Cover:
Late summer bull caribou in velvet walks along a lake shore on the North Slope. Photo by ABR © ConocoPhillips Alaska, Inc.
CARIBOU MONITORING STUDY FOR THE BEAR TOOTH UNIT,
ARCTIC COASTAL PLAIN, ALASKA, 2022

REVISED FINAL

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EXECUTIVE SUMMARY

• Caribou use of the Bear Tooth Unit area has been studied since 2001 using a combination of aerial surveys, analysis of telemetry data, and remote sensing to understand caribou distribution and movements prior to development. This report summarizes field research conducted in 2022 and analyses of data collected over the life of the project.

• During 2022, spring air temperatures and snow depth were near the 30-year average and the timing of snow melt was similar to the median date of snowmelt for the past 20 years. Early June was cooler than average, but temperatures in late June and early July were generally above average. Temperatures for the rest of July were below average followed by high variability in August and near-average temperatures in September.

• Temperatures and wind speeds resulted in 13 days with a high probability of mosquito harassment (mosquito index >50%) in late June and early July, zero days with a high probability of either mosquito or fly harassment for mid- and late July, and 2 days with a high probability of fly harassment in early August.

• We conducted all 7 planned aerial transect surveys of the Bear Tooth North (BTN) survey area and 6 of 7 surveys of the Bear Tooth South (BTS) survey area between March and October 2022. Due to persistent inclement weather during the late summer survey, we cancelled the BTS survey and only conducted a partial survey of the BTN survey area.

• In the BTN survey area, the estimated density ranged from 0.12 caribou/km² on 8–9 June to 1.32 caribou/km² on 11 September. We observed 4 calves during the calving survey on 9 June.

• In the BTS survey area, the estimated density ranged from 0.15 caribou/km² on 5 August to 0.69 caribou/km² on 17 June. We observed 3 calves during the calving survey on 8 June.

• We analyzed telemetry data using kernel density estimation, dynamic Brownian Bridge movement models, and species distribution models to examine seasonal patterns of movements and distribution for caribou from both the Teshekpuk Caribou Herd (TCH) and the Central Arctic Herd (CAH). In 2021 and 2022, we also conducted an integrated Step-Selection Analysis of TCH movements and examined selection for areas within 8 km of gravel roads and ice roads.

• We examined annual and seasonal spatial patterns in vegetative biomass based on Normalized Difference Vegetation Index (NDVI), and snow cover calculated on a regional scale using satellite imagery. We also estimated forage biomass and nitrogen levels using NDVI and phenology.

• TCH females use the BTN and BTS survey areas throughout the year, but the BTS survey area receives little use by females in June and July; male caribou of the TCH use the survey areas the most during June–September with little winter use. CAH caribou rarely use the BTN or BTS areas.

• The percentages of seasonal utilization distributions within 4 km of proposed roads and pads (Alternative E) based on kernel density estimation ranged from 0.0% to 1.9% with notable differences by sex. Males were most likely to be within 4 km of proposed roads and pads from June through September, whereas females maintained a consistent occurrence for most of the winter months, decreased occurrence in June and July, and increased occurrence in August–October.

• Species distribution models indicated that broad geographic patterns were important factors influencing caribou distribution during all seasons, but caribou distribution can also be explained by differences in lichen and graminoid abundance, snowmelt dates, topographic relief, and surface wetness.

• The integrated step-selection analysis indicated that TCH caribou had strong seasonal patterns of selection for areas with different lichen and graminoid abundance, snowmelt dates, topographic relief, and surface wetness. At this scale of analysis, TCH caribou avoided the area within 0–2 km of the GMT roads during the oestrid fly and fall migration seasons and
within 2–4 km of roads during the fall migration season after construction of the GMT/MT7 road. There was not enough data to analyze the impact of roads during other seasons. Sample sizes of caribou near roads were limited, so these results should be viewed as preliminary.

- The integrated step-selection analysis of movements during January–March 2019–2020 and 2022 indicated that TCH female caribou used the area within 4 km of ice roads less than expected during all years combined and used areas within 2–4 km of ice roads less than expected during individual years. The extent of ice roads was too limited in 2021 to conduct an annual analysis for that year.

- We observed 17 grizzly bears in 11 groups, all in the BTN survey area. All observations were in central or southeast BTN. In addition to bears, we recorded 2 observations of single wolverines, both in western BTN.
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<td>Teshekpuk Caribou Herd</td>
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<td>TDD</td>
<td>thawing degree day</td>
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<td>TPI</td>
<td>topographic position index</td>
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<td>U.S. Geological Survey</td>
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<td>VIF</td>
<td>Variance Inflation Factor</td>
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Suggested Citation:

INTRODUCTION

BACKGROUND

The caribou monitoring study for the Bear Tooth Unit (BTU) area is being conducted on the Arctic Coastal Plain of northern Alaska in the northeastern portion of the National Petroleum Reserve–Alaska (NPR-A; Figure 1). This area is used primarily by one herd of barren-ground caribou (*Rangifer tarandus granti*)—the Teshekpuk Caribou Herd (TCH), although some caribou from the Central Arctic Herd (CAH) use the area in some years.

Most TCH caribou remain on the Arctic Coastal Plain (hereafter, the coastal plain) year-round. The highest density of 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 westward, with some calving extending west of Atqasuk (Parrett 2015a; Prichard et al. 2019a).

Most TCH caribou winter on the coastal plain, generally west of the Colville River, although about one-third of the herd, including a disproportionate number of males, winter in the central Brooks Range or, to a lesser extent, with the Western Arctic Herd (WAH) in western Alaska (Carroll et al. 2005, Person et al. 2007, Parrett 2015a, Fullman et al. 2021). In a highly unusual movement, many TCH caribou 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. 2018).

The TCH has experienced large cyclical population changes typical of barren-ground caribou herds. The TCH increased substantially in size from a few thousand caribou in the mid-1970s, to 40,000+ in the early 1990s (Figure 2; Parrett 2021). The TCH experienced a dip in numbers in the mid-1990s but increased steadily from 1995 to its peak estimated size of 68,932 caribou in July 2008 (Parrett 2021). The herd subsequently declined to 39,172 caribou in 2013 and then increased to >56,255 caribou by July 2017 (Klimstra 2018, Parrett 2021), and again increased to 61,593 caribou in 2022 (C. Daggett, pers. comm.).

The summer range of the Central Arctic Herd (CAH) of caribou is generally between the Colville and Canning rivers outside of the study area, but large groups of animals sometime cross over to the west of the Colville River, particularly during mid- and late summer when the CAH typically moves to the Beaufort Sea coast during periods of mosquito harassment which generally begin in late June (White et al. 1975, Dau 1986, Lawhead 1988, Prichard et al. 2020a). Therefore, we include analysis of CAH animals for comparison and contrast but focus primarily on TCH animals. For more detailed information regarding CAH caribou movements and distribution in relation to CPAI North Slope infrastructure, see Welch et al. (2023) and Prichard and Welch (2023).

Population trends of the CAH have largely mirrored those of the TCH (Figure 2; Lenart 2009, 2015a, 2017, 2019, 2021). The herd grew rapidly from ~5,000 caribou in the mid-1970s to a peak size of 68,442 caribou in 2010 (Lenart 2021). The herd subsequently declined to 22,630 caribou by July 2016 (Lenart 2017). The herd then increased to 30,069 caribou by July 2019 (Lenart 2019) and 34,642 in 2022 (M. Nelson, pers. comm.). The magnitude of the decline from 2010 to 2016 may have been affected by emigration of some CAH caribou to the Porcupine Caribou Herd with which the CAH often intermixes on the 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 NPR-A beginning in 1999 (Jorgenson et al. 1997, 2003, 2004; Johnson et al. 2015). Since 1990, contemporaneous, collaborative telemetry studies of caribou distribution and movements have been conducted in the region west of the Colville River by the Alaska Department of Fish and Game (ADFG), the North Slope Borough (NSB), and the Bureau of Land Management (BLM) (Philo et al. 1993, Carroll et al. 2005,
Figure 1. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the BTN and BTS survey areas, 2001–2022.
Introduction


**STUDY OBJECTIVES**

Evaluation of the natural and anthropogenic factors affecting caribou in the study area falls into two broad categories: factors affecting movements of individuals and factors affecting distribution of herds. Clearly, these categories are linked and are not mutually exclusive, but the applicability of study methods differs between them. The potential effects of development on caribou distribution can be assessed using a variety of methods, including aerial transect surveys, radio telemetry, and other reported observations, such as those by local subsistence users and oil-field workers. But the potential effects on caribou movements cannot be addressed adequately without employing methods such as radio telemetry that allow consistent tracking of individually identifiable caribou.

Much of the research on caribou response to oilfield infrastructure has been conducted on the CAH (Murphy and Lawhead 2000, Cameron et al. 2005, Prichard et al. 2020a), which has interacted with the Prudhoe Bay and Kuparuk oilfields for over 4 decades (Prichard et al. 2020a), but the herd winters in or near the Brooks Range (Nicholson et al. 2016, Prichard et al. 2020b, Pedersen et al. 2021) and provides few insights on caribou reactions to infrastructure during winter. As development expands west of the Colville River, TCH caribou are increasingly interacting with winter oilfield drilling and exploration activity. This provides an opportunity to examine the reactions of a caribou herd with only limited

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**Figure 2.** Population size of the Teshekpuk and Central Arctic caribou herds, 1975–2022, based on Alaska Department of Fish and Game photocensus estimates (see text for details).
previous exposure to industrial development to oilfield infrastructure throughout the year.

The objectives for analysis in 2022 were to:

1. Evaluate the seasonal distribution, abundance, and movements of caribou in the study area, using a combination of historical and current data from aerial transect surveys and radio telemetry data.

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 and evaluate potential impacts of future development.

4. Record the distribution and abundance of other large mammals encountered incidentally during research conducted in the BTU region.

**STUDY AREA**

CPAI began funding caribou surveys in the northeastern NPR-A in 2001–2004. These studies continued during 2005–2014 under the NSB Amended Development Permit 04-117 stipulation for the CD-4 drill site project (constructed during winter 2004–2005) which called for a 10-year study of the effects of development on caribou. The Alpine Satellite Development Program (ASDP) study area was specified as the area within a 48-km (30-mi) radius around the CD-4 drill site (Lawhead et al. 2015). Initially, aerial transect surveys were conducted in 3 survey areas which encompassed most of that 48-km radius (Lawhead et al. 2015): the NPR-A survey area (expanded from 988 km² in 2001 to 1,310 km² in 2002; and again to 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). The Bureau of Land Management (BLM) required continued caribou studies in accordance with the Integrated Activity Plan (IAP) for the NPR-A. In 2016, the ASDP study area was redefined to focus on the NPR-A and CRD survey areas, so aerial surveys for the Colville East survey area were ended and results for the final year were reported elsewhere (Prichard et al. 2018a). In 2016 and 2017, the NPR-A survey area was expanded westward by 1 and 2 transects, respectively (1,818 km² in 2016; 2,119 km² in 2017). In November 2018, the NSB adopted Ordinance Serial No. 75-06-72, consolidating previous ordinances and rezoning lands for the GMT2/MT7 area as resource development districts. This ordinance required CPAI to fund a caribou study to use “a landscape analysis to investigate the distribution and movements of caribou around the Colville River Delta and adjacent areas including all Alpine and associated developments to assess habitat relationships and possible impacts from development.”

In 2018, the NPR-A survey area was therefore again redefined to focus on the 3 recently constructed drill sites and their connecting access roads and pipelines (Figure 1, bottom panel). The sites were CD-5 where construction began in the winter 2013–2014, GMT1/MT6 where construction began in winter 2016–2017, and GMT2/MT7 where construction began in winter 2018–2019 and first oil production occurred in December 2021 (Figure 1, bottom panel). This newly defined Greater Mooses Tooth (GMT) survey area (776.6 km²) encompasses the portion of the previous NPR-A survey area east of GMT2/MT7. It also includes the Nuiqsut Spur Road that was constructed by the Kuukpik Corporation in winter 2013–2014 to connect the village of Nuiqsut to the CD-5 access road. Although that road is not part of CPAI’s infrastructure, its presence in the study area warrants inclusion in this analysis. The CRD survey area has not been modified since surveys began in 2001. The results of research conducted in the CRD and GMT survey areas were reported separately (Welch et al. 2023).
The portion of the previous NPR-A survey area west of GMT2/MT7 was expanded west and south to focus on the Willow prospect and other potential future developments within the BTU. Results of studies within this new expanded study area are reported on here. For surveys and analysis, the BTU study area was split up into 2 survey areas, BTU North (BTN) and BTU South (BTS; Figure 1). To provide a wider context for analytical results and avoid duplication, some of the analyses in this report were conducted for all NPR-A survey areas (GMT, BTN, and BTS; Figure 1) and those results are included in both this report and the ASDP/GMT report (Welch et al. 2023). In 2021, the continuation of caribou studies was stipulated by the NSB as part of the rezoning process for the proposed Willow Project (NSB Ordinance 75-06-75).

The study area is located on the central coastal plain of northern Alaska (Figure 1, top). The climate in the region is arctic maritime (Walker and Morgan 1964). Winter lasts about 8 months and is generally cold and windy. The summer thaw period lasts about 3 months (June–August) and the mean summer air temperatures in Nuiqsut during 1990–2020 ranged from 6.2–9.9°C (43.2–49.9 °F; http://climate.gi.alaska.edu/Climate/Normals, accessed 27 January 2020) with a strong regional gradient of summer temperatures increasing with distance inland from the coast (Brown et al. 1975). Mean summer precipitation measured at Kuparuk and Colville Village was 9.7–12.5 cm (3.8–4.94 in), most of which fell as rain in July and August (http://climate.gi.alaska.edu/Climate/Normals, Accessed 27 January 2020). The soils are underlain by permafrost and the temperature of the active layer of thawed soil above permafrost ranges from 0 to 10 °C (32–50 °F) 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. 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 BTU study areas in 2022, ABR biologists conducted aerial transect surveys, calculated remote sensing metrics from satellite imagery, and analyzed existing telemetry data sets provided by ADFG, NSB, BLM, ExxonMobil Alaska Production (EMAP), Santos (previously Oil Search Alaska), 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, 2016–2017, 2019, and 2021–2022. In 2022, ADFG deployed 10 CPAI-funded GPS collars on CAH females and 12 CPAI-funded GPS collars on TCH females. The ADFG, BLM, and NSB funded most GPS collars for the TCH, and ADFG, CPAI, USGS, Oil Search/Santos, or EMAP funded most GPS collars for the CAH. Collars were generally programmed so that the collar would remain active for 3 years.

We used 8 seasons per year 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)
- **fall migration** (16 September–30 November, a period that includes the breeding season, or rut).
WEATHER AND INSECT CONDITIONS

To estimate spring and summer weather conditions in the area during 2022, we used meteorological data from National Weather Service reporting stations at Alpine and Nuiqsut. The Alpine weather station has weather data dating back to 2011 for temperature, wind, and precipitation (including snow depth) for the region, whereas Nuiqsut weather data lack snow depth but have hourly temperature and wind data that are more suitable for modeling current year insect harassment conditions in the nearby survey areas. We calculated spring snow depth and thawing degree-day sums (TDD; total daily degrees Celsius above zero) using average daily temperatures and snow depth data collected at the Alpine airstrip. 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). Mosquitoes in the study area usually emerge from the middle of June through early July depending on the timing of snowmelt and temperatures, whereas oestrid flies usually do not emerge until mid-July. We estimated average index values of mosquito activity based on hourly temperature and wind data from Nuiqsut using equations developed by Russell et al. (1993). We estimated the probability of oestrid-fly activity from average hourly wind speeds and temperatures recorded at Nuiqsut using equations developed by Mörschel (1999). To investigate potential long-term trends, we also graphed snow depth, TDD, and insect harassment using weather data from the Kuparuk airstrip, which dates back to 1983.

