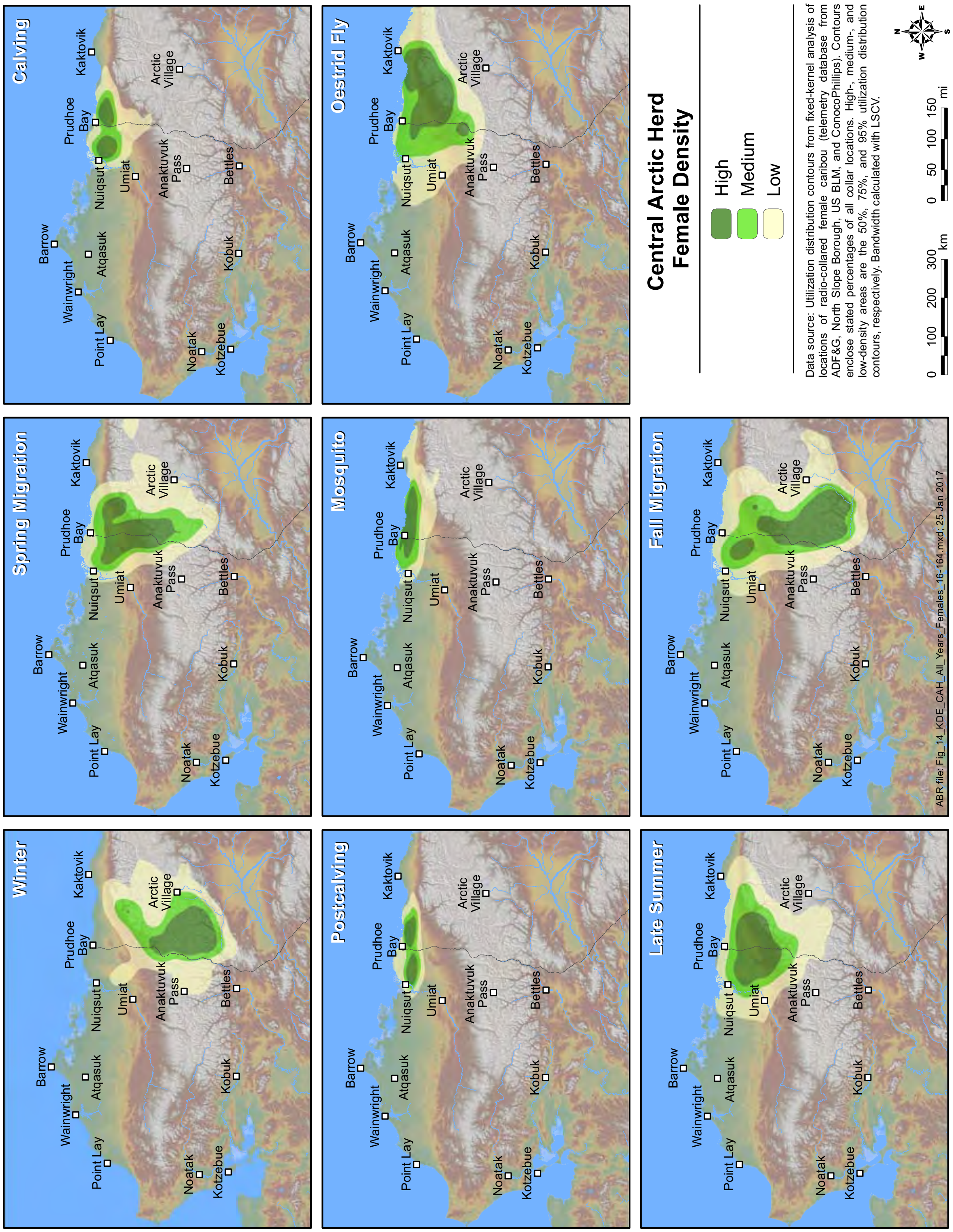


Figure 14. Seasonal distribution of CAH females based on fixed-kernel density estimation of telemetry locations, 2001–2016.

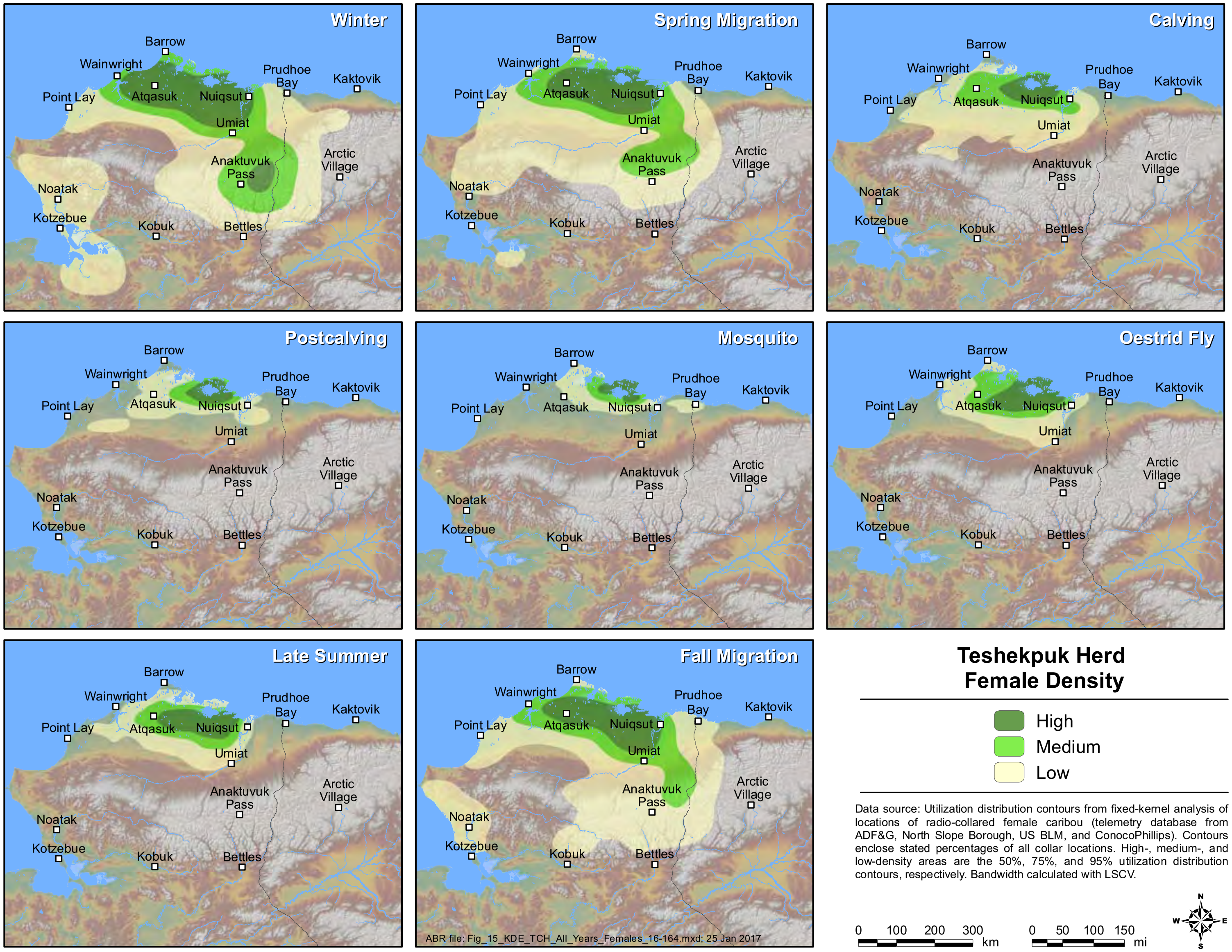


Figure 15. Seasonal distribution of TH females based on fixed-kernel density estimation of telemetry locations, 1990–2016.

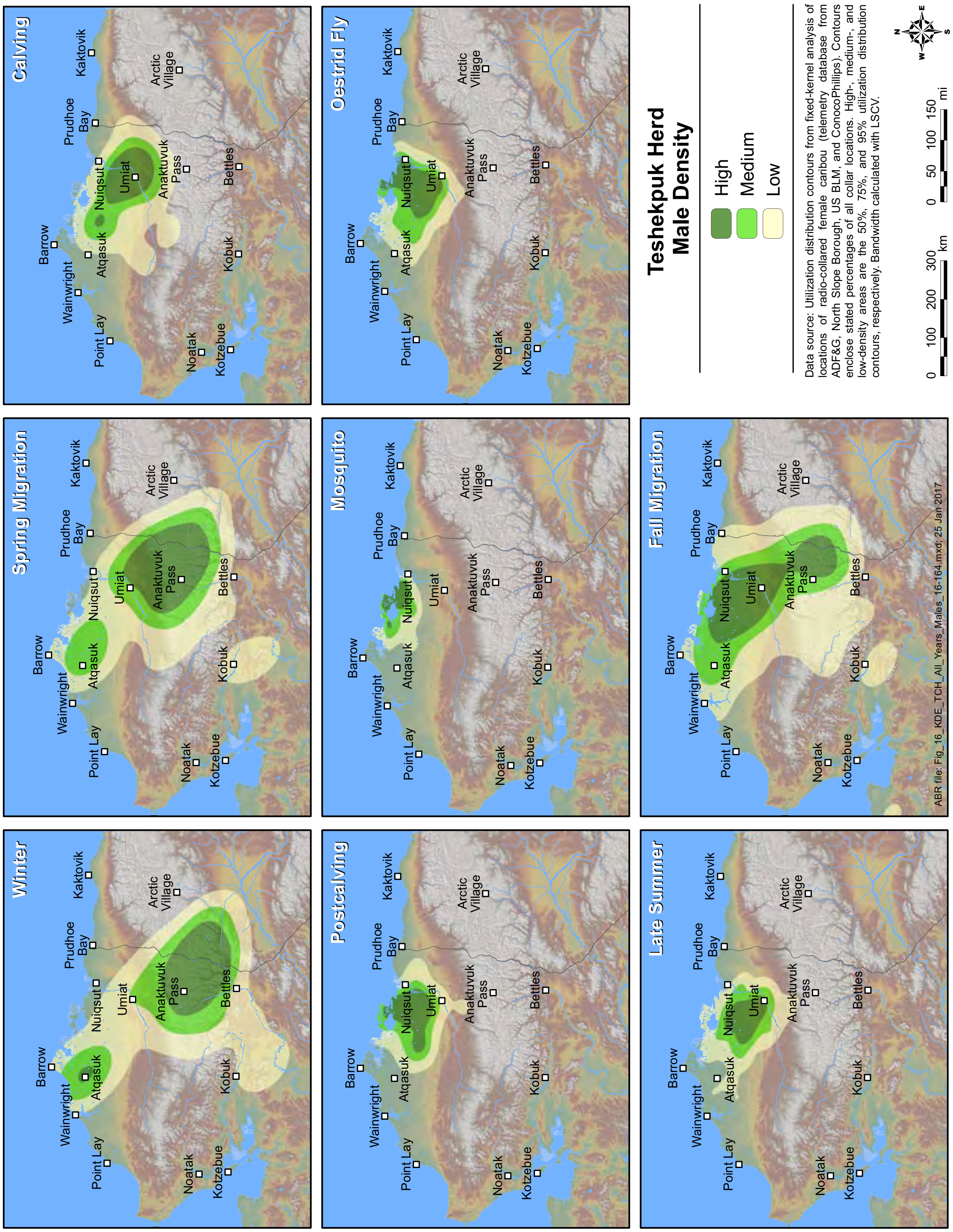


Figure 16. Seasonal distribution of TH males based on fixed-kernel density estimation of telemetry locations, 1997–2016.

