CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM AND GREATER MOOSE'S TOOTH UNIT, 2018

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Prepared for
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Anchorage, Alaska

Prepared by
ABR, Inc.—Environmental Research & Services
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EXECUTIVE SUMMARY

- Spring 2018 had higher than average snow cover and colder than average temperatures resulting in delayed snow melt. June temperatures remained colder than average, but July temperatures were above average and likely resulted in higher than average levels of insect harassment. August temperatures were generally below average and September temperatures close to average.
- We completed six of seven planned aerial transect surveys of the Greater Moose's Tooth (GMT) survey area between April and September 2018. The estimated density ranged from a high of 0.37 caribou/km² on 27 June to a low of 0.02 caribou/km² on 7–8 June and on 1 August. No calves were observed in the GMT area during the calving survey on 7–8 June.
- We completed two of three planned aerial transect surveys of the Colville River Delta (CRD) survey area. The estimated density in the survey area was 0.04 caribou/km² on June 27 and 0.01 caribou/km² on August 29.
- We deployed six time-lapse cameras along a ridgetop in the Stony Hill area south of Nuiqsut. Most cameras recorded photographs every two minutes from 23 May to early October. The cameras documented that the area was used by caribou at low levels all summer, with the highest numbers of caribou photographed in late May, late June, and in September.
- We monitored the movements of 14 caribou outfitted with GPS collars that were funded by CPAI and active during 1 December 2017–30 November 2018.
- We analyzed telemetry data using kernel density analysis, dynamic Brownian Bridge movement models, and resource selection function analyses to examine seasonal patterns of movements and distribution for caribou from both the Teshekpuk Herd (TH) and the Central Arctic Herd (CAH).
- We examined annual and seasonal spatial patterns in vegetative biomass (based on NDVI) and snow cover calculated on a regional scale using satellite imagery. We also estimated forage metrics including forage biomass and nitrogen levels based on new formulas available from Johnson et al. (2018).
- The GMT survey area is on the eastern edge of the TH range and gets some use by TH females throughout the year; use by TH males is highest during July with less use in August–October and little winter use. Use of the GMT area by the CAH is rare and largely occurs during summer.
- The CRD survey area is located between the ranges of the TH and CAH and typically has very low densities of caribou throughout the year, however large groups of caribou from both herds are occasionally observed on the delta during the summer.
- The existing ASDP and GMT infrastructure west of the Colville River is in an area that typically has low densities of caribou and is rarely crossed by collared caribou. As development expands to the west, it will occur in areas that typically have higher caribou densities.
- The resource selection function analysis indicated that broad geographic patterns were important factors influencing caribou distribution during all seasons, but caribou distribution can also be explained by differences in vegetative biomass, landscape ruggedness, snow cover, and habitat type.

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ACKNOWLEDGMENTS

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INTRODUCTION

BACKGROUND

The caribou monitoring study for the Alpine Satellite Development Program (ASDP) and Greater Moose's Tooth (GMT) Unit 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 Arctic Coastal Plain (hereafter, the coastal plain), generally west of the Colville River, although some caribou occasionally overwinter in the Brooks Range or with the Western Arctic Herd (WAH) in western Alaska (Carroll et al. 2005, Person et al. 2007, Parrett 2015a). In a highly unusual movement, many TH animals wintered far to the 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, when it consisted of only a few thousand animals, to the early 1990s (Figure 1;

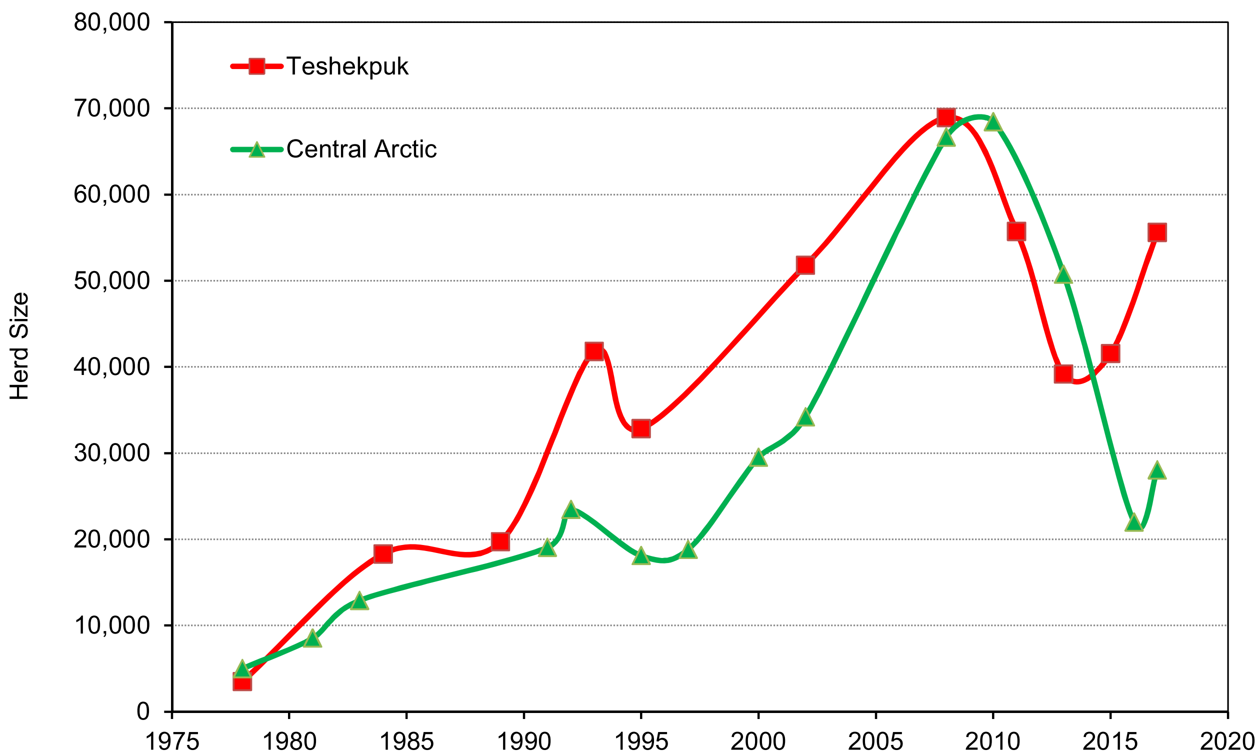

Figure 1. Population size of the Teshekpuk and Central Arctic caribou herds, 1975–2017, based on Alaska Department of Fish and Game census estimates (see text for details).

Parrett 2015a). The TH experienced a dip in numbers in the early 1990s, but increased steadily from 1995 to its peak estimated size of 68,932 animals in July 2008 (Parrett 2015a). The herd subsequently declined 19% by July 2011 when photocensus results estimated the herd at 55,704 animals (Parrett 2015a). Later photocensus results indicated the herd had decreased 30% from 2011 to 2013 to 39,172 animals, but stabilized to 41,542 (SE = 3,486) by July 2015 and increased to a minimum of 56,255 by July 2017 (Klimstra 2018, Parrett 2015a). The 2013 estimate included ~7,000 animals that were mixed with the WAH at the time of the census and the 2015 estimate used a homogeneity model for missing radio-collars. Although a portion of the higher population number since 2015 can be explained by the new higher-resolution digital photography used in 2017, the increase in estimated herd size indicates that the TH has remained stable or 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). The CAH typically moves to the Beaufort Sea coast during periods of mosquito harassment which generally begins in late June (White et al. 1975, Dau 1986, Lawhead 1988). The majority of the CAH winter in or south of the Brooks Range, predominantly 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 remain north of the Brooks Range in the foothills or on the coastal plain (Prichard et al. 2018b; E. Lenart, ADFG, pers. comm.).

From the early 1970s to 2002, the CAH grew at an overall rate of 7% per year (Figure 1; Lenart 2009). The herd grew rapidly from ~5,000 animals in the mid-1970s to the early 1990s, reaching a minimum count of 23,444 caribou in July 1992 before declining 23% to a minimum count of 18,100 caribou in July 1995, similar to the decline observed in the TH during that period. The herd then increased to an estimated 68,442 animals in July 2010 (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 28,051 caribou, indicating that the population has remained stable, and possibly increased, since the 2016 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. 2018b). 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

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, time-lapse cameras, 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 objectives were identified for study:

1. Evaluate the seasonal distribution, abundance, and movements of caribou in the study area, using a combination of historical and current data sets from aerial transect surveys and radio telemetry data obtained for this study and from ADFG under a cooperative agreement. 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.
3. Compare caribou distribution with habitat mapping, remote-sensing data, and other landscape features to better understand seasonal distribution of caribou.
4. Use time-lapse cameras to investigate caribou movements through the Stony Hill area, as an alternative to conducting low-level aerial surveys near Nuiqsut.
5. Map the distribution and abundance of muskoxen, grizzly bears, and other large mammals encountered incidentally during aerial transect surveys.

STUDY AREA

CPAI began funding caribou surveys in the northeastern NPRA in 2001–2004 and continued these studies during 2005–2014 under the North Slope Borough (NSB) Amended Development Permit 04-117 stipulation for the CD-4 drill site project. Based on the 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 2004–2017, aerial transect surveys were conducted in three survey areas, which encompassed most of that 48-km radius (Lawhead et al. 2015): the NPRA survey area (expanded from 988 km² in 2001 to 1,310 km² in 2002; 1,720 km² in 2005); the Colville River Delta survey area which encompasses CD-1 through CD-4 (494 km²); and the Colville East survey area (1,432–1,938 km², depending on the survey and year). Although 2014 was the tenth year of study, the NSB required continued studies for the GMT-2 rezoning process. In 2016, the study area was redefined to focus on the NPRA and Colville River Delta survey areas, so survey results for the Colville East survey area were reported elsewhere (Prichard et al. 2018a). In 2016 and 2017, the NPRA survey area was expanded westward by 1 and 2 transects, respectively (1,818 km² in 2016; 2,119 km² in 2017). In 2018, the NPRA survey area was again redefined to focus on the 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 (Figure 2, bottom). The newly defined Greater Mooses Tooth (GMT) survey area (776.6 km²) 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. The portion of the previous NPRA survey area west of GMT-2, which encompasses the Willow prospect within the Bear Tooth Unit (BTU), was expanded west and south to focus on those respective developments and data from that area are reported elsewhere (Prichard et. al 2019). To provide a wider context to analytical results and avoid duplication, some of the analyses in this report were conducted for the combined survey areas (GMT and BTU) and those results are included in both this report and the BTU report. This GMT report also includes results of time-lapse cameras deployed south of Nuiqsut in the Stony Hill area during May to October 2018.

The study area is located on the central Arctic Coastal Plain of northern Alaska (Figure 2, top).

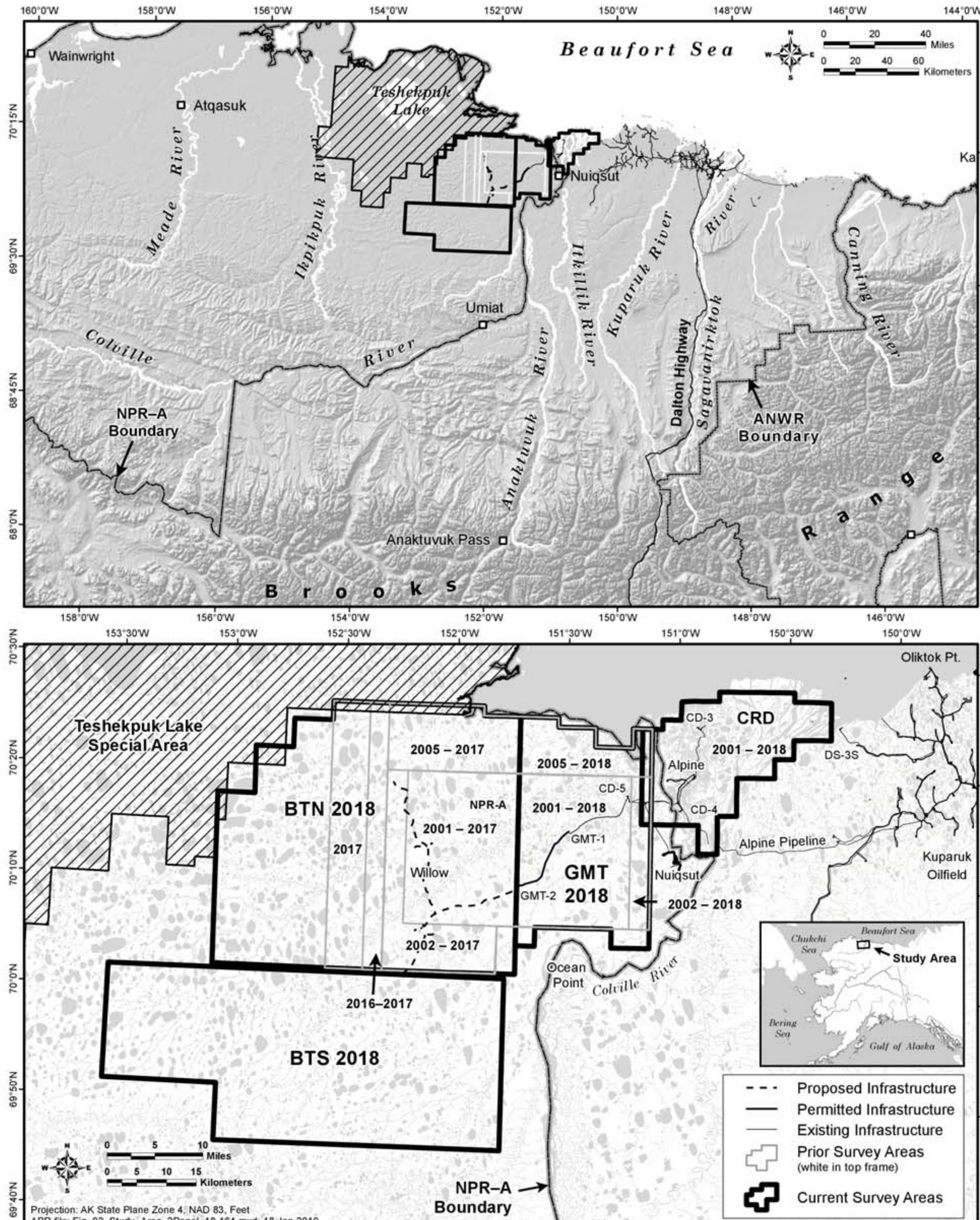

Figure 2. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the GMT and Colville River Delta survey areas, 2001–2018.

The climate in the region is arctic maritime (Walker and Morgan 1964). The summer thaw period only 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). 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.

METHODS

To evaluate the distribution and movements of TH and CAH caribou in the study area in 2018, ABR biologists conducted aerial transect surveys, calculated remote sensing metrics from satellite imagery, and analyzed existing telemetry data sets provided by ADFG, NSB, BLM, and the U.S. Geological Survey (USGS), and from GPS collars funded by CPAI and deployed by ADFG specifically for this study in 2006–2010, 2013–2014, and 2016–2017. The majority of telemetry collars were scheduled to record one location every two hours during summer with less frequent locations during the winter and a typical deployment lasted three years.

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).

WEATHER AND INSECT CONDITIONS

To estimate spring and summer weather conditions in the area during 2018, we used meteorological data from National Weather Service reporting stations at Kuparuk and Nuiqsut. Thawing degree-day sums (TDD; total daily degrees Celsius above zero) were calculated using average daily temperatures at the Kuparuk airstrip. Average index values of mosquito activity were estimated based on hourly temperatures from Nuiqsut, using equations developed by Russell et al. (1993). The estimated probability of oestrid-fly activity was calculated from average hourly wind speeds and temperatures recorded at Nuiqsut, using equations developed by Mörschel (1999).

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 GMT and Colville River Delta survey areas (Figure 2, bottom) were conducted periodically from April to September 2018 in a fixed-wing airplane (Cessna 206 or 207), following the same procedures used since 2001 (Lawhead et al. 2015 and references therein). In 2018, seven aerial transect surveys in the GMT survey area were scheduled for mid-April (late winter), mid-May (spring migration), early June (calving), late June (postcalving), late July (oestrid fly), late August (late summer), and late September (fall migration). Surveys in the Colville River Delta (CRD) survey area were scheduled for the postcalving, oestrid fly, and late summer seasons to correspond to seasons when caribou were most likely to be present based on previous aerial survey results and examination of available telemetry data. Due to inclement weather, the planned spring migration survey of the GMT survey area and the planned oestrid fly season survey of the CRD survey area were not completed.

During all aerial surveys, two observers looked out opposite sides of the airplane and, during calving surveys, a third observer was present to record data. 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. 2019).

DENSITY MAPPING

To summarize aerial survey data in the area for the period 2002–2018, we used the inverse distance-weighted (IDW) interpolation technique of the *gstat* package in *R* (Pebesma 2004) to map seasonal densities of caribou. To be consistent with previous reports and display caribou density in a wider context, we conducted these IDW calculations for the total area of aerial surveys including the GMT survey area, portions of the NPRA survey area that were surveyed in previous years (Prichard et al. 2018a), and the BTU survey areas surveyed in 2018 and reported separately (Prichard et al. 2019). Transect strips in this expanded survey area were subdivided into grid cells. Each grid cell was 1.6 km wide by 1.6 or 3.2 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 analysis 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

Table 1. Number of TH and CAH radio-collar deployments and total number of collared animals that provided movement data for the ASDP & GMT 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	1990–2018	98	87	87	78	185
GPS collars	2004–2018	254	182	6	6	260
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	2012–2018	6	6	6	6	12
GPS collars	2003–2018	173	119	0	0	173

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

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 BLM for TH animals during the period July 1990–November 2018 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015; Person et al. 2007; Prichard et al. 2017, 2018, this study) and for CAH caribou during the periods October 1986–July 1990 (from USGS), July 2001–September 2004, and April 2012–September 2016 (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), 185 collars deployed on 165 different caribou (87 females, 78 males) transmitted signals for a mean duration of 546 days per collar. The CAH 1986–1990 sample included 17 caribou (16 females, 1 male). The CAH 2001–2004 and 2012–2018 deployment samples included 24 collars deployed on 24 caribou (16 females, 8 males), transmitting for a mean duration of 585 days per collar. Satellite telemetry locations are considered accurate to within 0.5–1 km of the true locations (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 260 times by ADFG biologists on 188 different TH caribou (182 females, 6 males) during 2004 and 2006–2018, with a mean deployment duration of 524 days (Table 1). GPS collars (purchased by CPAI and ADFG) were deployed 173 times on 119 different female CAH caribou during 2003–2018, with a mean duration of 588 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 ADFG personnel 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 GMT 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 GPS- and satellite-collar data to describe caribou movements in the immediate vicinity of existing and proposed ASDP infrastructure.

To calculate kernels, we first calculated the mean location of each caribou for every two-day period during the year. Using the *ks* package for *R* (Duong 2017), fixed-kernel density estimation was employed to create utilization distribution contours of caribou distribution for every two-day period throughout the year (all years combined). We then calculated an average utilization distribution for each combination of season, herd, and sex. By calculating the average of utilization distribution based on the mean location for each animal we were able to account for movements within a season while not biasing the calculation due to autocorrelation among locations for a single caribou or due to unequal sample sizes among caribou. 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 during the calving season to delineate the calving range of the TH.

To visualize caribou movements of caribou outfitted with GPS collars, we used dynamic Brownian Bridge Movement Models (dBBMM) to create utilization distribution maps of movements based on the locations of collared individuals (Kranstauber et al. 2014). These dBBMM 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 in the area and then overlaid the isopleth layers for each season to calculate the relative proportion of collared caribou using each 100-m pixel. This visualization displays the seasonal use of the area by TH caribou as a function of both caribou distribution and movements. The dBBMM models were computed using the *move* package in *R* (Kranstauber et al. 2017).

TIME-LAPSE CAMERAS

Aerial surveys over the Stony Hill area were deemed not feasible due to local concerns over low-level aircraft and potential impacts on subsistence activities near Nuiqsut. As an alternative, we used time-lapse cameras to record caribou movements over a smaller area in the vicinity of the potential Stony Hill pad to complement our telemetry data analysis of caribou movements. While telemetry data can provide high-resolution information on the path of a small number of caribou throughout the year, it provides little data on local densities of caribou or on the distribution and movements of uncollared caribou.

Based on examination of telemetry data, we expected caribou to move through the Stony Hill area predominantly during spring and fall migrations, but small numbers of caribou from both the TH and CAH, may use the area during other seasons. We placed six time-lapse cameras strategically along a north–south oriented ridgeline in the Stony Hill area (Figure 3). Cameras were placed in locations where lakes, the Colville River, and local topography were most likely to funnel migrating caribou past cameras. Although time-lapse cameras only record caribou use of small areas, they can record caribou numbers during all daylight periods over the course of an extended time period, although fog, rain, and snow make some photographs unusable. By placing cameras on a ridgetop, we were able to increase the amount of area visible in the photographs.

We used helicopter support to deploy cameras on 23 May and to change the memory cards in the cameras on 31 July. The cameras recorded photos until the batteries ran too low, which occurred in early October for most cameras. Cameras were removed on 16 November by the ABR fall fishery survey team and a local guide from Nuiqsut by using snowmobiles to access the cameras.

Cameras were programmed to record photographs every two minutes, although an error during programming resulted in one camera recording locations every 30 seconds during the second deployment (>31 July). We reviewed all photographs and counted all caribou that were visible in photographs. We used local landmarks in the photos and Google Earth images to delineate consistent distance zones (<150 m, 151–300 m, >300 m). We assumed caribou could be consistently identified in the <150 m zone, but some number of caribou would be undetected in the middle and far distance zones. For each photo with caribou present, we recorded the number of adults and calves as well as the distance zone (near, middle, or far). We also recorded which photographs were unusable due to fog, darkness, snow, or other obstructions. Each separate group of caribou photographed by a camera was given a group ID and the maximum number of different caribou that could be counted for that group was recorded. In that way, we could summarize the number of different caribou photographed, although some groups may have been undercounted.

REMOTE SENSING

We analyzed 2018 snow cover and 2000–2018 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 2000–2017 (see Lawhead et al. 2015 and Prichard et al. 2017 and 2018 for detailed description of methods). The entire vegetation index record, based on atmospherically corrected surface reflectance data, was processed 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 2016–2018 imagery, probably due to changes in the data and data format from the aging MODIS sensors. For 2016–2018, 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 2017–2018. The 2018 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 2000–2018. Pixels with >50% water (or ice)

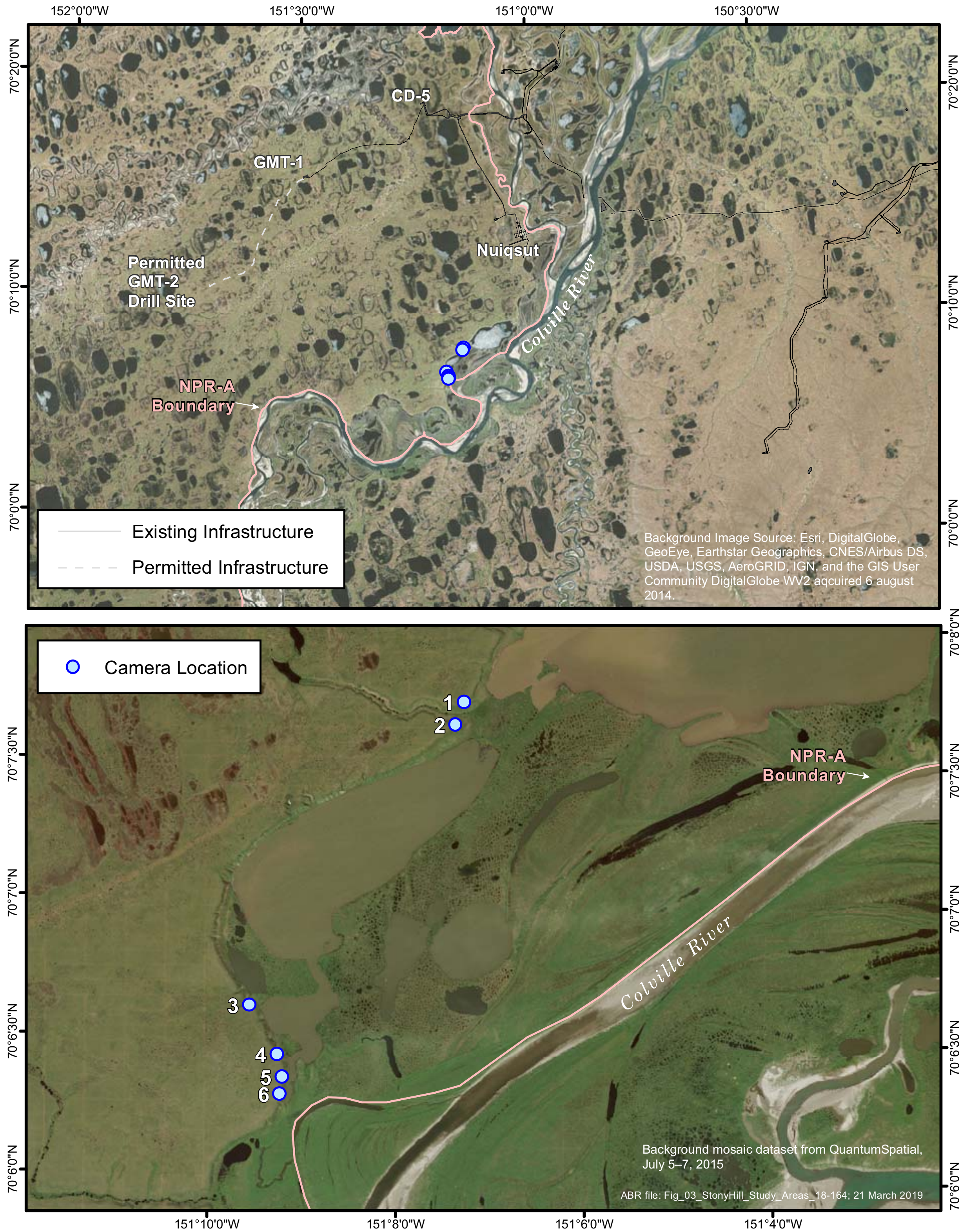

Figure 3. Location of six time-lapse cameras deployed south of Nuiqsut, May–October 2018.

