CARIBOU MONITORING STUDY FOR THE ALPINE SATELLITE DEVELOPMENT PROGRAM AND GREATER MOOSES TOOTH UNIT, 2022

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COVER
Caribou on the Colville River delta. Photograph by ABR © ConocoPhillips Alaska, Inc.
EXECUTIVE SUMMARY

- Caribou use of the Alpine Satellite Development (ASDP) and Greater Mooses Tooth (GMT) Unit areas 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, during, and after development of oilfield infrastructure in the area, including construction of the CD-5, GMT1/MT6, and GMT2/MT7 roads and drill sites. 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 snow melted 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, low probabilities 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 completed all 7 planned aerial transect surveys of the GMT survey area between May and October. The estimated density ranged from 0.04 caribou/km² on 12 October to 0.63 caribou/km² on 11 September. We only observed 1 calf in the GMT survey area during the calving survey on 9 June.

- We completed 2 of 3 planned aerial transect surveys of the Colville River Delta (CRD) survey area during the postcalving and oestrid fly seasons; the late summer survey was cancelled due to persistent inclement weather. The estimated density in the survey area ranged 0.05–0.6 caribou/km².

- 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.

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

- The GMT survey area is on the eastern edge of the TCH range and gets some use by TCH females throughout the year; use by TCH males is highest during July with less use in August–October and little winter use. Use of the GMT area by the CAH is rare and generally occurs during mid-summer.

- The CRD survey area is located between the ranges of the TCH and CAH and typically has very low densities of caribou throughout the year, however large groups of caribou from both herds are occasionally observed on the delta during the summer. Large numbers of CAH caribou were present in the CRD survey area in late July 2022.

- The existing ASDP and GMT infrastructure west of the Colville River is in an area that typically has low densities of caribou and is rarely crossed by collared caribou.

- 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, wetness, topography, and habitat type.

- 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 were no significant avoidance during winter and there was not enough data to analyze the impact of roads during other seasons. Sample sizes of caribou near roads were limited, so results should be viewed as preliminary.

• We also recorded incidental observations of other large terrestrial mammals. In and near the GMT survey area, we observed 4 groups of muskoxen that ranged in size from 2–10 adults. Groups were observed on 9 June, 29 July, and 6 and 14 August. A single grizzly bear was observed on 6 August and a sow with 2 cubs was observed on 11 September. In or near the CRD, 4 groups of muskoxen ranged in size from 2 adults and 2 calves to 29 adults and 8 calves. Groups were observed on 9 June, 29 July, and 8 August. A sow grizzly bear with 3 cubs was observed on 16 June.

• 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.
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INTRODUCTION

BACKGROUND

The caribou monitoring study for the Alpine Satellite Development Program (ASDP) and Greater Mooses Tooth (GMT) Unit is being conducted on the Arctic Coastal Plain of northern Alaska (hereafter, the coastal plain) in the northeastern portion of the National Petroleum Reserve-Alaska (NPR-A) and the adjacent Colville River delta (CRD; Figure 1). This area is used at various times of the year by two neighboring herds of barren-ground caribou (*Rangifer tarandus granti*)—the Teshekpuk Caribou Herd (TCH) and the Central Arctic Herd (CAH). The TCH generally ranges to the west and the CAH to the east of the CRD (Person et al. 2007, Arthur and Del Vecchio 2009, Wilson et al. 2012, Prichard et al. 2020b, Parrett 2021).

Most TCH caribou remain on the coastal plain year-round during most years. The highest density 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, Person et al. 2007, Yokel et al. 2009, Wilson et al. 2012). Since 2010, the observed calving distribution of the TCH has expanded, with some calving occurring as far west as the Ikipikpuk River and 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 overwinter in the 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. 2019). During the winter of 2021–2022, many CAH caribou wintered unusually far south in the Hodzana Hills south of the Brooks Range.

From the early 1970s to 2002, the CAH grew at an overall rate of 7% per year (Figure 2; Lenart 2009). The herd grew rapidly from ~5,000 caribou in the mid-1970s to the early 1990s, reaching a minimum count of 23,444 caribou in July 1992 before declining 23% to a minimum count of 18,100 caribou in July 1995, like the decline observed in the TCH during that period. The herd then increased to an estimated 68,442 caribou in July 2010 (Lenart 2015). The herd subsequently declined to an estimated 22,630 caribou by July 2016 (Lenart 2017) but increased to 30,069 caribou by July 2019 (Lenart 2019) and 34,642 in 2022 (M. Nelson, ADFG, pers. comm.). The magnitude of the decline from 2013 to 2016 may have been affected by emigration of some CAH caribou to the
Introduction

Figure 1. Location of the caribou monitoring study area on the central North Slope of Alaska and detailed view showing locations of the GMT and CRD survey areas, 2001–2022.
Porcupine Caribou Herd (PCH), with which the CAH often intermixes on the winter range (ADFG 2017, Prichard et al. 2020b).


**STUDY OBJECTIVES**

Evaluation of the natural and anthropogenic factors affecting caribou in the study area fall into two broad categories: those affecting movements of individuals and those affecting distribution of herds. Clearly, these categories are linked and are not mutually exclusive, but the applicability of study methods differs between them. The potential effects of development on caribou distribution can be assessed using a variety of methods, including aerial transect surveys, radio telemetry, time-lapse cameras, and observations by local subsistence users, but the potential effects of
development 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 5 decades (White et al. 1975, 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 previous exposure to industrial development to oilfield infrastructure throughout the year.

Several broad objectives were identified for study:

1. Compare the seasonal distribution, abundance, and movements of caribou herds in the study area, using a combination of historical and current data from aerial transect surveys and radio telemetry data obtained for this study and from ADFG under a cooperative agreement. Specific questions include:
   a) Which herds use the study area?
   b) How do patterns of seasonal use differ among herds?

2. Characterize important habitat conditions, such as snow cover, spatial pattern and timing of snowmelt, 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 the potential impacts of oilfield infrastructure.