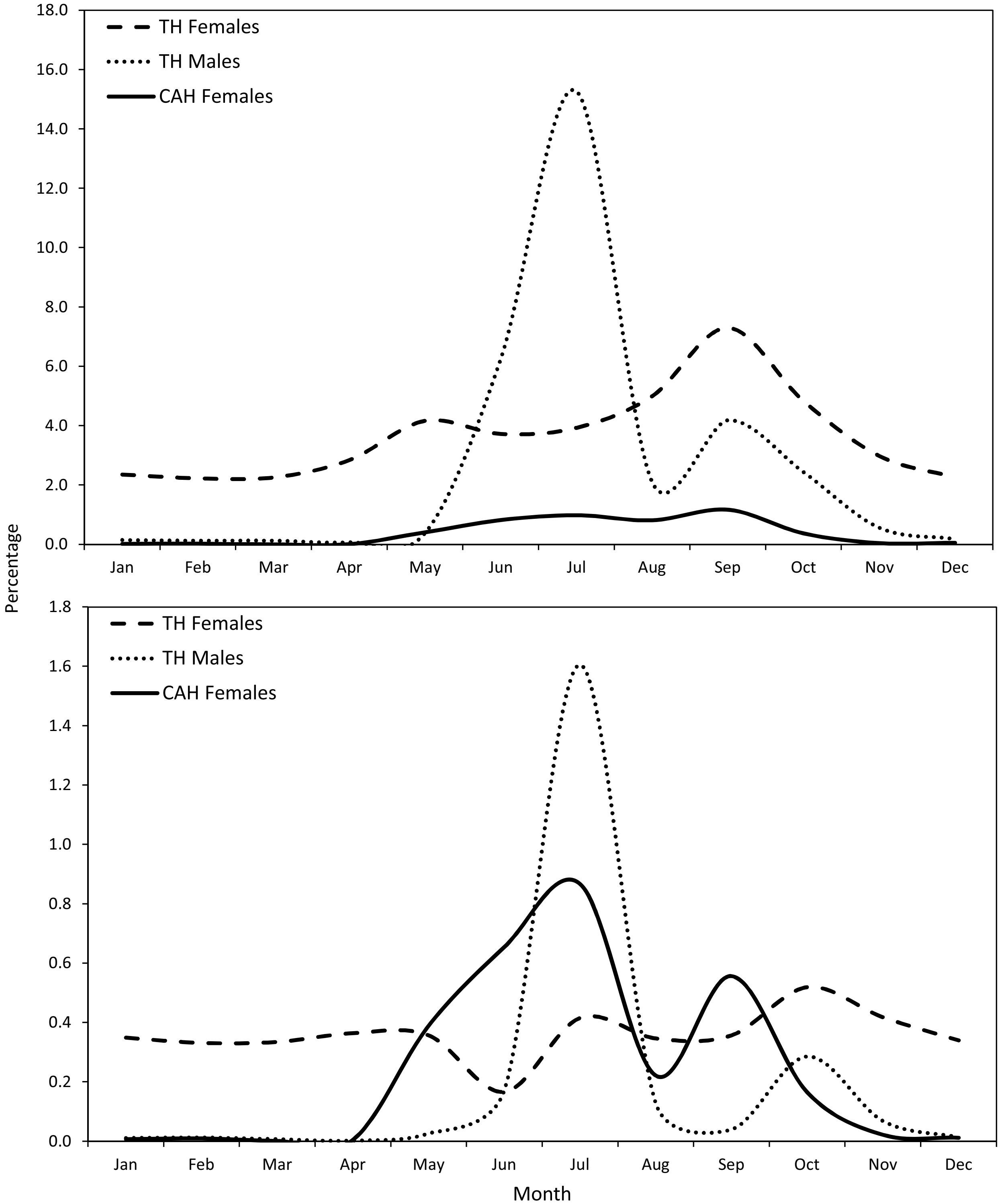


Figure 17. Percentage of CAH and TH caribou within the NPRA survey area (top panel) and Colville River Delta survey area (bottom panel), based on fixed-kernel density estimation, 1990–2016.

season. The percentage of collared TH males found in the NPRA survey area remained at lower levels (<5%) from August through October, and then dropped below 1% as males migrated into the foothills and mountains of the Brooks Range or toward the Atqasuk area during the winter (Figure 17). In contrast, collared TH females used the area at consistently low levels (2.2–7.3% of total utilization) throughout the year, with the highest level of use occurring in September (Figure 17).

Monthly use of the Colville River Delta survey area by collared animals was low for both CAH and TH caribou during the entire year (<2% of the utilization distribution; Figure 17). The highest percentages for TH males and CAH females occurred during July (1.6% and 0.9%, respectively) and the highest percentages for TH females occurred during October (0.5%; Figure 17).

Movements Near ASDP Infrastructure

Movements by collared TH and CAH caribou near ASDP infrastructure have occurred infrequently and sporadically—primarily 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 8– 9 and 18; Lawhead et al. 2015). From December 2014 through November 2016, no satellite or GPS-collared TH caribou were recorded within 4 km of the Alpine CD1 through CD4 facilities or associated roads. However, on 2 July 2015 one GPS-collared CAH female (Caribou C1330) passed within 3 km east of CD1, CD3, and CD4 while moving from north to south (Figure 18).

Movements across the CD5 access road and pad location also occurred only rarely before construction. In previous years, eight TH caribou outfitted with GPS collars crossed the CD5 road alignment prior to construction: one in June 2007, one in January 2008, two in July 2010, and four in July 2011. A total of 11 TH caribou outfitted with satellite collars crossed the CD5 road alignment in the years before it was constructed: one female in August 1992, one female in September 2004, one female in February and March 2005, one female in June 2007, one male in July 2007, five males in July 2010, and one female in August 2012. One CAH caribou outfitted with a GPS collar crossed the CD5 alignment in July 2010. No CAH caribou outfitted with satellite collars crossed the CD5 alignment, either before or after construction.

Although greater proportions of the collared TH and CAH samples have crossed the proposed road alignment in NPRA (from CD5 to GMT2) than have occurred near CD4, such movements have not occurred frequently (Figures 8–9 and 18; Lawhead et al. 2015). Only one satellite-collared TH male (Caribou 1407) crossed the proposed alignment in 2015 (four times in September 2015). Ten different GPS-collared TH females crossed the alignment 15 times in 2015 (once in May, November, and December; seven times in September; and four times in October). In addition, two GPS-collared CAH females crossed the alignment three times in 2015 (once each in July, August, and September) (Figure 18). From December 2015 through November 2016, two collared caribou crossed the proposed alignment: one GPS-collared TH female (Caribou 1526) crossed 12 times in January and on 26 February, and one satellite-collared TH male crossed in May 2016.

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 extending beyond the 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 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 in Arctic Alaska.

SNOW COVER

The timing of snow melt was earlier than average in both 2015 and 2016. In 2015, snow melt was well underway along some floodplains in the study area by 16 May (Figure 19). Snow melted rapidly over the next few days and widespread patchy snow cover was evident by 20 May, except along the coast and in the uplands south and southwest of the Kuparuk oilfield. By 23 May, most of the study area was snow-free, with patchy snow cover remaining along the coast and in the uplands southwest of the Kuparuk oilfield. By 27 May, snow appeared to be limited to gullies and drifts, although persistent cloud cover obscured the coast until 7–8 June. By that time, snow was absent throughout the study area.

In 2016, snow melt was well underway along some floodplains in the ASDP study area by 12 May (Figure 20). Snow melted rapidly over the next few days and widespread patchy snow cover and snow-free areas were ubiquitous in the study area by 19 May. By 26–28 May, the study area was snow-free, except for some gullies and drifts.

The median dates of snow melt for each pixel computed using 2000–2016 data (where the date of melt was known to within one week) indicate that nearly all of the snow on the coastal plain typically melted over a period of three weeks between 25 May and 11 June (Figure 21, Appendix C). Snow melt progressed northward from the foothills of the Brooks Range 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 melted during the last week of May (Figure 21). The central coastal plain and most of the Colville River delta usually melted in the first week of June, leaving snow on the northernmost coastal plain, in uplands, and in terrain features that trap snow, such as stream gullies. During the second week in June, most of the remaining snow melted, although some deep snow-drift remnants, lake ice, and *aufeis* persisted into early July (Figure 21).

In the NPRA survey area, snow melt occurred earliest near stream channels and a south-to-north gradient was apparent, with snow melt typically occurring several days later near the coast. Snow melt in 2015 and 2016 was more than a week early in most of the survey area, and more than two weeks early in some parts (Figures 22–23). Snow melt was most accelerated in areas near the coast and southwest of the Kuparuk oilfield, which generally melted about a week later than adjacent areas.

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).

VEGETATIVE BIOMASS

The estimated vegetative biomass during calving in 2015 and 2016 (NDVI_Calving) was greater than zero across the ASDP study area, consistent with the absence of snow cover (Figures 24–25). In 2016 (Figure 25), an extensive area with very low or negative values of NDVI_Calving was noted southeast of the study area, likely due to ephemeral fresh snow that happened to occur during the only cloud-free window. Compared with median NDVI since 2000, NDVI_Calving in 2015 and 2016 was above average across the study area (Figures 22–23; Appendix D).

NDVI_Calving in 2015 and 2016 was most elevated compared to the median since 2000 along the coast and in the uplands southwest of the Kuparuk oilfield, which were also the areas where snow melt occurred considerably earlier than normal (Figures 22–23; Appendix D). NDVI_Rate was uniformly low across both survey areas (Figures 24–25). In 2015 and 2016, NDVI_621 and NDVI_Peak both showed the typical pattern of higher values inland and lower values along small rivers and creeks with exposed barren ground (Figures 24–25). Based on comparisons with median values since 2000 (Appendix E), NDVI_621 was much higher than normal across the coastal plain in 2015, with the exception of recently disturbed areas along the Dalton Highway, which may have been affected by extensive spring flooding by the Sagavanirktok River in 2015. NDVI_621 in 2016 was above normal for much of the coastal plain, and was especially elevated in riverine areas compared to the 2000–2016 median, suggesting advanced phenology in dense stands of riparian shrubs. NDVI_Peak values in 2015 and 2016 were slightly higher than normal in both survey areas and across most of the coastal plain (Figures 22–23, Appendix F).

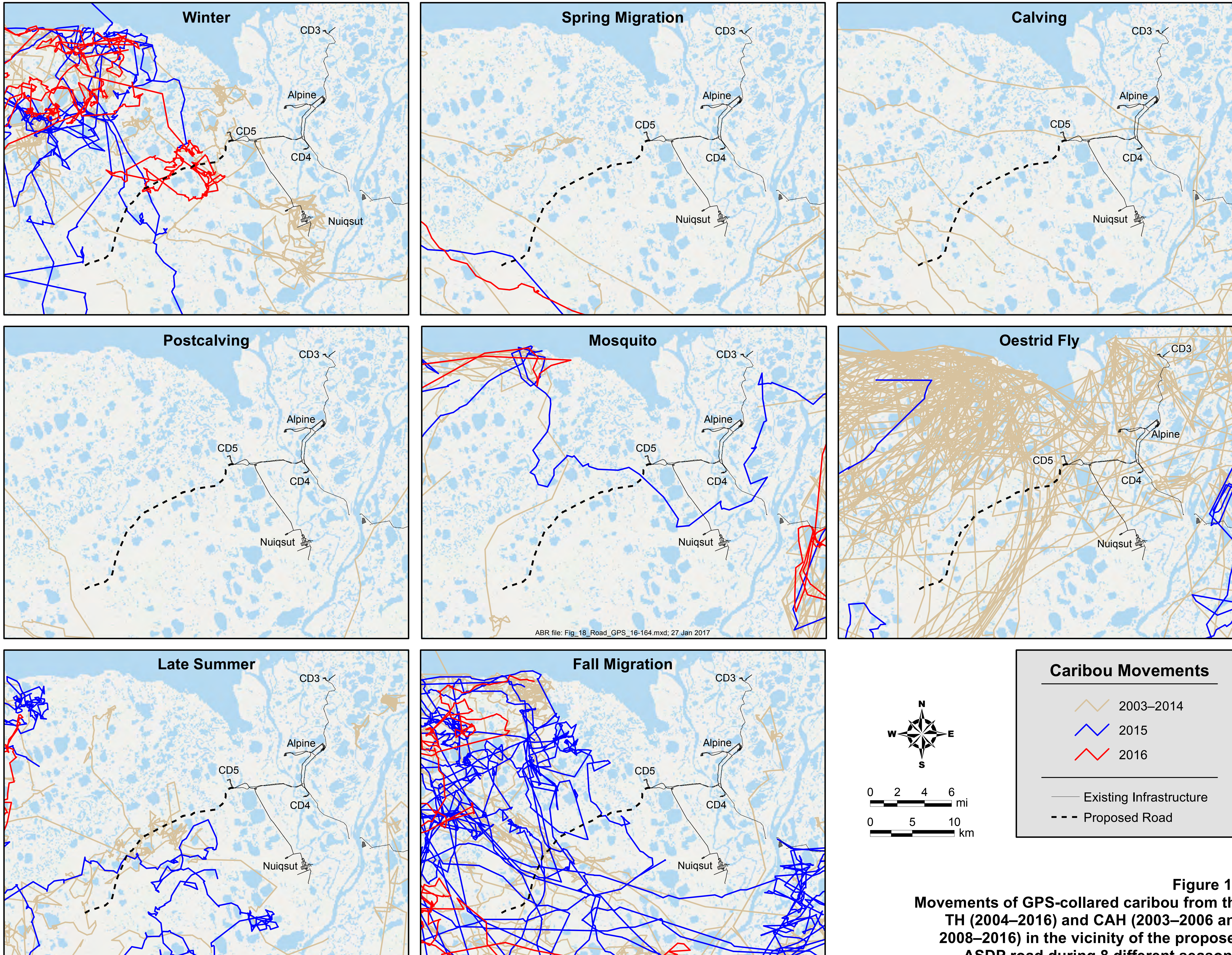


Figure 18.
Movements of GPS-collared caribou from the TH (2004–2016) and CAH (2003–2006 and 2008–2016) in the vicinity of the proposed ASDP road during 8 different seasons.