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 (Rouse et al. 1973). 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):

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

where:

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

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

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 2000–2018. 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 1 km and 500 m). NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) for each year during 2000–2018 (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 2000–2018. Due to the availability of new forage models, NDVI_Calving, NDVI_621, NDVI_Rate, and NDVI_Peak were not included in analyses of caribou distribution in 2018, but we included summaries of these metrics in this report for comparison with previous reports.

FORAGE MODELING

We applied forage models from Johnson et al. (2018) that incorporate daily NDVI values as well as habitat type, distance to coast, and days from peak NDVI to predict biomass, nitrogen, and digestible energy for a given location on a given day. These models may provide metrics that are more directly related to caribou forage needs than NDVI alone.

We used the MCD43A4.Version 6 daily product at 500 m resolution (Schaaf and Wang 2015). This is the Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance (NBAR) product, and it provides 500 meter reflectance data that are adjusted using a bidirectional reflectance distribution function (BRDF) to model the reflectance values as if they were collected from a nadir view (i.e., viewed from directly overhead). The NBAR data are produced daily within 16-day retrieval periods using data from both MODIS platforms (i.e., the Terra and Aqua satellites). The product is developed using a single observation from each 16-day period for each 500-m pixel, with priority given to the central day in each compositing period (i.e., the ninth day) to provide the most representative information possible for each period of the year. Other observations in the period are used to parameterize the BRDF model that is required to adjust the observation to nadir. Similar to other MODIS vegetation index products such as MOD13Q1, it has a 16-day composite period, but unlike other products it has a temporal frequency of one day, with the 16-day window shifting one day with each new image. Thus it avoids any artificial steps at the break between composite intervals, and is a good tool to assess daily phenology normals. It is more likely to provide an observation for a given day than true daily products such as the MOD09GA.006/MYD09GA.006 products used for the NDVI composite metrics (above).

Johnson et al. (2018) calibrated the forage models for four broad vegetation classes (tussock tundra, dwarf shrub, herbaceous mesic, and herbaceous wet). Following their approach, we used the Alaska Center for Conservation Science (ACCS) land cover map for Northern, Western, and Interior Alaska (Boggs et al. 2016), aggregated on the "Coarse_LC" attribute. This map is based on the North Slope Science Initiative (NSSI 2013) with the addition of the aggregation field. We calculated the modal land cover class for each 500-m pixel.

For each date from the start of the calving season through the end of the late summer season (30 May–15 September) and for each year with telemetry locations (2002–2018) we mapped NDVI, annual NDVIMax, and days to NDVIMax. Then, we applied the equations from Johnson et al. (2018) to calculate forage nitrogen content and forage biomass for the four broad vegetation classes. We set the forage metrics to zero for water, snow/ice, and barren classes and set it to undefined for other vegetation classes that were not included in the Johnson et al. (2018) models. The areas with undefined forage metrics within the study area were primarily low and tall shrub types which comprise a small proportion of the surface area.

HABITAT CLASSIFICATION

We used the NPRA earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 4) to classify habitats for analyses. The NPRA survey area contained 15 cover classes from the NPRA earth-cover classification (Appendix A), which we lumped into nine 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 fulva* classes were combined into a single Water type; these largely aquatic types are used very little by caribou, so the Water type was excluded from the analysis of habitat preference.

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 survey area and potentially resulted in 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

Caribou group locations were analyzed with respect to multiple factors including habitat, snow-cover classes, longitude, distance to coast, and estimated daily values of vegetative NDVI, estimated annual maximum values of vegetative NDVI, forage nitrogen content, and forage biomass to evaluate the relationship of those factors to caribou distribution 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

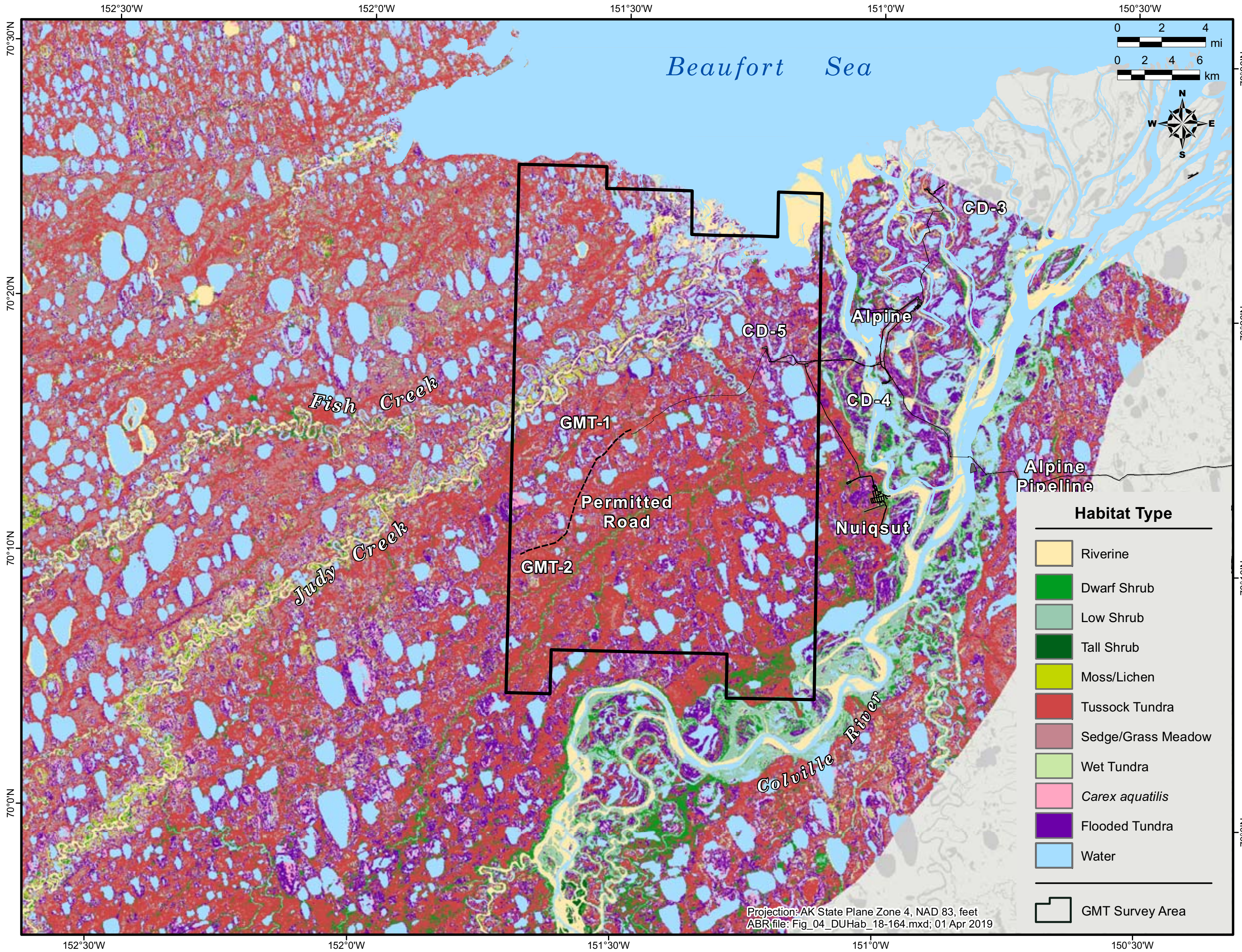

Figure 4. Habitat types used for caribou habitat-selection analysis in the NPRA survey area (adapted from BLM and Ducks Unlimited 2002).

2002–2018 in the BTN, BTS, and GMT combined survey areas, 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 2018 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 25 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 than expected or less than expected by caribou, when compared with random points.

We ran logistic regression models in *R* (*R* Core Team 2017) to compare actual caribou locations to random locations using the explanatory variables habitat type (merged into the eight non-water categories; Figure 3); daily NDVI, daily nitrogen, daily biomass, and maximum NDVI for each respective day and year the group location was recorded, calculated across 500-m pixels; 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]); 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. The median snow-free date was used only for the winter, spring migration, and calving seasons, and daily NDVI, nitrogen, and biomass variables were used only for the calving, postcalving, mosquito, oestrid fly, and late summer seasons.

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 one-fifth segment 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 multi-year model output from the RSF models and landscape variable rasters. 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). We used daily NDVI, and calculated nitrogen and biomass for the midpoint of each season in 2018 and maximum NDVI in 2018.

RESULTS

WEATHER CONDITIONS

Snow was present and snow cover was much higher than average into early June, resulting in patchy snow conditions for the early June calving survey which necessitated the use of a sightability correction factor to adjust the caribou count from that survey (Figure 5; Appendix B). Daily air temperatures at the Kuparuk Airstrip in 2018 were below average for most of May and June, above average for much of July, and below average for most of August (Figure 5; Appendix B).

Summer weather conditions can be used to predict the occurrence of harassment by mosquitoes (*Aedes* spp.) and oestrid flies (warble fly *Hypoderma tarandi* and nose bot fly *Cephenemyia trompe*) (White et al. 1975, Fancy 1983, Dau 1986, Russell et al. 1993, Mörschel 1999, Yokel et al. 2009). Mosquitos in the study area usually emerge from the middle of June through early July. Daily air temperatures in 2018 were generally below average in May and June (Appendix B) with strong winds in late-June resulted in timing of mosquito emergence that was likely later than in recent years. Conditions conducive to mosquito activity were not present until ~24–26 June and 2–3 July in 2018 (Figure 6). ABR biologists conducting ground-based surveys for other projects near the Colville River delta reported no noticeable mosquito activity before field work concluded on 26 June.

Temperatures in July were above average (Appendix B), likely resulting in high levels of mosquito harassment when winds were low (Figure 6). Oestrid flies typically emerge by mid-July and, based on the summer weather conditions in 2018, severe oestrid fly harassment likely occurred on multiple days in late July. All of August was estimated to have low mosquito and fly activity due to a combination of high winds and below average temperatures.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

GMT Survey Area

Seven aerial surveys of the GMT survey area were attempted between 16 April and 24 September 2018. The May spring migration survey could not be conducted due to persistent inclement weather, but all other surveys of the GMT area were completed as scheduled. The estimated density ranged from a high of 0.37 caribou/km² on 27 June to a low of 0.02 caribou/km² on 7–8 June and 1 August (Table 2, Figures 7–8). A total of 134 caribou (0.34 caribou/km²) were observed on the late winter survey on 17–18 April (Table 2, Figures 7–8). The density of caribou declined to 0.02 caribou/km² for the calving survey. Caribou density then peaked on the postcalving survey on 27 June (0.37 caribou/km²). Density declined again on the 1 August survey (0.02 caribou/km²) during the oestrid fly season and then increased slightly to 0.17 caribou/km² on the late summer survey (29 August), before increasing again to 0.25 caribou/km² during the fall migration survey (September 25). No calves were seen in the GMT area during the calving survey and only 12 calves were identified during the postcalving survey.

These results are within the normal seasonal ranges of caribou density observed in the GMT survey area since 2001 (Figure 8). However, caribou densities in 2018 were near or below the long-term mean for all seasons. These densities were calculated over different survey areas in different years, however. During most seasons, a decreasing gradient in caribou density from west to east was apparent in the NPRA survey area. The 2018 GMT survey area was in the eastern portion of the NPRA survey area and therefore expected to have lower densities of caribou. Results from the seasonal density mapping of caribou recorded on aerial surveys of the NPRA/GMT survey area during 2002–2018 also showed large differences among seasons (Figure 9). 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).

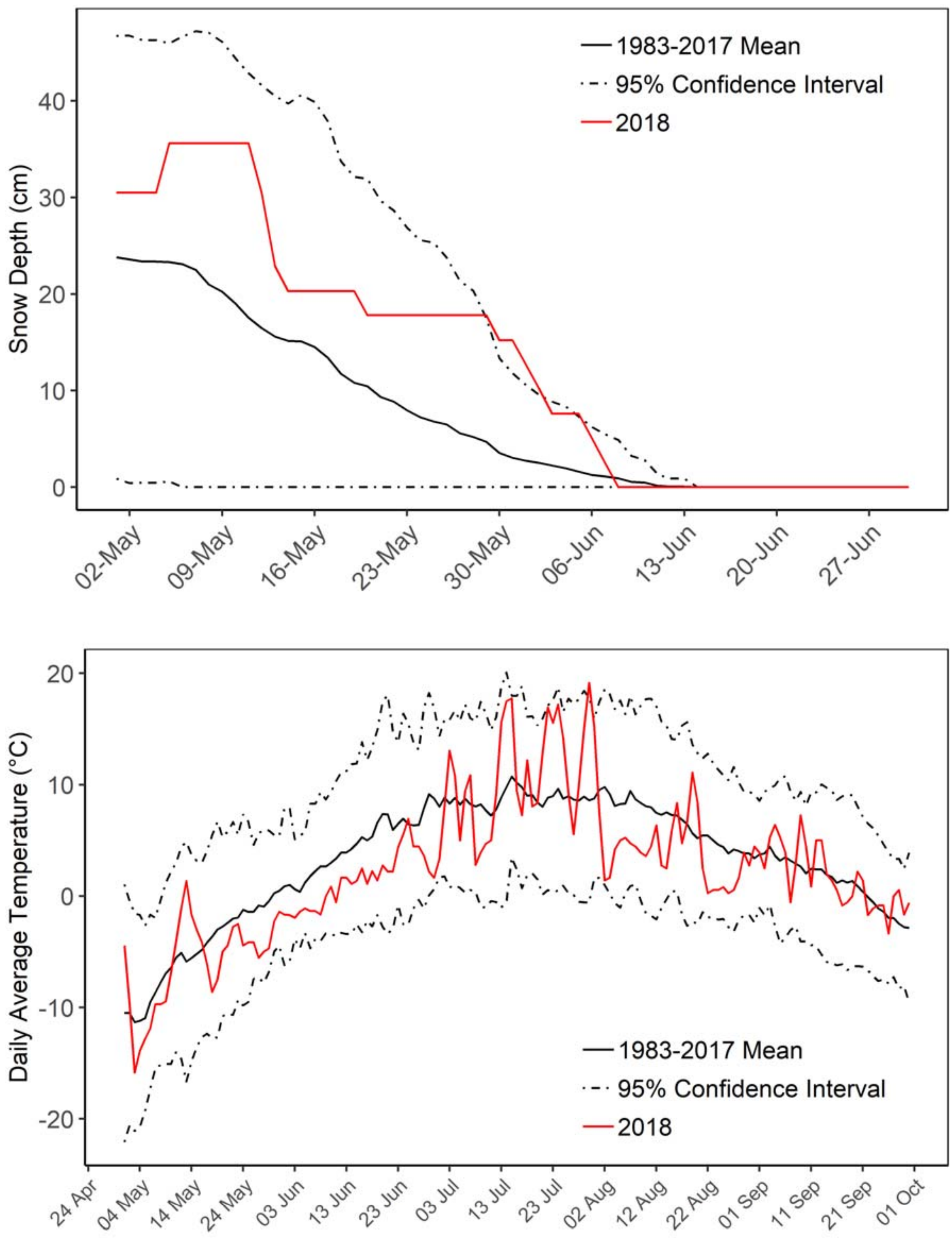

Figure 5. Snow depth at the Kuparuk airstrip, May–June 2018, compared with the long-term mean and 95% confidence interval (top panel) and daily average air temperature at Kuparuk, May–September 2018, compared with the long-term mean and 95% confidence interval (bottom panel).

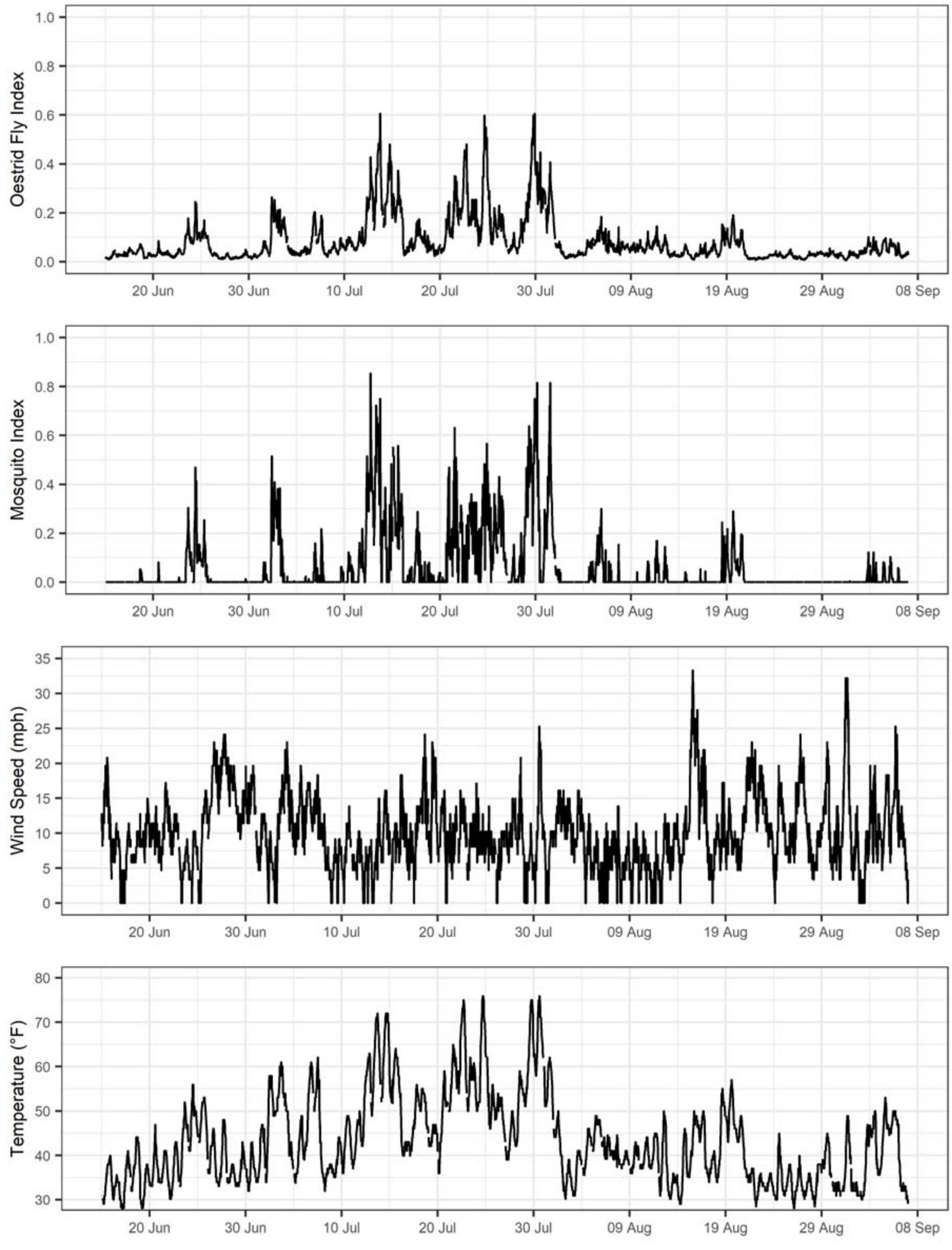

Figure 6. Hourly air temperature, wind speed, mosquito probability, and oestrid fly probability at Nuiqsut, 15 June–7 September 2018.

Table 2. Number and density of caribou in the GMT and Colville River Delta survey areas, April–September 2018.

Survey Area and Date	Total 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]
GMT								
April 17–18	778	134	nr	134	3.4	268	34.5	0.34
June 7–8	778	4	0	4	2.0	15 [h]	4.2 [h]	0.02 [h]
June 27	778	145	12	157	4.0	290	47.5	0.37
August 1	778	7	nr	7	1.0	14	3.7	0.02
August 29	778	68	nr	68	2.6	136	35.9	0.17
September 25	778	98	nr	98	4.9	196	58.1	0.25
Colville River Delta								
June 27	494	9	2	11	2.2	22	9.5	0.04
August 29	494	3	nr	3	1.0	6	4.3	0.01

[a] Survey coverage was 50% of this area.
[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% survey coverage).
[f] SE = Standard Error of Estimated Total Caribou, calculated following Gasaway et al. (1986), using transects as sample units.
[g] Density = Estimated Total Caribou ÷ Area.
[h] Applied a Sightability Correction Factor of 1.88 (Lawhead et al. 1994) to correct for low sightability due to patchy snow.

Colville River Delta Survey Area

Three surveys of the CRD survey area were scheduled for the postcalving, oestrid fly, and late summer seasons but the area was not scheduled to be surveyed during the other seasons due to low historical use of the Colville River Delta during those other periods (Table 2). The scheduled CRD survey was not completed during the oestrid fly season due to persistent inclement weather. Similar to most surveys conducted in previous years, the estimated density of caribou was very low on all surveys (0.01–0.04 caribou/km²) (Table 2; Figure 7). Two calves were observed during the postcalving survey.

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 10). 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 season (primarily oestrid fly season) and fall migration, followed closely by winter and late summer (Figures 11–12). The lowest level of 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 10) 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.

