CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM AND GREATER MOOSE'S TOOTH UNIT, 2019

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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

- Caribou use of the Alpine Satellite Development and Greater Moose's Tooth Unit areas has been studied since 2001 using a combinations of aerial surveys, analysis of telemetry data, and remote sensing in order to understand caribou distribution and movements prior to development in the area. This research has continued after construction of the CD-5 and GMT1/MT6 roads. This report summarizes field research conducted in 2019 and analyses of data collected over the life of the project.
- Spring 2019 was warmer than average and snow melted earlier than usual at the Kuparuk airport. June temperatures remained near average, but July temperatures were above average and likely resulted in higher than average levels of insect harassment. August temperatures were generally near average while September temperatures were above average.
- We completed 5 of 7 planned aerial transect surveys of the Greater Moose's Tooth (GMT) survey area between April and October 2019. The estimated density ranged from a maximum of 0.36 caribou/km² on 17–18 June to a minimum of 0.02 caribou/km² on 30 July. Only 3 calves were observed in the GMT area during the calving survey on 4–6 June.
- We completed all 3 planned aerial transect surveys of the Colville River Delta (CRD) survey area during the postcalving, oestrid fly, and late summer seasons. The estimated density in the survey area was 0.06 caribou/km² on each survey.
- 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 Caribou Herd (TCH) 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 NDVI and phenology.
- The GMT survey area is on the eastern edge of the TCH range and gets some use by TCH females throughout the year; use by TCH 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 TCH 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.
- We observed one grizzly bear in the survey areas during 2019. There were three observations of a muskoxen group east of the Colville River delta, outside of our survey area.

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ACKNOWLEDGMENTS

This study was funded by ConocoPhillips Alaska, Inc. (CPAI) and was administered by Robyn McGhee, CPAI Environmental Studies Coordinator, for whose support we are grateful. Valuable assistance with field logistics was provided by Justin Blank, Zac Hobbs, and Krista Kenny. Alaska Department of Fish and Game (ADFG) biologists played crucial collaborative roles in this study by capturing caribou, deploying radio collars, and providing telemetry data under a cooperative agreement among ADFG, CPAI, and ABR. We thank ADFG biologists Lincoln Parrett and Elizabeth Lenart for their professional cooperation and assistance. Brian Person of the North Slope Borough Department of Wildlife Management (NSB) provided GPS and satellite telemetry data, valuable information, and advice. Bob Gill and Ron Vogt of 70 North LLC provided safe and efficient piloting of survey airplanes under flying conditions that often were less than optimal. Assistance in the field was provided by ABR employees John Shook, Katie Hayden, Forrest Rosenbower, and Robert McNown. Support during data collection, analysis, and report production was provided by Christopher Swingley, Dorte Dissing, Will Lentz, Pamela Odom, and Tony LaCortiglia. Review by Adrian Gall of ABR improved this report.

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 (Figure 1), an area that is used at various times of the year by two neighboring herds of barren-ground caribou (*Rangifer tarandus granti*)—the Teshekpuk Caribou Herd (TCH) and the Central Arctic Herd (CAH). The TCH 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, Parrett 2015a, Lenart 2015, Nicholson et al. 2016).

The TCH tends to remain on the coastal plain year-round. Most calving occurs 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 TCH has expanded, with some calving occurring as far west as the Ikpikpuk River and west of Atqasuk (Parrett 2015a; Prichard et al. 2019a).

Most TCH 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 TCH animals wintered far to the east in the Arctic National Wildlife Refuge (ANWR) in 2003–2004 following an October rain-on-snow event (Carroll et al. 2004, Bieniek et al. 2019).

The TCH increased substantially in size from the mid-1970s, when it consisted of only a few thousand animals, to the early 1990s (Figure 2; Parrett 2015a). The TCH experienced a dip in numbers in the early 1990s, but increased steadily

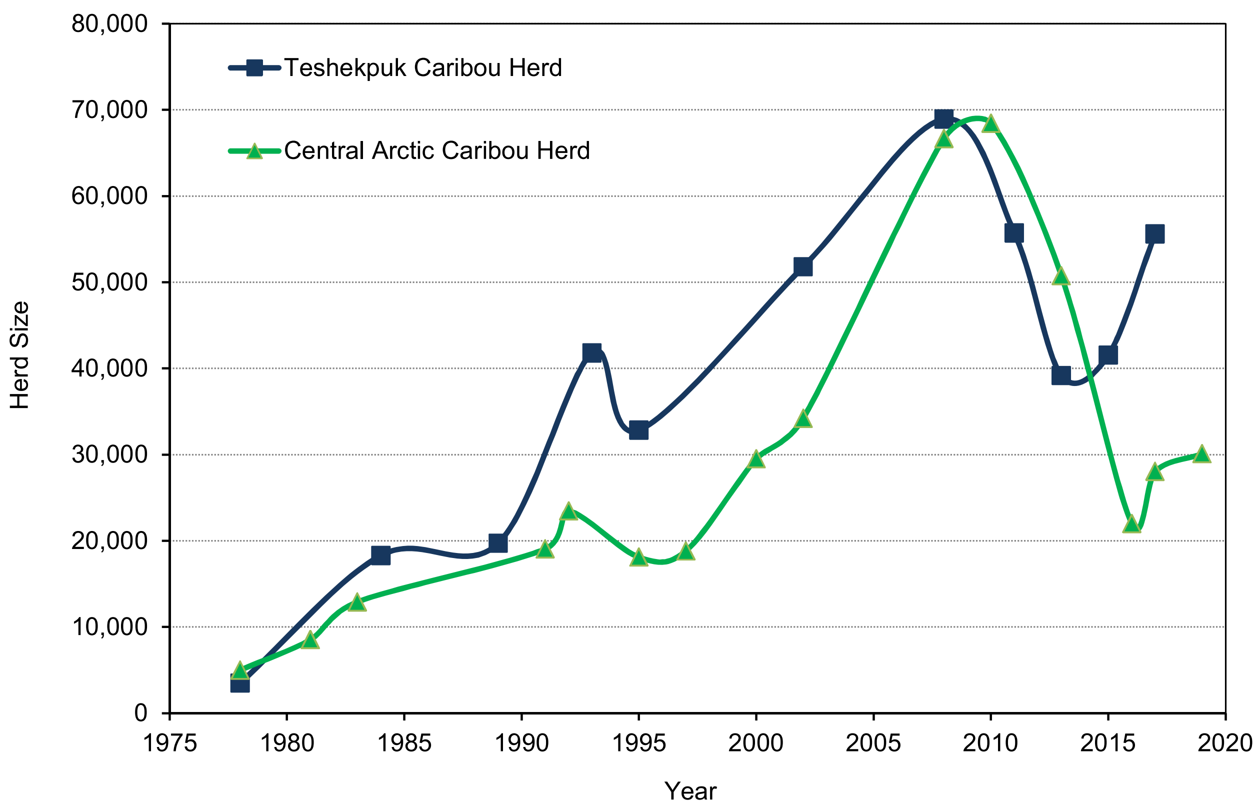

Figure 1. Population size of the Teshekpuk and Central Arctic caribou herds, 1975–2019, based on ADFG census estimates (see text for details).

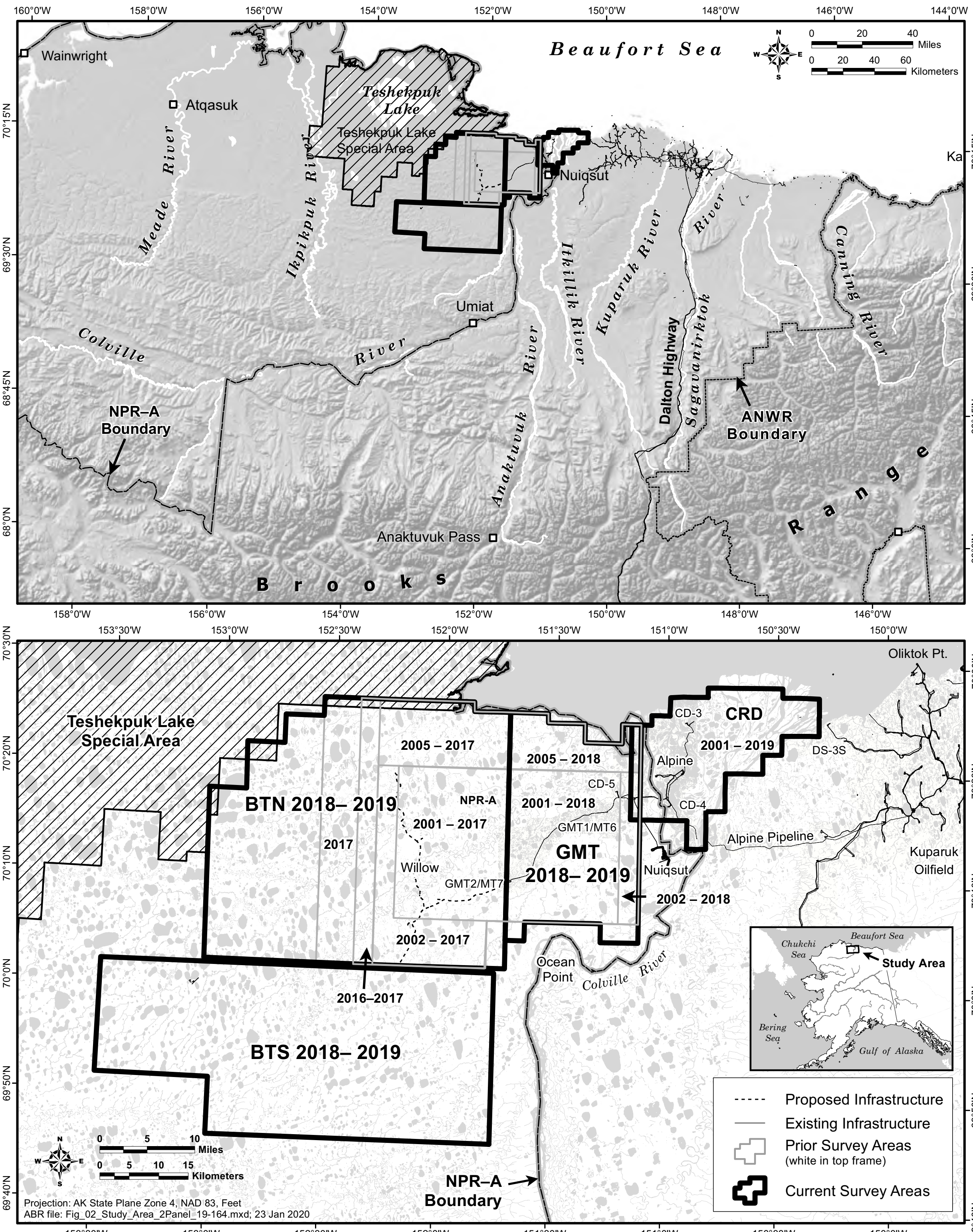

Figure 2. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the GMT and Colville River Delta survey areas, 2001–2019.

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 2015b). Although new higher-resolution digital photography introduced in 2017 may have contributed to higher population counts since 2015, the increase in estimated herd size indicates that the TCH 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, Nicholson et al. 2019). CAH caribou calving in the western area exhibit localized avoidance of the area within 2–5 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, Johnson et al. 2020, Prichard et al. 2020a). 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, Lenart 2015, Nicholson et al. 2016), although many animals have remained north of the Brooks Range in the foothills or on the coastal plain in recent years (Prichard et al. 2019b, 2019c; E. Lenart, ADFG, pers. comm.).

From the early 1970s to 2002, the CAH grew at an overall rate of 7% per year (Figure 2; 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 TCH 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), but increased to 30,069 by July 2019 (Lenart 2019). The magnitude of the decline from 2013 to 2016 may have been affected by emigration of some CAH animals to the PCH and TCH, with which the CAH often intermixes on winter range (ADFG 2017, Prichard et al. 2020b).

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) beginning in 1992 and in the northeastern portion of the NPRA beginning in 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. 2019b, 2019c). Consultants working for BP Exploration (Alaska), Inc., conducted aerial transect surveys over much of the TCH 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 of individuals and those affecting distribution of herds. 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 consistent 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 among 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 distribution, remote-sensing data, and other landscape features to better understand factors influencing the seasonal distribution of caribou.
4. Record and summarize observations of other large mammals in the study area.

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 3 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 (CRD) survey area that 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 GMT2/MT7 rezoning process. In 2016, the study area was redefined to focus on the NPRA and CRD 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 GMT1/MT6 constructed in winter 2013–2014 and 2016–2017, respectively), and the proposed GMT2/MT7 drill site, as well as their connecting access roads and pipelines (Figure 1, 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 GMT2/MT7, which encompasses the Willow prospect within the Bear Tooth Unit (BTU), was expanded west as the Bear Tooth North (BTN) survey area and south as the Bear Tooth South (BTS) survey area to focus on those respective developments and data from that area are reported elsewhere (Prichard et. al 2020d). 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.

The study area is located on the central Arctic Coastal Plain of northern Alaska (Figure 1, top). The climate in the region is arctic maritime (Walker and Morgan 1964). The summer thaw period lasts about 3 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 3 weeks from late May to mid-June, and is characterized by the flooding and break-up of rivers and smaller tundra streams. In late May, water from melting snow flows both over and under the ice on the Colville River, resulting in flooding on the Colville River delta that typically peaks during late May or the first week of June (Walker 1983). 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 TCH and CAH caribou in the study area in 2019, 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 2 hours during summer with less frequent locations during the winter; a typical collar deployment lasted 3 years.

Eight seasons per year 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 2019, 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 CRD survey areas (Figure 1, bottom) were conducted periodically from April to October 2019 in a fixed-wing airplane (Cessna 207), following the same procedures used since 2001 (Lawhead et al. 2015 and references therein). In 2019, 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 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 winter and spring migration surveys of the GMT survey area were not completed.

During all aerial surveys, 2 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). Transect lines were spaced at intervals of 3.2 km (2 mi), following section lines on USGS topographic maps (scale 1:63,360). Observers counted caribou within an 800-m-wide strip on each side of the airplane, thus sampling ~50% of the survey area on each survey. The number of caribou observed in the transect strips was therefore 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.

DENSITY MAPPING

To summarize aerial survey data in the area for the period 2002–2019, we used the inverse distance-weighted (IDW) interpolation technique of the *gstat* package (Pebesma 2004) in program *R* (R Core Team 2019) to map seasonal densities of caribou. To be consistent with previous reports and to display caribou density in a wider context, we conducted IDW calculations for all aerial survey areas 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 since 2018 (Prichard et al. 2019b, *in prep.*). 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. We calculated density in each grid cell by dividing the total number of caribou observed in a grid cell 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

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 TCH animals during the period July 1990–November 2019 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015; Person et al. 2007; Prichard et al. 2017, 2018b, 2019c, this study) and for CAH caribou during the periods October 1986–July 1990 (from USGS), July 2001–September 2004, and April 2012–November 2019 (Cameron et al. 1989, Fancy et al. 1992, Lawhead et al. 2006, Lenart 2015; Table 1). In the TCH sample (based on herd affiliation at capture), 185 collars deployed on 165 different caribou (86 females, 79 males) transmitted signals for a mean duration of 563 days per collar. The CAH 1986–1990 sample included 17 caribou (16 females, 1 male). The CAH 2001–2004 and 2012–2019 deployment samples

Table 1. Number of TCH and CAH radio-collar deployments and total number of collared animals that provided movement data for the ASDP and 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	1990–2019	97	86	88	79	185
GPS collars	2004–2019	289	207	15	14	304
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	2012–2019	6	6	6	6	12
GPS collars	2003–2019	182	127	0	0	182

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

included 24 collars deployed on 24 caribou (16 females, 8 males), transmitting for a mean duration of 641 days per collar. Only collars that transmitted for >14 d were included in analysis. Satellite telemetry locations are considered accurate to within 0.5–1.0 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 304 times by ADFG biologists on 221 different TCH caribou (207 females, 14 males; Table 1) during 2004 and 2006–2019, with a mean deployment duration of 575 days. GPS collars (purchased by CPAI and ADFG) were deployed 182 times on 127 different female CAH caribou during 2003–2019, with a mean duration of 563 days. Only collars that transmitted for >14 d were included in analysis. 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 14 collars deployed on TCH 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 CRD 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 movements of individual caribou in the immediate vicinity of existing ASDP infrastructure. All GPS-collared TCH segments were mapped to visualize movements in the study area. Then, to summarize crossings of the newly developed GMT1/MT6 and GMT2/MT7 roads, we also calculated the proportion of collared caribou that crossed each road during each season and year combination. Few collared CAH animals of either sex or TCH males were available for analysis, so we only summarized TCH females. Locations within 30 days of collaring were removed and animals with locations for less than half a season or fewer than 30 locations per season were excluded from analysis for that season.

To calculate kernels, we first calculated the mean location of each caribou for every 2-day period during the year. We used fixed-kernel density estimation in the *ks* package for *R* (Duong 2017) to create utilization distribution contours of caribou distribution for every 2-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 TCH females during the calving season to delineate the calving range of the TCH.

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 TCH 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 TCH 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).

REMOTE SENSING

We analyzed 2019 snow cover and 2000–2019 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 2018b 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 from 2000–2015, 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 2016–2019 imagery, probably due to changes in the data and data format from the aging MODIS sensors. For 2016–2019, 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). The Terra sensor was no longer reliable for snow mapping in 2017, so we used MODIS Aqua data for snow mapping in 2017–2019. The 2018–2019 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 2000–2019. Pixels with >50% water (or ice) cover were excluded from the analysis. For each pixel in each year, we identified:

- The first date with 50% or lower snow cover (i.e., "melted");
- The closest prior date with >50% snow cover (i.e., "snow");
- 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 2000–2019. The data products used were MOD09GA.006 (Terra Surface Reflectance Daily Global 1km and 500m) and MYD09GA.006 (MYD09GA.006 Aqua Surface Reflectance Daily L2G Global 1km and 500m). NDVI during the calving period (NDVI_Calving) was calculated from a 10-day composite period (1–10 June) for each year during 2000–2019 (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 2000–2019. 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 2019, 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 4 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 (2002–2019) 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 4 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 3) 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 fulv*a classes were combined into a single Water type; these largely aquatic types are used very little by caribou, so the Water type was excluded from the analysis of habitat preference.

Some previous reports (e.g., Lawhead et al. 2015) used a land-cover map created by Ducks Unlimited for the North Slope Science Initiative (NSSI 2013); however, discontinuities in classification methodology and imagery bisected our survey area and potentially resulted in land-cover classification differences in different portions of the survey area, and 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, estimated daily values of vegetative NDVI, estimated annual maximum values of vegetative NDVI, forage nitrogen content, and forage biomass. We evaluated the relationship of those factors to caribou distribution by using resource

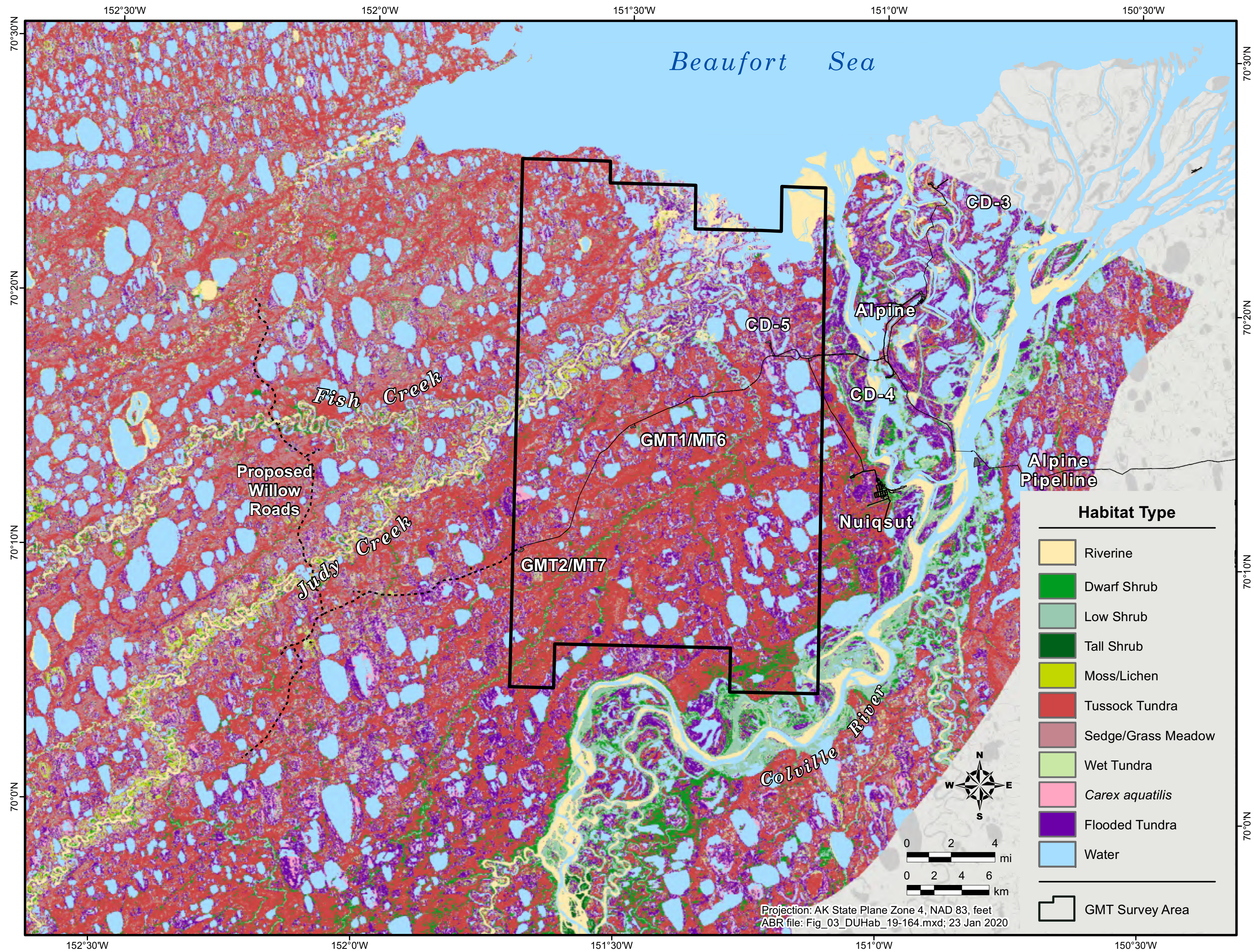

Figure 3. Habitat types used for caribou habitat-selection analysis in the NPRA survey area (adapted from BLM and Ducks Unlimited 2002).

selection function (RSF) models (Boyce and McDonald 1999, Manly et al. 2002). RSF models allow simultaneous comparison of selection for multiple variables and incorporate caribou locations from both aerial surveys and radio telemetry. RSF models compare actual locations with random locations (use vs. availability). They are a useful tool for quantifying important factors influencing habitat selection during different seasons and for assessing relative importance of different areas to caribou based on the spatial pattern of those factors.