4. Record and summarize observations of other large mammals in the study area.

**STUDY AREA**

CPAI began funding caribou surveys in the northeastern NPR-A in 2001–2004 (Figure 1). 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 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 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 NSB required continued studies for various ordinances, most recently the GMT2/MT7 rezoning process. In 2016, the study area was redefined to focus on the NPR-A and CRD survey areas, so results for the final year of aerial surveys in the Colville East survey area 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 North Slope Borough adopted Ordinance Serial No. 75-06-72, consolidating previous ordinances for the ASDP 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 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). The 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 and ASDP infrastructure. 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 portion of the previous NPR-A survey area west of GMT2/MT7, which includes the proposed Willow Development Project within the Bear Tooth Unit (BTU), was expanded west and defined as the Bear Tooth North (BTN) survey area and the portion of the Bear Tooth Unit to the south of the proposed Willow project was defined as the Bear Tooth South (BTS) survey area (Figure 1). Data from these two areas are reported elsewhere (Welch et al. in prep.). To provide a wider context to analytical results and avoid duplication, we conducted some of the analyses in this report for the combined survey areas (GMT, BTN, and BTS) and those results are included in both this report and the BTU report (Welch et al. in prep.).

The ASDP study area, which includes the GMT and CRD survey areas, 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). The summer thaw period lasts about three months (June–August) and the mean summer air temperatures in Nuiqsut during 1990–2020 range 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 is <8 cm (3.1 in), most of which falls as rain in August. The soils are underlain by permafrost and the temperature of the active layer of thawed soil above permafrost ranges from 0 to 10 °C (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. In late May, water from melting snow flows both over and under the ice on the Colville River, resulting in flooding on the CRD that typically peaks during late May or the first week of June (Walker 1983). Break-up of the river ice usually occurs when floodwaters are at maximal levels. Water levels subsequently decrease throughout the summer, with the lowest levels occurring in late summer and fall, just before freeze-up (Walker 1983; annual hydrology reports to CPAI by Michael Baker International). 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 ASDP/GMT study area 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 eight seasons per year for analysis of telemetry and aerial survey data, based on mean movement rates and observed timing of caribou
Methods

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 lacks snow depth but has 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 data 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).

CARIBOU DISTRIBUTION AND MOVEMENTS

AERIAL TRANSECT SURVEYS

Transect surveys provided information on the seasonal distribution and density of caribou in the study area. We conducted surveys of the GMT and CRD survey areas (Figure 1, bottom) periodically from March to October 2022 in a fixed-wing airplane (Cessna 185, 207; ADFG permit number 22-070), following the same procedures used since 2001 (Lawhead et al. 2015 and references therein). In 2022, we scheduled 7 aerial transect surveys in the GMT survey area for mid-March (winter), May (spring migration), early June (calving), late June (postcalving), late July/early August (oestrid fly), late August (late summer), and late September/October (fall migration). We scheduled surveys in the CRD survey area for the postcalving, oestrid fly, and late summer seasons to correspond to seasons when caribou were most likely to be present based on previous aerial survey results and examination of available telemetry data. 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.

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). We spaced transect lines at intervals of 3.2 km (2 mi), following section lines on USGS topographic maps (scale 1:63,360). Observers counted caribou within an 800-m-wide strip on each side of the airplane, thus sampling ~50% of the survey area on each survey. We therefore doubled the number of caribou observed in the transect strips to estimate the total number of caribou in the survey area. We delineated the strip width 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 200-m intervals. 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 also recorded observations of all other large mammals during aerial surveys.

DENSITY MAPPING

To map seasonal densities of caribou groups observed during aerial surveys since 2002, we used the inverse distance-weighted (IDW) interpolation technique of the gstat package (Pebesma 2004) in program R (Version 4.0.2, 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, 2022, in prep.). 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. 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

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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</th>
<th></th>
<th></th>
<th>Male</th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Deployments</td>
<td>Individuals</td>
<td></td>
<td>Deployments</td>
<td>Individuals</td>
<td></td>
<td>Deployments</td>
</tr>
<tr>
<td>Teshekpuk Herd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VHF collars</td>
<td>1980–2005</td>
<td>n/a b</td>
<td>n/a b</td>
<td>1980–2005</td>
<td>n/a b</td>
<td>n/a b</td>
<td>212</td>
<td></td>
</tr>
<tr>
<td>Central Arctic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VHF collars</td>
<td>1980–2005</td>
<td>n/a b</td>
<td>n/a b</td>
<td>1980–2005</td>
<td>n/a b</td>
<td>412</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS collars</td>
<td>2003–2022</td>
<td>421</td>
<td>300</td>
<td>2017–2022</td>
<td>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.
Methods


GPS Collars

ADFG deployed GPS collars 412 times on 301 different TCH caribou (279 females, 22 males; Table 1) during 2004 and 2006–2022. ADFG deployed GPS collars 459 times on 338 different female CAH caribou (300 female, 38 male) during 2003–2022. In keeping with ADFG procedures for the region, capture teams did not use immobilizing drugs (Parrett 2015a, 2021; Lenart 2021). ADFG personnel captured caribou by firing a handheld net-gun from a Robinson R-44 piston-engine helicopter.

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.

Collars were programmed to record locations at 2-, 3-, 5-, 8-, or 12-h intervals during different deployments (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 GMT and CRD survey areas using several methods. We calculated the proportion of each monthly utilization distribution calculated 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 contour 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 rasters 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 every 2 days, 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. Because caribou are sexually segregated during some seasons, we analyzed kernels separately for females and males, although the sample size for male CAH caribou was insufficient to allow kernel density analysis. We also calculated a separate kernel for parturient TCH females during the calving season to delineate the calving range of the TCH.

We also calculated KDE by month (all years combined) for TCH males, TCH females, and CAH females. 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 study 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). 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 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 or were within 1 km of the GMT1/MT6 and/or GMT2/MT7 road alignments at least once during a season for each year. Sample sizes of CAH caribou of either sex and TCH males in the vicinity of the new roads were low, so we only summarized crossings of TCH females. We removed locations within 30 days of collaring to allow collared animals (which are collared opportunistically) to mix with the rest of the herd (Prichard et al. 2022), and we excluded caribou with locations for less than half a season or fewer than 30 locations per season from analysis for that season.