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Transect surveys provided information on the seasonal distribution and density of caribou in the study area (ADFG permit number 22-070). We conducted surveys of the BTN and BTS survey areas (Figure 1, bottom) periodically from March to October 2022 in a fixed-wing airplane (Cessna 185 or 207), following the same procedures used since 2001 (Lawhead et al. 2015 and references therein). In 2022, we scheduled 7 aerial surveys in the BTN and BTS survey areas for mid-March (mid-winter), mid-May (spring migration), early June (calving), late June (postcalving), late July (oestrid fly), late August (late summer), and late September/October (fall migration). We coordinated our aerial surveys with CPAI Village Outreach Liaisons who provided notice of survey flights to the Kuukpikmiut Subsistence Oversight Panel (KSOP) and Nuiqsut subsistence users. Surveys may be cancelled if they have the potential to conflict with subsistence activities in the area and/or community events.

During all aerial surveys, 2 observers looked out opposite sides of the airplane and recorded data independently. The pilot navigated the airplane along transect lines using a GPS receiver and maintained an altitude of ~150 m (500 ft) above ground level (agl) or ~90 m (300 ft) agl. We flew surveys at 90 m agl only during the calving and postcalving surveys and only in the western portion of the BTN survey area. We chose the lower flight altitude to increase the ability to detect calves due to the anticipated higher levels of calving activity near Teshekpuk Lake.

We spaced transect lines at intervals of 3.2 km (2 mi) in BTN and 4.8 km (3 mi) in BTU South, 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 when flying at 150 m agl or a 400-m-wide strip when flying at 90 m agl. Therefore, we sampled ~50% of the BTN survey area when flying 150 m agl, 25% of the western portion of BTN when flying at 90 m agl during the calving and postcalving surveys, and 33% of the BTS survey area while flying 150 m agl. We adjusted the number of caribou observed in the transect strips (e.g., multiplied by 2, 3, or 4) to estimate the total number of caribou in the survey area on each survey. We visually delimited strip width for the observers by measuring distances to recognizable landscape features displayed on maps in GPS receivers.

When we observed caribou within the transect strip, we recorded the perpendicular location on the transect centerline using a GPS receiver. We also recorded the numbers of “large” caribou (adults and yearlings) and calves, and the perpendicular distance from the transect centerline estimated in
four 100-m or 200-m intervals, depending on the strip width. We plotted the locations of caribou at the midpoint of the distance interval (e.g., 300 m for the 200–400-m interval). Thus, we estimated the maximal mapping error to be ~100 m. We calculated confidence intervals for estimates of total caribou and calves with a standard error formula modified from Gasaway et al. (1986), using 3.2-km segments of the transects as the sample units. We recorded observations of all other large mammals during aerial surveys, as well.

In addition, beginning in 2022, the observers recorded the reaction of caribou groups to the survey airplane. Observers recorded the reaction levels as none, low or moderate, or strong. Low or moderate reactions included looking at the plane, standing up, or walking when previously not walking. Running was recorded as a strong reaction. We recorded the highest reaction level exhibited by any single caribou in the group.

**DENSITY MAPPING**

To map seasonal densities of caribou for the period 2002–2022, we used the inverse distance-weighted (IDW) interpolation technique of the gstat package (Pebesma 2004) in program R (Version 4.1.3, R Core Team 2021). We conducted IDW calculations for all aerial survey data located within the current GMT and BTU survey areas, consistent with previous and contemporary reports (Prichard et al. 2020c, 2020d, Welch et al. 2021a, 2021b, 2022b, 2023). We subdivided transect strips in the survey areas into grid cells. Each grid cell was 1.6 km wide by 1.6 or 3.2 km long, depending on the transect length, for a total of 208 cells and 114 cells in the BTN and BTS survey areas, respectively. 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. We selected the best power (from 1 to 1.2) and the best number of adjacent centroids (from 10 to 24) to use in the calculations 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). While collection schedules varied (Lawhead et al. 2015), during 1991–2002, most collars were programmed to transmit every other day throughout the year. After 2002, many collars were programmed to transmit once every 6 days in winter and every other day during summer.

We obtained satellite-collar data from ADFG and NSB for TCH caribou during the period July 1990–July 2021 (Lawhead et al. 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015; Person et al. 2007; Prichard et al. 2017, 2018b, 2019c, 2020d, 2021b) 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 2015a; Table 1). In the TCH sample (based on herd affiliation at capture), 184 collars were deployed on 164 different caribou (85 females, 79 males). The CAH 1986–1990 sample included 17 caribou (16 females, 1 male). In the CAH 2001–2004 and 2012–2018 sample, 25 collars were deployed on 24 caribou (16 females, 8 males). We include only collars that transmitted for >14 d 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**

ADFG or USGS biologists deployed GPS collars purchased by BLM, NSB, ADFG, EMAP, Oil Search/Santos, and CPAI on caribou during 2004–present. Current and past data from GPS collars purchased by EMAP and Santos became available in 2021. ADFG and the USGS deployed GPS collars 412 times on 301 different TCH caribou (279 females, 22 males; Table 1) during 2004 and 2006–2022. ADFG and the USGS deployed GPS collars 459 times on 338 different CAH caribou (300 female, 38 male) during 2003–2022.
**Methods**

By Dick et al. 2013). Nonetheless, increasing numbers of male caribou have been outfitted with GPS collars in recent years. ADFG personnel captured caribou by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter. In keeping with ADFG procedures for the region, capture teams did not use immobilizing drugs (Parrett 2015a, 2021; Lenart 2021).

Collars were programmed to record locations at 2-, 3-, 5-, 8-, or 12-h intervals, depending on the desired longevity of the collar (Arthur and Del Vecchio 2009, Lawhead et al. 2015). We downloaded data reports from satellite uplinks daily and the full dataset after the collars were retrieved. We screened the data to remove spurious locations using methods described in Lawhead et al. (2015). We removed data from the first 7 days after collaring from analyses.

**SEASONAL OCCURRENCE IN THE STUDY AREA**

We evaluated seasonal use of the BTN and BTS survey areas by collared caribou using several methods. We calculated the proportion of each monthly utilization distribution from kernel density estimation (KDE) that was located within the survey areas, by sex and herd, after first removing the portion of each seasonal utilization distribution raster that overlapped the ocean. 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 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 unequal sample sizes among individual caribou. We used the plug-in method to calculate the bandwidth of the smoothing parameter.

We calculated KDE by season and month (all years combined) for TCH males, TCH females, and CAH females separately because caribou are sexually segregated during some seasons. We also calculated a separate kernel for parturient TCH 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). Nonetheless, increasing numbers of male caribou have been outfitted with GPS collars in recent years. ADFG personnel captured caribou by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter. In keeping with ADFG procedures for the region, capture teams did not use immobilizing drugs (Parrett 2015a, 2021; Lenart 2021).

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

<table>
<thead>
<tr>
<th>Herd / Collar Type</th>
<th>Years</th>
<th>Female Deployments</th>
<th>Female Individuals</th>
<th>Male Deployments</th>
<th>Male Individuals</th>
<th>Total Deployments</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF collars b</td>
<td>1990–2022 96</td>
<td></td>
<td>2004–2022 387</td>
<td>279</td>
<td>212</td>
<td></td>
</tr>
<tr>
<td>Satellite collars</td>
<td>2004–2022 367</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS collars</td>
<td>2003–2022 421</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS collars</td>
<td>2003–2022 421</td>
<td></td>
<td>2017–2022 38</td>
<td>38</td>
<td>459</td>
<td></td>
</tr>
</tbody>
</table>

a Herd affiliation at time of capture.

b n/a = not available, but most collared animals were females.

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). Nonetheless, increasing numbers of male caribou have been outfitted with GPS collars in recent years. ADFG personnel captured caribou by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter. In keeping with ADFG procedures for the region, capture teams did not use immobilizing drugs (Parrett 2015a, 2021; Lenart 2021).

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We calculated KDE by season and month (all years combined) for TCH males, TCH females, and CAH females separately because caribou are sexually segregated during some seasons. We also calculated a separate kernel for parturient TCH
females during the calving season to delineate the calving range of the TCH. The sample size for male CAH caribou was insufficient to allow kernel density analysis. We then calculated the proportion of each monthly utilization distribution from KDE within the survey areas to determine the predicted monthly proportions of the herds expected to be using the survey areas.

To visualize movements of female TCH caribou outfitted with GPS collars, we used dynamic Brownian Bridge Movement Models (dBBMM) to create utilization distribution maps of movements based on the locations and movements of collared individuals (Kranstauber et al. 2014). We limited the analysis to female TCH animals because we have a large sample size across years and animals are consistently in the region in most seasons. 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 female caribou outfitted with a GPS collar in the area and then overlaid the isopleth layers by season and by year to calculate the relative proportion of collared caribou using each 100-m pixel. This visualization displays the seasonal and annual use of the area by female TCH caribou as a function of both caribou distribution and movements. We computed the dBBMM models using the move package in R (Kranstauber et al. 2017).

We examined GPS- and satellite-collar data to describe movements of individual caribou in the immediate vicinity of existing and proposed infrastructure. We mapped all GPS-collared TCH segments to visualize movements in the study area. We also calculated the proportion of collared female TCH caribou that crossed the proposed Willow development alignments (Alternative E; BLM 2022) at least once during a season for each year. We excluded caribou that were present for less than half the season or with fewer than 30 locations per season. We removed locations within 30 days of collaring to allow collared animals (which are collared opportunistically) adequate time to mix with the rest of the herd (Prichard et al. 2022), and we calculated the proportion of each monthly utilization distribution within 4 km of the proposed road and pad alignments (proposed road alignment from Alternative E, 1 Jan 2020). We also calculated the daily movement directions and speeds of caribou within 4 km of proposed road alignments.

REMOTE SENSING

The remote sensing methods are summarized here; a full description of remote sensing methods can be found in Appendix A. Because MODIS imagery covers large areas at a coarse resolution (250- to 500-m pixels), it was possible to evaluate snow cover and vegetation indices over a much larger region extending beyond the study area with no additional effort or cost. The region evaluated extends from the western edge of Teshekpuk Lake east to the Canada border and from the Beaufort Sea inland to the northern foothills of the Brooks Range. The ability to examine this large region allowed us to place the study area into a larger geographic context in terms of the chronology of snow melt and vegetation green-up, both of which are environmental variables that affect caribou distribution in northern Alaska (Kuropat 1984, Johnson et al. 2018).

We analyzed 2000–2022 snow cover and 2000–2022 vegetation greenness using gridded, daily reflectance and snow-cover products from MODIS Terra and Aqua sensors. We processed the entire snow cover and vegetation index record, based on atmospherically corrected surface reflectance data, to ensure comparability of snow and greenness metrics.

SNOWMELT DATE

We estimated snow cover using the daily 500-m snow cover products from MODIS Terra and Aqua sensors. We analyzed a time series of images covering the April–June period for each year during 2000–2022. Instead of estimating fractional snow cover as we had in past years, we applied a binary presence/absence threshold corresponding to a snow cover of approximately 50%; the snow fraction at specific dates was rarely an important habitat selection variable and, due to cloud cover, could not be reliably estimated during the critical dates each year. We excluded pixels with >50% water (or ice) cover from the analysis. We applied a two-step process to automatically
Methods

identify the date of snowmelt. First, for each pixel in each year, we applied the data provide cloud mask, then identified:

- The first date with 50% or lower snow cover (i.e., “conservative melted”)
- The closest prior date with >50% snow cover (i.e., “conservative snow”)
- Because melting snow is often mis-mapped as cloud, we then re-assessed the observations in between these two dates, this time without applying the cloud mask. We selected the earliest date within this window that had 50% or lower snow as the snowmelt date.

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, Kelley-house 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index.html):

\[
\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}
\]

where:

- \(\text{NIR}\) = near-infrared reflectance (wavelength 0.841–0.876 µm for MODIS), and
- \(\text{VIS}\) = visible light reflectance (wavelength 0.62–0.67 µm for MODIS).

We calculated NDVI during the calving period (NDVI_Calving) from a 10-day composite period (1–10 June) for each year during 2000–2022 (adequate cloud-free data were not available to calculate NDVI_Calving over the entire study area in some years). We interpolated NDVI values near peak lactation near 21 June (NDVI_621) based on the linear change from two composite periods (15–21 June and 22–28 June) in each year. We calculated NDVI_Rate as the linear change in NDVI from NDVI_Calving to NDVI_621 for each year. Finally, we calculated the peak NDVI value (NDVI_Peak) from all imagery obtained between 21 June and 31 August each year. We included NDVI_Calving, NDVI_621, NDVI_Rate, and NDVI_Peak in caribou habitat modeling efforts (see below).

HABITAT CLASSIFICATION

We used draft maps of the top cover of plant functional type (PFT) with pixel sizes of 30 m developed for the NASA Arctic-Boreal Vulnerability Experiment (ABoVE) project (Macander et al. 2022). We aggregated the 2020 maps for graminoids, forbs, deciduous shrubs, evergreen shrubs, and lichen to calculate the mean top cover of each PFT at 120-m resolution (Figure 3).

To characterize surface wetness, we applied the USGS Dynamic Surface Water Extent (DSWE) algorithm (Jones 2019). We analyzed Landsat 5, 7, and 8 data from June–August, 1999–2021 and the Interferometric Synthetic Aperture Radar Digital Terrain Model (IFSAR DTM) for Alaska. We filtered out hillshaded, cloud, cloud shadow, and snow results and retained all other observations (DSWE values of 0–4, Table 2). We then calculated the overall frequency of water as the count of observations classified as wet (DSWE classes 1–4) divided by the total count of retained observations (DSWE classes 0–4, Figure 3). The inclusion of the Partial Surface Water classes (classes 3 and 4) captures a gradient of wetness including vegetated areas that are sometimes flooded.

SPECIES DISTRIBUTION MODELING

We used machine learning methods to model a relationship between caribou group locations and a suite of environmental predictors that characterized habitat and topography in the study area. We modeled relationships between environmental covariates and caribou distribution using the Maxent Java application (Phillips et al. 2020). Maxent is a commonly used method for computing species distribution models due to its ease of use and its predictive performance relative to other methods, especially when sample sizes are small (Elith et al. 2006, Phillips et al. 2006, Warren and Seifert 2011, Merow et al. 2013). Maxent uses
Figure 3. Percent top cover of deciduous shrubs, evergreen shrubs, forbs, graminoids, and lichen as well as surface wetness used for caribou habitat-selection analysis in the National Petroleum Reserve-Alaska survey areas.
Methods

Presence-only data and environmental variables to model a relative environmental probability distribution (suitability) across a landscape using a maximum entropy model framework (Phillips et al. 2006). Maxent compares complex combinations of variables, variable transformations, and multiple variable interactions to find the best model for predicting the distribution of training and test data (Phillips et al. 2006, Elith et al. 2011, Merow et al. 2013, Phillips et al. 2017). Because this is a data mining method, the emphasis is on modeling predictions of distributions (mainly producing suitability maps). As a result, the reported relationships between caribou distribution and environmental variables are more likely to be due to spatial correlation rather than direct causal relationships when compared to methods like Resource Selection Functions (RSF). However, Maxent is generally more flexible and better at predicting suitability compared to RSFs, and provides tools for evaluating model performance and validity, variable contributions and relationships, and creating suitability maps.