We used group locations from aerial surveys and locations from GPS-collared individuals for the RSF analysis. Locations of satellite-collared animals were not used due to the lower accuracy of those locations. We used caribou locations from aerial transect surveys conducted during 2002–2019 in the BTN, BTS, and GMT combined survey areas, but the seasonal sample sizes for the CRD survey area were too small to support RSF analysis. The available telemetry data spanned the period 11 May 2003–30 December 2019 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 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 package AED in program 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 (testing data) and calculated relative probabilities of use for locations used by those caribou 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. 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). For values of explanatory variables, we used daily NDVI, calculated nitrogen and biomass for the midpoint of each season in 2019, maximum NDVI in 2019, and the median date of snowmelt for 2000–2019.

OTHER MAMMALS

Observations of other large mammals were recorded during field surveys (both aerial and ground-based) for this and other wildlife studies conducted for CPAI. Observations in other survey areas were summarized in separate reports (Prichard et al. 2020c, 2020d).

RESULTS

WEATHER CONDITIONS

Spring 2019 was warmer than the 30-year average (1983–2018) and snow melted earlier than usual at the Kuparuk airport (Figure 4, Appendix B). Temperatures were near or above average in May with daily temperatures above freezing on 21–25 May. Snow depth at the Kuparuk airstrip remained below or near average until 20 May before completely melting by 23 May when temperatures warmed. Temperatures were near average during the calving and postcalving periods in early and mid-June.

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). Mosquitoes in the study area usually emerge from the middle of June through early July depending on temperatures, whereas oestrid flies usually do not emerge until mid-July. Daily air temperatures in mid- and late June were near average, but a warm period with temperatures near the upper 95% confidence limit beginning June 21 led to a high probability of insect activity for several days (Figure 5). ABR biologists conducting ground-based surveys for other projects near the Colville River delta reported noticeable mosquito activity starting around the 23 June, but then cooler temperatures kept mosquito activity low until their departure on 27 June.

The remainder of the 2019 insect season generally had average temperatures in late June, well above average temperatures in July, and August temperatures near the long-term average (Figure 4, Appendix B). This resulted in 16 days with a high probability of mosquito harassment and 4 days with a high probability oestrid fly activity (>50% probability; Figure 5), although only two days with expected high oestrid fly activity occurred during the period when oestrid flies are typically active. Average estimated mosquito and fly activity started out near average in June, increased to above average in July, and was near average again for August. Although insects are likely to be less prevalent by September, early September temperatures in 2019 were well above average.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

GMT Survey Area

Seven aerial surveys of the GMT survey area were attempted between 14 April and 03 October 2019 (Figure 6). The winter and spring migration surveys could not be conducted due to persistent inclement weather, but all other surveys of the GMT area were completed as scheduled (Table 2). The estimated density ranged from a high of 0.36 caribou/km² on 17–18 June to a low of 0.02 caribou/km² on 30 July (Table 2, Figure 7). A total of 40 caribou (0.10 caribou/km²) were observed on calving survey on 4–6 June. Caribou density peaked on the postcalving survey on 17–18 June (0.36 caribou/km²), but then declined to the lowest density of the year on the 30 July survey (0.02

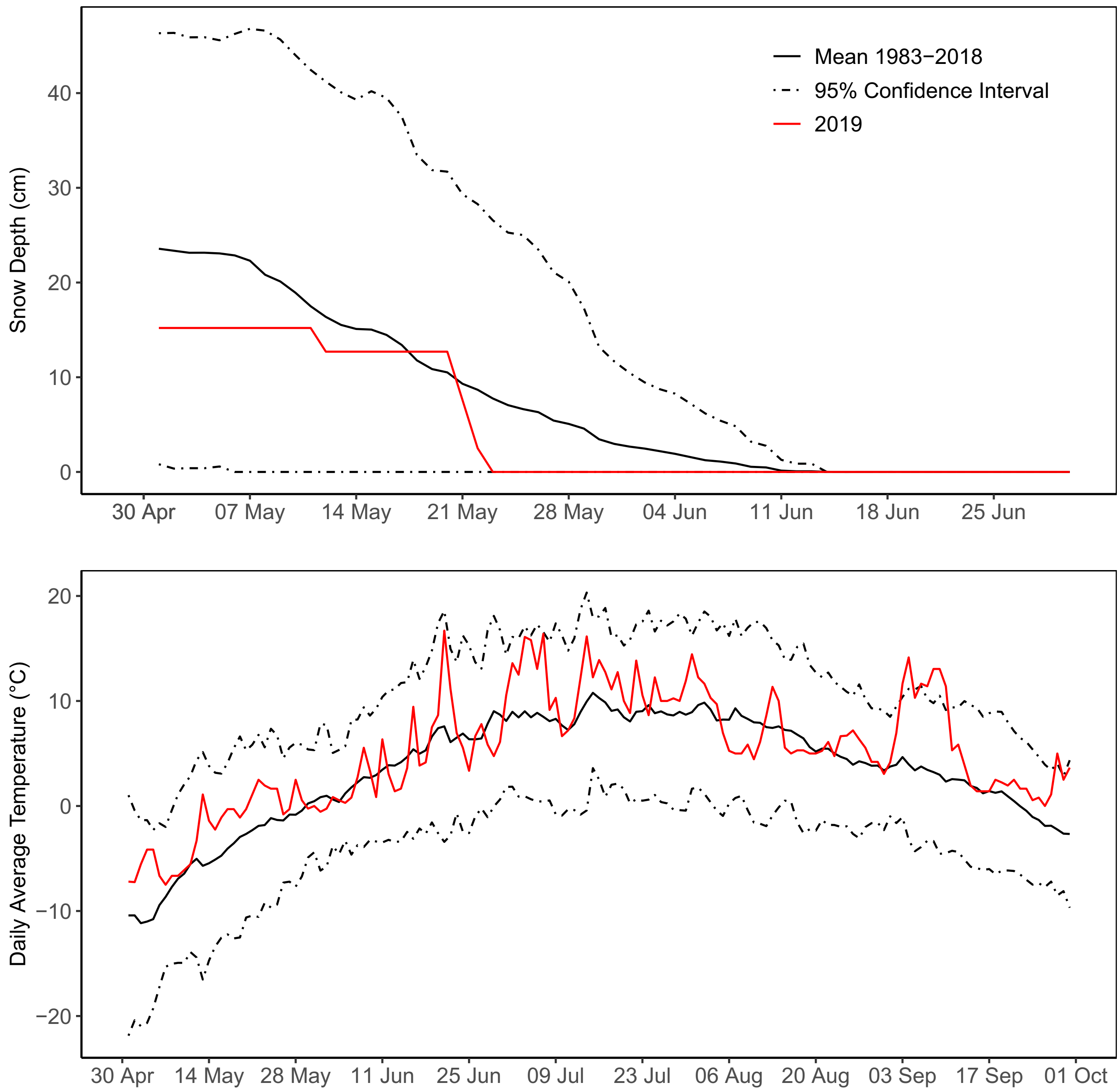

Figure 4. Snow depth at the Kuparuk airstrip during May–June 2019, compared with the long-term mean and 95% confidence interval (top panel) and daily average air temperature at Kuparuk during May–September 2019 compared with the long-term mean and 95% confidence interval (bottom panel).

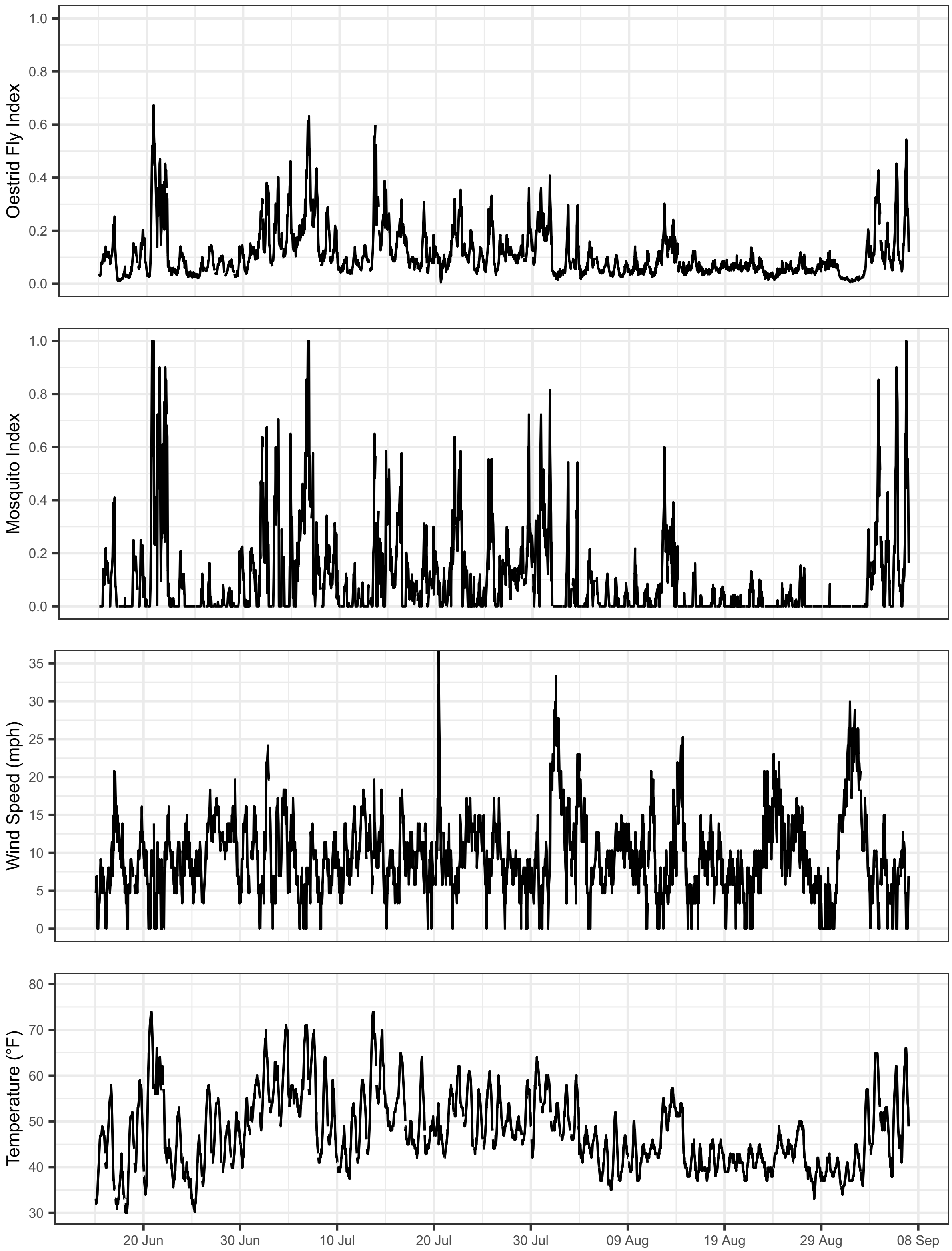

Figure 5. Hourly air temperature, wind speed, mosquito probability, and oestrid fly probability at Nuiqsut during 15 June–7 September 2019.

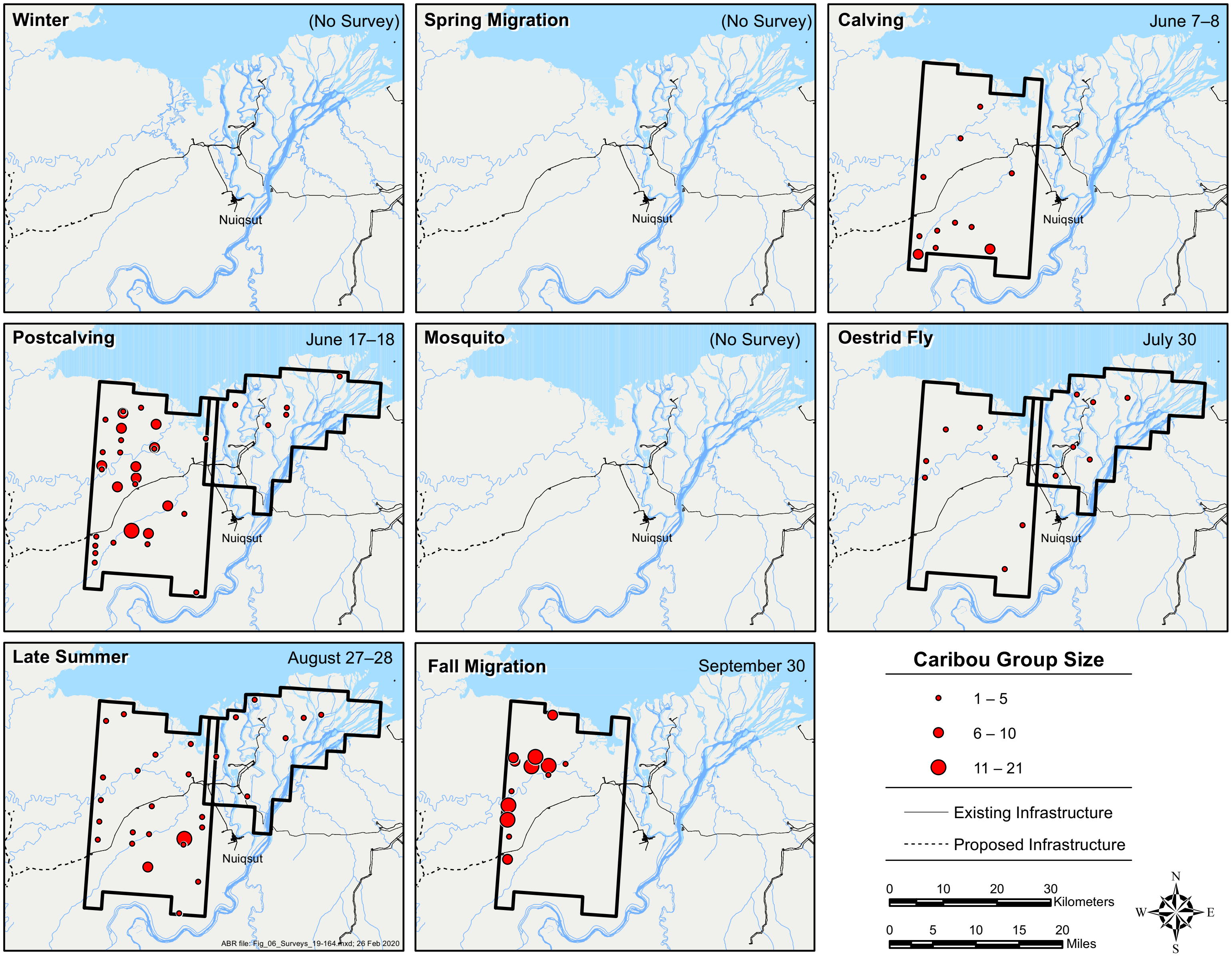

Figure 6. Distribution and size of caribou groups during different seasons in the GMT and Colville River Delta survey areas, April–September 2019.

Table 2. Number and density of caribou in the GMT and Colville River Delta survey areas, April–September 2019.

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								
June 4–6	778	37	3	40	3.6	80	18.0	0.10
June 17–18	778	141	0	141	4.8	282	55.4	0.36
July 30	778	7	nr	7	1.0	14	2.2	0.02
August 27–28	778	53	nr	53	2.5	106	27.1	0.14
September 30	778	131	nr	131	10.1	262	90.0	0.34
Colville River Delta								
June 18	494	13	1	14	2.8	28	10.6	0.06
July 30	494	15	nr	15	2.5	630	10.2	0.06
August 28	494	15	nr	15	2.1	30	8.0	0.06

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.

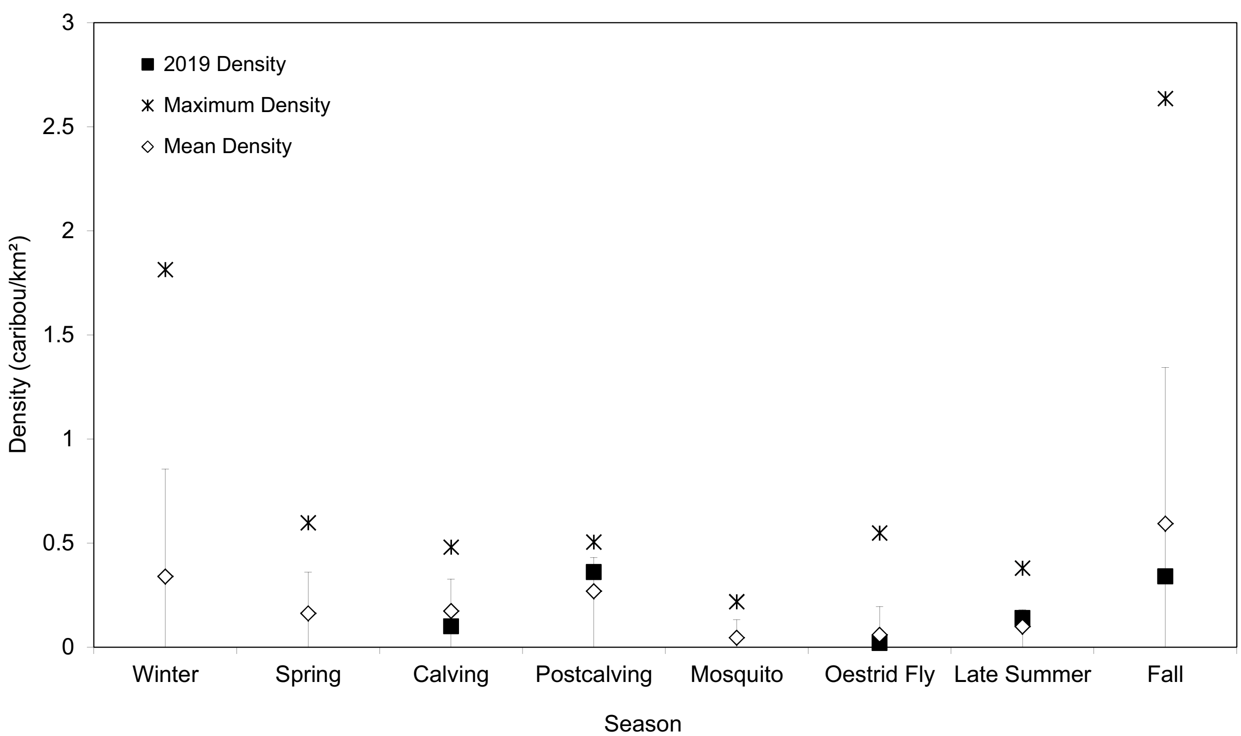

Figure 7. Seasonal density of caribou observed on 136 surveys of the GMT survey area, April–October 2001–2019. Error bars represent 95% confidence intervals. One oestrid fly survey with density 19.68 caribou/km² is not shown.

caribou/km²) during the oestrid fly season. The density of caribou increased slightly to 0.14 caribou/km² on the late summer survey (27–28 August), and increased again to 0.34 caribou/km² during the fall migration survey (30 September). We saw 3 calves in the GMT area during the calving survey and no calves during the postcalving survey.

These results are within the normal seasonal ranges of caribou density observed in the GMT survey area since 2001 (Figure 7). Caribou densities tend to be highest during the fall, winter and postcalving seasons, moderate during the spring migration, calving, and late summer seasons, and lowest during the mosquito and oestrid fly seasons, although the densities during the mosquito and oestrid fly seasons can be highly variable with large groups of caribou occasionally present as occurred in 2005 when an estimated of density of 19.68 caribou/km² was observed in the study area (not shown on Figure 7). In 2019, caribou densities followed these same trends. Results from the seasonal IDW density mapping of caribou recorded on aerial surveys of the NPRA/GMT survey area during 2002–2019 also showed large differences among seasons (Figure 8). 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; 19.68 caribou/km²).

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 other seasons were not surveyed due to low historical use of the Colville River delta during those periods (Figure 6, Table 2). Similar to most surveys conducted in previous years, the estimated density of caribou was low on all surveys (0.06 caribou/km²) and only one calf was observed during the postcalving survey (Figure 6, Table 2).

RADIO TELEMETRY

Radio collars provide detailed location and movement data throughout the year for a small number of individual caribou. The telemetry data also provide valuable insight into herd affiliation and distribution, which is not available from transect surveys. Mapping of the telemetry data from satellite (PTT) and GPS collars clearly shows that the study area is located at the interface of the annual ranges of the TCH and CAH (Figures 9–10). The majority of collar locations for the TCH occurred west of the Colville River and most of the CAH occurred east of it. The composite satellite and GPS telemetry data demonstrate that, although collared TCH caribou use the study area to some extent in all seasons, use of the area peaks during the summer insect season (primarily oestrid fly season) and fall migration, followed closely by winter (Figures 9–10). The lowest level of use of the area by collared TCH caribou occurred during the spring migration, calving, and postcalving seasons.

TCH GPS Collars and dBBMMs

Mapping of TCH movements derived from the dBBMMs in the study area shows that TCH females use the GMT survey area during all seasons, although their use of the area and movement rates vary widely among seasons (Figure 11). During winter, caribou are distributed widely but show low rates of movement. During the spring migration and calving seasons, TCH females move across the study area from southeast to northwest as they migrate toward the core calving area near 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, TCH females move rapidly and often tend to disperse inland away from Teshekpuk Lake with occasional large movements through the GMT survey area and some movements onto the Colville River delta. During late summer, caribou are usually found dispersed inland to the west of the GMT survey area. TCH caribou disperse widely during fall migration, including movements throughout much of the GMT survey area. The Colville River delta is used little by the TCH during all seasons (Figure 11).