REMOTE SENSING

The remote sensing methods are summarized here; a full description of remote sensing methods can be found in Appendix A. 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 automate the process of identifying 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, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index.html):

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

where:

- NIR = near-infrared reflectance (wave length 0.841–0.876 µm for MODIS), and
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 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 used the same method for selecting caribou location data for Maxent as we did for previously used RSF models (Prichard et al. 2020c, 2020d). However, unlike in 2020, we used group locations from aerial surveys conducted during 2002–2022 in the BTN, BTS, and GMT combined survey areas only, excluding GPS collar data. Therefore, our observations represent a random sample of all caribou from the population within the study area. Seasonal sample sizes for the CRD survey area were too small to support a similar analysis for the CRD. We modelled the GMT,
Figure 3. Estimated percent top cover of deciduous shrubs, evergreen shrubs, forbs, graminoids, and lichen (Macander et al 2022); and surface wetness (Jones 2019) used for caribou habitat-selection analysis in the NPR-A survey areas.
BTN, and BTS survey areas together to increase sample sizes and expand our area of inference.

We used the NDVI layer to define areas that were mostly water covered and excluded caribou group locations in waterbodies from analyses because these locations were mainly due to positional error resulting from taking waypoints from an aircraft. Similar to the RSF model, Maxent uses actual and random background locations to model selection. For each caribou group location, we generated 25 random locations in non-water covered locations within the same combined survey areas as the actual location (note that survey areas varied by year [Figure 1] and there were some partial surveys). We were therefore testing for selection at the level of specific areas or attributes for caribou that were within the area surveyed. For this analysis we use the terms “selection” and “avoidance” to refer to attributes that are used more than expected or less than expected by caribou, when compared with random points.

We ran 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 and Ducks Unlimited 2002, Welch et al. 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 retained the lichen and graminoid plant functional groups but used the proportion of habitat types, as well.

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 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

### Table 2. USGS Dynamic Surface Water Extent (DSWE) class codes and descriptions used to calculate surface wetness in the northeastern NPR-A, Alaska.

<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>
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_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., NDVI_calving, dailyNDVI, digestible nitrogen) and snow, habitat (e.g., graminoid top cover, wetness, proportion of 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 is 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
Method

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. Lower 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 (AUCtrain) when Maxent randomly changes the values of each variable in turn and re-runs the model. A large drop in AUCtrain 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

We used an integrated Step-Selection Analysis (iSSA) to test for differences in space-use and movement characteristics in northeastern NPR-A. 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 for 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 analysis, 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 postconstruction. Because caribou densities are typically low near the GMT1/MT6 road, we used the beginning of construction of the GMT2/MT7 road (winter 2018–2019) to define the end of the preconstruction period. The construction/postconstruction period (hereafter: postconstruction) 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 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. We scaled these space-use variables to z-scores (the value minus the mean and divided by the standard error) to improve the interpretability of the model coefficients. To assess potential changes in use of the area near the GMT roads explicitly, we included a covariate for (6) the interaction between the distance to the GMT roads and the pre- and postconstruction variable. The distance to the GMT road was a categorical variable with 0–2 km, 2–4 km, and 4–8 km as the distance classes. Because the area near the GMT road...
roads gets little use during some seasons, we only added the distance to road variable in the models for fall, winter, and the oestrid fly season. The sample size was too small 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. We used bootstrap randomizations to estimate the variance for model parameters. 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.

OTHER MAMMALS

We compiled observations of other large mammals from ABR field surveys (both aerial and ground-based) 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. in prep.).

RESULTS

WEATHER CONDITIONS

Spring 2022 was characterized by near normal temperatures and snow depths at the end of April and early May. Most 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 (Figures 4–5). 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 (Figures 4–5). 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. 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. 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

GMT Survey Area

Seven aerial surveys of the GMT survey area were planned between March and October 2022 (Figure 7, Table 3). We used data from only one observer during the oestrid fly survey on 6 August and therefore, survey coverage was 25%. All other surveys were flown as planned. The estimated densities during the surveys ranged from 0.63
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 index, and oestrid fly index at the Nuiqsut Airport during 15 June—7 September 2022.
Figure 6. Wind direction and speed in Nuiqsut, Alaska during summer 2022.
Figure 7. Distribution and size of caribou groups during different seasons in the GMT and CRD survey areas, March–October 2022.
caribou/km² to 0.04 caribou/km² on 12 October (Table 3, Figure 8). A total of 142
caribou (0.37 caribou/km²) were observed during the late winter survey on 9 March. A similar
number of caribou (114 caribou; 0.29 caribou/km²) were observed during the spring migration survey
on 3 May. A month later, only 22 caribou including 1 calf (0.06 caribou/km²) were observed during the
calving survey on 9 June. Caribou density remained low during the postcalving survey on 18
June (49 adults and 3 calves; 0.13 caribou/km²) and for the oestrid fly survey (0.08 caribou/km²)
on 6 August. We observed 245 caribou (0.63 caribou/km²) during the late summer survey on 11
September. However, we observed the lowest count of caribou (14 caribou) for the season one
month later during the fall migration survey on 12 October (0.04 caribou/km²). In 2022, caribou
densities followed general trends from winter through the oestrid fly season, but the 2022 late
summer density was the highest density observed during late summer surveys of the GMT survey
area while the fall migration survey density was among the lowest densities observed during that
season (Figure 8).

Results from the seasonal IDW density mapping of caribou recorded during aerial surveys
of the BTS/BTN/GMT survey area during all years combined (2002–2022) also showed large
differences among seasons (Figure 9). The highest mean density in the GMT survey area was
observed during the oestrid fly season, but that density was strongly affected by several large
groups that were observed in only one year (2005; 19.68 caribou/km²).

Colville River Delta Survey Area

Three surveys of the CRD survey area were scheduled for the postcalving, oestrid fly, and late
summer seasons, but the area was not surveyed in other seasons due to low historical use during those
seasons (Figure 7, Table 3). In 2022, the late summer CRD survey was cancelled due to inclement weather. The remainder of the surveys
were conducted as scheduled, although, like the GMT survey, only 25% of the area was surveyed.
on 8 August. Similar to most surveys conducted in previous years, the estimated density of caribou was low (0.05–0.06 caribou/km²) during both seasons. We observed 2 calves in the area during the postcalving survey.