We ran seasonal models to compare actual caribou locations to random locations. We used a subset of variables based on their performance in previous year’s models: distance-to-coast, west-to-east distribution, topographic position index (TPI; Jenness et al. 2013), gentle sloping landforms (Theobald 2011), annual snowmelt date, surface wetness, percent top cover of graminoid and lichen functional groups, and the proportion of different habitat types (BLM and Ducks Unlimited 2002). In 2021, we used new plant functional types (lichen, graminoids, deciduous shrub, evergreen shrub, and moss) in place of habitat types (BLM

<table>
<thead>
<tr>
<th>DSWE Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not Water</td>
</tr>
<tr>
<td>1</td>
<td>Water High Confidence</td>
</tr>
<tr>
<td>2</td>
<td>Water Moderate Confidence</td>
</tr>
<tr>
<td>3</td>
<td>Partial Surface Water, Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Partial Surface Water, Low Confidence</td>
</tr>
<tr>
<td>8</td>
<td>Hillshaded</td>
</tr>
<tr>
<td>9</td>
<td>Cloud, Cloud Shadow, or Snow</td>
</tr>
</tbody>
</table>

Table 2. USGS Dynamic Surface Water Extent (DSWE) class codes and descriptions used to calculate surface wetness in the northeastern NPR-A, Alaska.
and Ducks Unlimited 2002; Welch et al. 2022a, 2022b). Results from 2021 indicated that while percent top cover of lichen and graminoids were often important for modelling species distribution, model performance was generally lower than when using habitat types. Therefore, in 2022 we used the proportion of habitat types and retained the lichen and graminoid plant functional groups.

For habitat types, the NPR-A survey area contained 15 cover classes from the NPR-A earth-cover classification which we lumped into 9 classes to analyze caribou habitat use (Ducks Unlimited 2002). 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 class. The two flooded-tundra classes were combined as flooded tundra and the clear-water, turbid-water, and Arctophila fulva classes were combined into a single water class; these largely aquatic classes are used very little by caribou, so the water class was excluded from the analysis of habitat preference.

TPI compares the relative elevation of each pixel to the mean elevation of pixels within a defined radius. Positive TPI values indicate that a pixel has a high elevation relative to adjacent pixels (e.g., ridgetops) and negative values indicate valleys or lowlands, providing insights into topographic position not provided by other metrics. To calculate TPI, we used 5 m IFSAR DTM data aggregated to 30 m using the Aggregate Tool and the mean function in ArcGIS.

Because the spatial scale at which caribou select TPI and habitat classes is unknown, we calculated habitat classes at 5 different spatial scales and TPI at 4 different spatial scales. We calculated the mean proportions of each habitat at the 120-m scale using 30 m datasets and the Aggregate Tool with a cell factor of 4 and at the 0.5-km, 1.0-km, 2.0-km, and 3.2 km-scales using the 120-m results as inputs for the Focal Statistics Tool with a mean function and circular neighborhoods of 4 (0.5 km), 8 (1.0 km), 17 (2.0 km), and 27 (3.2 km) cells in ArcGIS Pro. To calculate TPI, we first aggregated 5-m IFSAR DTM data to 30 m using the Aggregate Tool and mean function in ArcGIS so it was the same resolution as other datasets. We then aggregated 30m elevation data to 120-m pixels using the mean function and then calculated TPI at four spatial scales using the mean elevation of 120-m pixels relative to the mean elevation of circular neighborhoods with radii of: 4 (0.5 km), 8 (1.0 km), 17 (2.0 km), 27 (3.2 km), or 54 cells (6.4 km).

For base models, we used the 500-m resolution median values for NDVI_Calving, NDVI_621, NDVI_Rate, and NDVI_Peak from 2000–2022 at each location. Annual snow-melt date was used only for the winter, spring migration, and calving seasons, NDVI_peak was used for all season, NDVI during calving was used for the spring migration and calving seasons, NDVI_621 was used for the postcalving, mosquito, and oestrid fly seasons, and NDVI_rate was used for the postcalving, mosquito, oestrid fly, and late summer seasons. In 2020 and 2021, we used daily NDVI, digestible nitrogen (DN; g/m² dry matter [DM]), and digestible energy (kJ/m² DM) calculated using equations from Johnson et al. (2018) and found these variables were rarely important during our growing season models. Johnson et al. (2021) expanded on the Johnson et al. (2018) models to estimate daily nutritional concentrations of digestible nitrogen (DN_conc; g/100 g DM) and energy (DE_conc; kJ/g DM), indicators of plant-level nutritional value. These nutritional concentration variables were useful in modelling habitat suitability for CAH caribou (Johnson et al. 2021). We tested the relative importance of these variables by comparing growing season (postcalving, mosquito, oestrid fly, and late summer) model performance of base models to those with daily forage quality variables included.

While Maxent is computationally capable of handling many highly correlated model coefficients (Elith et al. 2011, Phillips et al. 2017), high levels of correlation among variables can make it challenging to interpret the influence of specific variables, and it is recommended to remove highly correlated variables (Merow et al. 2013). For example, if elevation has a high positive correlation with distance-to-coast and both variables are included in a model, it would be very difficult to determine if animals are selecting for higher elevation or locations far from the coast. We therefore used a two-step process to reduce the number of variables, simplify the model, and aid in interpretation. In the first step, we selected a single spatial scale for each set of topographic variables.
For each season, we first calculated the test-ratio, the ratio of the mean values of environmental variables at caribou group locations to the mean of the randomly generated background locations, at each of the 5 spatial scales. A large test ratio indicates that the values of that variable are more different at locations used by caribou compared to random locations and therefore, suggests some selection of that variable by caribou. For each variable, we only retained the spatial scale with the largest test ratio (Dunk et al. 2019). This produced the scale-defined variable dataset (one spatial scale for each variable). For the second step of variable selection, we removed highly correlated variables. We categorized variables into 3 groups: forage quality (e.g., dailyNDVI) and snowmelt date, habitat (e.g., graminoid top cover, wetness, habitat types), and topography and geography (e.g. TPI, west-to-east). We then calculated the Variance Inflation Factor (VIF) for all variables within each of these categories and removed variables with VIF values >5. VIF scores of 4–5 are generally considered acceptable (Hair et al. 2010, Hair et al. 2011). Once the VIFs within a category were <5, we calculated the VIFs for all remaining variables combined and used a relaxed threshold of <6. The relaxed VIF thresholds were a compromise to retain variables while still minimizing the amount of correlation among variables. We performed all calculations in R using the usdm and raster packages (Naimi et al. 2014, Hijmans 2021).

Maxent allows users to choose what types of relationships the program will consider using in the model. Maxent calls these relationship types “features”. To reduce model complexity and aid in interpretability, we limited features to all combinations of linear, quadratic, and product (interactions). When including the product feature, Maxent evaluates all two-way interactions.

Ideally, the Maxent model will fit the training data well but also generalize outside of pixels with observations (Phillips et al 2006). To avoid overfitting the training data, Maxent employs L1 regularization to constrain modeled distributions to lie within a certain interval around the empirical mean rather than matching it exactly (Phillips et al. 2006, Warren and Seifert 2011, Merow et al. 2013). Maxent allows users to vary the constant regularization multiplier (RM) that penalizes all parameters to reduce over-fitting and shrinks coefficients towards or to zero, thus reducing the number of parameters in the model. Low values of the RM can lead to overly complicated models, overparameterization, and overfitting, while values that are too high can lead to overly simplified models that overpredict suitability (Cao et al. 2013). The Maxent default value of 1 has been optimized to best balance between overfitting and overgeneralizing the data and is based on a dataset from 226 species from 6 regions around the world (Phillips and Dudik 2008, Elith et al. 2006). However, models using this default value sometimes overfit the training data or can be overly simplistic (Anderson and Gonzalez 2011, Warren and Seifert 2011, Cao et al. 2013, Merrow et al. 2013, Radosavljevic and Anderson 2014).

Many researchers have investigated the best method for optimizing Maxent model performance (Warren and Seifert 2011, Cao et al. 2013, Radosavljevic and Anderson 2014, Galante et al. 2018) particularly by changing feature types and the RM. Warren and Seifert (2011) demonstrated that Akaike’s Information Criterion corrected for small sample size (AICc) is a robust method for model selection with Maxent. We used the package ENMeval in R (Kass et al. 2021) for model selection using all combinations of linear, product, and quadratic features and a range of RMs (0.5, 1, 2, 3, 4, 5, 6) for all seasonal datasets.

We ran the final seasonal models using the remaining variables with low VIF (<6) and the combination of features and RM with the lowest AICc. By default, Maxent automatically generates background points from within a study area, which does not work for this analysis because our random locations are drawn from multiple survey areas that have changed over time (Figure 1). Therefore, we used the samples-with-data (SWD) method in Maxent where the user supplies datasets for used and random locations with environmental data already extracted for both (Phillips 2017). We ran the final models while withholding 20% of the location data to be used for model performance evaluation. We used 1,000 maximum iterations and added caribou locations to background data. We left all other settings at their defaults.

For all models, Maxent provides receiver operating characteristic (ROC) curves with an associated area under the curve (AUC) that can be used to assess model performance (Phillips 2017).
AUC values from 0.7–0.8 are generally considered to be acceptable model performance, 0.8–0.9 indicate excellent model performance, and >0.9 indicate outstanding model performance (Hosmer and Lemeshow 2000). To assess variable importance, Maxent calculates a permutation importance (PI) value for each variable in the model. The PI value is equal to the drop in AUC for the training data (AUC_train) when Maxent randomly changes the values of each variable in turn and re-runs the model. A large drop in AUC_train indicates that the variable was important to overall performance. Maxent also provides response curves to show the relationship between each explanatory variable and the predicted suitability. These curves represent the effect of changing the values of one variable while holding all other variables in the model constant.

We mapped results of the model using the cloglog function (complimentary log-log), which is currently the best transformation for estimating the probability of presence/relative suitability (Fithian et al. 2015, Phillips et al. 2017). To map the suitability results, we needed to use a consistent set of rasters for each season. Because some variables varied over time, we used the 2000–2022 median values of daily NDVI_peak, NDVI_calving, NDVI_621, NDVI_rate, and snowmelt date as well as daily NDVI, DE_conc, and DN_conc sampled at the midpoint of each season as input variables for the suitability maps.

INTEGRATED STEP-SELECTION ANALYSIS

MOVEMENTS THROUGHOUT THE STUDY AREAS

We used an integrated Step-Selection Analysis (iSSA) to test for differences in space-use and movement characteristics in the BTU area. Typical Step-Selection Analyses (SSA) use random locations generated at each step along an animal’s path to compare where an animal goes to the choices available to that animal along its path of movement (Fortin et al. 2005, Thurfjell et al. 2014). This allows the choice the caribou makes at each GPS location to be directly compared to alternative locations to which it could have moved at that time. The scale of selection depends on the frequency of locations. We used locations of female TCH caribou with GPS-collars collected 12 hours apart (n = 647 collars-years; 114,007 locations); therefore, we examined resource selection choices made by caribou during each 12-h movement. Because various collars had fix intervals of 2, 3, 4, 6, 8, and 12 hours, the 12-h fix interval allowed us to maximize the number of collars used while keeping the fix interval low.

The iSSA extends typical SSA models by selecting random points from analytical distributions, which allows movement-related covariates (step length and turn angle) to be included in the model (Avgar et al. 2016). We selected random step lengths from a Gamma distribution, and random turning angles from a Von Mises distribution using package amt in R (Signer et al. 2018). This procedure makes it possible to simultaneously examine the factors influencing both the locations selected by caribou and the factors influencing their movement characteristics.

For the iSSA, we extended the study area to include the western CRD and the southeastern shore of Teshekpuk Lake (Figure 1). To account for other factors that can influence caribou movement choices, we used 5 remote sensing metrics (top cover of graminoids, and lichens, annual snowmelt date, TPI at 210 m, and wetness). We were originally going to include estimates of top cover of deciduous shrubs in the model, but it was strongly correlated with surface wetness. We also wanted to assess if caribou used the area within 8 km of the GMT1/MT6 and GMT2/MT7 roads (GMT roads) more or less after road construction because other studies have shown relative avoidance of infrastructure within this zone during some seasons (Dau and Cameron 1986, Cameron et al. 1992, Lawhead et al. 2004, Johnson et al. 2020, Prichard et al. 2020a); we therefore calculated the distance of each location from the GMT roads and classified locations as pre- or post-construction. We used the beginning of construction of the GMT2/MT7 road (winter 2018–2019) to define the end of the pre-construction period. The construction/post-construction period (hereafter: post-construction) includes continued road and pipeline construction during 2018–2021 and production activities until present. We excluded caribou-years with fewer than 10 locations within the expanded iSSA study area. For each caribou location, we
generated 15 random locations that fell on land within the iSSA study area. For each starting location and the 16 ending locations (1 real and 15 random), we calculated the various covariates. We excluded caribou with <10 locations within the telemetry data analysis area. For each caribou location, we generated 15 new random locations that fell within the iSSA study area and did not fall in waterbodies. For each starting location and the 16 ending locations (1 real and 15 random), we calculated the various covariates.

We compared the real and random locations using a conditional logistic regression model that treated each movement step as a stratum. We analyzed space-use parameters based on the end location of the movement (Avgar et al. 2016, Signer et al. 2018). The model included the movement covariates: (1) cosine of turning angle (1 equals no turn, –1 equals 180-degree turn); (2) step length (natural log transformed); and (3) an interaction between turning angle and step length. The model also included the following space-use covariates: (1) graminoids; (2) lichen; (3) TPI; (4) wetness index; (5) snowmelt date (winter, spring, and calving seasons only). We tested for multicollinearity among these variables using a VIF. To assess potential changes in use of the area near the GMT roads explicitly, we included a covariate for the interaction between the distance to the GMT roads and the pre- and post-construction variable. The distance to the GMT road was a categorical variable with 0–2, 2–4, 4–6, 6–8, and >8 km as the distance classes. We only included the distance to road variable in the models for fall, winter, and oestrid fly seasons due to limited samples sizes of animals near the road in other seasons. We also attempted to include Biomass, DN_conc, and DE_conc, but preliminary results indicated these variables had little or no predictive power in our study area.

We ran the model separately for each of the 8 seasons. For each season, we first restricted the data set to just the season of interest. We ran the model once, and then selected a random sample of caribou-years (with replacement), reran the model, and recorded the results. We repeated this randomization procedure 999 times for 1,000 total model runs. For each variable we excluded the top and bottom 2.5% of values and used the range of the remaining values as the 95% confidence interval for that variable. We scaled all independent variables to z-scores (the value minus the mean and divided by the standard error) to improve the interpretability of the model coefficients.

**WINTER MOVEMENTS NEAR ICE ROADS**

To assess the potential impact of winter ice roads on caribou movements, we analyzed a subset of the data used for the iSSA with respect to distance to ice roads. We first selected the iSSA data from January–March for the years 2019–2020 and 2022. We selected January–March to cover the period when ice roads were most likely to be active, and we used the years 2019–2020 and 2022 to analyze recent years where there was a large sample of GPS collars and GIS layers of ice roads were available. In 2019 and 2020, there were both extensive ice roads and caribou in the area. In 2021, there were few ice roads constructed and they were largely near existing gravel roads or in the eastern edge of the TCH range, therefore that year was excluded from this analysis. In 2022, there were more extensive ice roads constructed, but few collared TCH caribou were in the area during January–March, and therefore few data to assess the impact of distance to road during that year, but we still included data from that year in the multi-year analysis. Because we wanted to separate the potential impacts of ice roads from gravel roads and pads, we constrained the study area to be west of CD-5 for this analysis to avoid including ice roads that were near existing oilfield infrastructure. We also did not include ice road segments that were constructed adjacent to gravel roads when calculating the distance to ice roads for the analysis. We created a categorical variable of distances to ice roads with 5 categories (0–2, 2–4, 4–6, 6–8, >8 km).

When running the analyses, we first found the best model with same space-use variable used in the iSSA (graminoids, lichen, snowmelt date, TPI, and wet-habitat) for each season. We tested all combinations of these 5 variables (no interaction terms) and selected the model with the lowest AIC value as the best model in the candidate set of models for each season. We then added the distance to ice road variable to the best model and reran the model. We also included a categorical variable for distance to gravel roads with 2 categories (0–4 km, >4 km) in the models to
account for the effect of existing gravel roads on caribou movements.

