CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM, 2017

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Prepared for
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Anchorage, Alaska

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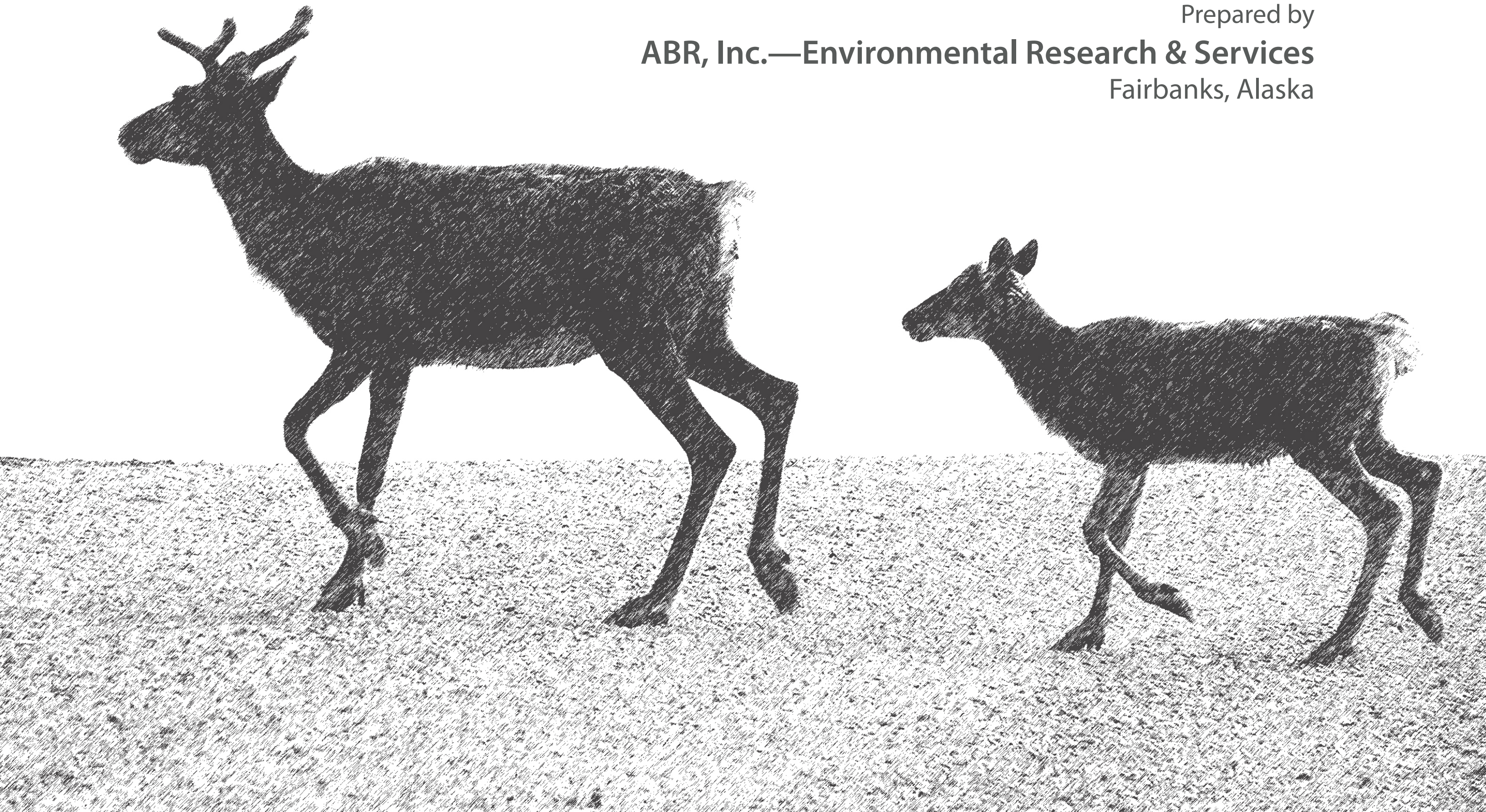

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13th ANNUAL REPORT

Prepared for

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INTRODUCTION

BACKGROUND

The caribou monitoring study for the Alpine Satellite Development Program (ASDP) is being conducted on the Arctic Coastal Plain of northern Alaska 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 2015a, Lenart 2015, Nicholson et al. 2016).

The TH tends to remain on the coastal plain year-round. The area of most concentrated calving typically is 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, 2015a; 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 2015a; L. Parrett, Alaska Department of Fish and Game [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 the last 15 years, substantial portions of the TH 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 2015a) 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 2015a; Figure 1). The TH experienced a dip in numbers in

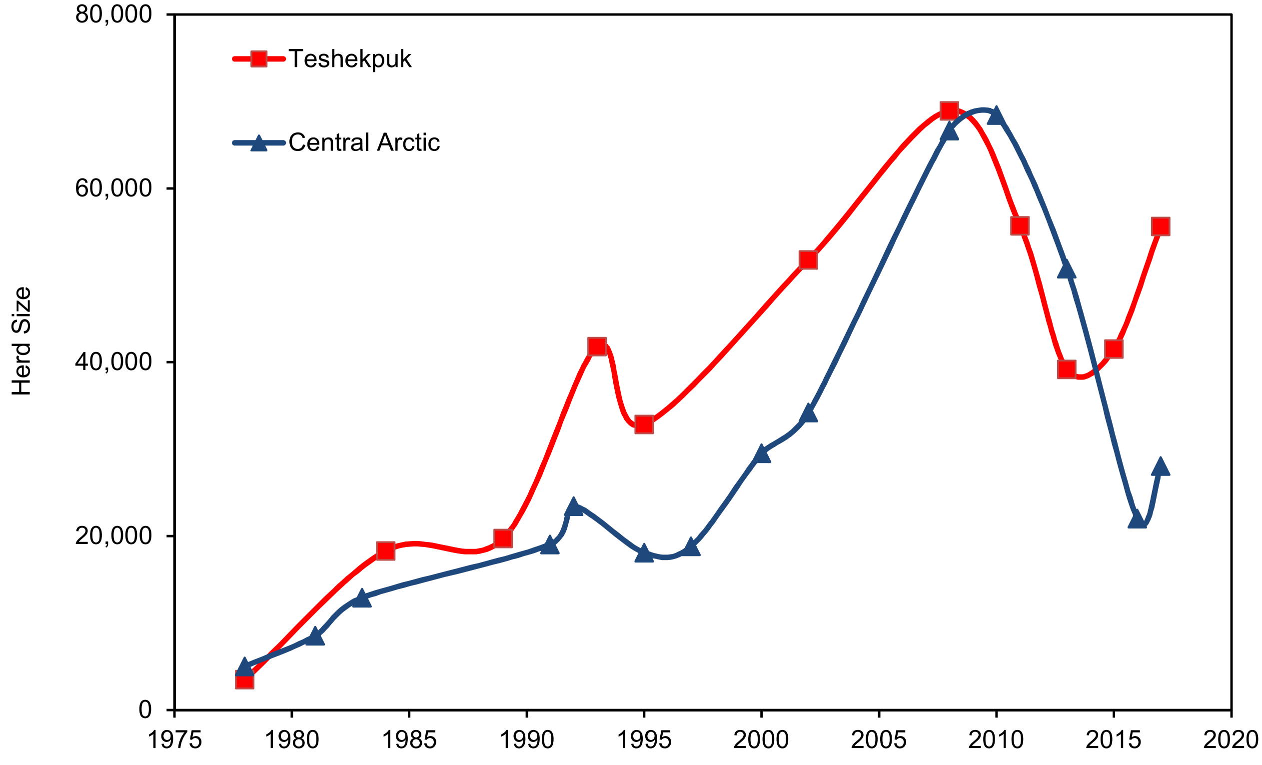


Figure 1. Population size of the Teshekpuk and Central Arctic caribou herds, 1975–2017, based on ADFG census estimates (see text for details).

the early 1990s, but increased steadily from 1995 to its peak estimated population size of 68,932 animals in July 2008 (Parrett 2015a). The herd subsequently declined. A photocensus in July 2011 produced a population estimate of 55,704 animals (Parrett 2015a), a decline of at least 19% from the 2008 estimate. A photocensus 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 2015a), a further decrease of at least 30% since 2011. A 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; Parrett 2015b), indicating the population had stabilized. A photocensus in July 2017 resulted in a minimum population count of 56,255 animals (Klimstra 2018). Although a portion of the higher population number since 2015 can be explained by the new higher-resolution digital photography used in 2017, the large difference in herd counts indicates that the TH has increased since 2015.

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). CAH caribou calving in the western area exhibit localized avoidance of the area within 2–4 km of active roads and pads during and for 2–3 weeks immediately after calving (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 some animals have remained north of the Brooks Range on the coastal plain in recent years (Prichard et al. 2017; E. Lenart, ADFG, pers. comm.).

From the early 1970s to 2002, the CAH grew at an overall rate of 7% per year (Lenart 2009; Figure 1). 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 22,630 animals by July 2016 (Lenart 2017). A photocensus conducted in July 2017 produced an estimate of caribou, indicating that the population has remained stable, and possibly increased, since the previous photocensus (Lenart 2018). The magnitude of the recent herd 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 ADFG, the North Slope Borough (NSB), and the Bureau of Land Management (BLM) (Philo et al. 1993, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015a, Prichard et al. 2017). Consultants working for BP Exploration (Alaska), Inc., 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).

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 surveys and radio telemetry. Specific questions included the following:
    a) Which herds use the study area?
    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 2, 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 three months (June–August) and the mean summer (June–August) air temperature in Nuiqsut is 7.6°C (National Oceanic and Atmospheric Administration, unpublished records 1998–2017). Monthly mean air temperatures at Nuiqsut range from about –4.6°C in May to 9.7°C in July, 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 CD-4 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

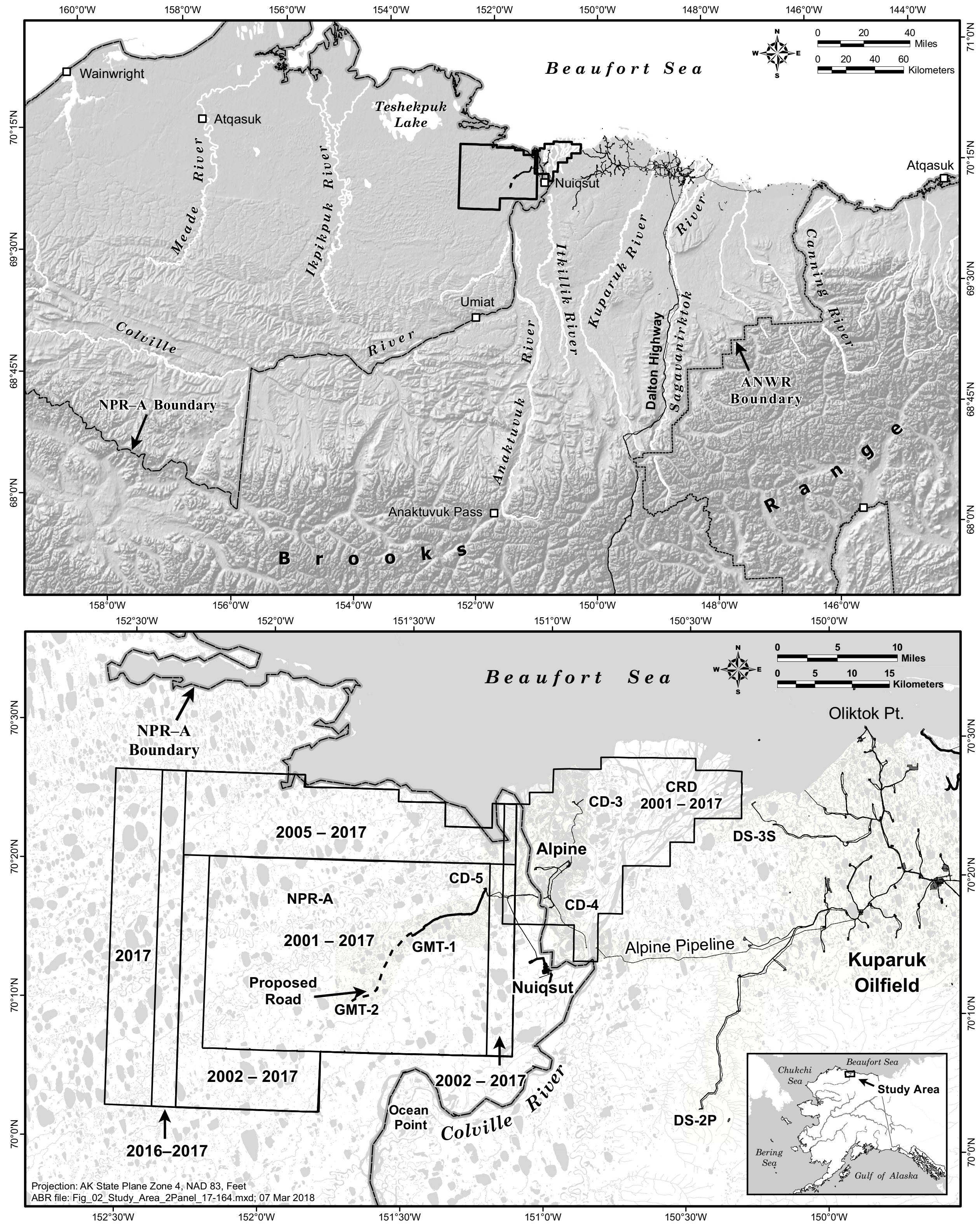


Figure 2. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the NPRA and Colville River Delta survey areas, 2001–2017.

(Lawhead et al. 2015): the NPRA survey area (expanded from 988 km² in 2001 to 1,310 km² in 2002; 1,720 km² in 2005; 1,818 km² in 2016; and 2,119 km² in 2017); 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, the study area was redefined to focus on the NPRA and Colville River Delta survey areas (Figure 2, bottom), so survey results for the Colville East survey area are reported elsewhere (Prichard et al. 2018). The Colville River Delta survey area encompasses Alpine drill sites CD-1 through CD-4. The NPRA survey area encompasses two recently constructed drill sites (CD-5 and GMT-1, constructed in winter 2013–2014 and 2016–2017, respectively) and the proposed GMT-2 drill site, as well as 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 CD-5 access road. Although that road is not part of CPAI's infrastructure, its presence in the study area warrants its inclusion in this analysis.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area, ABR biologists conducted aerial transect surveys in 2017 and analyzed existing 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 2016–2017.

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): winter (1 December–30 April); spring migration (1–29 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, a period that includes the breeding season, or 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 2, bottom) were conducted periodically from April to October 2017 in a fixed-wing airplane (Cessna 206 or 207), 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. northward in 2005, and additional transects were added to the western edge of the NPRA survey area in 2016 and 2017.

In 2017, aerial transect surveys in the NPRA and Colville River Delta survey areas were flown in mid-April (late winter), mid-May (spring migration), early June (calving), late June (postcalving), late July (oestrid fly), late August (late summer), and mid-September and early October (fall migration). Due to inclement weather, the NPRA survey area was only partially surveyed in May and the Colville River Delta survey area was only partially surveyed in October.

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) or 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 3.2-km 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 in a separate report (Prichard et al. 2018).

DENSITY MAPPING

To summarize aerial survey data in the NPRA survey area for the period 2002–2017, 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 2017 NPRA survey areas were subdivided into 211 grid cells. 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 mean seasonal density of caribou in each of the grid cells. Density was calculated by dividing the total number of caribou observed on each survey by the land area in the grid cell. The best power (from 1 to 1.2) and the best number of adjacent centroids (from 10 to 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 for each season.

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 by ADFG biologists 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 2016) 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).

Satellite-collar data were obtained from ADFG, NSB, and USGS for TH animals during the period July 1990–November 2017 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015; Person et al. 2007; Prichard et al. 2017, this study) 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), 182 collars deployed on 156 different caribou (86 females, 76 males) transmitted signals for a mean duration of 534 days per collar. The CAH 1986–1990 sample included 17 caribou (16 females, 1 male). The CAH 2001–2004 and 2012–2016 deployment samples included 24 collars deployed on 24 caribou (16 females, 8 males), transmitting for a mean duration of 634 days per collar.

Satellite telemetry locations are considered accurate to within 0.5–1 km of the true locations

Table 1. Number of TH and CAH radio-collar deployments and total number of collared animals that provided movement data for the ASDP caribou study.

Herd [a] / Collar Type	Years	Female Deployments	Female Individuals	Male Deployments	Male Individuals	Total Deployments
Teshekpuk Herd						
VHF collars [b]	1980–2005	n/a		n/a		212
Satellite collars	1990–2017	97	86	85	76	182
GPS collars	2004–2017	224	158	6	6	230
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	10	2	2	12
Satellite collars	2012–2017	6	6	6	6	12
GPS collars	2003–2017	168	114	0	0	168

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

(CLS 2016), but the data require screening to remove spurious locations (Lawhead et al. 2015).

GPS Collars

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 230 times by ADFG biologists on 164 different TH caribou (158 females, 6 males) during 2004 and 2006–2017, with a mean deployment duration of 483 days (Table 1). GPS collars (purchased by CPAI and ADFG) were deployed 168 times on 114 different female CAH caribou during 2003–2017, 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 six collars deployed on TH males. Females are preferred for GPS collar deployment because the collar models used are subject to antenna problems when using the expandable collars that are required for male caribou due to increased neck size during the rut (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 using 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 calculate the proportion of each monthly 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 visualize caribou movements based on GPS collars, we used dynamic bivariate Gaussian bridge (dBGB) models to create utilization distribution maps of movements based on the locations of collared individuals (Kranstauber et al. 2014). These dBGB models, a modification of earlier Brownian bridge models (Horne et al. 2007), use an animal's speed of movement and trajectory calculated from intermittent GPS locations to create a probability map describing relative use of the area traversed. We computed the 95% isopleth of movements for each individual TH caribou outfitted with a GPS collar moving through the area and then overlaid the isopleth layers for each season to calculate the proportion of collared caribou using each 250-m pixel. This visualization displays the seasonal use of the area by TH caribou as a function of both caribou distribution and movements. The dBGB models were computed using the *move* package in *R* (Kranstauber et al. 2017).

To calculate kernels, 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 winter season, 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.

Using the *ks* package for *R* (Duong 2017), fixed-kernel density estimation was employed to create utilization distribution contours of caribou distribution by month and season. The plug-in method 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. We also calculated a separate kernel for parturient TH females to delineate the calving range of the TH.

REMOTE SENSING

We analyzed 2017 snow cover and 2000–2017 vegetation greenness using gridded, daily reflectance and snow-cover products from MODIS Terra and Aqua sensors. The snow-cover data were added to the data compiled for 2000–2016 (see Lawhead et al. 2015 and Prichard et al. 2017 for detailed description of methods). The entire vegetation index record, based on atmospherically corrected surface reflectance data, was reprocessed to ensure comparability of greenness metrics.

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 on the 2016–2017 imagery, probably due to changes in the data from the aging MODIS sensors. For 2016–2017, we applied manual cloud masks for the snowmelt season and applied the standard cloud mask for images collected in June and later.

We analyzed and summarized the data using Google Earth Engine, a cloud computing service (Gorelick et al. 2017). For final analysis and visualization, we exported the results to the Alaska Albers coordinate system (WGS-84 horizontal datum) at 240-m resolution.

SNOW COVER

Snow cover was estimated using the fractional snow algorithm developed by Salomonson and Appel (2004). Only MODIS Terra data were used for snow mapping through 2016 because MODIS Band 6, which was used in the estimation of snow cover, was not functional on the MODIS Aqua sensor. However, a Quantitative Image Restoration algorithm has recently been applied to restore the missing Aqua Band 6 data to a scientifically usable state for snow mapping (Riggs and Hall 2015). At the same time, the aging Terra sensor was no longer reliable for snow mapping in 2017, so we used MODIS Aqua data for snow mapping in 2017. The 2017 analysis was based on MYD10A1.006 data (MODIS/Aqua Snow Cover Daily L3 Global 500m Grid).

A time series of images covering the April–June period was analyzed for each year during 2000–2017. 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 two images acquired on different days during green-up has been hypothesized to represent the amount of new growth occurring during that time interval (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index.html):

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

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 daily surface reflectance composites acquired over targeted portions of the growing season in 2000–2017. The data products used were MOD09GA.006 (Terra Surface Reflectance Daily Global 1 km and 500 m) and MYD09GA.006 (MYD09GA.006 Aqua Surface Reflectance Daily L2G Global 1km and 500m). NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) for each year during 2000–2017 (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 each year during 2000–2017.

HABITAT CLASSIFICATION

We used the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 3) for habitat classification and analysis. The NPRA survey area contained 15 cover classes from the NPRA earth-cover classification (Appendix A), which we lumped into 9 types to analyze caribou 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.