**RADIO TELEMETRY**

Radio collars provide detailed location and movement data throughout the year for a small number of individual caribou. The telemetry data also provide valuable insight into herd affiliation and distribution, which is not available from transect surveys. Mapping of the telemetry data from 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 (see below).

**KERNEL DENSITY ANALYSIS**

Seasonal herd distributions were estimated using fixed-kernel density estimation, based on caribou 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 listed earlier (Table 1) because some individuals switched herds after collaring. Kernels were used to produce 50%, 75%, and 95% utilization distribution contours (isopleths), which were assumed to correspond to density classes (high, medium, and low density) for female CAH caribou and for male and female TCH caribou (Figures 10–12); the sample size of CAH males was too small to conduct this analysis for males separately. Although these analyses use data collected over 20–30 years, the results are weighted towards recent years when more collars were deployed.

Female CAH caribou generally wintered between the Dalton Highway/TAPS corridor and Arctic Village (Figure 10), although since winter 2018–2019 more wintering has occurred on the north side of the Brooks Range (Pedersen et al.)

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**Figure 8.** Seasonal density of caribou observed on 136 surveys within the GMT survey area, April–October 2001–2022. Error bars represent 95% confidence intervals. One oestrifly survey conducted in 2005 with density 19.68 caribou/km² is not shown.
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.
Results

ASDP & GMT Caribou, 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.
They then migrated north in the spring to calve in 2 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 oestrus 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 (Figures 11–12). They 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).

Examination of the proportion of kernel densities by month showed that use of the CRD survey area by collared caribou was low for both CAH and TCH caribou during the entire year (<3% of the utilization distribution) with the highest use by CAH females during the insect season (2.6% of the utilization distribution; Figure 14). Use of the

![Figure 13. Distribution of parturient females of the Teshekpuk Herd during calving based on fixed-kernel density estimation of telemetry locations, 1990–2022.](image)

Data source: Utilization distribution contours from fixed-kernel analysis of locations of radio-collared female caribou (telemetry database from ADF&G, North Slope Borough, US. BLM, and ConocoPhillips). Contours enclose stated percentages of all collar locations: High-, medium-, and low-density areas are the 50%, 75%, and 95% utilization distribution contours, respectively. Bandwidth calculated using the plugin method.
Figure 14. Proportion of CAH and TCH caribou within the GMT survey area (top panel) and CRD survey area (bottom panel), based on fixed-kernel density estimation, 1990–2022.
CRD tends to be episodic with large groups occasionally using the delta, primarily during mid-summer when weather conditions can result in movements of insect harassed caribou into the area.

Use of the GMT survey area by CAH females was consistently low all year (<1%) but peaked from July–September when the herd is typically widely dispersed across the central coastal plain (Figure 14). Collared TCH females used the GMT survey area at consistently low levels (<2% of total utilization) throughout the year, with the highest predicted level of use occurring in October (Figure 14). Male TCH caribou had the highest use of the GMT survey area, with use increasing sharply from near zero in May to a peak in July (3.3% of the utilization distribution) before dropping to ~1% from August through October, and then near 0% during winter as many males migrated south into the foothills and mountains of the Brooks Range or west toward Atqasuk (Figure 14).

**MAPPING MOVEMENTS**

Maps of female TCH caribou movements in the study area derived from the dBMMs corroborated the results from the KDE analysis. The models showed that TCH females used the GMT survey area during all seasons, although their use of the area and movement rates varied widely among seasons and years (Figures 15–16). During winter, caribou were distributed widely but showed low rates of movement. During the spring migration and calving seasons, many TCH females moved across the study area from southeast to northwest as they migrated toward the core calving area near Teshekpuk Lake (Figure 15). 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 ocean (Yokel et al. 2009). During the oestrid fly season, TCH females moved rapidly and often tended to disperse inland away from Teshekpuk Lake with occasional large movements through the GMT survey area and some movements onto the CRD. During late summer, caribou were usually found dispersed inland to the west of the GMT survey area. TCH caribou dispersed widely during fall migration, including movements throughout much of the GMT survey area. The CRD received little use by the TCH during all seasons (Figure 15).

**MOVEMENTS NEAR ASDP/GMT INFRASTRUCTURE**

Since monitoring began in the late 1980s–early 1990s with satellite collars and then with GPS collars (first deployed in 2003), movements by collared TCH and CAH caribou within 4 km of ASDP/GMT infrastructure (Dau and Cameron 1986, Cameron et al. 1992, Lawhead et al. 2004, Johnson et al. 2020, Prichard et al. 2020a) have occurred infrequently and sporadically (Figure 15–17). Movements of CAH and TCH caribou near CD-1 through CD-4 infrastructure occurred primarily from calving (early June) through late summer (Figures 15, 17). From December 2021 through November 2022, numerous GPS-collared caribou came within 4 km of CD-1 through CD-4 infrastructure. During the postcalving season, the GPS tracks of one 2-year-old female TCH caribou crossed the CD-3 pipeline moving from east-to-west on its way towards traditional TCH insect relief habitat between Teshekpuk Lake and the coast. During the oestrid fly season, large numbers of the CAH moved onto the CRD with dozens of collared caribou moving within 4 km of CRD infrastructure from 20–31 July. During this period, 4 caribou crossed roads and pads several times and an additional 10 caribou crossed the CD-3 pipeline several times. Most collar tracks approached and then paralleled infrastructure without crossing, however.