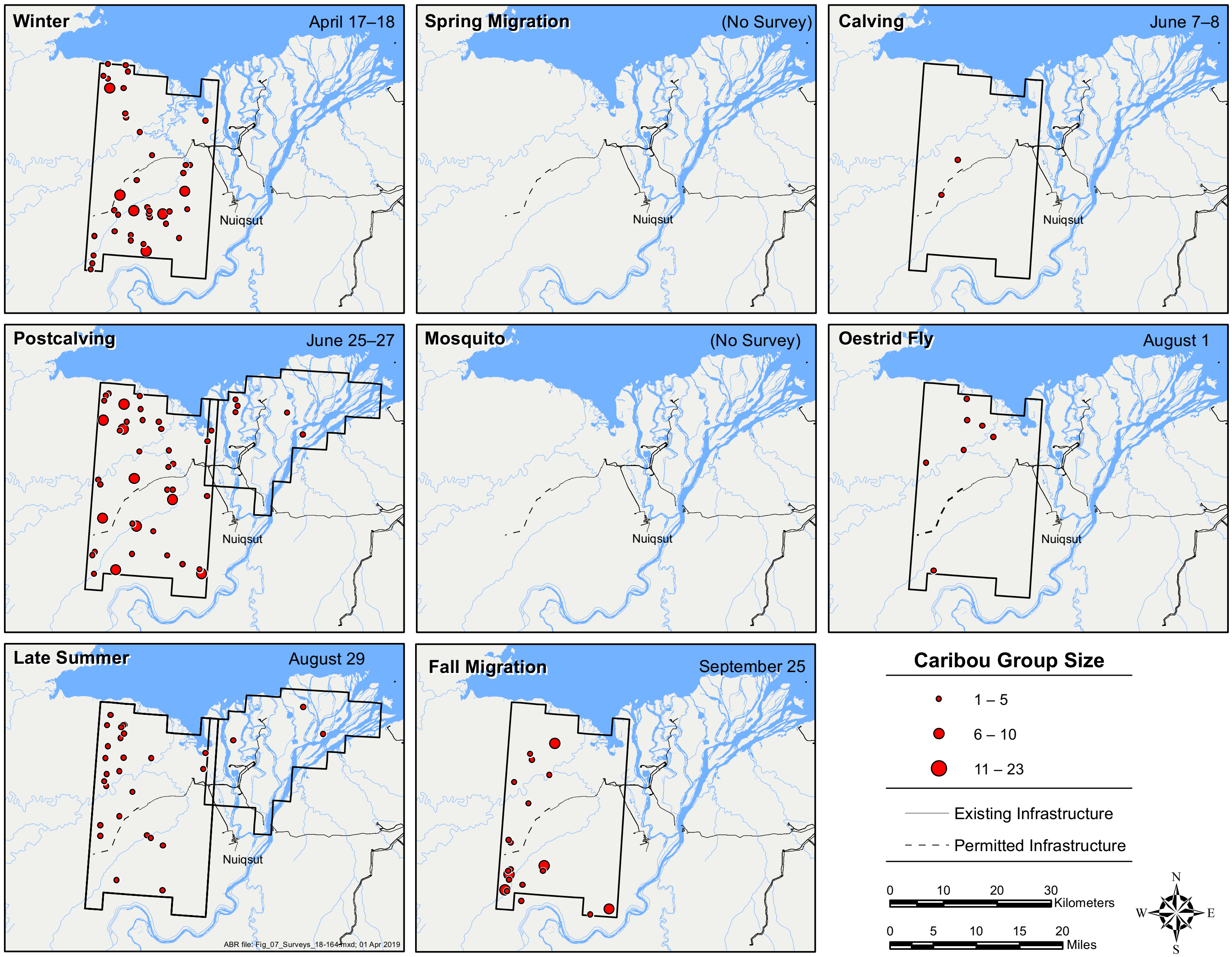

Figure 7. Distribution and size of caribou groups during different seasons in the GMT and Colville River Delta survey areas, April–September 2018.

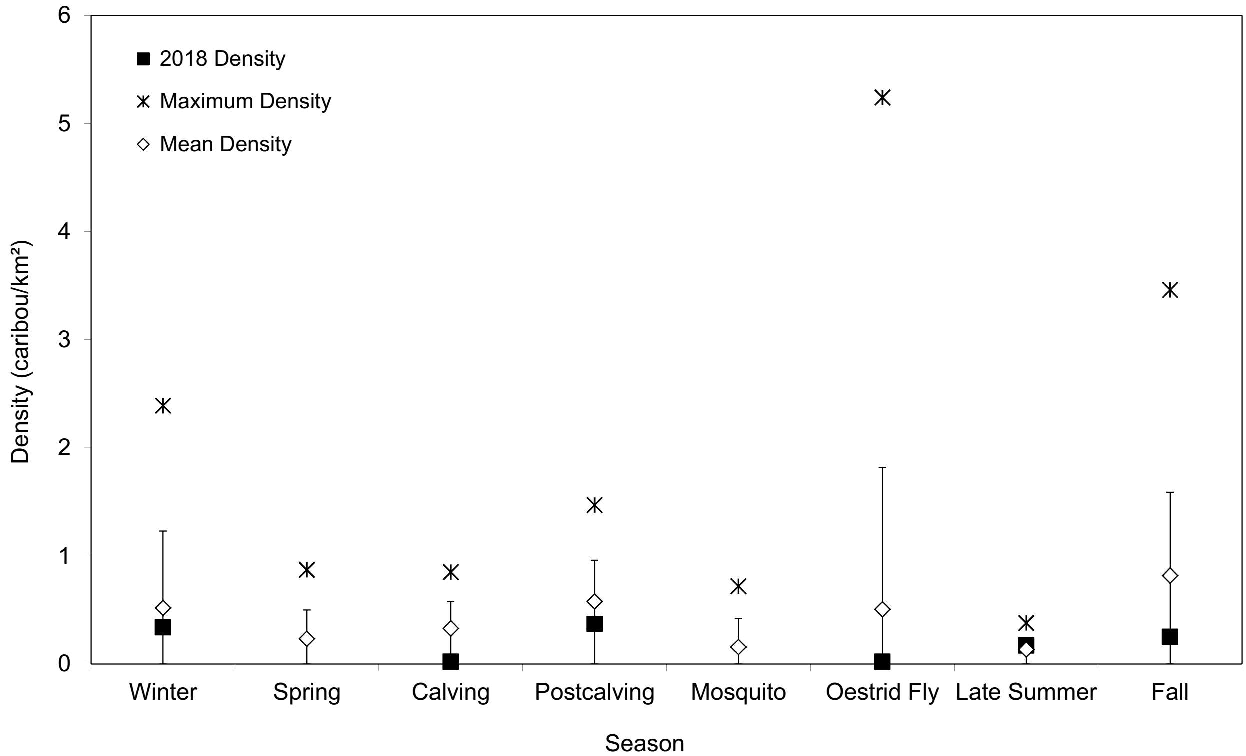

Figure 8. Seasonal density of caribou observed on 137 surveys of the NPRA survey area, April–October 2001–2018. Error bars represent 95% confidence intervals.

TH GPS Collars and dBBMMs

Mapping of TH movements derived from the dBBMMs in the study area shows that TH females use the GMT survey area during all seasons, although their use of the area and movement rates vary widely among seasons (Figure 13). 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 postcalving and mosquito seasons, caribou largely remain west and 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 GMT survey area. During late summer, caribou are usually found dispersed inland to the west of the GMT survey area. TH caribou disperse widely during fall migration, including movements throughout much of the GMT survey area (Figure 13).

CAH GPS Collars

The detailed movement tracks of 14 different female CAH caribou fitted with CPAI-funded GPS collars and active in 2018 were mapped for the period from December 2017 through November 2018 (Figures 14–16). Two of these caribou were captured and collared in April 2014 on winter range in the Brooks Range east of the Dalton Highway, five caribou were captured and collared in 2016 in early July near the coast, and seven animals were collared on the coastal plain in late June 2017. Two of those collars deployed in 2017 were deployed on previously uncollared animals and five were deployed on caribou that had previously been collared and were recaptured. Of the 14 different collared females active in 2018, three died in 2018: caribou C1309 died on 19 March, caribou C1747 died on 4 August, and caribou C1102 died on 18 September. Additionally,

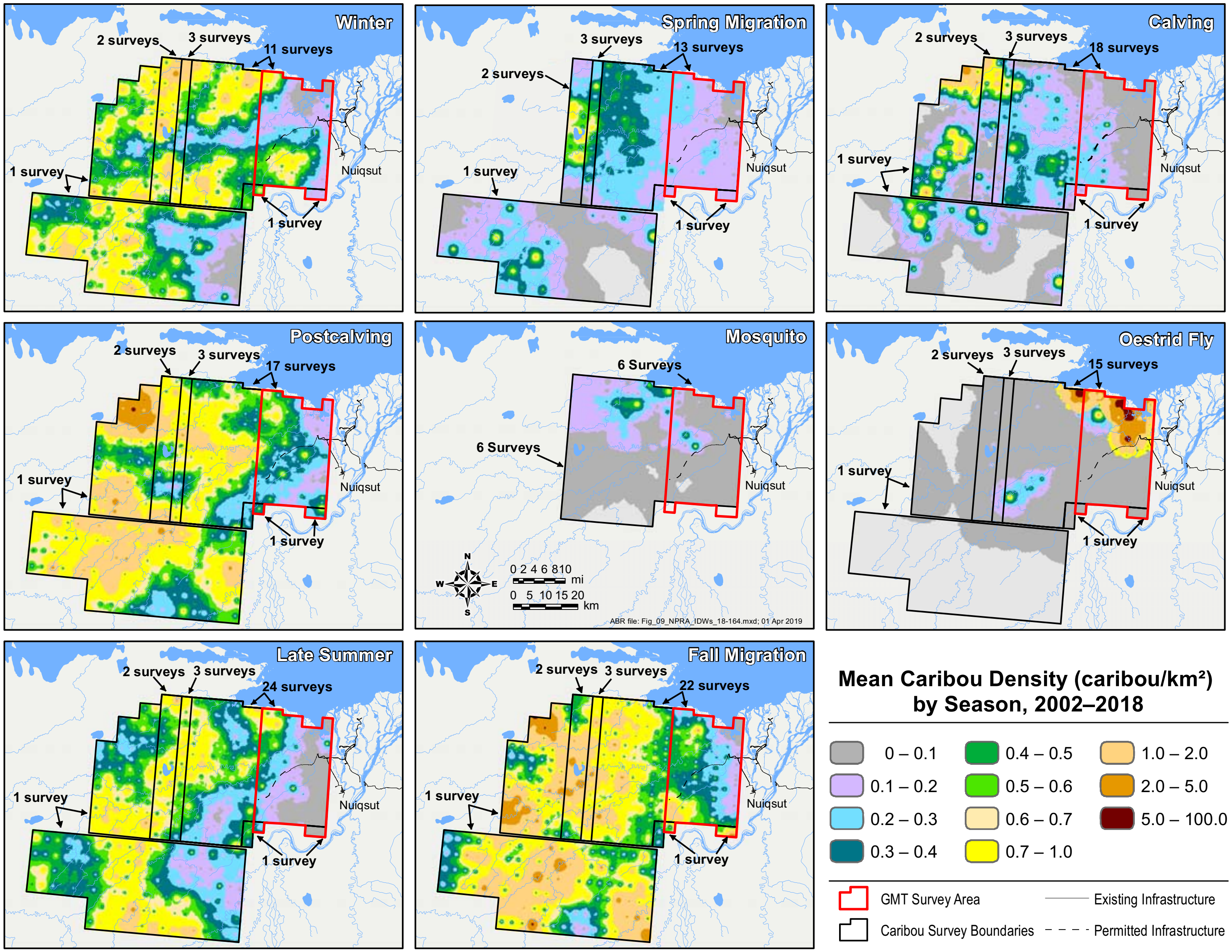

Figure 9. Seasonal density of caribou within the caribou survey areas based on IDW interpolation of aerial survey results, 2002–2018.

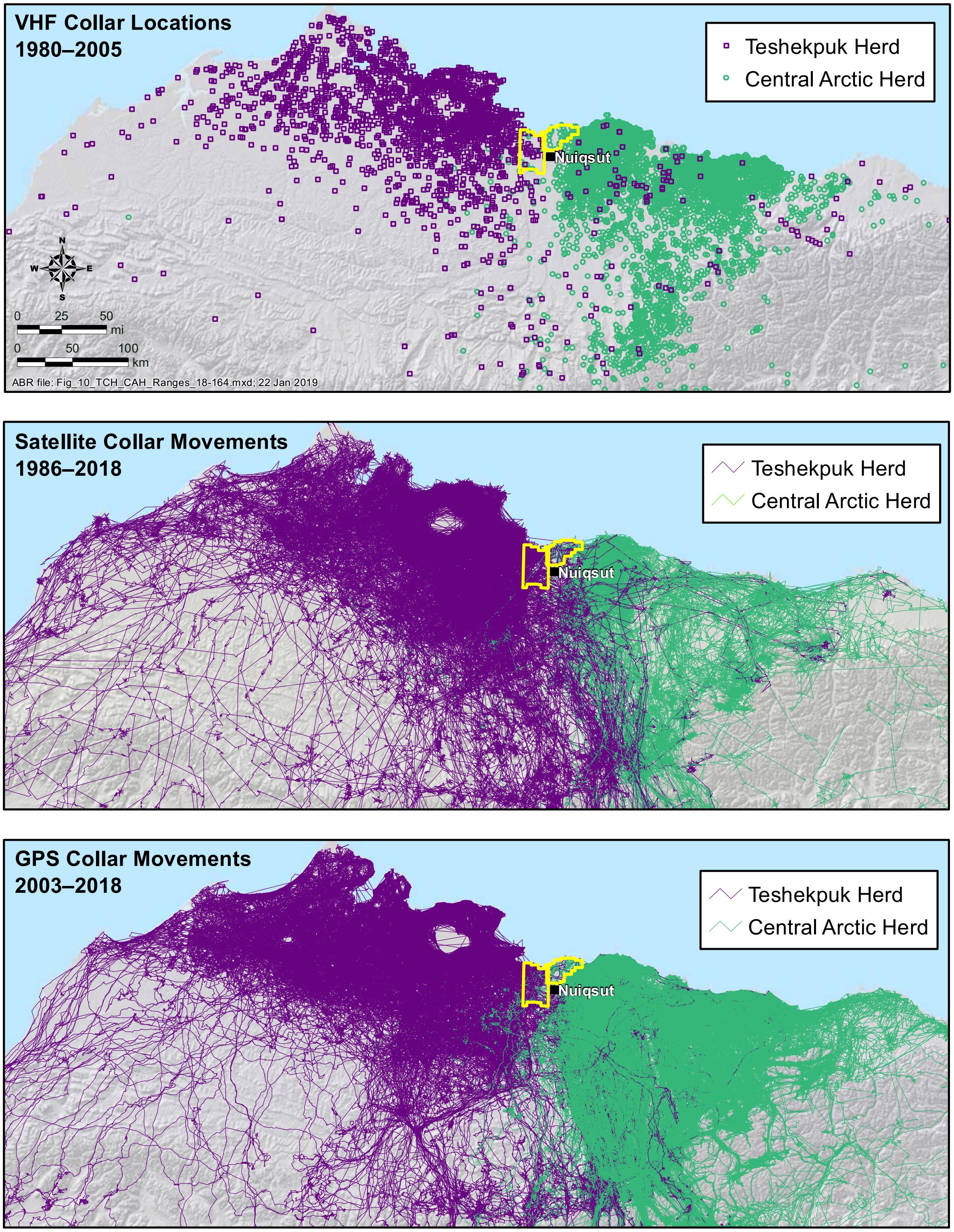

Figure 10. Ranges of TH and CAH caribou in northern Alaska in relation to the study areas, based on VHF, satellite, and GPS radio-telemetry, 1980–2018.

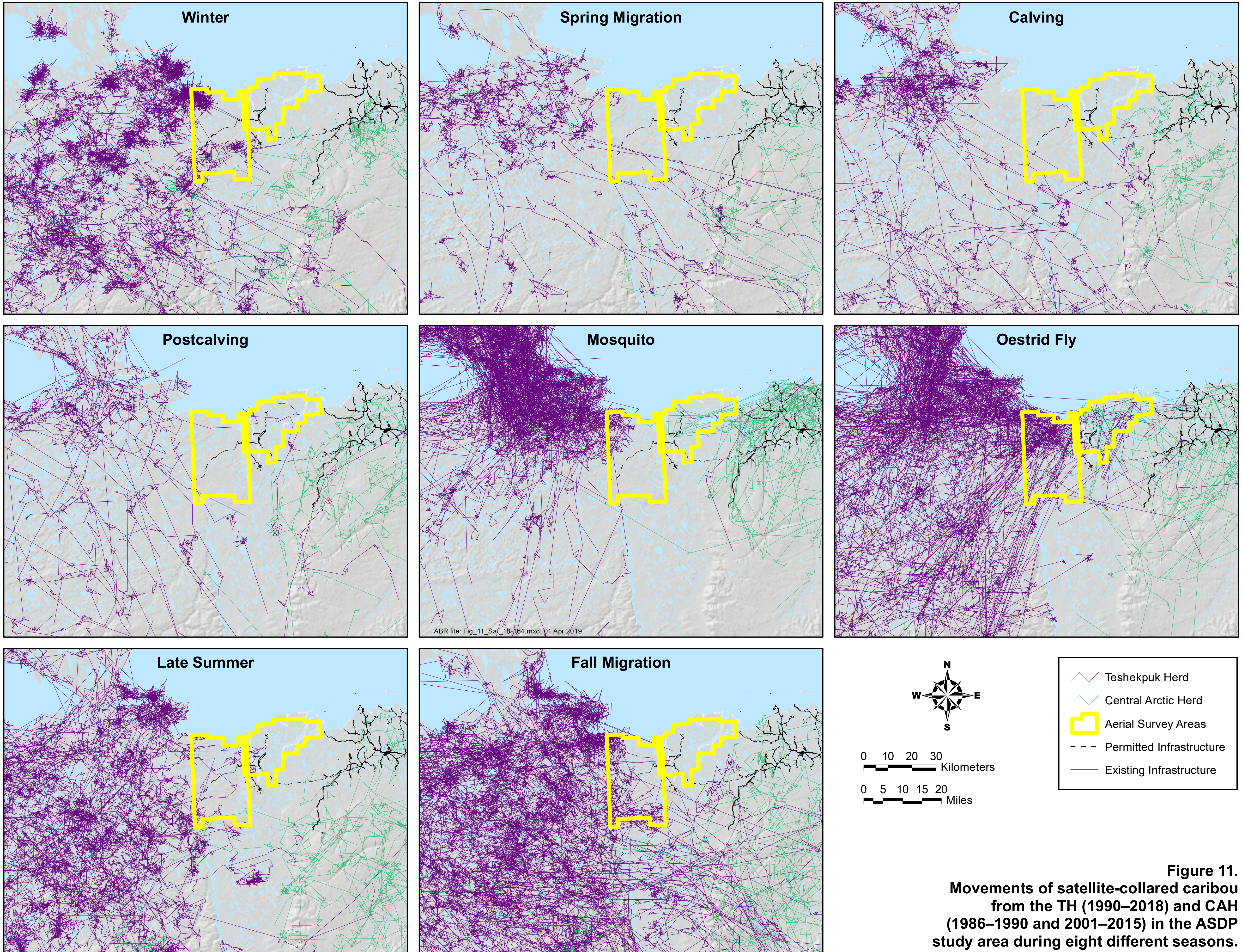

Figure 11.
Movements of satellite-collared caribou from the TH (1990–2018) and CAH (1986–1990 and 2001–2015) in the ASDP study area during eight different seasons.

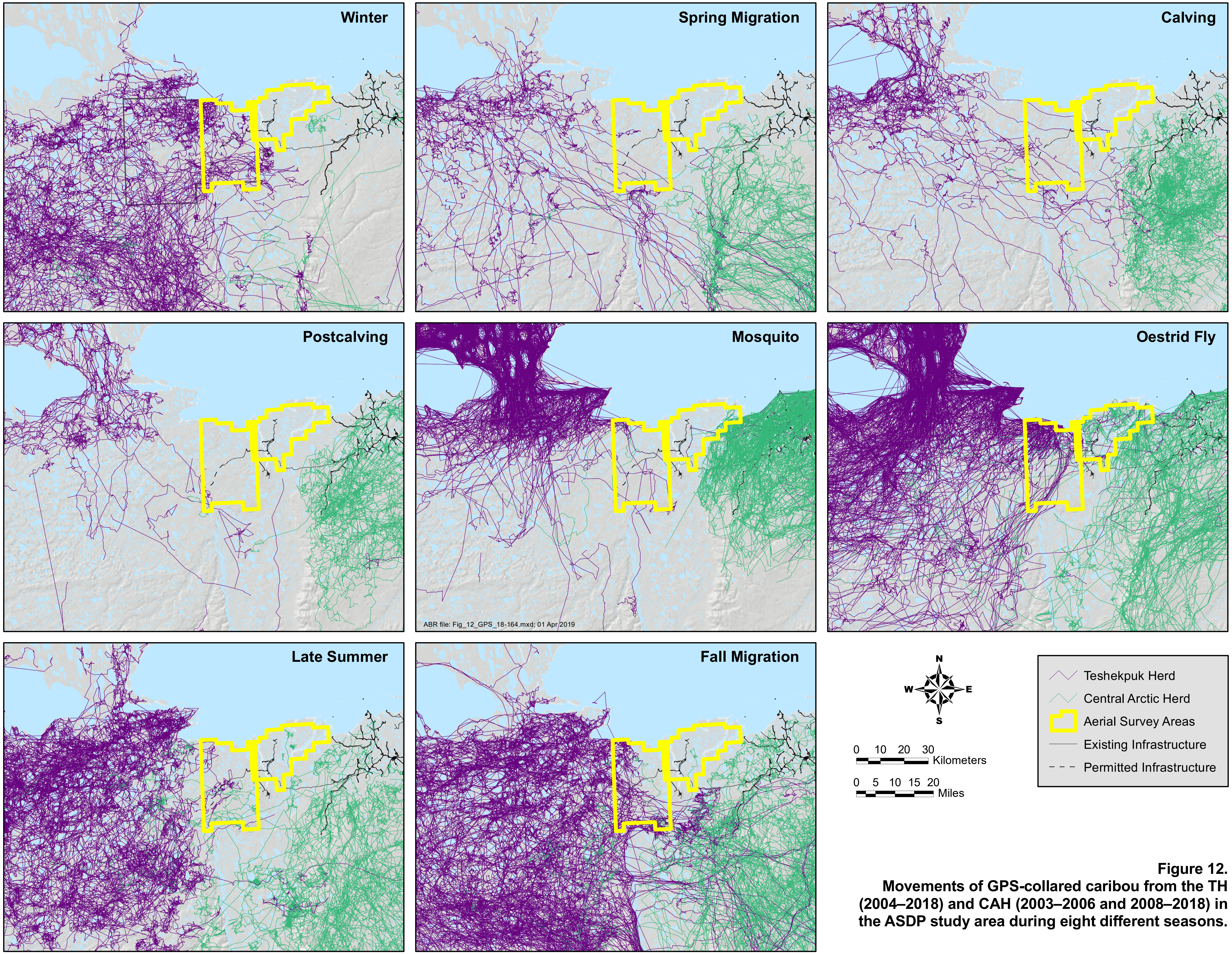

Figure 12.
Movements of GPS-collared caribou from the TH (2004–2018) and CAH (2003–2006 and 2008–2018) in the ASDP study area during eight different seasons.

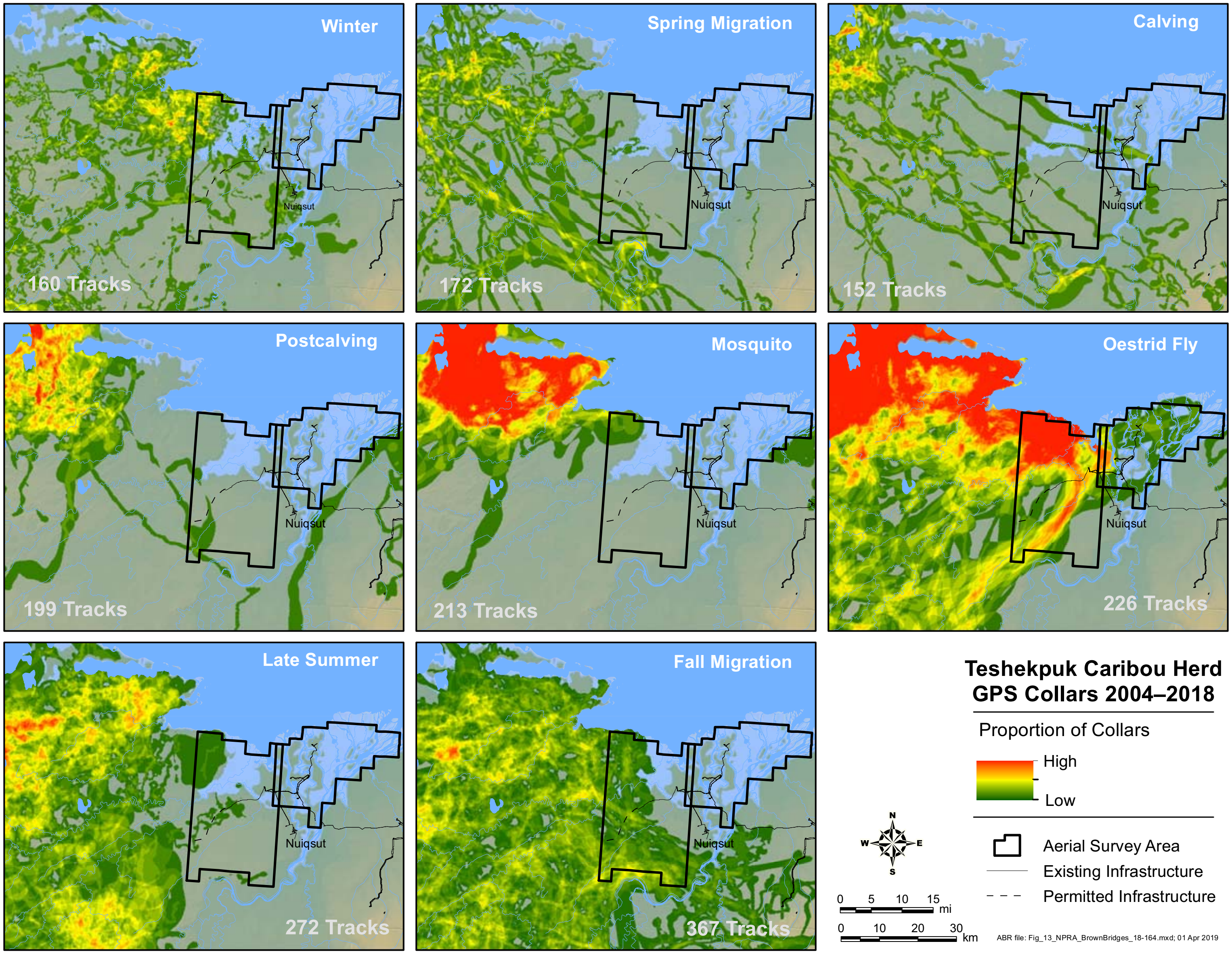

Figure 13. Proportion of GPS-collared caribou using an area based on 95% isopleth of dynamic Brownian Bridge movement models of individual caribou movements.

two animals (C1426 and C1001) had their collars removed by ADFG in 2018 during planned retrievals of collars near the end of their projected collar life.