Some 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

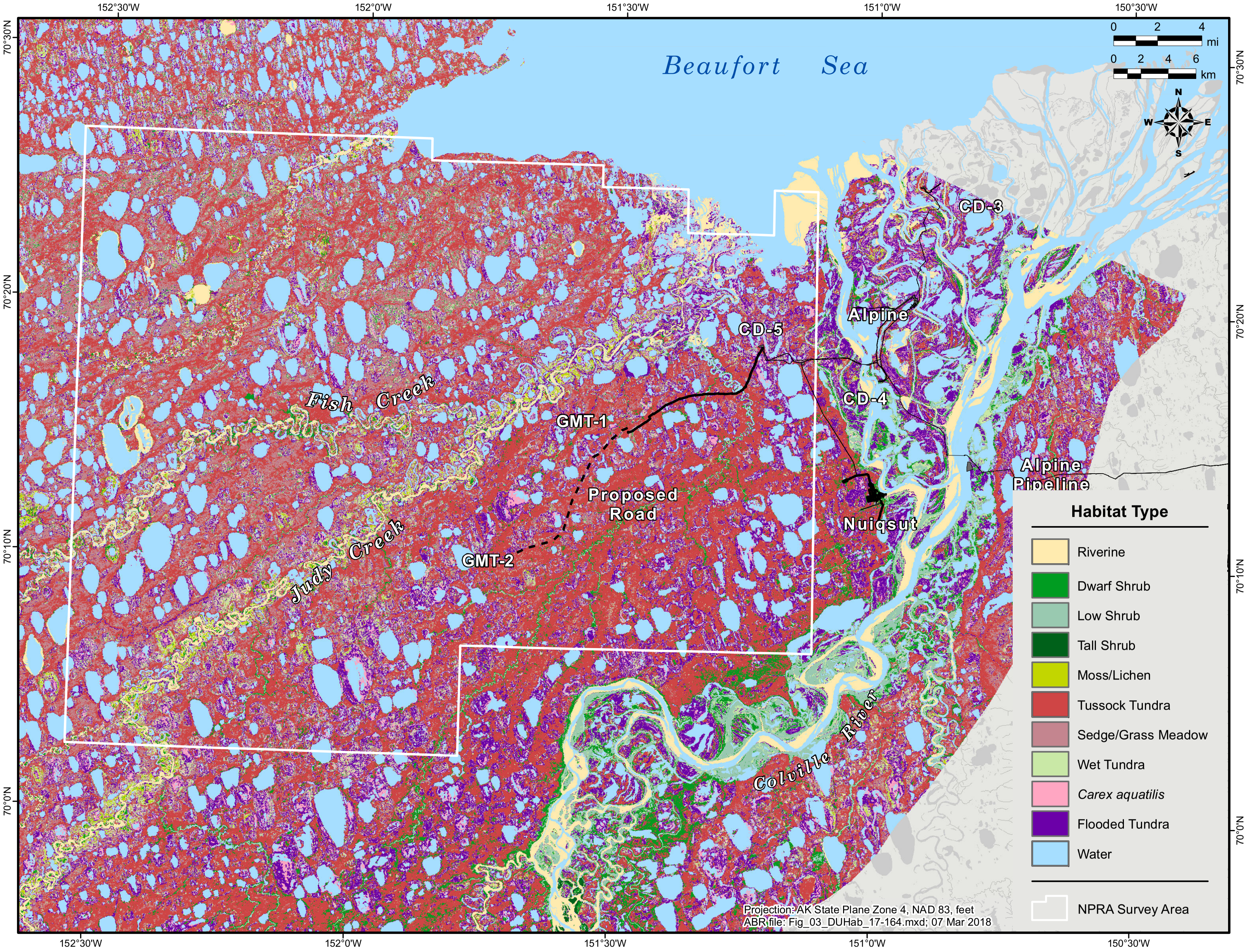


Figure 3. Habitat types used for caribou habitat-selection analysis in the NPRA survey area (adapted from BLM and Ducks Unlimited 2002).

land-cover classification differences in different portions of the survey area, so we reverted to 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 multiple 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. Beginning with the 2015 data (Prichard et al. 2017), we replaced those separate analyses with a single analytical approach by using resource selection function (RSF) models (Boyce and McDonald 1999, Manly 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 (use vs. availability) 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 for the RSF analysis. Locations of satellite-collared animals were not used due to the lower accuracy of those locations. We used caribou locations from aerial transect surveys conducted during 2002–2017 in the NPRA survey area, but the seasonal sample sizes for the Colville River Delta survey area were too small to support RSF analysis. The available telemetry data spanned the period 11 May 2003–31 December 2017 and were filtered to include only locations falling within the aerial survey area. To standardize the time between GPS-collar locations, maintain an adequate sample size, and reduce the effect of autocorrelation on results, we subsampled GPS 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, 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 (Manly 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 in *R* (*R* Core Team 2017) 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 3); median NDVI for the period 2000–2017 (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; and west to east distribution. We used the natural logarithm of the landscape ruggedness variable 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) using the *corvif* function from the AED library in *R* (Zuur et al. 2009). 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 100–200 m) compared to the habitat map (30-m pixels), 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 the variables (no interactions were included) using the *glmulti* package 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 based on the model output from the RSF models. 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

Daily air temperatures in 2017 were about average in May but below average in early June, and snow melted slightly earlier than average at the Kuparuk airstrip. Although patchy snow was present in parts of the NPRA survey area during the calving survey in early June, not enough was present to require the use of a sightability correction factor to adjust the caribou count from that survey. During the second half of June, all of July, and early August, daily air temperatures were at or above average (sometimes well above average) (Prichard et al. 2018; Appendix B).

ABR biologists conducting ground-based surveys for other projects near the Colville River delta first reported emergence of midges (which typically precede mosquito emergence by several days) on 20 June. Winds were relatively high for the following five days until the crew left, but mild mosquito harassment was noted on 25 June in microhabitats not exposed to the 10–15 mph wind occurring that day. Warm temperatures in July created weather conditions that were likely to produce severe insect harassment on multiple days (Prichard et al. 2018; Appendix B).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

NPRA Survey Area

Eight aerial surveys of the NPRA survey area were flown between 17 April and 10 October 2017. The estimated density ranged from a high of 1.01 caribou/km² on September 18–19 to a low of 0.05 caribou/km² on July 31 (Table 2, Figures 4–5). A total of 786 caribou (0.74 caribou/km²) were observed on the winter survey on 17 April (Table 2, Figures 4–5). The density of caribou decreased to 0.23 caribou/km² for the spring migration and calving surveys (the spring migration survey could not be completed due to inclement weather). Density almost doubled on the postcalving survey on 20 June (0.43 caribou/km²). Density decreased on the 31 July survey (0.05 caribou/km²) during the oestrid fly season and increased slightly to 0.14 caribou/km² on the late summer survey (August 28), before peaking at 1.01 caribou/km² on the first fall survey (September 18–19). Density decreased to 0.47 caribou/km² on the second fall survey (October 10). Only 11 and 38 calves were seen on the calving and postcalving surveys, respectively.

These results are generally consistent with the seasonal patterns of caribou density observed in the NPRA survey area since 2001 (Figure 5). Caribou densities in 2017 were near the long-term mean for all seasons except oestrid fly season, when density was substantially below the mean. Results from the seasonal density mapping of caribou recorded on aerial surveys of the NPRA survey area during 2002–2017 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).

Table 2. Number and density of caribou in the NPRA and Colville River Delta survey areas, April–October 2017.

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 17	2,119	786	nr	786	5.3	1,572	178.4	0.74
May 17	1,547	176	nr	176	4.6	352	83.1	0.23
June 7	2,119	235	11	246	3.7	492	48.5	0.23
June 20	2,119	422	38	460	3.6	920	118.4	0.43
July 31	2,119	57	nr	57	1.0	114	19.8	0.05
August 28	2,119	146	nr	146	2.6	292	35.0	0.14
September 18–19	2,119	1,068	nr	1,068	5.7	2,136	259.1	1.01
October 10	2,119	502	nr	502	6.5	1,004	146.0	0.47
Colville River Delta								
April 18	494	7	nr	7	3.5	14	9.9	0.03
May 15	494	3	nr	3	3.0	6	4.2	0.01
June 6	494	4	0	4	2.0	8	5.7	0.02
June 19	494	17	0	17	3.4	34	16.6	0.07
August 1	494	8	nr	8	1.1	16	6.9	0.03
August 29	494	12	nr	12	3.0	24	9.6	0.05
September 19	494	9	nr	9	4.5	18	12.7	0.03
October 10	463	0	nr	0	-	0		-

[a] Survey coverage was 50% of this area (1,059 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.

During most seasons, a decreasing gradient in caribou density from west to east was apparent in the NPRA survey area.

Colville River Delta Survey Area

Eight surveys of the Colville River Delta survey area were flown between 18 April and 10 October 2017 (Table 2). 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 (0–0.07 caribou/km²) (Table 2; Figure 4). No calves were observed during the calving and postcalving surveys and no caribou were recorded during the second fall migration survey on 10 October.

RADIO TELEMETRY

Radio collars provided detailed location and movement data throughout the year for a relatively 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 (Figure 7). The majority of collar locations for the TH and CAH occurred west and east of the Colville River, respectively. 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

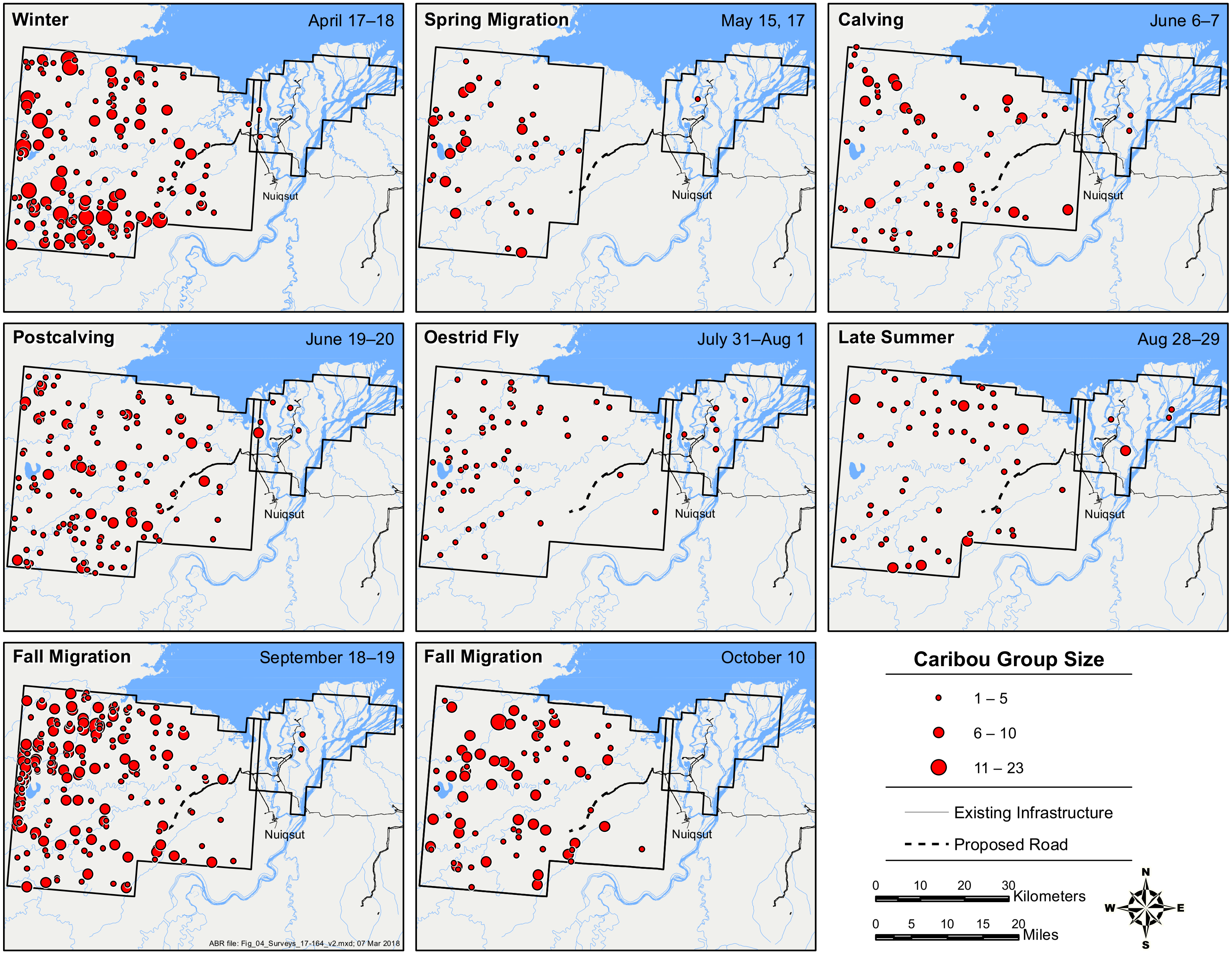


Figure 4. Distribution and size of caribou groups during different seasons in the NPRA and Colville River Delta survey areas, April–October 2017.

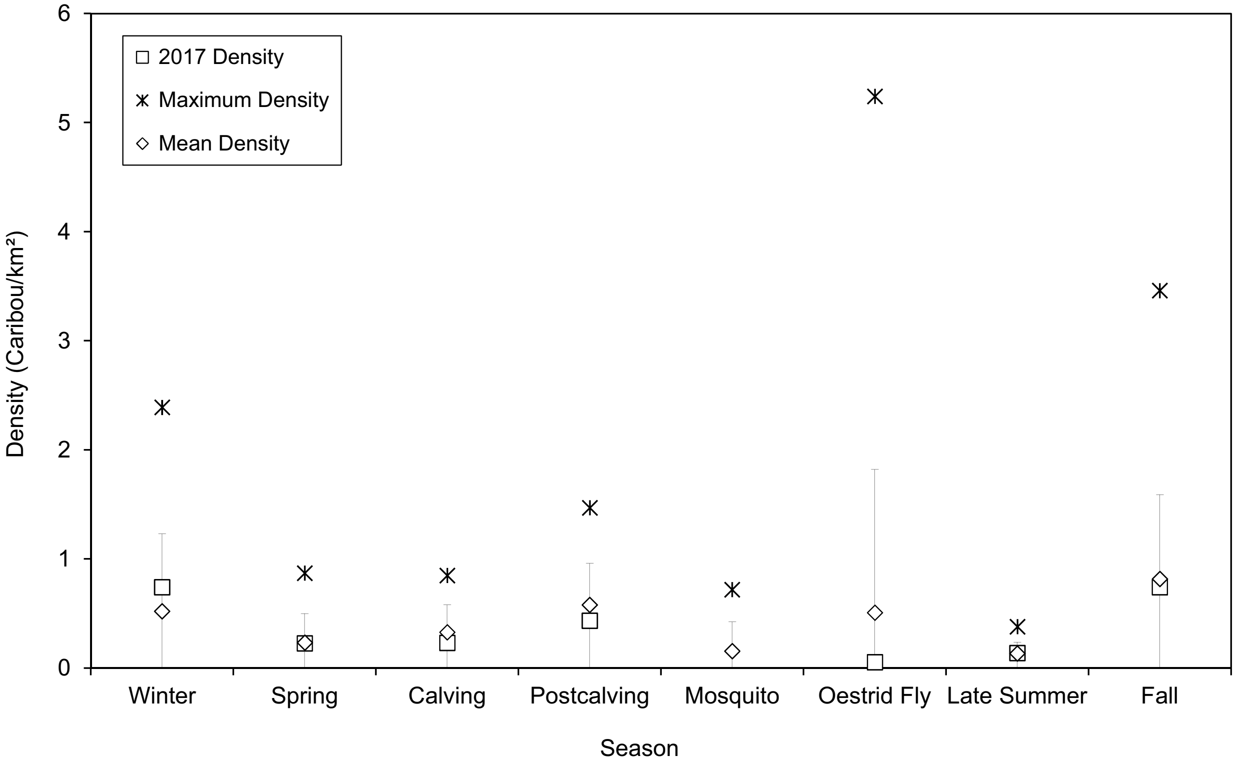


Figure 5. Seasonal density of caribou observed on 119 surveys of the NPRA survey area, April–October 2001–2017. Error bars represent 95% confidence intervals.

season (primarily oestrid fly season) and fall migration, followed closely by winter and late summer (Figures 8–9). The least use of the area by collared TH caribou occurred during the spring migration, calving, and postcalving seasons.

VHF Collars

Interpretation of VHF telemetry data (Figure 7) is constrained by the number, extent, and timing of radio-tracking flights and the fact that the distribution of collars on each flight is a snapshot from which only general conclusions can be drawn regarding caribou distribution and movements between successive tracking flights. VHF collar locations from previous years were discussed in more detail by Lawhead et al. (2006); no new VHF data were available for this study after 2005.

TH GPS Collars

Mapping of movements by TH caribou in the study area shows that TH females use the NPRA survey area during all seasons, although their use of the area and movement rates vary widely among seasons (Figure 10). During winter, caribou are distributed widely but show low rates of movement. During the spring migration and calving seasons, TH females move across the study area from southeast to northwest as they migrate toward the core calving area bordering Teshekpuk Lake. During the mosquito season, caribou largely remain north of the study area, often traversing the narrow corridors between Teshekpuk Lake and the ocean (Yokel et al. 2009). During the oestrid fly season, TH females move rapidly, but tend to disperse inland away from Teshekpuk Lake, with occasional large movements through the NPRA survey area. During summer, the highest densities occur in the western portion of the NPRA survey area. TH caribou disperse widely during fall migration (Figure 10).