Prior to construction in winter 2013–2014, movements across the CD-5 pad and access road alignments occurred rarely (Figures 15–17). Only 8 TCH caribou outfitted with GPS collars and 11 TCH caribou outfitted with satellite collars crossed the CD-5 road alignment in all years prior to construction. CAH caribou have crossed the CD-5 road even less frequently than TCH caribou; only one GPS-collared CAH caribou crossed the CD-5 alignment, this crossing occurred in July 2010 and no satellite-collared CAH caribou crossed the CD-5 alignment before construction. In 2022, no GPS collared caribou crossed the CD-5 road, although several CAH caribou were near the CD-5/CD-4 intersection during the oestrid fly season.
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Figure 15. Proportion of GPS-collared female caribou of the Teshekpuk Herd in the vicinity of the GMT and CRD survey areas during each of 8 seasons based on 95% isopleth 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 GMT and CRD survey areas by year based on 95% isopleth of dynamic Brownian Bridge movement models, 2007–2022.
Figure 17. Movements of GPS-collared caribou from the TCH (2004–2022) and CAH (2003–2006 and 2008–2022) in the ASDP study area during 8 different seasons.
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Greater proportions of collared TCH females crossed the GMT1/MT6 and GMT2/MT7 road alignments than crossed the CD-5 road alignment (Figures 15–17; Table 4), although such movements did not occur frequently (Lawhead et al. 2015; Prichard et al. 2017, 2018c, 2019c, 2020d, 2021b). Some crossings occurred during the spring migration and calving seasons as caribou moved north towards Teshekpu Lake for calving and later, mosquito-relief (Figures 15, 17). Very few crossings occurred during the postcalving and mosquito seasons because most TCH caribou were to the northwest near the Beaufort Sea coast. Crossings were more common during the oestrid fly, late summer, fall migration, and winter seasons as caribou dispersed inland from the coast. Crossings were most common during the fall migration season and then decreased to lower rates during the winter season (Table 4). No clear patterns of crossing rates are evident when comparing pre-GMT2/MT7 road and pipeline construction to the period after construction began in the winter of 2018–2019 due to high interannual variability in use of the area (Figure 16, Table 4).

During December 2021 through November 2022, several individual collared caribou came close to the GMT1/MT6 and GMT2/MT7 roads, but none crossed the roads (Figure 16–17), based on GPS locations. In February, a collared caribou approached the GMT2/MT7 road from the north and remained ~4.0 km away for a day before moving off to the west. During the spring migration season, 1 caribou approached within ~1.0 km of the GMT2/MT7 road from the south while migrating but based on its GPS track, it moved west of the drill pad without crossing the road (Figure 17). During the calving season, a female caribou approached the road from the

Table 4. Percent of GPS-collared female Teshekpuk Herd caribou crossing or within 1 km of the GMT1/MT6 and GMT2/MT7 access road alignments pre- or during construction of the GMT2/MT7 road and pipelines, by season. The construction period includes winter 2018–2019 when the road was installed through present drilling operations.

<table>
<thead>
<tr>
<th>Season</th>
<th>Construction Period</th>
<th>Collars</th>
<th>Crossed 1 km of GMT1/MT6</th>
<th>Crossed 1 km of GMT2/MT7</th>
<th>Crossed Either 1 km of GMT1/MT6</th>
<th>Crossed Either 1 km of GMT2/MT7</th>
<th>Crossed Either 1 km of Either</th>
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<tr>
<td>Spring Migration</td>
<td>Pre-GMT2/MT7 Construction</td>
<td>293</td>
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</table>

* Prior to analysis, we removed locations within 30 days of collaring and then we removed caribou with fewer than 50 locations or active less than half the season.
south, got to within 5 km of the road, and then moved west of GMT2/MT7 from ~3.0 km away. During the postcalving season, a caribou moved west of the GMT2/MT7 pad while moving from southeast to northwest. During the oestrid fly season, a caribou approached the GMT2/MT7 pad from the southwest but moved off to the west. During the fall migration season, a caribou spent 17–18 September to the south of the road, usually > 3.0 km away. Additionally, 3 CAH caribou crossed the Nuiqsut spur road on 27 or 30 July, a time when numerous CAH collars had moved onto the Colville River Delta.

REMOTE SENSING

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

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 GMT survey areas had patchy snow by 31 May 2022, and were mostly snow-free by 4 June, except for lakes, rivers, and areas near the coast. Remaining land in the survey areas was snow-free by 16 June. Snowmelt timing was similar to or slightly later than the median date of snowmelt calculated for the past 20 years (Figures 18–19).

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 19–20). 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 19–20). Those values are consistent with the above average temperatures in late June and early July 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 20). 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.
Figure 18. 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 19. Departure of 2022 values from median snowmelt date and vegetation index metrics (2000–2022), as estimated from MODIS satellite imagery time series.
Figure 20. 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.
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 AICc 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

<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>
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<tr>
<td>Spring Migration</td>
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<td>LQP</td>
<td>6</td>
<td>0.628</td>
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<tr>
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<tr>
<td>Postcalving</td>
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<td>LQP</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><strong>LQP</strong></td>
<td><strong>0.5</strong></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><strong>88</strong></td>
<td><strong>LQ</strong></td>
<td><strong>5</strong></td>
<td><strong>0.749</strong></td>
<td><strong>0.625</strong></td>
</tr>
<tr>
<td>Oestrid Fly</td>
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<td>LQP</td>
<td>0.5</td>
<td>0.736</td>
<td>0.658</td>
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<tr>
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<td><strong>LQP</strong></td>
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<td><strong>0.726</strong></td>
<td><strong>0.733</strong></td>
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<tr>
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<td>0.615</td>
<td>0.558</td>
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<tr>
<td><strong>Daily Forage Quality</strong></td>
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<td><strong>LQP</strong></td>
<td><strong>0.5</strong></td>
<td><strong>0.633</strong></td>
<td><strong>0.577</strong></td>
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<tr>
<td>Fall Migration</td>
<td>2,615</td>
<td>LQP</td>
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<td>0.614</td>
<td>0.599</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12,843</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

* L=linear, Q=quadratic, P=product
suitability evident in all seasons (Figure 21). 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 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 similar to the base models, the importance values of variables were often different. The variables with the highest relative PI included west-to-east distribution, graminoids, gentleslope, 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.