All but one of the 14 collared caribou spent the majority of the year within the normal annual range of the CAH (Figures 14–16). Of the 12 caribou that exhibited typical CAH movement patterns (excluding C1309 which died on 19 March), seven spent the majority of the year west of the Sagavanirktok River, one spent the majority of the year on the east side of the Sagavanirktok River, and four spent large portions of time on both sides of the Sagavanirktok River. All caribou except one were west of the Sagavanirktok River during calving. Caribou C0801 was east of the Sagavanirktok River during the calving season and then remained east of the Sagavanirktok River for the rest of the time period. Most of the other CAH caribou spent the mosquito season near the Kuparuk oilfield or along the coast and either stayed around the Kuparuk oilfield or migrated south into the foothills of the Brooks Range between the Itkillik River and Chandalar Lake during the oestrid fly and late summer seasons (Figures 14–16). All but one of the collared caribou that were active during the 2018 fall migration season were located in the foothills of the Brooks Range between the Dalton Highway and the Anaktuvuk River during fall 2018. The remaining caribou, caribou C1409, crossed to the west side of the Colville River in late summer and was with the TH in fall 2018 (Figure 15).

Similar to 2017, caribou C1001 was the only caribou to spend the entire period with the TH (Figure 14). She wintered in the foothills west of Anaktuvuk Pass and moved west of Teshekpuk Lake near the Ikpikpuk River during the calving season where she was recaptured and her collar was removed during a planned retrieval.

KERNEL DENSITY ANALYSIS

Seasonal herd distributions were estimated using fixed-kernel density estimation, based on caribou locations from satellite and GPS collars deployed on 249 TH females and 83 TH males during 1990–2018 and on 140 CAH females and 8 CAH males during 2001–2018. These numbers differ from the number of collar deployments listed earlier (Table 1) because some individuals switched herds after collaring. Kernels were used to produce 50%, 75%, and 95% utilization distribution contours (isopleths), which were assumed to correspond to density classes (high, medium, and low density) for female CAH caribou and for male and female TH caribou (Figures 17–19); the sample size of CAH males was too small to conduct this analysis for males separately. Although these analysis use data covering a long time period, the results are more heavily weighted for more recent years when more collars were deployed.

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/TAPS corridor, spent the mosquito season near the coast (predominantly east of the Sagavanirktok River), 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 17). During fall migration, many collared CAH caribou crossed the Dalton Highway to return to the wintering area.

TH caribou generally wintered on the 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 18–19). Compared with females, males were more likely 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 18–19). The distribution of parturient TH females during calving (Figure 20) was similar to the distribution of all TH females during calving (Figure 18), but was more concentrated near Teshekpuk Lake.

Examination of the proportion of kernel densities by month in the GMT survey area showed that collared TH females used the area at consistently low levels (1–2% of total utilization) throughout the year, with the highest level of use occurring in October (Figure 21). Use of the survey area by TH males increased sharply from near zero in May to a peak in July (~4% of the utilization distribution). The percentage of collared TH males

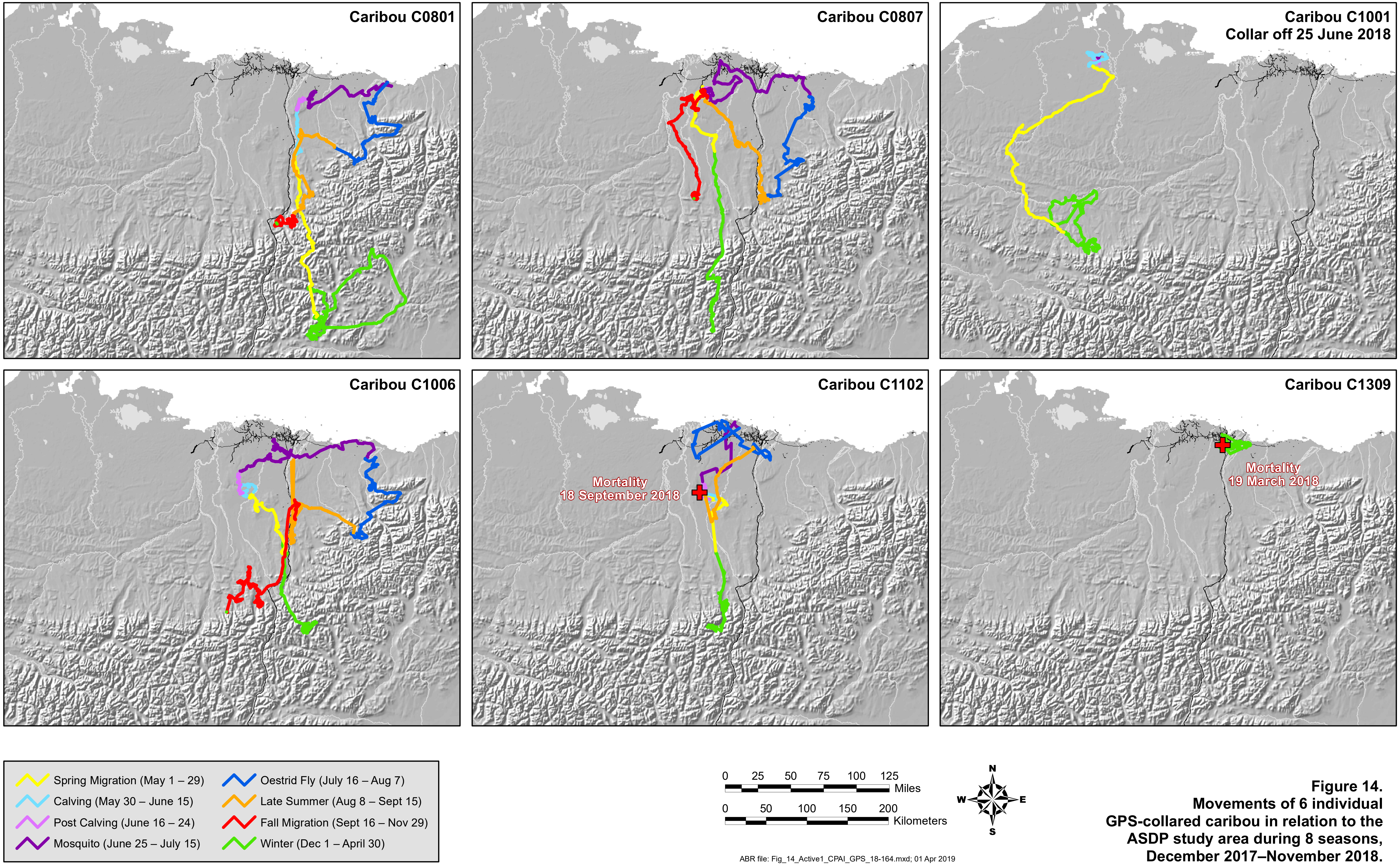

Figure 14.
Movements of 6 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2017–November 2018.

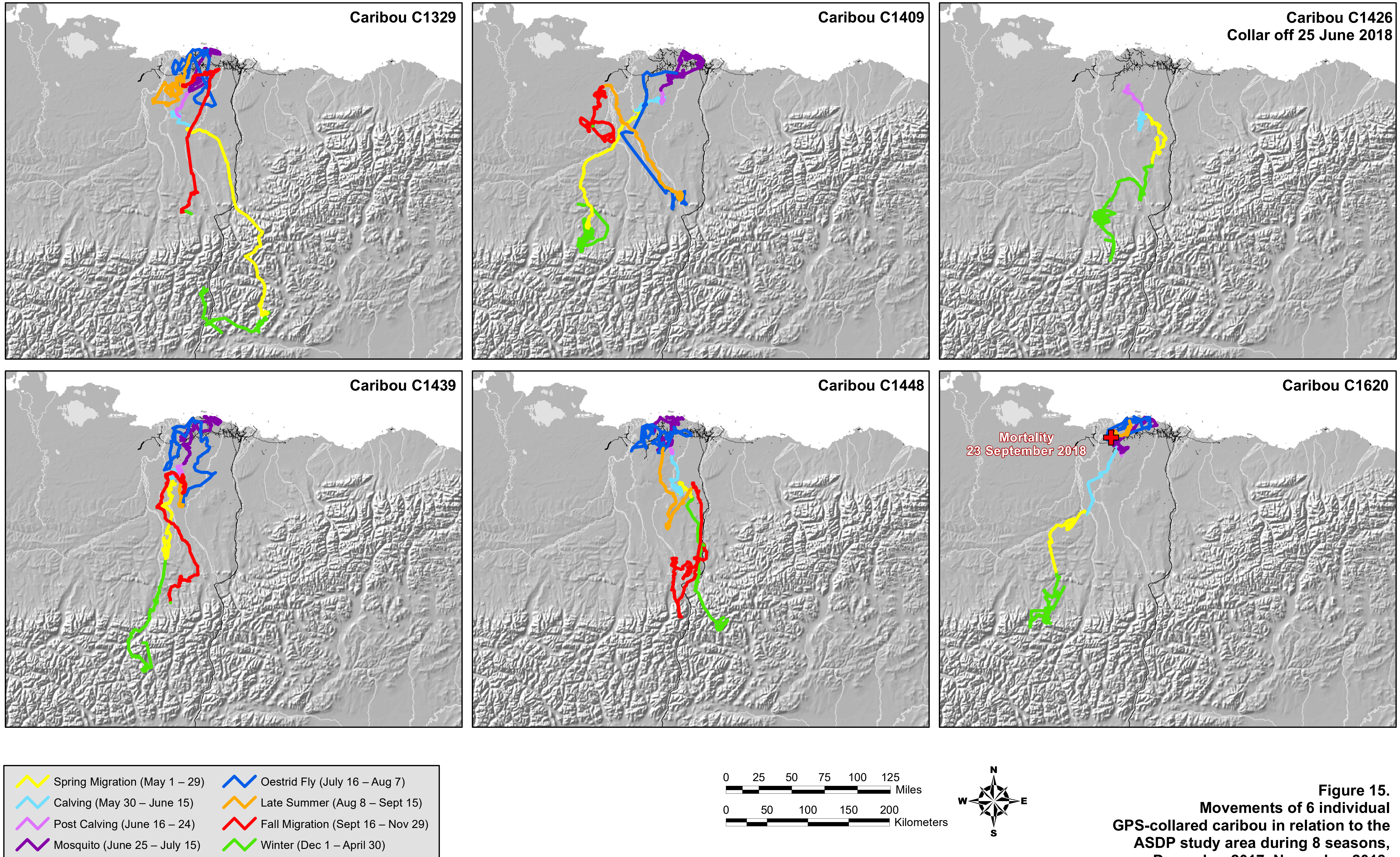

Figure 15.
Movements of 6 individual GPS-collared caribou in relation to the ASDP study area during 8 seasons, December 2017–November 2018.

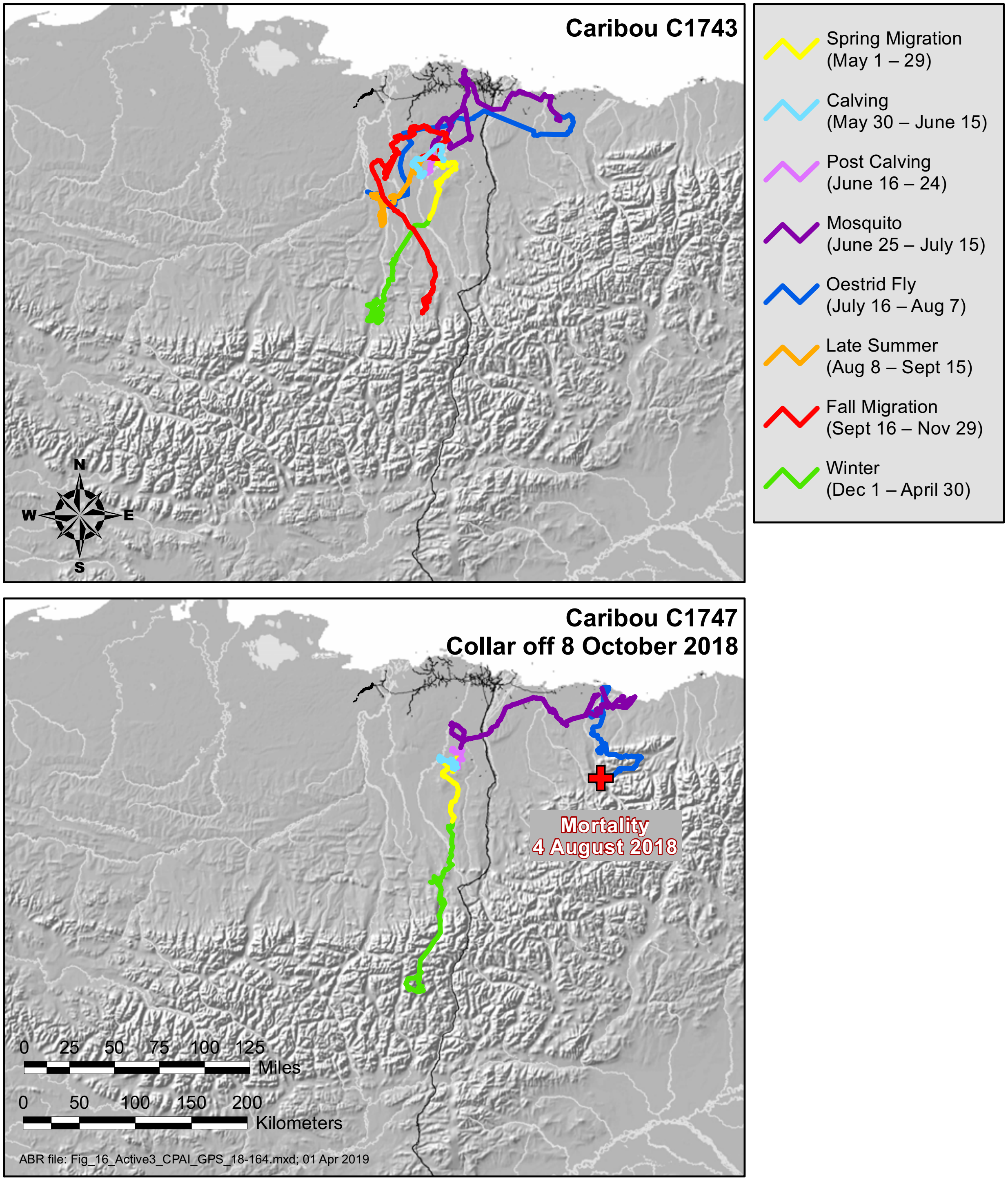

Figure 16. Movements of two individual GPS-collared caribou in relation to the study area during eight seasons, December 2017–November 2018.

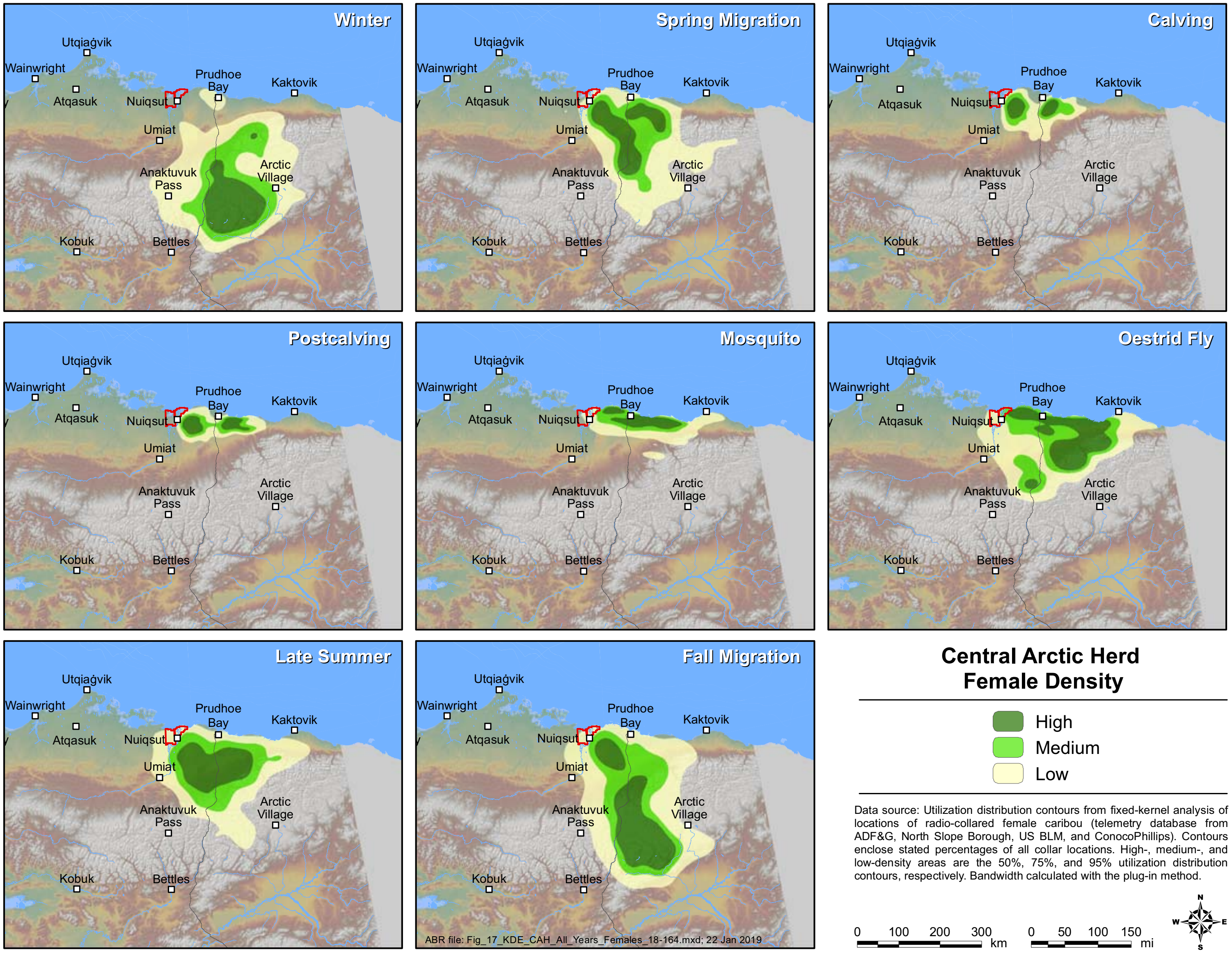

Figure 17. Seasonal distribution of CAH females based on fixed-kernel density estimation of telemetry locations, 2001–2018.

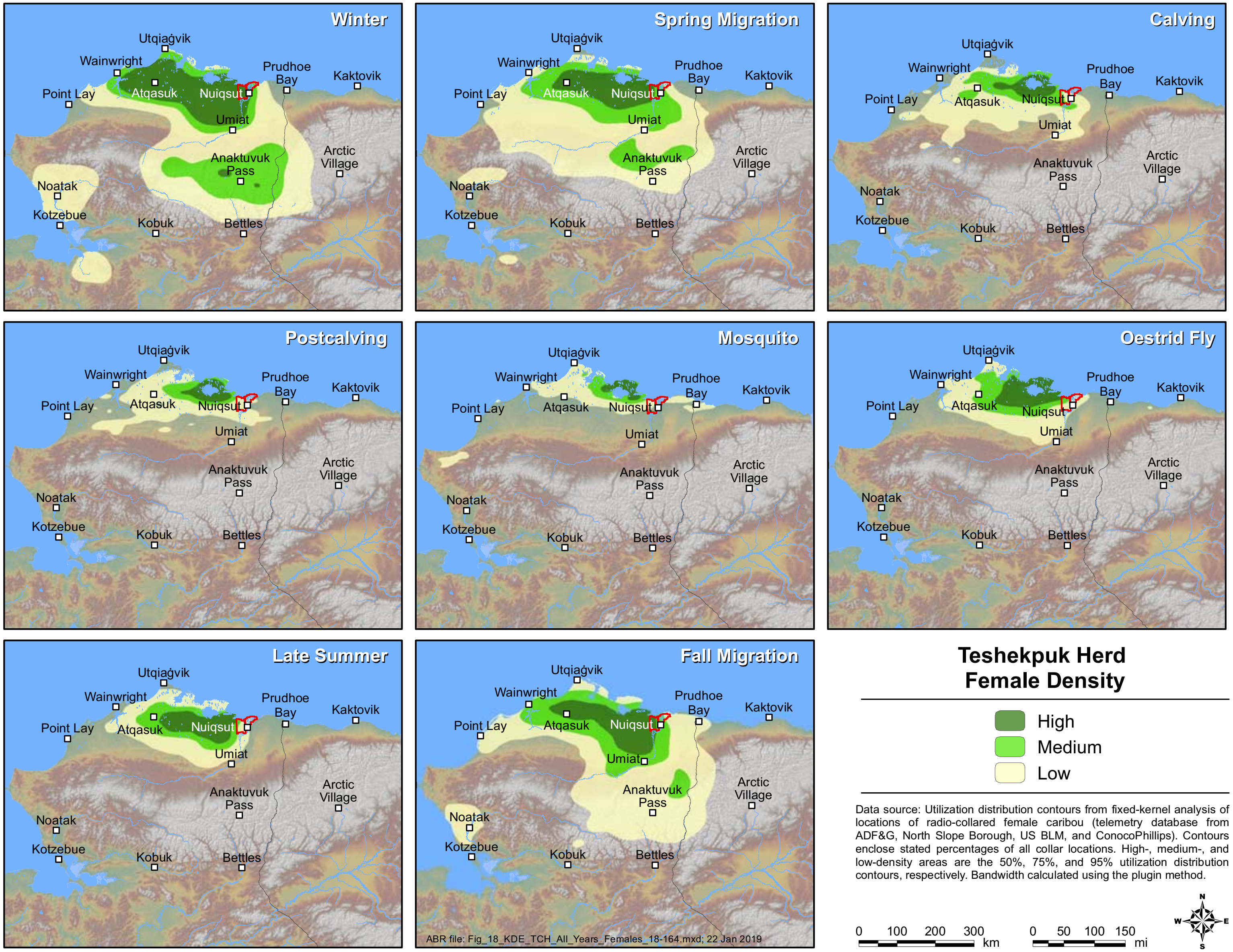

Figure 18. Seasonal distribution of TH females based on fixed-kernel density estimation of telemetry locations, 1990–2018.