KERNEL DENSITY ANALYSIS

Seasonal herd distributions were estimated using fixed-kernel density estimation, based on caribou locations from satellite and GPS collars deployed on 273 TCH females and 89 TCH males during 1990–2019 and on 138 CAH females and 8

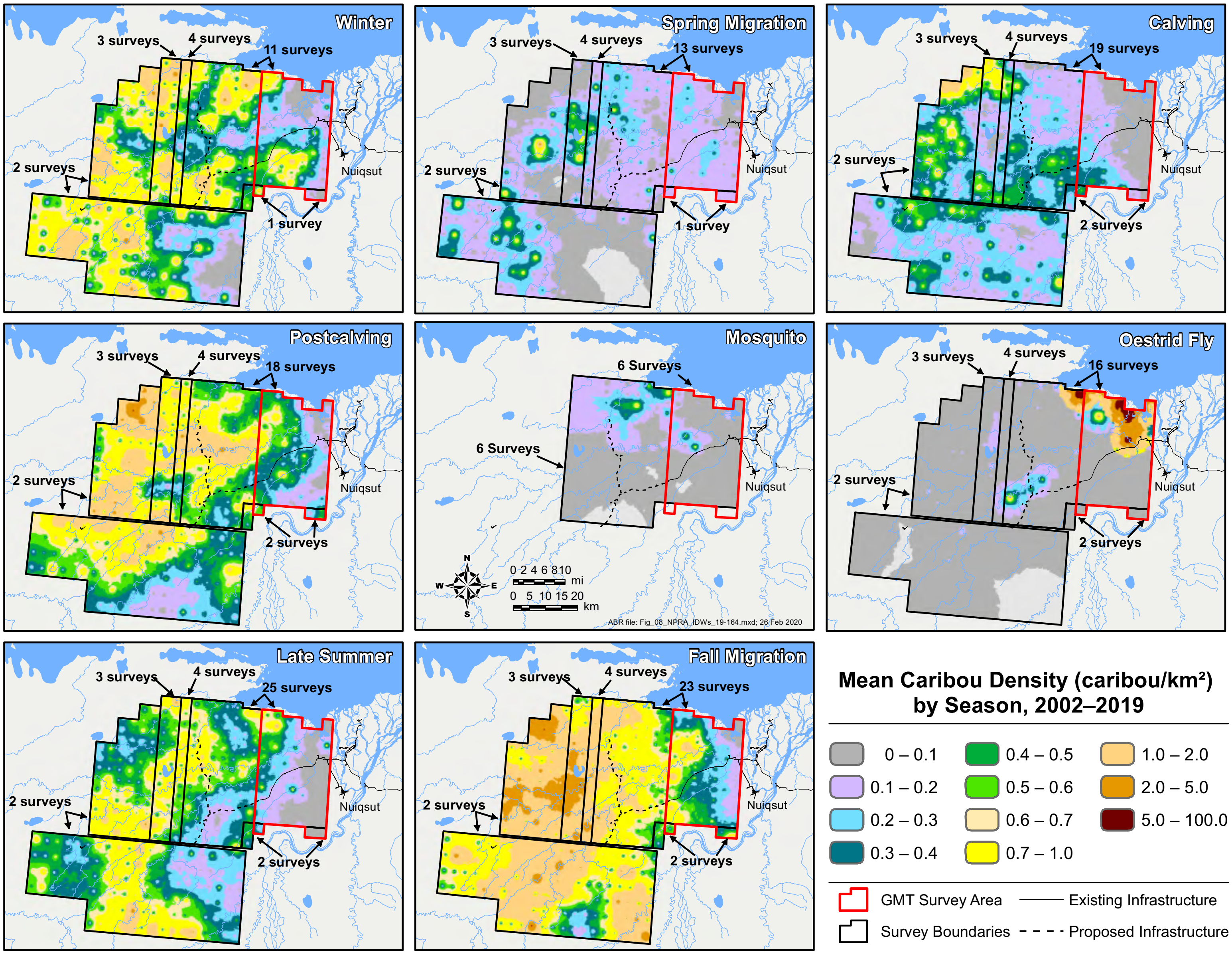

Figure 8. Seasonal density of caribou within the caribou survey areas based on IDW interpolation of aerial survey results, 2002–2019.

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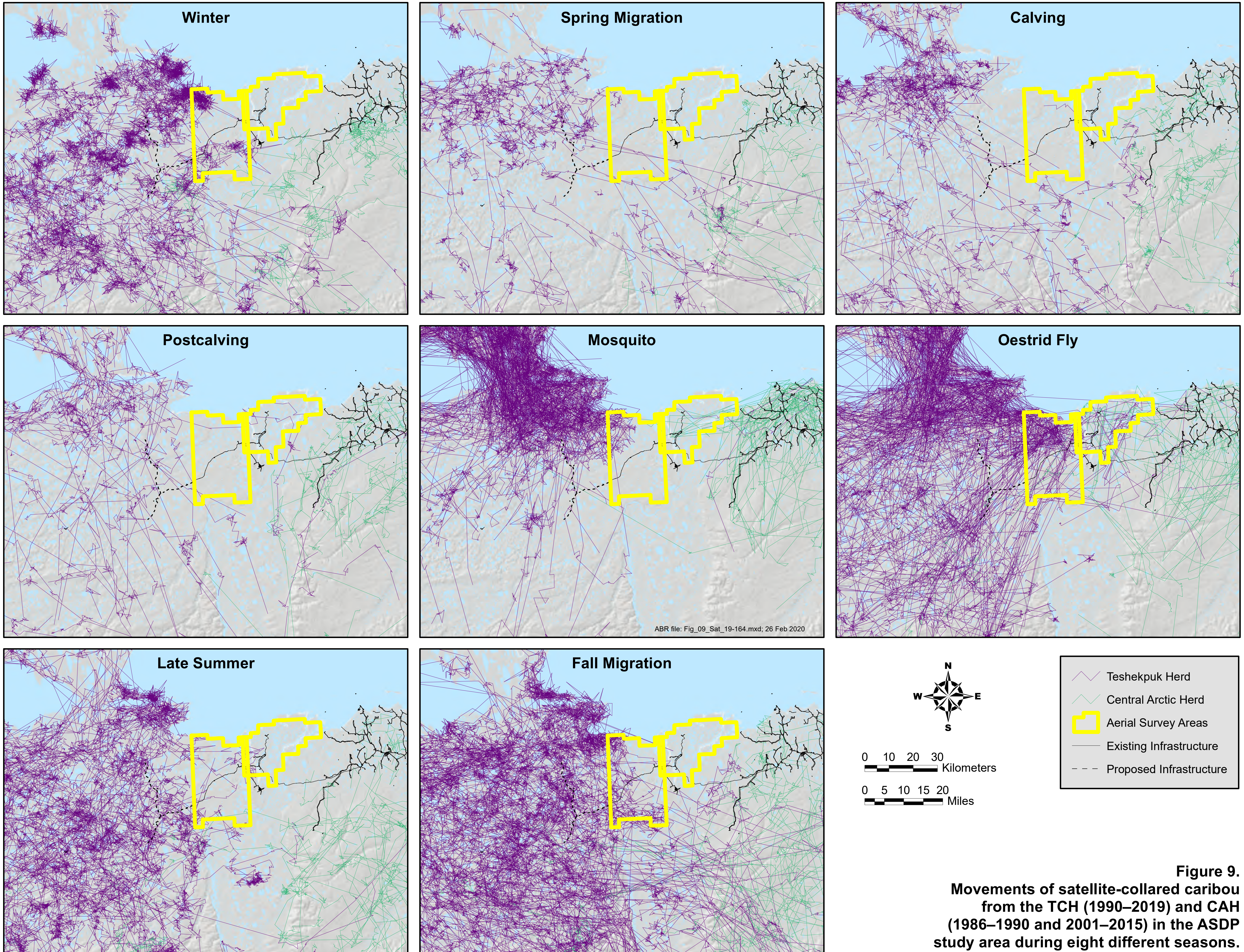

Figure 9.
Movements of satellite-collared caribou from the TCH (1990–2019) and CAH (1986–1990 and 2001–2015) in the ASDP study area during eight different seasons.

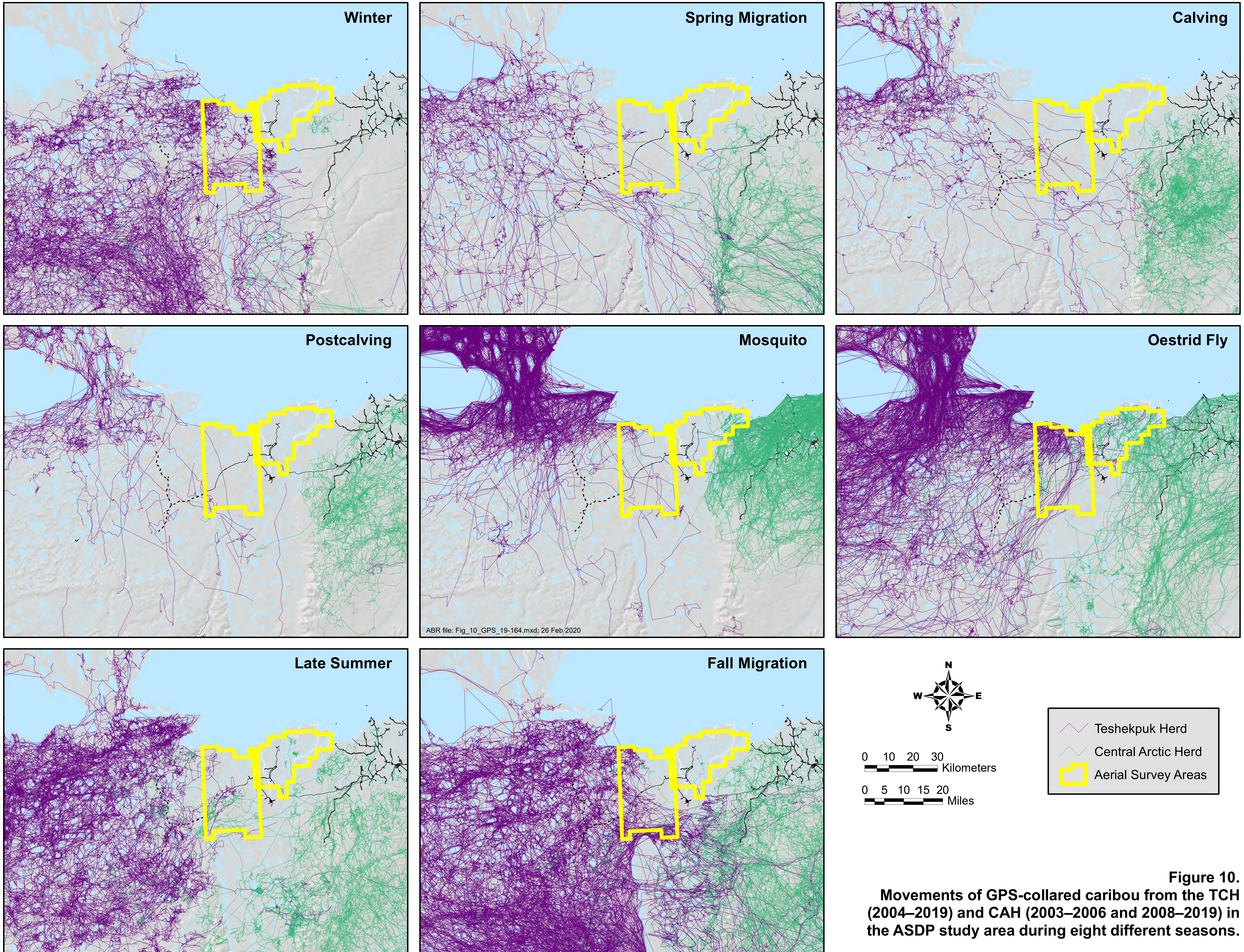

Figure 10.
Movements of GPS-collared caribou from the TCH (2004–2019) and CAH (2003–2006 and 2008–2019) in the ASDP study area during eight different seasons.

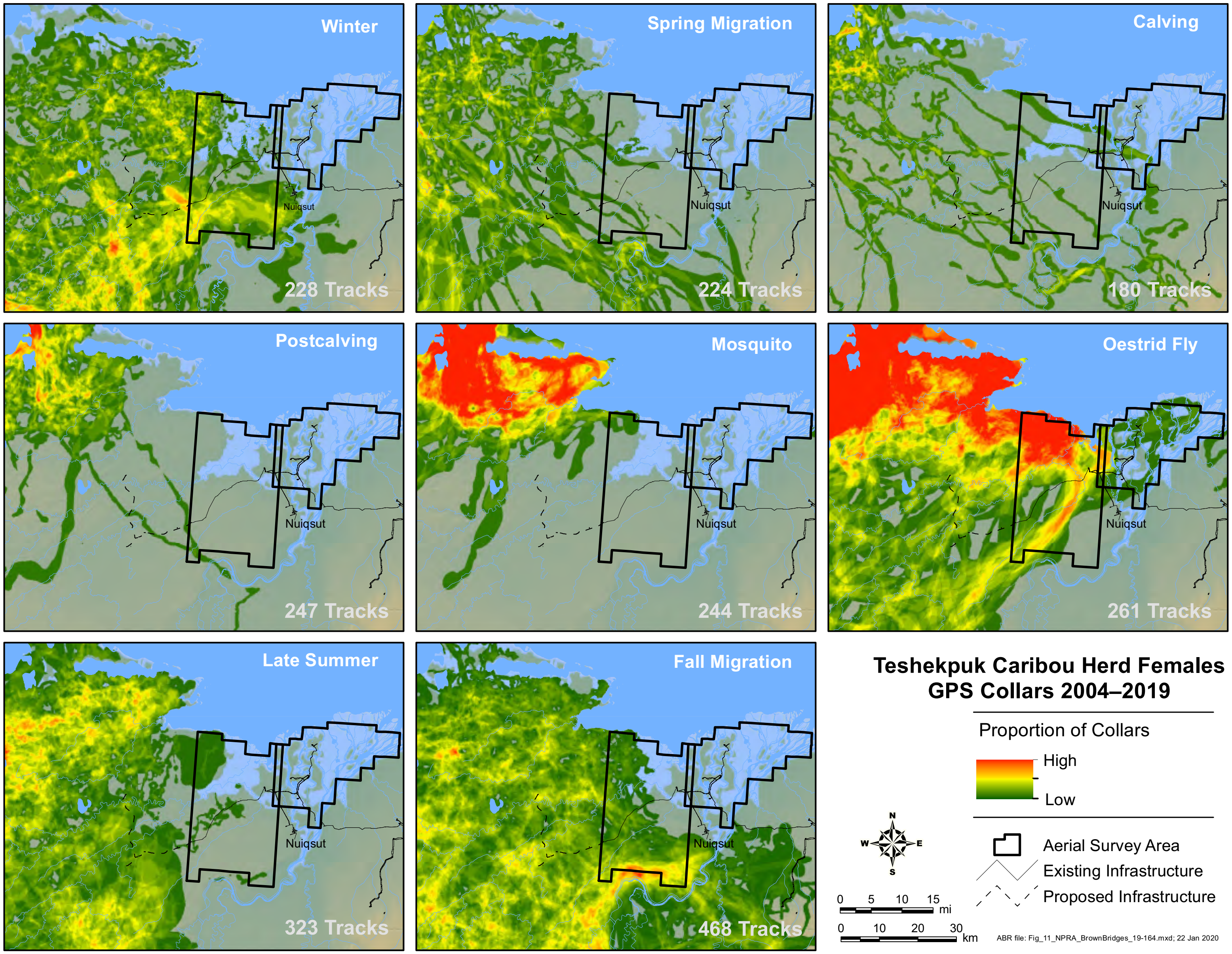

Figure 11. Proportion of GPS-collared caribou using an area based on 95% isopleth of dynamic Brownian Bridge movement models of individual caribou movements.

CAH males during 2001–2019. 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 TCH caribou (Figures 12–14); the sample size of CAH males was too small to conduct this analysis for males separately. Although these analyses use data covering 20–30 years, 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 12). During fall migration, many collared CAH caribou crossed the Dalton Highway to return to the wintering area.

TCH 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 13–14). Compared with females, males were more likely to overwinter in the central Brooks Range instead of on the coastal plain. They also migrated to the summer range later and were not distributed as far west during summer (Figures 13–14). The distribution of parturient TCH females during calving (Figure 15) was similar to the distribution of all TCH females during calving, but was more concentrated near Teshekpuk Lake.

Examination of the proportion of kernel densities by month in the GMT survey area showed that use of the CRD survey area by collared animals was low for both CAH and TCH caribou during the entire year (<2% of the utilization distribution; Figure 16). Collared TCH 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 16). Use of the survey area by TCH males increased sharply from near zero in May to a peak in July (~4% of the utilization distribution). The percentage of collared TCH males 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 16). 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 16).

MOVEMENTS NEAR ASDP INFRASTRUCTURE

Movements by collared TCH and CAH caribou near ASDP infrastructure have occurred infrequently and sporadically since monitoring began in the late 1980s–early 1990s for satellite collars and in 2003–2004 for GPS collars. Movements of TCH caribou near CD-1–CD-4 infrastructure are primarily during calving (early June) and the oestrid fly season (mid-July to early August; Figure 17). From December 2018 through November 2019, only one GPS-collared TCH or CAH caribou was recorded within 4 km of the CD-1 through CD-4 facilities or associated roads. This female caribou (C1706) crossed under the CD-3 pipeline during the oestrid fly season.

Prior to construction in winter 2013-2014, movements across the CD-5 pad and access road areas also occurred rarely (Figure 17). Only eight TCH caribou outfitted with GPS collars crossed the CD-5 road alignment in all years prior to construction (2004–2013). An additional 11 TCH caribou outfitted with satellite collars crossed the CD-5 road alignment in the years before construction (1990–2013). CAH caribou have crossed the CD-5 road even less frequently than TCH caribou; only one GPS-collared CAH caribou crossed the CD-5 alignment in July 2010 and no satellite-collared CAH caribou crossed the CD-5 alignment either before or after construction. In 2019, only one GPS collared caribou, C1706, crossed the CD-5 road multiple times during the oestrid fly season (Figure 17).

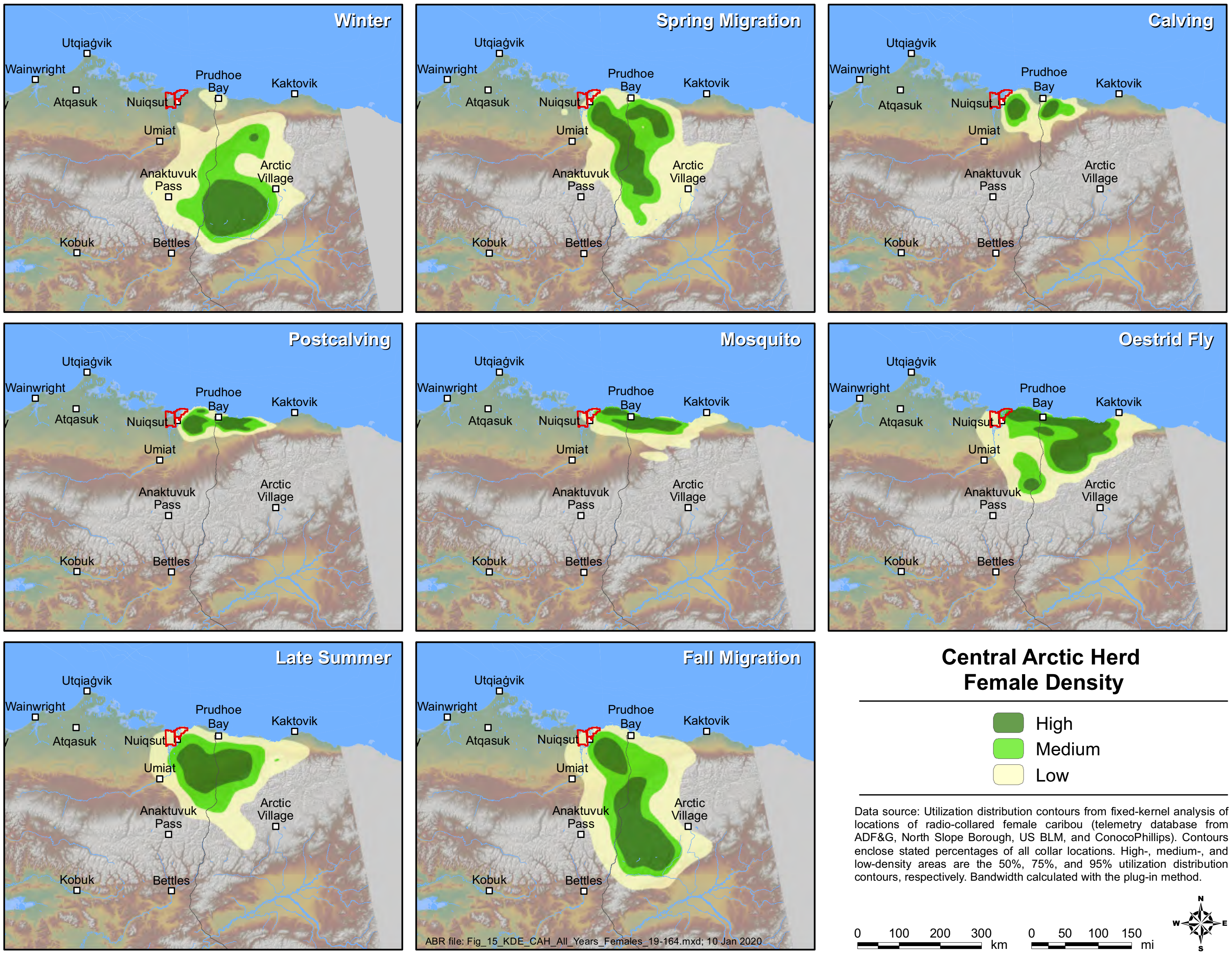

Figure 12. Seasonal distribution of CAH females based on fixed-kernel density estimation of telemetry locations, 2001–2019.