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 suitability maps for all survey areas, suitability during the mosquito season was generally higher closer to the coast, particularly along drainages (Figure 21). In the GMT survey area, suitability was higher to the north and along drainages. The variables with the largest PI for the base mosquito season model included tussock tundra (14.4), gentles 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 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 and increased to the west (Figure 21). In the GMT survey area, suitability increased in the northwest and was highest along Fish and Judy Creek and in northeast along the Colville Delta. 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),
Figure 21. 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.
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. Suitability in the GMT survey area was highest along creeks and increased to the west (Figure 21). 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 were lower (<0.64), but better than a random model (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 lower in the GMT survey area with the highest suitability predominantly in western BTN and most of BTS where lichen abundance is higher (Figure 21). Spring suitability was highest west of the GMT survey area, particularly in western BTN and BTS in locations with higher lichen abundance (Figure 21). Calving season suitability was generally lowest in the eastern portion of GMT, lower along creeks and streams, and highest near the border of the BTN and BTS survey areas and in western BTN (Figure 21). Late summer suitability was predicted to be lowest in the eastern GMT survey area and highest along streams and when lichen abundance was higher or when daily NDVI was lower (Figure 21). Finally, during fall migration, the lowest suitability was predicted to be in northeast GMT survey area and suitability was higher to the west in the BTN and BTS survey areas and along streams (Figure 21). The variables with the largest PI varied greatly by season (Appendices F–Q).

INTEGRATED STEP SELECTION ANALYSIS

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 22). Areas with higher proportions of graminoids were avoided during oestrid fly season through spring and selected during mosquito season (Figure 22). 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 22).

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 (β = -0.85; 95%
Figure 22. Integrated step-selection analysis results modeling selection for different variables (top) and distance to road categories (bottom) by season using locations recorded every 12 hours from GPS-collared female caribou of the Teshekpuk Herd 2006–2022. We scaled variables (subtracted the mean and divided by the standard deviation) prior to analysis. Values with confidence intervals that did not overlap 0 indicated significant selection (if positive) or avoidance (if negative).
Results

C.I. = -1.77 – 0.12) and 2–4 km of roads (β = -0.86; 95% C.I. = -1.53 – 0.12; Figure 22). During the oestrid fly season, there was significant avoidance of the area within 2 km of the roads after construction started (β = -4.11; 95% C.I. = -14.42 – -0.22), no significant change in use of the area within 2–4 km of the roads (β = -0.04; 95% C.I. = -1.05 – 1.15), a significant increase in selection for the area within 4–6 km of the roads (β = 1.22; 95% C.I. = -1.05 – 1.15), a significant increase in selection for the areawhich were also within 4 km of the roads (β = 1.00; 95% C.I. = 0.58 – 1.50; Figure 22). During the fall migration season, after construction there was significant avoidance of the area within 2 km of the roads (β = -1.89; 95% C.I. = -3.09 – -0.98) and 2–4 km (β = -0.66; 95% C.I. = -1.31 – -0.09), and no significant change in use of the area within 4–6 km of the roads (β = -0.28; 95% C.I. = -0.93 – 0.33) or 6–8 km of the roads (β = 0.09; 95% C.I. = -0.35 – 0.49).

OTHER MAMMALS

In addition to caribou, ABR biologists or other personnel working in and near the ASDP/GMT study area recorded observations of brown bears and muskoxen in 2022 (Figure 23). Muskoxen were recorded on multiple occasions in or near the GMT survey area (Figure 23). On 9 June, 2 adult muskoxen were observed ~1.5 km south of the southeast corner of the GMT survey area on the west side of the Colville River very close to where 7 muskoxen were observed the previous year on 10 June. On 6 August, 6 adult muskoxen were observed northwest of CD-5 along Judy Creek. On 14 August, 10 adult muskoxen were observed in nearly the same location. On 29 July, a group of 7 adult muskoxen were observed along the Tinmiaqsiuqqvik River ~1.5 km south of the GMT1/MT6 road. Four observations of muskoxen groups occurred in or adjacent to the CRD survey area. Two groups composed of 31 adults and 8 calves were observed on 9 June on the east side of the Colville River east of CD-4. On 29 July, a group of 8 adults and 5 calves was observed in the same general area. The only muskox group observed on the CRD was a group of 2 adults and 2 calves observed on an island in the northeastern CRD on 8 August.

During 2022, there were 2 grizzly bear observations in the GMT survey area and 1 grizzly bear observation in the CRD survey area. A sow with 3 cubs was observed on 16 June on the CRD. A single grizzly was observed on 6 August in the northwest corner of the GMT survey area (Figure 23) and on 11 September, a sow with 2 cubs was observed along Judy Creek. No other observations of large mammals were observed in or near the survey areas in 2022 by ABR biologists, however.
Figure 23. Observations of large mammals other than caribou observed in the CRD or GMT areas during 2022 (top panel) and 1991–2022 (bottom panel).
muskoxen and grizzly bears are often observed by oilfield workers (C. Pohl, pers. comm).

DISCUSSION

The emphasis of this study is to monitor caribou distribution and movements in relation to the existing facilities in the ASDP/GMT study area and compare them to the predevelopment baseline data available on caribou density and movements in the northeastern NPR-A. 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.

For this report, we incorporated several data collection methods and analyses to better understand the seasonal distributions, movements, and herd associations 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 caribou using this area. These 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 movements of individual animals in relation to infrastructure and habitat characteristics, as well as examine differences among the 2 herds that use the area. By analyzing both of these datasets in relation to remote sensing information on land cover, vegetative biomass, and 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 or a changing climate.

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).

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.

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 good insect conditions for much of the 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 suggesting that aside from short periods in late
June, early July, and early August, insect and weather conditions were likely favorable for caribou nutritional status during summer and fall 2022.

**CARIBOU DISTRIBUTION AND MOVEMENTS**

Distribution of TCH and CAH caribou varies greatly by season for both survey areas. Caribou density typically is lower in the GMT and CRD survey areas compared to the BTN or BTS survey areas to the west (Welch et al. 2021a, 2021b). The TCH consistently uses the GMT survey area to some extent during all seasons of the year. CAH caribou rarely use the GMT survey area, although several notable incursions have been recorded sporadically over the years. Use of the CRD survey area by both the TCH and CAH is variable with episodic, high use events, most frequently occurring during the mosquito and oestrid fly seasons, and low use during the remainder of the year. Use of the area is primarily by CAH caribou during the mosquito season and by caribou from both herds during the oestrid fly season. High use of the CRD by the CAH has occurred in both of the last 2 summers.