CAH GPS Collars

The detailed movement tracks of 21 different female CAH caribou fitted with CPAI-funded GPS collars were mapped for the period from

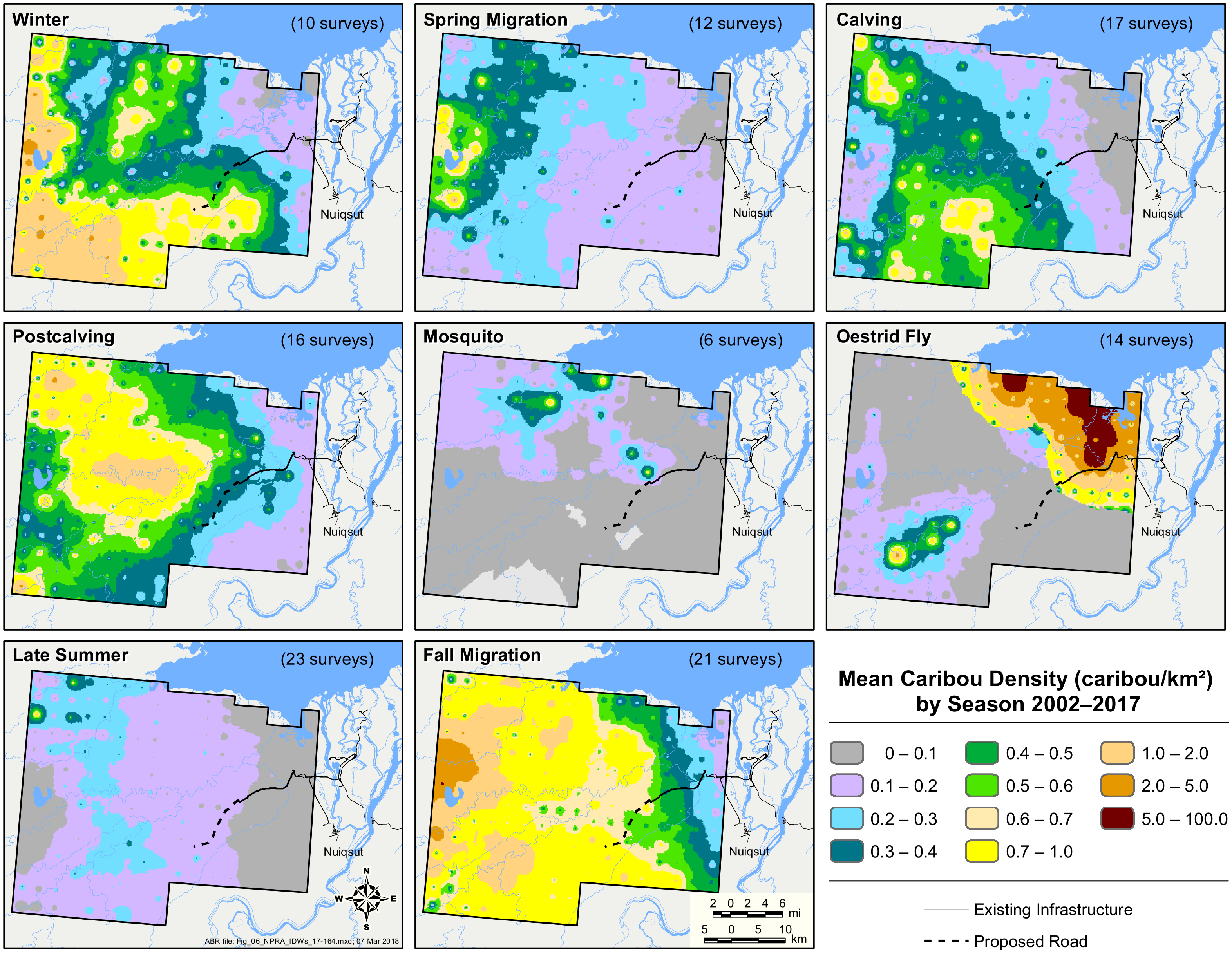
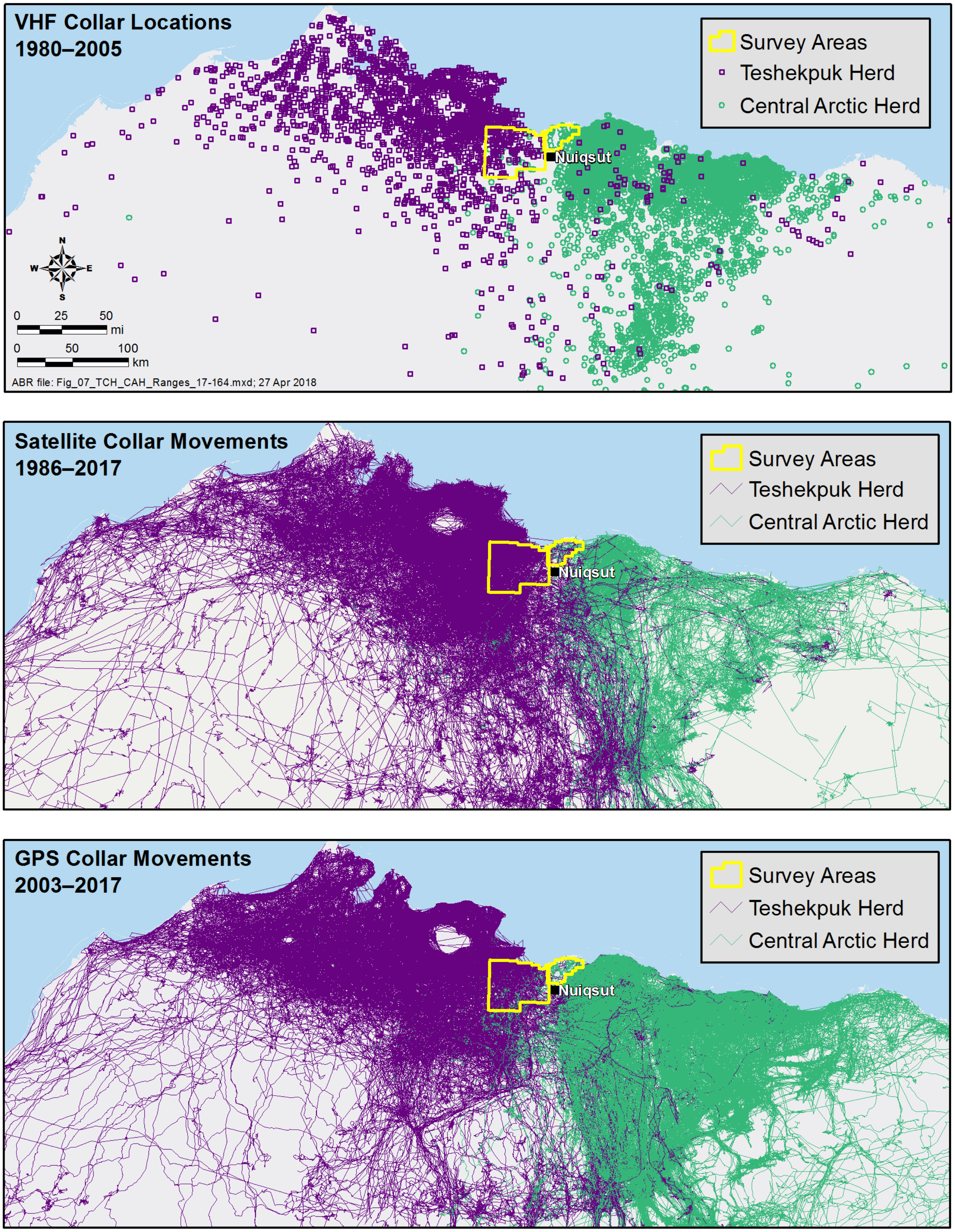


Figure 6. Seasonal density of caribou within the NPRA survey area based on IDW interpolation of aerial survey results, 2002–2017.


VHF Collar Locations 1980–2005

Satellite Collar Movements 1986–2017

GPS Collar Movements 2003–2017

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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, 1980–2017.

December 2016 through November 2017 (Figures 11–14). These caribou were collared in 2013, 2014, 2016, or 2017 and remained active until at least December 2017.

All but one of the caribou collared in 2013 and 2014 were captured in April on winter range in the Brooks Range east of the Dalton Highway; the 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. On the coastal plain in late June 2017, two collars were deployed on previously uncollared animals and seven caribou previously collared with CPAI collars were recollared. Four animals died in 2017: caribou C02120 on 12 April, C1437 on 5 August, C1501 on 12 August, and C06338 on 6 October.

All but 5 of the 21 collared caribou spent the majority of the year within the normal annual range of the CAH (Figures 11–14). Of the 16 caribou that exhibited typical CAH movement patterns, 12 spent the majority of the year west of the Sagavanirktok River. Most of these caribou spent the calving season and early summer near the Kuparuk oilfield or along the Dalton Highway before migrating south into the foothills of the Brooks Range between the Anaktuvuk River and Chandalar Lake. Caribou C1329 began the year west of the Colville River before moving east to calve with the CAH and then remained with the CAH for the remainder of the year (Figure 12). Caribou C1409, C1426, C1439, and C1620 spent most of the year with the CAH but moved west toward the Colville and Anaktuvuk rivers during late summer and wintered in the central Brooks Range in an area often used by the TH (Figure 12). One CAH caribou (C02120) died on 12 April 2017 along the Sagavanirktok River (Figure 11).

Three CAH caribou (C06338, C1427, C1309) spent most of the year east of the Sagavanirktok River (Figures 11–12). Caribou C06338 moved east toward the Canning River during the oestrid fly season and then migrated south into the Brooks Range with other caribou from the eastern portion of the CAH range before dying in the central Brooks Range on 6 October (Figure 11). Caribou C1309 spent almost the entire year on the coastal plain between Prudhoe Bay and the Canning River (Figure 11). Caribou C1427 was in the eastern calving area of the CAH during calving, but its collar was removed on 28 June and was not replaced (Figure 12).

Caribou C1001 was the only caribou to spend the entire year with the TH (Figure 13). She wintered in the foothills south of Teshekpuk Lake, moved to the south side of Teshekpuk Lake for the calving season, spent most of the insect season north of Teshekpuk Lake or west toward Atqasuk, and then moved east toward the NPRA study area before migrating back to the same general wintering area used the previous year.

Four collared caribou (C1108, C0801, C06335, and C1437) moved with PH caribou for much of the year (Figure 14). The collars for caribou C06335 and C1108 were retrieved on 19 March and 16 May, respectively, while those individuals were still on the PH winter range. Caribou C1437 wintered in the Brooks Range near the Canada border, migrated to the PH calving ground east of the Canning River, and then spent most of the summer in the eastern Brooks Range before dying on 6 August near the Canada border (Figure 14). Caribou C0801 wintered near Chandler Lake and Arctic Village, in a wintering area used by both the CAH and PH, before calving with the PH south of Kaktovik. She spent the summer on the coastal plain in Alaska and in the Brooks Range in Canada before migrating to the south side of the Brooks Range near Chandalar Lake in fall 2017 (Figure 14).

The five caribou that were collared with the CAH, but which exhibited movements more typical of PH and TH caribou, may have been PH or TH animals that were inadvertently collared while on overlapping winter ranges, 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 analyzed using fixed-kernel density estimation, based on locations from satellite and GPS collars deployed on 226 TH females and 81 TH males during 1990–2017 and on 126 CAH females and 8 CAH males during 2001–2017. These numbers differ from the number of collar deployments listed earlier (Table 1) because some individuals

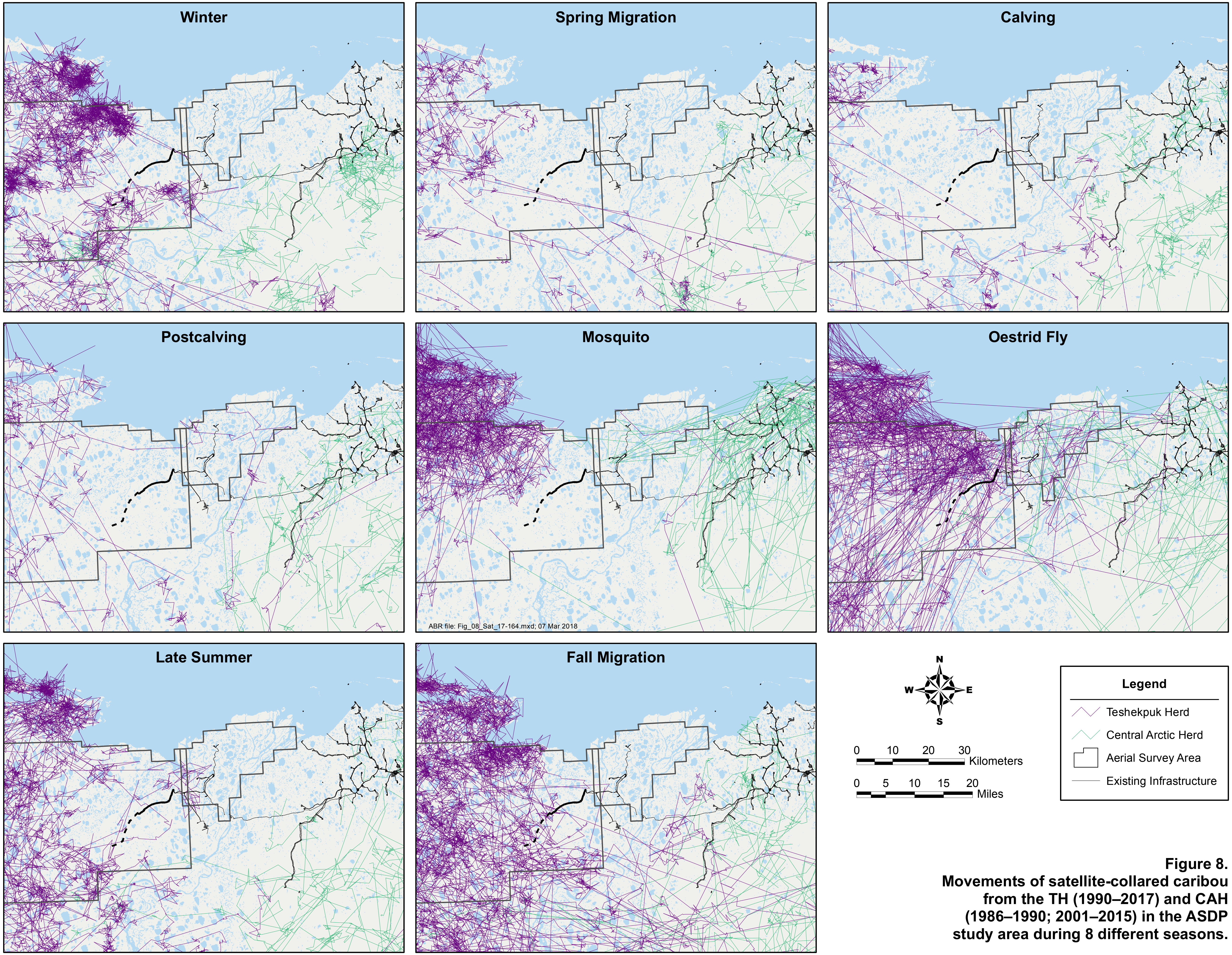

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Figure 8.
Movements of satellite-collared caribou from the TH (1990–2017) and CAH (1986–1990; 2001–2015) in the ASDP study area during 8 different seasons.

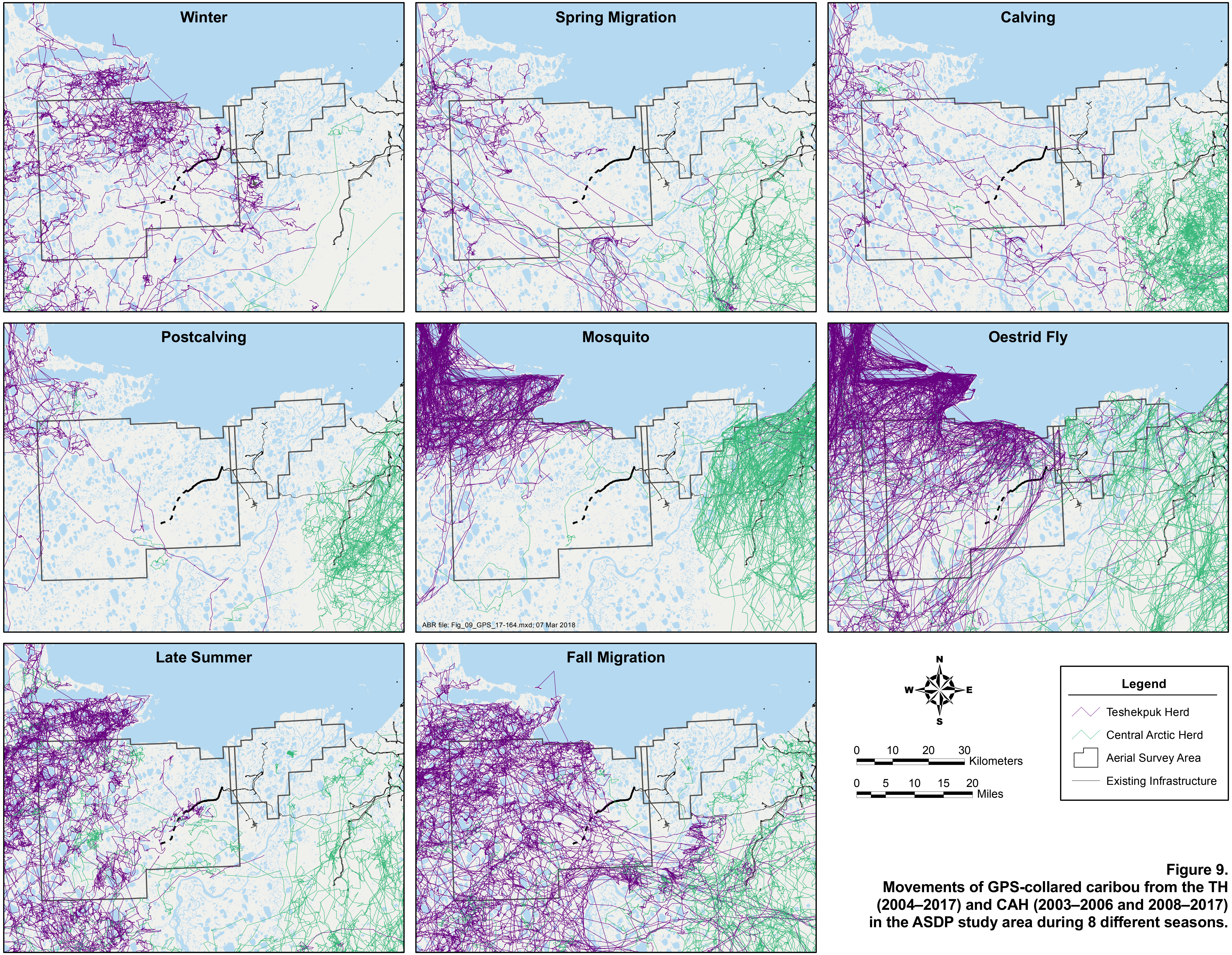

Figure 9.
Movements of GPS-collared caribou from the TH (2004–2017) and CAH (2003–2006 and 2008–2017) in the ASDP study area during 8 different seasons.

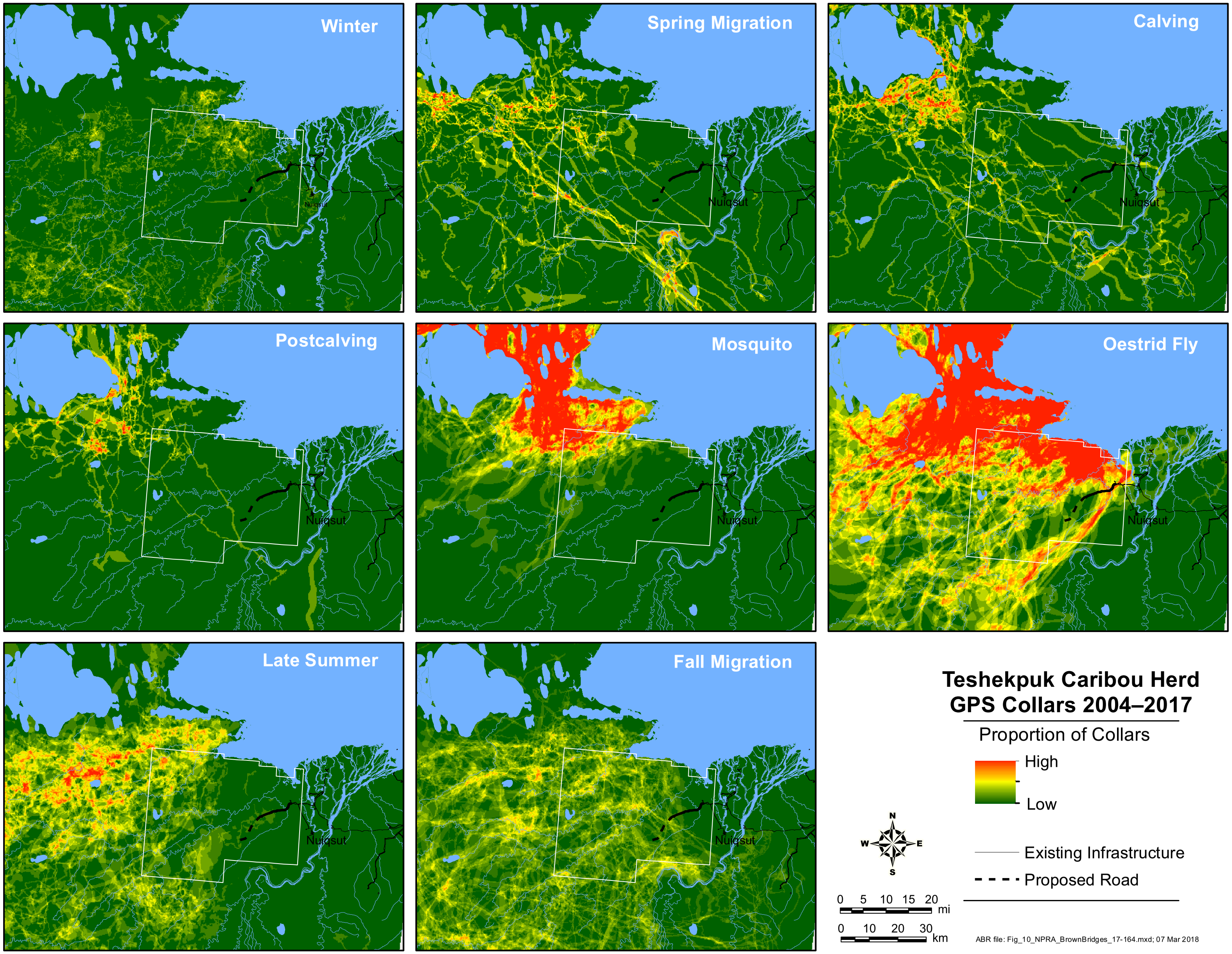

Figure 10. Proportion of GPS-collared caribou using an area based on 95% isopleth of dynamic Bivariate Gaussian Bridge models of individual caribou movements.