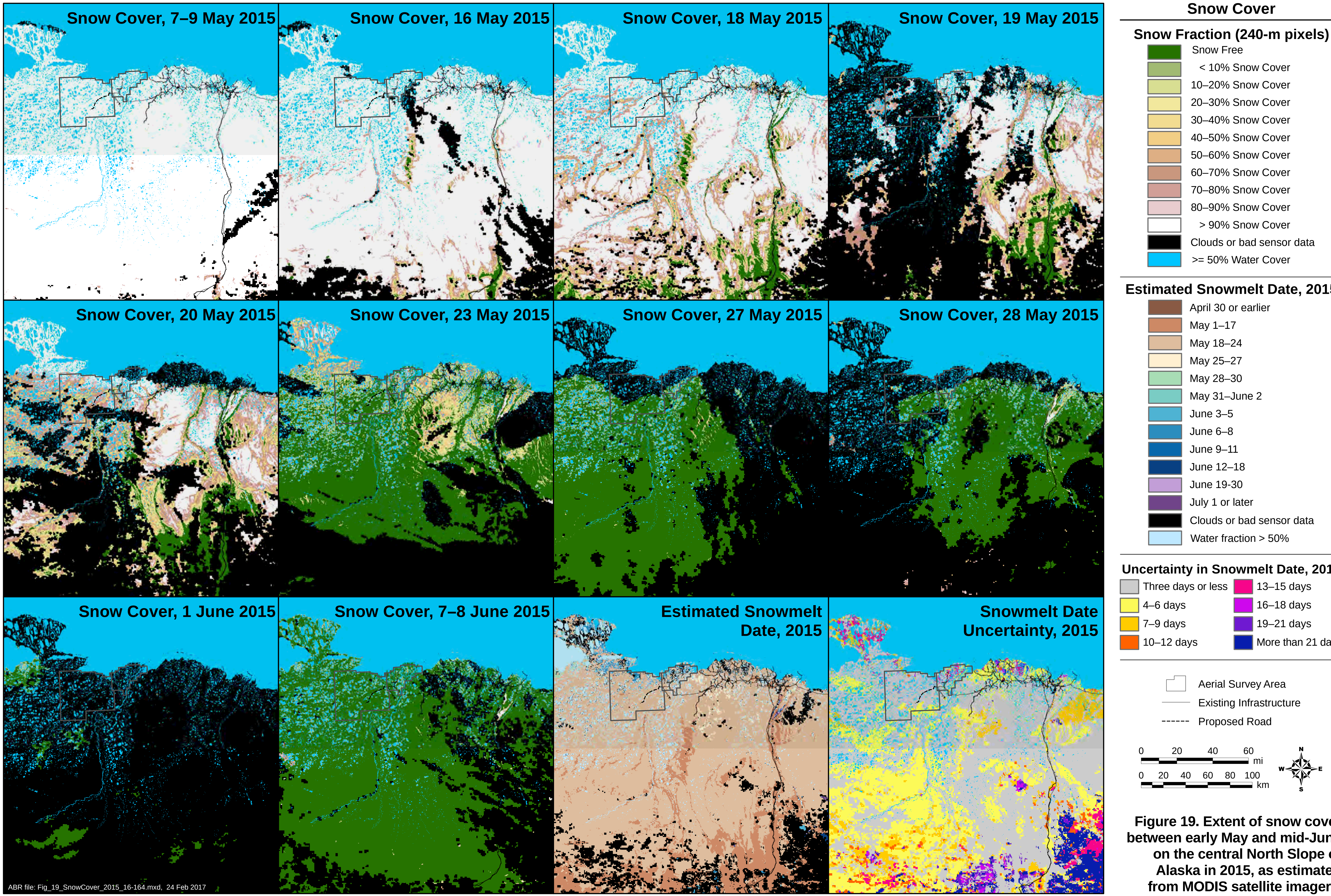


Figure 19. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2015, as estimated from MODIS satellite imagery.

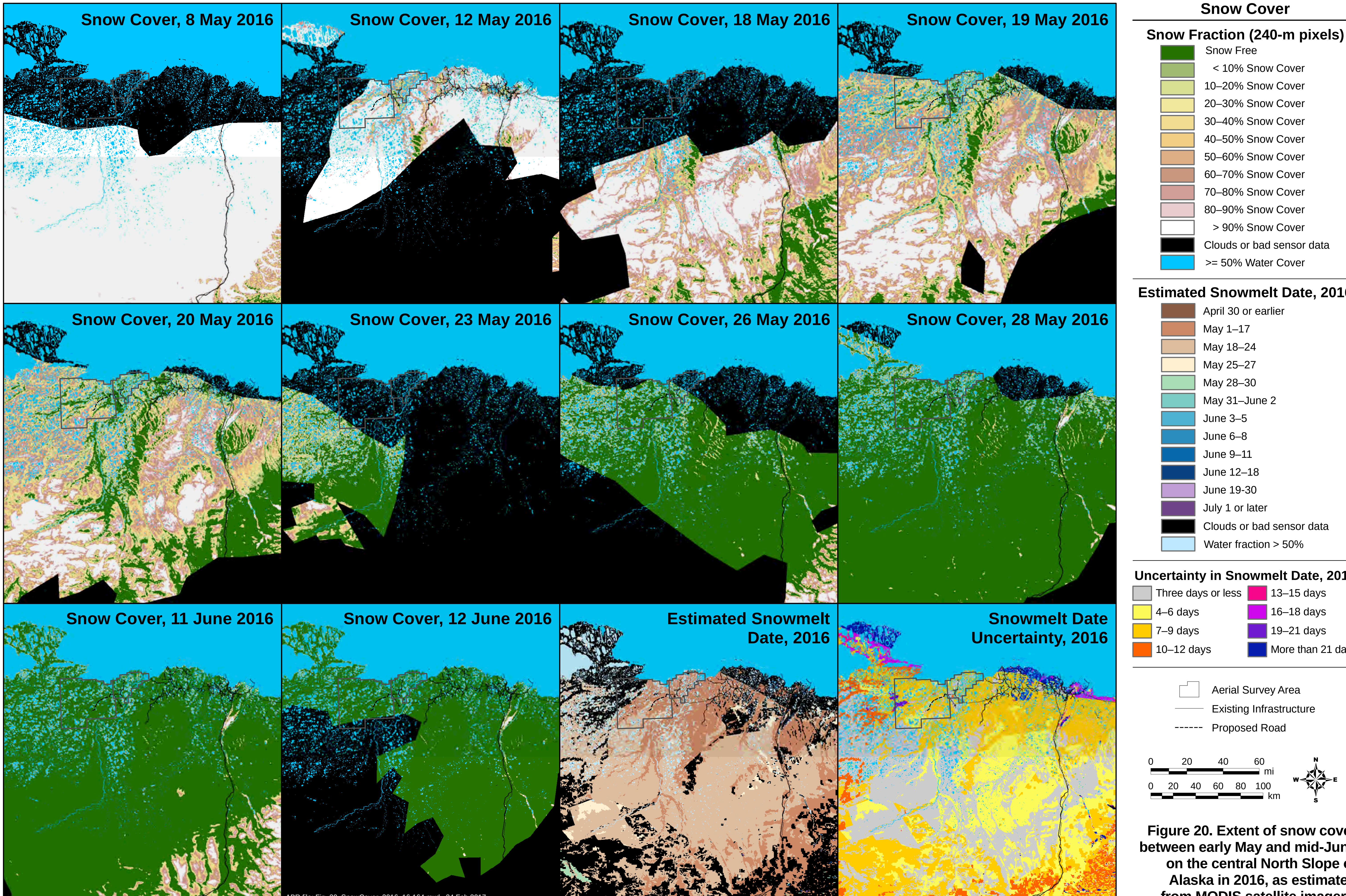


Figure 20. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2016, as estimated from MODIS satellite imagery.

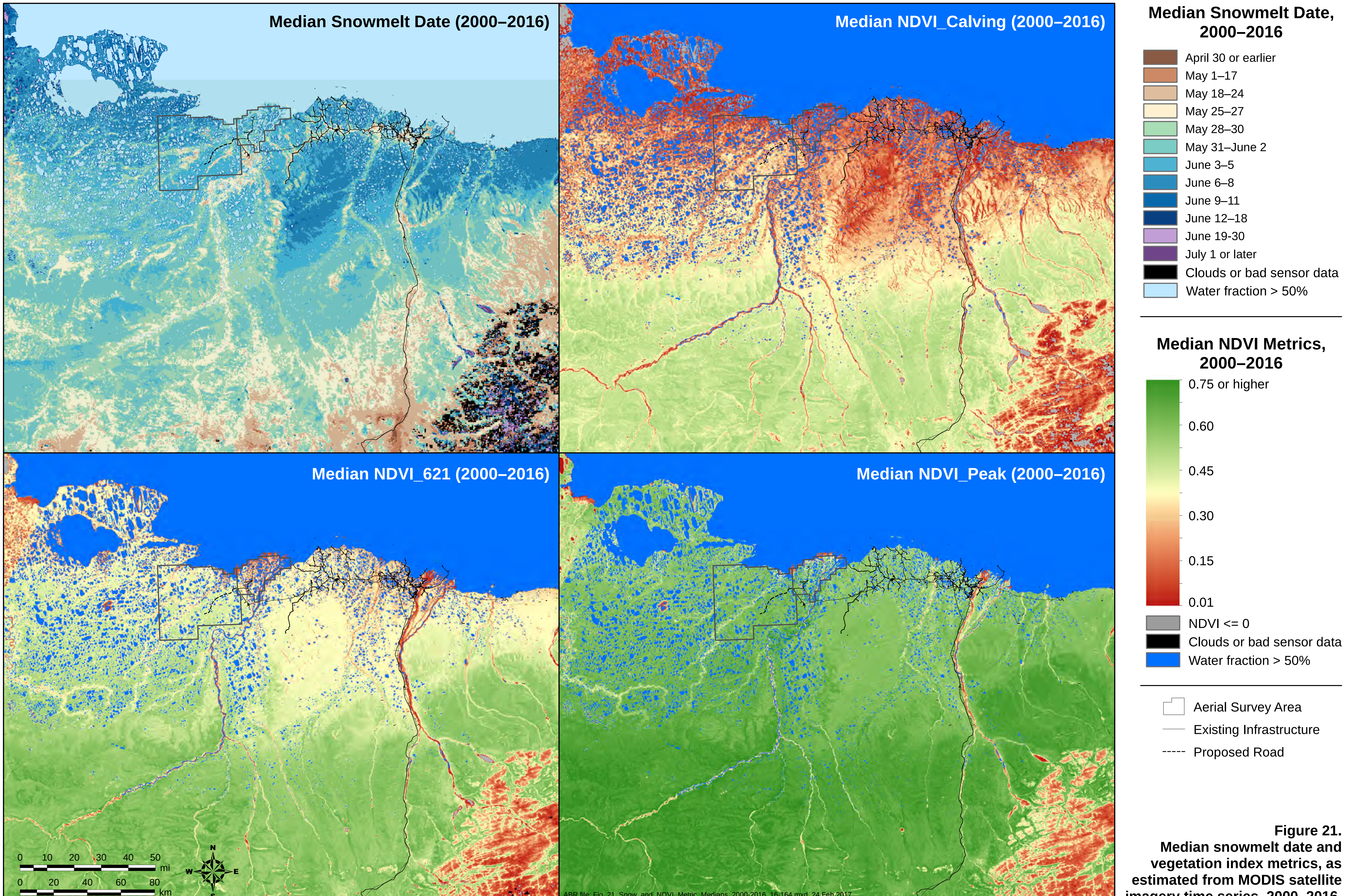


Figure 21.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2016.