OTHER MAMMALS

We compiled observations of other large mammals from ABR field surveys (both aerial and ground-based, excluding camera trap data) for this and other wildlife studies conducted for CPAI. We also compiled observations of other large mammals from ADFG observations and from other ground based CPAI personnel. We summarized observations in other survey areas in separate reports (Prichard and Welch 2023, Welch et al. 2023).

RESULTS

WEATHER CONDITIONS

Spring 2022 was characterized by near normal temperatures and snow depths at the end of April and early May. Most of the remaining snow melted during warm weather on 25 May (Figure 4). Early June was cooler than average, but temperatures in late June and early July were generally above average (Figure 4). Biologists working west of the Colville River noted that mosquito harassment first occurred on 23 June and the first severe harassment conditions occurred on 29 June. They also recorded severe insect harassment from 1–11 July. Temperatures for the remainder of July were below average followed by highly variable temperatures in August and near-average temperatures in September (Figure 4). The warm temperatures in late June and early July resulted in 13 days with a high probability of mosquito harassment (mosquito index >50%), whereas cool temperatures for the remainder of July resulted in low probabilities of either mosquito or fly harassment (Figure 5). There was a brief warm period in early August that resulted in 2 days with a high probability of fly harassment and another warm period in late August, but insect harassment is typically lower by this period of the summer (Figures 4–5). Hourly winds in Nuiqsut were mostly out of the northeast, the predominant wind direction for this area, in early June, predominantly out of the north in late June, out of the northeast or southwest in early July and late August, and more variable in late July and early August (Figure 6).

Weather data at the Kuparuk airstrip, which has a data record beginning in 1983, indicate that snow depth has been increasing in early April but not in mid- or late May (Appendix B). Snow depth was somewhat higher than average in early April, near average in mid-May, and below average in late May. The annual patterns in sum of TDD measured at Kuparuk was similar to temperature patterns measured at Alpine (Appendix C). There is a slight increasing trend in TDD in late May, which could explain why deeper late winter snow did not result in deeper late May snow. Additionally, there are trends for increasing TDD with year for most time periods of the summer. There were also trends for increasing predicted mosquito harassment in late June and early July while predicted oestrid fly harassment in late July was neither increasing or decreasing and oestrid fly harassment in early August has decreased since ~2000 (Appendices D–E).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Seven aerial surveys of the BTU survey area were originally planned between February and October 2022. Due to persistent inclement weather during the late summer survey, we only conducted a partial survey of the BTN survey area and could not survey the BTS survey area (Figure 7). The remainder of the surveys were conducted as scheduled (Figure 7). We used data from only one observer during the oestrid fly survey on 5–6 August due to a medical issue that compromised one observer’s ability to collect accurate data. Survey coverage was therefore 25% for this survey.

The observed reactions of caribou groups to the survey airplane varied by season (Figure 8). Over all surveys combined, 794 caribou groups (62%) exhibited no reaction, 258 groups (20%) exhibited low/moderate reactions, and 207 groups (16%) exhibited strong reactions. A total of 1.8% of groups had no reaction recorded because the observers did not have adequate information to assess the reaction to the plane. This was often in cases where caribou group was only observed briefly. Strong and moderate reactions were most frequently recorded during the calving season (Figure 8).
Results

Figure 4. Snow depth at Alpine during May–June 2022, compared with the long-term mean and 95% confidence interval (top panel) and daily average air temperature at Alpine during May–September 2022 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 the Nuiqsut Airport during 15 June–7 September 2022. Red dashed line is the 50% probability of insect harassment.
Results

BTN Survey Area
The estimated density ranged from 0.12 caribou/km² in the eastern portion of the survey area on 8–9 June during the calving survey to 1.32 caribou/km² during the 11 September late summer survey (Table 3). The second highest density was during the winter season survey (0.85 caribou/km²). We observed 4 calves in the BTN survey area during the calving survey whereas we observed 10 calves during the postcalving survey (Table 3).

BTS Survey Area
The estimated density of caribou in BTS ranged from 0.15 caribou/km² on the 5 August oestrild fly season survey to 0.69 caribou/km² on the 17 June postcalving survey (Table 3). The second highest density of caribou was observed during the winter season survey (0.58 caribou/km²). We observed 3 calves during the calving and postcalving surveys.

Results from the seasonal IDW density mapping of caribou recorded on aerial surveys of the GMT BTN & BTS survey areas during all years combine (2002–2022) also showed large differences among seasons (Figure 9). Caribou are widely distributed during winter, less common in both survey areas during spring migration, and then increase in density from the calving season,

Figure 6. Wind direction and speed at the Nuiqsut Airport during summer 2022.
Figure 7. Distribution and size of caribou groups during different seasons in the BTN and BTS survey areas, Alaska, March–October 2022.
Results

particularly in the west, to the postcalving season as caribou density increases near Teshekpuk Lake and the coast, and then to the oestrid fly season both inland and near the coast, decline during the late summer season when caribou are distributed more widely, and then densities are highest in central BTS and west-central BTN during the fall migration season as caribou congregate and migrate to areas south and west.

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 aerial surveys. Mapping of the telemetry data from PTT and GPS collars clearly shows that the study area is located at the eastern edge of the annual range of the TCH and west of the annual range of the CAH.

Kernel Density Analysis

Seasonal concentration areas were analyzed using fixed-kernel density estimation, based on locations from satellite and GPS collars deployed on 346 TCH females and 97 TCH males during 1990–2022 and on 312 CAH females and 38 CAH males during 2001–2022. These numbers differ from the number of collar deployments (Table 1) because some individuals switched herds after collaring. Kernels were used to produce 50%, 75%, and 95% utilization distribution contours

Figure 8. Counts of caribou groups and reaction severity during aerial surveys of caribou in the BTN, BTS, GMT, and CRD survey areas. Low-moderate reactions included looking at the aircraft or standing or walking in response to the aircraft, while running in response to the aircraft constituted a strong response.
Results

Female CAH caribou generally wintered between the Dalton Highway/TAPS corridor and Arctic Village (Figure 10), although since 2018–2019, the CAH has generally tended to winter on the north side of the Brooks Range (Pederson et al. 2021). The herd then migrated north in the spring to calve in two areas on either side of the Sagavanirktok River/TAPS corridor (Figure 10). They spent the mosquito season near the coast and were widely dispersed across the central coastal plain on both sides of the Sagavanirktok River and Dalton Highway/TAPS corridor during the oestrid fly and late summer seasons (Figure 10). During fall migration, many collared CAH caribou crossed the Dalton Highway to return to the wintering areas (Figure 10).

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 11–12). Compared with females, males were more likely to overwinter in the central Brooks Range instead of on the coastal plain. They

Table 3. Number and density of caribou in the Bear Tooth North and Bear Tooth South survey areas, Alaska, March–October 2022.

<table>
<thead>
<tr>
<th>Survey Area and Date</th>
<th>Total Area (km²)a</th>
<th>Observed Large Caribou b</th>
<th>Observed Calves c</th>
<th>Observed Total Caribou</th>
<th>Mean Group Size d</th>
<th>Estimated Total Caribou e</th>
<th>SE f</th>
<th>Density (caribou/km²) g</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>March 7–9</td>
<td>2,122</td>
<td>901</td>
<td>nr</td>
<td>901</td>
<td>4.4</td>
<td>1,802</td>
<td>142.9</td>
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<td>394</td>
<td>nr</td>
<td>394</td>
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<td>788</td>
<td>92.4</td>
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<td>0</td>
<td>61</td>
<td>4.4</td>
<td>122</td>
<td>28.1</td>
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<td>10</td>
<td>746</td>
<td>4.1</td>
<td>1,802</td>
<td>152.6</td>
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<td>August 5–6</td>
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<td>nr</td>
<td>152</td>
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<tr>
<td>March 7</td>
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</table>

a Survey coverage was 50% of this area in BTN, 25% in BTN West on June 6–8, and 33% in BTS.
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 adjusted for survey coverage.
f SE = Standard Error of Estimated Total Caribou, calculated following Gasaway et al. (1986), using transects as sample units.
g Density = Estimated Total Caribou ÷ Area.
h Survey coverage was 25% of total area.
i Survey coverage was 16.5% of total area.
Figure 9. Seasonal density of caribou within the caribou survey areas in NPR-A based on IDW interpolation of aerial survey results, 2002–2022.
Figure 10. Seasonal distribution of CAH females based on fixed-kernel density estimation of telemetry locations, 2001–2022.
Figure 11. Seasonal distribution of TCH females based on fixed-kernel density estimation of telemetry locations, 1990–2022.
Figure 12. Seasonal distribution of TCH males based on fixed-kernel density estimation of telemetry locations, 1997–2022.
also migrated to the summer range later and were generally not distributed as far west during summer (Figures 11–12). The distribution of parturient TCH females during calving was similar to the distribution of all TCH females during calving but was more concentrated near Teshekpuk Lake (Figure 13).

The BTN survey area was located within the 95% utilization distribution of female TCH caribou from fall migration through spring migration and within at least the 50% utilization distribution in all summer seasons (Figure 14). As a result, 4.1–12.5% of female TCH caribou (based on the proportion of the utilization distribution) are expected to be in the survey area at any time during the year, with the highest levels of use expected during September (Figure 14). Use of the BTN survey area by TCH males increased sharply from May to a peak in July (13.8% of the utilization distribution) during the oestrid fly season. Use by males dipped in August (5.7%) but then rose again in September (10.4%) during the onset of the fall migration before dropping below 1% by November as males migrated into the foothills and mountains of the Brooks Range or toward Atqasuk during the winter (Figure 14). In contrast, there was almost no use (0.0%–0.7%) of the BTN survey area by collared CAH females throughout the year (Figure 14). The BTN survey area is far to the west of the typical CAH summer range, so little use of the area was expected.

TCH females used the BTS survey area to a similar or lesser extent than the BTN survey area in all months (0.5–6.4% of the population based on the proportion of the utilization distribution; Figure 14). The main differences were apparent in May,

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**Figure 13.** Distribution of parturient females of the Teshekpuk Herd during calving based on fixed-kernel density estimation of telemetry locations, 1990–2022.
Figure 14. Proportion of CAH and TCH caribou within the BTN survey area (top panel) and BTS survey area (bottom panel) by month, based on fixed-kernel density estimation, 1990–2022.
June, and July when use of the BTS dropped off dramatically. Caribou were located closer to Teshekpuk Lake from pre-calving through the mosquito season. The difference was also apparent in September when more female caribou were located in the BTN survey area. Use of the survey area by males followed a similar pattern to their use of the BTN survey area with little use from November through May (0.3%–1.7%) when males are in their winter ranges, and moderate use (4.5%–13.4%) from June through October. When compared to the BTN survey area, use of the BTS by males was similar in June as males were still migrating north from their winter range, lower in July when caribou were closer to the coast for mosquito relief, and higher in August and September when caribou dispersed inland as insect harassment abated. There was almost no expected use (0.1%–0.6%) of the BTS survey area by collared CAH females throughout the year (Figures 10, 14).

Mapping Movements

Maps of female TCH caribou movements in the study area derived from the dBMMs corroborated the results from the KDE analysis but provided more high-resolution movement details. The models showed that TCH females used the BTU survey areas during all seasons, although their use of the area and movement rates varied widely among seasons and years (Figure 15–16). During winter, female caribou exhibited low rates of movement and were distributed widely but concentrated in and around the BTS survey area. During the spring migration and calving seasons, TCH females moved across the study area from the south and southeast to the northwest as they migrated toward the core calving area bordering Teshekpuk Lake. During the postcalving and mosquito seasons, caribou largely remained west and north of the study area, often traversing the narrow corridors between Teshekpuk Lake and the Beaufort Sea (Yokel et al. 2009). During the oestrid fly season, TCH females were still more concentrated near the coast, but moved rapidly and often dispersed inland away from Teshekpuk Lake, with occasional large movements through the survey areas and proposed Willow alignment in some years (see 2009, 2015, 2021 in Figure 16). During late summer, caribou were usually found dispersed inland throughout much of both survey areas. During the fall migration season, female TCH caribou dispersed even more widely and moved towards wintering grounds. Approximately 30 percent of the herd typically overwinters in the Brooks Range and some of those caribou moved through the BTS survey area during migration.

MOVEMENTS NEAR PROPOSED WILLOW INFRASTRUCTURE

Consistent with the location of existing infrastructure on the eastern edge of the TCH range, movements by collared TCH and CAH caribou within 4 km (Dau and Cameron 1986, Cameron et al. 1992, Lawhead et al. 2004, Johnson et al. 2020, Prichard et al. 2020a) of proposed Willow infrastructure have occurred more frequently than movements near existing infrastructure in the GMT and CRD survey areas to the east (Figures 15–17). The percentages of the utilization distributions within 4 km of proposed roads and pads ranged from 0.0%–1.9% with notable differences by sex (Figure 18). Males were most likely to be within 4 km of proposed roads and pads from June through September and almost no use of this area occurred after the fall migration, whereas females maintained a consistent presence for most of the winter months, decreased occurrence in June and July, and increased occurrence in August, September, and October.

Analysis of GPS collars during 2004–2022 indicated that there were 1,482 track crossings of the proposed Willow road alignment and 0–14% of collared caribou tracks cross the proposed Willow road alignment during a season (Table 4). The highest average proportion of collared caribou crossings was during the fall migration season (mean = 14%; annual range = 8–30%), followed by the oestrid fly season (mean = 10%; annual range = 0–39%), late summer (mean = 6%; annual range = 0–20%), and winter (mean = 5%; annual range = 0–11%). The lowest proportion of collared caribou track crossings was during the postcalving (mean = 1%; annual range = 0–3%) and mosquito seasons (mean = 0%). Analysis of daily movement directions by month indicate that caribou within 4 km of the proposed Willow infrastructure are more likely to move faster and to the southwest during July when crossing rates are high during the oestrid fly season. From late summer through
Figure 15. Proportion of GPS-collared female caribou of the Teshekpuk Herd in the vicinity of the proposed Willow development during each of 8 seasons based on 95% isopleths of dynamic Brownian Bridge movement models, 2004–2022.
Figure 16. Proportion of GPS-collared female caribou of the Teshekpuk Herd in the vicinity of the proposed Willow development by year based on 95% isopleths of dynamic Brownian Bridge movement models, 2007–2022.
Figure 17. Movements of GPS-collared caribou from the TCH (2004–2021) and CAH (2003–2006 and 2008–2022) in the vicinity of the proposed Willow development during 8 different seasons.
Results

Figure 18. Proportion of caribou from the Teshekpuk Herd within 4 km of the proposed Willow development alignments by month, based on fixed-kernel density estimation, 1990–2022.

Table 4. Proportion of GPS-collared female caribou from the Teshekpuk Herd that crossed the proposed Willow road alignment at least once in each season, 2004–2022. Numbers in parenthesis indicate the number of collared caribou used in the analysis. Locations within 30 days of collaring were removed and then animals with fewer than 50 locations or active less than half the season were removed from the analysis. Winter 2022 includes 1 Dec 2022–30 April 2023, therefore data not yet collected and analyzed.