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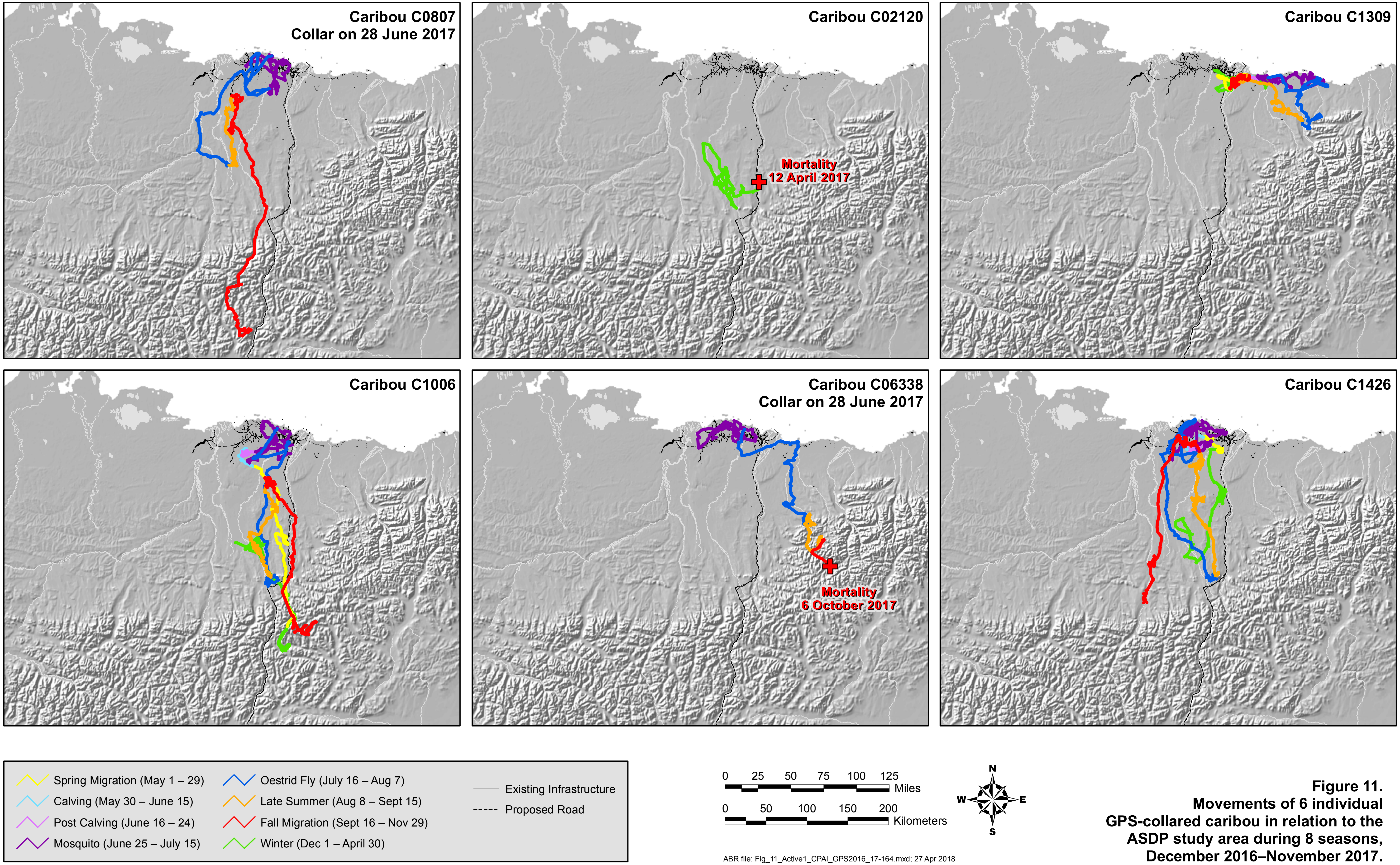

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Figure 11.
Movements of 6 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2016–November 2017.

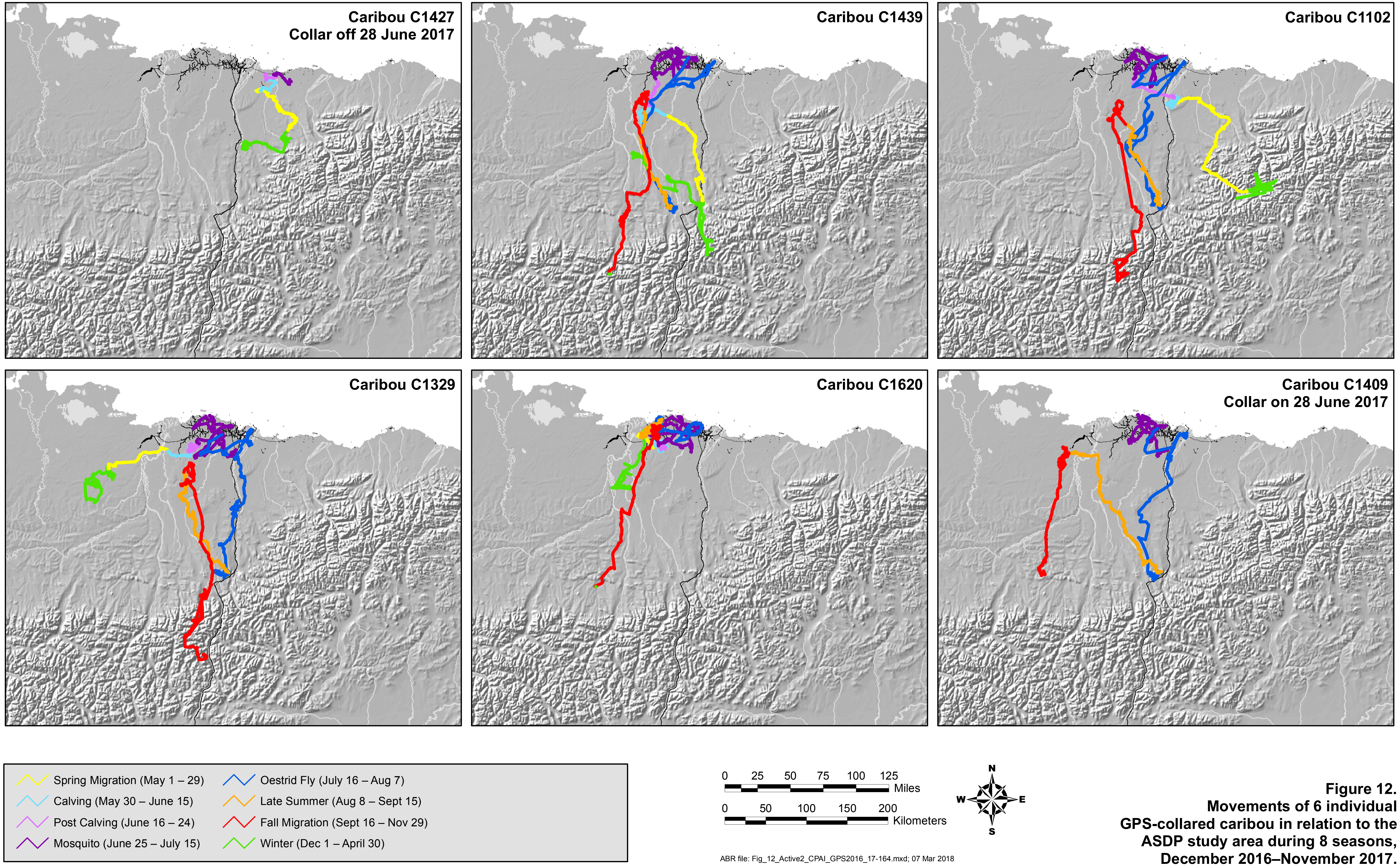

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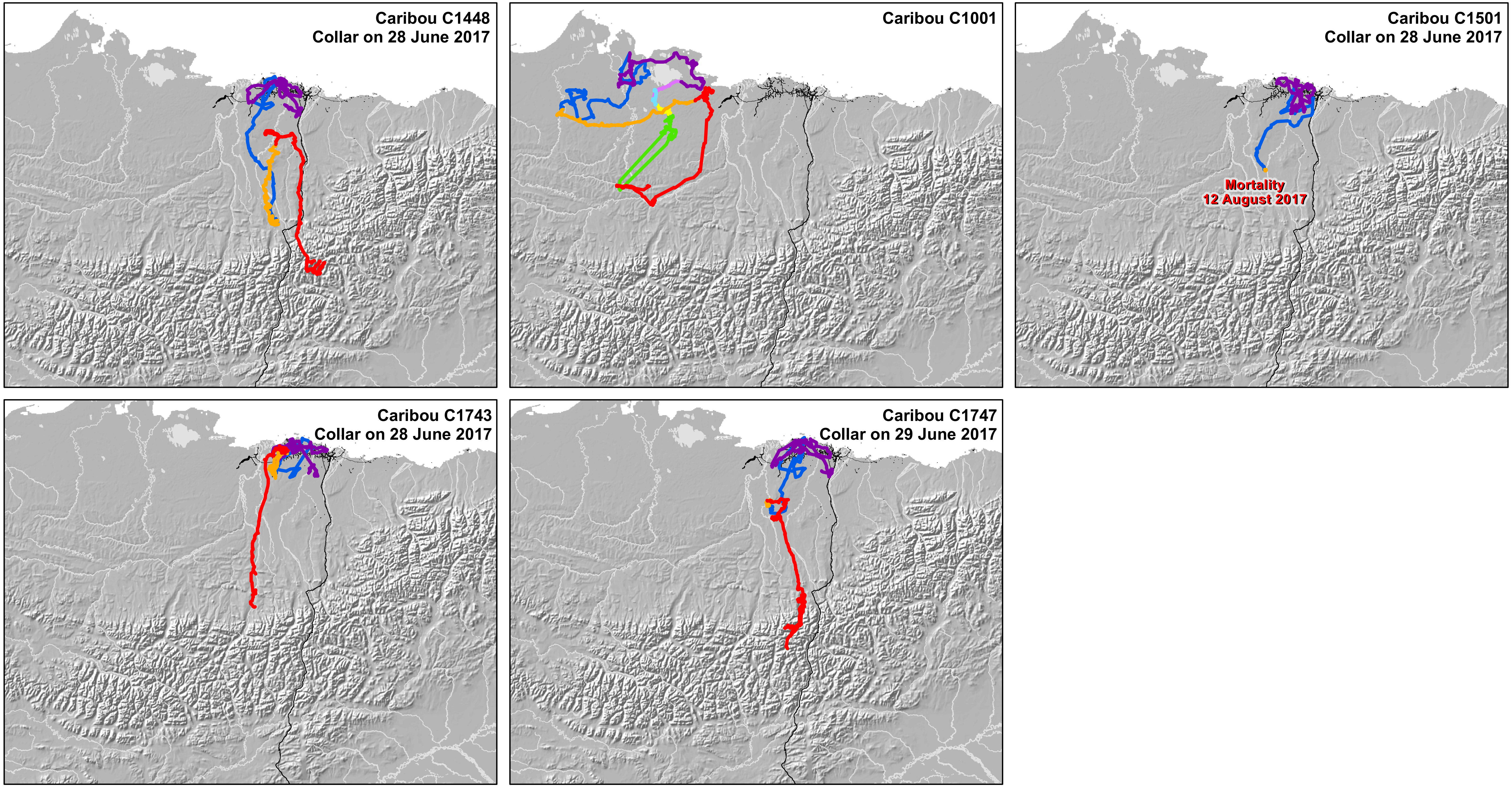
Figure 12.
Movements of 6 individual
GPS-collared caribou in relation to the
ASDP study area during 8 seasons,
December 2016–November 2017.



ABR file: Fig_13_Active3_CPAI_GPS2016_17-164.mxd; 07 Mar 2018

Figure 13.
Movements of 5 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2016–November 2017.

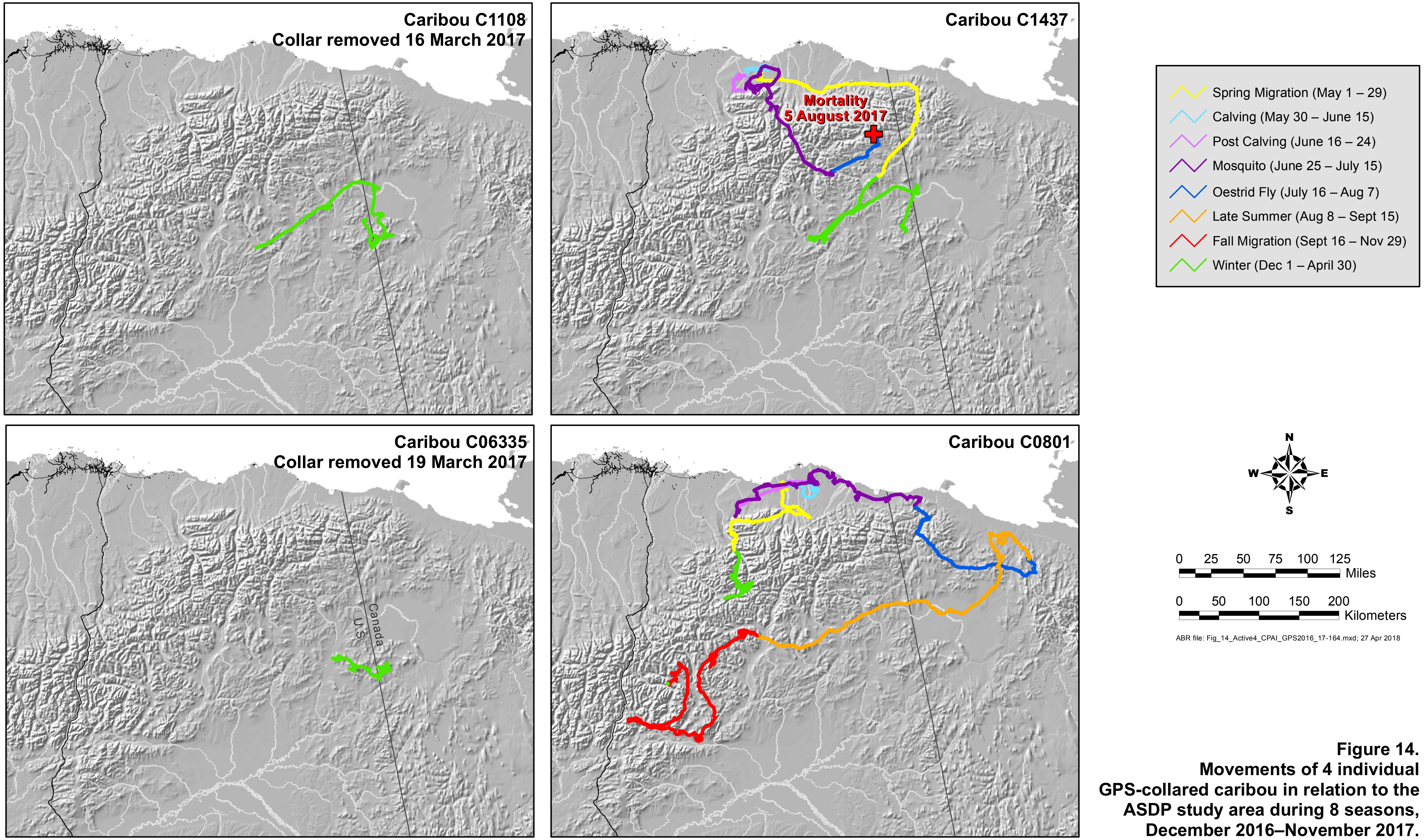


Figure 14.
Movements of 4 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2016–November 2017.

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 15–17); the sample size of CAH males was too small for this analysis.

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

TH caribou generally wintered 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 16–17). Compared with females, males tended to overwinter in the central Brooks Range instead of on the coastal plain, migrated to summer range later, and were not distributed as far west during summer (Figures 16–17). The distribution of parturient TH females during calving (Figure 18) was similar to the distribution of all TH females during calving (Figure 16), but was more concentrated around Teshekpuk Lake.

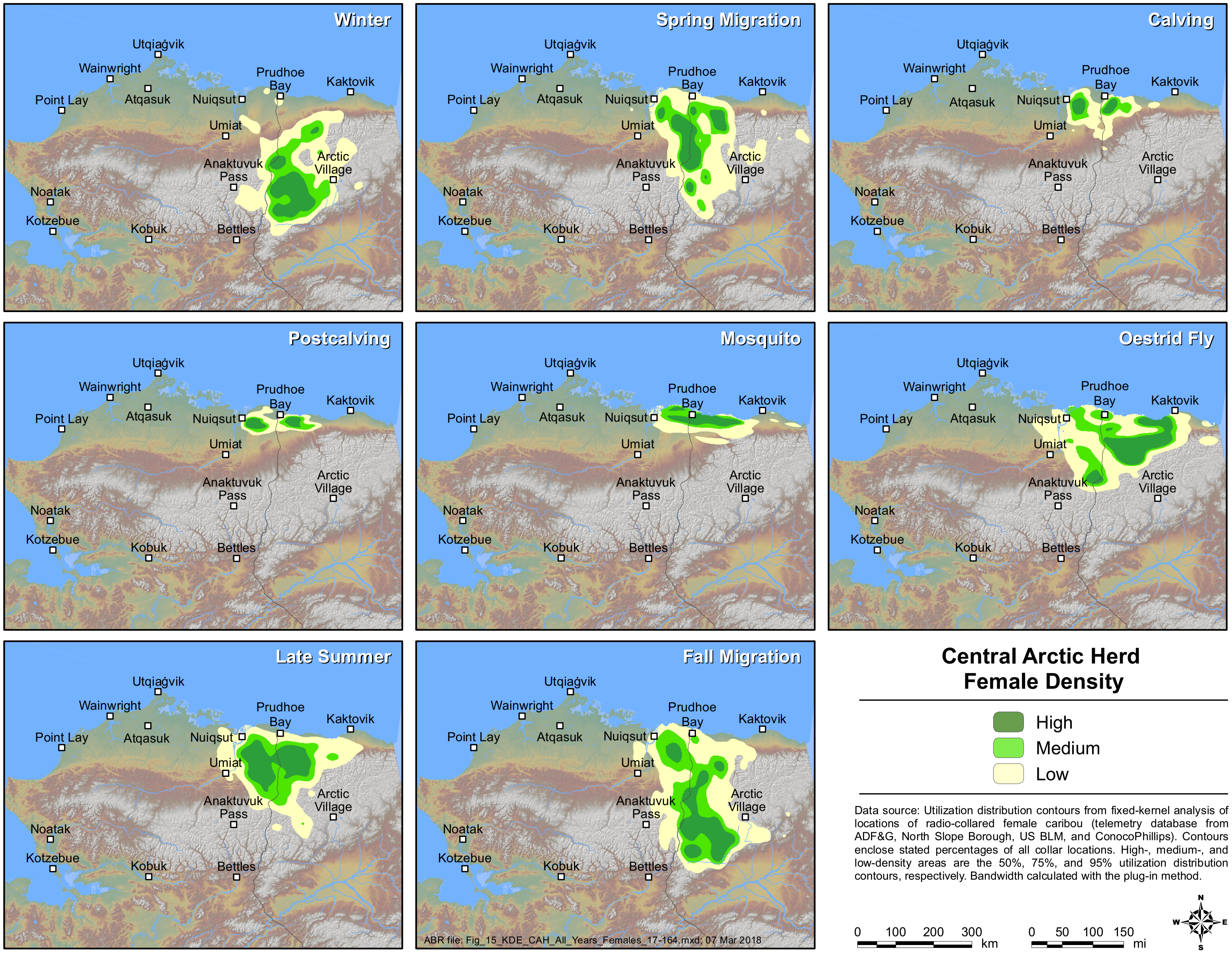
Examination of the percentage of kernel densities by month showed that collared TH females used the NPRA survey area at consistently low levels (3.7–9.2% of total utilization) throughout the year, with the highest level of use occurring in September (Figure 19). Use of the survey area by TH males increased sharply from May to a peak in July (18.3% of the utilization distribution) during the oestrid fly season. The percentage of collared TH males found in the NPRA survey area remained at lower levels (<7%) from August through October, and then dropped below 1% as males migrated into the foothills and mountains of the Brooks Range or toward Atqasuk during the winter (Figure 19). In contrast, collared CAH females used the NPRA survey area at low levels (<1% of the total female CAH utilization distribution) from May through October, with almost no use during the rest of the year (Figure 18).

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 19). The highest percentages for TH males and CAH females occurred during July (1.1% and 1.2%, respectively) and the highest percentages for TH females occurred during January (0.4%; Figure 18).

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 9–11; Prichard et al. 2017). From December 2016 through November 2017, no satellite or GPS-collared TH or CAH caribou were recorded within 4 km of the Alpine CD-1 through CD-5 facilities or associated roads. Movements across the CD-5 pad and access road also occurred only rarely before construction of those facilities. In previous years, eight TH caribou outfitted with GPS collars crossed the CD-5 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 CD-5 road alignment in the years before construction: 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 GPS-collared CAH caribou crossed the CD-5 alignment in July 2010. No satellite-collared CAH caribou crossed the CD-5 alignment either before or after construction.