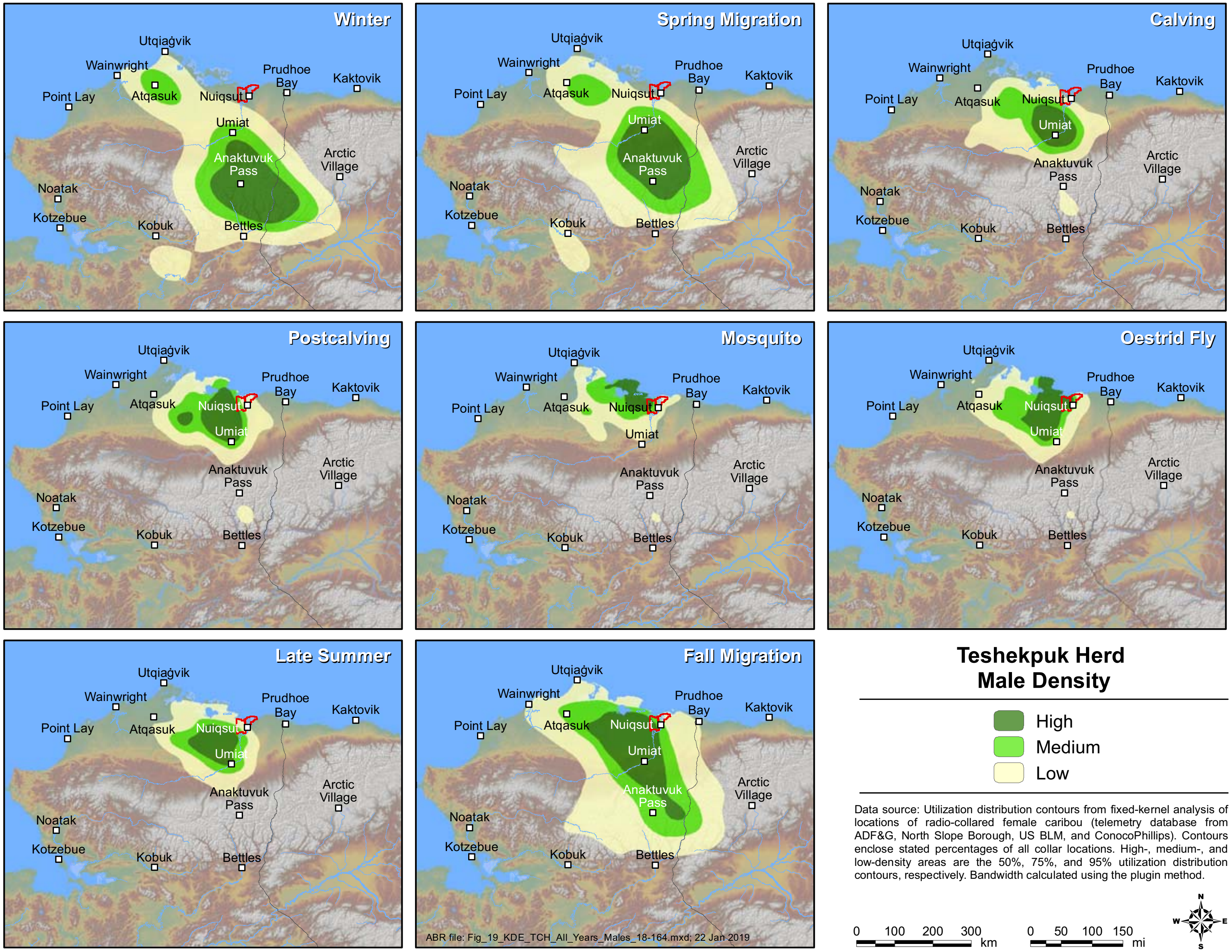

Figure 19. Seasonal distribution of TH males based on fixed-kernel density estimation of telemetry locations, 1997–2018.

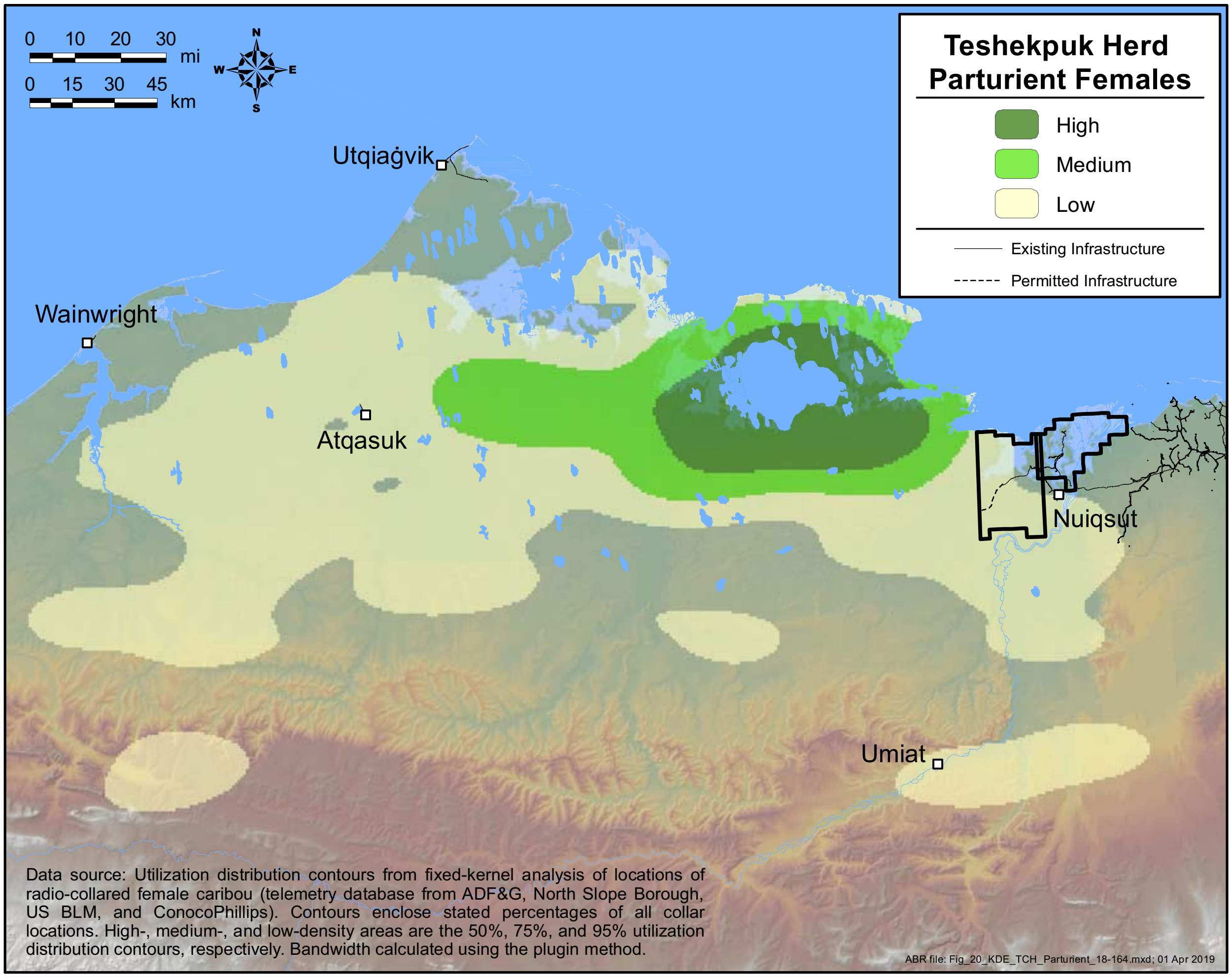

Figure 20. Distribution of parturient females of the Teshekpuk Herd during calving based on fixed-kernel density estimation of telemetry locations, 1990–2018.

found in the GMT survey area was then (~1%) from August through October, and then dropped to near 0% 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 GMT 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 21).

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 21). The highest percentages for TH males and CAH females occurred during July (~1%) and the highest percentages for TH females occurred during winter (~0.3%; Figure 21).

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 to late November)—since monitoring began in the late 1980s–early 1990s for satellite collars and in 2003–2004 for GPS collars (Figures 11–13, 22). From December 2017 through November 2018, 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

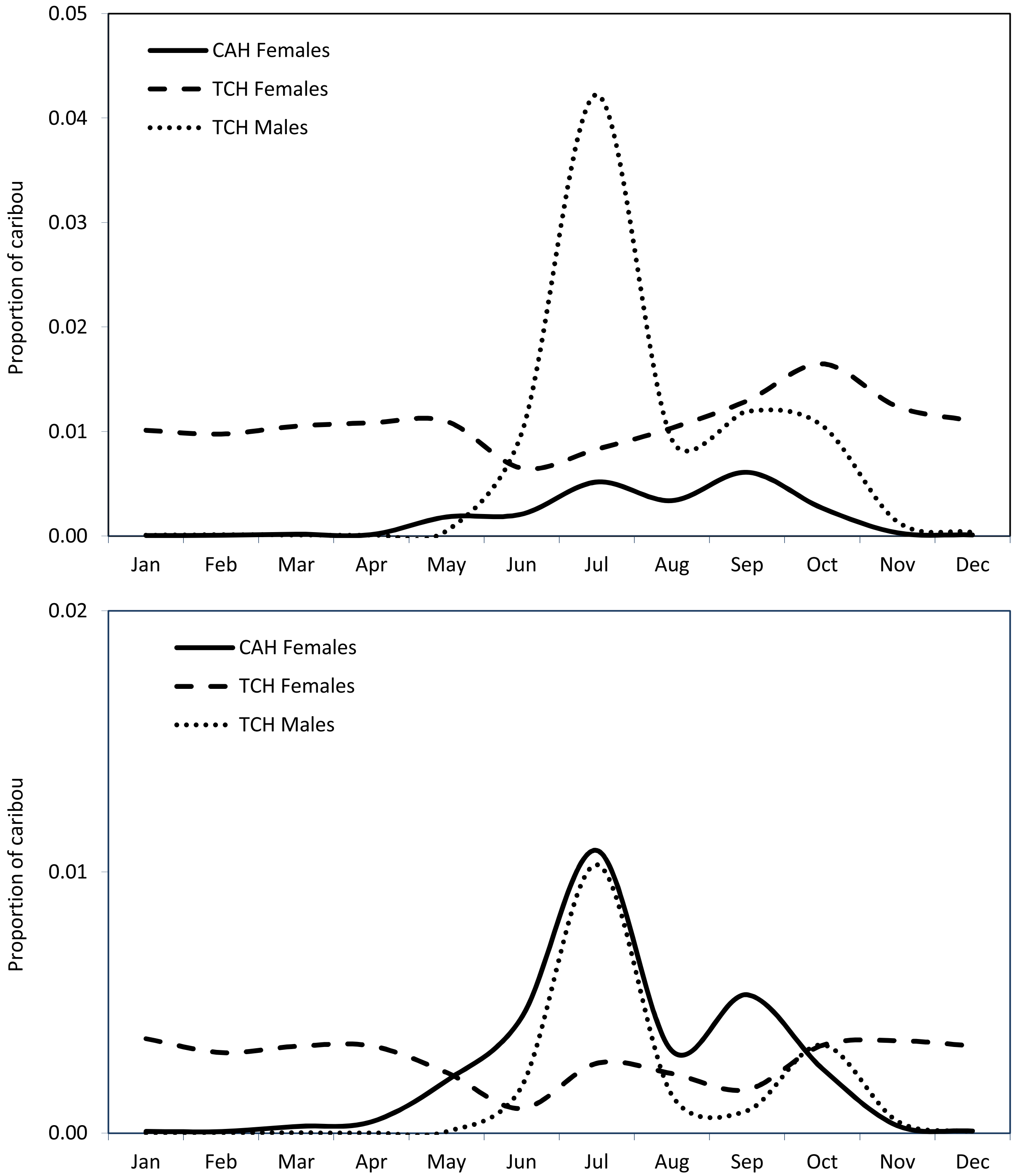

Figure 21. Proportion of CAH and TH caribou within the GMT survey area (top panel) and Colville River Delta survey area (bottom panel), based on fixed-kernel density estimation, 1990–2018.

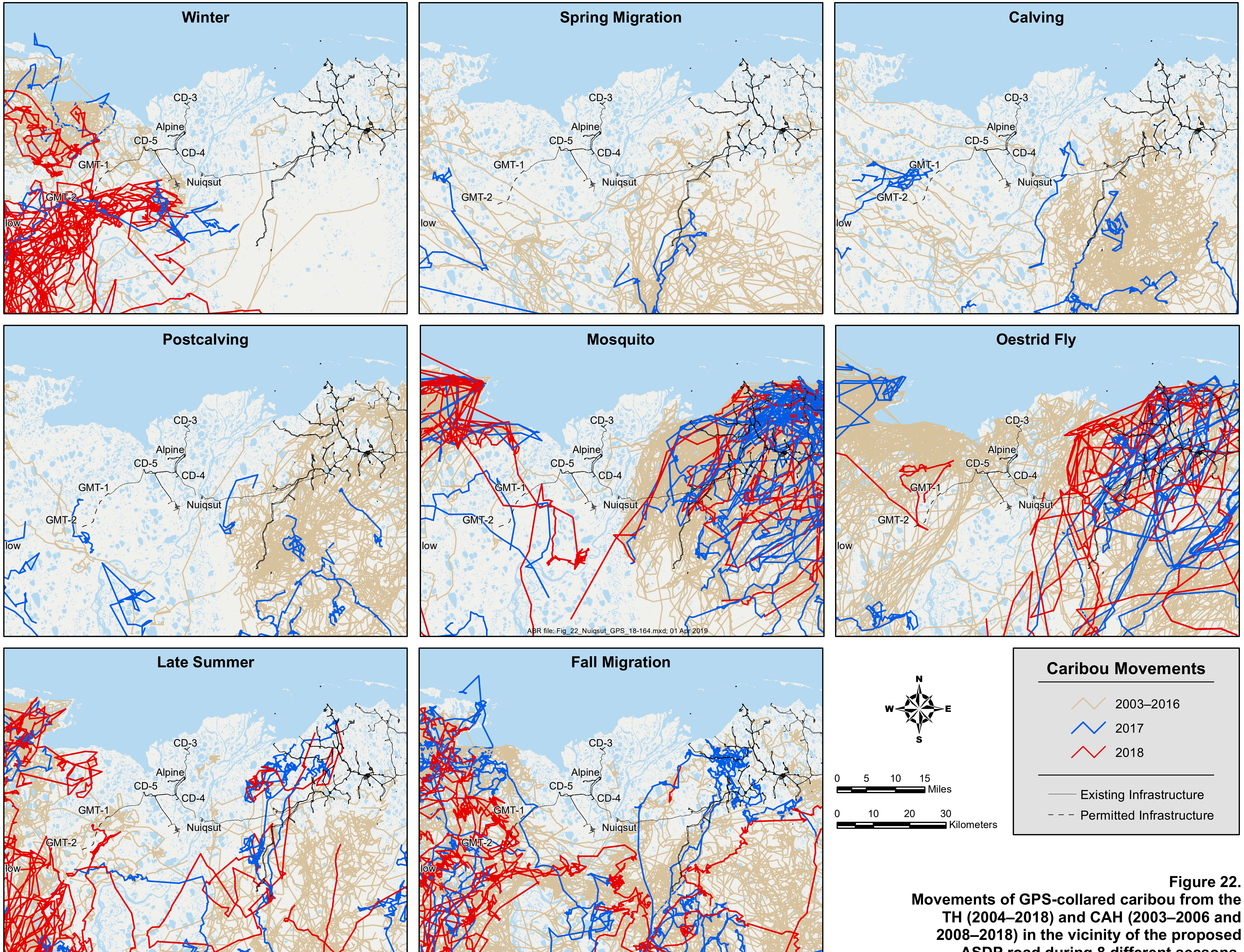

Figure 22.
Movements of GPS-collared caribou from the TH (2004–2018) and CAH (2003–2006 and 2008–2018) in the vicinity of the proposed ASDP road during 8 different seasons.

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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 planned road alignment from GMT-1 to GMT-2 than have occurred near CD-5, such movements have not occurred frequently (Figure 22; Table 3) (Lawhead et al. 2015; Prichard et al. 2017, 2018). In 2018, only one caribou crossed the GMT-1 road a total of three times (based on straight-line distances between locations). Caribou M1709, a GPS-collared male TH caribou crossed the GMT-1 road northward on 3 July, recorded one location between the GMT-1 road and pipeline, and then crossed back to the south side of the road. On 14 July, while moving northward, consecutive locations of caribou M1709 were located on either side of the GMT-1 road, although a straight line between the GPS locations indicated the crossing occurred close to the GMT-1 pad and, therefore, it is possible the animal moved around the existing infrastructure rather than crossing it.

In 2018, six caribou crossed the planned GMT-2 road corridor a total of 14 times. Caribou FY1701 crossed the planned road corridor four times, twice on 19 September, once on 20 September, and once on 25 September. Caribou M1407 crossed the planned road corridor once on 29 October, caribou F1732 crossed once on 26 June, caribou M1709 crossed three times on 29 and 30 July and 9 August. Caribou FY1721 crossed four times (on 2 February, 2 July, 26 October, and 29 October), and caribou M1724 crossed once on 3 July.

TIME-LAPSE CAMERAS

The time-lapse cameras were deployed on 21 May. The cameras all worked as planned except that Camera 3 tilted down during the first deployment limiting the view to the near distance zone (Figures 23–24). Additionally, during the second deployment Camera 3 was mistakenly programmed to record locations every 30 seconds instead of every two minutes. As a result Camera 3 ran out of batteries sooner (21 August) than the other five cameras (12 September–6 October; Table 4). Over all six cameras, between 92.7% and 99.4% of the photographs were useable during the first deployment, but only 65.6% to 93.2% of photographs were useable during the second deployment due primarily to shorter daylength (Table 4).

Caribou were visible in 25–717 photographs per camera for both deployments combined (Table 5). Cameras 3 and 4 had low numbers of photographs of caribou present during both deployments. The minimum counts of caribou in the near zone (<150 m) ranged from 1–41 caribou per camera during the first deployment and from 3–60 caribou per camera during the second deployment. Only five different calves were counted in the near zone (Table 6). The cameras suggested that there was some seasonality in the timing of caribou use of the Stony Hill area. The highest numbers of caribou photographed occurred soon after deployment in late May during spring migration, during the postcalving season in late June, and near the end of the second deployment in September (Figure 25). Based on examination of existing telemetry data, we expected most use of the area to occur during migratory movements by TH caribou.

In addition to caribou, grizzly bears were photographed multiple times during the summer (Figure 26). Lone adult bears were photographed on three occasions at Camera 1 (16 June, 18 June, and 14 July), two occasions at Camera 3 (28, 29 July), and on one occasion at Camera 5 (16 July). Although it was impossible to identify individual bears from these photos, it is likely that many of these photos were of the same bear. Cameras 5 and

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	89	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	38	0	0	0	0	0	0
	2018	51	0	0	0	0	0	0
	All Years	265	0	0	0.01	0.01	0.01	0.01
Calving	2004–08	28	0.04	0.04	0.04	0.04	0.07	0.07
	2009–13	66	0	0	0.05	0.05	0.05	0.05
	2014	16	0	0	0	0	0	0
	2015	18	0	0	0	0	0	0
	2016	23	0	0	0	0	0	0
	2017	29	0	0	0	0	0	0
	2018	20	0	0	0	0	0	0
	All Years	200	0.01	0.01	0.02	0.02	0.03	0.03
Postcalving	2004–08	28	0	0	0	0	0	0
	2009–13	77	0	0	0	0	0	0
	2014	15	0	0	0	0	0	0
	2015	12	0	0	0	0	0	0
	2016	14	0	0	0	0	0	0
	2017	19	0	0	0	0	0	0
	2018	12	0	0	0	0	0	0
	All Years	177	0	0	0	0	0	0
Mosquito	2004–08	24	0	0	0	0	0	0
	2009–13	105	0	0	0	0	0	0
	2014	25	0	0	0	0	0	0
	2015	19	0	0	0	0	0	0
	2016	26	0	0	0	0	0	0
	2017	27	0	0	0	0	0	0
	2018	24	0	0	0.04	0.04	0.04	0.04
	All Years	250	0	0	0.00	0.00	0.00	0.00
Oestrid Fly	2004–08	24	0	0.04	0	0	0	0.04
	2009–13	109	0.09	0.13	0.05	0.05	0.13	0.16
	2014	26	0	0	0	0	0	0
	2015	20	0	0	0	0	0	0
	2016	33	0	0	0	0	0	0
	2017	29	0	0	0	0	0	0
	2018	27	0	0	0	0	0	0
	All Years	268	0.04	0.06	0.02	0.02	0.05	0.07
Late Summer	2004–08	60	0.02	0.02	0.02	0.02	0.02	0.02
	2009–13	122	0	0	0	0	0	0
	2014	25	0	0	0	0	0	0
	2015	26	0	0	0	0	0	0
	2016	50	0	0	0	0	0	0
	2017	68	0	0	0	0	0	0
	2018	79	0	0	0	0	0	0
	All Years	430	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	65	0.02	0.02	0	0.02	0.02	0.02
	2018	78	0	0	0.04	0.04	0.04	0.04
	All Years	418	0.00	0.00	0.04	0.05	0.05	0.05

Table 3. Continued.

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
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	45	0	0	0	0	0	0
	2017	59	0	0	0.02	0.02	0.02	0.02
	2018	0	–	–	–	–	–	–
	All Years	307	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.

6 also showed heavy, almost continuous grazing by geese during the snowmelt period in late May and early June suggesting that this area is high quality spring goose foraging habitat, at least in years with late snowmelt such as 2018.

REMOTE SENSING

Because MODIS imagery covers large areas at a relatively coarse resolution (250- to 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 northern Alaska.

SNOW COVER

Based on observations from survey crews and records from weather stations in the area (Figure 5; Appendix B), the timing of snow melt was later than average for most of the region in 2018. However, due to persistent cloud cover during early June, there was little satellite imagery available to determine the exact timing or regional pattern of snow melt (Figure 27).

The median dates of snow melt for each pixel computed using 2000–2018 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 28; 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 28). 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 28). In the GMT survey area, snow melt occurs earliest near stream channels and a south-to-north gradient was apparent, with snow typically melting several days later near the coast.

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 (Figures 29–30), the estimated vegetative biomass during calving (NDVI_Calving) and during peak lactation (NDVI_621) in 2018 was below average through much of the study area (Figures 29–30;

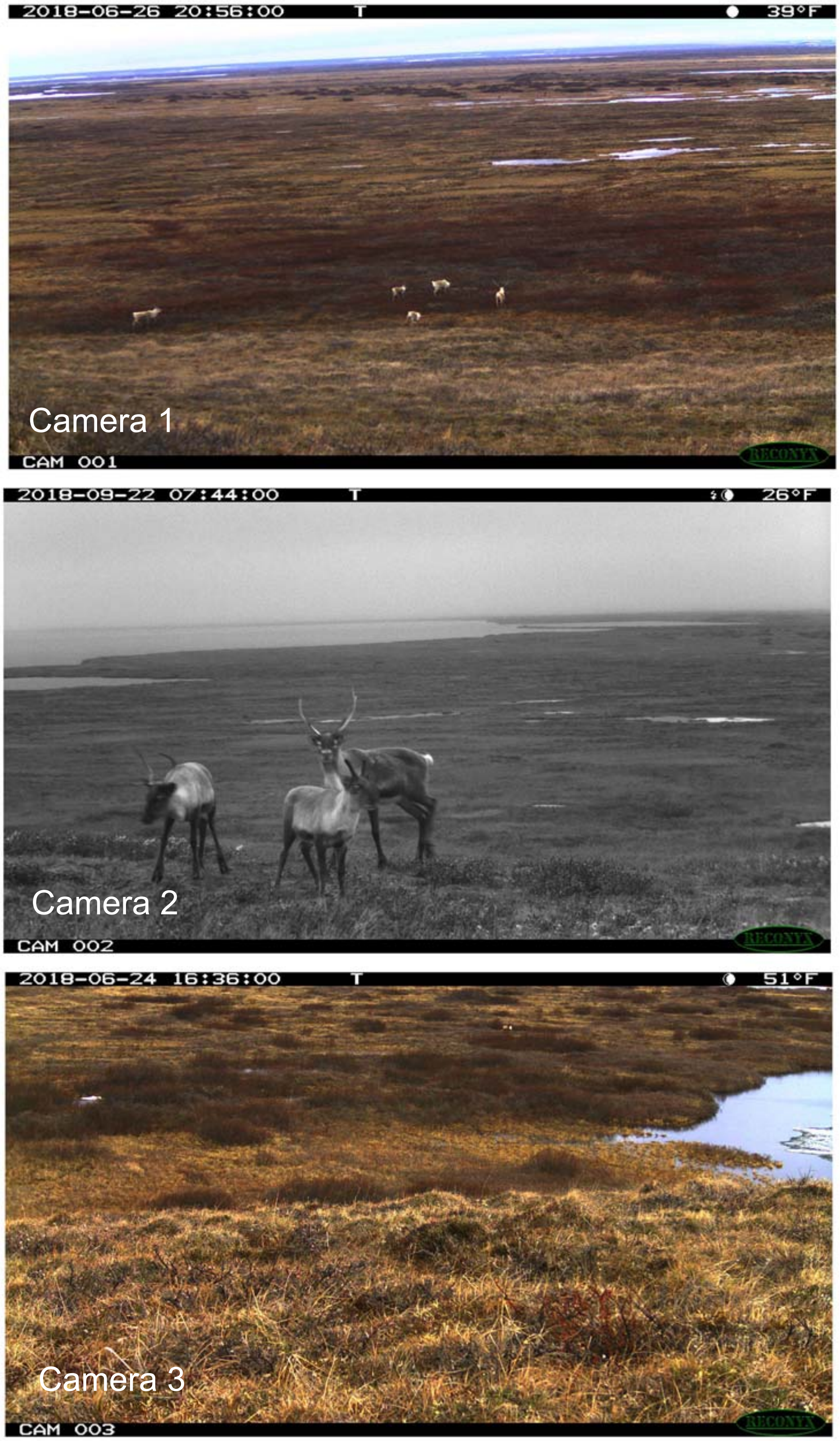

Figure 23. Example photographs taken from time-lapse cameras 1–3 during 2018.

