Aerial survey and telemetry data analysis of a peripheral caribou calving area in northwestern Alaska

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Abstract: With industrial development expanding in the Arctic, there is increasing interest in quantifying the impacts of development projects on barren ground caribou (*Rangifer tarandus granti*). The primary data source to assess caribou distribution and predict impacts in remote areas of Alaska has shifted in recent decades from aerial survey data to telemetry data, but these techniques have different strengths and weaknesses. The ranges of two caribou herds, the Western Arctic Herd and the Teshekpuk Herd, overlap in northwest Alaska between Wainwright and Atqasuk, Alaska. Based on long-term telemetry data sets, this region was thought to be outside of the core calving ranges of both herds. Calving has long been reported to occur in this general area, but early reports assumed caribou were from the Western Arctic Herd and only one systematic aerial survey of caribou density and distribution during calving has been conducted in this area in recent decades. Following interest in industrial development in this area, we conducted aerial strip-transect surveys during early to mid-June 2013–2015 to directly assess the density and distribution of caribou in the area and we used existing telemetry data to compare our results to the seasonal distribution of both herds. Total caribou densities varied between 0.36 and 1.06 caribou/km² among years, and calf densities varied 0.04 and 0.25 calves/km² among years. Contrary to assumptions by early researchers in the area, telemetry data indicated that caribou in this area during early to mid-June were from the Teshekpuk Herd. The use of telemetry data alone underestimated the importance of this area for calving, but the combination of aerial surveys and telemetry data provided complementary information on caribou use of this area showing the importance of collecting the appropriate types of data for assessing potential impacts of development on caribou.

Key words: Alaska; calving distribution; caribou; *Rangifer tarandus*; Teshekpuk Herd; Western Arctic Herd.

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Introduction

Caribou (*Rangifer tarandus granti*) herds exhibit high fidelity to specific calving areas and herds are defined based on their calving area (Lent, 1964; Skoog, 1968). In Arctic Alaska caribou are thought to select calving areas that have a combination of low predator densities, nutritious newly-emergent forage during calving, and access to insect-relief habitat (Kuropat, 1984; Whitten *et al.,* 1992; Russell *et al.,* 1993; Carroll *et al.,* 2005). But parturient females may be displaced up to 4 km by active roads during calving (Dau & Cameron, 1986; Cameron *et al.,* 1992; Cameron *et al.,* 2005), therefore, the potential for development impacts on calving caribou is a major management concern in northern Alaska (Murphy & Lawhead, 2000). However, calving areas can also shift through time (e.g., Valkenburg & Davis, 1986; Gunn *et al.,* 2010) and adjacent caribou herds can occasionally merge (Hinkes *et al.,* 2005), therefore, accurately defining and tracking changes in calving distribution is important for assessing potential implications of development plans (Taillon *et al.,* 2012). The primary tools currently available include aerial surveys and telemetry data, but each of these has advantages and limitations.

In northwestern Alaska, two caribou herds, the Teshekpuk Herd (TCH) and the Western Arctic Herd (WAH), range widely over a largely undeveloped landscape with both herds using the area between the communities of Wainwright and Atqasuk during some portions of the year (Fig. 1). Although at the time the study began, telemetry data indicated that this area is outside the main calving range (75% kernel isopleth contour) of either herd (Person *et al.,* 2007; Wilson *et al.,* 2012), an aerial survey flown in this study area in 2009 by the Alaska Department of Fish and Game (ADFG) and the North Slope Borough Department of

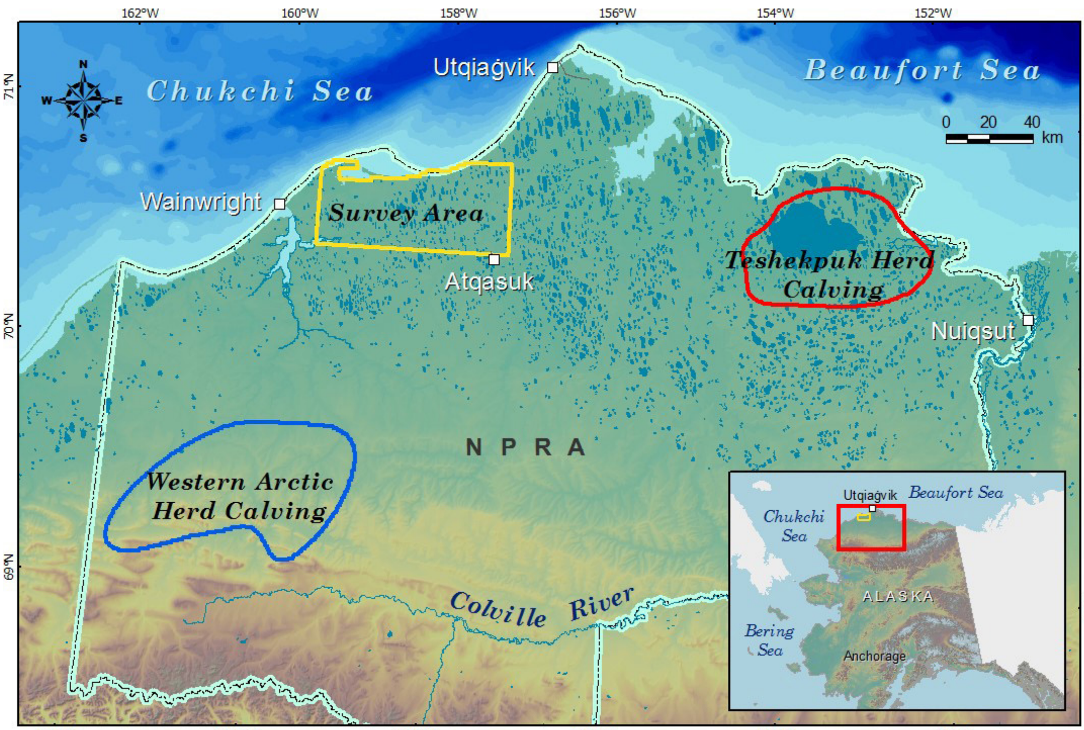

Figure 1. The caribou study area for surveys conducted during mid-June 2013–2015 in relation to high density (50% isopleth of all collared females) calving areas for the two adjacent herds.