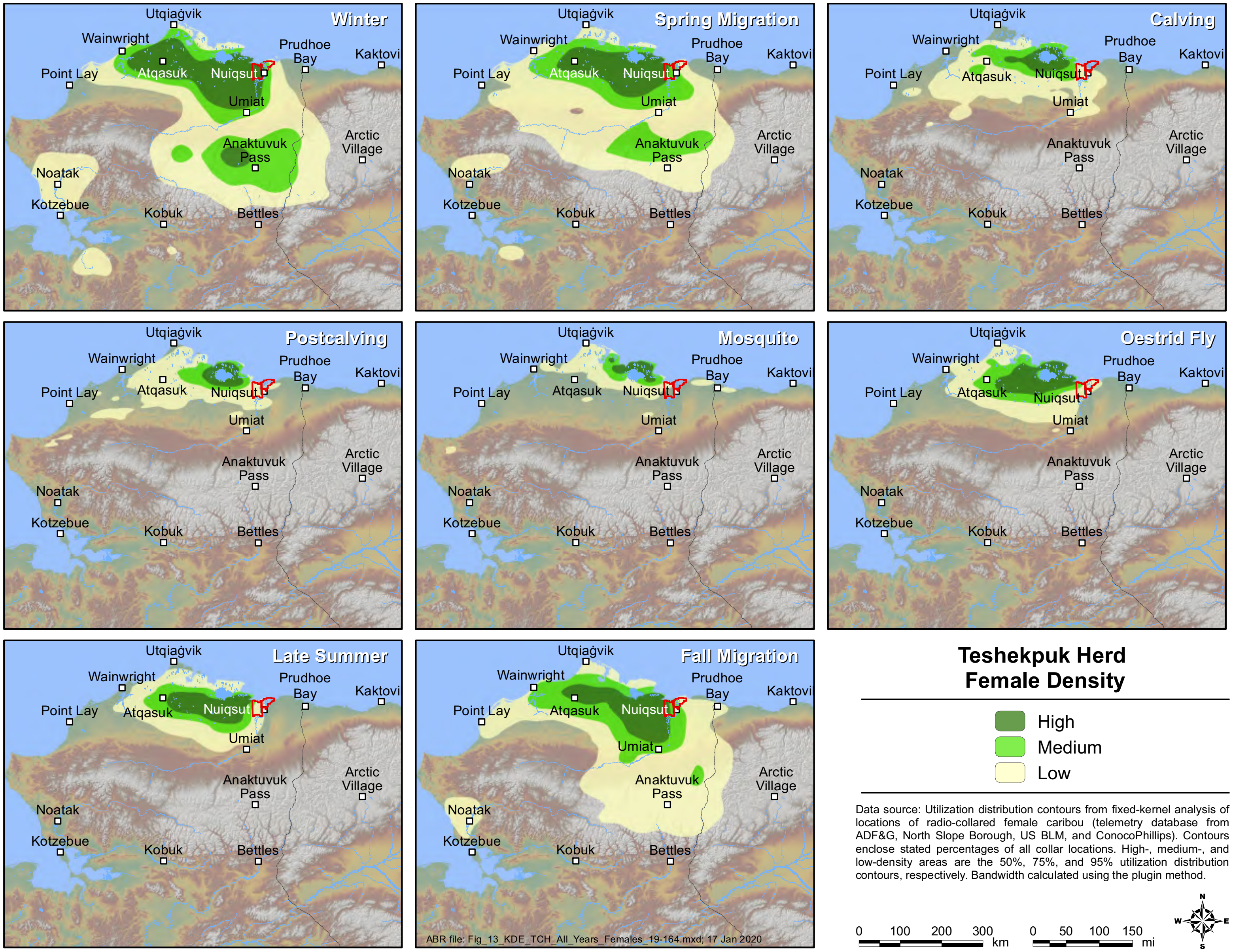

Figure 13. Seasonal distribution of TCH females based on fixed-kernel density estimation of telemetry locations, 1990–2019.

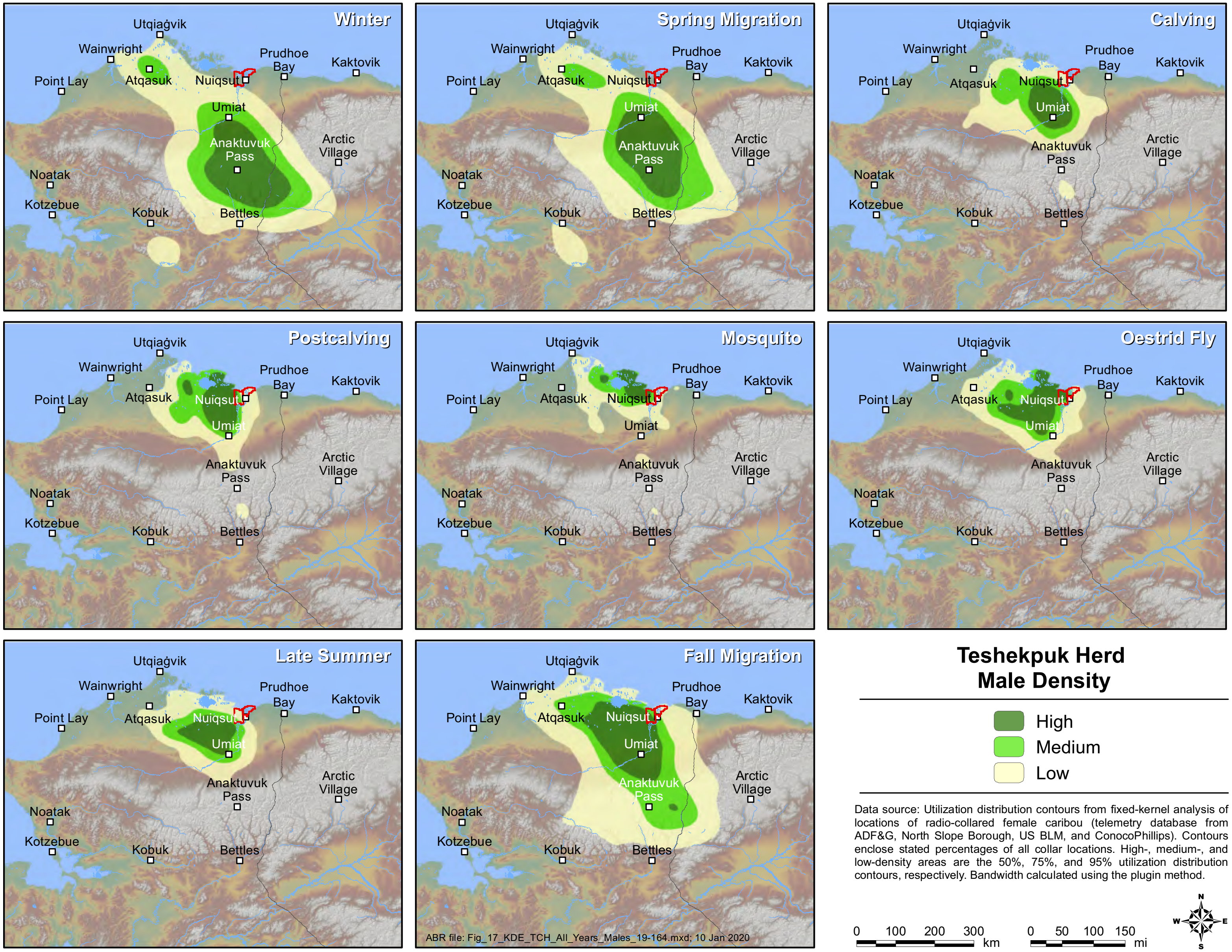

Figure 14. Seasonal distribution of TCH males based on fixed-kernel density estimation of telemetry locations, 1997–2019.

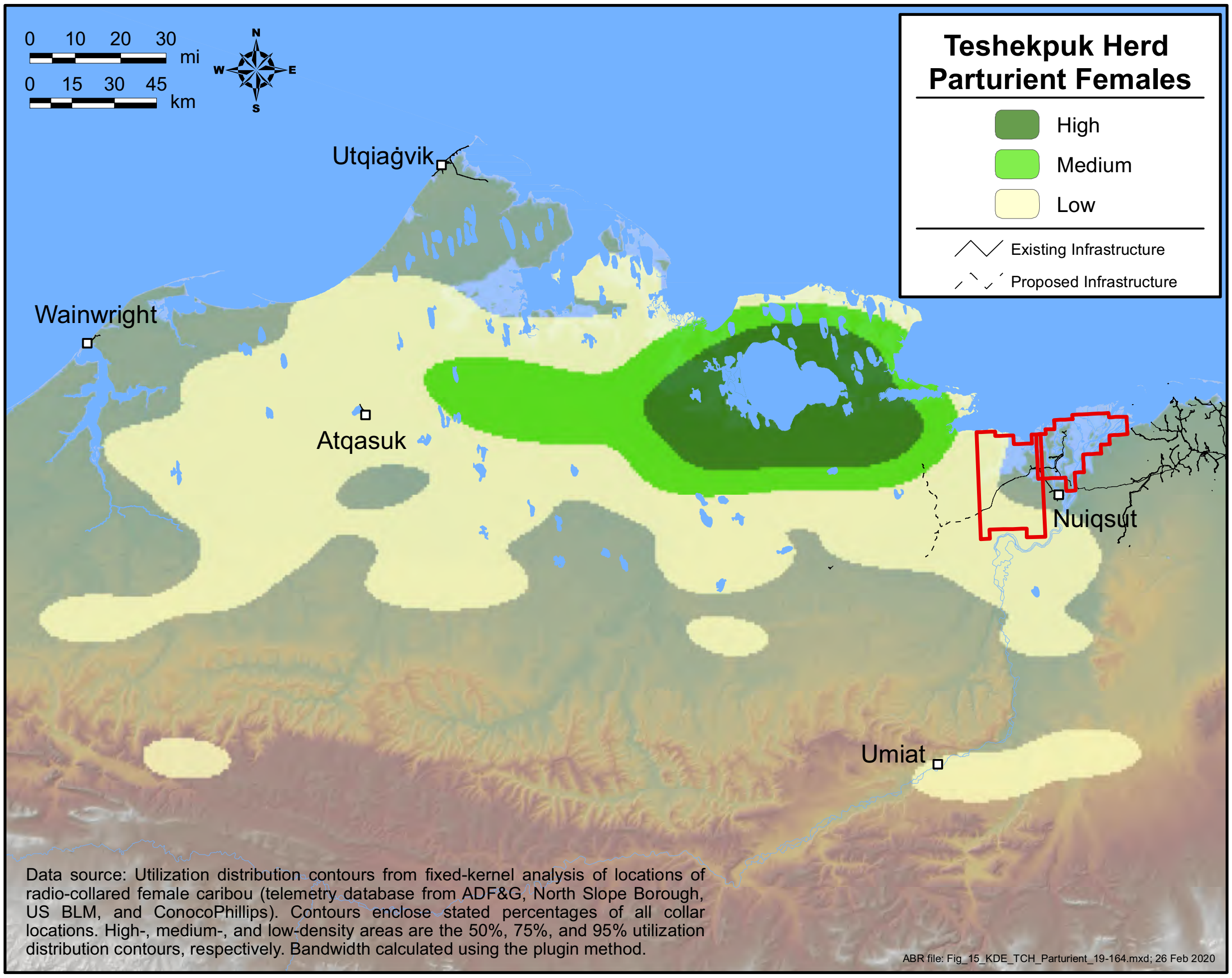

Figure 15. Distribution of parturient females of the Teshekpuk Herd during calving based on fixed-kernel density estimation of telemetry locations, 1990–2019.

Greater proportions of collared TCH have crossed the GMT1/MT6 road corridor and the planned road alignment from GMT1/MT6 to GMT2/MT7 than have occurred near CD-5, although such movements have not occurred frequently (Figure 17; Table 3) (Lawhead et al. 2015; Prichard et al. 2017, 2018c). Some crossings occur during the spring migration and calving seasons as caribou move north towards Teshekpuk Lake for calving, but no crossings were recorded during the postcalving season and few have occurred during the mosquito season as most TCH caribou are still northwest of the region near the Beaufort Sea coast. Crossings are much more common during the oestrid fly and late summer seasons as caribou disperse inland from the coast. Crossings are most common during the fall migration season and then decrease to lower rates during the winter season.

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

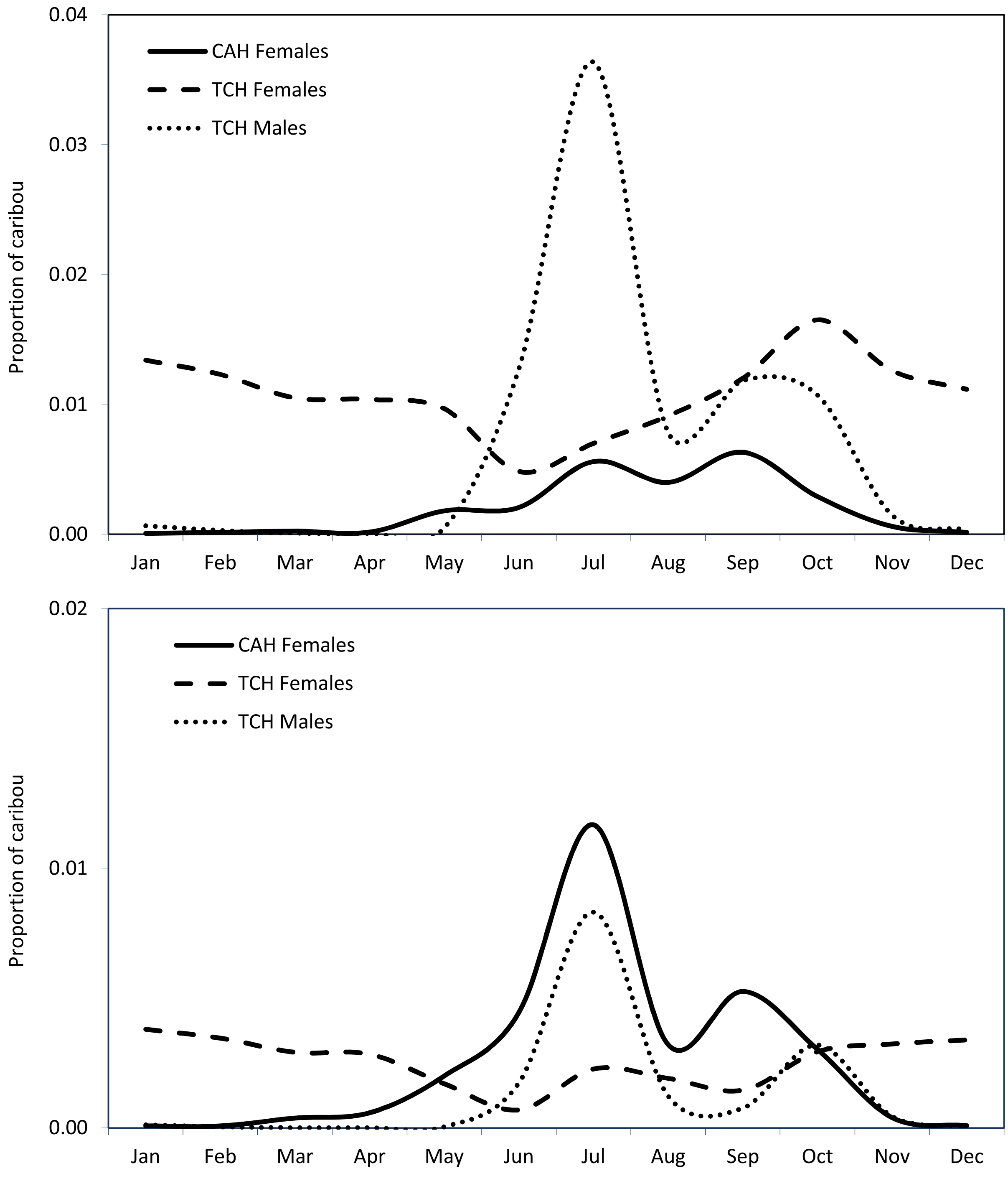

Figure 16. Proportion of CAH and TCH caribou within the GMT survey area (top panel) and Colville River Delta survey area (bottom panel), based on fixed-kernel density estimation, 1990–2019.

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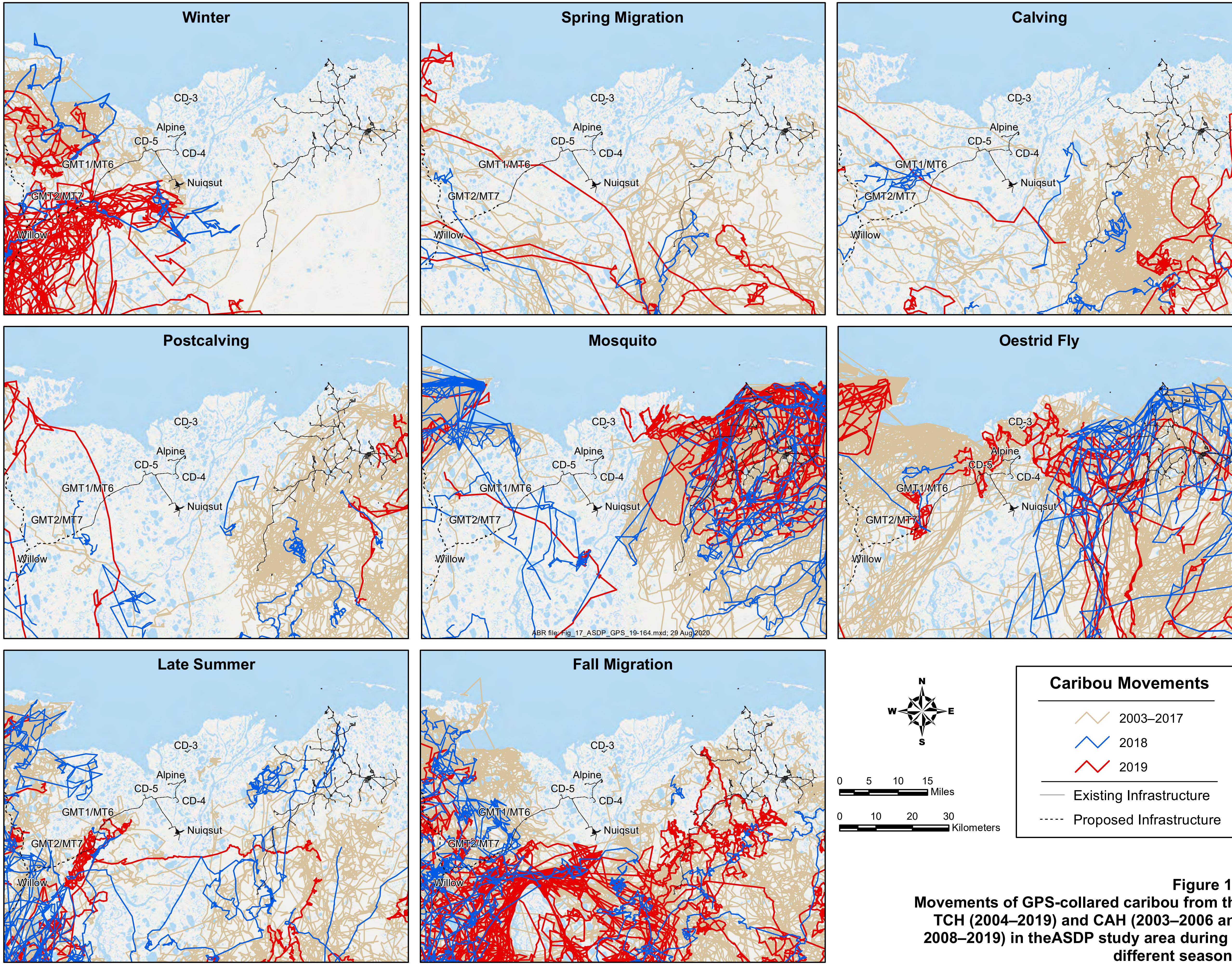

Figure 17.
Movements of GPS-collared caribou from the TCH (2004–2019) and CAH (2003–2006 and 2008–2019) in theASDP study area during 8 different seasons.

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Table 3. Proportion of female Teshekpuk Herd caribou crossing or within 1 km of the GMT1/MT6 and GMT2/MT7 access roads, by season and year.

Season	Year(s)	Collars[a]	Crossed GMT1/MT6	1 km of GMT1/MT6	Crossed GMT2/MT7	1 km of GMT2/MT7	Crossed Either	1 km of Either
Spring Migration	2004–08	29	0	0	0	0	0	0
	2009–13	96	0	0	0.01	0.01	0.01	0.01
	2014–17	105	0	0	0.01	0.01	0.01	0.01
	2018–19	93	0	0	0.01	0.02	0.01	0.02
	All Years	323	0	0	0.01	0.01	0.01	0.01
Calving	2004–08	28	0	0.04	0.04	0.04	0.04	0.07
	2009–13	91	0	0	0.03	0.03	0.03	0.03
	2014–17	99	0	0	0	0	0	0
	2018–19	91	0	0	0.01	0.01	0.01	0.01
	All Years	309	<0.01	<0.01	0.02	0.02	0.02	0.02
Postcalving	2004–08	28	0	0	0	0	0	0
	2009–13	97	0	0	0	0	0	0
	2014–17	101	0	0	0	0	0	0
	2018–19	97	0	0	0	0	0	0
	All Years	323	0	0	0	0	0	0
Mosquito	2004–08	36	0	0	0	0	0	0
	2009–13	109	0	0	0	0	0	0
	2014–17	111	0	0	0	0	0	0
	2018–19	101	0	0	0.01	0.01	0.01	0.01
	All Years	357	0	0	<0.01	<0.01	<0.01	<0.01
Oestrid Fly	2004–08	48	0	0	0	0	0	0
	2009–13	125	0.04	0.12	0.04	0.04	0.08	0.14
	2014–17	155	0	0	0	0	0	0
	2018–19	109	0	0	0	0	0	0
	All Years	437	0.01	0.03	0.01	0.01	0.02	0.04
Late Summer	2004–08	60	0	0.02	0.02	0.02	0.02	0.02
	2009–13	123	0	0	0	0	0	0
	2014–17	157	0	0.02	0.03	0.04	0.03	0.04
	2018–19	109	0	0.01	0.02	0.02	0.02	0.03
	All Years	428	0	0.01	0.02	0.02	0.02	0.02
Fall Migration	2004–08	60	0	0	0.10	0.10	0.10	0.10
	2009–13	126	0	0	0.01	0.01	0.01	0.01
	2014–17	156	0	<0.01	0.04	0.04	0.04	0.04
	2018–19	118	0	0	0.01	0.01	0.01	0.01
	All Years	460	0	<0.01	0.03	0.03	0.03	0.03
Winter	2004–08	58	0	0.03	0.02	0.02	0.02	0.03
	2009–13	115	0	0	0	0	0	0
	2014–17	150	0	<0.01	0.01	0.03	0.01	0.03
	2018	122	0	0	0.02	0.02	0.02	0.02
	All Years	445	0	<0.01	0.01	0.02	0.01	0.02

environmental variables that have been reported to be important factors affecting caribou distribution in northern Alaska (Kuropat 1984, Johnson et al. 2018).