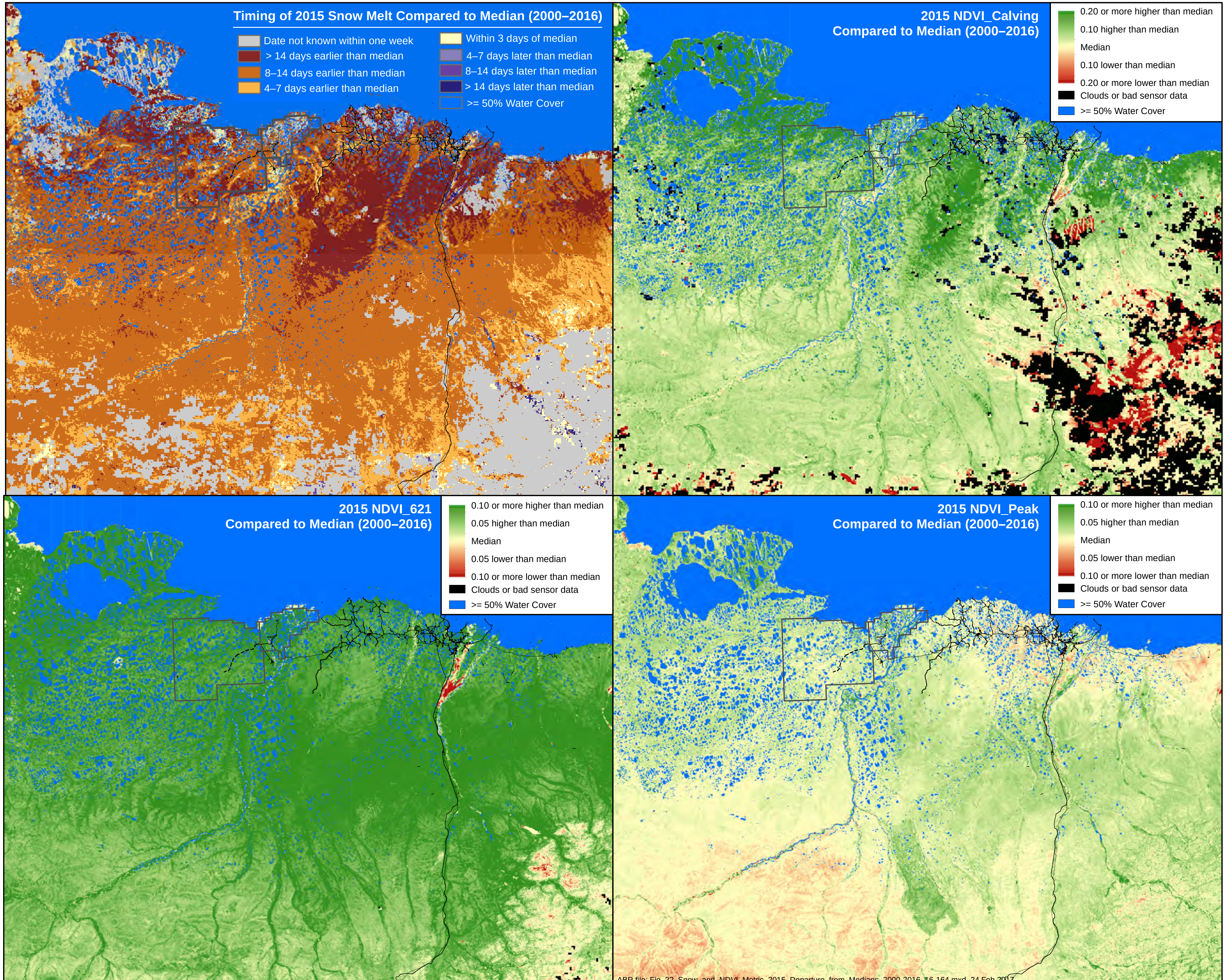
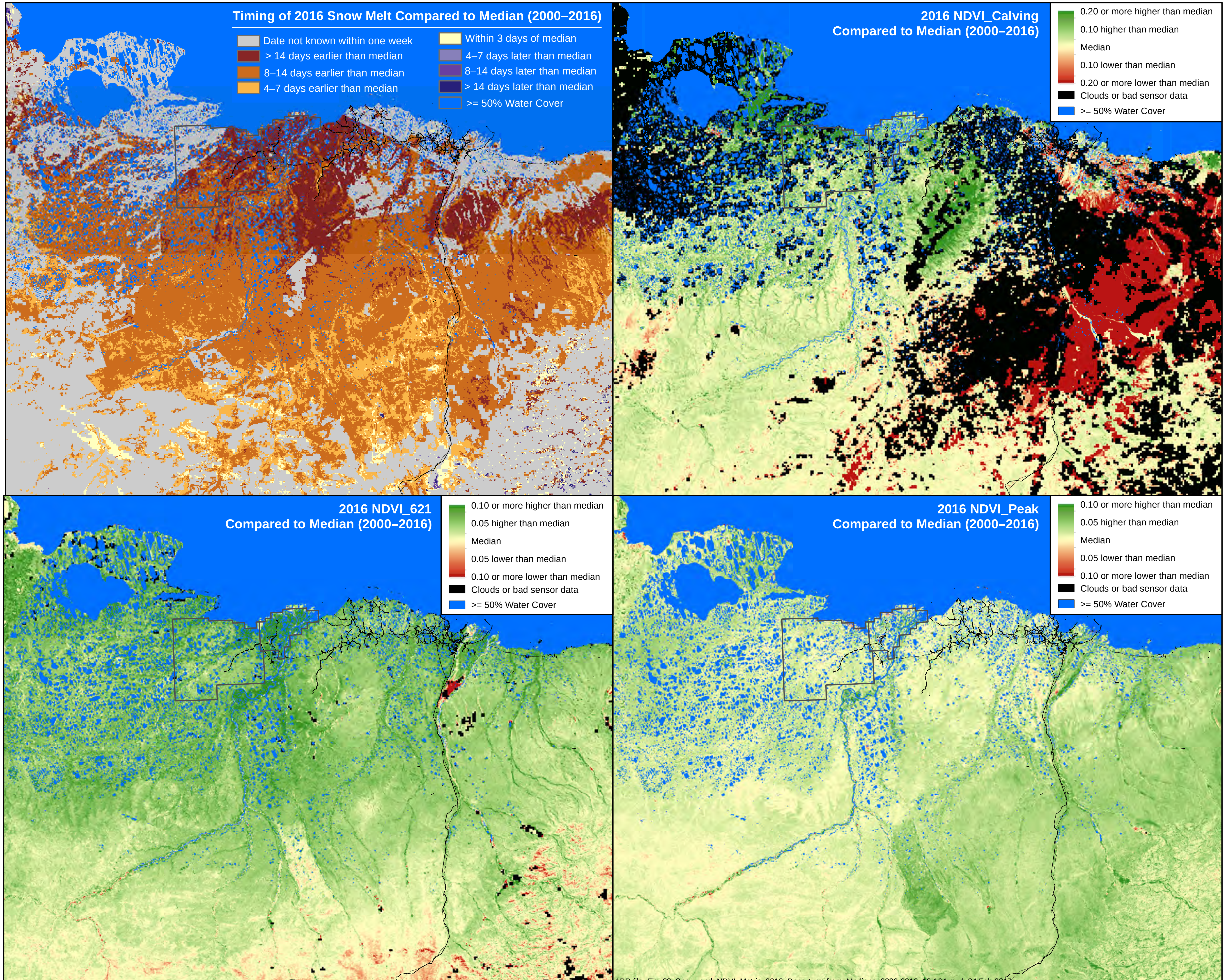


Figure 22.
Departure of 2015 values from median snowmelt date and vegetation index metrics (2000–2016), as estimated from MODIS satellite imagery time series.



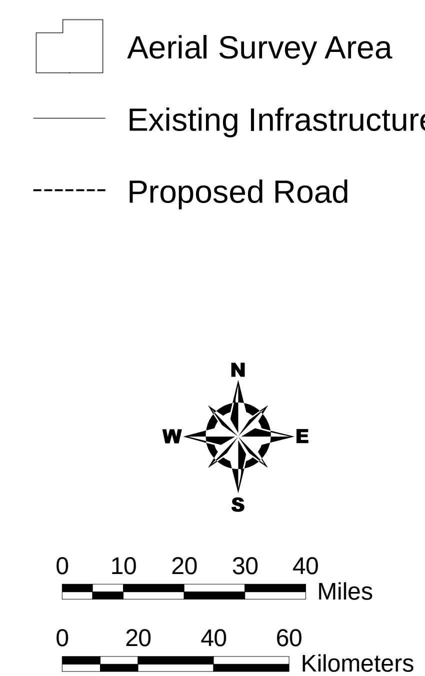


**Figure 23.
Departure of 2016 values from median snowmelt date and vegetation index metrics (2000–2016), as estimated from MODIS satellite imagery time series.**

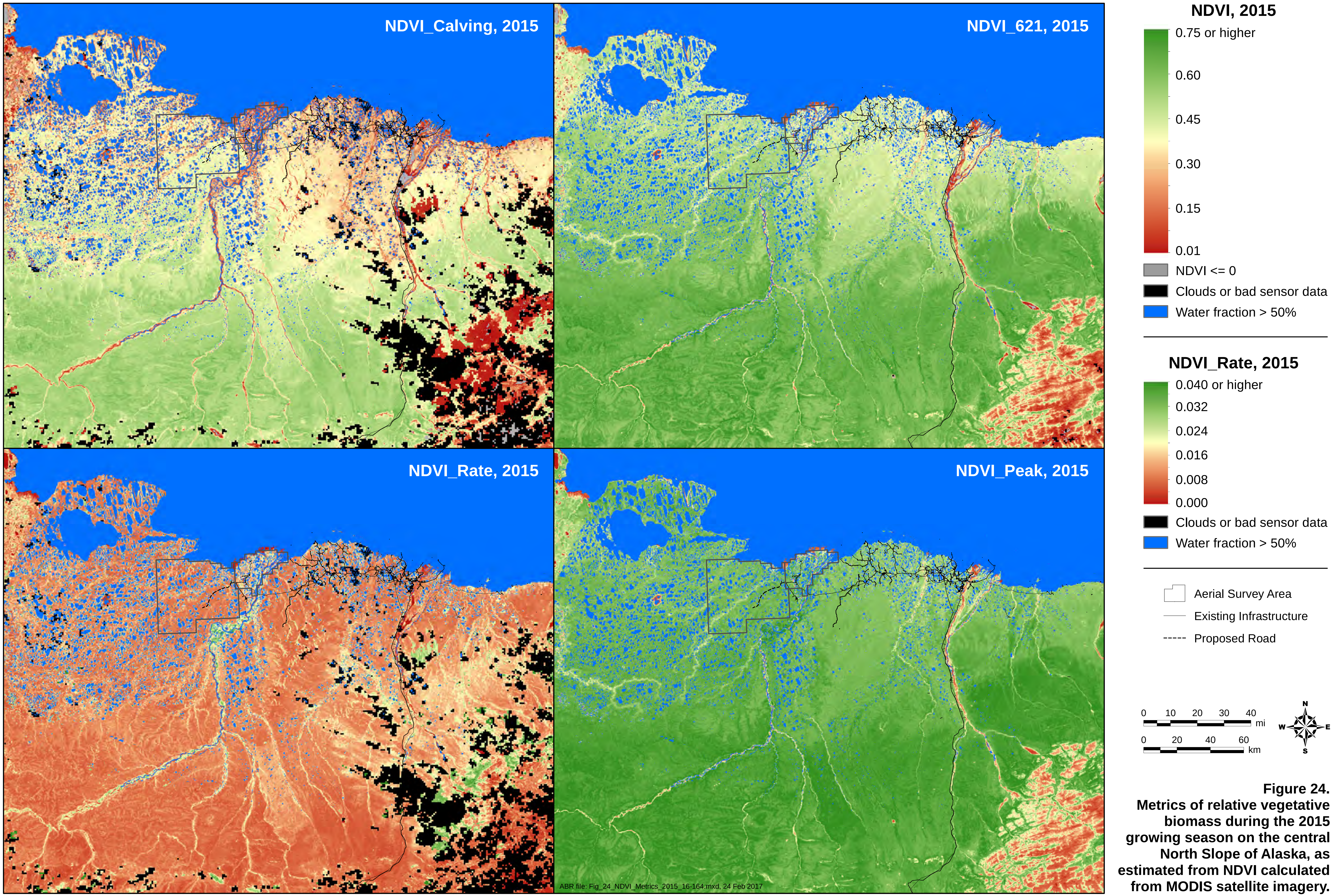


Figure 24.
Metrics of relative vegetative biomass during the 2015 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

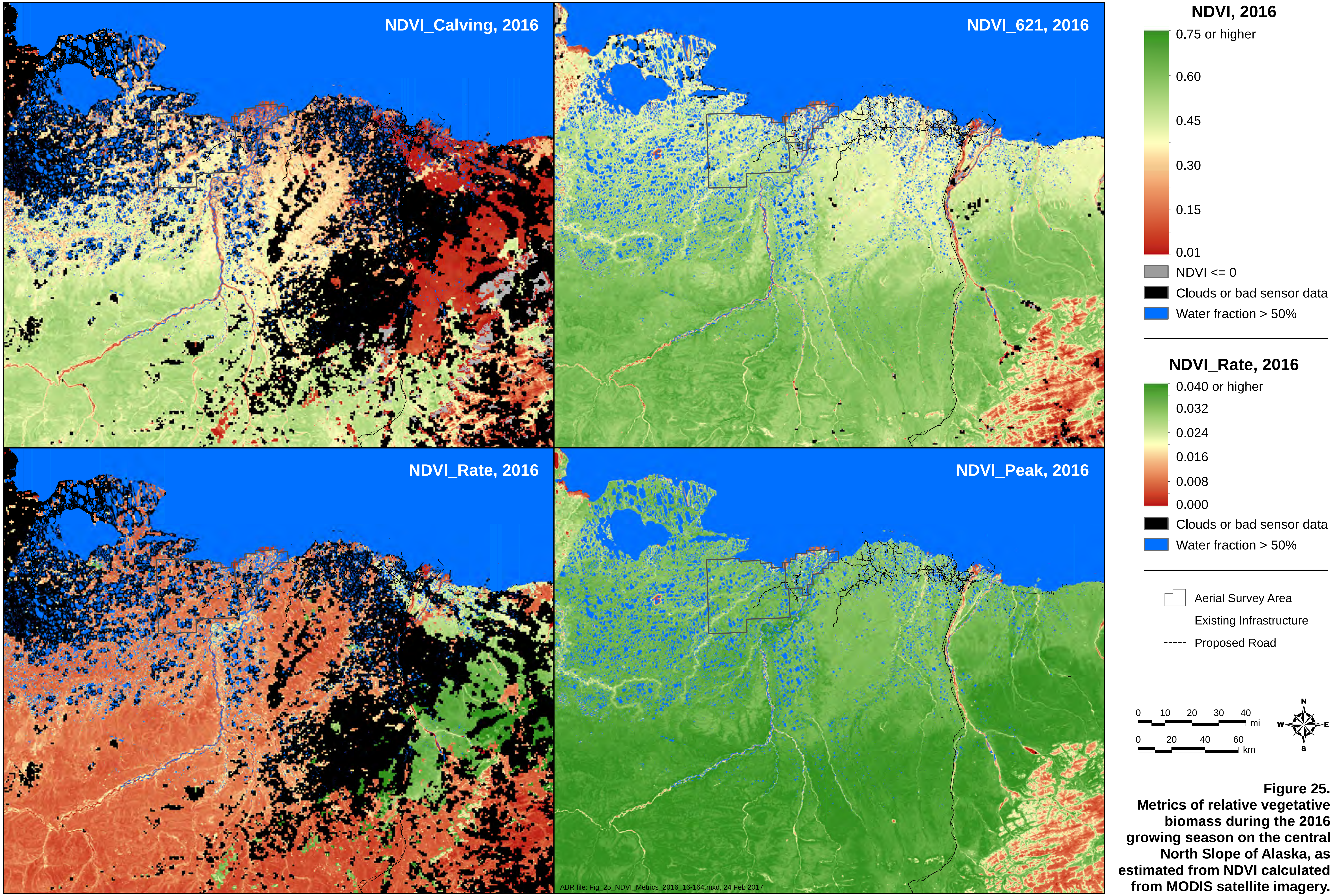


Figure 25.
Metrics of relative vegetative biomass during the 2016 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

Table 4. Number of aerial surveys, radio collars, and locations for each sample type used in RSF analysis for the NPRA survey area, 2002–2016.