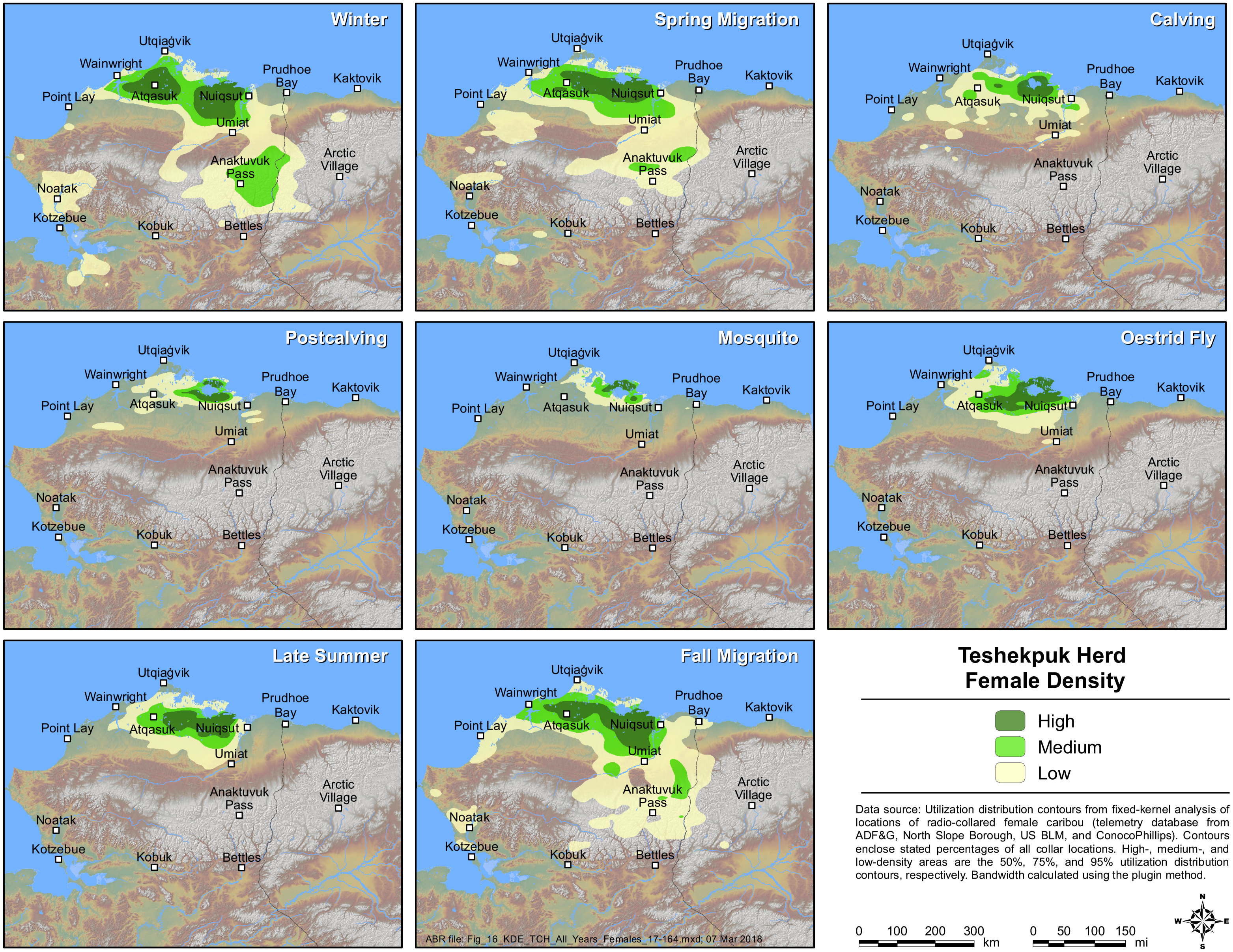
Although greater proportions of the collared TH and CAH samples have crossed the GMT-1 road corridor and the proposed road alignment from GMT-1 to GMT-2 than have occurred near CD-5, such movements have not occurred frequently (Figures 9–10 and 18; Table 3, Lawhead



Data source: Utilization distribution contours from fixed-kernel analysis of locations of radio-collared female caribou (telemetry database from ADF&G, North Slope Borough, US BLM, and ConocoPhillips). Contours enclose stated percentages of all collar locations. High-, medium-, and low-density areas are the 50%, 75%, and 95% utilization distribution contours, respectively. Bandwidth calculated with the plug-in method.

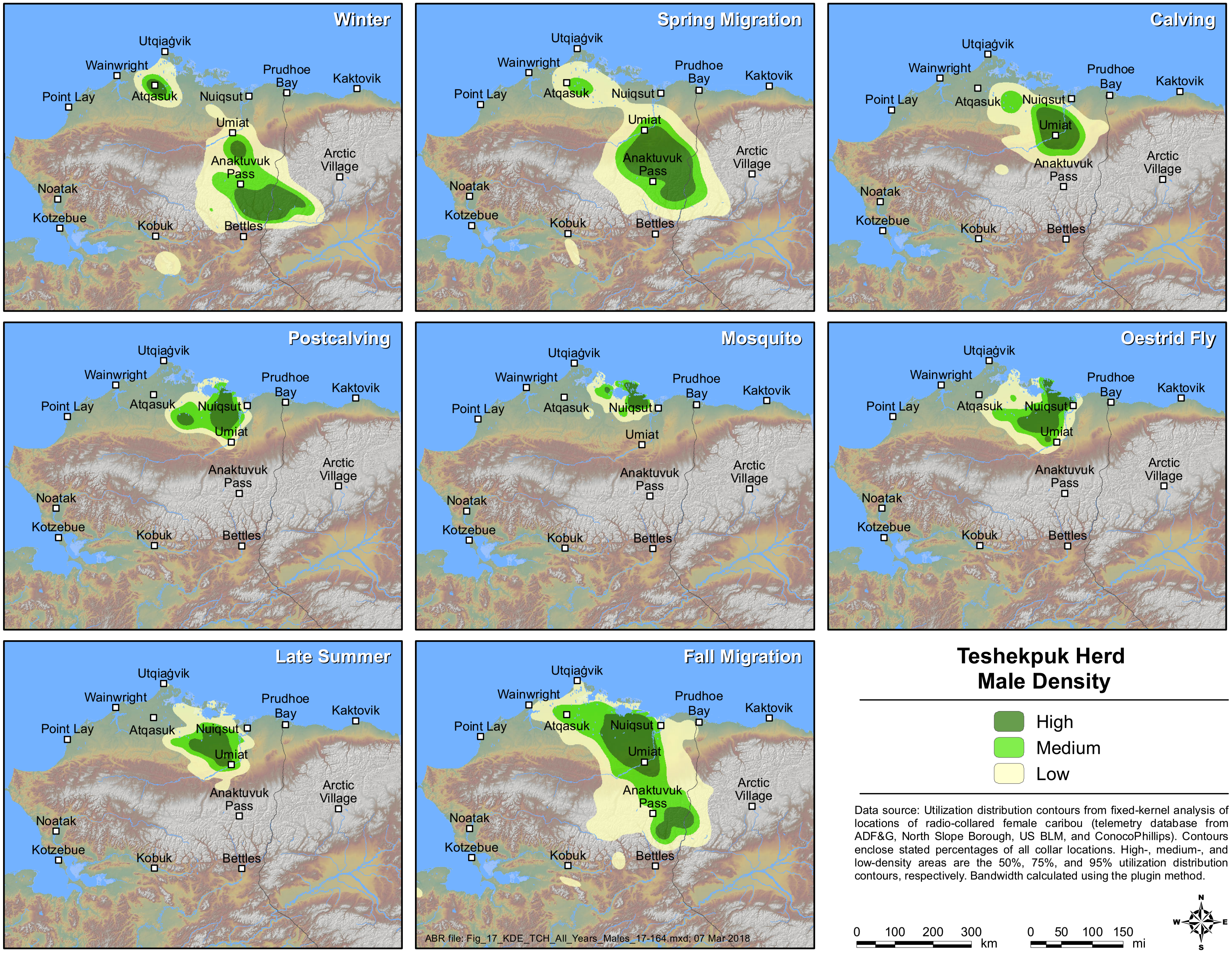
ABR file: Fig_15_KDE_CAH_All_Years_Females_17-164.mxd; 07 Mar 2018

Figure 15. Seasonal distribution of CAH females based on fixed-kernel density estimation of telemetry locations, 2001–2017.



Data source: Utilization distribution contours from fixed-kernel analysis of locations of radio-collared female caribou (telemetry database from ADF&G, North Slope Borough, US BLM, and ConocoPhillips). Contours enclose stated percentages of all collar locations. High-, medium-, and low-density areas are the 50%, 75%, and 95% utilization distribution contours, respectively. Bandwidth calculated using the plugin method.

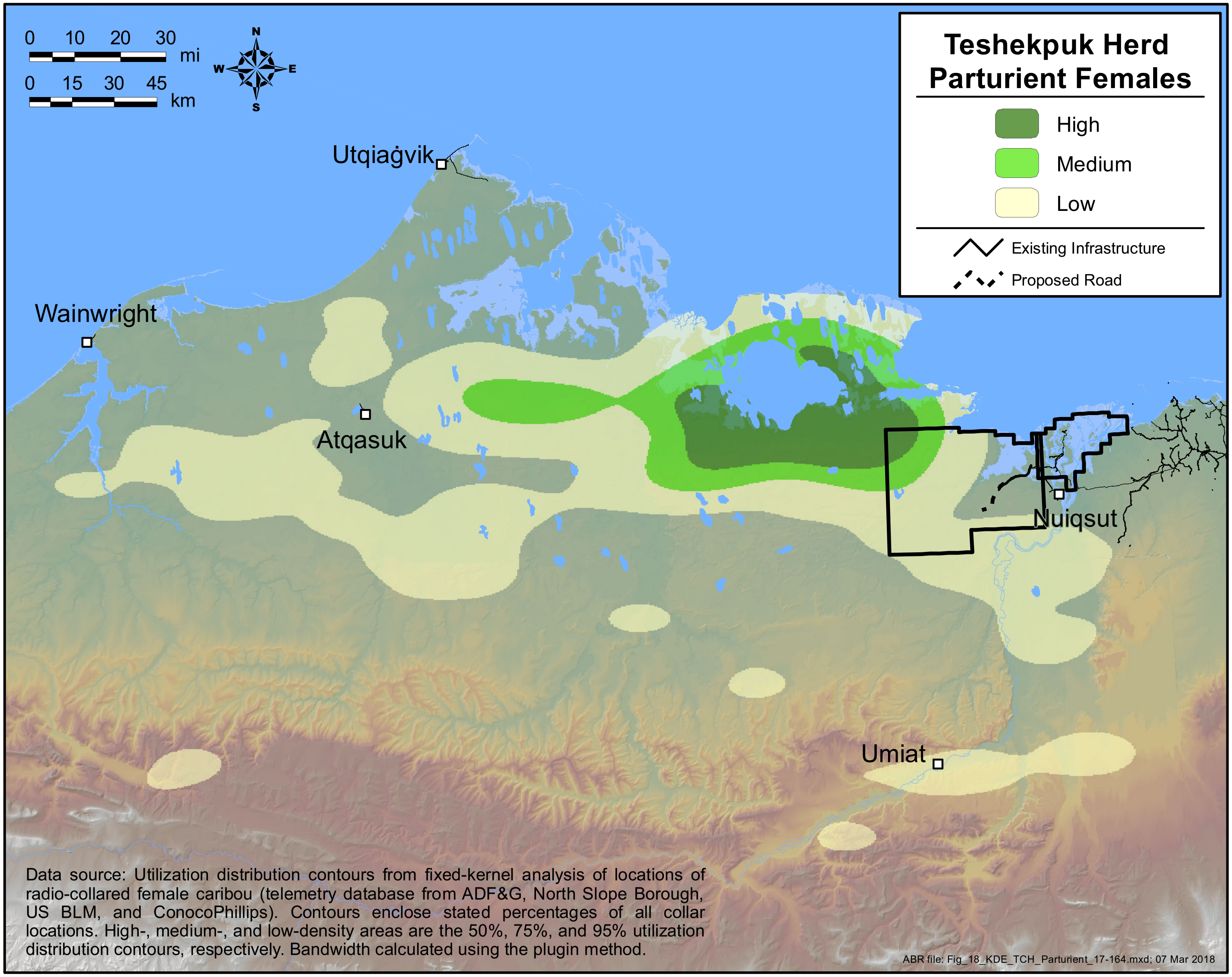
Figure 16. Seasonal distribution of TH females based on fixed-kernel density estimation of telemetry locations, 1990–2017.



Data source: Utilization distribution contours from fixed-kernel analysis of locations of radio-collared female caribou (telemetry database from ADF&G, North Slope Borough, US BLM, and ConocoPhillips). Contours enclose stated percentages of all collar locations. High-, medium-, and low-density areas are the 50%, 75%, and 95% utilization distribution contours, respectively. Bandwidth calculated using the plugin method.

ABR file: Fig_17_KDE_TCH_All_Years_Males_17-164.mxd; 07 Mar 2018

Figure 17. Seasonal distribution of TH males based on fixed-kernel density estimation of telemetry locations, 1997–2017.



Data source: Utilization distribution contours from fixed-kernel analysis of locations of radio-collared female caribou (telemetry database from ADF&G, North Slope Borough, US BLM, and ConocoPhillips). Contours enclose stated percentages of all collar locations. High-, medium-, and low-density areas are the 50%, 75%, and 95% utilization distribution contours, respectively. Bandwidth calculated using the plugin method.

Figure 18. Distribution of parturient females of the Teshekpuk Herd during calving based on fixed-kernel density estimation of telemetry locations, 1990–2017.

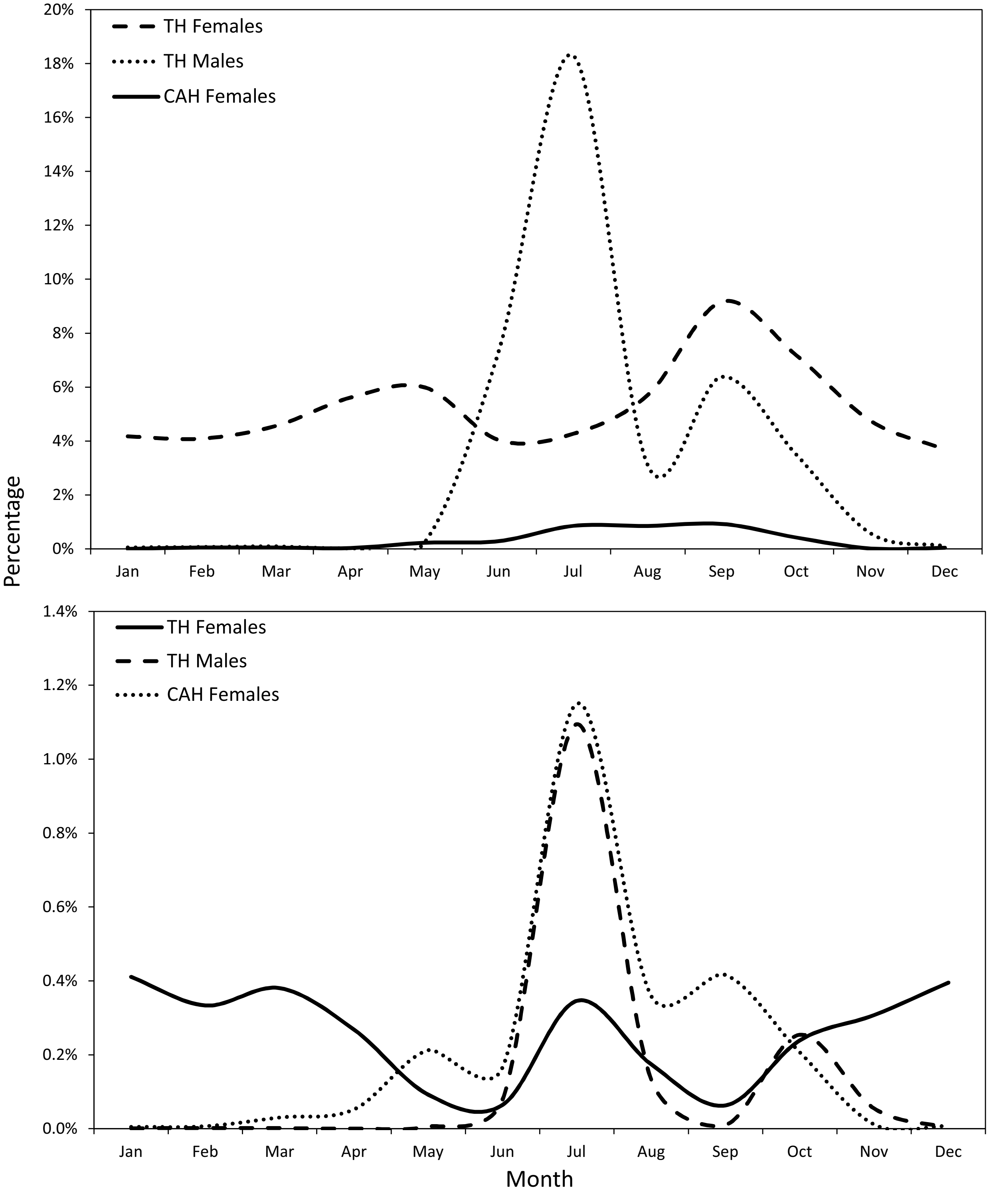


Figure 19. Percentage of CAH and TH caribou within the NPRA survey area (top panel) and Colville River Delta survey area (bottom panel), based on fixed-kernel density estimation, 1990–2017.

Table 3. Proportion of female TH caribou crossing or within 1 km of the GMT-1 and GMT-2 access roads, by season and year.

Season	Year(s)	Collars[a]	Crossed GMT-1	1 km of GMT-1	Crossed GMT-2	1 km of GMT-2	Crossed Either	1 km of Either
Spring Migration	2004–08	28	0	0	0	0	0	0
	2009–13	91	0	0	0.01	0.01	0.01	0.01
	2014	16	0	0	0	0	0	0
	2015	20	0	0	0.05	0.05	0.05	0.05
	2016	23	0	0	0	0	0	0
	2017	41	0	0	0	0	0	0
	All Years	219	0	0	0.01	0.01	0.01	0.01
Calving	2004–08	28	0	0.04	0.04	0.04	0.04	0.07
	2009–13	66	0	0	0.05	0.05	0.05	0.05
	2014	15	0	0	0	0	0	0
	2015	18	0	0	0	0	0	0
	2016	22	0	0	0	0	0	0
	2017	29	0	0	0	0	0	0
	All Years	178	0	0.01	0.02	0.02	0.02	0.03
Postcalving	2004–08	28	0	0	0	0	0	0
	2009–13	69	0	0	0	0	0	0
	2014	14	0	0	0	0	0	0
	2015	12	0	0	0	0	0	0
	2016	12	0	0	0	0	0	0
	2017	18	0	0	0	0	0	0
	All Years	153	0	0	0	0	0	0
Mosquito	2004–08	0	–	–	–	–	–	–
	2009–13	55	0	0	0	0	0	0
	2014	15	0	0	0	0	0	0
	2015	9	0	0	0	0	0	0
	2016	18	0	0	0	0	0	0
	2017	28	0	0	0	0	0	0
	All Years	125	0	0	0	0	0	0
Oestrid Fly	2004–08	10	0	0	0	0	0	0
	2009–13	93	0.12	0.15	0.04	0.04	0.15	0.17
	2014	15	0	0	0	0	0	0
	2015	20	0	0	0	0	0	0
	2016	18	0	0	0	0	0	0
	2017	30	0	0	0	0	0	0
	All Years	186	0.06	0.08	0.02	0.02	0.08	0.09
Late Summer	2004–08	53	0.02	0.02	0.02	0.02	0.02	0.02
	2009–13	122	0	0	0	0	0	0
	2014	24	0	0	0	0	0	0
	2015	26	0	0	0	0	0	0
	2016	42	0	0	0	0	0	0
	2017	71	0	0	0	0	0	0
	All Years	338	0.00	0.00	0.00	0.00	0.00	0.00
Fall Migration	2004–08	60	0	0	0.10	0.10	0.10	0.10
	2009–13	114	0	0	0.01	0.01	0.01	0.01
	2014	26	0	0	0	0	0	0
	2015	26	0.04	0.04	0.27	0.35	0.31	0.35
	2016	49	0	0	0	0	0	0
	2017	66	0.02	0.02	0	0.02	0.02	0.02
	All Years	341	0.01	0.01	0.04	0.05	0.05	0.05
Winter	2004–08	56	0.04	0.04	0.02	0.02	0.04	0.04
	2009–13	102	0	0	0	0	0	0
	2014	22	0	0	0	0.05	0	0.05
	2015	23	0.04	0.04	0.04	0.04	0.04	0.04
	2016	46	0	0	0	0	0	0
	2017	0	–	–	–	–	–	–
	All Years	249	0.01	0.01	0.01	0.01	0.01	0.02

[a] Locations within 30 days of collaring were removed and then animals with fewer than 50 locations or active less than half the season were removed from the analysis.

et al. 2015, Prichard et al. 2017). In 2017, only two caribou crossed the GMT-1 and GMT-2 road corridors a total of three times. Caribou C1330, a GPS-collared female that was captured with CAH caribou but later displayed movements typical of TH caribou, crossed the proposed GMT-2 road northward on 11 June and later crossed southward on 15 October. Caribou 1721, a GPS-collared TH female, crossed the GMT-1 road near the pad on 24 October, heading south.