SNOW COVER

Based on observations from survey crews and records from weather stations in the area (Figure 4; Appendix B), the timing of snow melt was approximately average for most of the region in 2019. Estimated snow cover from MODIS data indicated snowmelt was partially underway by 22 May, southern portions of the GMT survey area were snow free by 28–29 May, and the entire region was generally snow-free by 7 June with the exception of a partially snow covered area near the coast (Figure 18). This timing was similar or slightly earlier than the median date of snowmelt computed for the past 20 years (Figures 19–20, Appendix C).

The median dates of snow melt for each pixel computed using 2000–2019 data (where the date of melt was known within one week) indicate that nearly all of the snow on the coastal plain typically melts over a period of three weeks between 25 May and 11 June (Figure 19; 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 19). 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 19). 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 (Figure 19), the estimated vegetative biomass during calving (NDVI_Calving) and during peak lactation (NDVI_621) in 2019 was above average through much of the study area (Figures 19–21; Appendices D–E). Those values are consistent with the average or slightly early snow melt in 2019. Peak NDVI was also higher than average in 2019 (Figure 20; Appendix F), indicating that 2019 was a good growing season. This is consistent with the above average temperatures recorded in much of July (Figure 4). In 2019, NDVI_Rate was low in inland areas with earlier snowmelt, but high in more coastal areas where snowmelt occurred later (Figure 21). 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 277 to 5,397 use locations for the years 2002–2019 (Table 4). Most of the top-ranking seasonal models for the survey areas contained habitat type, vegetative biomass (maximum NDVI or daily NDVI), a west-to-east distributional gradient, distance to coast, and landscape ruggedness (Table 5). 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 NPRA had reasonably good model fits (Spearman's r = 0.88–0.96; Table 6). The variables with the highest probability of being in the best RSF model (Table 7) 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 higher selection closer to the coast in most seasons (Figure 22). These results are consistent with the location of the survey area near the eastern edge of the TCH annual range.

The RSF model output produced several types of results. These results include the probability of

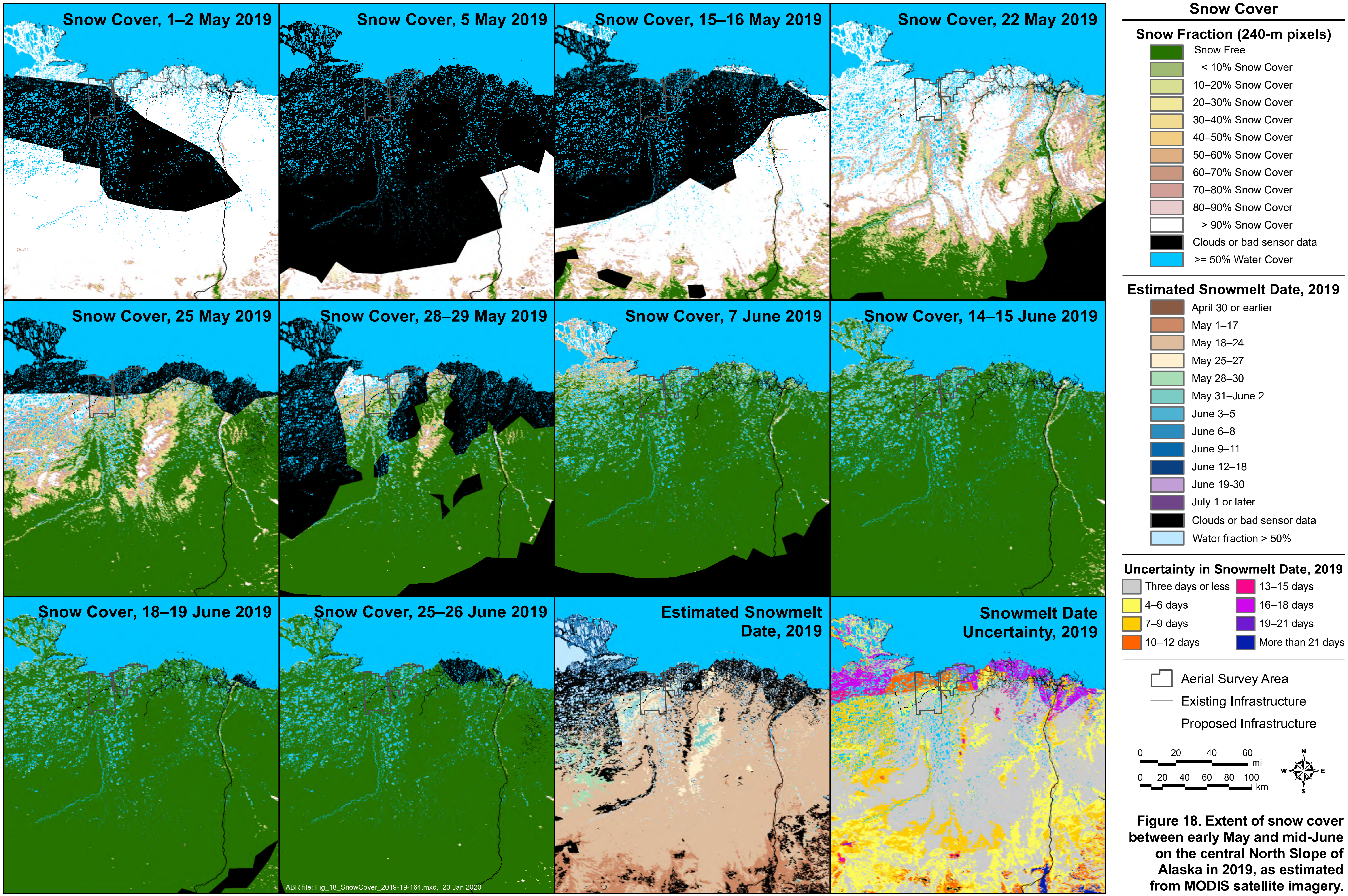


Figure 18. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2019, as estimated from MODIS satellite imagery.

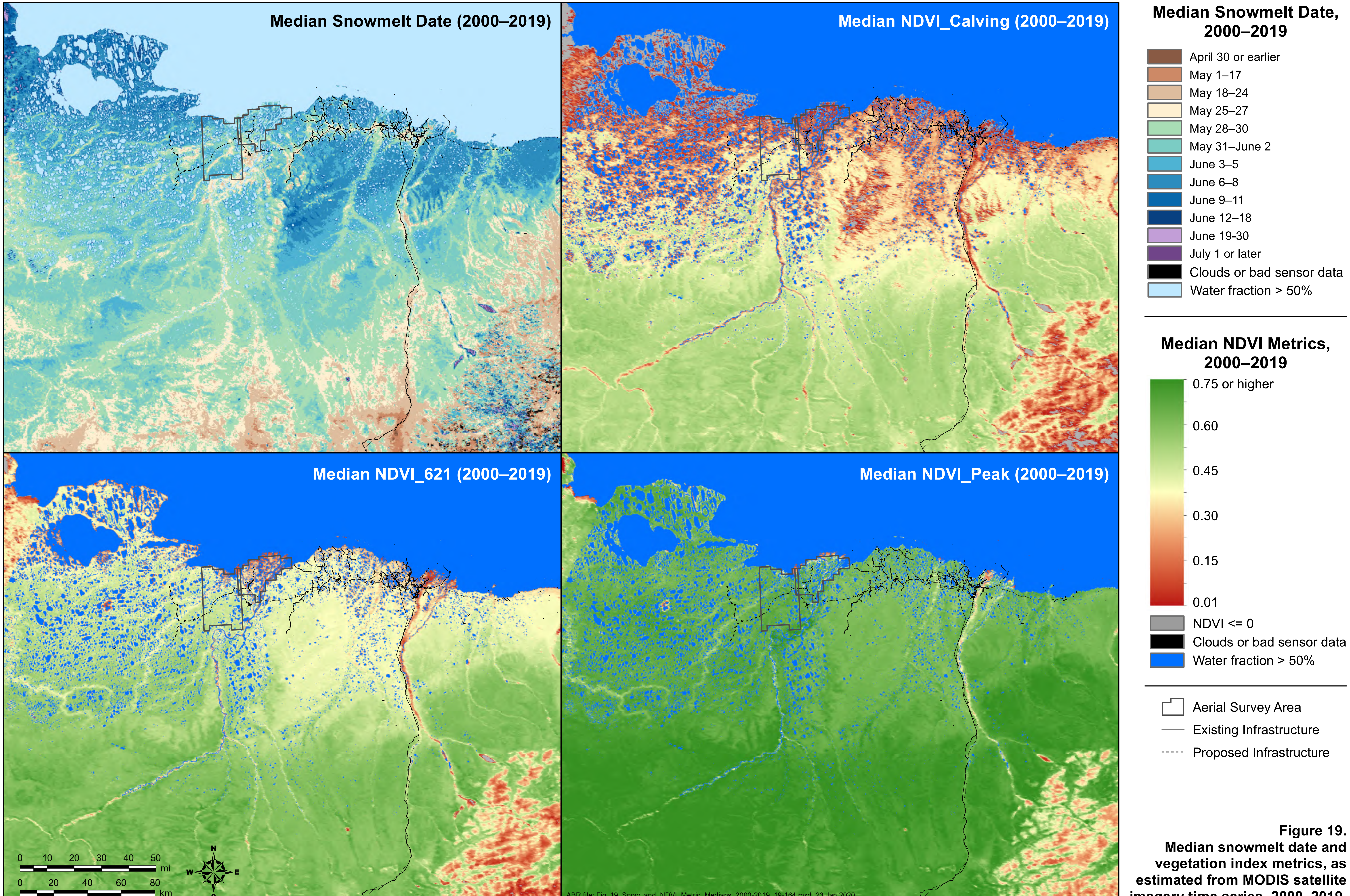


Figure 19.
Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series, 2000–2019.

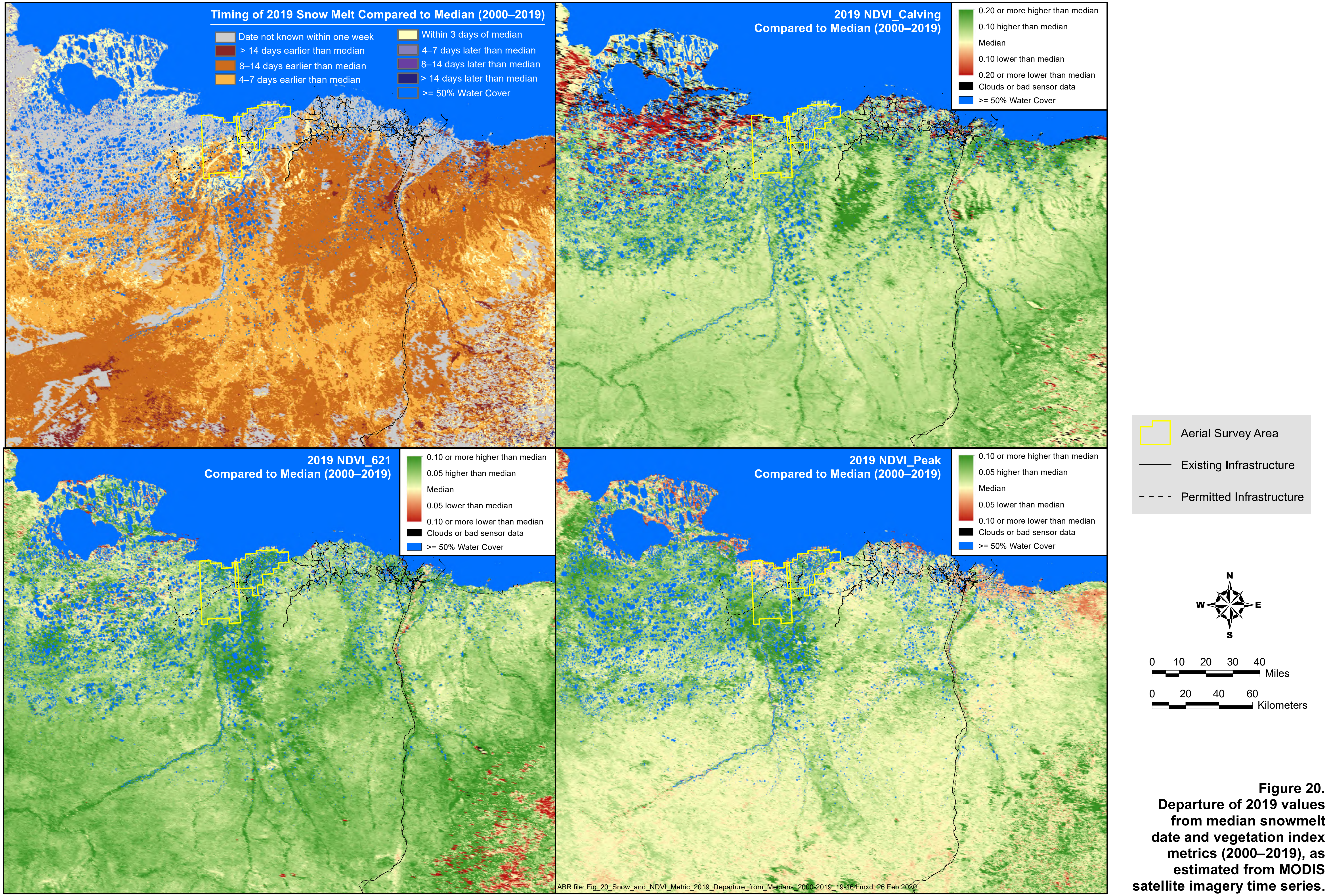
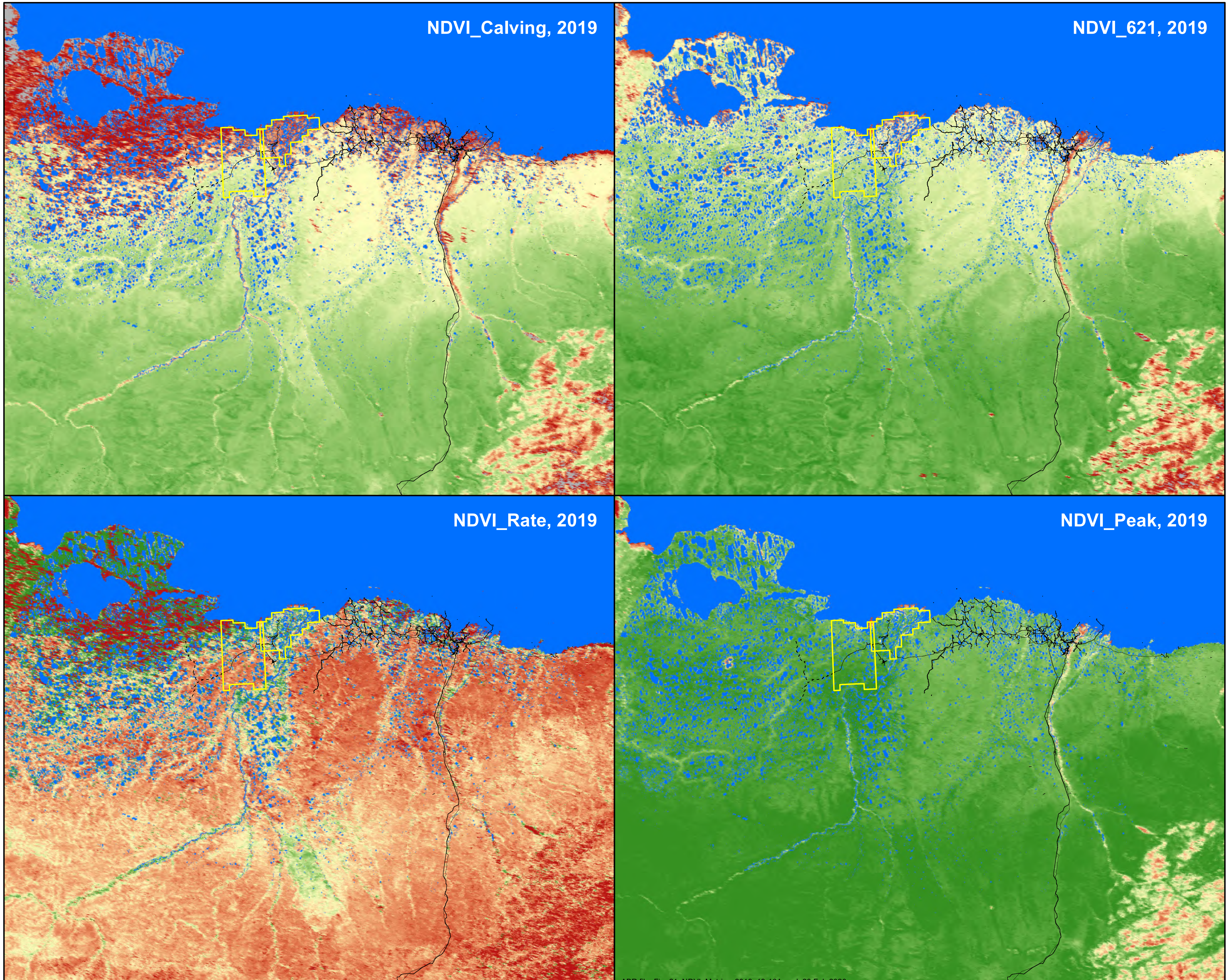


Figure 20. Departure of 2019 values from median snowmelt date and vegetation index metrics (2000–2019), as estimated from MODIS satellite imagery time series.



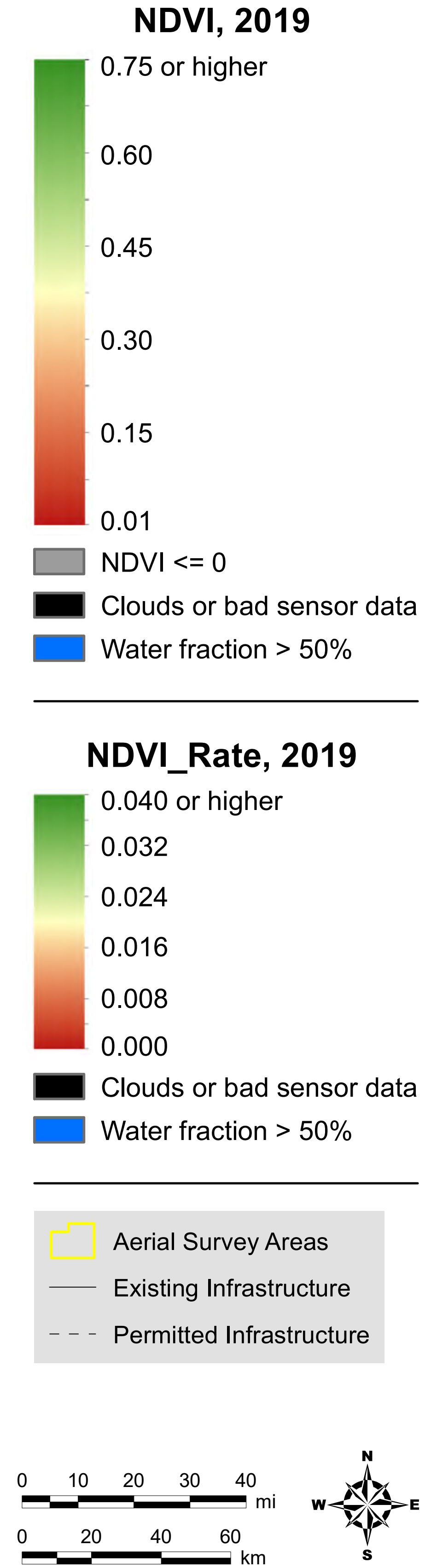


Figure 21.
Metrics of relative vegetative biomass during the 2019 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.

Table 4. Number of aerial surveys, radio collars, and locations for each sample type used in RSF analysis for the NPRA survey area, 2002–2019.

Season	Aerial Surveys		Telemetry Data		Total Locations
	Surveys	Locations	Collars	Locations	
Winter	15	1,022	131	3,648	4,670
Spring Migration	14	433	64	423	856
Calving	25	1,205	41	158	1,363
Postcalving	22	1,596	33	72	1,668
Mosquito	5	82	79	195	277
Oestrid Fly	16	316	110	379	695
Late Summer	29	1,384	126	1,344	2,728
Fall Migration	27	2,106	208	3,291	5,397
Total	135	8,144	792	9,510	17,654

each model being the best model in the set of candidate models (i.e., Akaike weight), which was used to rank the various models (Table 5) and to estimate the probability that each variable is included in the best model (i.e., the sum of Akaike weights for all models containing that variable; Table 7). We used all variables with a 50% or greater probability of being in the best model to produce seasonal RSF maps (Figure 22). 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), after accounting for model uncertainty (Table 8). These individual parameter estimate results were useful for examining the effect of each habitat type on caribou distribution.

For the winter season, all variables were included in the best model (Tables 5 and 7), with the snowmelt date being considered a surrogate for snow depth. This model performed very well with a 77% chance of being the best model in the candidate set (Table 5). Areas that were farther west, with higher values of landscape ruggedness, with later snowmelt dates and with higher MaxNDVI values were selected by caribou (Figure 22). Although distance to coast was included in the best model, the model-weighted variable was not significant. All habitat types (*Carex aquatilis*, Flooded Tundra, Moss/Lichen, Riverine, Tussock Tundra, and Wet Tundra) were avoided relative to the reference habitat (Sedge/Grass Meadow; Table 8).

All of the variables were also included in the best model for spring migration (Tables 5 and 7). This model had a 48% chance of being the best model in the candidate set (Table 5). 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 TCH (Figure 15). Areas with higher landscape ruggedness were selected, as well are areas closer to the coast. Although the habitat variable was included in the best model and improved model performance, none of the individual habitat classes were significantly different from the reference class (Sedge/Grass Meadow; Table 8). 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, and landscape ruggedness were included in the best model (Tables 5 and 7), although all of the top models had low Akaike weights (Table 7) indicating substantial model uncertainty. Caribou were more likely to be located in the western portion of the study area and in areas with higher daily NDVI and lower terrain ruggedness values

Table 5. Three top-performing seasonal RSF models, AICc scores, and the probability (Akaike weight) that each model was the best model in the candidate set for the GMT, BTN, and BTS survey areas, 2002–2019 (combined aerial survey and telemetry data).