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring Migration</th>
<th>Calving</th>
<th>Postcalving</th>
<th>Mosquito</th>
<th>Oestrid Fly</th>
<th>Late Summer</th>
<th>Fall Migration</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>0.00 (49)</td>
<td>0.08 (49)</td>
<td>0.00 (49)</td>
<td>0.00 (39)</td>
<td>0.21 (43)</td>
<td>0.07 (76)</td>
<td>0.08 (75)</td>
<td>0.00 (70)</td>
</tr>
<tr>
<td>2005–2009</td>
<td>0.05 (88)</td>
<td>0.02 (84)</td>
<td>0.03 (72)</td>
<td>0.00 (85)</td>
<td>0.04 (104)</td>
<td>0.03 (123)</td>
<td>0.08 (117)</td>
<td>0.02 (102)</td>
</tr>
<tr>
<td>2010–2014</td>
<td>0.05 (219)</td>
<td>0.01 (214)</td>
<td>0.00 (122)</td>
<td>0.00 (216)</td>
<td>0.00 (283)</td>
<td>0.03 (329)</td>
<td>0.13 (319)</td>
<td>0.11 (301)</td>
</tr>
<tr>
<td>2015–2019</td>
<td>0.04 (89)</td>
<td>0.01 (89)</td>
<td>0.02 (44)</td>
<td>0.00 (91)</td>
<td>0.10 (101)</td>
<td>0.20 (109)</td>
<td>0.17 (109)</td>
<td>0.01 (101)</td>
</tr>
<tr>
<td>2020</td>
<td>0.07 (96)</td>
<td>0.00 (94)</td>
<td>0.00 (40)</td>
<td>0.00 (92)</td>
<td>0.39 (111)</td>
<td>0.03 (110)</td>
<td>0.26 (109)</td>
<td>0.01 (104)</td>
</tr>
<tr>
<td>2021</td>
<td>0.01 (90)</td>
<td>0.05 (88)</td>
<td>0.00 (41)</td>
<td>0.00 (88)</td>
<td>0.08 (119)</td>
<td>0.03 (119)</td>
<td>0.10 (116)</td>
<td>-</td>
</tr>
<tr>
<td>2022</td>
<td>0.04 (631)</td>
<td>0.02 (618)</td>
<td>0.01 (368)</td>
<td>0.00 (611)</td>
<td>0.10 (761)</td>
<td>0.06 (876)</td>
<td>0.14 (855)</td>
<td>0.05 (688)</td>
</tr>
</tbody>
</table>

All Years | 0.04 (631)       | 0.02 (618) | 0.01 (368) | 0.00 (611) | 0.10 (761)  | 0.06 (876)   | 0.14 (855)     | 0.05 (688) |
Results

winter when crossing rates are also moderate–high, caribou move slower and in variable directions (Figure 19). From May through June, when crossing rates are low, caribou move through the area to the west and northwest as they migrate to the calving grounds and insect relief habitat. In 2022, no large movements through the Willow area occurred during any season.

REMOTE SENSING

SNOW COVER

Based on records from weather stations in the area (Figure 4; Appendix C), temperatures were near average in spring 2022 and the timing of snowmelt was slightly early in 2022. Estimated snow cover from MODIS data indicates that the survey areas and adjacent areas to the south had a mostly intact snowpack through 26 May 2022. The BTN and BTS survey areas had patchy snow by 27 May 2022, and were mostly snow-free by 4 June, except for lakes. Remaining land in the survey areas was snow-free by 6 June. Snowmelt timing was similar to the median date of snowmelt calculated for the past 20 years (Figures 20–21).

VEGETATIVE BIOMASS

Compared with the median NDVI since 2000, the estimated vegetative biomass during calving in 2022 (NDVI_Calving) was lower than normal on the coastal plain, and near normal in the foothills; some areas in the coastal plain had snow cover during the calving period and were well below normal (Figures 21–22). NDVI during peak lactation (NDVI_621) was near normal and peak NDVI (NDVI_Peak) was slightly above normal across most of the study area in 2022 (Figures 21–22). Those values are consistent with the above average temperatures in late June and early July.
Figure 20. Extent of snow cover between early May and mid-June on the central North Slope of Alaska in 2022, as estimated from MODIS satellite imagery.
Figure 21. Median snowmelt date and vegetation index metrics, as estimated from MODIS satellite imagery time series.
Figure 22. Metrics of relative vegetative biomass during the 2022 growing season on the central North Slope of Alaska, as estimated from NDVI calculated from MODIS satellite imagery.
2022 (Figure 4). In 2022, NDVI_Rate was high in coastal areas with late snowmelt, including most of the survey areas, and lower in inland areas where snowmelt occurred later (Figure 22). 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.

**SPECIES DISTRIBUTION MODELING**

**FACTORS INFLUENCING SUITABILITY**

Results from 2020, 2021, and preliminary models in 2022 indicated the smallest spatial scales (120 m) for habitat variables often had the highest or nearly highest test-ratio. Therefore, we used the 120 m scale for all habitat variables except 4. We used the 0.5-km scale for the sedge habitat because of high collinearity with tussock tundra habitat at the 120-m scale. We subjectively chose the 1-km scale for the riverine habitat because previous results indicated the general importance of many streams and coastal habitats in the study area. TPI consistently had the highest test ratio at the larger scales, so we used the 3.2-km scale for all models to capture broad scale topography. And the gentle slope dataset had the highest test ratios at the smaller spatial scales, so we chose the 0.5-km scale over the 120-m scale because we felt the slightly broader spatial scale better described geographic regions near the slopes of streams, lakes, and slightly rugged terrain. Therefore, TPI best characterized broad-scale topography while gentle slopes best characterized fine-scale topography.

Due to high VIF values, we removed the following variables from base models: NDVI_621 and NDVI_rate during the calving season and NDVI_calving during the postcalving season. Additionally, when including the daily forage quality variables in postcalving, mosquito, oestrid fly, and late summer models, we removed the following variables due to high VIF: distance to coast during all seasons, NDVI_621 during the postcalving season, NDVI_621 and NDVI_max during the mosquito season, NDVI_max during the oestrid fly season, and NDVI_max during the late summer season all seasons. Due to persistent snow during the calving season in most years, we did not model the daily forage quality variables during that season. The remaining variables had VIFs <6 in all models. Depending on the season, 15–19 different variables were included in each model.

After combining all aerial survey data for the years 2002–2022 for the GMT, BTN, and BTS survey areas, sample sizes for seasonal Maxent models ranged from 88 to 2,615 use locations (Table 5). The best performing RM based on AIC_c varied by season from 0.5 to 5.0 (Table 5). Feature type combinations for the best performing models included linear-quadratic (2 models) and linear-quadratic-product (10 models). All models were able to predict caribou locations better than expected by random chance (Training AUC > 0.5; Table 5). In general, the daily forage quality variables did not improve seasonal model performance as measured by training or test AUC (Table 5). The best performing model as measured by training AUC was the base mosquito season model (Training AUC = 0.859) and the worst performing model was for the fall migration season (AUC = 0.614; Table 5). Test AUC was similar to training AUC in most models, indicating that most models developed with the training data performed almost as well with separate test data. The difference in AUC values for the mosquito season is likely due to a small sample size (88 observations).

Maps of the results of our models for the GMT, BTN, and BTS survey areas were generally similar between base models and those with daily forage quality variables and all maps showed clear spatial patterns and localized areas of high suitability evident in all seasons (Figure 23). In general, the variables with the highest relative PI (>4.0) for the base seasonal models included west-to-east distribution, distance to coast, lichens, tussock tundra, gentle slopes, riverine, lichen, graminoids, and wetness (Appendices F–Q). West-to-east and/or distance to coast were consistently in the top 4 variables for PI for base models. Suitability was higher further to the west in all seasons except the mosquito season. Seasonal avoidance or selection of habitats near streams was evident during all seasons except the spring migration and mosquito seasons, although the importance of variables associated with these regions (i.e. TPI, riverine and moss habitats, snowmelt date, gentle slopes, forage quality) varied greatly by season. Lichen was a top variable (PI 13.7, 24.5, 15.0) for fall, winter, and spring
Results

respectively. NDVI measurements were only important during the winter (NDVI_Peak: PI = 6.6) and calving (NDVI_calving: PI = 6.0) seasons. During all seasons, suitability consistently declined as wetness and the proportion of graminoids increased, although the importance of each variable varied greatly by season.

While models with daily forage quality variables (postcalving to late summer seasons) produced maps like the base models, the importance values of variables were often different. The variables with the highest relative PI included west-to-east distribution, graminoids, gentle slope, and daily NDVI (Appendices J, L, N, P). DN_conc had seasonal PI values of 3.4, 20.3, 0.2, and 3.7, DE_Conc had seasonal PI values of 1.4, 0.7, 0.0, and 0.9, and daily NDVI had seasonal PI values of 2.3, 10.8, 15.2, and 7.1 for the postcalving, mosquito, oestrid fly, and late summer seasons, respectively. Distance to coast was not included in these models because it had high VIF values when the daily forage variables were included and tended to be correlated with DN_conc, complicating the interpretation of the importance of the latter variable.

Table 5. Feature types, regularization multipliers (RM), samples sizes, and the Area Under the Curve (AUC) estimates of model fit for training and test data for the top performing Maxent models (according to AICc) for caribou habitat suitability in the NPR-A survey area, 2002–2022. We set aside 20% of locations for testing the model. Bold font indicates models that included variables for daily NDVI, digestible energy content, and digestible nitrogen concentration.

<table>
<thead>
<tr>
<th>Season</th>
<th>Aerial Locations</th>
<th>Features*</th>
<th>RM</th>
<th>Training AUC</th>
<th>Test AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1,989</td>
<td>LQP</td>
<td>1</td>
<td>0.627</td>
<td>0.611</td>
</tr>
<tr>
<td>Spring Migration</td>
<td>679</td>
<td>LQP</td>
<td>6</td>
<td>0.628</td>
<td>0.581</td>
</tr>
<tr>
<td>Calving</td>
<td>1,951</td>
<td>LQP</td>
<td>1</td>
<td>0.640</td>
<td>0.623</td>
</tr>
<tr>
<td>Postcalving</td>
<td>2,286</td>
<td>LQ</td>
<td>3</td>
<td>0.649</td>
<td>0.606</td>
</tr>
<tr>
<td><strong>Daily Forage Quality</strong></td>
<td><strong>2,286</strong></td>
<td>LQP</td>
<td>0.5</td>
<td><strong>0.668</strong></td>
<td><strong>0.634</strong></td>
</tr>
<tr>
<td>Mosquito</td>
<td>88</td>
<td>LQP</td>
<td>1</td>
<td>0.859</td>
<td>0.675</td>
</tr>
<tr>
<td><strong>Daily Forage Quality</strong></td>
<td>88</td>
<td>LQ</td>
<td>5</td>
<td><strong>0.749</strong></td>
<td><strong>0.625</strong></td>
</tr>
<tr>
<td>Oestrid Fly</td>
<td>1,048</td>
<td>LQP</td>
<td>0.5</td>
<td>0.736</td>
<td>0.658</td>
</tr>
<tr>
<td><strong>Daily Forage Quality</strong></td>
<td><strong>1,048</strong></td>
<td>LQP</td>
<td>2</td>
<td><strong>0.726</strong></td>
<td><strong>0.733</strong></td>
</tr>
<tr>
<td>Late Summer</td>
<td>2,187</td>
<td>LQP</td>
<td>1</td>
<td>0.615</td>
<td>0.558</td>
</tr>
<tr>
<td><strong>Daily Forage Quality</strong></td>
<td><strong>2,187</strong></td>
<td>LQP</td>
<td>0.5</td>
<td><strong>0.633</strong></td>
<td><strong>0.577</strong></td>
</tr>
<tr>
<td>Fall Migration</td>
<td>2,615</td>
<td>LQP</td>
<td>1</td>
<td>0.614</td>
<td>0.599</td>
</tr>
<tr>
<td>Total</td>
<td>12,843</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* L=linear, Q=quadratic, P=product

SUITABILITY BY SEASON

The training AUC value for the base mosquito season model (0.859) was the highest of all the seasonal models (Table 5). The training AUC for the mosquito season daily forage quality model (0.749) was the second highest for the models, but lower than the base model indicating poorer performance (Table 5). Based on the suitability maps for all survey areas, suitability during the mosquito season was generally higher closer to the coast, particularly along drainages (Figure 23). There was little suitable habitat in the BTS survey area, but suitability was high in the northern half of the BTN survey. The variables with the largest PI for the base mosquito season model included tussock tundra (14.4), gentle slopes (14.3), distance to coast (14.1), dwarf shrub (13.1), TPI (9.4), riverine (7.6), sedge (7.2), and moss (5.6; Appendix K). The response curves indicated selection increased closer to the coast, with moderate proportions of gentle slopes, when the proportion of dwarf shrubs and riverine habitat is low, and when TPI is negative (low topography relative to the surroundings), when the proportion of flat landforms and tussock tundra habitat was low, and when NDVI_rate is high (Appendix K). For the daily forage quality model, the variables...
Figure 23. Predicted relative suitability for use of the GMT, BTN, and BTS survey areas by caribou during 8 different seasons, 2002–2022, based on Maxent analysis. Relative probabilities calculated using median seasonal values for daily NDVI, biomass, nitrogen, and snow water equivalent.
with the largest PI included gentleslopes (36.8), DN_conc (20.3), tussock tundra (19.9), daily NDVI (10.8), and TPI (4.6; Appendix L). The response curves indicated suitability increased as the proportion of gentle slopes and DN_conc increased, when daily NDVI was lower, and when TPI was negative (Appendix L).

The training AUC for the oestrid fly season (0.736) was the third highest for the seasonal models (Table 5). The training AUC for the daily forage quality model (0.726) was similar to the base model (Table 5). Based on both suitability maps, suitability for all survey areas was highest along streams, particularly Fish and Judy creeks, and increased to the west (Figure 23). The variables with the largest PI for the base oestrid fly season model included west-to-east distribution (36.1), gentle slopes (12.7), wetness (8.1), distance to coast (7.5), riverine habitat (7.0) and tussock tundra (6.5) and graminoids (5.7; Appendix M). Based on the response curves, suitability increased to the west, closer to the coast, when graminoids and mean wetness were low, when TPI was either low or high, when moss habitat was intermediate, and when riverine habitat was high (Appendix M).

For the daily forage quality model, the variables with the largest PI included west to east (21.8), gentle slopes (18.0), daily NDVI (15.4), graminoids (11.5), tussock tundra (7.1), wetness (5.9), riverine (4.8) and sedge (4.5; Appendix N). The response curves indicated suitability was higher to the west, with a higher proportion of gentle slopes, when graminoids and wetness were lower, and when the proportion of riverine habitat increased.

The training AUC for the base postcalving season model (0.649) and daily forage quality model (0.668) indicated lower predictive power (Table 5). Based on both suitability maps, suitability across all survey areas was highest in the northwest and along drainages with the highest suitability in the BTN survey area (Figure 23). The variables with the largest PI for the postcalving season model included west to east (49.2), distance to coast (32.5), graminoids (5.5), wetness (3.2), gentle slopes (3.2) and median snowmelt date (2.5; Appendix I). Based on the response curves for the base postcalving season model, suitability was higher to the west, closer to the coast, when wetness and graminoids were low, when gentle slopes were higher, and at earlier snowmelt dates (Appendix I). For the daily forage quality model, the variables with the largest PI included gentle slopes (23.8), west to east (16.9), tussock tundra (12.4), NDVI Peak (9.5), graminoids (5.9), sedge (4.5), and wetness (4.0; Appendix J). The response curves indicated suitability was higher with intermediate proportions of gentle slopes, in the west and middle of the study area, when tussock tundra was high and NDVI Peak was low, and when graminoids and wetness were low (Appendix J).

Model performance for the remaining seasons was lower (<0.64), but better than random (Table 5). Seasonal training AUC was 0.627 for winter, 0.628 for spring, 0.640 for calving, 0.615 for the base late summer model, 0.633 for the daily forage quality model, and 0.614 for fall migration (Table 5). Winter suitability tended to be highest in the BTS survey area, moderate in the other survey areas, and lowest along streams (Figure 23). Spring suitability increased to the west in all survey areas, particularly in western BTN and BTS in locations with higher lichen abundance (Figure 23). Calving season suitability was lowest in northeast BTN, and along streams and high most other places in the BTN and BTS survey areas (Figure 23). Late summer suitability was moderate throughout much of the BTN and BTS survey areas and highest along streams and when lichen abundance was higher or when daily NDVI was lower (Figure 23). Finally, during fall migration, suitability was lowest in eastern BTN and high throughout the remainder of the BTN and BTS survey areas (Figure 23). The variables with the largest PI varied greatly by season (Appendices F–Q).