Season	Aerial Surveys		Telemetry Data		Total
	Surveys	Locations	Collars	Locations	Locations
Winter	8	540	19	509	1,049
Spring Migration	9	359	16	68	427
Calving	15	1,050	13	38	1,088
Postcalving	14	1,073	7	15	1,088
Mosquito	5	81	27	59	140
Oestrid Fly	9	212	60	179	391
Late Summer	21	981	28	251	1,232
Fall Migration	17	1,397	53	556	1,953
Total	98	5,693	223	1,675	7,368

RESOURCE SELECTION ANALYSIS

The following RSF analysis of seasonal caribou density is restricted to the NPRA survey area to characterize pre-construction patterns of use in the area where additional ASDP infrastructure has been constructed or proposed for the GMT1 and GMT2 projects. Sample sizes for the location data used in the RSF analysis ranged among season from 140 to 1,953 for the years 2002–2016 (Table 4). Most of the top-ranking seasonal models for the survey area contained habitat type, west-to-east distributional gradient, and distance to coast (Table 5). Landscape ruggedness, vegetative biomass (three different NDVI variables), and median date of snow melt were included in some of the top seasonal models. Results of the k-fold cross-validation test indicated that the best model for the combined datasets for NPRA had a reasonably good model fit (Pearson's r = 0.83–0.98; Table 6). The variables included in the best RSF model (Table 7) varied by season but caribou resource selection in the NPRA survey area generally followed a gradient of increasing selection from east to west in all seasons and from south to north in most seasons (Figure 26, Table 8), as was expected from the survey area location along the eastern edge of the TH annual range.

The RSF model output produces several types of results to interpret. These results include the probability of each model being the best model in the set of candidate models (i.e., Akaike weight), which was used to rank the various models (Table 5) and to determine the probability that each variable is included in the best model (i.e., the sum of Akaike weights for all models containing that variable; Table 7). We used all variables with a 50% or greater probability of being in the best model in the candidate model set to produce seasonal RSF maps (Figure 26). In addition, by examining the unconditional parameter estimates we determined which individual parameters were significant (i.e., the 95% confidence interval did not contain zero) while also accounting for model uncertainty (Table 8). These individual parameter estimate results were useful for examining the effect of each habitat type.

For the winter season, all variables were included in the best model (Figure 26, Tables 5 and 7), with date of snow melt being considered a surrogate for snow depth. Areas closer to the coast and farther west and areas with high NDVI_Peak and high ruggedness were selected. Although date of snow melt was included in the best model, the model-weighted variable was not significant. The *Carex aquatilis*, Flooded Tundra, and Riverine habitat types were avoided, relative to the reference category (Sedge/Grass Meadow; Table 8).

All of the variables except habitat were included in the best model for spring migration (Figure 26, Tables 5 and 7), but the model results were driven primarily by a west-to-east density gradient and distance to the coast, with caribou selecting areas farther west and closer to the coast (Table 8).

Table 5. Three top-performing seasonal RSF models, AICc scores, and the probability (Akaike weight) that each model was the best model in the candidate set for the NPRA survey area, 2002–2016 (combined aerial survey and telemetry data).

Season	RSF Model	AICc	Akaike Weight
Winter	Habitat + NDVI Peak + West to East + Distance to Coast + Ruggedness + Snowmelt Date	11,456	0.87
	Habitat + NDVI Peak + West to East + Distance to Coast + Ruggedness	11,460	0.12
	NDVI Peak + West to East + Distance to Coast + Ruggedness + Snowmelt Date	11,471	0.00
Spring Migration	NDVI Peak + West to East + Distance to Coast + Ruggedness + Snowmelt Date	4,736	0.17
	NDVI Peak + West to East + Distance to Coast + Ruggedness	4,736	0.17
	NDVI Peak + West to East + Distance to Coast	4,737	0.14
Calving	Habitat + NDVI Calving + West to East + Distance to Coast + Snowmelt Date	11,946	0.44
	NDVI Calving + West to East + Distance to Coast + Snowmelt Date	11,947	0.26
	Habitat + NDVI Calving + West to East + Distance to Coast + Ruggedness + Snowmelt Date	11,948	0.20
Postcalving	Habitat + NDVI 621 + West to East + Distance to Coast + Ruggedness	11,944	0.80
	Habitat + West to East + Distance to Coast + Ruggedness	11,947	0.16
	NDVI 621 + West to East + Distance to Coast + Ruggedness	11,952	0.02
Mosquito	West to East + Distance to Coast + Ruggedness	1,407	0.56
	NDVI Peak + West to East + Distance to Coast + Ruggedness	1,408	0.29
	Habitat + NDVI Peak + West to East + Distance to Coast + Ruggedness	1,411	0.07
Oestrid Fly	Habitat + NDVI Peak + West to East + Distance to Coast + Ruggedness	4,282	0.48
	NDVI Peak + West to East + Distance to Coast + Ruggedness	4,283	0.28
	Habitat + West to East + Distance to Coast + Ruggedness	4,284	0.24
Late Summer	Habitat + West to East + Ruggedness	13,578	0.52
	Habitat + NDVI Peak + West to East + Ruggedness	13,579	0.21
	Habitat + West to East + Distance to Coast + Ruggedness	13,580	0.19
Fall Migration	Habitat + West to East + Distance to Coast	21,681	0.32
	Habitat + NDVI Peak + West to East + DistCoast	21,681	0.21
	Habitat + West to East + Distance to Coast + Ruggedness	21,682	0.18

Table 6. Mean Pearson's rank correlation coefficient (r) of seasonal RSF model fit using k-fold cross-validation for the NPRA survey area, 2002–2016 (combined aerial survey and telemetry data).

Season	Correlation Coefficient
Winter	0.94
Spring Migration	0.83
Calving	0.95
Postcalving	0.98
Mosquito	0.96
Oestrid Fly	0.95
Late Summer	0.96
Fall Migration	0.93

During the calving season, all variables except landscape ruggedness were included in the best model (Figure 26, Tables 5 and 7). Caribou selected areas farther west, farther from the coast, with higher biomass (NDVI_Calving), and later snow melt (i.e., northwest portion of the survey area) (Table 8).

During the postcalving season, all variables were included in the best model (Figure 26, Tables 5 and 7). Caribou selected areas farther west, closer to the coast with higher landscape ruggedness, and selected Riverine habitat (Table 8).

During the mosquito season, west-to-east, distance to coast, and landscape ruggedness were included in the best model (Figure 26, Tables 5 and 7). Caribou primarily selected areas farther west, closer to the coast, and with higher ruggedness (Table 8).

During the oestrid fly season, all variables were included in the best model (Figure 26, Tables 5 and 7). Caribou selected areas farther west, closer to the coast, and with higher landscape ruggedness (Table 8).

During late summer, habitat type, west-to-east, and landscape ruggedness were included in the best models (Figure 26, Tables 5 and 7). Caribou selected areas farther west, with higher ruggedness, and in Dwarf Shrub–*Dryas* and Riverine habitat types (Table 8).

During fall migration, habitat type, west-to-east, and distance to coast were included in the best RSF model (Figure 26, Tables 5 and 7). Caribou selected areas farther west and avoided *Carex aquatilis* and Flooded Tundra habitats (Table 8).

DISCUSSION

WEATHER, SNOW, AND INSECT CONDITIONS

Weather conditions exert strong effects on caribou populations. 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 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).

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. On the central Arctic Coastal Plain (including the study area), caribou typically move upwind and toward the coast in response to mosquito harassment and then disperse inland when mosquito activity abates in response to cooler temperatures and increased winds (Murphy and Lawhead 2000, Yokel et al. 2009, Wilson et al. 2012). Hence, temperature and wind data can be used to predict the occurrence of harassment by mosquitoes (at least five *Aedes* species) and oestrid flies (warble fly *Hypoderma tarandi* and nose bot fly *Cephenemyia trompe*) (White et al. 1975, Fancy 1983, Dau 1986, Russell et al. 1993, Mörschel 1999, Yokel et al. 2009).

The unusually early melt of seasonal snow cover in May 2015 contributed directly to the unusually early onset of mosquito emergence in mid-June 2015, which in turn caused early movements of caribou to coastal relief habitats, at least a week earlier than expected from past studies. The weather in May and early June 2016 was even warmer than 2016 and could have resulted in even earlier mosquito emergence than in 2015 but, due to cool and windy conditions in mid-June, the onset of severe mosquito harassment did not occur until 23 June. Early onset of the insect season, a period that places heavy energetic demands on all caribou, but especially lactating females (Fancy 1986, Russell et al. 1993), is likely to increase stress on young calves that are forced to move rapidly to reach relief habitat. The cooler temperatures later in summer 2015—and the correspondingly lower activity of mosquitoes and oestrid flies—likely resulted in more favorable conditions for caribou, contributing to improved body condition by fall.

CARIBOU DISTRIBUTION AND MOVEMENTS

Analysis of GPS, satellite, and VHF telemetry data sets spanning nearly three decades clearly demonstrates that the study area is at the interface of the annual ranges of the TH and CAH. The TH consistently uses the western half of the 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 mosquito and oestrid fly seasons, and then tend to increase during fall migration before declining again in winter; a seasonal increase often occurs during spring migration. In contrast, the CAH uses the area east of the Colville River, primarily during the calving season and the postcalving season; CAH use of the study area is more variable during the mosquito and oestrid fly seasons and is low during the remainder of the year.

Research to date shows that caribou are more likely to occur on the Colville River delta 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. When mosquito harassment begins in late June or early July, caribou move toward the coast in both study areas where lower temperatures and higher wind speeds prevail (Murphy and Lawhead 2000, Parrett 2007, Yokel et al. 2009, Wilson et al. 2012). The TH typically moves to the area between Teshekpuk Lake and the Beaufort Sea, while the CAH typically moves to the coast east of the Colville delta and often moves far east during late June and July. 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 inland, seeking elevated or barren habitats such as sand dunes, mudflats, and river bars, with some using shaded locations in the oilfields under elevated pipelines and buildings (Lawhead 1988, Murphy and Lawhead 2000, Person et al. 2007, Wilson et al. 2012).

The annual harvest of caribou by Nuiqsut hunters correspondingly peaks during the months of July and August, with lower percentages being taken in June and September–October and the smallest harvests occurring in other months (Pedersen 1995; Brower and Opie 1997; Fuller and George 1997; SRBA 2016). The greatest proportion of the Nuiqsut caribou harvest is taken by boat-based hunters during midsummer (SRBA 2016). 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 Colville delta more during the insect season than did CAH caribou (Lawhead et al. 2008). Beginning in 2004, the distribution of the CAH during the insect season shifted farther eastward than in earlier years, so fewer caribou from that herd used the Colville delta than did so in earlier years. Since 2014, however, more CAH caribou have remained in the western portion of their range, near the Colville River, and have used the delta more in midsummer than in most other years since 2004. In 2016, many collared CAH caribou remained on the outer coastal plain near the Colville River late into the fall, as found on surveys flown on 20 September and 11–12 October.