Season	RSF Model	AICc	Akaike Weight
Winter	Habitat + MaxNDVI + EtoW + DistCoast + Ruggedness + Snow	38740	0.769
	Habitat + MaxNDVI + EtoW + Ruggedness + Snow	38743	0.219
	Habitat + MaxNDVI + EtoW + Ruggedness	38750	0.006
Spring Migration	Habitat + MaxNDVI + EtoW + DistCoast + Ruggedness + Snow	7020	0.483
	MaxNDVI + EtoW + DistCoast + Ruggedness + Snow	7021	0.315
	Habitat + MaxNDVI + EtoW + DistCoast + Ruggedness	7024	0.058
Calving	Habitat + dailyNDVI + Nitrogen + EtoW + Ruggedness	10551	0.082
	Habitat + dailyNDVI + EtoW + Ruggedness	10552	0.065
	Habitat + dailyNDVI + Nitrogen + EtoW + Ruggedness + Snow	10552	0.063
Postcalving	Habitat + dailyNDVI + Biomass + EtoW + DistCoast + Ruggedness	13609	0.246
	Habitat + dailyNDVI + EtoW + DistCoast + Ruggedness	13609	0.170
	Habitat + dailyNDVI + MaxNDVI + Biomass + EtoW + DistCoast + Ruggedness	13610	0.106
Mosquito	Habitat + dailyNDVI + EtoW + DistCoast + Ruggedness	2007	0.136
	Habitat + Nitrogen + EtoW + DistCoast + Ruggedness	2007	0.122
	Habitat + Biomass + EtoW + DistCoast + Ruggedness	2007	0.121
Oestrid Fly	Habitat + dailyNDVI + EtoW + DistCoast + Ruggedness	5655	0.186
	Habitat + Biomass + EtoW + DistCoast + Ruggedness	5655	0.142
	Habitat + Nitrogen + EtoW + DistCoast + Ruggedness	5655	0.124
Late Summer	Habitat + dailyNDVI + Biomass + EtoW + DistCoast + Ruggedness	21669	0.255
	Habitat + dailyNDVI + Biomass + EtoW + Ruggedness	21670	0.148
	Habitat + dailyNDVI + MaxNDVI + Biomass + EtoW + DistCoast + Ruggedness	21671	0.095
Fall Migration	Habitat+ EtoW + DistCoast + Ruggedness	45458	0.347
	Habitat + EtoW + Ruggedness	45459	0.312
	Habitat + MaxNDVI + EtoW + Ruggedness	45460	0.151

Table 6. Mean Spearman's correlation coefficient of seasonal RSF model fit using 5-fold cross-validation for the NPRA survey area, 2002–2019 (combined aerial survey and telemetry data).

Season	Correlation Coefficient
Winter	0.96
Spring Migration	0.89
Calving	0.92
Postcalving	0.90
Mosquito	0.89
Oestrid Fly	0.88
Late Summer	0.93
Fall Migration	0.88

(Table 8; Figure 22), reflecting the western distribution of high-density calving by the TCH. The lack of a strong performing top model likely indicates that aside from the above three variables, the remaining variables are not particularly influential in predicting habitat selection.

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 5 and 7). This model had a 25% chance of being the best model in the candidate set (Table 5). Caribou tended to select areas farther west, closer to the coast, with higher NDVI, and with higher landscape ruggedness, although NDVI was not a significant variable in the model (Table 8; Figure 22). 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, habitat, daily NDVI, west-to-east gradient, distance to coast, and landscape ruggedness were included in the best model. Models with biomass or nitrogen in place of NDVI performed almost as well as the top model with NDVI but neither of the coefficients were significant (Tables 5 and 7–8). Caribou primarily selected areas farther west, closer to the coast, and with higher ruggedness (Table 8; Figure 22). 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 5 and 7), although there was a fair amount of model uncertainty. As with the mosquito season, nitrogen and biomass appear to be almost interchangeable with daily NDVI with regards to model performance, though neither was significant in the model. Caribou selected areas farther west, closer to the coast, and with greater ruggedness (Table 8; Figure 22). Relative to Sedge/Grass Meadow habitat, caribou 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 5 and 7). This model had a 26% chance of being the best model in the candidate set (Table 5). Caribou selected areas farther west, and with higher ruggedness. Although the analysis indicated that caribou tended to select areas closer to the coast and with lower biomass, neither variable was significant in the model (Table 8). Relative to Sedge/Grass Meadow habitat, caribou selected Riverine habitat types and avoided *Carex aquatilis* and Flooded Tundra habitat types (Table 8, Figure 22).

During fall migration, habitat type, west-to-east, distance to coast, and landscape ruggedness were included in the best RSF model (Tables 5 and 7). This model performed moderately well with a 35% chance of being the best model in the candidate set (Table 5). 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 (Table 8; Figure 22).

OTHER MAMMALS

We observed a single adult grizzly bear in the northwestern Colville River Delta on 28 August. There were 3 observations of muskoxen east of the Colville River delta in 2019. A single adult was

Table 7. Independent variables and their probability of being in the best RSF model (i.e., the sum of all Akaike weights for all models that included the variable) for the NPRA survey area during 8 seasons, 2002–2019 (combined aerial survey and telemetry data). Variables with a probability ≥0.5 were used in RSF maps (Figure 22).

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	0.77	1.00	0.40	1.00	1.00	1.00	0.63	0.51
Max NDVI	1.00	0.91	0.40	0.30	0.28	0.33	0.29	0.30
Daily NDVI	–	–	1.00	0.89	0.47	0.49	0.84	–
Nitrogen	–	–	0.58	0.34	0.43	0.42	0.31	–
Biomass	–	–	0.33	0.60	0.44	0.44	0.92	–
Snowmelt Date	0.99	0.88	0.40	–	–	–	–	–
Ruggedness	1.00	1.00	0.99	1.00	0.99	1.00	0.99	0.95
Habitat	1.00	0.67	0.70	0.84	0.28	1.00	1.00	1.00

Table 8. Model-weighted parameter estimates for RSF models for the NPRA survey area during 8 seasons, 2002–2019 (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	**-0.11**	**-0.60**	**-0.38**	**-0.48**	**-1.03**	**-0.50**	**-0.27**	**-0.21**
Distance to Coast	0.03	**-0.49**	-0.02	**-0.48**	**-1.61**	**-0.61**	-0.03	-0.01
Max NDVI [a]	**0.04**	-0.09	0.02	0.00	0.01	-0.01	0.00	0.00
Daily NDVI [a]	–	–	**0.42**	0.16	0.03	-0.05	0.11	–
Biomass [a]	–	–	-0.02	0.08	-0.01	-0.01	-0.10	–
Nitrogen [a]	–	–	-0.07	0.01	0.01	-0.01	0.00	–
Snowmelt Date	**0.06**	-0.08	0.01	–	–	–	–	–
Ruggedness	**0.10**	**0.30**	**-0.11**	**0.19**	**0.25**	**0.19**	**0.07**	**-0.04**
Carex aquatilis [b]	**-1.30**	-0.35	-0.30	-0.34	-0.47	0.23	**-0.48**	**-0.91**
Dwarf Shrub [b]	**-0.52**	-0.04	-0.49	0.03	0.14	**1.06**	0.14	**-0.23**
Flooded Tundra [b]	**-0.99**	-0.12	**-0.44**	-0.19	-0.70	**0.49**	**-0.32**	**-0.61**
Moss/Lichen [b]	**-1.41**	-0.33	-0.82	0.23	-0.25	**1.18**	0.38	0.18
Riverine [b]	**-1.50**	-0.29	-0.35	**0.32**	-0.09	**1.22**	**0.38**	**-0.36**
Tussock Tundra [b]	**-0.13**	-0.12	-0.16	0.02	-0.12	**0.35**	-0.02	**-0.14**
Wet Tundra [b]	**-0.94**	0.04	-0.26	0.09	-0.43	**0.44**	0.00	**-0.44**

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

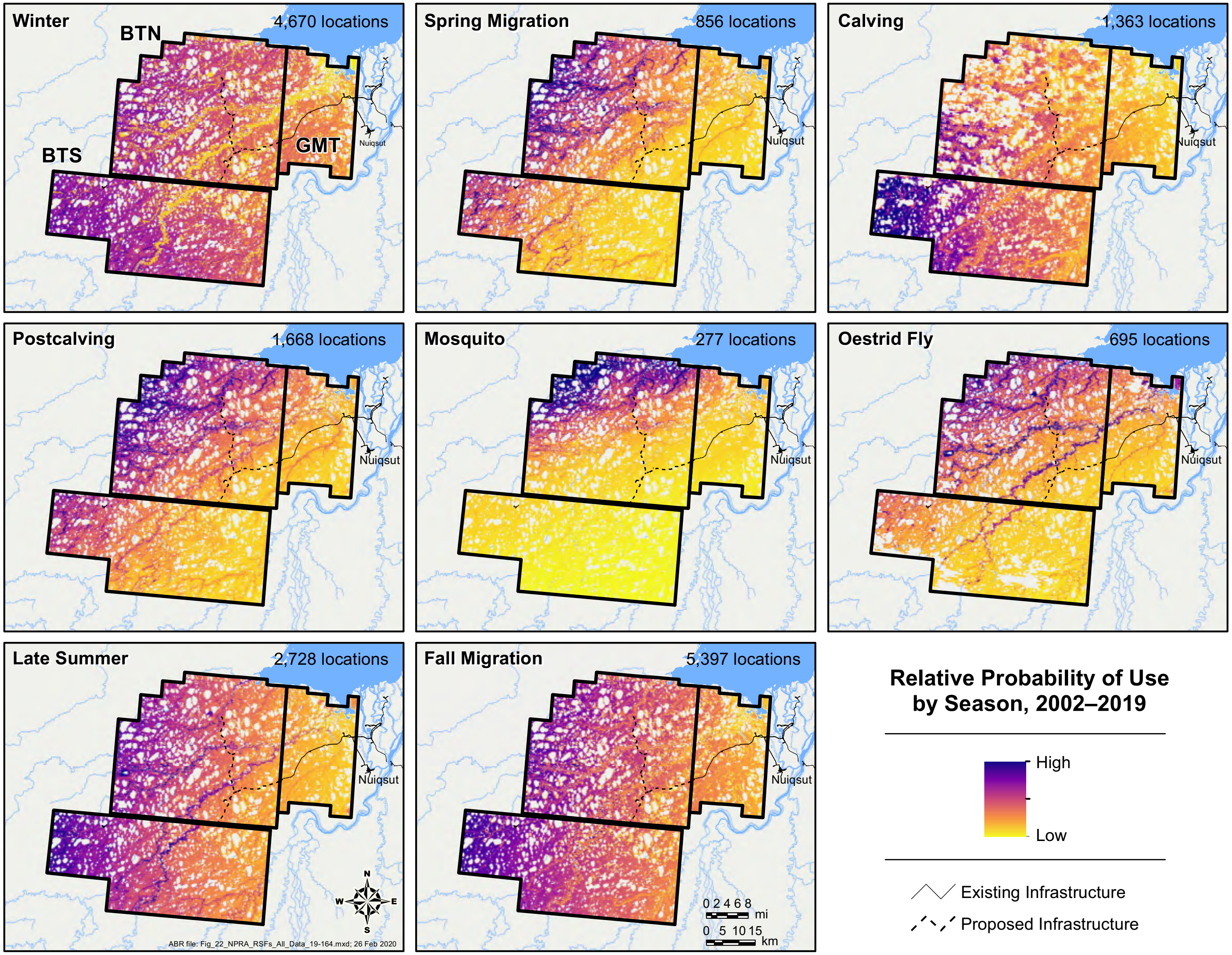


Figure 22. Predicted relative probability of use of the NPRA survey area by caribou during 8 different seasons, 2002–2019, based on RSF analysis. Relative probabilities calculated using the 2019 values for daily NDVI, biomass, and nitrogen.

observed on 11 June, and a group of 12 (8 adults and 4 calves) was observed on 30 July and the 27 August (Figure 17). The observation on 27 August was southeast of Nuiqsut, but most likely the same group observed on 30 July.

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 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 mid- to late June likely improved caribou body condition after calving, but the warm temperatures during July likely resulted in increased movement rates, decreased foraging, which can cause a decline in body condition. Cool conditions in late summer and delayed onset of seasonal snow cover due high temperatures in September (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, although forage quality is greatly diminished in the fall compared to the summer.

CARIBOU DISTRIBUTION AND MOVEMENTS

The TCH consistently uses the area west of the Colville River to some extent during all seasons of the year. Female TCH caribou numbers in the GMT and CRD survey areas are generally lowest during the calving and postcalving seasons, increase to their highest levels during the fall migration season, and then slowly decline through winter and spring migration. Male numbers, in contrast, are highest from calving–oestrid fly seasons, moderate during late summer and fall migration, and lowest during winter and spring migration. The CAH primarily uses the area east of the Colville River, although movements across the Colville River and onto the Colville River delta are not uncommon. CAH use of the CRD survey area is variable with rare episodic events with high use during the mosquito and oestrid fly seasons and low use during the remainder of the year. CAH caribou rarely use the GMT survey area, 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 in the GMT and CRD survey areas. East of the Colville River delta, high density calving occurs by CAH caribou (Lawhead et al. 2015). This result is consistent with analysis of telemetry data, which confirms that most TCH females calve around Teshekpuk Lake or areas to the west (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015a, Prichard et al. 2019a). A few collared CAH females have switched to the TCH 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).

In 2019, we observed our highest density of caribou in the GMT survey area during the postcalving season (Figure 7, Table 2). Telemetry data indicate that animals were still migrating north from wintering in the Brooks Range. These caribou are often males and non-parturient females (Figure 14; Person et al. 2007).

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 distributions. 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). In 2019, caribou density was low during the oestrid fly season survey on 30 July, reflecting the high variability in densities.

Caribou density increased on the late summer survey on 29 August and on the late September survey as caribou disperse inland and a portion of the herd moves towards the Brooks Range to winter (Table 2). The highest average (0.6 caribou/km²) and maximum (2.6 caribou/km²) densities of caribou in the GMT survey area are usually in the fall migration season (Figure 7). However, poor flying conditions caused by persistent inclement weather have limited our ability to conduct surveys consistently during fall migration. Only 10 surveys could be conducted in September and October during the years 2009–2019, so we have not been able to sample that period as much as planned. High caribou densities have also been recorded sporadically in the GMT survey region in late winter (e.g., 1.8 caribou/km² in April 2003).

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 2019, surveys of the CRD were not planned during the postcalving, oestrid fly, and late summer seasons due to predicated low use. Use of the area is primarily by CAH animals during the mosquito season and animals from both the TCH and CAH during the oestrid fly season (Figures 12–14). 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 TCH 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 GMT1/MT6 road and planned GMT2/MT7 road. The highest number of caribou seen on Colville River delta transect surveys during 2001–2019 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 TCH 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 River 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. During 2019, at least 5 collared CAH caribou did use the Colville River delta or the area directly to the east during the mosquito and oestrid fly seasons primarily during 16–19 July (Figure 17). Numerous caribou were reported in the vicinity of the oilfield facilities on the Colville River delta during July and early August (Plates 1–5).

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 TCH 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 in 2013–2014, only one collared caribou has 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 TCH caribou and, to a lesser extent, CAH caribou have occasionally crossed the GMT1/MT6 or GMT2/MT7 road corridor alignments, with the highest crossing rates during fall migration and lowest during the postcalving and mosquito seasons (Table 3). However, the GMT2/MT7 alignment is located in a geographic area that currently receives low-density use by caribou.

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 TCH animals.

Using harvest data (Braem et al. 2011) and telemetry data from 2003–2007, Parrett (2013) estimated that TCH 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 River 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 GMT1/MT6 road and planned GMT2/MT7 road are likely to increase subsistence hunter access to seasonal ranges used consistently year-round by TCH caribou.

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, mostly female. 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.

PLATES

1. Alpine facility, 4 July 2019

2. CD-4 road, 29 July 2019

3. CD-5 road, 29 July 2019

4. Near CD-1, 30 July 2019

5. Near CD-2, 2 August 2019

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 12–14).

These geographic patterns in TCH distribution are most pronounced during calving and the mosquito season. Because the GMT survey area is on the eastern edge of the TCH 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 TCH females typically calve near Teshekpuk Lake (Figure 15; 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 GMT1/MT6 and GMT2/MT7 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 GMT1/MT6 and planned GMT2/MT7 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 River 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 among years.

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 avoidance of *Carex aquatilis*, Flooded Tundra, and Wet Tundra during fall and winter has 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 8). The riparian habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation (Figure 4) that provide good oestrid 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 TCH 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 TCH 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 TCH caribou consistently selected Sedge/Grass Meadow and avoided flooded vegetation. In general, caribou appear to avoid wetter habitats during most seasons.

During calving, caribou in the RSF analysis area tended to use areas further to the west, with higher vegetative biomass (daily NDVI) and lower terrain ruggedness, and selected for the reference habitat, sedge/grass meadow. Nitrogen was also in the best model but was not a significant variable suggesting caribou were not selecting for areas predicted to have high nitrogen. Habitat selection during the calving season may vary annually, depending on the timing of snow melt and plant phenology. In 2019, the distribution of collared TCH females, as well as our aerial survey results, suggests that the highest density TCH calving occurred around Teshekpuk Lake as typically occurs.

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 Porcupine Caribou Herd (PCH) 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 had higher biomass (NDVI_Calving and NDVI_621) 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 PCH 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 and were never significant variables, indicating no large effect. 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 TCH females selected areas of low snow cover during calving and Carroll et al. (2005) reported that TCH 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 PCH 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 GMT2/MT7 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 TCH 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 (TCH) and July 2019 (CAH). In recent years, the TCH 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 using the area. By conducting aerial surveys during different seasons over the course of 19 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. 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.

OTHER MAMMALS

There were few observations of other mammals in the GMT and CRD survey areas in 2019, likely as a result of fewer observers working in the area. In the past, there have been regular sightings of grizzly bears, and occasional observations of moose, wolves, wolverines, and polar bears along the coast (Figure 23). Spotted seals are regularly observed hauled out in several locations of the Colville River delta during mid- to late summer.

In recent years, two mixed-sex groups of muskoxen generally have been seen during surveys for other species, one along the Colville River and delta and the other between the Kuparuk River delta and Milne Point (Prichard et al. 2019c). No muskoxen have been observed on ABR surveys in NPRA since 2007.

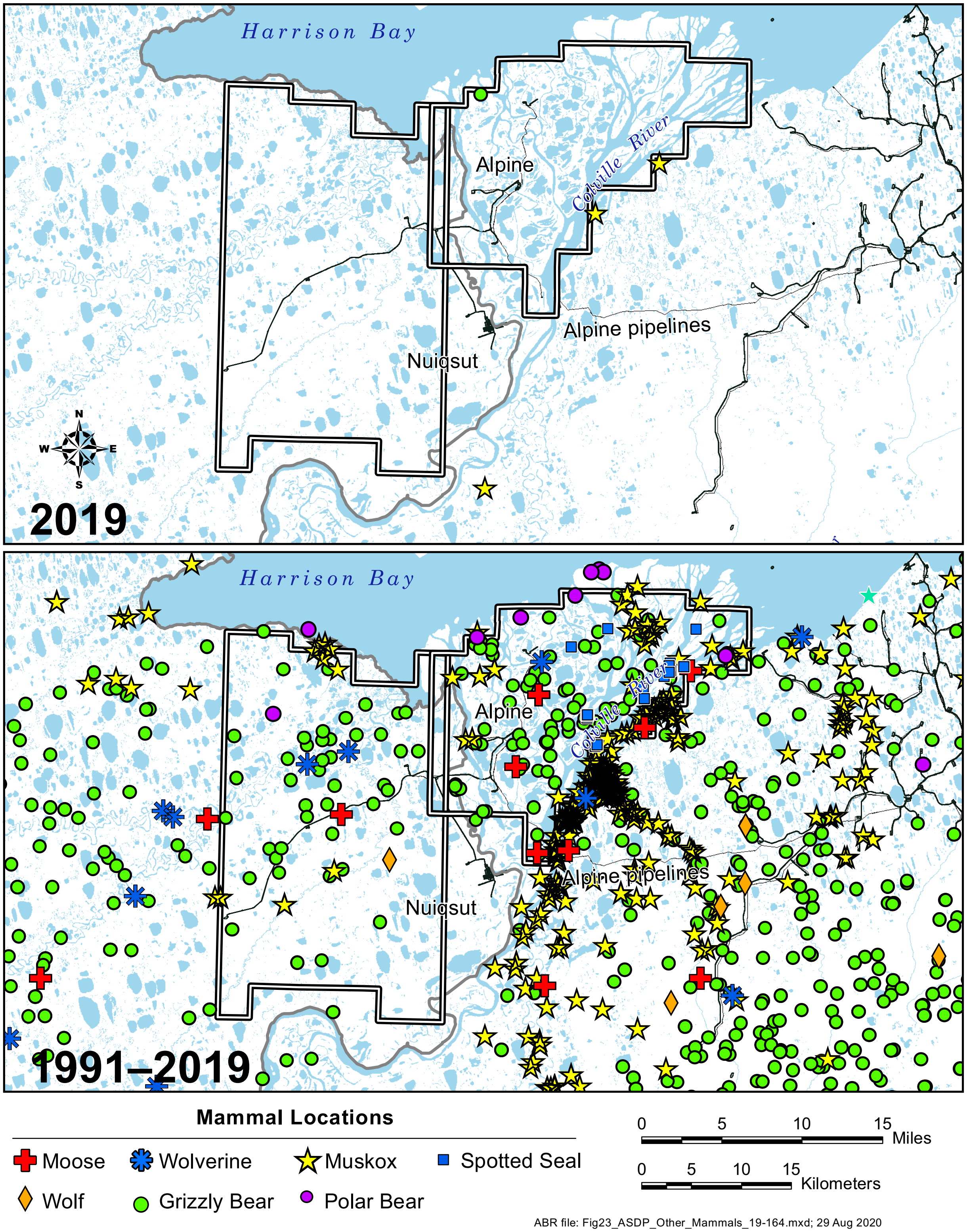


Figure 23. Observations of other large mammals observed during April–October 2019 (top panel) and all observations recorded during 1991–2019 combined in the vicinity of the GMT and Colville River Delta survey areas (bottom panel).