**INTEGRATED STEP SELECTION ANALYSIS**

**MOVEMENTS THROUGHOUT THE STUDY AREAS**

We used the iSSA of movement metrics to test for selection of different site attributes at the scale of space-use decisions made by caribou every 12 hours. At this scale, there were strong seasonal patterns of selection for the different land cover metrics (Figure 24). Areas with higher proportions of graminoids were avoided during oestrid fly season through spring and selected during
Figure 24. Results of an integrated step-selection analysis of movements 12 hours apart from GPS-collared female caribou of the Teshekpuk Herd 2006–2022, including selection for environmental characteristics by season (top panel), and selection for areas within 8 km of existing gravel roads during season with adequate data available (compared to pre-construction levels; bottom panel). Environmental characteristic variables were scaled to represent standard errors from the mean prior to analysis by subtracting the mean and dividing by the standard error. Grey shading indicates the 95% confidence interval of annual results for individual variables. The lower confidence interval for oestrid fly season, for the 0–2 km was -14.
mosquito season (Figure 24). Areas with a higher proportion of lichens were selected from late summer through winter and during calving but avoided during the oestrid fly season. Caribou selected areas with later snowmelt dates during calving and there was no selection during winter and spring. Areas with high TPI were selected from winter and spring and marginally avoided during the late summer season. Wetter areas were avoided during all 8 seasons (Figure 24).

Due to sample size constraints (Table 6), we could only model the effect of the area within 8 km of the GMT1/MT6 and GMT2/MT7 roads during the winter, oestrid fly, and fall seasons. For these 3 seasons, we recorded between 28–384 steps from 21–35 animal-years within 4 km of the roads (Table 6). Results for the fall migration and winter seasons should be interpreted with caution as a few individuals were overrepresented in the sample; a single animal-year accounted for 16.9% and 38.5% of the steps within 4 km of roads for each season, respectively. During the winter season, there was no significant difference in selection for any of the distance zones after construction started, although 95% confidence intervals (C.I.) nearly did not include zero for areas within 2 km ($\beta = -0.85; 95\%$ C.I. = -1.77 – 0.12) and 2–4 km ($\beta = -0.86; 95\%$ C.I. = -1.53 – 0.12; Figure 24). During the oestrid fly season, there was significant avoidance of the area within 2 km of the roads ($\beta = -4.11; 95\%$ C.I. = -14.42 – -0.22), and no significant change in use of the area within 4–6 km of the roads ($\beta = -0.04; 95\%$ C.I. = -0.58 – 0.12; Figure 24). During the fall migration season, after construction there was significant avoidance of the area within 2 km of the roads ($\beta = -1.89; 95\%$ C.I. = -3.09 – -0.98) and 2–4 km ($\beta = -0.66; 95\%$ C.I. = -1.31 – -0.09), and no significant change in use of the area within 6–8 km of the roads ($\beta = 0.09; 95\%$ C.I. = -0.35 – 0.49).

**WINTER MOVEMENTS NEAR ICE ROADS**

The analysis of ice roads indicated that the yearly models for January–March had similar results for the 6 space-use covariates (Figure 25) as were found for the winter season in the full iSSA (Figure 24). Selection for graminoids was mixed with avoidance in 2 years, selection in one year, and avoidance for all years combined (Figure 25). Lichen and TPI were selected in all years and wet habitats were avoided in all years. The snowmelt date variable was not selected or avoided in 2019, 2022, and all years combined but was avoided in 2020. Graminoids was only included in the final model in 2022 and was avoided. Due to the lack of ice roads in 2021 and caribou locations near ice roads in 2022 (Table 7), we only ran the distance to ice roads analysis for 2019, 2020, and all years.

<table>
<thead>
<tr>
<th>Season</th>
<th>Number of animal-years within 4 km</th>
<th>Proportion of animal-years within the study area that were also within 4 km of the roads</th>
<th>Max proportion of steps within 4 km of the roads accounted for by a single animal-year.</th>
<th>Total steps within 4 km of the roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>27</td>
<td>0.073</td>
<td>0.385</td>
<td>384</td>
</tr>
<tr>
<td>Spring Migration</td>
<td>5</td>
<td>0.019</td>
<td>0.333</td>
<td>6</td>
</tr>
<tr>
<td>Calving</td>
<td>9</td>
<td>0.044</td>
<td>0.400</td>
<td>15</td>
</tr>
<tr>
<td>Postcalving</td>
<td>1</td>
<td>0.006</td>
<td>1.000</td>
<td>2</td>
</tr>
<tr>
<td>Mosquito</td>
<td>2</td>
<td>0.008</td>
<td>0.667</td>
<td>6</td>
</tr>
<tr>
<td>Oestrid Fly</td>
<td>21</td>
<td>0.048</td>
<td>0.107</td>
<td>28</td>
</tr>
<tr>
<td>Late Summer</td>
<td>17</td>
<td>0.039</td>
<td>0.505</td>
<td>111</td>
</tr>
<tr>
<td>Fall Migration</td>
<td>35</td>
<td>0.066</td>
<td>0.169</td>
<td>225</td>
</tr>
</tbody>
</table>

**Table 6.** Summary statistics of movements of female caribou from the Teshekpuk Herd within 4 km of the GMT1/MT6 and GMT2/MT7 roads used for integrated step-selection analysis. An animal-year is data from one animal for one year.
Figure 25. Results of an integrated step-selection analysis of movements 12 hours apart from GPS-collared female caribou of the Teshekpuk Herd during January–March 2019–2022, including selection for environmental characteristics by year (top panel), and selection for areas within 8 km of annual ice roads and 4 km of existing gravel roads (in years with adequate data; bottom panel). Environmental characteristic variables were scaled to represent standard errors from the mean prior to analysis by subtracting the mean and dividing by the standard error. Grey shading indicates the 95% confidence interval of annual results for individual variables.
combined (excluding 2021). The distance to road analysis indicated that areas within 2 km of ice roads were avoided in 2020 and for all years combined, and areas within 2–4 km of ice roads were avoided in 2019 and for all years combined (Figure 25). Areas within 4 km of gravel roads were significantly avoided during 2020 and for all years combined (Figure 25).

OTHER MAMMALS

During aerial and ground surveys in 2022, we observed 17 grizzly bears (Ursus arctos) in 11 groups in the BTN and no grizzly bears in the BTS survey areas (Figure 26). We recorded 5 groups near the northern end of the proposed Willow development including 3 single adults on 19 July, a single adult on 5 August, and two adults on 13 October. We recorded 6 groups along or south of Fish and Judy creeks near the proposed Willow development including single adults on 16 June and 11 September (2 groups), a sow with a single cub on 14 and 15 June (likely the same animals), and a sow with 3 cubs on 14 June.

In addition to bears, 2 wolverines (Gulo gulo) were recorded in the BTN survey area in 2022, both in the western portion of the study area. Both observations were of single animals, one on 5 June and one on 5 August. No other observations of large mammals were reported in the BTN or BTS survey areas in 2022.

DISCUSSION

The current emphasis of this study is to collect predevelopment baseline data on caribou distribution and movements, particularly in relation to proposed roads and facilities in the BTN and BTS survey areas. Because barren-ground caribou have large and distinct seasonal ranges and high levels of interannual variability in distribution, detailed analyses of the existing patterns of seasonal distribution, density, and movements provide important insights about the ways in which caribou currently use the study area. CPAI has funded aerial surveys of the northeastern NPR-A since 2001 and satellite (PTT) or GPS telemetry collars have been deployed on TCH caribou since 1990. We used this extensive baseline of caribou data to assess caribou distribution and movements in relation to static and dynamic habitat characteristics. This information is invaluable for predicting potential impacts from future developments and for quantifying impacts after project construction occurs.

For this report, we incorporated several data collection methods and analyses to better understand the seasonal distributions and movements of caribou. By conducting aerial surveys during different seasons over more than 20 years in northeastern NPR-A, we have compiled an extensive dataset that allows us to understand the seasonal patterns of, and variability in, caribou distribution for the two herds using this area. Aerial surveys provide location data for the entire survey area during snapshots in time and are independent of collared caribou locations. The use of telemetry data for the iSSA allows us to explore fine-scale seasonal resource selection and analyze individual movements in relation to infrastructure and habitat characteristics. By analyzing both of these datasets in relation to remote sensing information on land cover, vegetative biomass, and

Table 7. Summary statistics of movements of female caribou of the Teshekpuk Herd within 4 km of the ice roads used for integrated step-selection analysis.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of animals within 4 km</th>
<th>Proportion of animals within the study area that were also within 4 km of the roads</th>
<th>Max proportion of steps within 4 km of the roads accounted for by a single animal</th>
<th>Total steps within 4 km of the roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>20</td>
<td>0.426</td>
<td>0.283</td>
<td>325</td>
</tr>
<tr>
<td>2020</td>
<td>29</td>
<td>0.537</td>
<td>0.195</td>
<td>609</td>
</tr>
<tr>
<td>2022</td>
<td>2</td>
<td>0.125</td>
<td>0.571</td>
<td>7</td>
</tr>
</tbody>
</table>
Figure 26. Distribution of other large mammals observed during aerial and ground surveys in the Bear Tooth Unit Area during 2022 and 1991–2022.
snow cover, we better understand the factors determining seasonal distribution of caribou at two spatial scales of selection. This understanding of the underlying factors that are important to caribou is useful when evaluating potential future changes in caribou distribution that may be attributable to development, a changing climate, or other factors.

WEATHER, SNOW, AND INSECT CONDITIONS

Weather conditions exert strong effects on caribou populations throughout the year in northern Alaska. Autumn snowfall can influence migration and wintering locations (Cameron et al. 2021, Pedersen et al. 2021). 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, Bieniek et al. 2018). 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, Joly et al. 2020). Increased maturation of forage could lead to decreased nutrient content and availability (Finstad and Prichard 2000, Johnson et al. 2021).

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). Low mosquito severity during mid- to late June likely improves caribou body condition after calving, and warm temperatures during July likely result in increased movement rates and decreased foraging, which can cause a decline in body condition.

The median dates of snow melt for each pixel over the past ~2 decades indicate that nearly all the snow on the coastal plain typically melts over a period of 3 weeks between 25 May and 11 June. Snow melt typically progresses 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. Later snowmelt near the coast delays green-up, providing highly nutritious, newly emerged vegetation during the postcalving and insect seasons.

In 2022, the timing of snowmelt was likely slightly earlier than the long term normal based on the timing of nearby cloud-free pixels, but NDVI during calving was estimated to be lower than normal on the coastal plain. The rate of NDVI increase from calving to peak lactation around June 21 was high resulting in near normal NDVI on 21 June and slightly above normal peak NDVI for the year. Therefore, forage nutrition was likely above average during the calving and post-calving seasons and near average for the remainder of the year.

In 2022, we estimated insect harassment to be somewhat higher than average in late June and early July, low in mid- and late July, high in early August and then low for the rest of the season. These conditions likely resulted in low insect harassment for caribou for much of the summer. Therefore, aside from short periods in late June, early July, and early August, insect and forage conditions were likely favorable for caribou nutritional status during summer. Early onset of seasonal snow cover, as occurred in September 2021 (atypical of recent years on the coastal plain; Cox et al. 2017), can exacerbate the nutritional stress from summers with high insect harassment by decreasing foraging rates, initiating an earlier fall migration (Cameron et al. 2021), and increasing the energetic cost of accessing forage under snow cover. Low parturition rates observed in spring 2022 (B. Person, pers. comm.) may have been the result of the long winter. The timing of snowfall and migration was near-average in 2022 and therefore was not expected to cause additional nutritional stress.
Discussion

CARIBOU DISTRIBUTION AND MOVEMENTS

Distribution of TCH and CAH caribou varies greatly by season for both survey areas. The study area is in the eastern portion of the annual range of the TCH, and west of the annual range of the CAH. Use of the BTN and BTS survey areas by CAH caribou is usually very low, although several sporadic incursions have been recorded over the years. A few collared CAH females have switched to the TCH or calved west of the Colville River in isolated years (notably 2001), but it is a rare occurrence (Arthur and Del Vecchio 2009; Lenart 2009, 2015a; Prichard 2020b).

The TCH consistently uses the BTN and BTS survey areas to some extent during all seasons of the year. Most females overwinter on the coastal plain whereas a disproportionately high number of males and non-parturient females migrate south into the foothills and mountains of the Brooks Range to winter, often moving through the BTN and BTS survey areas during the migration. Most TCH females calve near Teshekpuk Lake, northwest of the BTN and BTS survey areas (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015a, Prichard et al. 2019, Fullman et al. 2021). Males that wintered in the Brooks Range usually arrive on the coastal plain in June. When mosquito harassment begins in late June or early July, caribou move toward the Beaufort Sea 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 uses the area between Teshekpuk Lake and the Beaufort Sea for their primary mosquito-relief habitat. 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 gravel roads and shaded locations in the oilfields under elevated pipelines and buildings (Lawhead 1988, Noel et al. 1998, Murphy and Lawhead 2000, Wilson et al. 2012, Prichard et al. 2020a). After insect harassment abates in late summer, caribou are often distributed widely on the coastal plain and then congregate and move rapidly during the rut and fall migration and seasons.

In 2022, caribou density was high during the late winter survey on 7–9 March, with slightly more caribou located in the BTN survey area compared to the BTS survey area. 2020 was the first year we attempted an aerial survey in February or March, and we observed over 2,000 caribou in both survey areas combined. In 2021 and 2022, we observed ~1,000 caribou during the late winter survey. During winter, most of the TCH caribou that remain on the coastal plain are widely distributed between Nuiqsut and Wainwright with high annual variation in distribution in and near the survey areas. This was true in 2022, but a higher proportion of the herd relative to most years was in the Brooks Range foothills south of Umiat and there was a large movement of caribou into the area near Utqiaġvik in early winter. These mid-winter surveys will provide valuable information about caribou distributions in relation to exploration activities, ice roads, and permanent infrastructure as development progresses west into areas that are more heavily used by caribou during winter.

During the spring migration survey, caribou density was moderate in the BTN survey area and similar to the late winter density in the BTS survey area. Telemetry data indicate that many of the TCH caribou were west of the study area and near Teshekpuk Lake, having migrated either from the west or from the area south of Umiat. Those that migrated from south of Umiat generally travelled to the west of the survey area. Densities during the calving surveys in both survey areas were similar to historical spring migration densities as many caribou had already moved to Teshekpuk Lake but others, particularly males, were still migrating through the region to the calving grounds. During the postcalving survey, densities increased in both survey areas to moderately high levels as lagging migrants moved into the area towards the Beaufort Sea coast in anticipation of mosquito emergence. Aerial surveys during the mosquito season are inefficient for describing caribou habitat use because caribou are typically aggregated in large groups and moving rapidly (Prichard et al. 2014), so variability within a survey area is very high. The probability of insect harassment was high into
mid-July and telemetry data indicate much of the herd spent the mosquito season north of Teshekpuk Lake along the coast before splitting into 2 groups by 15 July, with one group to the east and one group to the west of Teshekpuk Lake. These caribou started distributing inland by late July, with some animals from both groups moving south of Teshekpuk Lake, while others from the western group moved off towards Atquasuk. Most caribou were therefore west of the survey area during the oestrid fly season survey on 5–6 August.