Figure 24. Example photographs taken from time-lapse cameras 4–6 during 2018.

Table 4. Timing, viewing distance, and number of useable photos in time-lapse camera coverage at six locations during two deployment periods in 2018.

	23 May–31 July (2-minute interval)		31 July–6 Oct (2-minute interval)[b]			
Camera Number	Number of Useable Photos[a]	% of Total Photos	Number of Useable Photos[a]	% of Total Photos	End Date	Viewing distance
1	47173	94.7	23437	75.6	12 Sept	View >500 m
2	46201	92.7	31798	65.6	6 Oct	View >500 m, a rising slope at 500 m aids detection of distant herds, and a large lake funnels herd movements pass the camera
3	46328 [b]	93.1 [b]	57128[c]	93.2[c]	21 Aug[c]	View limited to 400 m with brush screening 30% of the land
4	47325	95.1	33719	70.3	6 Oct	The camera aimed at a potential lake crossing site; 150–500 m zone is water; 50% of land is screened by tall shrubs.
5	47468	95.4	32452	69.8	4 Oct	Viewing good to 300 m, then 50% of the land screened by tall shrubs.
6	49423	99.4	33328	70.8	5 Oct	Viewing good to 150 m, and fair to 300 m

[a] Useable photos included photos with ≥ 150 m of visibility.
[b] On the first deployment camera 3 tilted down slightly after deployment limiting the view in the far distance zone.
[c] On the second deployment camera 3 recorded photos at 30-second intervals resulting in a greater number of photos, shorter battery life, and less exposure to frost, therefore a higher % of useable photos, compared to other cameras.

Table 5. Number of time-lapse photographs in which caribou were recorded in the near, middle, and far distance zones during two deployment periods in 2018.

Camera Number	Near Zone (<150 m)	Middle Zone (150-300 m)	Far Zone (>300 m)	Total
Deployment 1 (23 May–31 July)				
1	211	27	267	405
2	23	21	64	108
3	5	13	0	29
4	1	1	5	21
5	5	266	9	282
6	293	148	0	405
Deployment 2 (31 July–6 Oct)				
1	3	2	3	8
2	15	23	112	150
3	7	1	4	12
4	2	0	2	4
5	186	234	15	435
6	100	106	0	206

Table 6. Minimum counts of different caribou counted in the near zone (within 150 m) on time-lapse camera photographs during two deployment periods 2018.

Camera Number	Adult Caribou	Calf Caribou	Total Caribou
Deployment 1 (23 May–31 July)			
1	24	0	24
2	12	0	12
3	8	0	3
4	1	0	1
5	2	0	2
6	39	2	41
Deployment 2 (31 July–6 Oct)			
1	3	0	3
2	18	1	19
3	5	1	5
4	7	1	7
5	60	0	60
6	40	0	40

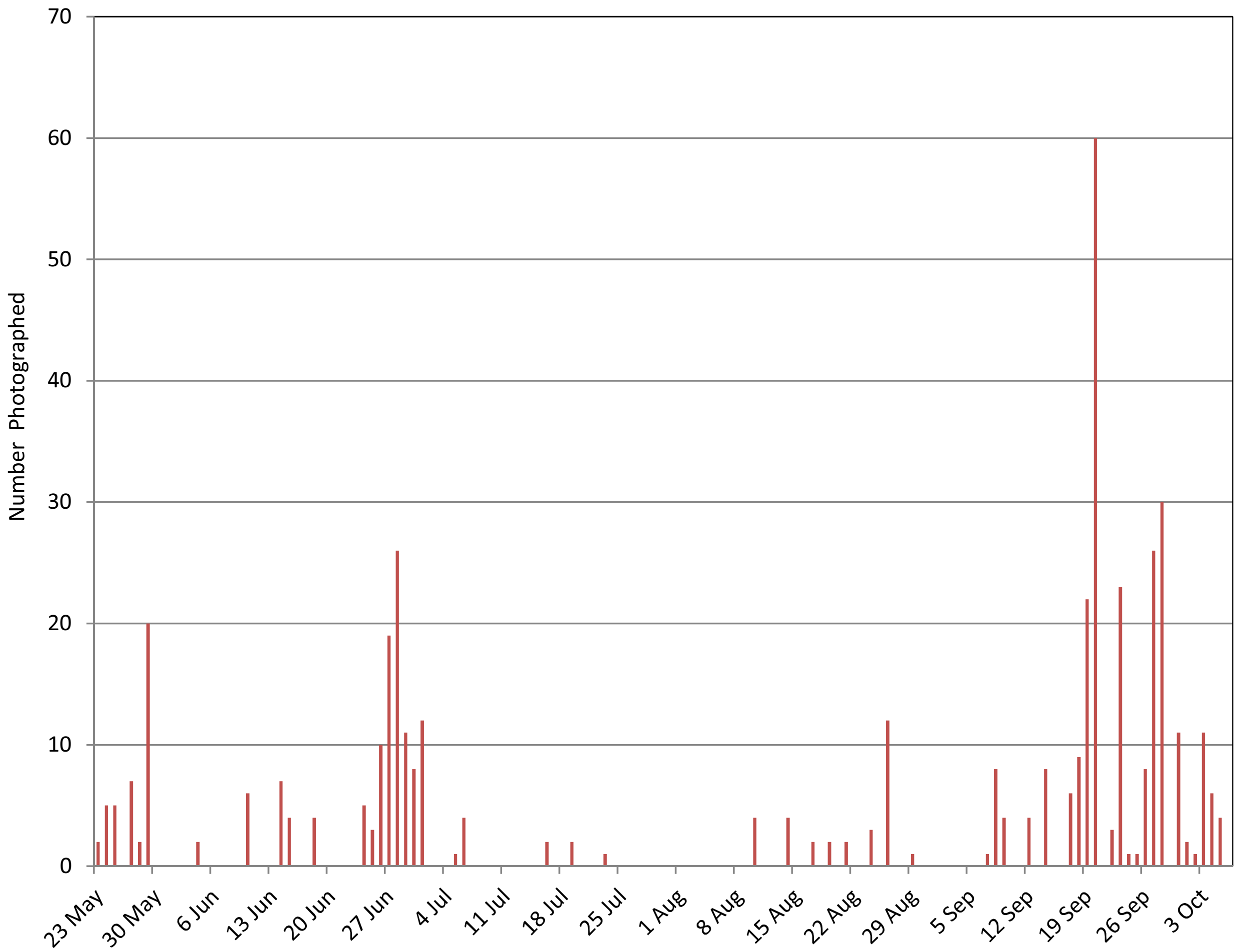

Figure 25. The number of caribou photographed on time-lapse cameras by day, 23 May–6 October 2018.

Appendices D–E). Those values are consistent with the persistent snow cover observed during aerial surveys in early June. But peak NDVI was higher than average in 2018 (Figures 29–30; Appendix F), indicating that vegetation grew rapidly after late June. This is consistent with the above average temperatures recorded in much of July (Figure 6). 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 30).

Although persistent cloud cover limited that area of analysis, NDVI_Rate in 2018 was low in inland areas with earlier snowmelt, but high in more coastal areas where snowmelt occurred later (Figure 30). This is consistent with a rapid increase in NDVI values soon after snowmelt, as standing dead biomass is exposed and rapid new growth of vegetation occurs.

RESOURCE SELECTION ANALYSIS

The RSF analysis of seasonal caribou density is restricted to the GMT and BTU survey areas. Seasonal sample sizes for the location data used in the RSF analysis ranged from 242 to 2,414 for the years 2002–2018 (Table 7). 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 8). Vegetative biomass (maximum NDVI or daily NDVI), biomass, nitrogen, 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

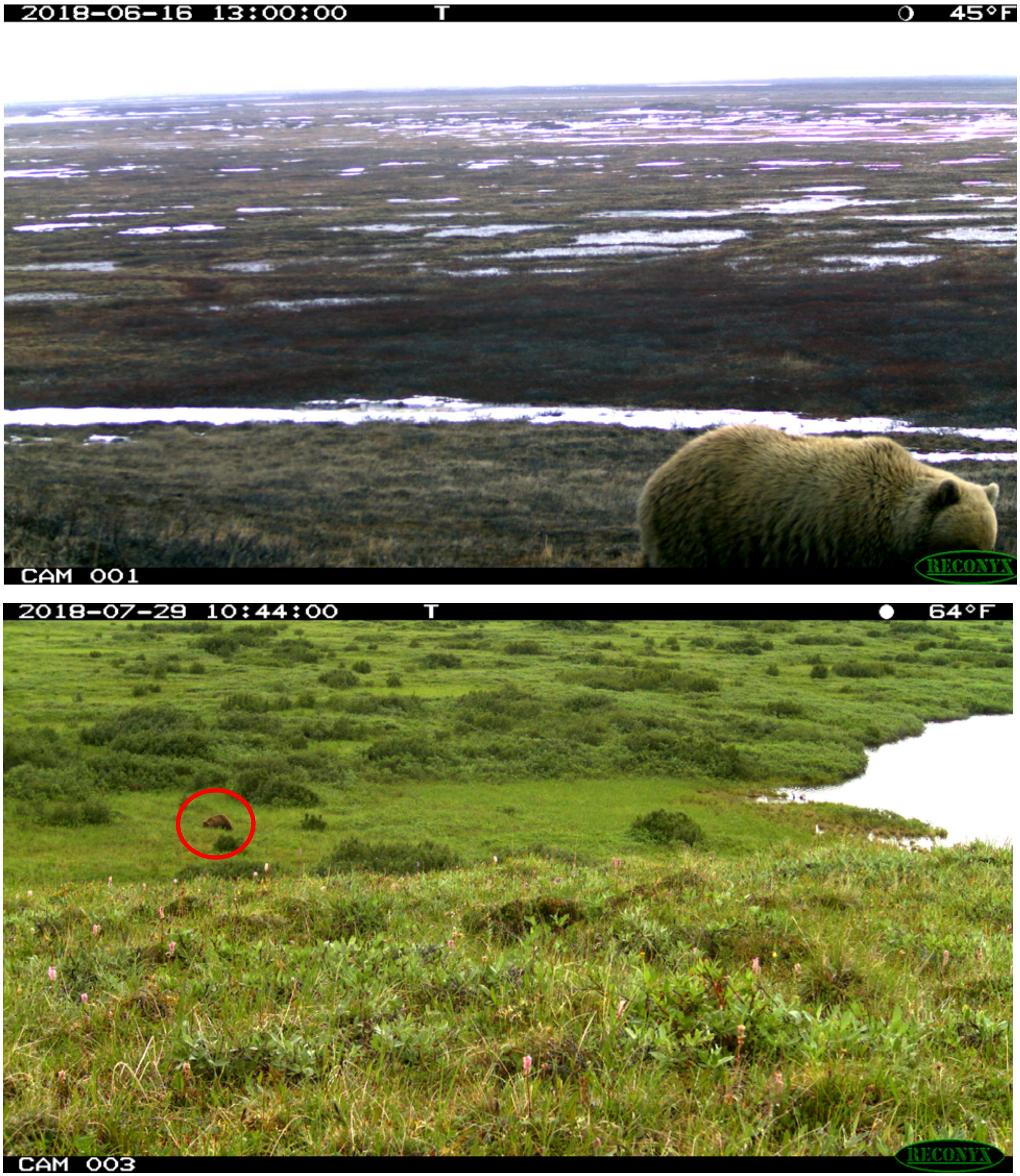

Figure 26. Example photographs taken of Grizzly Bears from time-lapse cameras during 2018.

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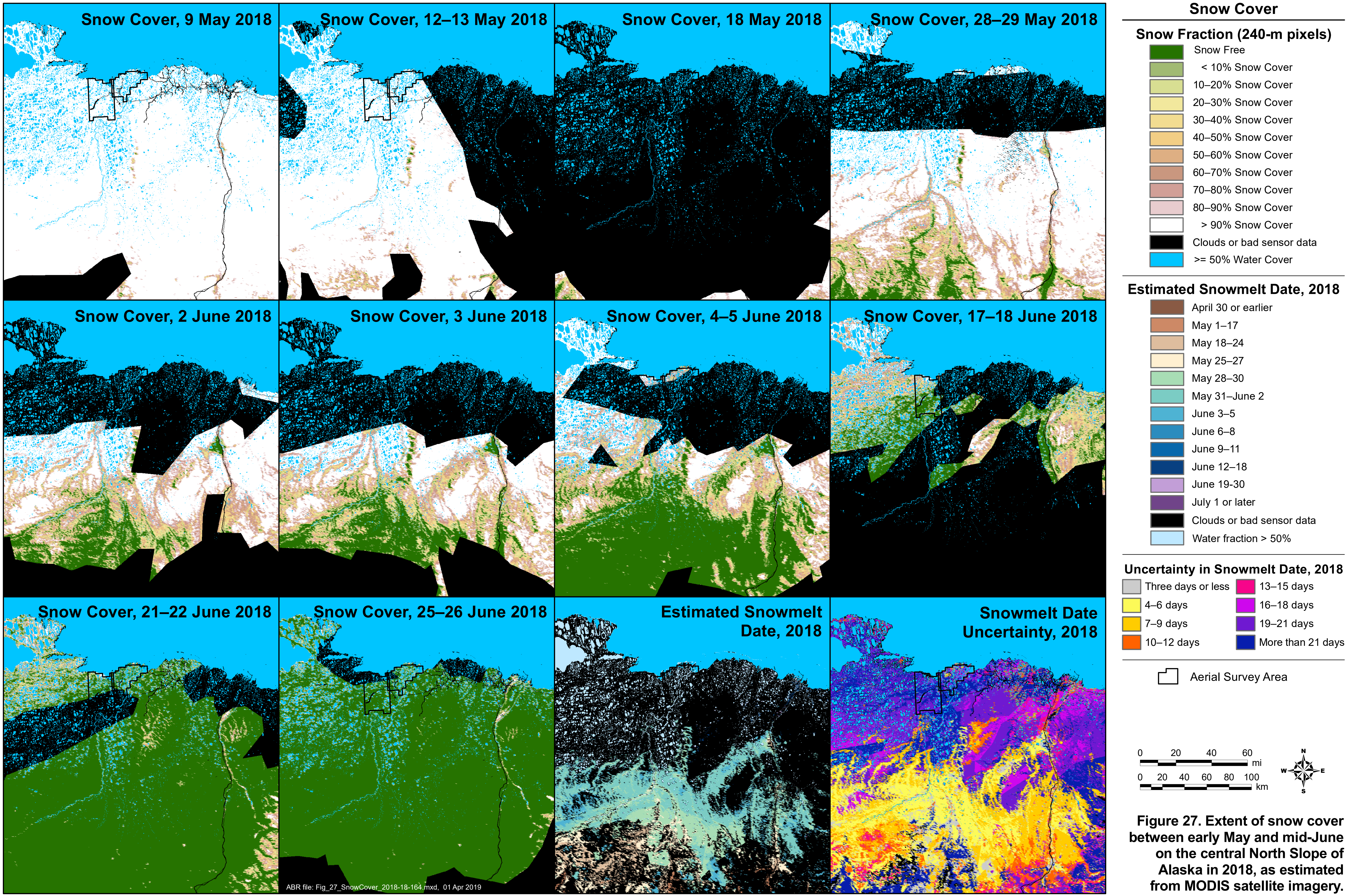

Figure 27. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2018, as estimated from MODIS satellite imagery.

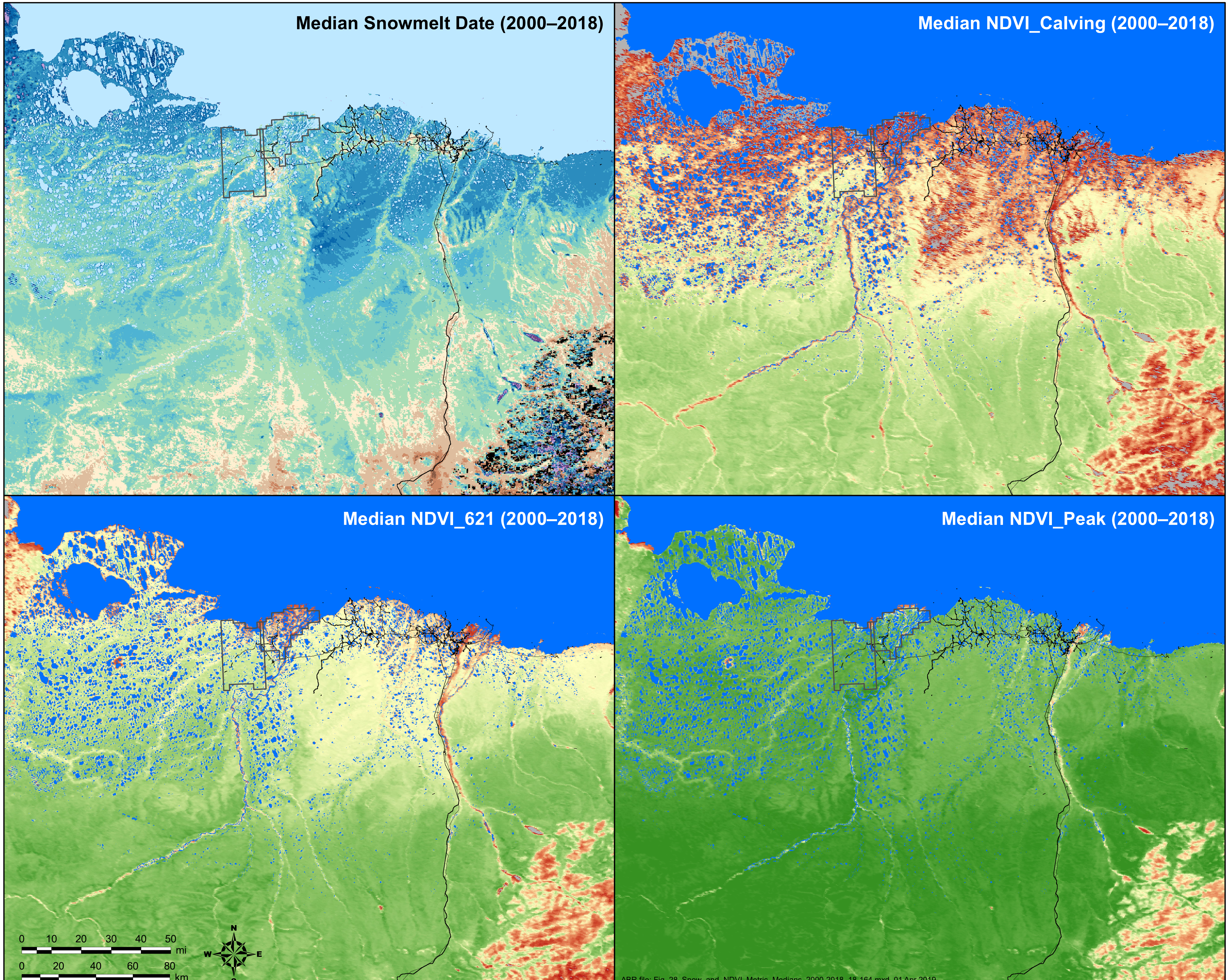

Figure 28.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2018.

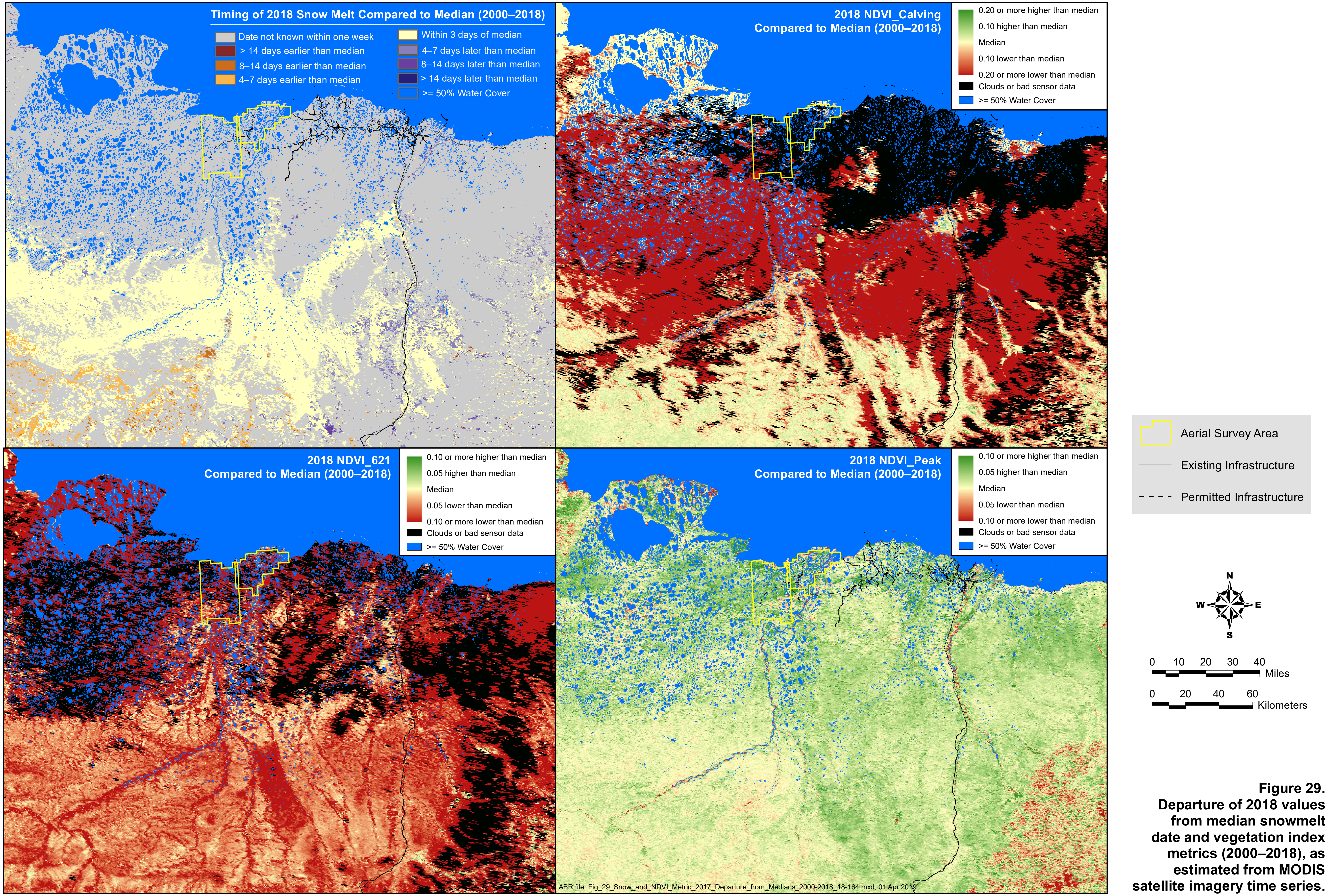

Figure 29.
Departure of 2018 values from median snowmelt date and vegetation index metrics (2000–2018), as estimated from MODIS satellite imagery time series.