LITERATURE CITED

ADFG (Alaska Department of Fish and Game). 2017. Central Arctic caribou herd news. Winter 2016–17 edition. Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, Alaska. 6 p.

Arthur, S. M., and P. A. Del Vecchio. 2009. Effects of oil field development on calf production and survival in the Central Arctic Herd. Final research technical report, June 2001–March 2006. Federal Aid in Wildlife Restoration Project 3.46, Alaska Department of Fish and Game, Juneau, Alaska. 40 p.

Bergerud, A. T., and R. E. Page. 1987. Displacement and dispersion of parturient caribou as antipredator tactics. Canadian Journal of Zoology 65: 1597–1606.

Bieniek, P.A., U.S. Bhatt, J.E. Walsh, R. Lader, B. Griffith, J. K. Roach, and R.L. Thoman. 2018. Assessment of Alaska rain-on-snow events using dynamical downscaling. Journal of Applied Meteorology and Climatology 57: 1847–1863.

BLM (Bureau of Land Management) and Ducks Unlimited. 2002. National Petroleum Reserve–Alaska earth-cover classification. U.S. Department of the Interior, BLM Alaska Technical Report 40, Anchorage, Alaska. 81 p.

Boggs, K., L. Flagstad, T. Boucher, T. Kuo, D. Fehringer, S. Guyer, and M. Aisu. 2016. Vegetation Map and Classification: Northern, Western, and Interior Alaska. Second edition. Alaska Center for Conservation Science, University of Alaska Anchorage, Anchorage, Alaska. 110 p.

Boyce, M. S., and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology and Evolution 14: 268–272.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281–300.

Braem, N. M., S. Pedersen, J. Simon, D. Koster, T. Kaleak, P. Leavitt, J. Patkotak, and P. Neakok. 2011. Monitoring of annual caribou harvests in the National Petroleum Reserve in Alaska: Atqasuk, Barrow, and Nuiqsut, 2003–2007. Technical Paper No. 361, Alaska Department of Fish and Game, Division of Subsistence, Fairbanks, Alaska. 201 p.

Brower, H. K., and R. T. Opie. 1997. North Slope Borough subsistence harvest documentation project: data for Nuiqsut, Alaska, for the period July 1, 1994 to June 30, 1995. North Slope Borough Department of Wildlife Management, Barrow, AK.

Brown, J., R. K. Haugen, and S. Parrish. 1975. Selected climatic and soil thermal characteristics of the Prudhoe Bay region. Pages 3–11 *in* J. Brown, editor. Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report No. 2, Fairbanks.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information–Theoretic Approach. 2nd edition. Springer–Verlag, New York, NY. 488 pp.

Calcagno, V., and C. de Mazancourt. 2010. *glmulti*: an *R* package for easy automated model selection with (Generalized) Linear Models. Journal of Statistical Software 34: 1–29.

Cameron, R. D., W. T. Smith, and S. G. Fancy. 1989. Distribution and productivity of the Central Arctic Caribou Herd in relationship to petroleum development. Research progress report, Federal Aid in Wildlife Restoration Project 3.35, Alaska Department of Fish and Game, Juneau. 52 pp.

Cameron, R. D., D. J. Reed, J. R. Dau, and W. T. Smith. 1992. Redistribution of calving caribou in response to oil-field development on the Arctic Slope of Alaska. Arctic 45: 338–342.

Cameron, R. D., W. T. Smith, S. G. Fancy, K. L. Gerhart, and R. G. White. 1993. Calving success of female caribou in relation to body weight. Canadian Journal of Zoology 71: 480–486.

Carroll, G. M., A. K. Prichard, R. S. Suydam, L. S. Parrett, and D. A. Yokel. 2004. Unexpected movements of the Teshekpuk caribou herd. Paper presented at the 10th North American Caribou Workshop, 4–6 May 2004, Girdwood, AK. [abstract only]

Carroll, G. M., L. S. Parrett, J. C. George, and D. A. Yokel. 2005. Calving distribution of the Teshekpuk caribou herd, 1994–2003. Rangifer, Special Issue 16: 27–35.

CLS. 2016. Argos user's manual. CLS, Toulouse, France. Available online: http://www.argos-system.org/manual/ (accessed 16 February 2018).

Cox, C. J., R. S. Stone, D. C. Douglas, D. M. Stanitski, G. J. Divoky, G. S. Dutton, C. Sweeney, J. C. George, and D. U. Longenecker. 2017. Drivers and environmental responses to the changing annual snow cycle of northern Alaska. Bulletin of the American Meteorological Society 98: 2559–2577.

Dau, J. R. 1986. Distribution and behavior of barren-ground caribou in relation to weather and parasitic insects. M.S. thesis, University of Alaska, Fairbanks. 149 pp.

Dau, J. 2005. Two caribou mortality events in northwestern Alaska: possible causes and management implications. Rangifer, Special Issue 16: 37–50.

Dau, J. R., and R. D. Cameron. 1986. Effects of a road system on caribou distribution during calving. Rangifer, Special Issue 1: 95–101.

Dick, B. L., S. L. Findholt, and B. K. Johnson. 2013. A self-adjusting expandable GPS collar for male elk. Journal of Wildlife Management 37: 887–892.

Duong, T. 2017. *ks*: Kernel Smoothing. *R* package version 1.10.7. Available online: https://CRAN.R-project.org/package=ks (accessed 16 February 2018).

Eastland, W. G., R. T. Bowyer, and S. G. Fancy. 1989. Caribou calving sites relative to snow cover. Journal of Mammalogy 70: 824–828.

Fancy, S. G. 1983. Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. Arctic 36: 193–197.

Fancy, S. G. 1986. Daily energy budgets of caribou: a simulation approach. Ph.D. dissertation, University of Alaska, Fairbanks. 226 pp.

Fancy, S. G., and R. G. White. 1985. Energy expenditure by caribou while cratering in snow. Journal of Wildlife Management 49: 987–993.

Fancy, S. G., K. R. Whitten, N. E. Walsh, and R. D. Cameron. 1992. Population dynamics and demographics of caribou in developed and undeveloped areas of the Arctic Coastal Plain. Pages 1–21 *in* T. R. McCabe, D. B. Griffith, N. E. Walsh, and D. D. Young, editors. Terrestrial research: 1002 Area, Arctic National Wildlife Refuge. Interim report, 1988–1990. U.S. Fish and Wildlife Service, Anchorage.

Finstad, G. L., and A. K. Prichard. 2000. Climatic influence on forage quality, growth, and reproduction of reindeer on the Seward Peninsula, II: Reindeer growth and reproduction. Rangifer, Special Issue 12: 144.

Fuller, A. S., and J. C. George. 1997. Evaluation of subsistence harvest data from the North Slope Borough 1993 census for eight North Slope villages for calendar year 1992. North Slope Borough Department of Wildlife Management, Barrow,AK.

Gasaway, W. C., S. D. DuBois, D. J. Reed, and S. J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biological Papers of the University of Alaska, No. 22, Fairbanks. 108 pp.

Gorelick, N., M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, and R. Moore. 2017. Google Earth Engine: planetary-scale geospatial analysis for everyone. Remote Sensing of Environment 202: 18–27.

Griffith, D. B., D. C. Douglas, N. E. Walsh, D. D. Young, T. R. McCabe, D. E. Russell, R. G. White, R. D. Cameron, and K. R. Whitten. 2002. Section 3: The Porcupine caribou herd. Pages 8–37 *in* D. C. Douglas, P. E. Reynolds, and E. B. Rhode, editors. Arctic Refuge coastal plain terrestrial wildlife research summaries. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001.

Hope, A. S., J. S. Kimball, and D. A. Stow. 1993. The relationship between tussock tundra spectral properties and biomass and vegetation composition. International Journal of Remote Sensing 14: 1861–1874.

Horne, J. S., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology 88: 2354–2363.

Jensen, P. G., and L. E. Noel. 2002. Caribou distribution in the northeast National Petroleum Reserve–Alaska, summer 2001. Chapter 3 *in* M. A. Cronin, editor. Arctic Coastal Plain caribou distribution, summer 2001. Report for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage.

Johnson, C. B., B. E. Lawhead, J. R. Rose, M. D. Smith, A. A. Stickney, and A. M. Wildman. 1998. Wildlife studies on the Colville River delta, Alaska, 1997. Sixth annual report for ARCO Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 144 pp.

Johnson, C. B., J. P. Parrett, T. Obritschkewitsch, J. R. Rose, K. B. Rozell, and P. E. Seiser. 2015. Avian studies for the Alpine Satellite Development Project, 2014. 12th annual report for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corp., Anchorage, by ABR, Inc., Fairbanks. 124 pp.

Johnson, H.E., T.S. Golden, L.G. Adams, D.D. Gustine, and E.A. Lenart. 2020. Caribou use of habitat near energy development in Arctic Alaska. Journal of Wildlife Management DOI: 10.1002/jwmg.21809

Johnson, H. E., D. D. Gustine, T. S. Golden, L. G. Adams, L. S. Parrett, E. A. Lenart, P. S. Barboza. 2018. NDVI exhibits mixed success in predicting spatiotemporal variation in caribou summer forage quality and quantity. Ecosphere 9: 10.

Johnstone, J., D. E. Russell, and D. B. Griffith. 2002. Variations in plant forage quality in the range of the Porcupine caribou herd. Rangifer 22: 83–91.

Jorgenson, M. T., J. E. Roth, E. R. Pullman, R. M. Burgess, M. Raynolds, A. A. Stickney, M. D. Smith, and T. Zimmer. 1997. An ecological land survey for the Colville River delta, Alaska, 1996. Report for ARCO Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 160 pp.

Jorgenson, M. T., J. E. Roth, M. Emers, S. Schlentner, D. K. Swanson, E. R. Pullman, J. Mitchell, and A. A. Stickney. 2003. An ecological land survey for the Northeast Planning Area of the National Petroleum Reserve–Alaska, 2002. Report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 84 pp.

Jorgenson, M. T., J. E. Roth, M. Emers, W. Davis, E. R. Pullman, and G. V. Frost. 2004. An ecological land survey for the Northeast Planning Area of the National Petroleum Reserve–Alaska, 2003. Addendum to 2002 report for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks. 40 pp.

Kelleyhouse, R. A. 2001. Calving-ground selection and fidelity: Teshekpuk Lake and Western Arctic herds. M.S. thesis, University of Alaska, Fairbanks. 124 pp.

Klein, D. R. 1990. Variation in quality of caribou and reindeer forage plants associated with season, plant part, and phenology. Rangifer, Special Issue 3: 123–130.

Klimstra, R. 2018. Summary of Teshekpuk caribou herd photocensus conducted July 14, 2017. State of Alaska memorandum, Department of Fish and Game, Division of Wildlife Conservation (Northwest), Fairbanks. 6 pp.

Kranstauber, B., K. Safi, and F. Bartumeus. 2014. Bivariate Gaussian bridges: directional factorization of diffusion in Brownian bridge models. Movement Ecology 2: 5. doi.org/10.1186/2051-3933-2-5.

Kranstauber, B., M. Smolla, and A.K. Scharf. 2017. *Move*: visualizing and analyzing animal track data. *R* package version 3.0.1. Available online: https://CRAN.R-project.org/package=move (accessed 16 February 2018).

Kuropat, P. J. 1984. Foraging behavior of caribou on a calving ground in northwestern Alaska. M.S. thesis, University of Alaska, Fairbanks. 95 pp.

Lair, H. 1987. Estimating the location of the focal center in red squirrel home ranges. Ecology 68: 1092–1101.

Lawhead, B. E. 1988. Distribution and movements of Central Arctic Herd caribou during the calving and insect seasons. Pages 8–13 *in* R. Cameron and J. Davis, editors. Reproduction and calf survival. Proceedings of the 3rd North American Caribou Workshop. Wildlife Technical Bulletin No. 8, Alaska Department of Fish and Game, Juneau.

Lawhead, B. E., and A. K. Prichard. 2002. Surveys of caribou and muskoxen in the Kuparuk–Colville region, Alaska, 2001. Report for Phillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 37 pp.

Lawhead, B. E., A. K. Prichard, M. J. Macander, and M. Emers. 2004. Caribou mitigation monitoring study for the Meltwater Project, 2003. Third annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 104 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2006. Caribou monitoring study for the Alpine Satellite Development Program, 2005. First annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 102 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2007. Caribou monitoring study for the Alpine Satellite Development Program, 2006. Second annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 75 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2008. Caribou monitoring study for the Alpine Satellite Development Program, 2007. Third annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 89 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2009. Caribou monitoring study for the Alpine Satellite Development Program, 2008. Fourth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 91 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2010. Caribou monitoring study for the Alpine Satellite Development Program, 2009. Fifth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 101 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2011. Caribou monitoring study for the Alpine Satellite Development Program, 2010. Sixth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 101 pp.

Lawhead, B. E., A. K. Prichard, and M. J. Macander. 2012. Caribou monitoring study for the Alpine Satellite Development Program, 2011. Seventh annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 90 pp.

Lawhead, B. E., A. K. Prichard, M. J. Macander, and J. H. Welch. 2013. Caribou monitoring study for the Alpine Satellite Development Program, 2012. Eighth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 88 pp.

Lawhead, B. E., A. K. Prichard, M. J. Macander, and J. H. Welch. 2014. Caribou monitoring study for the Alpine Satellite Development Program, 2013. Ninth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 94 pp.

Lawhead, B. E., A. K. Prichard, M. J. Macander, and J. H. Welch. 2015. Caribou monitoring study for the Alpine Satellite Development Program, 2014. Tenth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 100 pp.

Lenart, E. A. 2009. GMU 26B and 26C, Central Arctic Herd. Pages 299–325 *in* P. Harper, editor. Caribou management report of survey and inventory activities, 1 July 2006–30 June 2008. Federal Aid in Wildlife Restoration Project 3.0, Alaska Department of Fish and Game, Juneau.

Lenart, E. A. 2015. Units 26B and 26C, Central Arctic. Chapter 18 *in* P. Harper and L. A. McCarthy, editors. Caribou management report of survey and inventory activities, 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

Lenart, E. A. 2017. 2016 Central Arctic caribou photocensus results. State of Alaska memorandum, Department of Fish and Game, Division of Wildlife Conservation, Fairbanks. 5 pp.

Lenart, E. A. 2019. 2019 Central Arctic caribou photocensus results. State of Alaska Memorandum. Alaska Department Of Fish and Game, Division of Wildlife Conservation. Fairbanks. 8 pp.

Macander, M. J., C. S. Swingley, K. Joly, and M. K. Raynolds. 2015. Landsat-based snow persistence map for northwest Alaska. Remote Sensing of Environment 163: 23–31.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht, The Netherlands. 209 pp.

McNay, R. S., J. A. Morgan, and F. L. Bunnell. 1994. Characterizing independence of observations in movements of Columbian black-tailed deer. Journal of Wildlife Management 58: 422–429.

Mörschel, F. M. 1999. Use of climatic data to model the presence of oestrid flies in caribou herds. Journal of Wildlife Management 63: 588–593.

Muller, S. V., D. A. Walker, F. E. Nelson, N. A. Auerbach, J. G. Bockheim, S. Guyer, and D. Sherba. 1998. Accuracy assessment of a land-cover map of the Kuparuk River basin, Alaska: considerations for remote regions. Photogrammetric Engineering and Remote Sensing 64: 619–628.

Muller, S. V., A. E. Racoviteanu, and D. A. Walker. 1999. Landsat-MSS-derived land-cover map of northern Alaska: extrapolation methods and a comparison with photo-interpreted and AVHRR-derived maps. International Journal of Remote Sensing 20: 2921–2946.

Murphy, S. M., and B. E. Lawhead. 2000. Caribou. Chapter 4, pages 59–84 *in* J. Truett and S. R. Johnson, editors. The Natural History of an Arctic Oil Field: Development and the Biota. Academic Press, San Diego, CA.

Nellemann, C., and R. D. Cameron. 1996. Effects of petroleum development on terrain preferences of calving caribou. Arctic 49: 23–28.

Nellemann, C., and M. G. Thomsen. 1994. Terrain ruggedness and caribou forage availability during snowmelt on the Arctic Coastal Plain, Alaska. Arctic 47: 361–367.

Nicholson, K. L., S. M. Arthur, J. S. Horne, E. O. Garton, and P. A. Del Vecchio. 2016. Modeling caribou movements: seasonal ranges and migration routes of the Central Arctic Herd. PLoS One 11(4): e0150333. doi:10.1371/journal.pone.0150333.

Noel, L. E. 1999. Calving caribou distribution in the Teshekpuk Lake area, June 1998. Data report for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 31 pp.

Noel, L. E. 2000. Calving caribou distribution in the Teshekpuk Lake area, June 1999. Report for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 29 pp.

Noel, L. E., and J. C. George. 2003. Caribou distribution during calving in the northeast National Petroleum Reserve–Alaska, June 1998 to 2000. Rangifer, Special Issue 14: 283–292.

NSSI. 2013. North Slope Science Initiative land-cover mapping summary report. Report for NSSI by Ducks Unlimited, Inc., Rancho Cordova, CA. 51 pp. + maps.

Parrett, L. S. 2007. Summer ecology of the Teshekpuk caribou herd. M.S. thesis, University of Alaska, Fairbanks. 149 pp.

Parrett, L. S. 2013. Unit 26A, Teshekpuk Caribou Herd. Pages 314–355 *in* P. Harper, editor. Caribou management report of survey and inventory activities, 1 July 2010–30 June 2012. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2013-3, Juneau.

Parrett, L. S. 2015a. Unit 26A, Teshekpuk caribou herd. Chapter 17 *in* P. Harper and L. A. McCarthy, editors. Caribou management report of survey and inventory activities, 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

Parrett, L. S. 2015b. Summary of Teshekpuk caribou herd photocensus conducted July 6, 2015. State of Alaska memorandum, Department of Fish and Game, Division of Wildlife Conservation (Northwest), Fairbanks. 6 pp.

Pebesma, E. J. 2004. Multivariate geostatistics in S: the *gstat* package. Computers & Geosciences 30: 683–691.

Pedersen, S. 1995. Nuiqsut. Chapter 22 *in* J. A. Fall and C. J. Utermohle, editors. An investigation of the sociocultural consequences of Outer Continental Shelf development in Alaska, Vol. V: Alaska Peninsula and Arctic. Technical Report No. 160, OCS Study MMS 95-014, Minerals Management Service, Anchorage.

Pennycuick, C. J., and D. Western. 1972. An investigation of some sources of bias in aerial transect sampling of large mammal populations. East African Wildlife Journal 10: 175–191.

Person, B. T., A. K. Prichard, G. M. Carroll, D. A. Yokel, R. S. Suydam, and J. C. George. 2007. Distribution and movements of the Teshekpuk caribou herd, 1990–2005: prior to oil and gas development. Arctic 60: 238–250.

Philo, L. M., G. M. Carroll, and D. A. Yokel. 1993. Movements of caribou in the Teshekpuk Lake herd as determined by satellite tracking, 1990–1993. North Slope Borough Department of Wildlife Management, Barrow; Alaska Department of Fish and Game, Barrow; and U.S. Department of Interior, Bureau of Land Management, Fairbanks. 60 pp.

Prichard, A.K. 2016. Section 9. caribou distribution, habitat use, and herd fidelity. [In] Macander, M.J., G.V. Frost, and S.M. Murphy. Shell onshore/nearshore environmental studies, 2015. Draft report prepared for Shell Onshore/Nearshore Environmental Studies Program by ABR Inc., Fairbanks, Alaska.

Prichard, A.K., R.L. Klimstra, B.T. Person, and L.S. Parrett. 2019a. Aerial survey and telemetry data analysis of a peripheral caribou calving areain northwestern Alaska. Rangifer 43–58.

Prichard, A.K., B.E. Lawhead, E.A. Lenart, and J.H. Welch. 2020a. Caribou distribution and movements in a Northern Alaska Oilfield. Early View. Journal of Wildlife Management. https://doi.org/10.1002/jwmg.21932

Prichard, A. K., M. J. Macander, J. H. Welch, and B. E. Lawhead. 2017. Caribou monitoring study for the Alpine Satellite Development Program, 2015 and 2016. Twelfth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 62 p.

Prichard, A.K., L.S. Parrett, E.A. Lenart, J. Caikoski, K. Joly, and B.T. Person. 2020b. Interchange and overlap among four adjacent Arctic caribou herds. Journal of Wildlife Management. Journal of Wildlife Management. Early View. https://doi.org/10.1002/jwmg.21934

Prichard, A. K., J. H. Welch, and B. E. Lawhead. 2018a. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2017. Report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 52 p.

Prichard, A. K., J. H. Welch, M. J. Macander, and B. E. Lawhead. 2018b. Caribou monitoring study for the Alpine Satellite Development Program, 2017. Thirteenth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 63 p.

Prichard, A. K., J. H. Welch, M. J. Macander, and B. E. Lawhead. 2019b. Caribou monitoring study for the Bear Tooth Unit Program, Arctic Coastal Plain, Alaska, 2018. Annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 96 p.

Prichard, A. K., J. H. Welch, M. J. Macander, and B. E. Lawhead. 2019c. Caribou monitoring study for the Alpine Satellite Development Program, 2018. Fourteenth annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 88 p.

Prichard, A. K., and J. H. Welch. 2020c. Mammal surveys in the Greater Kuparuk Area, northern Alaska, 2018–2019. Report for ConocoPhillips Alaska, Inc., and Greater Kuparuk Area, Anchorage, by ABR, Inc., Fairbanks.

Prichard, A. K., J. H. Welch, and M. J. Macander. 2020d. Caribou monitoring study for the Bear Tooth Unit Program, Arctic Coastal Plain, Alaska, 2019. Annual report for ConocoPhillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks.

Prichard, A. K., D. A. Yokel, C. L. Rea, B. T. Person, and L. S. Parrett. 2014. The effect of frequency of telemetry locations on movement-rate calculations in arctic caribou. Wildlife Society Bulletin 38: 78–88.

R Core Team. 2019. R: A language and environment for statistical computing. *R* Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org.