During the late summer season, caribou were dispersed widely across the coastal plain, from Umiat to Wainwright. Our 2022 late summer survey was later than normal (11 September) and BTN densities were the highest recorded for either survey area in 2022 while the BTS densities were the second lowest recorded. Telemetry data indicate that caribou were beginning to constrict their distribution to the south of Teshekpuk Lake in the lead up to the rut. The rut likely began in early October between the late summer and fall migration surveys when concentrations of caribou were present throughout the survey area and south of Teshekpuk Lake. However, they were dispersing out of the region to the south by 13–14 October when the survey occurred.

There were differences in seasonal abundance patterns among years. The highest densities observed in 2020 occurred during the winter, postcalving, and oestrid fly seasons whereas in 2021, we observed the highest densities during the oestrid fly and fall migration surveys as large seasonal movements occurred through the area. In 2022, the highest densities were during the winter, postcalving, and late summer seasons. In 2021, the BTS fall migration densities were 8.73 caribou/km², which was >2 times greater than any density observed in the past 4 years. Telemetry data indicates that had the 2022 fall migration survey been conducted a few weeks earlier, we may have observed densities similar to those observed in 2022, indicating the Willow area in recent years has been heavily used during the rut. Prior to expanding the surveys west into the Willow region, periodic shifts in distribution were common and moderately high densities had been recorded sporadically in the eastern NPR-A in late winter (2.4 caribou/km² in April 2004), oestrid fly (5.2 caribou/km² in early August 2005) and fall migration seasons (3.46 caribou/km² in late September 2003). However, no densities > 2.0 caribou/km² were observed in the NPR-A survey area during 2005–2017 or in the GMT survey area since it was defined in 2018, consistent with higher densities of caribou further to the west during all seasons.

Caribou distribution patterns can change over time. In recent years, the TCH calving distribution has expanded to the west, whereas the winter distribution has varied widely among years (Prichard et al. 2019, Fullman et al. 2021). The CAH has shown indications of changes in seasonal distribution, with more caribou calving west of the Sagavanirktok River in recent years, remaining farther north for longer during fall, wintering on the north side of the Continental Divide, and possibly intermixing more with adjacent herds (ADFG 2017, Prichard et al. 2020b, Pedersen et al. 2021). In fall 2021, caribou wintering in the mountains moved south earlier than usual following an early onset of snow cover and much of the CAH wintered farther south than usual in the Hodzana Hills south of the Brook Range (Prichard and Welch 2022). Also, in fall 2021, the majority of the TCH animals wintering on the coastal plain made a rapid movement from the BTS region to Utqiaġvik and back within ~4–6 weeks. And in 2022, a higher proportion of TCH females wintered south of Umiat.

The area near proposed Willow infrastructure is used more often than the area near existing and proposed ASDP and GMT infrastructure. Few crossings of the new GMT1/MT6 or GMT2/MT7 road alignments (constructed during the winters of 2017–2018 and 2018–2019 respectively) have occurred by collared caribou since 2004 (Prichard et al. 2018b, 2019c, 2020d; Welch et al. 2021b, 2022b, 2023). Approximately 14% of collared caribou crossed the proposed Willow alignments at least once during fall migration in a typical year, with 10% crossing in 2022 (Table 4).

We recorded no response or low-moderate responses to the survey aircraft for the majority of caribou groups. However, overall, 16% of caribou groups exhibited strong responses. It is difficult to observe the behavioral state of the caribou prior to the plane influencing the animals, so these results should be viewed with caution. We assume that an animal laying down likely did not change state, but
without observing groups well in advance, it is difficult to know if a standing or walking animal changed behavioral state. Therefore, we may be underestimating the proportion of low-moderate responses and overestimating the proportion with no response. Measurement of strong responses are likely accurate, however, as there is little reason for a caribou to be running other than in response to the plane, except possibly in response to insect harassment. While we did not categorize the strong responses, anecdotally, a large proportion of these animals ran only a short distance (<50 m), often in a random direction relative to the aircraft. Animals exhibiting low-moderate responses also did not generally seem to recognize the aircraft and associate it with the noise. This was the first year that we recorded caribou reactions to the survey aircraft, and we will continue to refine and standardize our methods in the future.

There is limited scientific literature on the effects of low-level aircraft on caribou behavior (Reimers and Colman 2006). Studies of the effect of low-level overflights of caribou with military jet aircraft reported that caribou exhibited short flight responses or temporary changes in behavior (Maier et al. 1998, Lawler et al. 2005) and overflights did not result in higher calf mortality or increased movements of cow/calf pairs (Lawler et al. 2005). The response to our small, fixed-wing survey aircraft is likely lower than the response to a military jet. Maier et al. (1998) reported that reactions were low in late winter, moderate in midsummer, and strongest after calving occurred, with females accompanied by young showing the strongest responses. We found the highest proportion of strong reactions occurred during the calving surveys and responses were lower during winter.

Miller and Gunn (1979) reported stronger responses to low-level aircraft in caribou than we found. They reported that 53.6% of caribou exhibited an extreme response to helicopters flying lower than 200 m agl. (656 feet), and 16.1% exhibited an extreme reaction in response to aircraft at high altitudes. The level of reaction increased with when the helicopter engaged in circling behavior. There is evidence that the effect of aircraft on caribou behavior declines with habituation (Miller and Gunn 1979, 1980, Valkenburg and Davis 1985) and that herds with high aircraft traffic exhibit lower levels of response (Valkenburg and Davis 1985). There are currently fairly high levels of air traffic on the eastern portion of the TCH range (Stinchcomb et al. 2019), but lower levels of air traffic farther west.

**SPECIES DISTRIBUTION MODELING**

Starting in 2020, we chose to use a machine learning approach (Maxent) instead of an RSF model to map and model caribou distributions and habitat associations and starting in 2021, we added an iSSA to examine fine-scale resource selection by caribou along a movement path. Caribou resource selection is complex and difficult to predict. The highly flexible machine learning approach can model nonlinear relationships and interactions with many variables in a way that may be more effective at capturing that complexity and predicting suitability than a RSF model (Phillips et al. 2006, 2017, Elith et al. 2011, Merow et al. 2013). Results from the 2021 and 2022 models generally produced similar habitat suitability maps compared to previous results even though we changed modeling techniques, variables, and datasets (Prichard et al. 2020d, Welch et al. 2021b, 2022b). Based on AUC values, our mosquito and oestrid fly season models performed adequately, and our winter, calving, postcalving, late summer, and fall migration models did not perform well, although they did perform better than a random model. This was not entirely unexpected. Caribou are a migratory species that range over a wide region and our study area is on the eastern edge of their distribution. Lower AUC values likely reflect the generalist habits and non-selective movement patterns of caribou as they move through the study area during most seasons.

Maxent is better suited towards producing a predictive map rather than identifying causal relationships and care must be taken in interpreting the importance and modeled relationship of each variable. Maxent can produce maps with high predictive power, but interpretation of variable importance and influence becomes more difficult, if not impossible, as model complexity increases (Phillips et al. 2006, Phillips 2017). In 2022, we restricted the possible feature types to only linear, quadratic, and product relationships to simplify the models and aid in interpretability. Maxent can produce very similar and accurate predictions even
if different variable combinations, feature types, or settings are used (Phillips 2017) as is evident by the similar maps produced over 3 years of Maxent modeling with various predictor variables. The simplified models from 2022 performed almost identically to models from 2020 and 2021 with regard to predicting suitability but the 2022 response curves are more interpretable than previous, more complex models.

In 2021 and 2022, we conducted the Maxent analysis only on aerial survey data as opposed to a combination of aerial survey and GPS-collar data, which we had used for previous year’s models, and as stated above, our predictive maps were generally similar to those produced in 2020. There are advantages and disadvantages for using each dataset. Telemetry data have higher spatial accuracy than do aerial survey data and they are collected continuously throughout the year, albeit for a relatively small sample of individual caribou, mostly female. A single collared caribou that spends long periods of time within the study area can exert a large influence on distribution analysis. 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 (~100 m), and surveys are conducted only periodically throughout the year. The two data types also had different timing, especially during the winter season; we conducted only one aerial survey during the winter season in any given year (in mid- to late April from 2002–2019 and in February–March 2020–2022 for the BTS and BTN survey areas only), whereas telemetry locations are collected throughout the entire season. The addition of the iSSA, which uses GPS telemetry data at every movement step, provided an opportunity to compare results from two different models using different datasets from the same population of caribou.

In general, broad geographic patterns in distribution (west-to-east, distance to coast) and selection or avoidance of riparian areas were the strongest drivers of large-scale caribou distribution in almost every season, due in large part to the seasonal distribution patterns during key life cycle stages, but other factors such as abundance of vegetation types were also important seasonally. Because the survey areas are on the eastern edge of the TCH range, a natural west-to-east gradient of decreasing density occurs throughout much of the year. During calving, the highest densities of TCH females typically calve near Teshekpuk Lake outside of the study area (Person et al. 2007, Wilson et al. 2012, Parrett 2015a). The past 5 years of aerial survey data in the BTN and BTS survey areas, as well as previous years of surveys in the GMT survey area, suggest limited calving activity occurs in survey areas. Therefore, our suitability results for the calving season likely reflect the distribution of non-parturient females and males, many of which are migrating north from the Brooks Range towards Teshekpuk Lake. These migrations can last well into the postcalving season. Migrating caribou often cross the Colville River at Ocean Point and enter our study area near the southwest portion of GMT2/MT7.

Comparison of caribou habitat use across studies is complicated by the fact that different investigators have used different habitat classifications, but multiple studies have indicated that caribou avoid wetter habitats during summer (Wilson et al. 2012, Prichard et al 2020a). We found a weak avoidance of wetter habitats and an avoidance of graminoid cover (common in wetter habitats) in almost all seasons. The abundance of lichen was very important for modeling suitability in the winter, spring, and fall migration seasons consistent with higher use of lichen during periods of snow cover observed in most caribou herds (Klein 1982, Russel et al. 1993, Ehlers et al. 2021). Graminoids are the dominant vegetation cover in moist habitats, while the wetness variable is an index of the proportion of time a location is flooded. Therefore, while similar, these variables represent different metrics and were not highly correlated.

At the large scale of selection, the timing of snowmelt was not an important variable during the winter, spring, or calving seasons, although the response curve for the calving season indicates higher suitability at later snowmelt dates. Reducing the topography and plant functional group layers and the reintroduction of the proportion of habitat layers in 2022 yielded simpler models that performed similarly to previous models but the response curves were easier to interpret. However, during each season, different combinations of variables influence suitability near streams.
The selection of areas along Fish and Judy creeks during the postcalving, oestrid fly, and late summer seasons and avoidance of riverine habitat during winter has been documented previously using different analyses and variables (Lawhead et al. 2015, Prichard et al. 2020d). The riparian habitats along Fish and Judy creeks provide a complex interspersion of barren ground, dunes, and sparse vegetation that provide good oestrid fly-relief habitat near foraging areas (Nellemann and Thomsen 1994, Nellemann and Cameron 1996). The strong selection for riparian areas during the oestrid fly and late summer seasons is apparent from aerial surveys conducted in those seasons.

Johnson et al. (2018, 2021) used NDVI values as well as habitat type, distance to coast, and days from peak NDVI to develop models to predict daily digestible nitrogen and digestible energy over broad areas. These models should, if successful, provide metrics that are more directly related to caribou foraging needs than NDVI alone. However, in the Maxent models, DN_conc was the only variable of the two with a seasonal PI value >4 and only during the mosquito season. Distance to coast was removed from seasonal models because of a high correlation with DN_conc (higher DN_conc closer to the coast), so it is likely that selection for DN_conc is driven by the seasonal selection of locations close to the coast for insect harassment relief.

It is also possible that these models do not predict digestible energy and digestible nitrogen well in this area. Johnson et al. (2018, 2021) used a land cover map derived from mapping conducted by Ducks Unlimited for the North Slope Science Initiative (NSSI 2013) that has discontinuities in classification methodology and imagery in our analysis area (Boggs et al. 2016). These discontinuities could translate into inaccurate forage metrics in our analysis area. Alternatively, caribou may not be selecting for digestible nitrogen or digestible energy within our study area. Caribou movements are influenced by many factors other than forage availability and only a portion of locations represent caribou that are actively feeding. It does not appear that our study area is heavily used by calving caribou and the study area likely has many non-parturient and migrating caribou present during the calving and postcalving seasons. A mixture of sex and age classes in the local caribou population could complicate modeling efforts, especially when one demographic is likely moving long distances and not exhibiting highly selective behavior.

The iSSA tested for resource selection at the scale of each caribou location at 12-h intervals, while the Maxent analysis described the distribution of caribou within the aerial survey study areas by season. At the survey area scale, caribou distribution was largely described by broad geographic patterns (e.g., distance to coast, west-to-east gradients), but the iSSA indicated that within these broad seasonal distribution patterns, caribou were selecting for and against site-specific attributes including top cover of different plant functional groups. Caribou avoided wetter areas during all seasons and selected areas with high lichen cover from late summer–winter and calving, consistent with results found in other studies (Ehlers et al. 2021).

At the step-scale of selection, caribou were selecting for patches that melted out later in the year during the calving season, whereas at the survey-area scale in the Maxent analysis, caribou distribution is primarily driven by large-scale geographic patterns as caribou migrate to preferred calving areas. Therefore, the iSSA results suggests that within the seasonal range, caribou are selecting for patches where snowmelt was more recent and newly emergent, highly nutritious forage species were more abundant (Kuropat 1984, Klein 1990, Johnstone et al. 2002, Johnson et al. 2020). Patchy snow may also create a complex visual pattern that reduces predation (Bergerud and Page 1987, Eastland et al. 1989). Selection for areas with high TPI during winter and spring is likely related to lower snow depth and easier access to forage in areas that tend to be more windblown.

We continue to compile data on caribou movements in the GMT area following construction of the GMT1/MT6 and GMT2/MT7 roads and pads to gain insights into potential impacts of Willow infrastructure. Seasonal patterns of movements can vary widely among years and the GMT survey area is near the eastern edge of the TCH range. Therefore, our samples for the iSSA were often limited by a single animal with many of the available steps near the road, few animals
walking within 4 km of the roads, or few total steps within 4 km of roads to analyze. However, there is some evidence that the GMT roads caused alterations in TCH range use during the three seasons with enough data to analyze, although our results should be viewed as preliminary and interpreted with caution. The iSSA indicated that, after the road was constructed, there was a decrease in selection for the area within 2 km of the GMT roads during the oestrid fly and fall migration seasons, and a decrease in use within 2–4 km of the road during fall migration. There was also a nearly significant avoidance within 4 km during winter. During the oestrid fly season, groups of caribou have appeared to shift direction and moved parallel to the road during some large caribou movements in recent years (Welch et al. 2022a).

During mid-August 2020, many TCH caribou moved towards the GMT1/MT6 and GMT2/MT7 roads from the north and west. Only a few individuals continued across the roads, while most caribou turned to the southwest and paralleled the road along the west side maintaining a distance of ~1–6 km until they passed the end of the infrastructure. A similar large movement of caribou occurred during late July 2021. A large group of caribou approached the north end of the GMT1/MT6 road from the west and turned southwest, appearing to parallel the GMT1/MT6 and GMT2/MT7 roads. This movement pattern could indicate a deflection away from the road, but it is also possible that they were following Fish Creek, which has preferred oestrid fly habitat and roughly parallels the GMT road, as they moved inland. These 2 potential alterations in the direction of travel to parallel the road may be attributed to road effects and possibly a natural tendency of caribou to follow linear features (LeResche and Linderman 1975, Bergerud et al. 1984, Lawhead et al. 1993). Caribou are especially likely to follow linear features when the features are roughly parallel to the direction of movement of the caribou or when caribou are not motivated to move in any specific direction.