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 Canada 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, both of 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 close to average for most of the region in 2017. Snow melt was minimal through 24 May but was well underway along some floodplains in the study area by 27–28 May (Figure 20). Extensive areas were snow-free on 1 June, except along the coast and in the uplands south and southwest of the Kuparuk oilfield. Snow melt then appeared to slow through a period of extensive cloud cover. Extensive snow remained in uplands and along the coast on 11 June, but had mostly melted by 15 June.

The median dates of snow melt for each pixel computed using 2000–2017 data (where the date of melt was known 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 typically melting several days later near the coast. The timing of snow melt in 2017 was average near stream channels and was 4–7 days earlier than average in the remainder of the survey area (Figure 22). The timing of snow melt between the Colville River delta and the Kuparuk oilfield was close to average, whereas it was 4–7 days later than average southwest of the Kuparuk oilfield and in the Kuparuk and Prudhoe Bay oilfields.

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

Compared with median NDVI since 2000 (Figure 22), the estimated vegetative biomass during calving (NDVI_Calving) in 2017 was average to above average through much of the study area, but was well below average for the upland area southwest of the Kuparuk oilfield (Figures 23–24; Appendix D). Those values are consistent with the persistent snow cover observed in that area, combined with extensive cloud cover in the latter portion of the 1–10 June window.

NDVI_Rate in 2017 was low in areas with high NDVI_Calving (Figure 24) and high in areas with low NDVI_Calving. NDVI_621 and NDVI_Peak in 2017 both showed the typical pattern of higher values inland and lower values along small rivers and creeks with exposed barren ground (Figure 24). Based on comparisons with

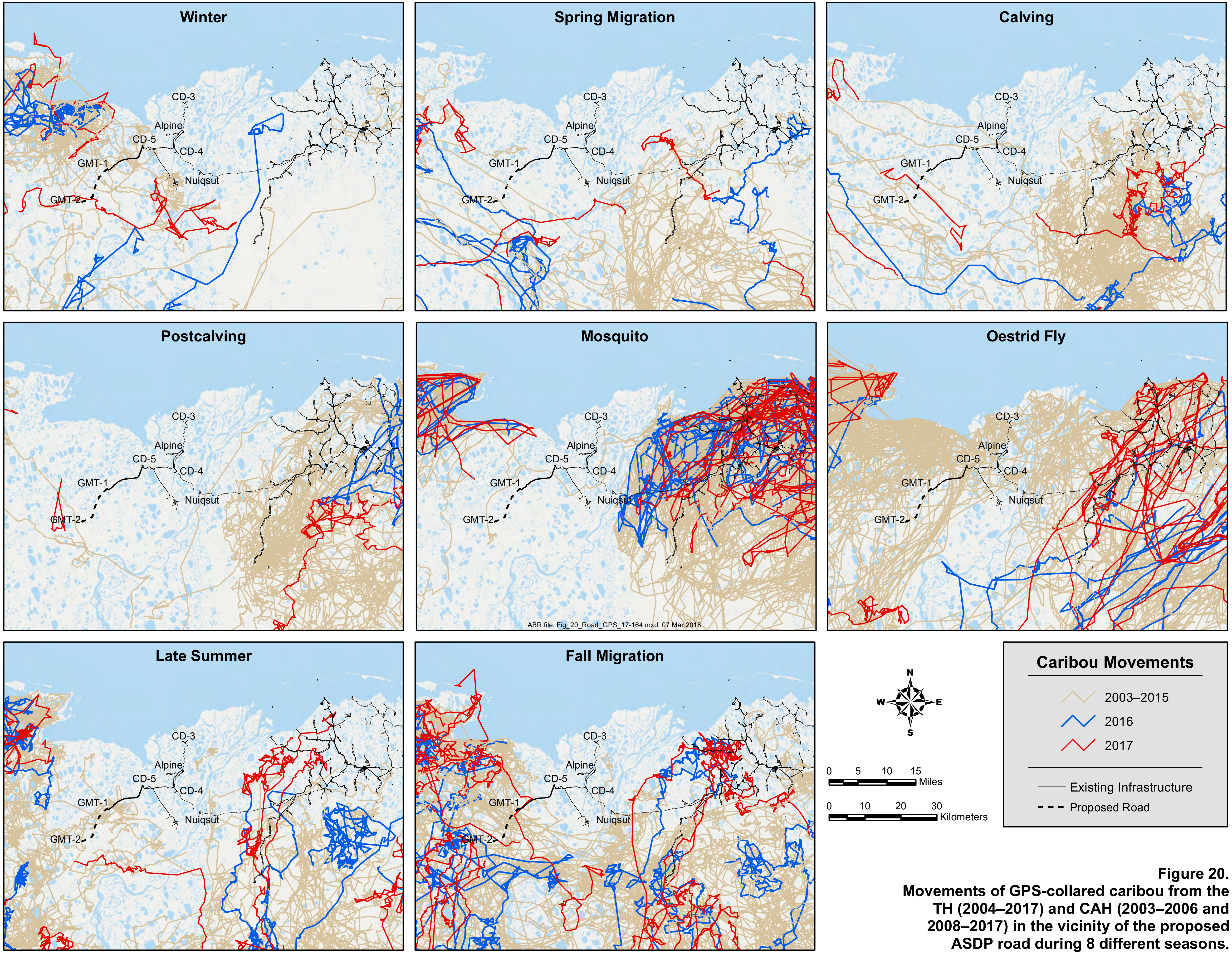


Figure 20.
Movements of GPS-collared caribou from the TH (2004–2017) and CAH (2003–2006 and 2008–2017) in the vicinity of the proposed ASDP road during 8 different seasons.

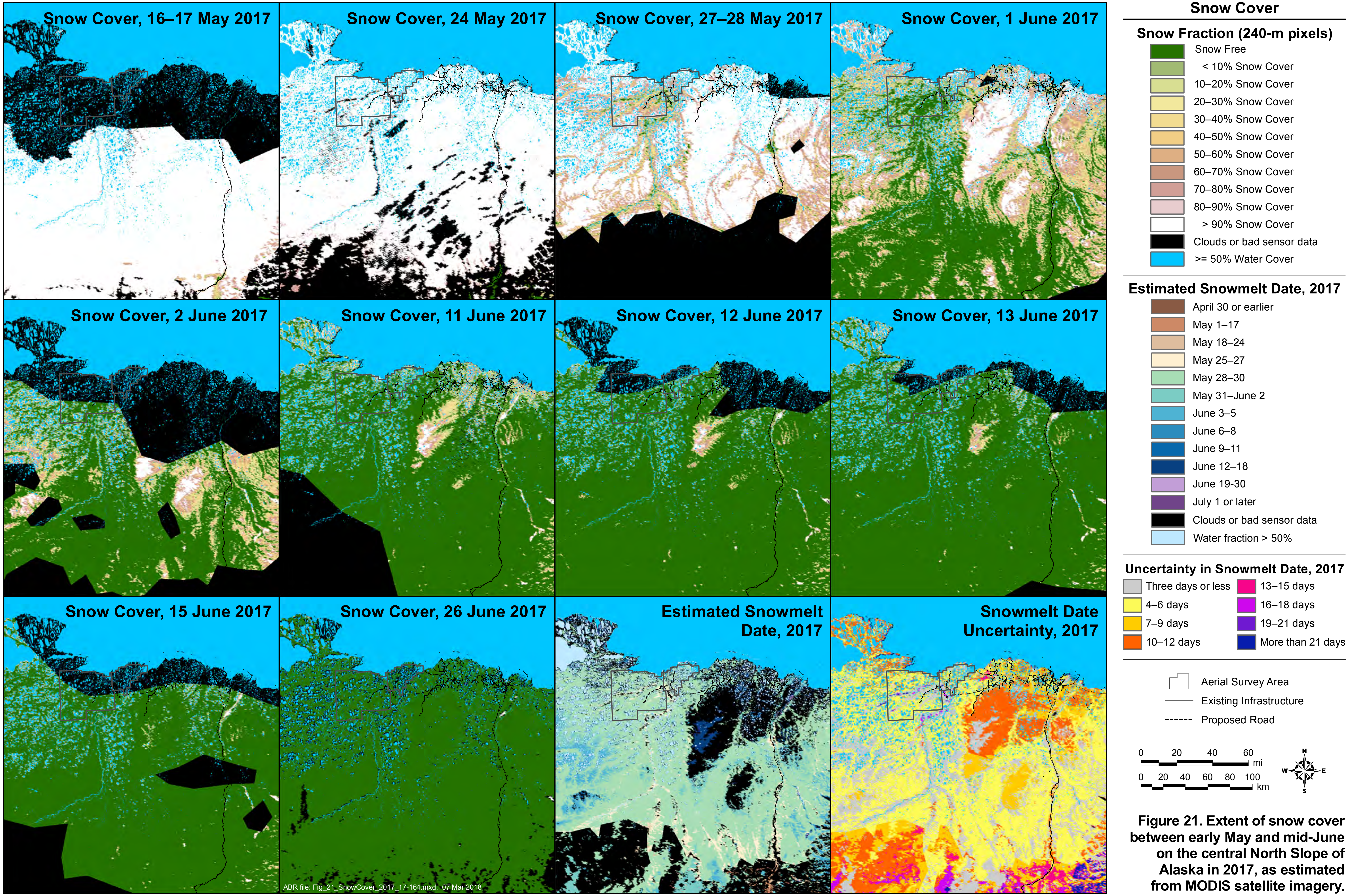
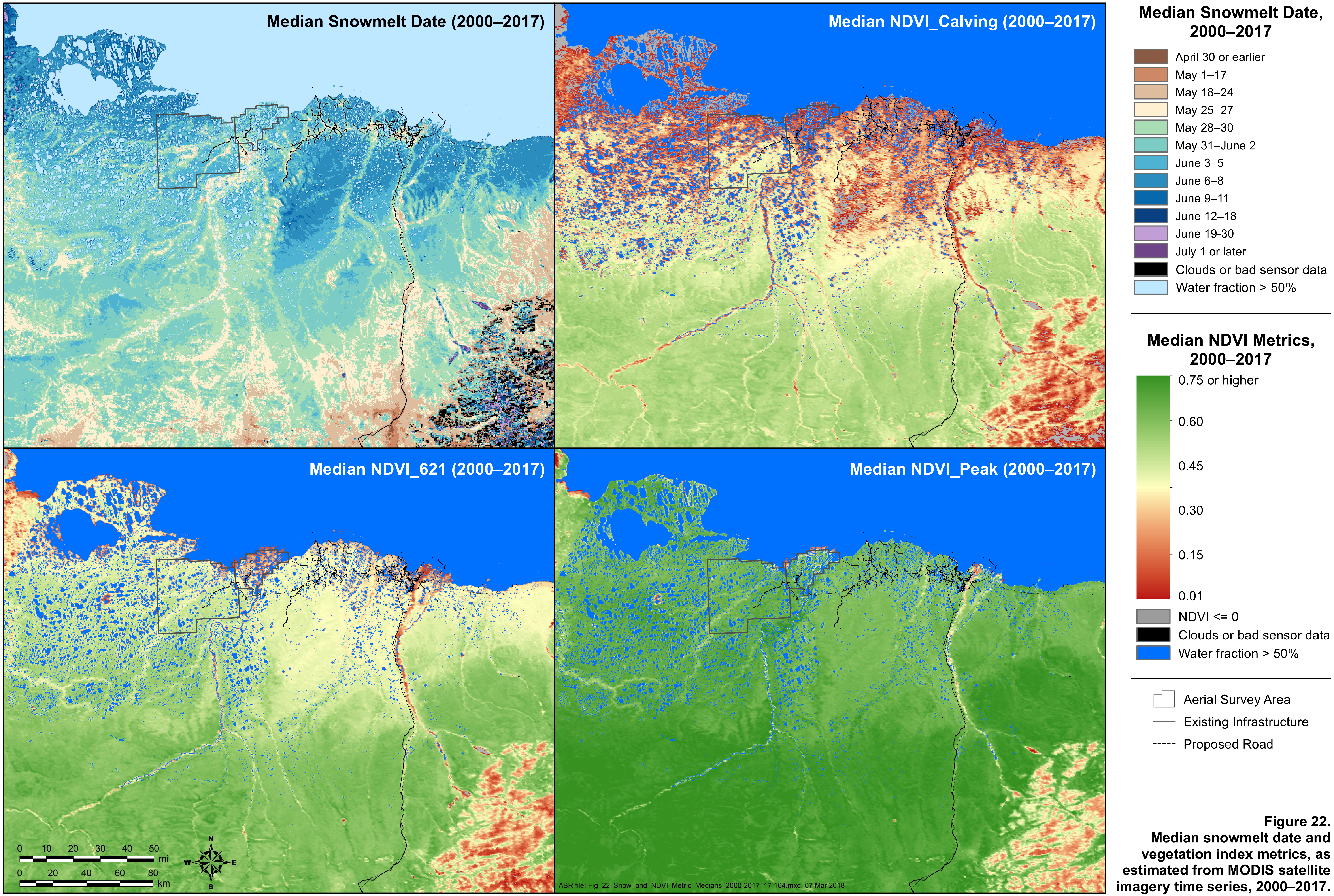
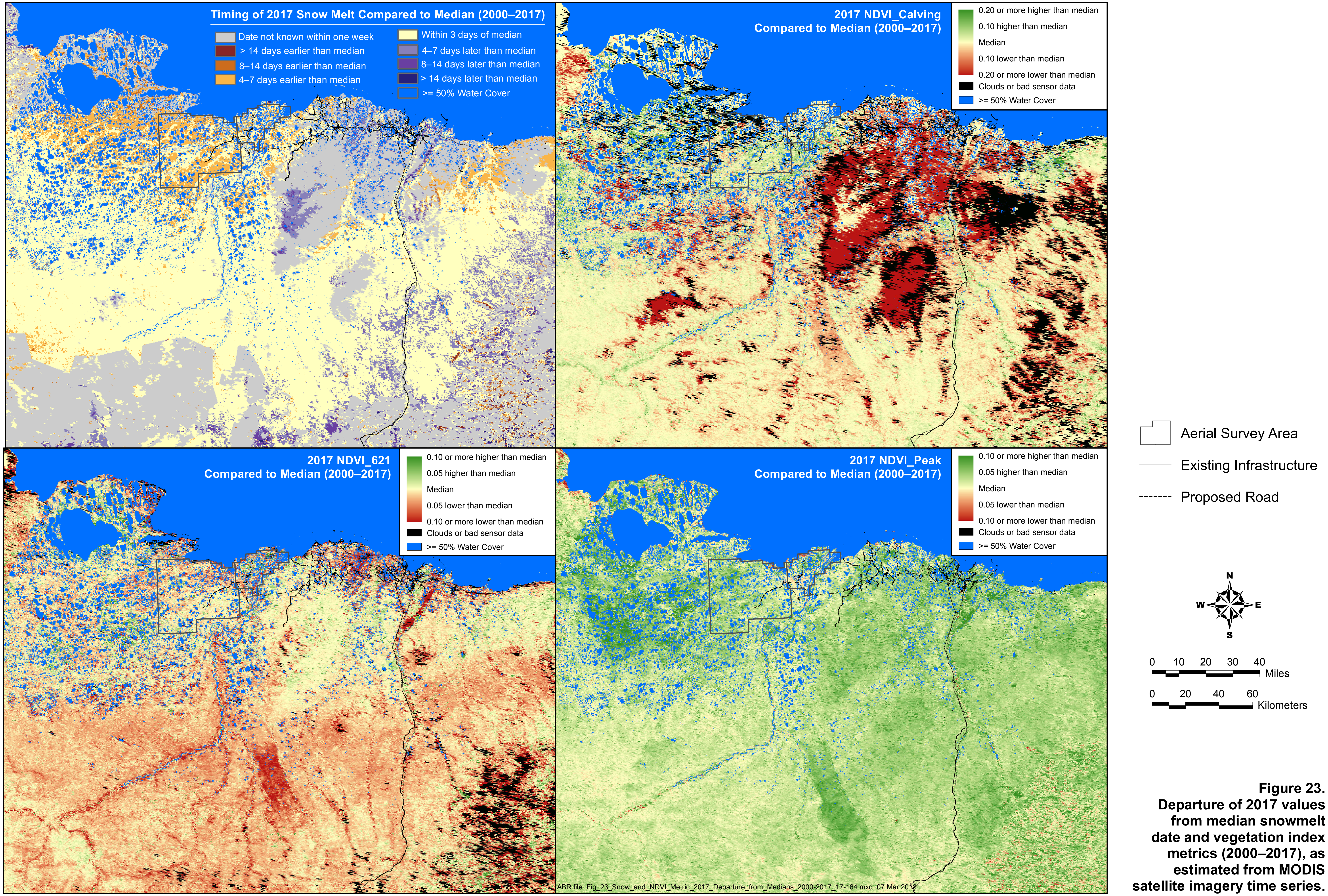


Figure 21. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2017, as estimated from MODIS satellite imagery.



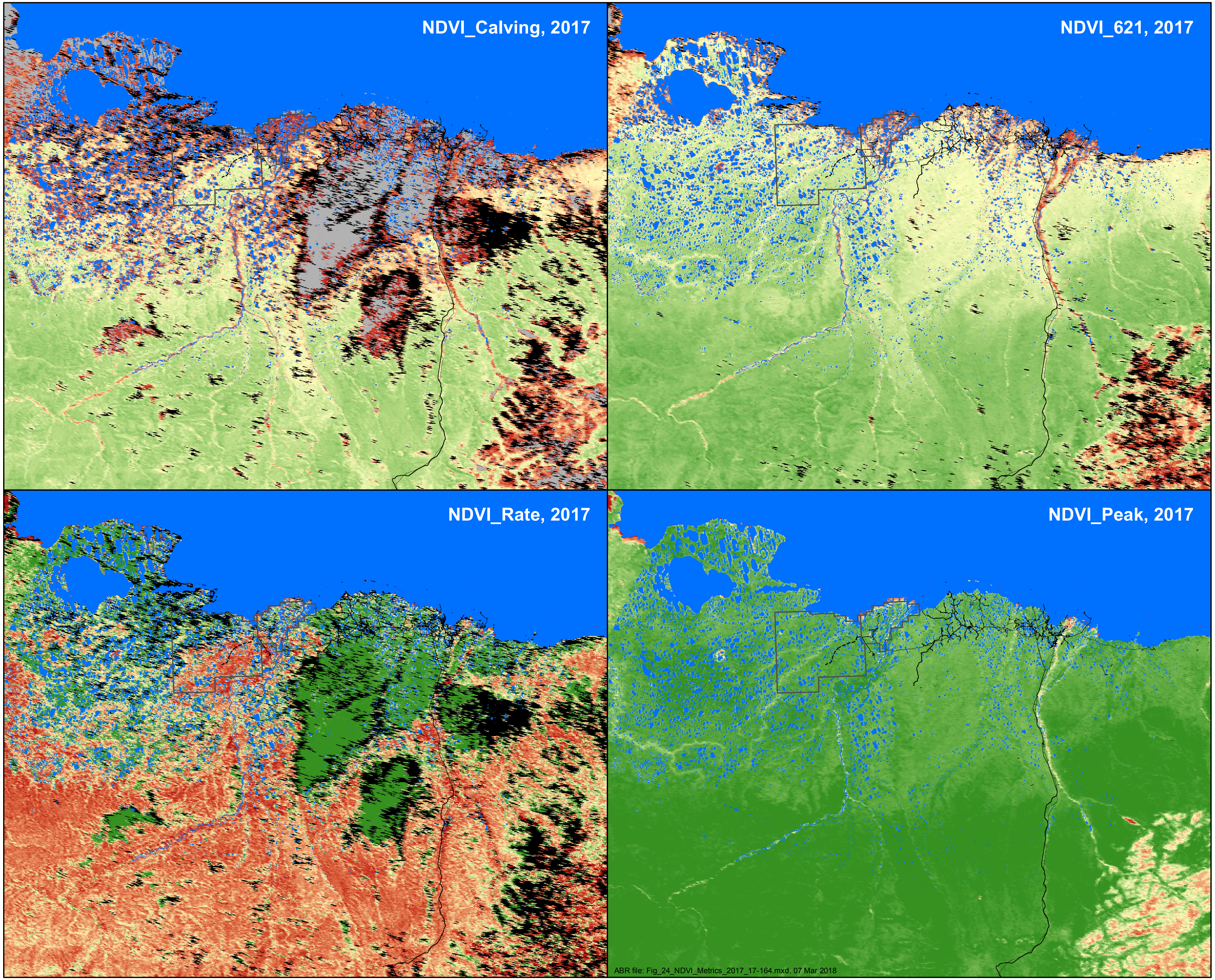
ABR file: Fig_22_Snow_and_NDVI_Metric_Medians_2000-2017_17-164.mxd, 07 Mar 2018

Figure 22.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2017.