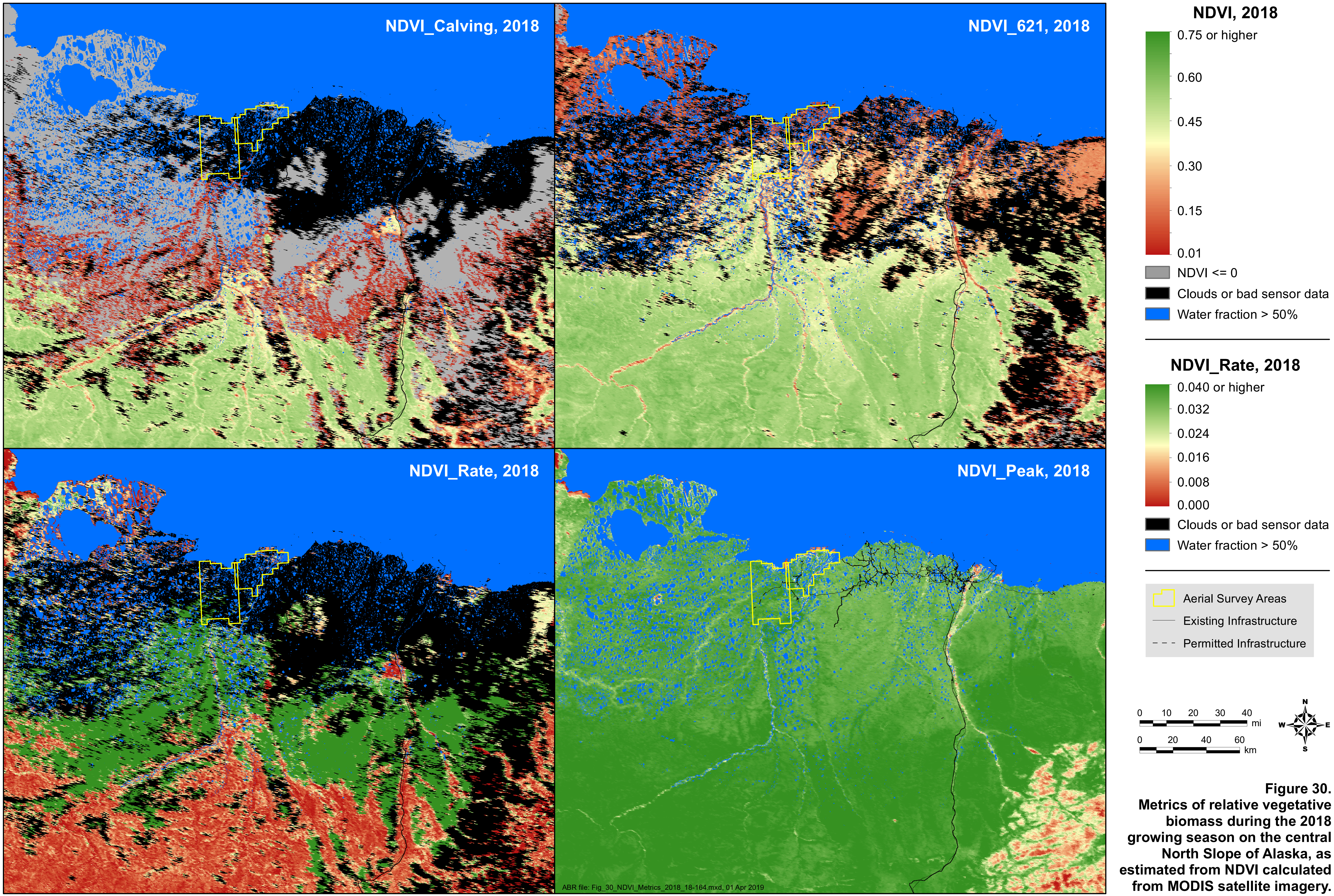

Figure 30.
Metrics of relative vegetative biomass during the 2018 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

Table 7. Number of aerial surveys, radio collars, and locations for each sample type used in RSF analysis for the NPRA survey area, 2002–2018.

Season	Aerial Surveys		Telemetry Data		Total Locations
	Surveys	Locations	Collars	Locations	
Winter	13	880	21	686	1,566
Spring Migration	12	392	24	273	665
Calving	20	1,060	27	109	1,169
Postcalving	19	1,392	19	55	1,447
Mosquito	5	82	36	160	242
Oestrid Fly	13	259	57	325	584
Late Summer	26	1,222	48	1,027	2,249
Fall Migration	20	1,207	64	1,207	2,414
Total	128	6,494	296	3,842	10,336

NPRA had reasonably good model fits (Pearson's r = 0.94–0.99; Table 9). The variables with the highest probability of being in the best RSF model (Table 10) varied by season but caribou resource selection in the area generally followed a gradient of increasing selection from east to west in all seasons and from south to north in most seasons (Figure 31; Table 11). 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 8) 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 10). We used all variables with a 50% or greater probability of being in the best model to produce seasonal RSF maps (Figure 31). 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 11). These individual parameter estimate results were useful for examining the effect of each habitat type.

For the winter season, all variables except maximum NDVI were included in the best model (Tables 8 and 10), 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 landscape ruggedness were selected by caribou (Figure 31). Although snowmelt date was included in the best model, the model-weighted variable was not significant. Five habitat types (*Carex aquatilis*, Flooded Tundra, Moss/Lichen, Riverine, and Wet Tundra) were avoided by caribou, relative to the reference category (Sedge/Grass Meadow; Table 11).

All of the variables except snowmelt date were included in the best model for spring migration (Tables 8 and 10), although a model with snowmelt date was the second best model (Table 8). 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 20). Areas with higher landscape ruggedness were selected. Although the habitat variable was included in the best model, none of the individual habitat classes were significantly different from the reference class (Sedge/Grass Meadow; Table 11). This selection for higher landscape ruggedness may reflect selection for areas having less snow and spring flooding, or higher proportions of preferred forage species (Nellemann and Thomsen 1994, Nellemann and Cameron 1996).

During the calving season, the variables habitat, daily NDVI, nitrogen, west-to-east, landscape ruggedness, and snowmelt date were included in the best model (Tables 8 and 10), although there was considerable model uncertainty

Table 8. 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 GMT, BTN, and BTS survey areas, 2002–2018 (combined aerial survey and telemetry data).

Season	RSF Model	AICc	Akaike Weight
Winter	Habitat + EtoW + DistCoast + logRuggedness + Snow	13,048.48	0.576188
	Habitat + maxNDVI + EtoW + DistCoast + logRuggedness + Snow	13,050.28	0.233387
	Habitat + EtoW + DistCoast + logRuggedness	13,051.42	0.132372
Spring Migration	Habitat + MaxNDVI + EtoW + DistCoast + logRuggedness	5,541.74	0.319818
	Habitat + MaxNDVI + EtoW + DistCoast + logRuggedness + Snow	5,542.96	0.174002
	EtoW + DistCoast + logRuggedness	5,543.53	0.130256
Calving	Habitat + dNDVI + Nitrogen + EtoW + logRuggedness + Snow	9,730.46	0.063564
	Habitat + dNDVI + EtoW + logRuggedness + Snow	9,730.95	0.049914
	Habitat + dNDVI + MaxNDVI + Nitrogen + EtoW + logRuggedness + Snow	9,731.12	0.045703
Postcalving	Habitat + dNDVI + Biomass + EtoW + DistCoast + logRuggedness	12,111.20	0.247756
	Habitat + dNDVI + Biomass + Nitrogen + EtoW + DistCoast + logRuggedness	12,112.62	0.121862
	Habitat + dNDVI + EtoW + DistCoast + logRuggedness	12,112.78	0.112792
Mosquito	EtoW + DistCoast + logRuggedness	1,760.88	0.129886
	dNDVI + EtoW + DistCoast + logRuggedness	1,761.64	0.088855
	Biomass + EtoW + DistCoast + logRuggedness	1,761.74	0.084195
Oestrid Fly	Habitat + dNDVI + EtoW + DistCoast + logRuggedness	4,842.70	0.164223
	Habitat + dNDVI + Biomass + EtoW + DistCoast + logRuggedness	4,843.40	0.115823
	Habitat + dNDVI + Nitrogen + EtoW + DistCoast + logRuggedness	4,843.56	0.107226
Late Summer	Habitat + dNDVI + Biomass + EtoW + DistCoast + logRuggedness	18,995.67	0.404707
	Habitat + dNDVI + MaxNDVI + Biomass + EtoW + DistCoast + logRuggedness	18,997.64	0.150864
	Habitat + dNDVI + Biomass + Nitrogen + EtoW + DistCoast + logRuggedness	18,997.67	0.149032
Fall Migration	Habitat + EtoW + DistCoast + logRuggedness	20,073.75	0.698580
	Habitat + MaxNDVI + EtoW + DistCoast + logRuggedness	20,075.49	0.292806
	Habitat + EtoW + DistCoast	20,083.23	0.006127

Table 9. Mean Pearson's rank correlation coefficient (*r*) of seasonal RSF model fit using k-fold cross-validation for the NPRA survey area, 2002–2018 (combined aerial survey and telemetry data).

Season	Correlation Coefficient
Winter	0.98
Spring Migration	0.93
Calving	0.87
Postcalving	0.99
Mosquito	0.98
Oestrid Fly	0.94
Late Summer	0.95
Fall Migration	0.98

(Table 8). Caribou were more likely to be located in the western portion of the study area and in areas with high NDVI levels, but lower landscape ruggedness (Table 11; Figure 31), reflecting the western distribution of high-density calving by the TH.

During the postcalving season, the variables habitat, daily NDVI, biomass, west-to-east, distance to coast, and landscape ruggedness were included in the best model (Tables 8 and 10), although there was also some support for nitrogen in the best model (Table 8). Caribou selected areas farther west, closer to the coast, with higher NDVI, and with higher landscape ruggedness (Table 11; Figure 31). 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 ruggedness were included in the best model. Models with biomass and nitrogen also had some support, but habitat only had a 28% chance of being in the best model (Tables 8 and 10). Caribou primarily selected areas farther west, closer to the coast, and with higher ruggedness (Table 11; Figure 31). These results suggest that mosquito harassment is the primary driver of caribou distribution during this season, and the need to access mosquito-relief habitat near the coast is more important than factors such as habitat quality.

During the oestrid fly season, the variables habitat, daily NDVI, west-to-east, distance to coast, and landscape ruggedness were included in the best model (Tables 8 and 10), although there was a fair amount of model uncertainty. Caribou selected areas farther west, closer to the coast, and with greater ruggedness (Table 11; Figure 31). Relative to Sedge/Grass Meadow habitat, caribou also selected for all other habitats.

During late summer, habitat type, daily NDVI, biomass, west-to-east gradient, distance to coast, and landscape ruggedness were included in the best model (Tables 8 and 10). Caribou selected areas farther west, closer to the coast, with higher ruggedness, and with lower biomass. Relative to Sedge/Grass Meadow habitat, caribou also selected Moss/Lichen and Riverine habitat types and avoided *Carex aquatilis* and Flooded Tundra habitat types (Table 11, Figure 31).

During fall migration, habitat type, west-to-east, distance to coast, and landscape ruggedness were included in the best RSF model (Tables 8 and 10). Caribou selected areas farther west, closer to the coast, and with low landscape ruggedness. Relative to Sedge/Grass Meadow habitat, caribou also avoided *Carex aquatilis*, Flooded Tundra, Tussock Tundra, and Wet Tundra habitats and selected Moss/Lichen habitat (Table 11; Figure 31).

DISCUSSION

WEATHER, SNOW, AND INSECT CONDITIONS

Weather conditions exert strong effects on caribou populations throughout the year in northern 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 snowmelt 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

Table 10. 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, 2002–2018 (combined aerial survey and telemetry data). Variables with a probability ≥0.5 were used in RSF maps (Figure 31).

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	1.00	0.50	1.00	1.00	1.00	0.96	1.00
Max NDVI	0.29	0.64	0.55	0.33	0.30	0.40	0.28	0.30
Daily NDVI	–	–	1.00	0.99	0.36	0.61	0.80	–
Nitrogen	–	–	0.55	0.37	0.29	0.35	0.28	–
Biomass	–	–	0.36	0.67	0.33	0.36	0.98	–
Snowmelt Date	0.81	0.32	0.74	–	–	–	–	–
Ruggedness	1.00	1.00	0.96	1.00	0.99	1.00	1.00	0.99
Habitat	1.00	0.67	0.70	0.84	0.28	1.00	1.00	1.00

Table 11. Model-weighted parameter estimates for RSF models for the NPRA survey area during eight seasons, 2002–2018 (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	**-0.36**	**-0.52**	**-0.40**	**-0.49**	**-1.06**	**-0.42**	**-0.29**	**-0.46**
Distance to Coast	**-0.32**	**-0.41**	-0.04	**-0.42**	**-1.71**	**-0.53**	**-0.08**	**-0.31**
Max NDVI [a]	0.00	-0.06	0.03	0.01	0.01	-0.02	0.00	0.00
Daily NDVI [a]	–	–	**0.42**	**0.27**	0.04	-0.17	0.11	–
Biomass [a]	–	–	-0.03	0.09	0.03	0.02	**-0.13**	–
Nitrogen [a]	–	–	-0.07	0.02	0.02	0.02	0.00	–
Snowmelt Date	0.05	-0.01	0.05	–	–	–	–	–
Ruggedness	**0.14**	**0.22**	**-0.10**	**0.21**	**0.19**	**0.22**	**0.08**	**-0.08**
Carex aquatilis [b]	**-0.54**	-0.25	-0.14	-0.25	0.00	**0.59**	**-0.44**	**-1.19**
Dwarf Shrub [b]	0.25	-0.12	-0.26	0.10	0.11	**1.06**	0.17	0.13
Flooded Tundra [b]	**-0.55**	-0.04	-0.26	-0.11	-0.22	**0.56**	**-0.24**	**-0.50**
Moss/Lichen [b]	**-1.23**	-0.37	-0.52	0.16	-0.14	**1.54**	**0.54**	**0.64**
Riverine [b]	**-1.20**	-0.59	-0.14	0.33	0.02	**1.25**	**0.45**	-0.09
Tussock Tundra [b]	-0.03	-0.10	-0.08	0.02	0.01	**0.44**	0.02	**-0.17**
Wet Tundra [b]	**-0.65**	0.09	-0.16	0.07	-0.12	**0.60**	0.02	**-0.34**

[a] Max NDVI values were used all year, while the daily NDVI, Biomass, and Nitrogen values which are derived daily during the growing season were used for the Calving, Postcalving, Mosquito, Oestrid Fly, and Late Summer seasons.

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

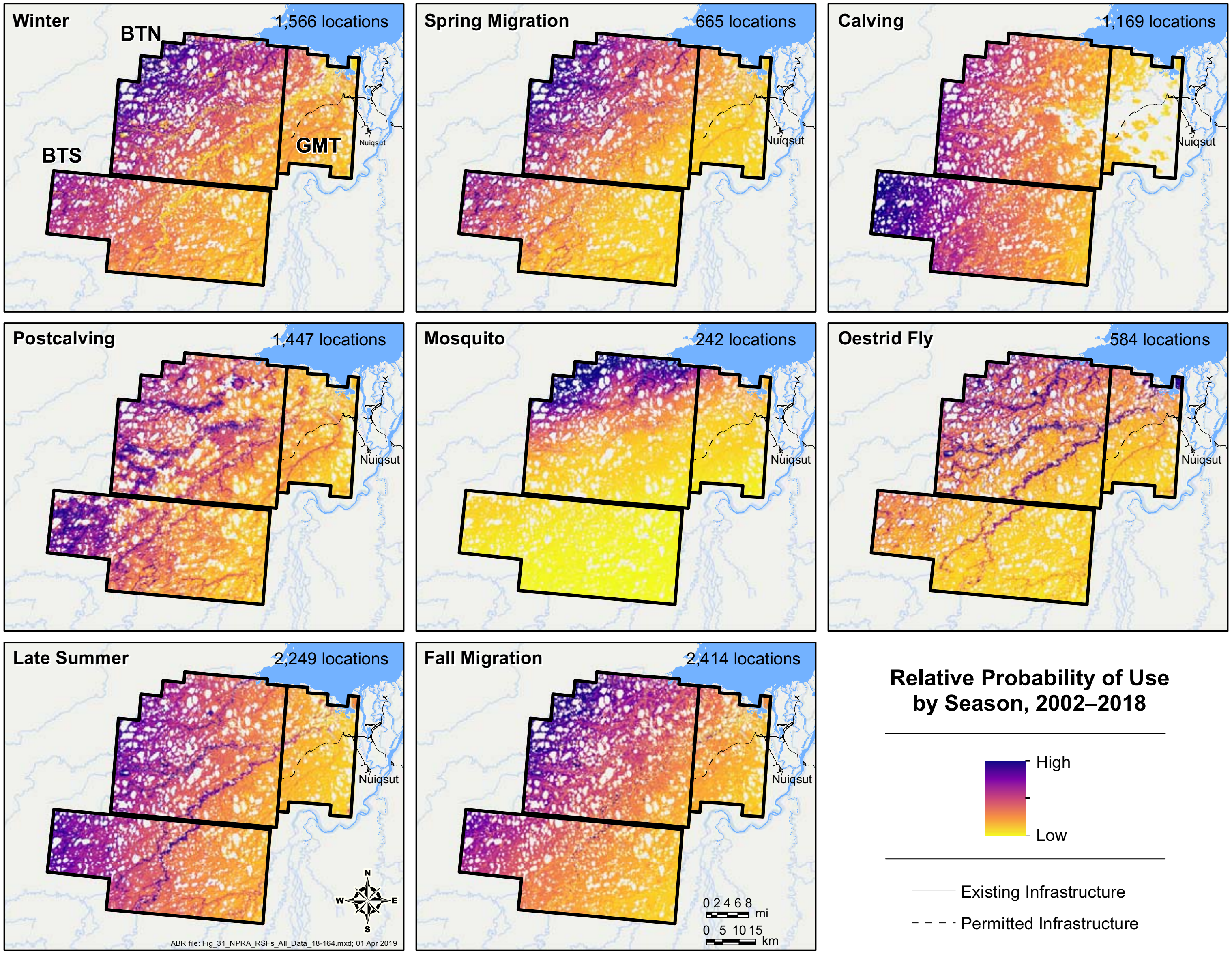

Figure 31. Predicted relative probability of use of the NPRA survey area by caribou during eight different seasons, 2002–2018, based on RSF analysis. Relative probabilities calculated using the 2018 values for daily NDVI, biomass, and nitrogen.

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 wind conditions and changes in insect activity. On the central 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).

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. This combination of a late spring and hot summer likely resulted in a lower than average body condition of caribou by late July 2018. Cool conditions in late summer and delayed onset of seasonal snow cover (typical of recent years on the coastal plain; Cox et al. 2017) may have allowed caribou to increase their forage rate and improve their body condition prior to the onset of winter.

CARIBOU DISTRIBUTION AND MOVEMENTS

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 only low levels of calving occur the GMT and CRD survey areas which are used mainly by TH caribou, in contrast to the area east of the Colville River delta, where high density calving occurs and is used mainly by CAH caribou for calving (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 GMT study area (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015a). A few collared CAH females have switched to the TH and 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 rapid speed of caribou movements during that period (Prichard et al. 2014), and the highly aggregated and unpredictable nature of caribou 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 GMT survey area was on 2 August 2005 (Lawhead et al. 2006). Since we began transect surveys in the NPRA in 2001, the highest densities in that region have tended to occur during the oestrid fly season (which overlaps with the typical period of mosquito activity) and fall migration (Figure 6). In 2018, however, caribou density was low during the oestrid fly season survey on 1 August and highest during the postcalving survey on 27 June (Table 2), reflecting the high variability during that season.

Density increased on the late summer survey on 29 August and again on the late September survey (Table 2). Poor flying conditions caused by persistent inclement weather have limited our ability to conduct surveys consistently during fall migration. Only nine surveys could be conducted in September and October during the years 2009–2018, so we have not been able to sample that period as much as planned. Therefore, due to poor weather and limited daylight in October, we only scheduled one aerial survey during the fall migration season in 2018.

High caribou densities also have been recorded sporadically in the GMT survey region in late winter (e.g., 2.4 caribou/km² in April 2003) and the postcalving season (e.g., 1.5 caribou/km² in late June 2001) (Burgess et al. 2002, Johnson et al. 2004, Lawhead et al. 2010). It is important to highlight that in previous years, the ASDP survey area in the NPRA extended further west than the current GMT survey area reported on here. Since caribou densities tend to increase in areas farther west and closer to Teshekpuk Lake, densities reported in earlier years for a larger survey area were expected to be higher than densities in the smaller, more eastern GMT survey area, so direct comparisons of mean density are not possible.

Research to date shows that caribou are most likely to occur in the CRD survey area during the insect season (mosquito and oestrid fly periods, from late June to early August), and during the late summer season in late August when oestrid flies may still be active. In 2018, surveys of the CRD outside of the postcalving, oestrid fly, and late summer seasons were suspended due to low use outside of those seasons. Use of the area is primarily by CAH animals during the mosquito season and animals from both the TH and CAH during the oestrid fly season. When mosquito harassment begins in late June or early July, caribou move toward the coast 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 to the 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 3- to 5-year intervals in past summers (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 GMT-1 road and planned GMT-2 road. The highest number of caribou seen on Colville River delta transect surveys during 2001–2018 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 and GMT 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, 2 TH caribou crossed in 2016, 2 crossed in 2017, and 6 crossed in 2018.

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 of the delta on the Colville River 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 summers 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.

TIME-LAPSE CAMERAS

The time-lapse camera results indicated that the Stony Hill area had low density use by small groups of caribou between 23 May and early October. The cameras were deployed near the end of spring migration, and continued to function until early in the fall migratory period. Due to the cold weather during migratory periods and the increasing darkness during fall, collecting photographs for longer periods becomes increasingly challenging. We were, however, able to document caribou use of the area for over four months of the summer with only one visit to the cameras during midsummer.

The camera results were largely consistent with the expected timing of use of the area by caribou as determined from the available telemetry data in the area. We found that there was a low level of use throughout the time period monitored, but the highest number of caribou photographed occurred during the spring and fall migratory periods and during the postcalving season in late June (Figure 25). Based on our understanding of caribou movements in the area from telemetry data, caribou using the area during late May or September are most likely migrating TH animals. Caribou in the area during the late June postcalving period could be male TH moving to the summer range from wintering areas in the Brooks Range or CAH caribou that were unusually far west. Caribou counts from time-lapse cameras were highest on either end of the large lake where caribou movements are likely to be funneled (Figure 4; Table 6).

RESOURCE SELECTION

The two data sets (aerial transect surveys and radio telemetry) that were 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 48 hours. 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 conducted only periodically throughout the year. The lower spatial accuracy of aerial survey data necessitated the consolidation of the most common mapped habitats into 210-m 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–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 coastal plain.

Use of the RSF analysis 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 17–19).

These geographic patterns in TH distribution are most pronounced during calving and the mosquito season. Because the GMT 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 lower in the GMT survey area than in the larger NPRA survey area used in previous years (Prichard et al. 2018b). During calving, the highest densities of TH females typically calve near Teshekpuk Lake (Figure 20; 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 west of the survey area 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 densities in the area of the GMT-1 and planned GMT-2 road alignment are generally low during the mosquito and oestrid fly seasons, but large groups occur occasionally in the area during the oestrid fly season, 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 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 locations with 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*, Flooded Tundra, and Wet 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 postcalving, oestrid fly season and late summer and avoidance of Riverine habitat during winter (Table 11). The riparian habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 4) 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 habitat classification of BLM and Ducks Unlimited (2002), as in this study, to investigate summer habitat selection at two different spatial scales, and concluded that TH caribou consistently selected Sedge/Grass Meadow and avoided flooded vegetation.