Use of the Colville River delta by large numbers of caribou is relatively uncommon and does not occur annually. Large numbers have been recorded periodically at irregular intervals in past summers (3–5 years; e.g., 1992, 1996, 2001, 2005,

Table 7. Independent variables and their probability of being in the best RSF model (i.e., the sum of all Akaike weights for all models that included the variable) for the NPRA survey area during eight seasons, 2002–2016 (combined aerial survey and telemetry data). Variables with a probability ≥0.5 were used in RSF maps (Figure 26).

Variable	Winter	Spring Migration	Calving	Postcalving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
West to East	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Distance to Coast	1.00	0.97	1.00	1.00	1.00	1.00	0.27	0.82
NDVI [a]	1.00	0.71	1.00	0.82	0.39	0.76	0.29	0.38
Snowmelt Date	0.88	0.40	1.00	–	–	–	–	–
Ruggedness	1.00	0.66	0.30	1.00	0.92	1.00	1.00	0.35
Habitat	1.00	0.38	0.64	0.96	0.09	0.72	1.00	1.00

[a] Median NDVI_Peak values were used from the mosquito season through spring migration, median NDVI_Calving was used for the calving season, and median NDVI_621 was used for the postcalving season.

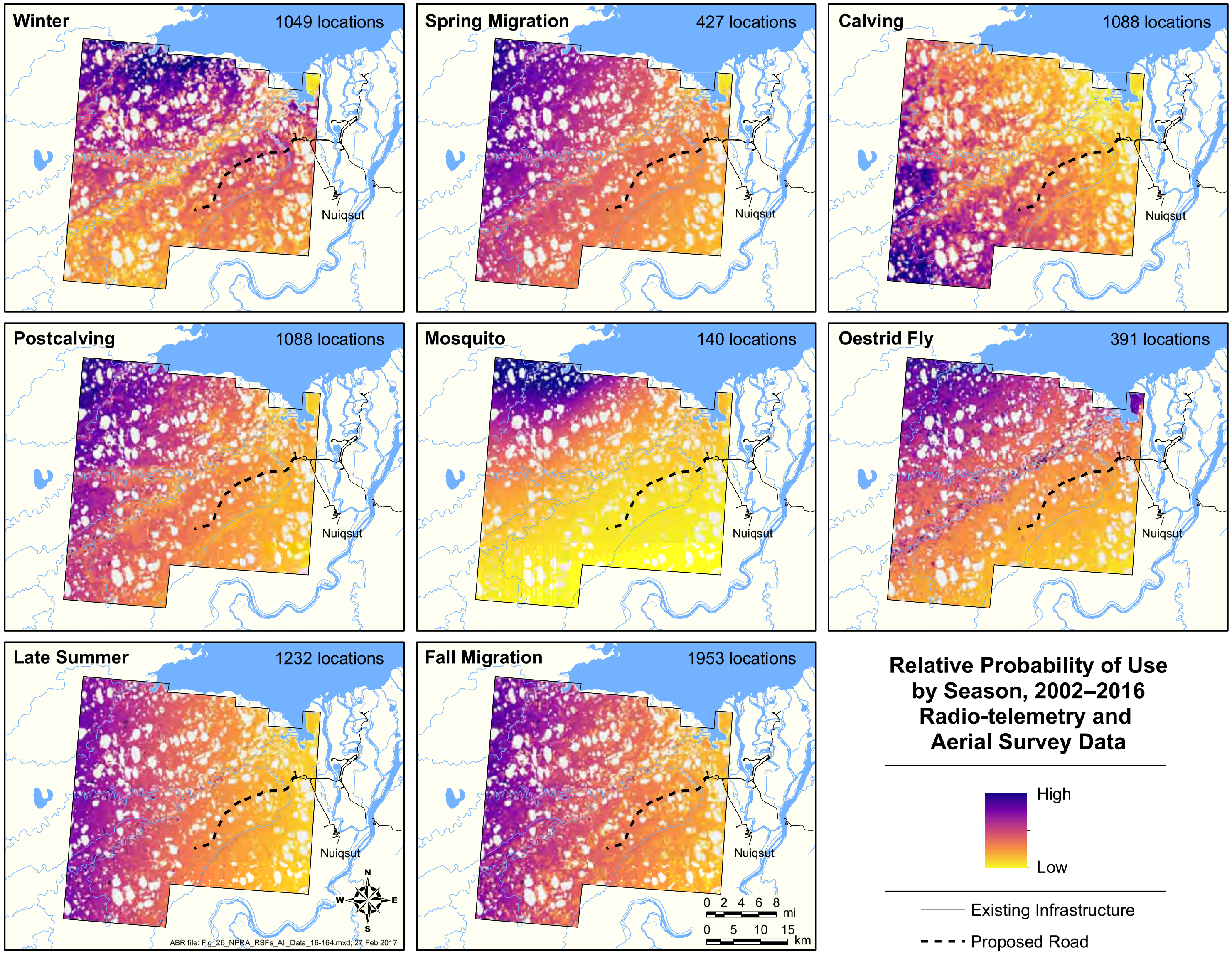


Figure 26. Predicted relative probability of use of the NPRA survey area by caribou, based on RSF analysis of aerial survey and radio-telemetry data, 2002–2016.

Table 8. Model-weighted parameter estimates for RSF models for the NPRA survey area during eight seasons, 2002–2016 (combined aerial survey and telemetry data). Coefficients in bold type indicate that the 95% confidence interval did not contain zero.

Variable	Winter	Spring Migration	Calving	Postcalving	Mosquito	Oestrid Fly	Late Summer	Fall Migration
West to East	**–0.24**	**–0.39**	**–0.31**	**–0.44**	**–0.97**	**–0.34**	**–0.36**	**–0.33**
Distance to Coast	**–0.45**	**–0.17**	**0.15**	**–0.18**	**–1.05**	**–0.28**	0.00	–0.05
NDVI [a]	**0.26**	0.11	**0.27**	0.08	0.05	–0.10	0.00	0.01
Snowmelt Date	0.08	0.02	**0.13**	–	–	–	–	–
Ruggedness	**0.13**	0.06	0.00	**0.22**	**0.18**	**0.20**	**0.12**	–0.01
Carex aquatilis [b]	**–0.93**	–0.33	–0.19	–0.52	0.01	0.18	–0.35	**–0.53**
Dwarf Shrub [b]	-0.06	–0.12	–0.02	0.09	0.06	0.16	**0.48**	0.35
Flooded Tundra [b]	**–0.35**	0.00	–0.18	0.03	0.01	0.20	–0.05	**–0.18**
Moss/Lichen [b]	–1.16	–0.47	–0.41	0.56	–1.09	0.79	0.48	0.39
Riverine [b]	**–0.83**	–0.39	0.03	**0.51**	0.09	0.69	**0.64**	–0.04
Tussock Tundra [b]	–0.02	–0.04	0.00	0.11	–0.01	0.14	0.03	0.11
Wet Tundra [b]	–0.31	–0.08	–0.21	0.14	0.01	0.36	–0.09	–0.10

[a] Median NDVI_Peak values were used from the mosquito season through spring migration, median NDVI_Calving was used for the calving season, and median NDVI_621 was used for the postcalving season.

[b] Habitat classes were compared to the reference class “Sedge/Grass Meadow.”

2007, 2010) as aggregations moved onto or across the delta during or immediately 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 traversed by the proposed ASDP road. The highest number of caribou seen on Colville River delta transect surveys during 2001–2016 was recorded on 2 August 2005, when 994 caribou were found in the survey area (2.01 caribou/km²; Lawhead et al. 2006). At least 3,241 TH caribou were photographed by ADFG 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 for a different study, but the herd affiliation of those animals was not clear (Lawhead et al. 2011). Because such movements by large numbers of insect-harassed caribou often occur quickly, telemetry data are more useful for describing caribou distribution and movements during the insect season than are periodic aerial transect surveys.

The area near ASDP infrastructure on and adjacent to the Colville River delta is used sporadically by caribou from both herds. Movements by satellite- and GPS-collared TH and CAH caribou into the vicinity have occurred 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. In the short time since its construction, no collared caribou have crossed the CD5 road (based on straight-line movements between locations), but very few crossings were recorded there in the years before construction either. In recent years, radio-collared TH caribou and, to a lesser extent, CAH caribou have occasionally crossed the proposed 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. Thirteen radio-collared caribou (11 TH and 2 CAH) crossed the proposed road corridor in 2015, and two TH caribou crossed the proposed road corridor in 2016.

Aerial transect surveys conducted since 2001 have demonstrated that the NPRA survey area, which is used mainly by TH caribou, is not a high-density calving area, in contrast to the area east of the Colville River delta, which is used mainly by CAH caribou (Lawhead et al. 2015). This result is consistent with analysis of telemetry data, which confirms that most TH females calve around Teshekpuk Lake, west of the ASDP study area (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015). A few collared CAH females have calved west of the Colville River in isolated years (notably 2001), but it is a rare occurrence (Arthur and Del Vecchio 2009; Lenart 2009, 2015).

Transect surveys during mosquito season are inefficient for locating caribou aggregations because of the highly clumped nature of their distribution. 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 2 August 2005 (Lawhead et al. 2006). Since we began transect surveys in NPRA in 2001, the highest densities in that survey area have tended to occur during the oestrid fly season (which overlaps with the typical period of mosquito activity) and fall migration (Figure 5). In 2016, densities increased from late summer through Fall migration from moderate densities of 0.21 caribou/km² to 1.14 caribou/km². Poor flying conditions caused by persistent inclement weather have limited our ability to conduct surveys consistently during fall migration. Only six surveys could be conducted in September and October during the years 2009–2016 (though both scheduled surveys in 2016 were flown successfully), so we have not been able to sample that period as much as planned. High densities also have been recorded sporadically in the NPRA survey area 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).

The winter of 2016–2017 was unusual with most collared CAH caribou remaining on the coastal plain during early winter. In contrast, most collared CAH caribou wintered in the southern Brooks Range over the last decade or more (Lenart 2015, Nicholson et al. 2016).

RESOURCE SELECTION

Although the two data sets (aerial transect surveys and radio telemetry) we combined for the RSF analyses have some differences and limitations, the combination provided a complementary approach for investigating broad patterns of resource selection. Radio-telemetry data have much higher spatial accuracy than do aerial survey data and are collected continuously throughout the season, albeit for a fairly small sample of individual caribou. A single collared caribou that spends long periods within the study area can exert a large influence on RSF results. Because of high variability in the amount of time spent in the study area by collared animals, we did not attempt to adjust for individual differences, other than limiting the frequency of locations to 48-h intervals. In contrast, aerial transect survey data provide information on all caribou groups detected in the area (subject to sightability constraints) at the time of each survey, but the locations have lower spatial accuracy. That lower accuracy necessitated the consolidation of the most common mapped habitats into 210-by-210-m quadrats, rather than the habitat types in individual 30-m pixels that could have been used for the telemetry data alone. This need to consolidate adjacent habitat pixels may have reduced the accuracy of habitat selection analysis for uncommon habitats in the survey area. The two different data types also had different timing, especially during the winter season; only one aerial survey was conducted in that season (mid to late April) in any given year, whereas telemetry locations were collected throughout the entire season. Despite these limitations, the combination of the two survey methods produced larger samples than were available for either data set alone and the resulting RSF models are broadly interpretable within the context of general patterns of caribou movements on the central Arctic Coastal Plain.

Use of the NPRA survey area by caribou varies widely among seasons. These differences are related to snow cover, vegetative biomass, distribution of habitat types, distance to the coast and west-to-east gradients, and landscape ruggedness. In general, broad geographic patterns in distribution (west to east, distance to coast) were the strongest predictors of caribou distribution, but other factors such as vegetative biomass and habitat types were important in some seasons, after taking into account the broad geographic patterns.

Because the NPRA survey area is on the eastern edge of the TH range, a natural west-to-east gradient of decreasing density occurs throughout the year. Caribou density typically is lowest in the southeastern section of the NPRA survey area (in which the proposed road alignment would be located; Lawhead et al. 2015). During calving, the highest densities of TH females typically calve near Teshekpuk Lake (Person et al. 2007, Wilson et al. 2012, Parrett 2015), so caribou density decreases with increasing distance to the east, away from the lake. Hence, more caribou are likely to occur in the western portion of the NPRA survey area than in the eastern portion in that season. It is important to recognize that this pattern of distribution exists before construction of the proposed GMT pipeline/road corridors from the Colville delta into NPRA.

Because caribou aggregate into large groups when mosquitoes are present and move quickly when harassed by insects, density during the mosquito season and early part of the oestrid fly season fluctuates widely. Caribou density in the area of the proposed road alignment in the NPRA survey area generally is low during the mosquito and oestrid fly seasons, but large groups occur occasionally in the area during these seasons, as was documented by the aerial survey on 2 August 2005 and the large movement of CAH caribou across the Colville delta and 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 significant patterns with regard to distance from the proposed road alignment.