Female TCH caribou numbers in the GMT survey areas are generally lowest during the calving and postcalving seasons, increase to their highest levels during the fall migration season, and then slowly decline through winter and spring migration. Male numbers, in contrast, are highest during calving through oestrid fly seasons, moderate during late summer and fall migration, and lowest during winter and spring migration. However, there is substantial variability in the seasonal movements and abundance of caribou within the GMT survey area. The aerial survey results from 2022 were generally within the normal seasonal ranges of caribou density observed in the GMT survey area since 2001 (Figure 8). Caribou densities tend to be highest during the fall and winter seasons, moderate during the spring migration, calving, postcalving, and late summer seasons, and lowest during the mosquito and oestrid fly seasons, although the densities during some seasons can be highly variable with large groups of caribou occasionally present as occurred in 2005 when an estimated density of 19.68 caribou/km² was observed in the study area (not shown on Figure 8).

Telemetry data indicate that most TCH caribou winter to the west of the survey areas and most CAH caribou winter in the Brooks Range or northern foothills to the southeast of the survey areas. However, approximately one-third of the TCH, including a disproportionate number of male caribou, winter in the central Brooks Range in most years (Person et al. 2007, Prichard et al. 2019a, Fullman et al. 2021). Some of the TCH caribou wintering in the Brooks Range move through the GMT survey area during their spring migration back to the summer range (Welch et al. 2021a, 2021b). Decades of aerial transect surveys have demonstrated that only low levels of calving typically occur in the GMT and CRD survey areas. This result is consistent with analysis of telemetry data, which confirms that most TCH females calve near Teshekpuk Lake or in areas to the west (Kelleyhouse 2001, Carroll et al. 2005, Person et al. 2007, Wilson et al. 2012, Parrett 2015a, Prichard et al. 2019a). The highest density calving for the western calving segment of the CAH occurs south of the Kuparuk Oilfields (Murphy and Lawhead 2000, Cameron et al. 2005, Prichard et al. 2020a). Male TCH caribou that wintered in the Brooks Range typically arrive on the coastal plain during the late calving or postcalving seasons. CAH caribou calving in the Greater Kuparuk Area move north during the postcalving season, in anticipation of insect emergence (Murphy and Lawhead 2000).

When mosquito harassment begins in late June or early July, TCH and CAH caribou move toward the coast where lower temperatures and higher wind speeds prevail (Murphy and Lawhead 2000, Parrett 2007, Yokel et al. 2009, Wilson et al. 2012). Aerial transect surveys during mosquito season are inefficient for locating caribou aggregations because of the rapid speed of caribou movements during that period (Prichard et al. 2014) and the highly aggregated and unpredictable nature of caribou distributions. But telemetry data indicate that most TCH animals move to the area between Teshekpuk Lake and the Beaufort Sea, while the CAH typically moves to the coast east of the CRD. In some years during June and July, CAH caribou move far to the east, past the Canning
Discussion

River. Use of the CRD by large numbers of caribou is relatively uncommon and unpredictable. Large numbers have been recorded periodically in past summers, including the last 2 years (e.g., 1992, 1996, 2001, 2005, 2007, 2010, 2019, 2021–2022) as aggregations moved onto or across the delta during or immediately after periods of insect harassment (Johnson et al. 1998, Lawhead and Prichard 2002, Lawhead et al. 2008).

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, gravel roads, and river bars, with some using shaded locations in the oilfields under elevated pipelines and buildings (Lawhead 1988, Noel et al. 1998 Murphy and Lawhead 2000, Person et al. 2007, 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.

Telemetry data indicate that most TCH caribou wintered to the south and west of the survey areas during the winter of 2021–2022. A large number of TCH caribou spent a portion of the winter near Utqiagvik and Wainwright, many were dispersed west of Willow and south of Teshekpk Lake, and many were in the Brooks Range to the south. Caribou migrating north from the Brooks Range during spring migration generally remained west of the GMT survey area. Westerly distributions during the winter and spring migration seasons resulted in low densities of caribou during the calving and postcalving surveys in the GMT survey area. Many of the TCH caribou calved to the south, southwest, and west of Teshekpk Lake. Similar to the previous 4 years, most CAH caribou calved to the west of the Sagavanirktok River and used coastal areas near Kuparuk for mosquito relief. During the postcalving season in 2022, TCH caribou remained in the area near Teshekpk Lake. During the mosquito season, the TCH animals moved closer to the coast, primarily north and west of Harrison Bay. As the insect season progressed into the oestrid fly season, the CAH moved into western Kuparuk and many made a large movement onto the CRD before moving inland and away from the study area to the southeast for the rest of the year. Many TCH animals spent the oestrid fly season west of Teshekpk Lake and north of Atqasuk, while others were between Teshekpk Lake and Harrison Bay. No large movements along Fish and Judy Creek or near GMT infrastructure were observed during summer 2022. By late summer, caribou were widely distributed from Chukchi Sea to the Colville River, but the highest concentrations were west of the GMT survey area and south of Teshekpk Lake. No collared animals were located in the survey area during the late summer season, but we observed our highest density of caribou during this survey. Caribou spent the rut in these same general regions before migrating towards the wintering ranges.

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. 2019a, Fullman et al. 2020). The CAH has shown indications of changes in seasonal distribution, with more caribou calving west of the Sagavanirktok River, 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). During the winter of 2021–2022, many collared caribou of the CAH wintered farther south than usual in the Hodzan Hills east of Bettles, Alaska where they overlapped with the small Hodzan Hills Herd (Horne et al. 2014).

**SPECIES DISTRIBUTION MODELING**

In 2020, we began using 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 an RSF model (Phillips et al. 2006, 2017, Elith et al. 2011, Merow et al. 2013). Results
from the 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). 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 for modeling a predictive space 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 modelling 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 GMT survey area is on the eastern edge of the TCH range, a natural west-to-east gradient of decreasing density occurs throughout much of the year. Few caribou are located in the far east of the GMT survey area year-round. During calving, the highest densities of TCH females typically calve near Teshekpuk Lake outside of the GMT, BTN, and BTS survey areas (Person et al. 2007, Wilson et al. 2012, Parrett 2015a, Welch et al. 2021a). Therefore, our results likely reflect habitat suitability for non-parturient females and males, many of which are migrating north from the Brooks Range towards Teshekpuk Lake. Northward migrating caribou often cross the Colville River at Ocean Point and enter our study area near and southwest 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.
For this study, we investigated different habitat layers and a surface wetness layer. We found a weak avoidance of wetter habitats and an avoidance of graminoid cover (common in wetter habitats) in almost all seasons. 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. 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).