During calving, caribou in the RSF analysis area tended to use areas of higher vegetative biomass (daily NDVI) but the confidence interval for date of snowmelt and habitat both included zero indicating no large effect. Habitat selection during the calving season may vary annually, depending on the timing of snow melt and plant phenology. In 2018, the distribution of collared TH females, as well as our aerial survey results, suggest that the TH calving distribution was farther west than usual.

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 our RSF analysis area 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 NDVI values in both late June and midsummer.

Johnson et al. (2018) used NDVI values as well as habitat type, distance to coast, and days from peak NDVI to develop models to predict biomass, nitrogen, and digestible energy for a given location on a given day. These models should, if successful, provide metrics that are more directly related to caribou forage needs than NDVI alone. In our RSF models, however, biomass and nitrogen were rarely in any of the top models. The only season in which biomass was significant was late summer and the model indicated that areas with higher estimated forage biomass values were avoided (Table 11). These results suggest that these derived values are not good predictors of caribou distribution in this area and at this scale of selection.

It is possible that these models do not predict biomass and nitrogen well in this area. Johnson et al. (2018) used a land cover map (Boggs et al. 2016) that was based on a land cover map created by Ducks Unlimited for the North Slope Science Initiative (NSSI 2013) that has discontinuities in classification methodology and imagery in our RSF analysis area. These discontinuities could translate into inaccurate forage metrics in our analysis area. Alternatively, caribou may not be selecting for forage nitrogen or forage biomass at this scale of selection and caribou distribution may be better predicted by high NDVI values which tend to be correlated with locations that have both large amounts of vegetation and less surface water in the pixel. Caribou movements are influenced by many factors other than forage and only a portion of GPS locations represent caribou that are actively feeding.

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 snowmelt 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/GMT study area and to compile predevelopment baseline data on caribou density and movements in the GMT-2 portion of the 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).

For this report, we incorporated multiple types of data and several different analyses to better understand the seasonal distributions, movements, and herd associations of caribou in the area. Aerial surveys provided detailed information on caribou density and distribution at a specific time during the year and by conducting aerial surveys during different seasons over the course of 18 years in northeastern NPRA, we have compiled an extensive dataset that allows us to understand the seasonal patterns as well as the variability in caribou distribution over this specific area. The use of telemetry data provided high-resolution locations for a subset of caribou throughout the year. This large and growing database allows us to understand caribou movements through the area for the two different herds which use the area but it also allows us to put local caribou movements in the study area into the broader context of the annual herd ranges and seasonal herd distributions. Lastly, we incorporated aerial survey results and telemetry data with remote sensing information on land cover, vegetative biomass, and snow cover to better understand the factors determining caribou seasonal distribution. This understanding of the underlying factors that are important to caribou will be useful when evaluating potential future changes in caribou distribution that may be attributable to development or a changing climate.

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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, 1983–2018.

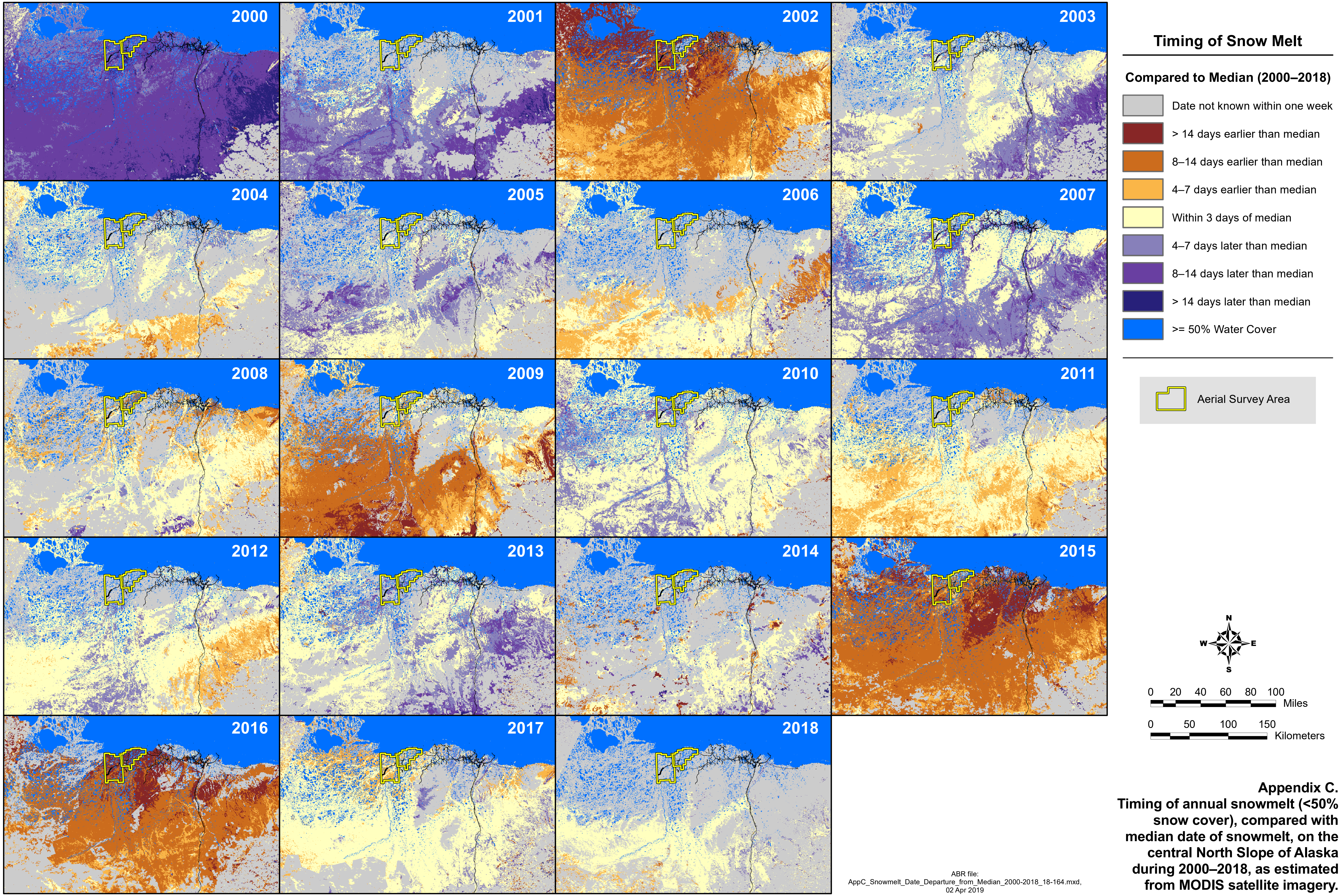
	Snow Depth (cm)			Cumulative Thawing Degree-days (ºC)						
Year	1 April	15 May	31 May	1–15 May	16–31 May	1–15 June	16–30 June	1–15 July	16–31 July	1–15 August
1983	10	5	0	0	3.6	53.8	66.2	74.7	103.8	100.3
1984	18	15	0	0	0	55.6	75.3	122.8	146.4	99.5
1985	10	8	0	0	10.3	18.6	92.8	84.7	99.4	100.0
1986	33	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
2018	41	20	15	1.35	0	6.6	47.7	137	195.9	55.25
Mean	25.6	14.4	3.3	1.3	11.8	41.8	101.9	128.0	144.9	125.0

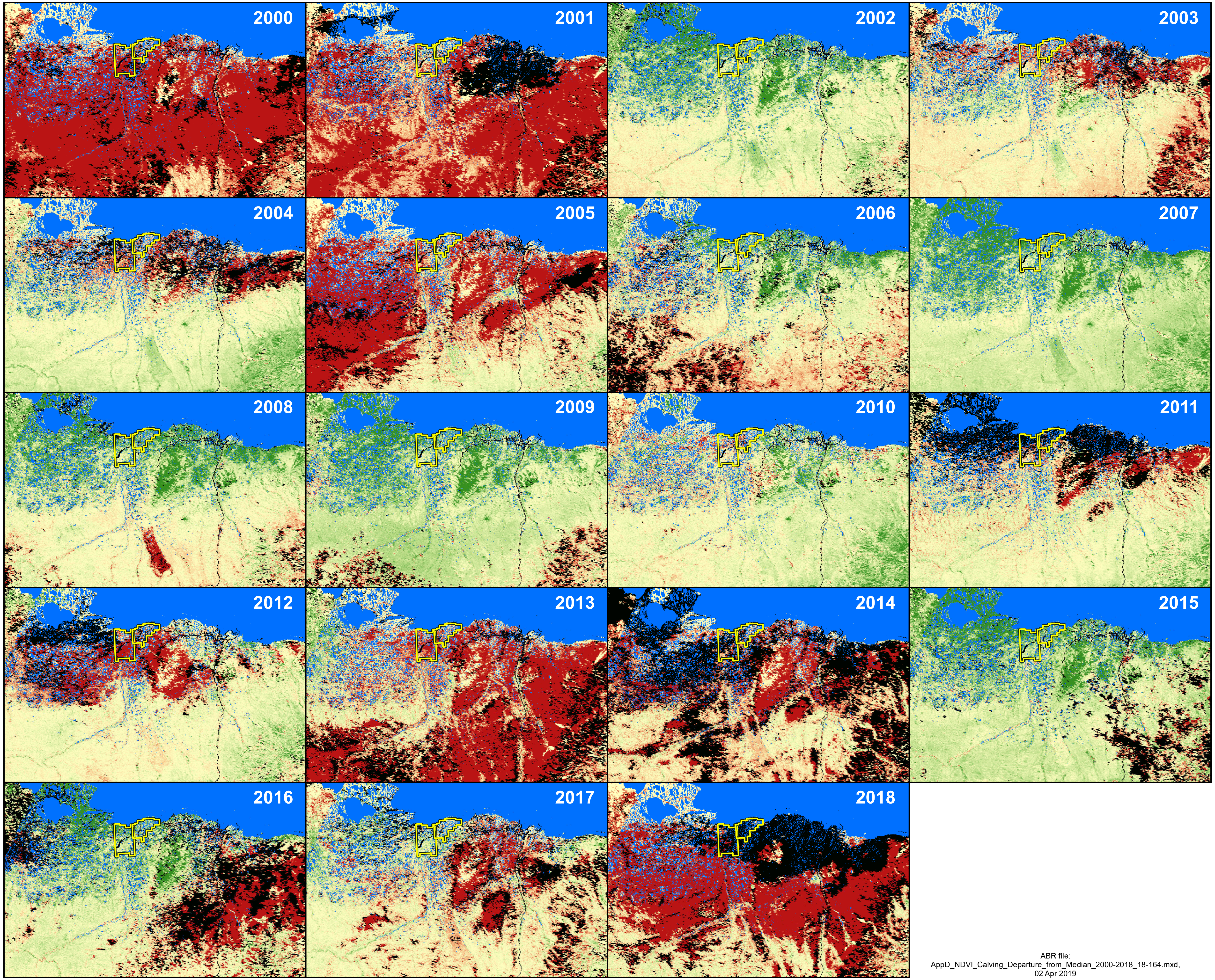
[a] Kuparuk weather data were not available for 17 June–9 December 2011, 4–14 August 2012, and 30–31 August 2012, so cumulative TDD for those periods were estimated by averaging Deadhorse and Nuiqsut temperatures (Lawhead and Prichard 2012).

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



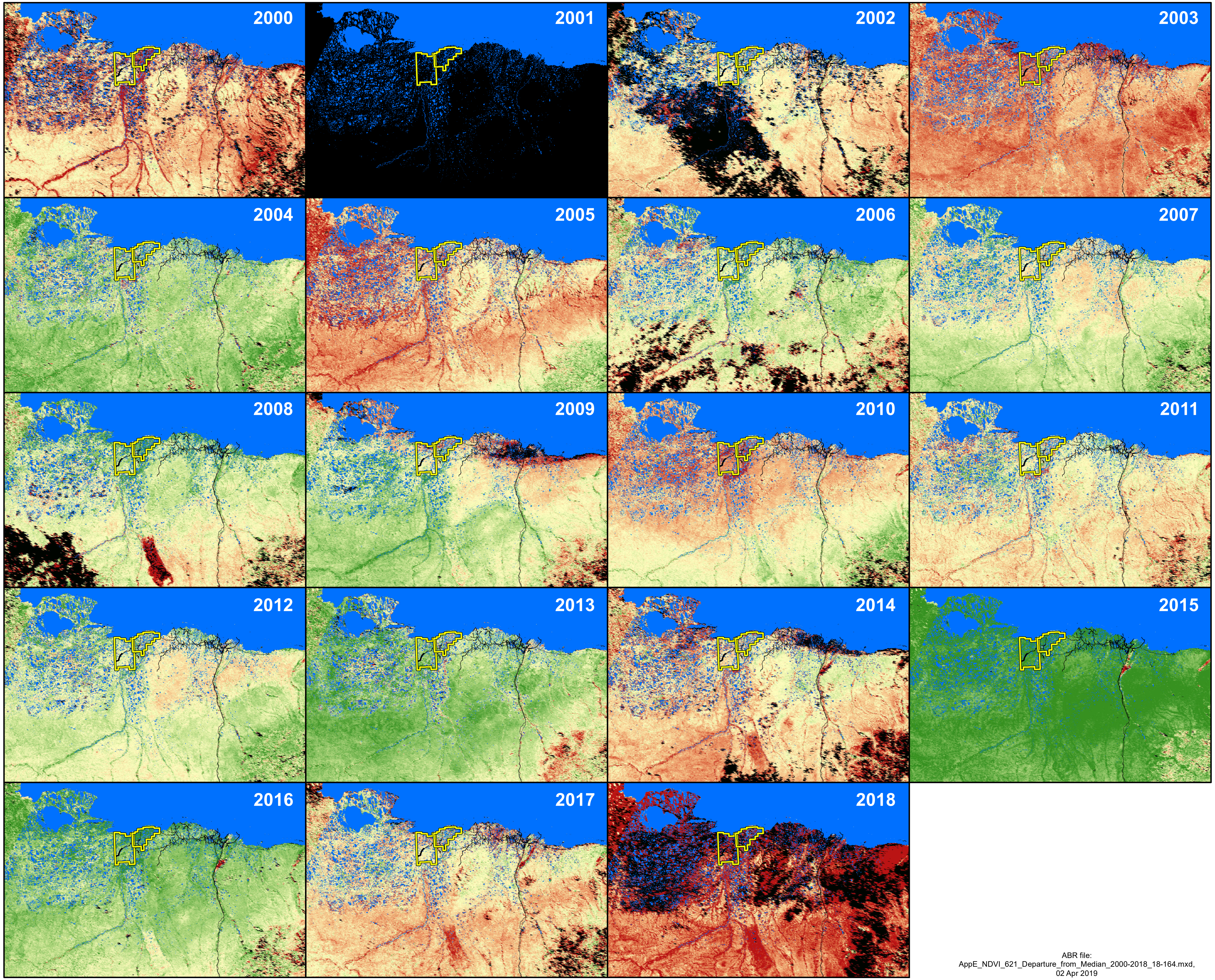
ABR file:
AppC_Snowmelt_Date_Departure_from_Median_2000-2018_18-164.mxd,
02 Apr 2019

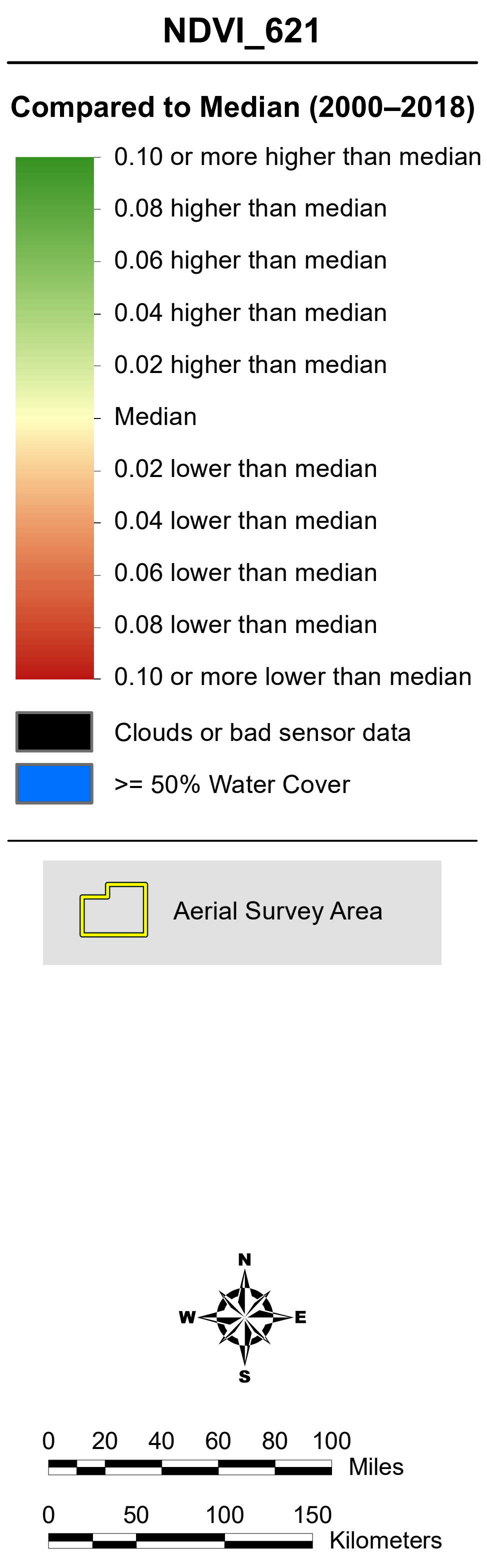
Appendix C.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2018, as estimated from MODIS satellite imagery.



ABR file:
AppD_NDVI_Calving_Departure_from_Median_2000-2018_18-164.mxd,
02 Apr 2019

**Appendix D.
Differences between annual relative vegetative biomass values and the 2000–2018 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.**





Appendix E. Differences between annual relative vegetative biomass values and the 2000–2018 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:
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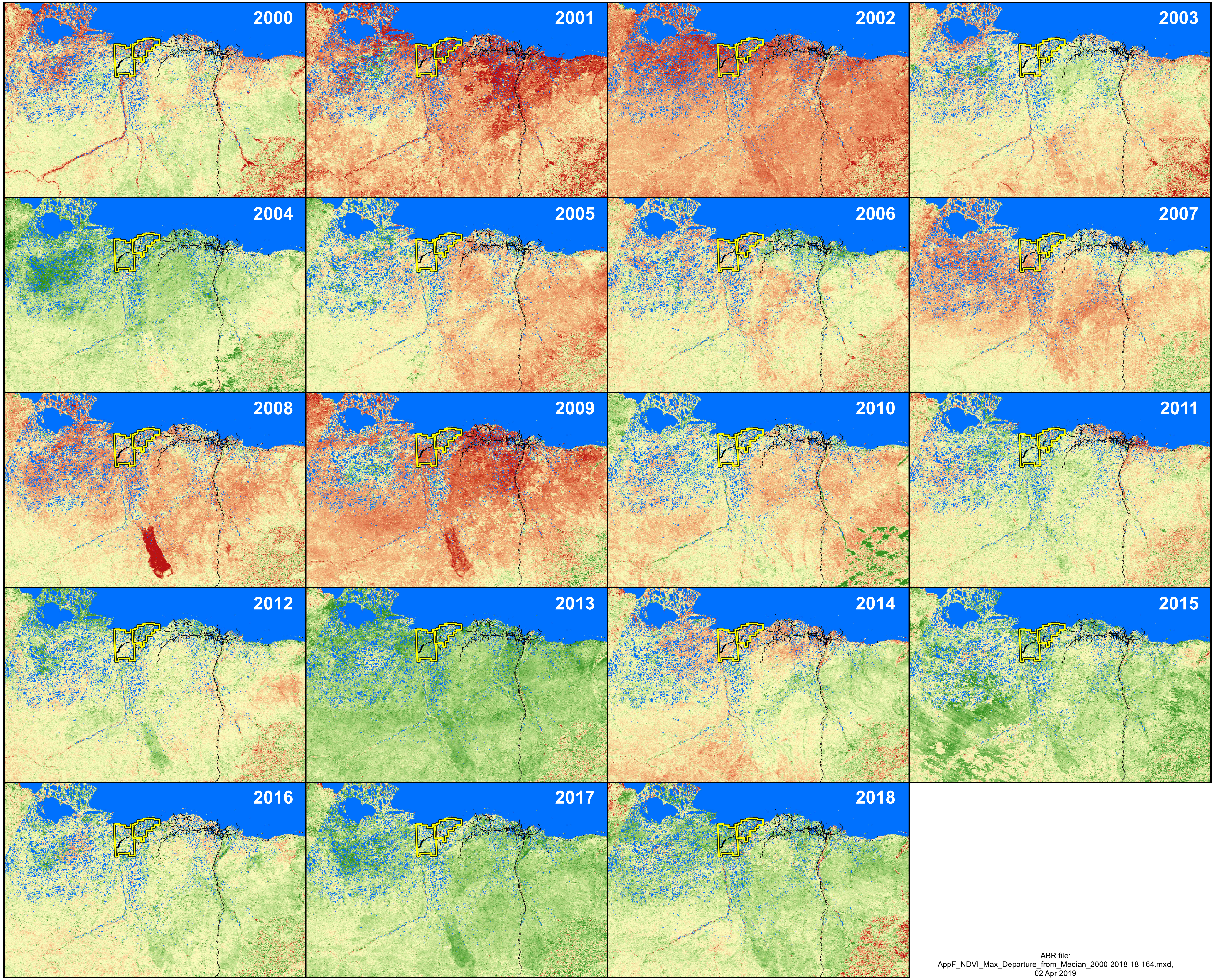
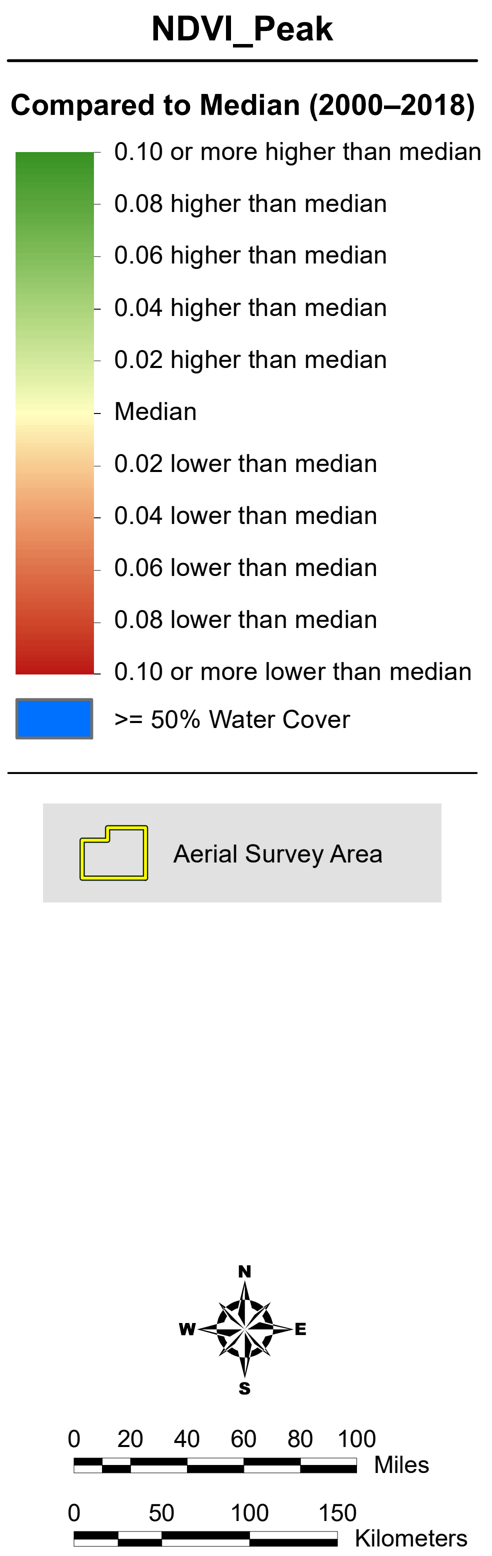
02 Apr 2019





ABR file:
AppF_NDVI_Max_Departure_from_Median_2000-2018-18-164.mxd,
02 Apr 2019

Appendix F.
Differences between annual relative vegetative biomass values and the 2000–2018 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.