During most seasons, caribou selected for higher landscape ruggedness, which tends to occur in riparian areas in the study area. Different studies have reported conflicting conclusions regarding the importance of ruggedness, which may be related in part to the ways in which it has been calculated. Nellemann and Thomsen (1994) and Nellemann and Cameron (1996) reported that CAH caribou selected areas of greater terrain ruggedness (as calculated by hand from topographic maps) in the Milne Point calving concentration area, but Wolfe (2000) and Lawhead et al. (2004), using a digital method of calculating terrain ruggedness, found no consistent relationship with terrain ruggedness in a larger calving area used by CAH females during calving. Those calculations of terrain ruggedness differed from the landscape ruggedness method we used in this study (developed by Sappington et al. 2007), which provides a finer-scale analysis based on digital elevation models and is much less correlated with slope than the previous methods.

The primary finding of the habitat selection analysis was avoidance of *Carex aquatilis* and Flooded Tundra during fall and winter, patterns that had been documented in previous years using different analyses (Lawhead et al. 2015), as well as selection of Riverine habitat along Fish and Judy creeks during postcalving and late summer and avoidance of Riverine habitat during winter (Table 8). The riparian habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 2) that provide good fly-relief habitat near foraging areas. By late summer and into winter, caribou usually disperse inland, away from the study area (Figures 14–16).

Comparison of caribou habitat use 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 in their study area, during calving. Wilson et al. (2012) used the same habitat classification as we did (BLM and Ducks Unlimited 2002) and TH telemetry data to investigate summer habitat selection at two different spatial scales, concluding that TH caribou consistently avoided patches of flooded vegetation and selected areas of Sedge/Grass Meadow.

During calving, caribou in the NPRA survey area generally used areas of higher vegetative biomass (estimated by NDVI_Calving) and lower proportions of wet habitats. Calving tended to occur in areas of patchy snow cover. Calving habitat selection may vary annually, depending on the timing of snow melt and plant phenology, and may vary between the two herds.

We used NDVI to estimate vegetative biomass in this study because other researchers have reported significant relationships between caribou distribution and biomass variables (NDVI_Calving, NDVI_621, and NDVI_Rate) during the calving period. 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 recently melted areas. Snow, water, and lake ice all depress NDVI values. Therefore, estimates of NDVI variables (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.

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 than was available over the entire calving grounds. In addition, the area of concentrated calving contained higher biomass (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). We found that there was selection for areas that typically have high biomass values during calving in the NPRA survey areas for all years combined.

Because of the high correlation between biomass values and habitat, it is difficult to distinguish whether caribou select specific habitats and areas with greater vegetative biomass or simply avoid wet areas and barrens during the calving season in this area. Vegetation sampling in 2005 indicated that moist tussock tundra had higher biomass than did moist sedge–shrub tundra (similar to Tussock Tundra and Sedge/Grass Meadow types in our classification), but that difference disappeared when evergreen shrubs, which are unpalatable caribou forage, were excluded (Lawhead et al. 2006). Tussock Tundra supports higher biomass of plant species that are preferred by caribou, such as *E. vaginatum*, forbs, and lichens, however. Caribou appear to use wetter habitats (*Carex aquatilis*, Wet Tundra, and Flooded Tundra) less during calving and those areas tend to have lower biomass values in both late June and midsummer.

Previous studies have not produced consistent results concerning the calving distribution of northern Alaska caribou herds in relation to snow cover. Kelleyhouse (2001) concluded that TH females selected areas of low snow cover during calving and Carroll et al. (2005) reported that TH caribou calved farther north in years of early snow melt. Wolfe (2000) did not find any consistent selection for snow-cover classes during calving by the CAH, whereas Eastland et al. (1989) and Griffith et al. (2002) reported that calving 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.

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 GMT portion of the NPRA survey area where further development is planned and proposed. Detailed analyses of the existing patterns of seasonal distribution, density, and movements are providing important insights about the ways in which caribou currently use the study area and why. 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 among years, and some evidence suggests decreasing birth rates and increasing rates of emigration to other herds (Parrett 2013; L. Parrett, ADFG, pers. comm.). The CAH also has shown indications of increased mortality, as well as changes in seasonal distribution, with more caribou remaining farther north during fall and early winter and more intermixing with adjacent herds (ADFG 2017). 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, 1983–2016.

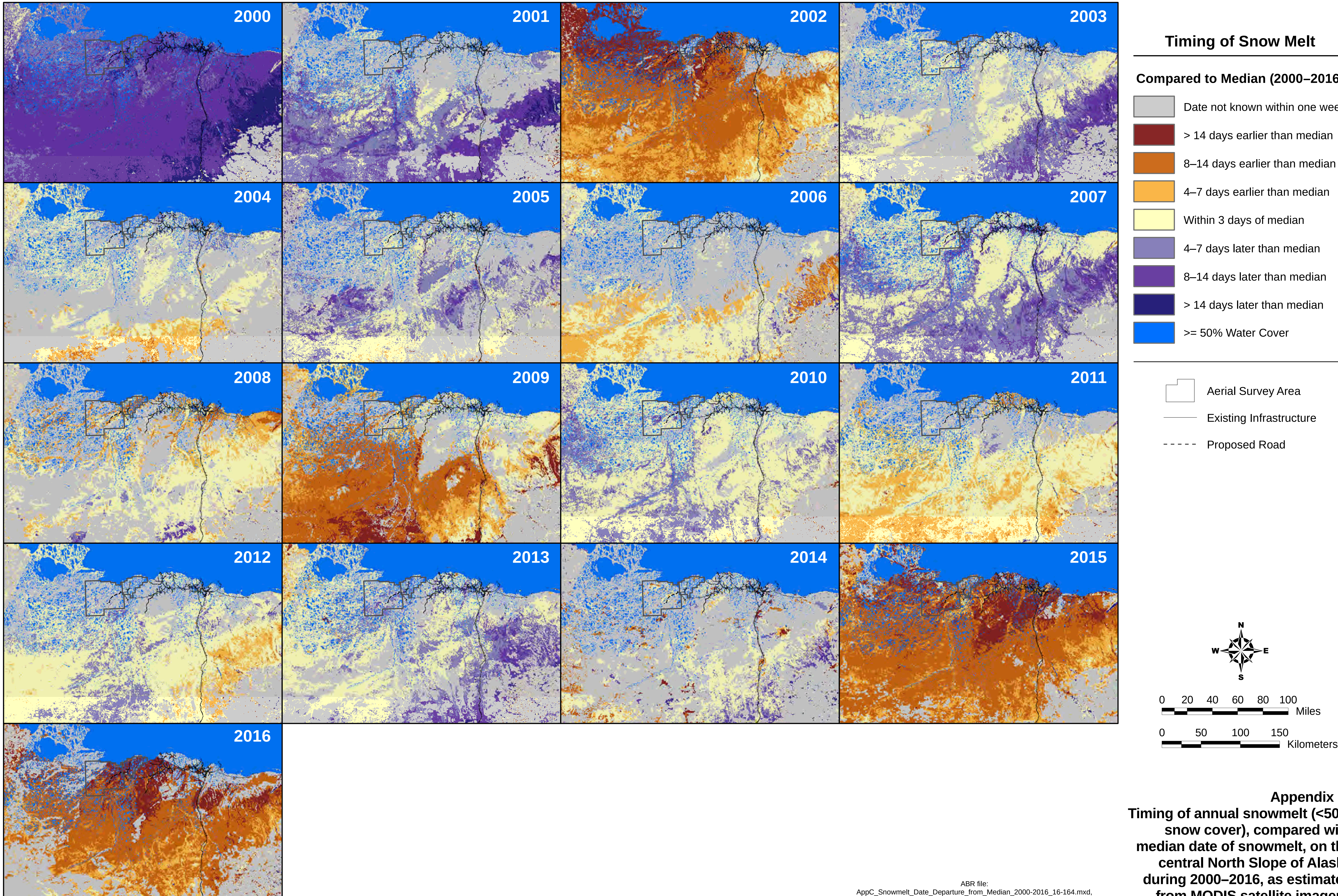
Year	Snow Depth (cm)			Cumulative Thawing Degree-days (ºC)						
	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	66.2	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	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
2013	33	18	2	0	4.2	79.2	131.7	112.8	188.0	185.4

Appendix B. Continued.

Year	Snow Depth (cm)			Cumulative Thawing Degree-days (ºC)						
	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
2014	33	0[b]	0[b]	11.1	4.2	28.6	82.0	127.2	102.3	67.9
2015	38	14	3	1.4	46.4	78.9	197.2	117.9	95.7	106.9
2016	35	0	0	15.6	12.4	63.7	131.2	174.7	130.8	98.1
Mean	**25.1**	**14.3**	**3.1**	**1.3**	**12.1**	**43.9**	**102.9**	**126.4**	**142.5**	**126.3**

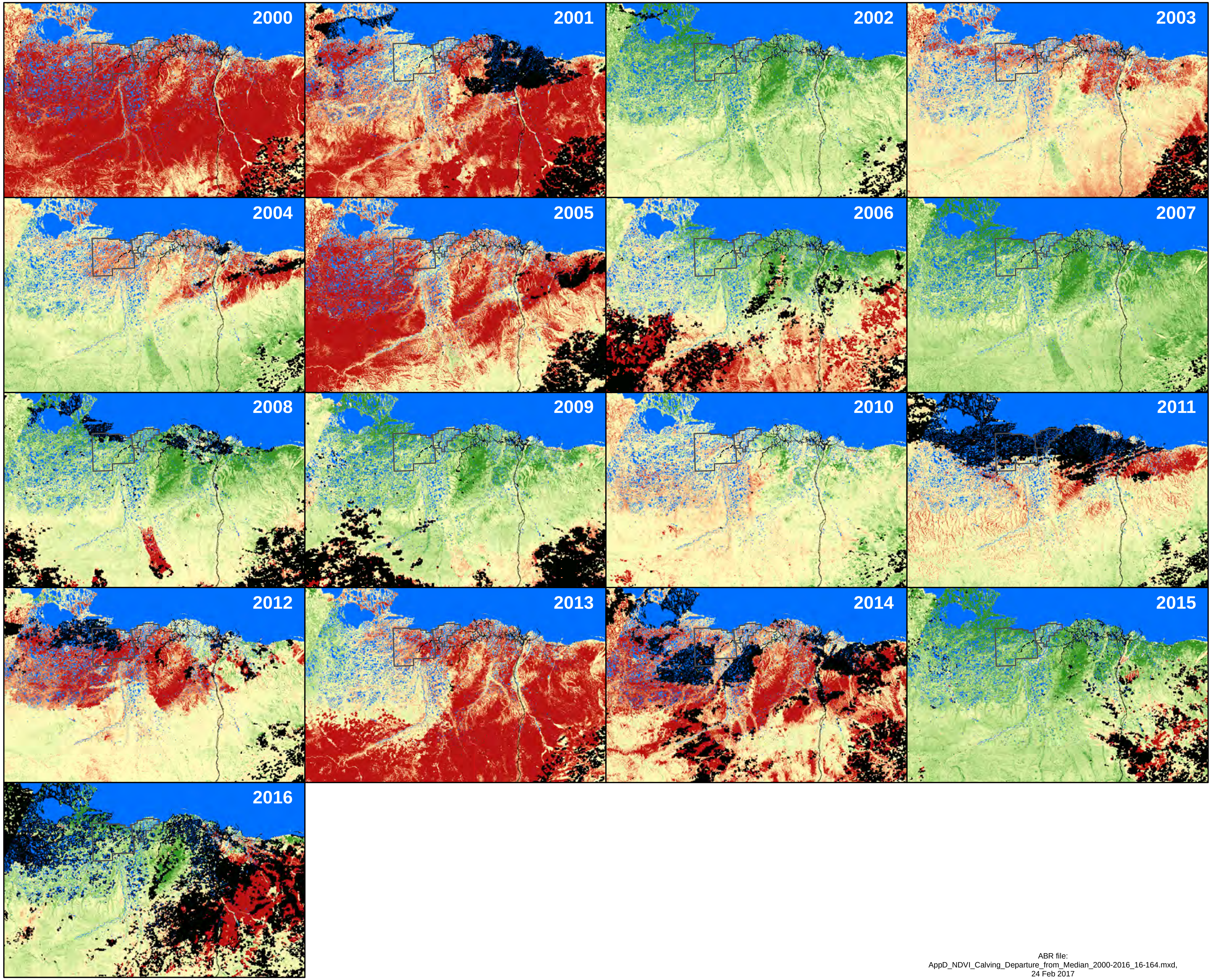
[a] Kuparuk weather data were not available for 17 June–9 December 2011, 4–14 August 2012, and 30–31 August 2012, so cumulative TDD for those periods were estimated by averaging Deadhorse and Nuiqsut temperatures (Lawhead and Prichard 2012).

[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.