ABR file: Fig_23_Snow_and_NDVI_Metric_2017_Departure_from_Medians_2000-2017_17-164.mxd, 07 Mar 2018

Figure 23.
Departure of 2017 values from median snowmelt date and vegetation index metrics (2000–2017), as estimated from MODIS satellite imagery time series.



ABR file: Fig_24_NDVI_Metrics_2017_17-164.mxd, 07 Mar 2018

Figure 24.
Metrics of relative vegetative biomass during the 2017 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

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median values since 2000 (Figure 23; Appendix E), NDVI_621 was low to average across the coastal plain in 2017. NDVI_Peak values in 2017 were slightly higher than average in both survey areas and across most of the coastal plain (Figure 23, Appendix F).

RESOURCE SELECTION ANALYSIS

The RSF analysis of seasonal caribou density is restricted to the NPRA survey area. Seasonal sample sizes for the location data used in the RSF analysis ranged from 166 to 2,524 for the years 2002–2017 (Table 4). Most of the top-ranking seasonal models for the survey area contained habitat type, a west-to-east distributional gradient, distance to coast, and landscape ruggedness (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 models for the combined datasets for NPRA had reasonably good model fits (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 25, Table 8). These results are consistent with the location of the survey area near the eastern edge of the TH annual range.

The RSF model output produced several types of results. 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 estimate 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 to produce seasonal RSF maps (Figure 25). 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 (Tables 5 and 7), with the snowmelt date being considered a surrogate for snow depth. Areas closer to the coast and farther west and areas with higher values of NDVI_Peak and landscape ruggedness were selected by caribou (Figure 25). Although snowmelt date was included in the best model, the model-weighted variable was not significant. Four habitat types (*Carex aquatilis*, Flooded Tundra, Riverine, and Wet Tundra) were avoided by caribou, relative to the reference category (Sedge/Grass Meadow; Table 8).

All of the variables except NDVI and snowmelt date were included in the best model for spring migration (Tables 5 and 7). The model results were driven primarily by a west-to-east density gradient, with caribou selecting areas farther west reflecting the western distribution of high-density calving by the TH (Figure 25). Areas with higher landscape ruggedness were selected, while Riverine habitats were avoided by caribou (Table 8). This selection for higher landscape ruggedness and avoidance of riverine areas may reflect selection for areas having less snow and spring flooding, or higher proportions of preferred forage species.

During the calving season, all variables were included in the best model (Tables 5 and 7). Caribou selected areas located farther west with higher NDVI_Calving and later snow melt, primarily in the northwest portion of the survey area (Table 8, Figure 25), reflecting the western distribution of high-density calving by the TH.

During the postcalving season, all variables except habitat types were included in the best model (Tables 5 and 7). Caribou selected areas farther west, closer to the coast, and with higher landscape ruggedness (Table 8, Figure 25). Selection of areas in the northwestern portion of the survey area likely reflects caribou movement toward the primary area of mosquito-relief habitat north of Teshekpuk Lake. Selection for higher landscape ruggedness may reflect higher densities of preferred forage species (Nellemann and Thomsen 1994, Nellemann and Cameron 1996).

During the mosquito season, west-to-east gradient, distance to coast, and landscape

Table 4. Number of aerial surveys, radio collars, and locations for each sample type used in RSF analysis for the NPRA survey area, 2002–2017.

Season	Aerial Surveys		Telemetry Data		Total Locations
	Surveys	Locations	Collars	Locations	
Winter	9	698	25	719	1,417
Spring Migration	10	409	25	112	521
Calving	16	1,146	23	58	1,204
Postcalving	15	1,253	12	24	1,277
Mosquito	5	88	45	78	166
Oestrid Fly	10	277	61	182	459
Late Summer	22	1,081	44	325	1,406
Fall Migration	19	1,699	72	825	2,524
Total	106	6,651	307	2,323	8,974

ruggedness were included in the best model, but habitats again were not significant (Tables 5 and 7). Caribou primarily selected areas farther west, closer to the coast, and with higher ruggedness (Table 8, Figure 25).

During the oestrid fly season, all variables except NDVI were included in the best model (Tables 5 and 7). Caribou selected areas farther west, closer to the coast, and with greater ruggedness (Table 8, Figure 25). Relative to Sedge/Grass Meadow habitat, caribou also selected for all habitats except Dwarf Shrub.

During late summer, habitat type, west-to-east gradient, distance to coast, and landscape ruggedness were included in the best model (Tables 5 and 7). Caribou selected areas farther west, closer to the coast, with higher ruggedness, and in Dwarf Shrub, Moss/Lichen, and Riverine habitat types (Table 8, Figure 25).

During fall migration, habitat type, NDVI, west-to-east, and distance to coast were included in the best RSF model (Tables 5 and 7). Caribou selected areas farther west and closer to the coast, and avoided *Carex aquatilis*, Flooded Tundra, and Wet Tundra habitats (Table 8, Figure 25).

DISCUSSION

WEATHER, SNOW, AND INSECT CONDITIONS

Weather conditions exert strong effects on caribou populations throughout the year in Arctic Alaska. 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*)

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, 2002–2017 (combined aerial survey and telemetry data).

Season	RSF Model	AICc	Akaike Weight
Winter	Habitat + NDVI + EtoW + DistCoast + logRuggedness + Snow	14,993.16	0.998438
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	15,006.74	0.001124
	Habitat + NDVI + EtoW + DistCoast + Snow	15,008.67	0.000427
Spring Migration	Habitat + EtoW + DistCoast + logRuggedness	5,551.75	0.414799
	Habitat + EtoW + DistCoast + logRuggedness + Snow	5,553.67	0.159194
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	5,553.73	0.154255
Calving	Habitat + NDVI + EtoW + DistCoast + logRuggedness + Snow	12,937.22	0.518650
	Habitat + NDVI + EtoW + logRuggedness + Snow	12,939.75	0.146359
	Habitat + NDVI + EtoW + DistCoast + Snow	12,940.36	0.107774
Postcalving	NDVI + EtoW + DistCoast + logRuggedness	13,255.85	0.349082
	EtoW + DistCoast + logRuggedness	13,256.12	0.304863
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	13,256.75	0.222911
Mosquito	EtoW + DistCoast + logRuggedness	1,574.11	0.492270
	NDVI + EtoW + DistCoast + logRuggedness	1,574.93	0.326456
	Habitat + EtoW + DistCoast + logRuggedness	1,577.74	0.080343
Oestrid Fly	Habitat + EtoW + DistCoast + logRuggedness	4,773.05	0.719893
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	4,774.94	0.279495
	Habitat + EtoW + logRuggedness	4,789.15	0.000230
Late Summer	Habitat + EtoW + DistCoast + logRuggedness	15,131.09	0.486399
	Habitat + EtoW + logRuggedness	15,132.67	0.221078
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	15,132.81	0.206253
Fall Migration	Habitat + NDVI + EtoW + DistCoast	27,028.47	0.525327
	Habitat + NDVI + EtoW + DistCoast + logRuggedness	27,030.16	0.226174
	Habitat + EtoW + DistCoast	27,030.66	0.175949

Table 6. Mean Pearson's rank correlation coefficient (r) of seasonal RSF model fit using k-fold cross-validation for the NPRA survey area, 2002–2017 (combined aerial survey and telemetry data).

Season	Correlation Coefficient
Winter	0.93
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

(White et al. 1975, Fancy 1983, Dau 1986, Russell et al. 1993, Mörschel 1999, Yokel et al. 2009).

Although daily air temperatures were near average in May 2017, cool temperatures in early June (Appendix B) and strong winds in mid-June resulted in timing of mosquito emergence that was similar to or slightly later than observed in other recent years. Temperatures in late June, July, and early August were above average (Appendix B), likely resulting in high levels of mosquito harassment. Oestrid flies typically emerge by mid-July and, based on the summer weather conditions in 2017, severe oestrid fly harassment likely occurred on multiple days in late July and early August (Prichard et al. 2018). The absence of mosquitoes during much of June would have been expected to improve caribou body condition after calving, but the warm temperatures during July likely resulted in increased movement rates, decreased foraging, and poorer body condition. Cool conditions in late summer and delayed onset of seasonal snow cover (typical of recent years on the North Slope; Cox et al. 2017) may have allowed improvement of caribou body condition before winter.

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 area west of the Colville River to some extent during all seasons of the year. TH 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 and postcalving seasons; CAH use of the Colville River Delta survey area is more variable during the mosquito and oestrid fly seasons and is low during the remainder of the year. CAH caribou use the NPRA survey area very little, although several notable incursions have been recorded sporadically over the years, as described below.

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 2015a). 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 from 200 to 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 6). In 2017, however, caribou density was low during the oestrid fly season survey on 31 July (Table 2), reflecting the high variability during that season. Density

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, 2002–2017 (combined aerial survey and telemetry data). Variables with a probability ≥0.5 were used in RSF maps (Figure 24).

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	0.89	0.75	1.00	1.00	1.00	0.70	1.00
NDVI [a]	1.00	0.30	1.00	0.57	0.41	0.28	0.29	0.75
Snowmelt Date	1.00	0.29	0.98	–	–	–	–	–
Ruggedness	1.00	1.00	0.82	1.00	0.97	1.00	1.00	0.30
Habitat	1.00	0.89	0.81	0.34	0.16	1.00	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.

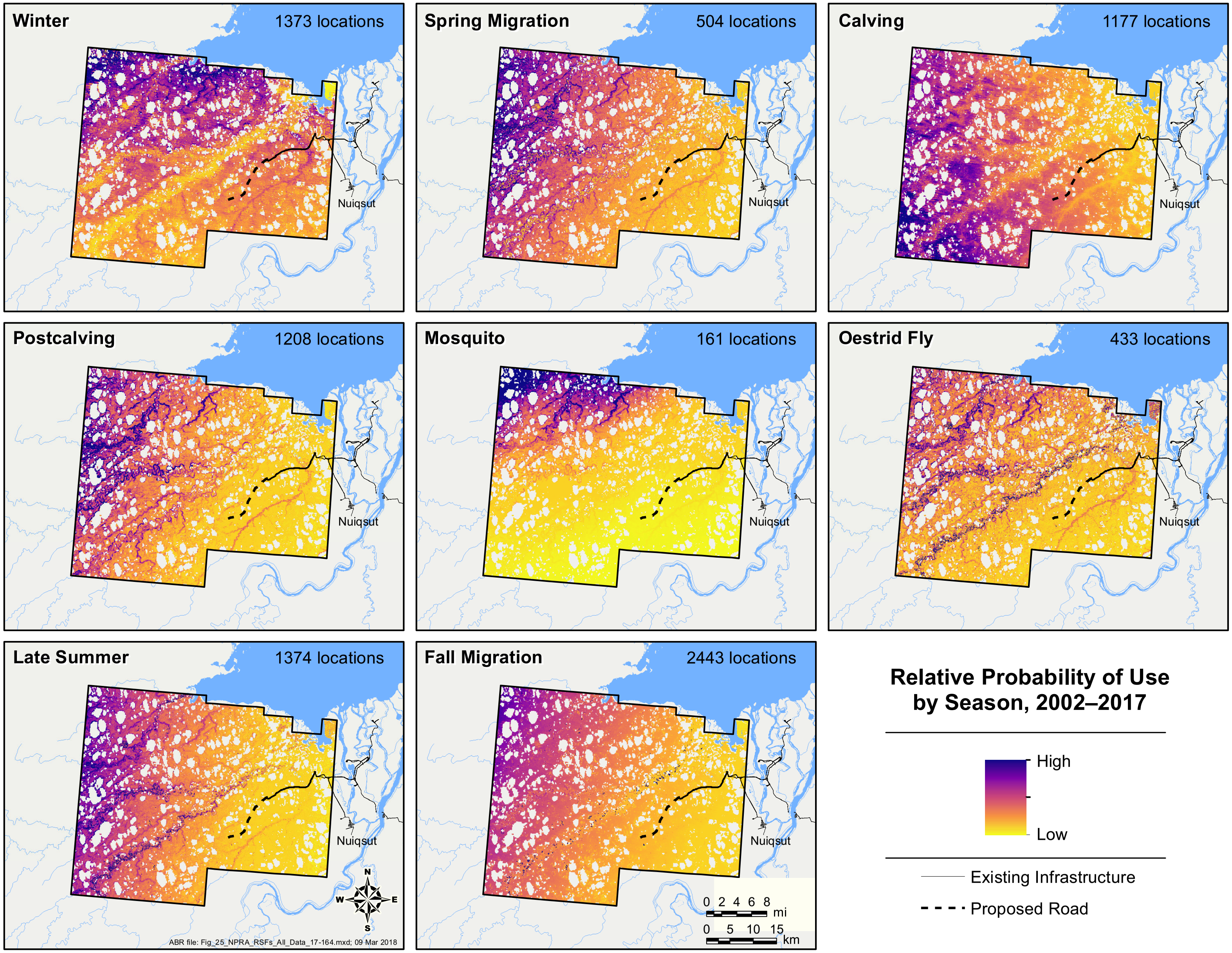

Figure 25. Predicted relative probability of use of the NPRA survey area by caribou during 8 different seasons, 2002–2017, based on RSF analysis.

Table 8. Model-weighted parameter estimates for RSF models for the NPRA survey area during eight seasons, 2002–2017 (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	**–0.26**	**–0.38**	**–0.40**	**–0.40**	**–1.08**	**–0.28**	**–0.37**	**–0.39**
Distance to Coast	**–0.38**	–0.12	0.06	**–0.13**	**–1.26**	**–0.23**	-0.04	**–0.12**
NDVI [a]	**0.34**	0.00	**0.20**	0.03	0.05	0.00	0.00	0.05
Snowmelt Date	0.12	0.00	**0.11**	–	–	–	–	–
Ruggedness	**0.12**	**0.18**	-0.06	**0.26**	**0.22**	**0.21**	**0.10**	0.00
Carex aquatilis [b]	**–0.55**	–0.21	–0.35	–0.09	0.11	**0.70**	–0.08	**–0.48**
Dwarf Shrub [b]	-0.27	–0.36	–0.02	0.00	0.17	0.50	**0.56**	0.27
Flooded Tundra [b]	**–0.80**	-0.36	–0.18	0.00	0.08	**0.65**	–0.01	**–0.23**
Moss/Lichen [b]	–1.02	–0.17	–0.30	0.11	–2.05	**1.74**	**0.83**	0.16
Riverine [b]	**–0.79**	**–1.15**	-0.18	0.12	0.04	**1.19**	**0.65**	–0.12
Tussock Tundra [b]	–0.06	–0.19	0.02	0.05	0.02	**0.36**	0.09	0.05
Wet Tundra [b]	**–0.60**	–0.18	–0.21	0.02	-0.07	**0.75**	0.02	**-0.28**

[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."

increased slightly on the late summer survey on 28 August and peaked on the mid-September survey before declining again on the mid-October survey (Table 2). Poor flying conditions caused by persistent inclement weather have limited our ability to conduct surveys consistently during fall migration. Only eight surveys could be conducted in September and October during the years 2009–2017 (though both scheduled surveys during both 2016 and 2017 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 the postcalving season (1.5 caribou/km² in late June 2001) (Burgess et al. 2002, Johnson et al. 2004, Lawhead et al. 2010).

Research to date shows that caribou are most likely to occur in the Colville River Delta survey area during the 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 River delta, often moving far east during late June and July. After oestrid fly harassment begins in 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).

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, 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 2001–2017 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 occasionally 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 CD-5 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 GMT-1 road corridor or the proposed pipeline/road-corridor alignment extending from GMT-1 to the proposed GMT-2 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 CD-5 to GMT-2 road corridor in 2015, and two TH caribou crossed in 2016, and two crossed in 2017.

The harvest of caribou by Nuiqsut hunters tends to peak during the months of July and August, with lower percentages usually 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, Braem et al. 2011, SRB&A 2017). Historically, the greatest proportion of the Nuiqsut caribou harvest has been taken by boat-based hunters during the open-water period (SRB&A 2017). The timing of hunting activity in relation to seasonal use of the study area by caribou suggests that caribou harvested on the Colville River delta by hunters in July and August could be from either herd, depending on the year. In contrast, caribou harvested upstream on the Colville River from the delta during the open-water period and west and south of Nuiqsut during October and the winter months are likely to be TH animals. Using harvest data (Braem et al. 2011) and telemetry data from 2003–2007, Parrett (2013) estimated that TH caribou comprised 86% of the total annual harvest by Nuiqsut hunters during those years. Beginning in 2004, the distribution of the CAH during the insect season shifted farther eastward than had been observed in earlier years, so fewer caribou from that herd used the Colville delta in summer 2004–2007. 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, similar to the years preceding 2004. The construction of the Nuiqsut Spur Road and CD-5 access road resulted in increased use of those roads for subsistence harvest of caribou (SRB&A 2017) and the new GMT-1 road and planned GMT-2 road are likely to increase subsistence hunter access to seasonal ranges used consistently year-round by TH caribou.

RESOURCE SELECTION

The two data sets (aerial transect surveys and radio telemetry) that we combined for the RSF analysis provided complementary information for investigating broad patterns of resource selection. Telemetry data have higher spatial accuracy than do aerial survey data and are collected continuously throughout the year, 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 in the analytical data set to one every per 48 h. 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 and surveys are only conducted periodically throughout the year. 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 potential 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 exhibited during key life cycle stages and reflected in the seasonal distribution patterns (Figures 16–17).

These geographic patterns in TH distribution are most pronounced during calving and the mosquito season. 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 (Figure 18; Person et al. 2007, Wilson et al. 2012, Parrett 2015a), 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 existed before construction of the GMT-1 and GMT-2 pipeline/road corridor from the Colville River 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 obvious 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 are 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 the oestrid fly season and late summer and avoidance of Riverine habitat during winter and spring (Table 8). The riparian habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 3) that provide good fly-relief habitat near foraging areas.

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 TH telemetry data and the same habitat classification as we did (BLM and Ducks Unlimited 2002) to investigate summer habitat selection at two different spatial scales, concluding that TH caribou consistently selected Sedge/Grass Meadow and avoided flooded vegetation.

During calving, caribou in the NPRA survey area tended to use areas of higher vegetative biomass (estimated by NDVI_Calving) and patchy snow cover and lower proportions of wet habitats, although differences were not statistically significant. Calving habitat selection may vary annually, depending on the timing of snow melt and plant phenology.

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. Vegetation sampling in the NPRA survey area 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 tussock cottongrass (*Eriophorum vaginatum*), forbs, and lichens, however. Caribou appear to use wetter habitats (*C. 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 tussock cottongrass (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-2 portion of the NPRA survey area. 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. Although both the TH and CAH recently underwent sharp declines in population due to decreased survival of both adults and calves, particularly after the prolonged winter of 2012–2013, both herds increased in size in the latest counts from July 2017. In recent years, the TH calving distribution has expanded both to the west and the southeast, whereas the winter distribution has varied widely among years (Parrett 2013). The CAH 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).

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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., *Astragalus* 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., *Astragalus* 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, 1983–2017.