The results of the iSSA during the oestrid fly season indicate that caribou avoided the area within 2 km of the road and selected the area within 4–6 km of the road. This is consistent with caribou moving parallel to the road at a distance and moving along Fish Creek. CAH caribou often use oilfield roads and pads for oestrid fly relief (Prichard et al. 2020a). Whether or not TCH will use gravel roads for oestrid fly relief may depend on the degree of habituation that occurs, which will be influenced by the level of hunting that occurs along the road. In addition, the availability of alternative oestrid-fly relief habitat along Fish and Judy creeks may lower the importance of gravel roads for insect-relief for the TCH. While continued monitoring and analysis of caribou movements near the GMT1/MT6 and GMT2/MT7 roads will continue to add statistical power to our analysis, it is clear from decades of collar data that use of the area is low during most years, therefore any impacts that may occur will be limited to a small proportion of the herd under current movement patterns. However, as additional roads are built to the west for the Willow Project in areas with higher caribou densities, the impacts on caribou distribution may be higher.

Changes in caribou behavior near roads can be influenced by many factors including season, motivation, activity on the road, road design, and a caribou’s previous experience with development. Previous research on the CAH has found that caribou do avoid active roads and pads during the calving season (Cameron et al. 1995, Lawhead et al. 2004, Johnson et al. 2020), but the degree of avoidance declines following calving (Smith et al. 1994, Lawhead et al. 2004, Johnson et al. 2020), and caribou use roads and pads preferentially for oestrid fly-relief habitat (Pollard et al. 1996, Prichard et al. 2020a). Because the CAH does not winter in the oilfields, data from that herd provides little information on road impacts during fall and winter. Caribou of the WAH were reported to exhibit long delays and deflections when approaching the road to the Red Dog Mine in northwestern Alaska during fall migration (Wilson et al. 2016) and unusual GPS data movements have been observed near the mine road area in more recent years, however it is not clear if these movement changes were due to road design, road activity, or other factors.

There are several reasons to expect more avoidance of the GMT road area by TCH caribou compared to the behavior of CAH caribou in the Kuparuk area. The GMT roads have periodically high rates of use by vehicles since they are still in a
post-construction drilling period, and, unlike the roads in Kuparuk, there is use of the area on and near the road by subsistence hunters targeting caribou which may influence caribou behavior (Paton et al. 2017). The harvest of caribou by Nuiqsut hunters tends to peak during the months of July and August, with somewhat lower harvest in June and September–October and little harvest occurring in other months (Pedersen 1995, Brower and Opie 1997, Fuller and George 1997, Braem et al. 2011, SRB&A 2021). Using harvest data (Braem et al. 2011) and telemetry data from 2003–2007, Parrett (2013) estimated that TCH caribou composed 86% of the total annual harvest by Nuiqsut hunters during those years. Historically, the greatest proportion of the Nuiqsut caribou harvest has been taken by boat-based hunters during the open-water period (SRB&A 2022). The construction of the Nuiqsut Spur Road and CD-5 access road resulted in access to the CPAI road network, and the expansion of roads west to GMT2/MT7 has resulted in increasing use by local residents (SRB&A 2022). Because the density of TCH caribou is higher to the west, the proposed Willow roads are likely to increase subsistence hunter access to seasonal ranges used consistently year-round by TCH caribou.

There is also evidence that impacts from development are largest during and right after construction and when caribou have had less previous exposure to infrastructure (Smith et al. 1994, Prichard et al. 2020a). Post-construction activity should remain relatively high on the road and pads during the drilling period but should decline once drilling is complete, which could take several years. TCH caribou are also widely distributed across their range during the fall and winter seasons, therefore, they may have little motivation to use areas near roads during those seasons. Caribou have a low energetic cost of locomotion (Fancy and White 1987) and the GMT roads are in an area that gets limited use by TCH caribou, so small changes in behavior may not have large energetic or demographic impacts on caribou, but changes in distribution could influence availability for subsistence hunters.

**WINTER MOVEMENTS NEAR ICE ROADS**

The winter ice road iSSA for 2019–2020 and 2022 indicated that lichen and TPI were selected in all years and wet habitats were avoided in all years. Selection for high TPI could indicate selection for areas with more forage and/or lower snow depths. Areas with high TPI are likely to have more wind scouring and shallower snow and better visibility to spot predators.

Due to limited sample sizes in some years, we only analyzed distance to ice-roads in 2019, 2020, and all years combined (2019, 2020 and 2022). We found a significant avoidance of the area within 2 km of ice roads in 2020 and all years combined and avoidance of the area within 2–4 km of ice roads in 2019 and all years combined. These distances are similar to the apparent avoidance of gravel roads during other seasons. Assessing road avoidance in caribou can be complex because it depends on both the level of risk caribou associate with areas near roads as well as their degree of motivation to be near roads. During calving, female caribou and newborn calves are very vulnerable to predation and the perceived risk of being near roads and human activity is likely high. Caribou of the CAH have shown little indication of habituation to roads during the calving period even after about 50 years of exposure (Johnson et al. 2020, Prichard et al. 2020a), but there is more evidence of habituation to roads during other seasons (Smith et al. 1994, Prichard et al. 2020a, Prichard et al. 2022). During the insect seasons, caribou calves are mobile, which decreases the perceived risk, and caribou are highly motivated to cross roads to reach the coast or use roads for oestrid fly relief. Caribou of the CAH cross roads frequently during the insect seasons and some individuals and groups will use roads and pads as oestrid fly relief (Pollard et al. 1996, Noel et al. 1998, Prichard et al. 2020a).

The northern coastal plain is largely in darkness during the winter months and the lights of drill pads and vehicle traffic are very visible from long distances. Caribou are also typically widely dispersed during this period and they move less than at any other time of year (Person et al. 2007, Prichard et al. 2014). Caribou may therefore have low motivation to use the areas near roads and ice roads unless there are especially favorable foraging conditions nearby. The perceived risk may also be low but could depend on the activity level and amount of hunting associated with the ice road. Unlike the roads in the Kuparuk area, the GMT roads receive a fairly high level of use by
subsistence hunters during some periods. This hunting could increase avoidance of the roads and potentially delay habituation of caribou to road traffic.

Other Mammals

In 2022, we observed 11 grizzly bears groups and 2 single wolverines in the BTU area during aerial surveys. Bears are commonly observed during surveys, while wolverine and other species of large mammal are observed far less frequently. Only 11 observations (10 singles, 1 pair) of wolverines have been recorded by ABR biologists in the region encompassing the BTU survey areas since 1993. Additional wolverine observations have been made near or west of the Colville River. Wolverines are found throughout the North Slope of Alaska but at low densities (Carroll 2013, Poley et al. 2018) and the lack of observations of wolverine in the BTS and western BTN survey areas is a function of the small sample size of surveys in those regions.

Muskoxen are rarely observed in the BTN and BTS survey areas and instead, are often found farther east along the Colville River (Welch et al. 2021b). A single muskox was observed in the BTN survey area in 2021 (Welch et al. 2022b) but none were observed in BTN or BTS in 2022. In recent years, more muskoxen have been observed west of the Colville River near or in the GMT survey areas (Welch et al. 2021b, 2022b). The muskox population on the North Slope of Alaska has declined since 1999, evidently due to a combination of predation by grizzly bears, human interactions, disease, and unusual mortality events such as drowning (Reynolds et al. 2002, Shideler et al. 2007, Lenart 2015b). The decline was noted first in the Arctic National Wildlife Refuge but later was documented farther west on the central coastal plain. Population surveys by ADFG in late winter (April) found 216 muskoxen in 2006. Since then, the population on the central North Slope has remained relatively stable at approximately 190–200 muskoxen (Arthur and Del Vecchio 2017; Lenart 2015b). Predation by grizzly bears was the most common cause of death, responsible for an estimated 58% of calf mortalities and 62% of adult mortalities when a cause of death could be determined (Arthur and Del Vecchio 2017). The recent observations of muskoxen west of the Colville River have been of small groups of 1–7 animals, though CPAI observations indicate the group may be as large as 15 animals (C. Pohl, pers. comm.). Therefore muskoxen may be expanding their range westward.

CONCLUSIONS

The current emphasis of this study is to monitor caribou distribution and movements in relation to the proposed infrastructure in the BTN and BTS survey areas and to compile predevelopment baseline data on caribou density and movements. Detailed analyses of the existing patterns of seasonal distribution, density, and movements are providing important insights about how caribou currently use the study area. Although both the TCH and CAH recently underwent declines in population since their peaks in ~2010, both herds appeared to have stabilized in size and preliminary estimates suggest they increased in size in the most recent population surveys conducted in 2022. The TCH calving distribution has recently expanded to the west and the fall and winter distribution has varied widely among years (Parrett 2013, Welch et al. 2021a). The CAH has shown some changes in seasonal distribution, with more caribou remaining farther north during fall and early winter and more intermixing with adjacent herds (ADFG 2017, Prichard et al. 2020b).

For this report, we incorporated multiple types of data and several different analyses to better understand the seasonal distributions, movements, and habitat associations of caribou in the area. By conducting aerial surveys during different seasons over 22 years in northeastern NPR-A, 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. With this large and growing database, we can quantify caribou movements 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, topography, NDVI, and snow cover to better understand the factors determining caribou seasonal distribution and movements near ice and gravel roads. 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. Results will inform the development of strategies to minimize operational impacts on a herd that remains on the coastal plain during winter and has had little contact with development until recently. Our results suggested that selection at the survey area scale is best described by geographic variables as caribou use distinct seasonal ranges, but at a finer scale of selection, caribou are selecting for specific plant functional types during different seasons. The recently constructed GMT roads are at the eastern edge of the TCH range in an area that gets only limited use by caribou during some seasons, but preliminary results from this area suggest that winter caribou use of areas within 4 km of the gravel roads is lower after construction of the roads and that caribou may be avoiding areas within 2–4 km of ice roads.

LITERATURE CITED


———. 2015b. Units 26B and 26C—Muskox. Chapter 4, pp. 4-1 through 4-26 in P. Harper and L. A. McCarthy, editors. Muskox management report of survey and inventory


Appendix A. Full methods for calculating remote sensing metrics.

We analyzed 2000–2022 snow cover and 2000–2022 vegetation greenness using gridded, daily reflectance and snow-cover products from MODIS Terra and Aqua sensors. We processed the entire snow cover and vegetation index record, based on atmospherically corrected surface reflectance data, to ensure comparability of snow and greenness metrics.

For analysis and visualization, we reprojected the MODIS results to the Alaska Albers coordinate system (WGS-84 horizontal datum) at 240-m resolution.

SNOW COVER

We estimated snow cover using the daily 500-m snow cover products from MODIS Terra and Aqua sensors (MOD10A1.006 data [MODIS/Terra Snow Cover Daily L3 Global 500m Grid] and MYD10A1.006 data [MODIS/Aqua Snow Cover Daily L3 Global 500m Grid]). We analyzed a time series of images covering the April–June period for each year during 2000–2022. Instead of estimating fractional snow cover as we had in past years, we applied a binary presence/absence threshold corresponding to a snow cover of approximately 50% (Normalized Difference Snow Index ≥ 0.3517 = snow). The snow fraction at specific dates was rarely an important habitat selection variable and, due to cloud cover, could not be reliably estimated during the critical dates each year. We excluded pixels with >50% water (or ice) cover from the analysis. We applied a two-step process to automatically identify the date of snowmelt. First, for each pixel in each year, we applied the data provide cloud mask, then identified:

· The first date with 50% or lower snow cover (i.e., “conservative melted”),

· The closest prior date with >50% snow cover (i.e., “conservative snow”)

Because melting snow is often mis-mapped as cloud, we then re-assessed the observations in between these two dates, this time without applying the cloud mask. We selected the earliest date within this window that had 50% or lower snow as the snowmelt date.

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
NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index.html):

\[
\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}
\]

where:

- \(\text{NIR}\) = near-infrared reflectance (wavelength 0.841–0.876 µm for MODIS), and
- \(\text{VIS}\) = visible light reflectance (wavelength 0.62–0.67 µm for MODIS).

We derived constrained view-angle (sensor zenith angle \(\leq 40^\circ\)) maximum-value composites from daily surface reflectance composites acquired over targeted portions of the growing season in 2000–2022. We used the MOD09GA.061 (Terra Surface Reflectance Daily Global 1km and 500m) and MYD09GA.061 (Aqua Surface Reflectance Daily L2G Global 1km and 500m) data products; these were an updated version of the version 6 products used in past years. We calculated NDVI during the calving period (NDVI_Calving) from a 10-day composite period (1–10 June) for each year during 2000–2021 (adequate cloud-free data were not available to calculate NDVI_Calving over the entire study area in some years). We interpolated NDVI values near peak lactation (NDVI_621) based on the linear change from two composite periods (15–21 June and 22–28 June) in each year. We calculated NDVI_Rate as the linear change in NDVI from NDVI_Calving to NDVI_621 for each year. Finally, we calculated NDVI_Peak from all imagery obtained between 21 June and 31 August each year during 2000–2022.

**HABITAT CLASSIFICATION**

We used the NPR-A earth-cover classification created by BLM and Ducks Unlimited (2002; Figure 3) to classify habitats for analyses. The NPR-A survey area contained 15 cover classes from the NPR-A earth-cover classification which we lumped into nine types to analyze caribou habitat use. We combined the barren ground/other, dunes/dry sand, low shrub, and sparsely vegetation classes, which mostly occurred along Fish and Judy creeks, into a single riverine habitat type. We combined the two flooded-tundra classes flooded tundra and we combined the clear-water, turbid-water, and *Arctophila fulva* classes into a single water type; these largely aquatic types are used very little by caribou, so we excluded the water type 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.
Appendix B. Snow depth (cm) at the Kuparuk airstrip recorded on 1 April, 15 May, and 31 May 1983–2022. Trendlines were created with ggplot2 in R using geom_smooth (method = mgcv::gam). Red points represent the current year.
Appendix C. Sum of thawing degree-days (°C above freezing) at the Kuparuk airstrip during eight periods from spring migration through the insect season 1983–2022. Trendlines were created with ggplot2 in R using geom_smooth (method = mgcv::gam). Red points represent the current year.
Appendix D. Average index values of mosquito activity (adapted from Russell et al. 1993) during June–August 1983–2022, based on daily maximum temperatures at the Kuparuk airstrip. For Average Mosquito Index: if daily maximum temperature <6 °C, then index = 0; if daily maximum temperature >18 °C, then index = 1; otherwise, index = 1 − [(18 − daily maximum temperature)/13]. Trendlines were created with ggplot2 in R using geom_smooth (method = mgcv::gam). Red points represent the current year.
Appendix E. Average index values of oestrid fly activity (adapted from Russell et al. 1993) during June–August 1983–2022, based on daily maximum temperatures at the Kuparuk airstrip. For Average Fly Index: if daily maximum temperature <13 °C, then index = 0; if daily maximum temperature >18 °C, then index = 1; otherwise, index = 1 – [(18 – daily maximum temperature)/5]. Trendlines were created with ggplot2 in R using geom_smooth (method = mgcv::gam). Red points represent the current year.
Appendix F. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the winter season.
Appendix G. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the spring migration season.
Appendix H. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the calving season.
Appendix I. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the postcalving season.
Appendix J. Response curves and percent contributions of the top 8 variables in the Maxent daily forage quality model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the postcalving season.
Appendix K. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the mosquito season.
Appendix L. Response curves and percent contributions of the top 8 variables in the Maxent daily forage quality model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the mosquito season.
Appendix M. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the oestrid fly season.
Appendix N. Response curves and percent contributions of the top 8 variables in the Maxent daily forage quality model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the oestrid fly season.
Appendix O. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the late summer season.
Appendix P. Response curves and percent contributions of the top 8 variables in the Maxent daily forage quality model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the late summer season.
Appendix Q. Response curves and percent contributions of the top 8 variables in the Maxent model to predict caribou suitability in the GMT, BTN, and BTS surveys areas during the fall migration season.