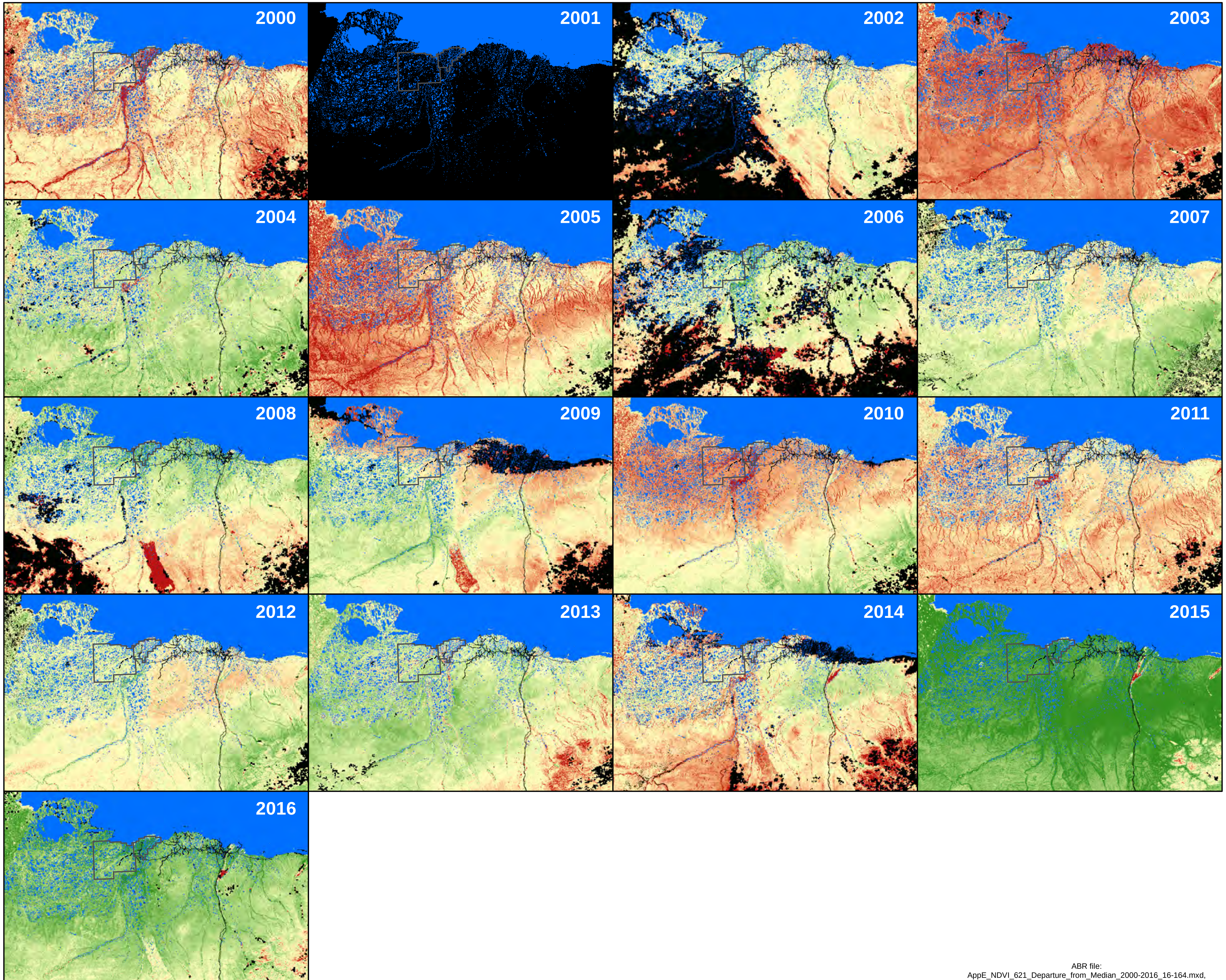
ABR file:
AppC_Snowmelt_Date_Departure_from_Median_2000-2016_16-164.mxd,
24 Feb 2017

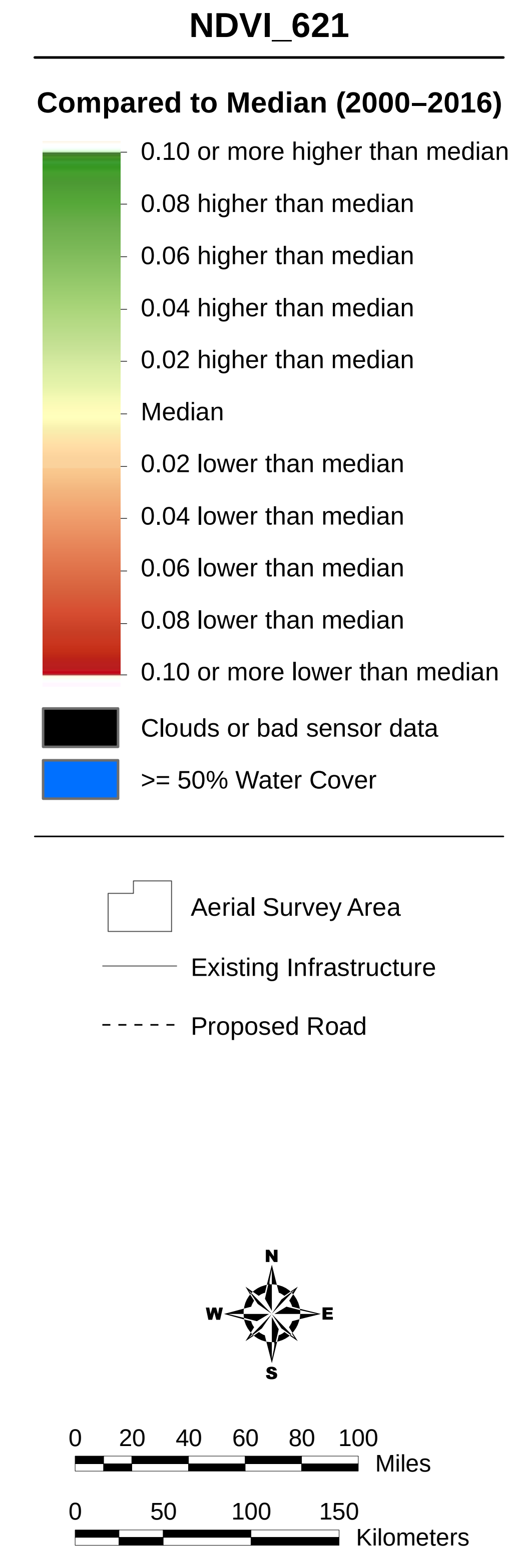
Appendix C.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2016, as estimated from MODIS satellite imagery.



Appendix D. Differences between annual relative vegetative biomass values and the 2000–2016 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

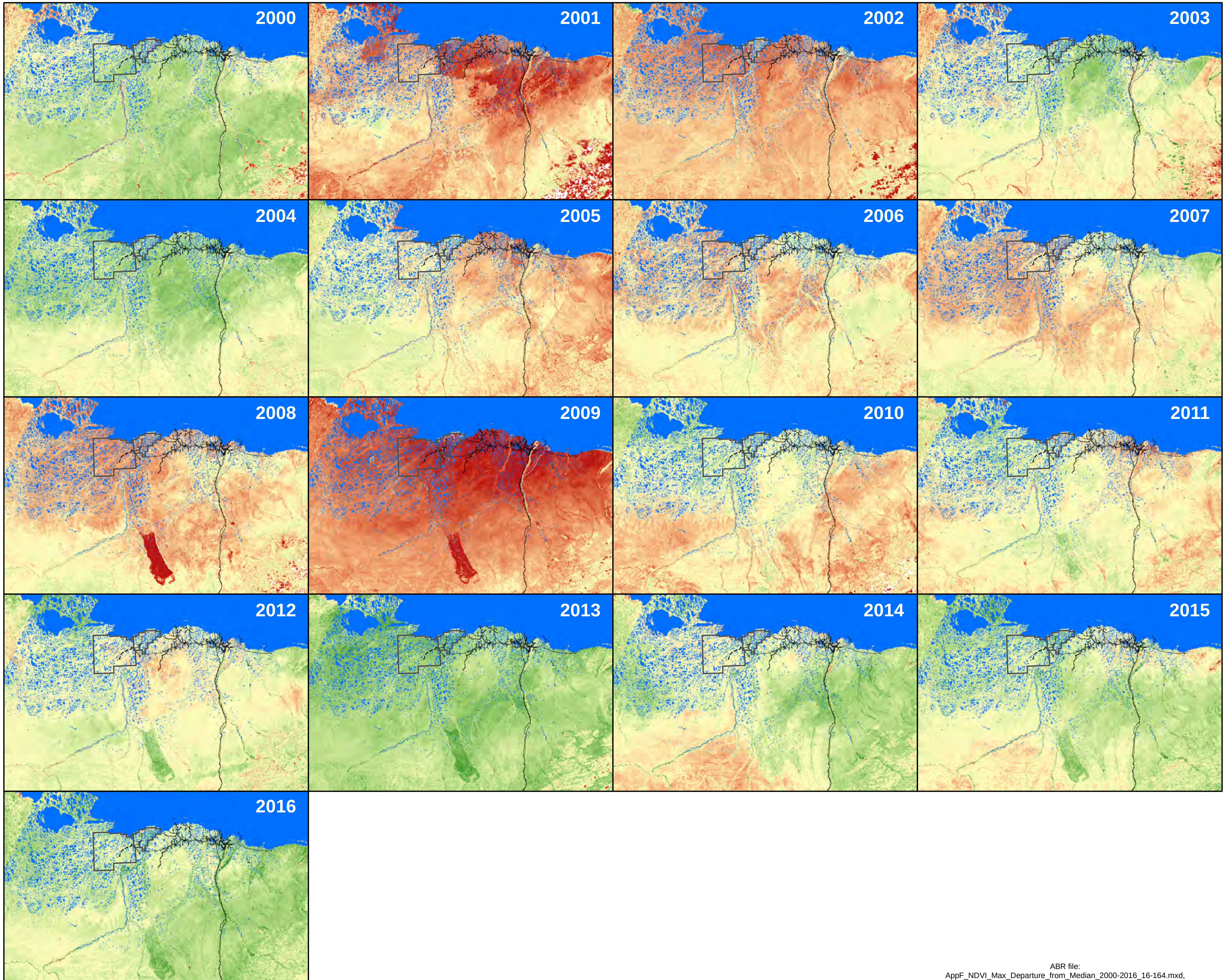
ABR file:
AppD_NDVI_Calving_Departure_from_Median_2000-2016_16-164.mxd,
24 Feb 2017

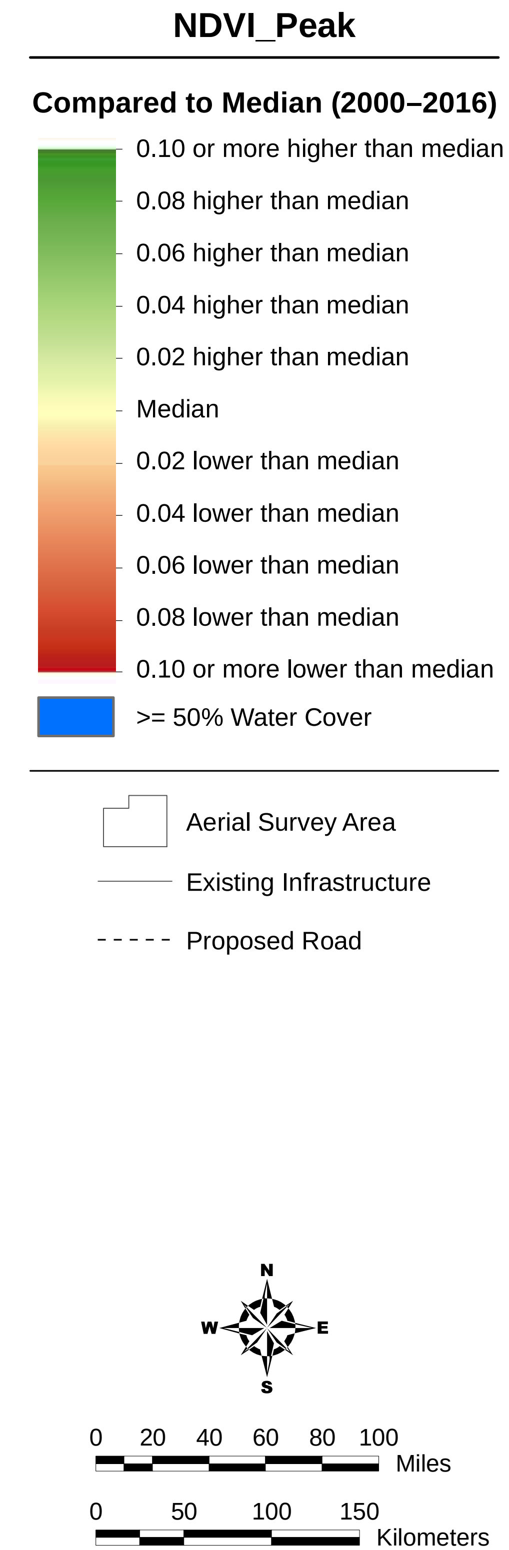




ABR file:
AppE_NDVI_621_Departure_from_Median_2000-2016_16-164.mxd,
24 Feb 2017

Appendix E.
Differences between annual relative vegetative biomass values and the 2000–2016 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 F.
Differences between annual relative vegetative biomass values and the 2000–2016 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

ABR file:
AppF_NDVI_Max_Departure_from_Median_2000-2016_16-164.mxd,
24 Feb 2017