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 similar to previous models, but the response curves were easier to interpret. However, during each season, different combinations of variables are being used to 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 in previous reports using different analyses and variables (Lawhead et al. 2015, Prichard et al. 2020d). The riparian habitats along Fish and Judy creeks provide a complex interperssion 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 very 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 nonparturient 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 study 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 suggest 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.

DISTRIBUTION AND MOVEMENTS NEAR ROADS

The ASDP and GMT infrastructure on and adjacent to the CRD is encountered occasionally by caribou from both herds. Movements by satellite- and GPS-collared TCH and CAH caribou within 4 km of ASDP infrastructure have occurred infrequently during the calving, mosquito, and oestrid fly seasons and during fall migration since monitoring began in the 1980s, well before the first oilfield infrastructure was built on the Colville River delta in 1998. In the time since its construction in 2013–2014, only one collared caribou has crossed the CD-5 road (based on straight-line movements between locations), but we recorded very few crossings of the road alignment in the years prior to construction either. In recent years, radio-collared TCH caribou and, to a lesser extent, CAH caribou have occasionally crossed the GMT1/MT6 or GMT2/MT7 road corridor alignments, with the highest crossing rates during fall migration and lowest during the postcalving and mosquito seasons when caribou are concentrated near Teshekpuk Lake and along the coast for insect relief.

We continue to compile data on caribou movements in the GMT area following construction of the GMT1/MT6 and GMT2/MT7 roads and pads. 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. If additional roads are built to the west 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 postconstruction 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 2021). 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 2021). 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). Postconstruction 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.

**OTHER MAMMALS**

The few incidental observations of other mammals in the GMT and CRD survey areas in 2022 comprised only muskoxen and bears, likely a result of fewer observers working in the area. Historically, there have been regular sightings of grizzly bears, and occasional observations of moose, wolves, wolverines, and polar bears along the coast. In recent years, two mixed-sex groups of muskoxen have been in the area, one along the Colville River and delta and the other between the Kuparuk River delta and Milne Point (Prichard et al. 2018a, 2019c; Prichard and Welch 2020, 2021). In 2019, most of the muskoxen along the Kuparuk River moved to the Sagavanirktok River, and ADFG observed only 4 muskoxen along the Kuparuk River in 2020 (Lenart 2020). In 2021, we observed only 7 muskoxen in this area, all adults (Prichard and Welch 2022). In contrast, the muskox group along the Colville River was larger in 2021 and 2022 than has been observed in recent years.

The muskox population across 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 2020). 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) 2006 found 216 muskoxen. The population on the central North Slope then remained relatively stable at 190–200 muskoxen for approximately a decade (Arthur and Del Vecchio 2017, Lenart 2020). Calf production and survival have been high in recent years which appeared to result in an increase in the population. The minimum population was 297 muskoxen in April 2019 (Lenart 2020). 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). Muskoxen have been observed in northeastern NPRA in the past, but the pair observed in southeast GMT in 2020 were the first muskoxen observed by ABR west of the Colville River in recent years (Welch et al 2021b). We estimated that there were 10–20 and 10–17 muskoxen using the area west of the Colville River in 2021 and 2020, respectively (Welch et al. 2022b), and in 2022, 10–17 muskox indicating a persistent presence west of the Colville River. The large group observed east of the Colville Delta may reflect high calf productivity in recent years and/or movements from other nearby groups.

In 2022, there were no reports of lynx sightings in the project area and a local trapper in Nuiqsut reported that there were few snowshoe hare tracks and no lynx sign in the area (A. Nukapigak, pers. comm). In 2021, there were large numbers of lynx observations in the area likely as a result of climate change-related increase in shrubs and an associated range expansion of snowshoe hares (Lepus americanus; Tape et al. 2015), the principal prey of lynx. Snowshoe hares require a mean riparian shrub height of at least 1.24–1.36 m to provide adequate browse, but following increased shrub growth on the coastal plain, they became abundant on the Colville River as far north as the delta by 1993 (Tape et al. 2015). Lynx were first observed during ADFG moose surveys along the Colville River in 1998 and the first lynx harvest from the area were reported in 2002 (Tape et al. 2015). Lynx also have highly cyclical population swings and high dispersal rates during periods of decline. The high numbers of lynx observations near the coast in 2021 may have been a result of both increasing numbers on the coastal plain and dispersal following a cyclical population peak and decline. The lack of lynx observations in 2022 suggests that the lower Colville River area likely experienced a steep decline in both lynx and snowshoe hare populations in 2022 that is typical of these cyclical populations.

**CONCLUSION**

The emphasis of this study is to describe caribou distribution and movements in the GMT and CRD survey areas in order to understand baseline distribution and movements and identify changes related to infrastructure in the area. 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, 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 likely expanded to the west in recent years and the fall and winter distribution has varied widely among years (Parrett 2013, Welch et al. 2021a, Fullman et al. 2021). The CAH has shown some changes in seasonal distribution, with more caribou remaining farther north during fall and early winter and possibly 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 at multiple scales of selection. 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 using the area. It also allows us to put local caribou movements in the study area into the broader context of the annual herd ranges and seasonal herd distributions. Lastly, we incorporated aerial survey results and telemetry data with remote sensing information on land cover, vegetative biomass, and snow cover to better understand the factors determining caribou seasonal distribution. This understanding of the underlying factors that are important to caribou will be useful in 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 suggest that caribou use of areas within 2-4 km of the roads is lower after construction of the roads during the oestrid fly, fall migration, and winter seasons.

**LITERATURE CITED**


Literature Cited


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 2000, Kelleyhouse 2001, Griffith et al. 2002). NDVI is calculated as follows (Rouse et al. 1973; http://modis-atmos.gsfc.nasa.gov/NDVI/index.html):

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

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

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 vegetated 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\textsuperscript{a} (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 \textdegree C, then index = 0; if daily maximum temperature >18 \textdegree 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 mosquito 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 late summer 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 late summer 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 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.