	Snow Depth (cm)			Cumulative Thawing Degree-days (ºC)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	66.2	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	20	10	0	0	5.0	100.8	112.2	124.7	109.4
1987	15	8	3	0	0.6	6.7	61.4	112.2	127.8	93.1
1988	10	5	5	0	0	16.7	78.1	108.3	143.1	137.5
1989	33	–	10[a]	0	5.6	20.6	109.4	214.7	168.1	215.8
1990	8	3	0	0	16.1	39.7	132.2	145.0	150.0	82.5
1991	23	8	3	0	7.8	14.4	127.6	73.3	115.0	70.6
1992	13	8	0	0.3	20.3	55.0	85.3	113.9	166.1	104.2
1993	13	5	0	0	8.6	33.6	94.4	175.8	149.7	96.1
1994	20	18	8	0	4.4	49.2	51.7	149.7	175.8	222.2
1995	18	5	0	0	1.1	59.4	87.5	162.8	106.9	83.3
1996	23	5	0	8.1	41.7	86.1	121.1	138.9	168.1	95.8
1997	28	18	8	0	20.8	36.1	109.7	101.7	177.8	194.2
1998	25	8	0	3.6	45.8	74.2	135.0	158.9	184.4	174.4
1999	28	15	10	0	1.4	30.3	67.8	173.3	81.1	177.5
2000	30	23	13	0	0	36.7	169.7	113.3	127.5	118.6
2001	23	30	5	0	0.8	51.9	72.2	80.0	183.9	131.7
2002	30	trace	0	4.2	30.3	57.8	70.3	92.2	134.4	106.1
2003	28	13	trace	0	10.8	23.6	77.5	140.0	144.7	91.9
2004	36	10	5	0	8.9	26.4	185.6	148.1	151.4	153.3
2005	23	13	0	0	2.5	14.2	78.1	67.5	79.4	176.7
2006	23	5	0	0	23.3	93.3	153.1	82.2	186.1	109.7
2007	25	46	5	0	0	46.4	81.7	115.0	138.9	134.4
2008	20	18	0	0	32.8	71.7	138.9	172.2	132.5	86.1
2009	36	13	0	0	16.7	71.7	44.4	142.8	126.4	133.6
2010	41	43	13	0	1.4	53.3	51.1	126.7	168.9	149.2
2011[a]	25	18	0	0	27.8	12.5	101.2	122.4	171.6	143.2
2012[a]	48	53	2	0	1.7	26.8	137.3	140.2	195.2	143.5
2013	33	18	2	0	4.2	79.2	131.7	112.8	188.0	185.4

Appendix B. Continued.

	Snow Depth (cm)			Cumulative Thawing Degree-days (ºC)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
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	25	0	0	15.6	12.4	63.7	131.2	174.7	130.8	98.1
2017	36	14	0	0	12.1	5.2	121.3	173.4	174.5	150.5
Mean	**25.2**	**14.3**	**3.0**	**1.3**	**12.1**	**42.8**	**103.5**	**127.8**	**143.4**	**126.9**

[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.

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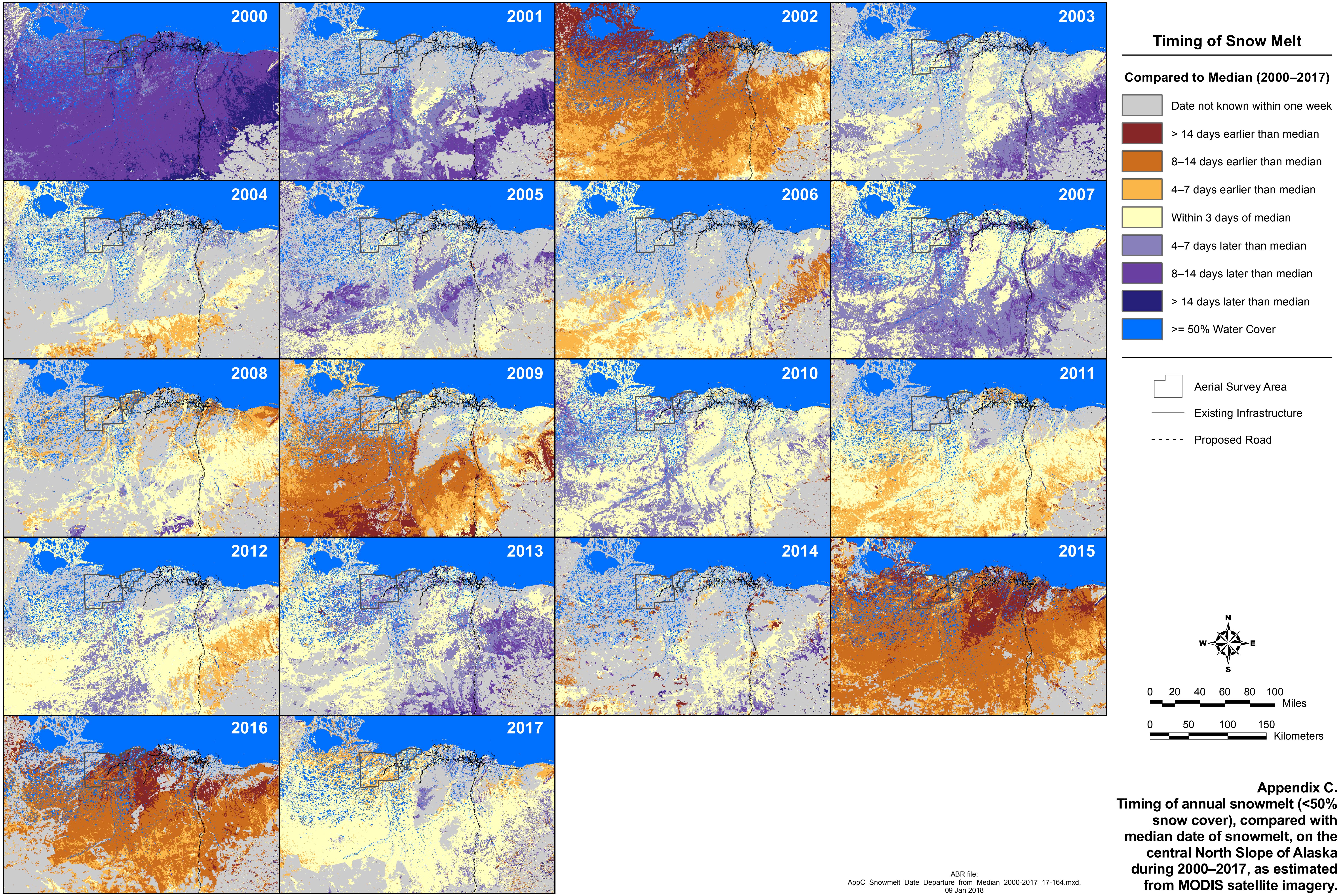
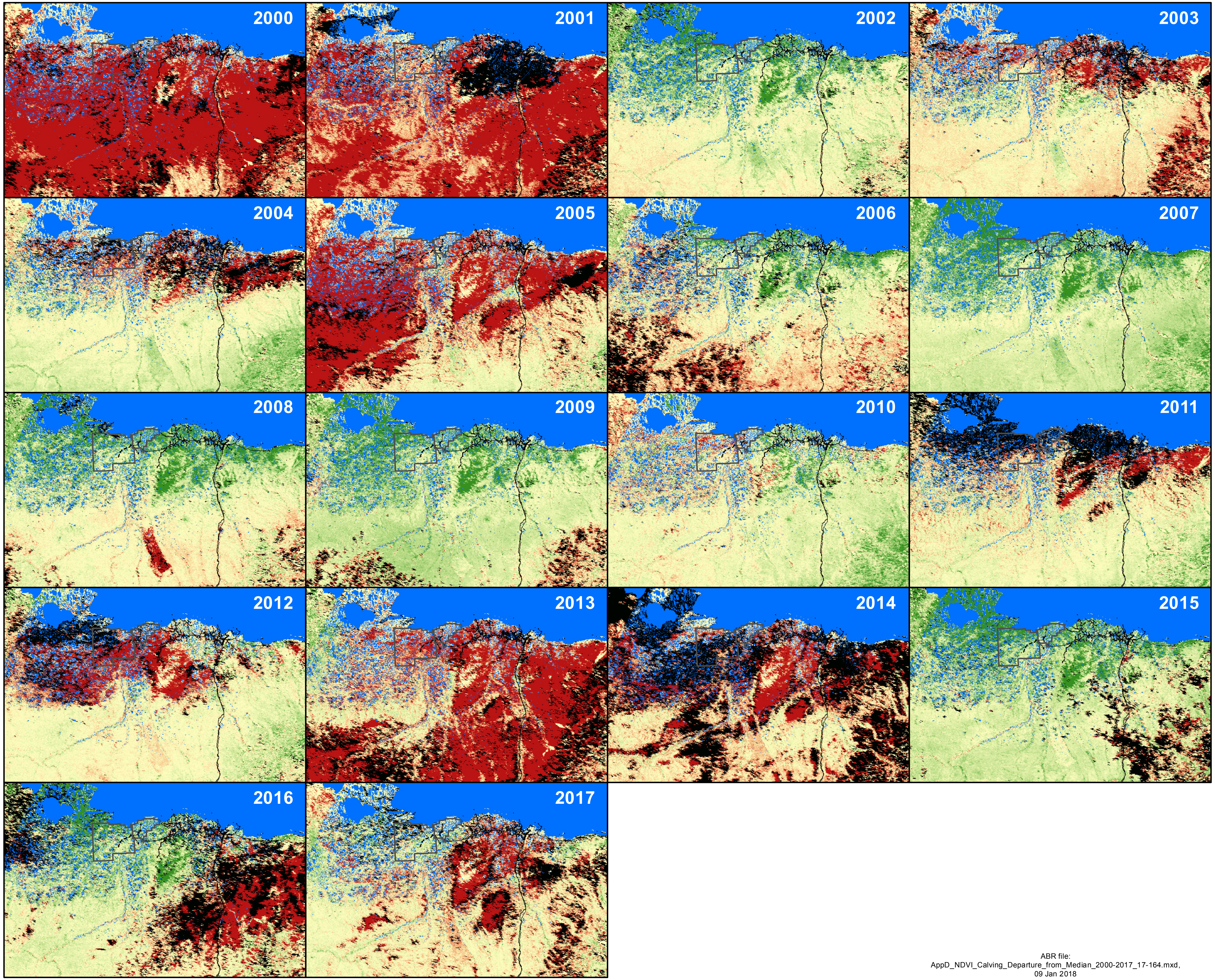
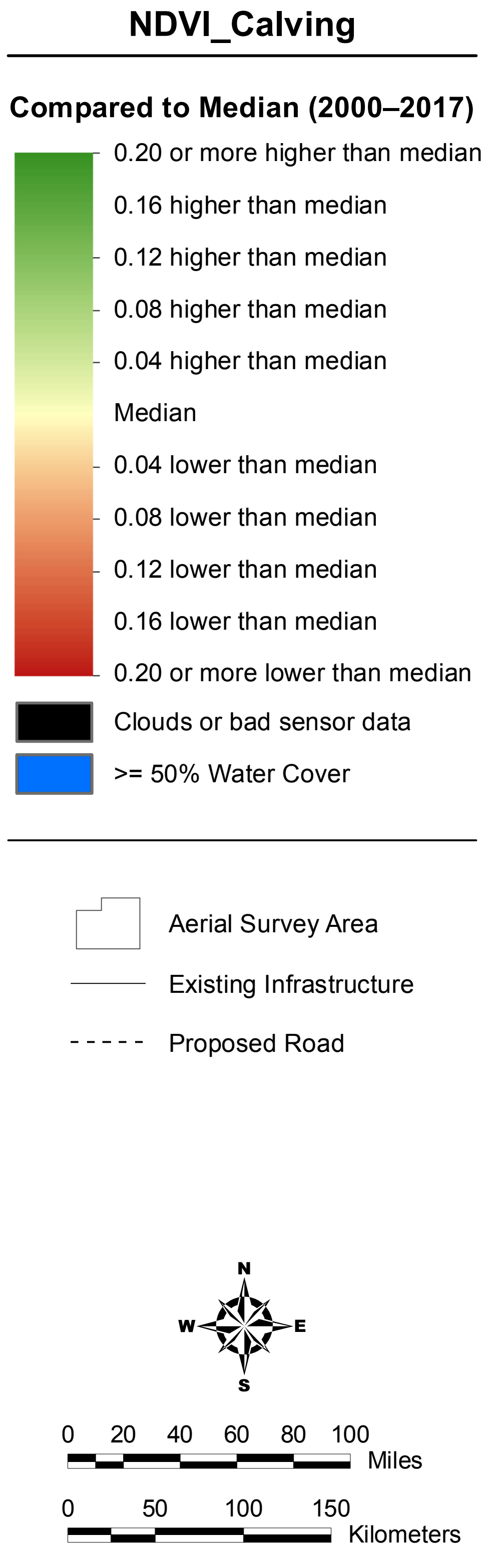


ABR file:
AppC_Snowmelt_Date_Departure_from_Median_2000-2017_17-164.mxd,
09 Jan 2018

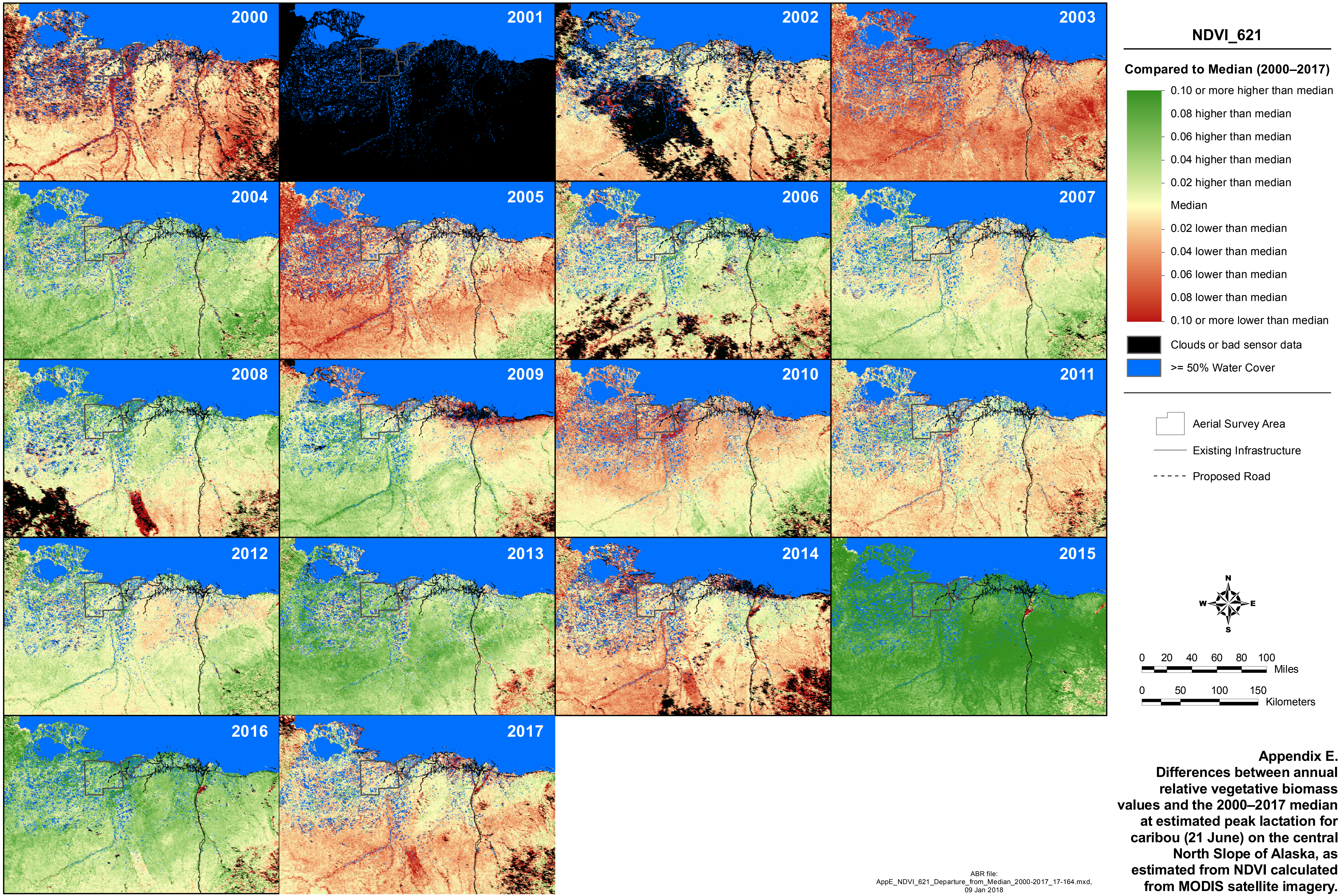
Appendix C.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2017, as estimated from MODIS satellite imagery.





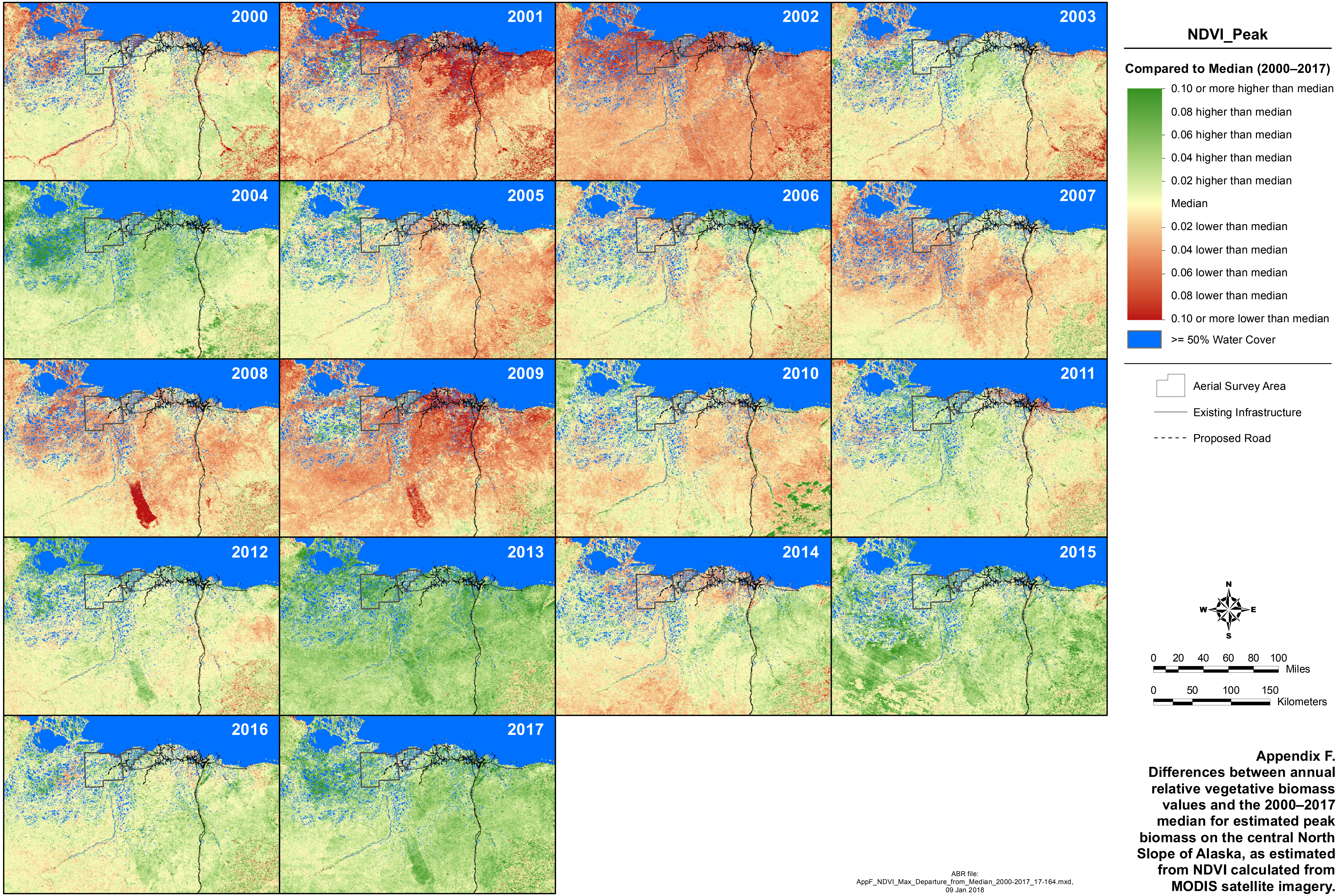
ABR file:
AppD_NDVI_Calving_Departure_from_Median_2000-2017_17-164.mxd,
09 Jan 2018

Appendix D.
Differences between annual relative vegetative biomass values and the 2000–2017 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:
AppE_NDVI_621_Departure_from_Median_2000-2017_17-164.mxd,
09 Jan 2018

Appendix E.
Differences between annual relative vegetative biomass values and the 2000–2017 median at estimated peak lactation for caribou (21 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.



ABR file:
AppF_NDVI_Max_Departure_from_Median_2000-2017_17-164.mxd,
09 Jan 2018

Appendix F.
Differences between annual relative vegetative biomass values and the 2000–2017 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.