Riggs, G. A., and D. K. Hall. 2015. MODIS snow products Collection 6 user guide. National Snow and Ice Data Center. Available online: https://nsidc.org/sites/nsidc.org/files/files/MODIS-snow-user-guide-C6.pdf (accessed 16 February 2018).

Rouse, J. W., R. H. Haas, J. A. Schell, and D. W. Deering. 1973. Monitoring vegetation systems in the Great Plains with ERTS. Third Earth Resources Technology Satellite Symposium, Greenbelt, MD, NASA (SP-351) 1: 309–317.

Russell, D. E., A. M. Martell, and W. A. C. Nixon. 1993. Range ecology of the Porcupine caribou herd in Canada. Rangifer, Special Issue 8. 167 pp.

Salomonson, V. V., and I. Appel. 2004. Estimating fractional snow cover from MODIS using the normalized difference snow index. Remote Sensing of Environment 89: 351–360.

Sappington, J., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71: 1419–1426.

Schaaf, C., and Z. Wang. 2015. MCD43A4 MODIS/Terra+Aqua BRDF/Albedo Nadir BRDF Adjusted Ref Daily L3 Global - 500m V006. Distributed by NASA EOSDIS Land Processes DAAC, https://doi.org/10.5067/MODIS/MCD43A4.006

Sellers, P. J. 1985. Canopy reflectance, photosynthesis, and transpiration. International Journal of Remote Sensing 21: 143–183. [original not seen; cited in Hope et al. 1993]

SRB&A. 2017. Nuiqsut caribou subsistence monitoring project: results of year 8 hunter interviews and household harvest surveys. Report for ConocoPhillips Alaska, Inc., Anchorage, by Stephen R. Braund & Associates, Anchorage. 47 pp. + appendices.

Stow, D. A., A. Hope, D. McGuire, D. Verbyla, J. Gamon, F. Huemmrich, S. Houston, C. Racine, M. Sturm, K. Tape, L. Hinzman, K. Yoshikawa, C. Tweedie, B. Noyle, C. Silapaswan, D. Douglas, B. Griffith, G. Jia, H. Epstein, D. Walker, S. Daeschner, A. Pertersen, L. Zhou, and R. Myneni. 2004. Remote sensing of vegetation and land-cover change in arctic tundra ecosystems. Remote Sensing of Environment 89: 281–308.

Walker, H. J. 1983. Guidebook to permafrost and related features of the Colville River delta, Alaska. Guidebook 2. Alaska Division of Geological and Geophysical Surveys, Anchorage. 34 pp.

Walker, H. J., and H. H. Morgan. 1964. Unusual weather and riverbank erosion in the delta of the Colville River, Alaska. Arctic 17: 41–47.

Weladji, R. B., G. Steinheim, Ø. Holand, S. R. Moe, T. Almøy, and T. Ådnøy. 2003. Use of climatic data to assess the effect of insect harassment on the autumn weight of reindeer (*Rangifer tarandus*) calves. Journal of Zoology 260: 79–85.

White, R. G., B. R. Thomson, T. Skogland, S. J. Person, D. E. Russell, D. F. Holleman, and J. R. Luick. 1975. Ecology of caribou at Prudhoe Bay, Alaska. Pages 151–201 *in* J. Brown, editor. Ecological investigations of the tundra biome in the Prudhoe Bay region, Alaska. Biological Papers of the University of Alaska, Special Report No. 2, Fairbanks.

Wilson, R. R., A. K. Prichard, L. S. Parrett, B. T. Person, G. M. Carroll, M. A. Smith, C. L. Rea, and D. A. Yokel. 2012. Summer resource selection and identification of important habitat prior to industrial development for the Teshekpuk caribou herd in northern Alaska. PLoS One 7(11): e48697. doi:10.1371/journal.pone.0048697.

Wolfe, S. A. 2000. Habitat selection by calving caribou of the central arctic herd, 1980–95. M.S. thesis, University of Alaska, Fairbanks. 83 pp.

Yokel, D. A., A. K. Prichard, G. Carroll, L. Parrett, B. Person, and C. Rea. 2009. Teshekpuk caribou herd movement through narrow corridors around Teshekpuk Lake, Alaska. Alaska Park Science 8(2): 64–67.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed-effects models and extensions in ecology with *R*. Springer, New York, NY. 574 pp.

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, 1983–2019.

	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	137.0	195.9	55.25
2019	23	13	0	1.1	11.9	31.1	108.5	180.3	181.3	118.0
Mean	**25**	**14**	**3**	**1.3**	**11.8**	**41.5**	**102.1**	**129.5**	**145.8**	**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.

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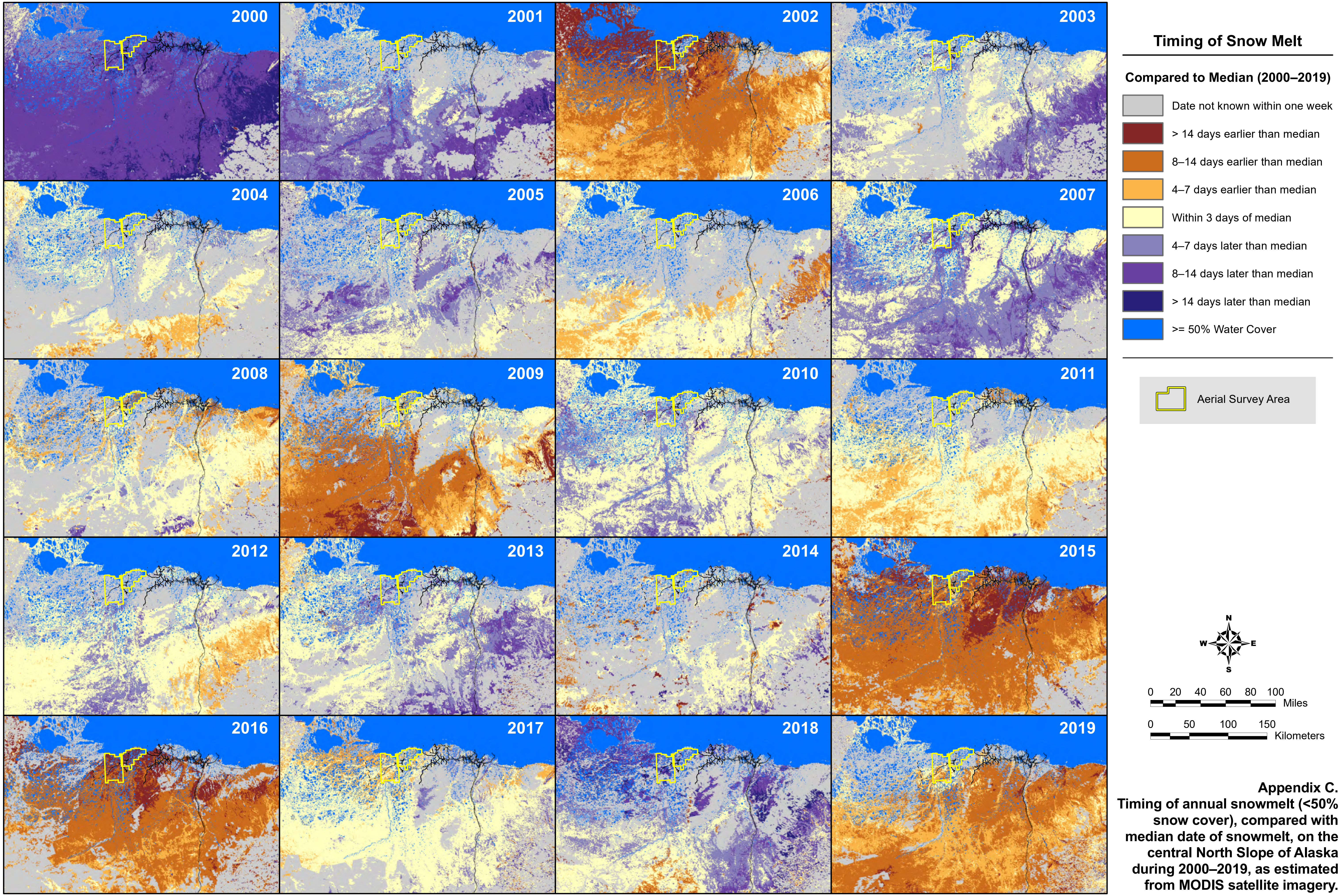
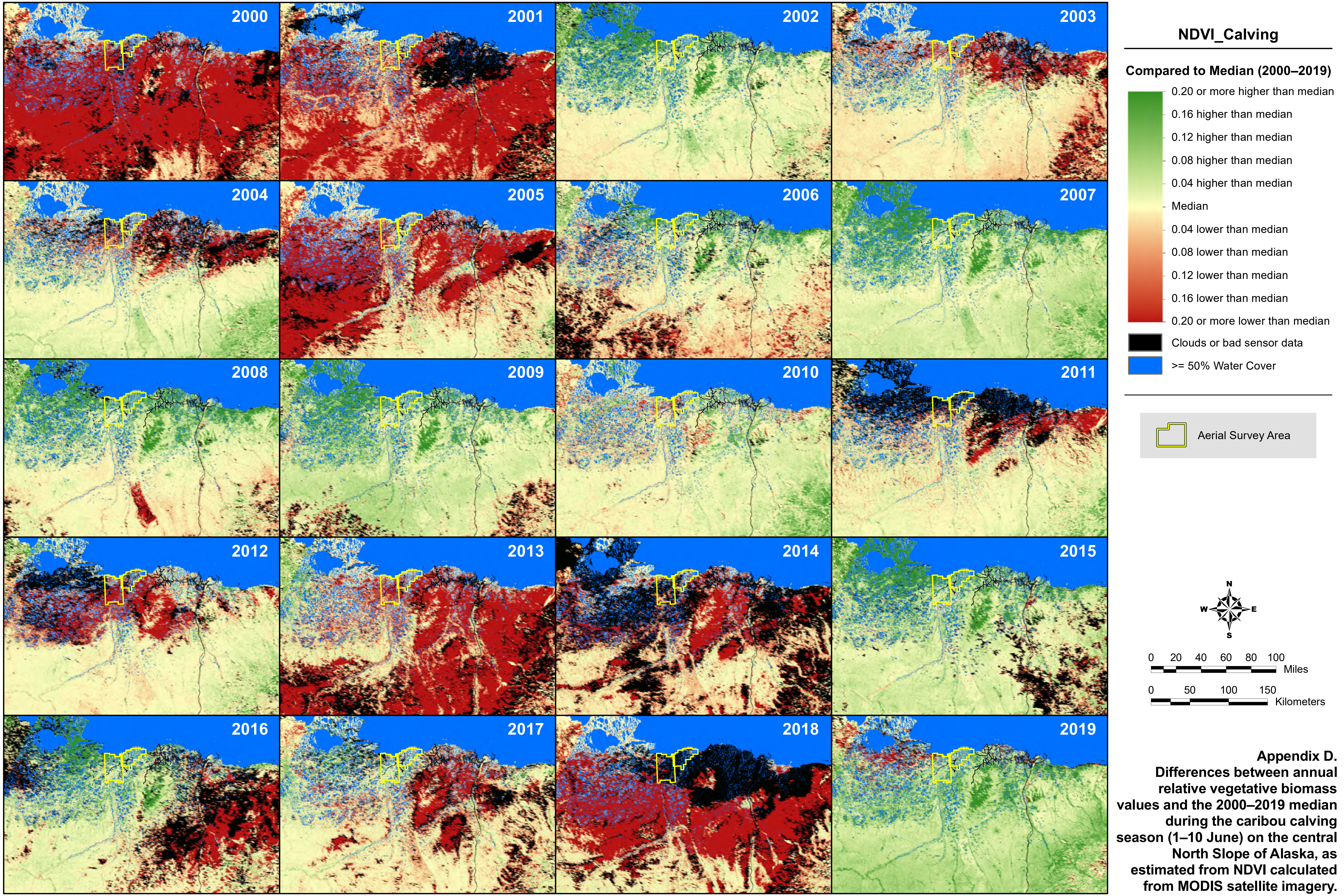
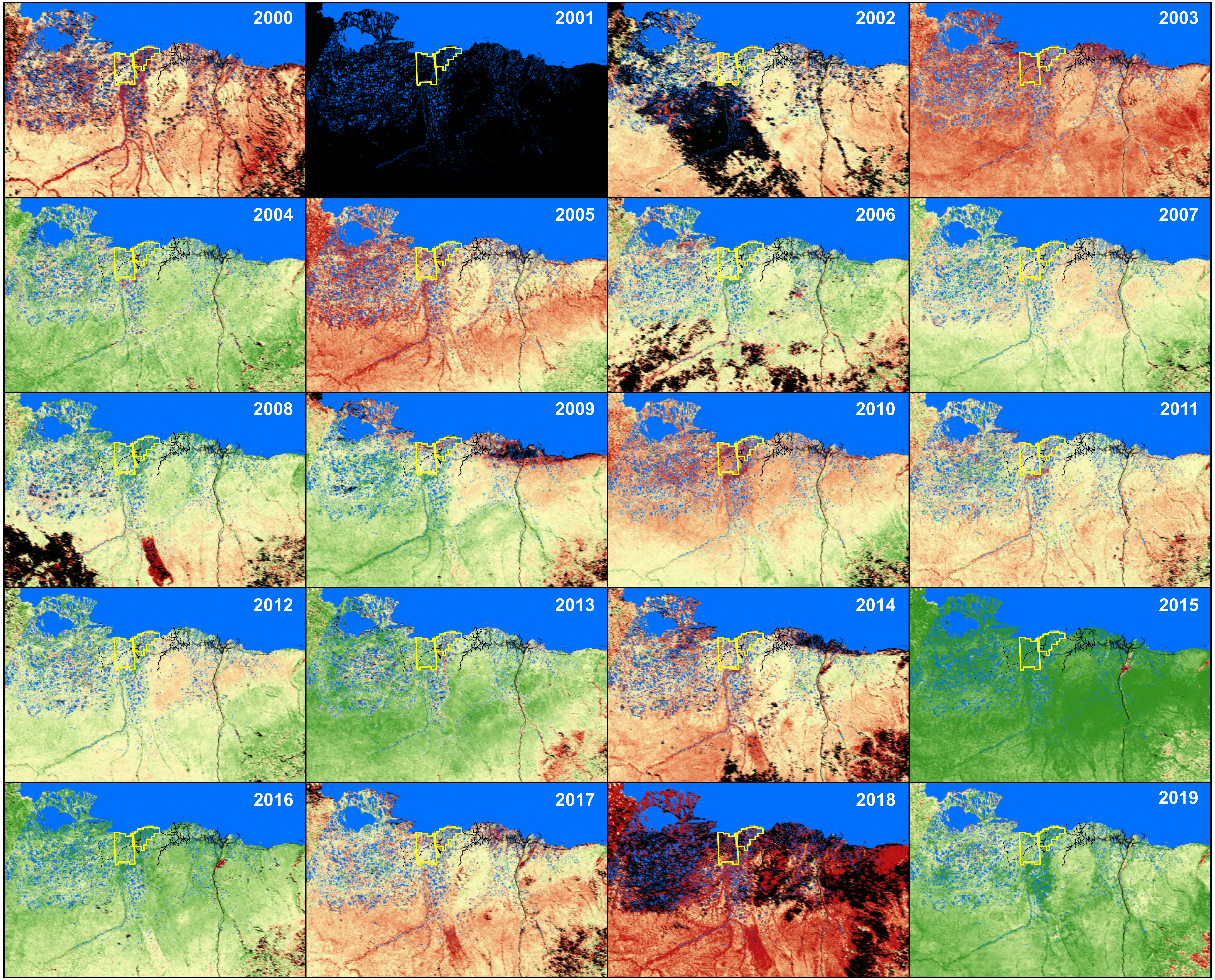
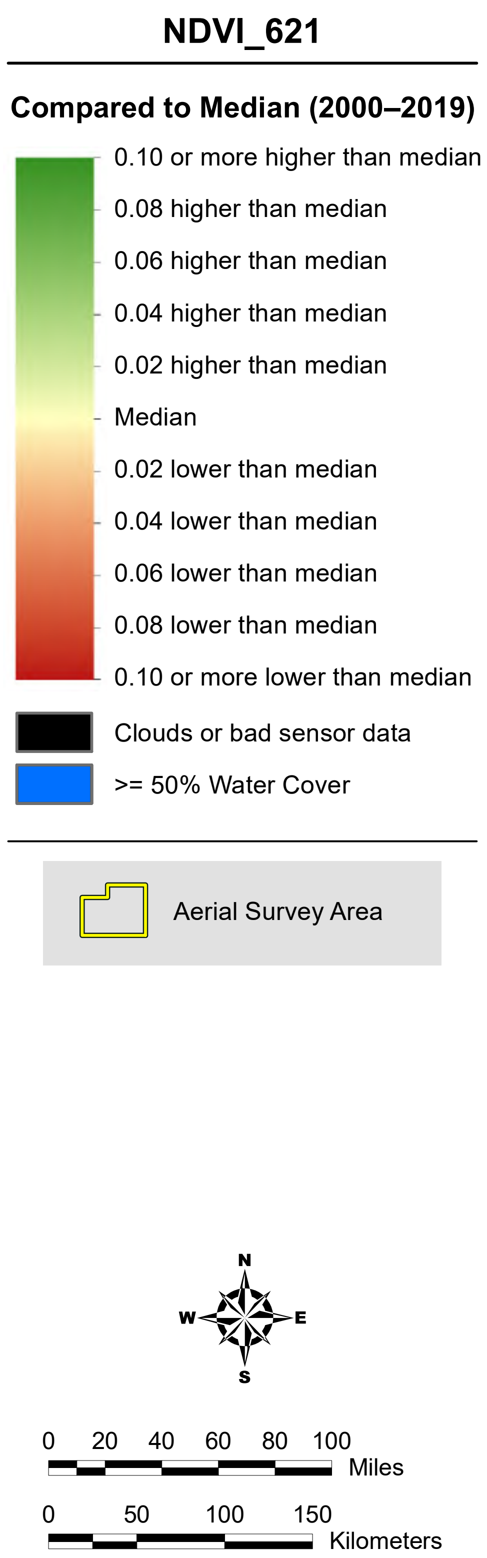


Appendix C.
Timing of annual snowmelt (<50% snow cover), compared with median date of snowmelt, on the central North Slope of Alaska during 2000–2019, as estimated from MODIS satellite imagery.

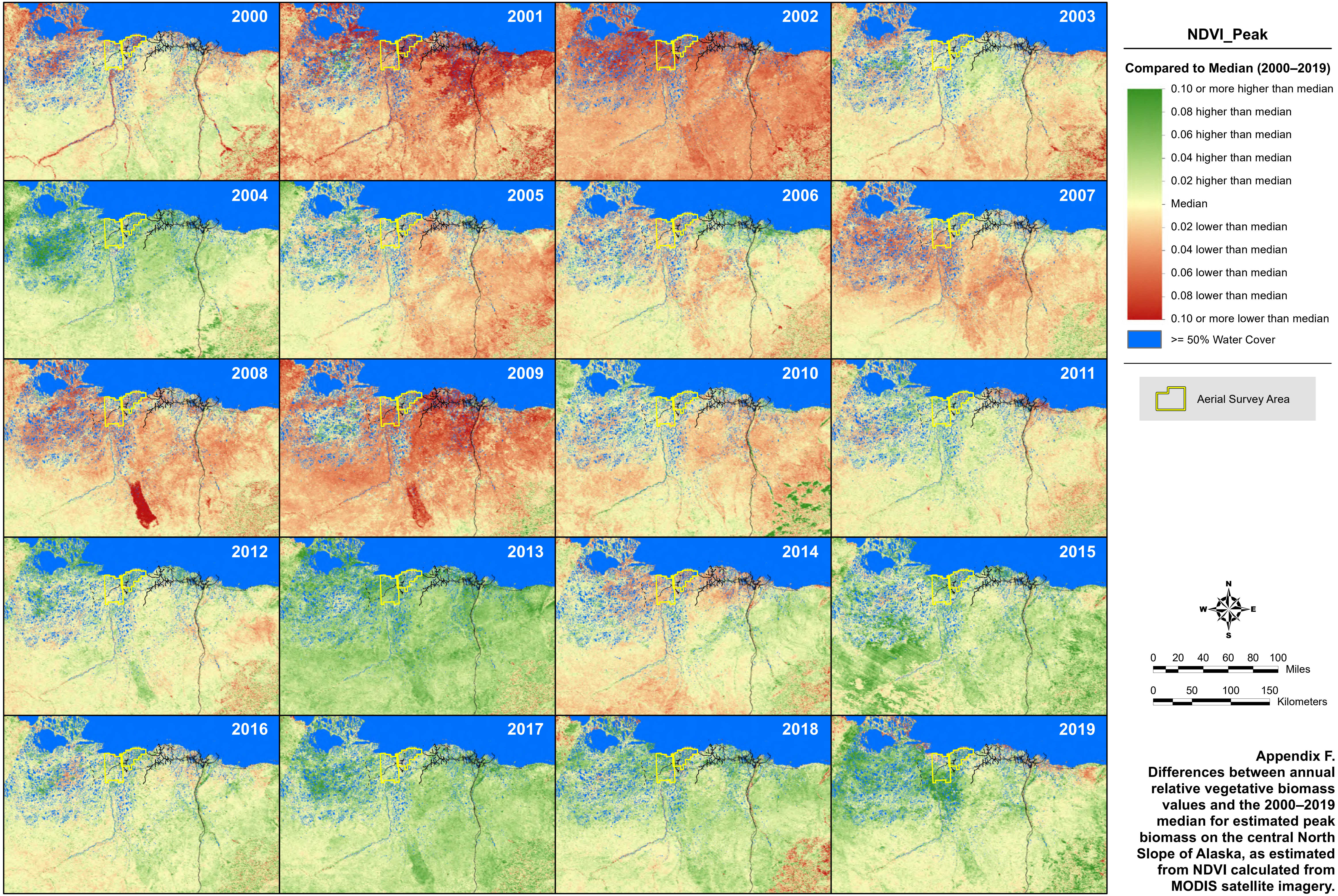


Appendix D. Differences between annual relative vegetative biomass values and the 2000–2019 median during the caribou calving season (1–10 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.





Appendix E.
Differences between annual relative vegetative biomass values and the 2000–2019 median at estimated peak lactation for caribou (21 June) on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.



Appendix F. Differences between annual relative vegetative biomass values and the 2000–2019 median for estimated peak biomass on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.