Wildlife Management (NSB), and calf captures conducted in 2011–2013 by ADFG, revealed that some calving occurred in this region, and local residents have reported the area has been used for calving for at least two generations (Davis & Valkenburg, 1978; NSB unpublished data).

This area has also been a source of increasing interest in oil development in recent years including recent exploration of oil and gas reserves in the Chukchi Sea northwest of Wainwright. Scenarios for developing this resource included the construction of an above-ground pipeline and possible road through the area. Currently, the Integrated Activity Plan for the National-Petroleum Reserve–Alaska (NPRA), which includes much of the western Arctic Coastal Plain in Alaska, is being rewritten and the stipulations for protection for caribou calving areas in future lease sales determined.

In 2013, 2014, and 2015, the NSB conducted aerial surveys of caribou during calving (early to mid-June) in a 3186 km² study area along the Chukchi Sea coast between Wainwright and Atqasuk, Alaska (Fig. 1). Because of concerns regarding potential displacement of calving caribou (Dau & Cameron, 1986; Cameron *et al.,* 1992; Cameron *et al.,* 2005), a more thorough understanding of calving distribution in this region was desired prior to development to inform decisions about lease stipulations.

Prior to the advent of telemetry collars that made tracking individual caribou possible, aerial surveys, traditional ecological knowledge, and local observations were the primary tools available to assess caribou herd distribution, but the large areas involved and the uncertainty in herd identity often complicated these studies. In the Alaska Arctic, the range of four caribou herds often overlap and the two smaller herds were not identified as separate herds until the 1970's. Thus, the use of remote areas in northwestern Alaska by caribou was not always clearly understood. Early research in the Wainwright area found that "During the mid-1970's some caribou have been present near Wainwright in all or most months of the year. This fact, combined with reports of caribou being seen with newborn calves in late June and early July by Wainwright residents, caused speculation that a small resident herd discrete from the WAH occupied the area from Wainwright to Point Lay" (Davis & Valkenburg, 1978).

In more recent decades, most data on caribou distribution in this area came from telemetry data deployed on a limited number of animals (Dau, 2015; Parrett, 2015). With recent advances in radio-telemetry collars, telemetry data have become increasingly available and precise and these data are more frequently used to predict caribou distribution across the seasonal ranges of a herd. Often, techniques such as kernel density estimation (KDE) are used to create a utilization distribution (UD) of caribou densities by applying a smoothing algorithm to fit a model to locations from a single caribou or from a number of collared caribou (Silverman, 1986; Worton, 1989; Seaman & Powell, 1996). Alternatively, continuous time movement models (e.g., dynamic Brownian Bridge models; Kranstauber *et al.,* 2012) can map the movement paths of individual collared caribou. Although these techniques provide valuable information on seasonal herd ranges and the movement paths of individual caribou across the entire herd range and throughout the entire year, they lack the fine resolution information on localized caribou density produced by aerial surveys conducted in a specific area of interest. In addition, it is not possible to determine if cows are associated with calves without direct observation obtained from aerial surveys.

Telemetry data can also be subject to various sources of bias and other limitations (Hebblewhite & Haydon, 2010; Prichard *et al.,* 2012, 2014; Hofman *et al.,* 2019). Logistical and budget constraints also often limit the number of collars deployed and only a small fraction of the herd is typically collared. The number collared may be too low to get accurate estimates of the UD. Seaman et al. (1999) estimated that at least 30 observations (but preferably ≥ 50) are necessary using KDE with least-squares cross validation to estimate the smoothing bandwidth and other studies have suggested much larger samples are necessary (Arthur & Schwartz, 1998; Lindberg & Walker, 2007; Roberts *et al.,* 2018). In practice, this means that achieving an adequate sample size from collared individuals may require combining multiple years of location data or may not be possible. Deriving herd-wide inference from a sample of collared caribou that have been selected from a much larger herd also assumes that collared caribou are selected randomly with each caribou in the herd having an equal chance of being selected. If seasonal movement patterns vary among different portions of the herd (e.g., subherd structure or different migratory strategies) leading to different availability during collaring, or if sex and age structure are not adequately replicated, these conditions may not always be met. But even if this condition is met, a smoothing algorithm applied to a small sample of the herd will necessarily result in some localized patterns of density being missed. With small samples of collars deployed on large herds (e.g., <50 collars for >50 000 caribou), even large groups of caribou may not include any collared animals. Hence, telemetry data and aerial surveys provide complementary information: long-term continuous movement paths of a small number of individuals from telemetry data and fine-scale spatial information on herd density in one region during a single time period from aerial surveys. When assessing potential impacts from development, using data of a spatial scale appropriate for the questions of interest should be carefully assessed and in some cases, a multi-scalar approach may be necessary, especially for a highly mobile species like caribou

With the Integrated Activity Plan for NPRA currently being updated and the increase in interest in predicting impacts from proposed development projects across the Arctic on caribou, we used data from this study to add to our knowledge about the calving distribution of the TCH and to examine the strengths and limitations of different types of data to understand caribou distribution. We analyzed both aerial survey data and the available telemetry data to determine: 1) the density of adults and calves in the study area during late calving; 2) the herd identity of caribou in the area during late calving; and 3) how much difference there was in inferences derived from the analysis of telemetry data versus observations from aerial surveys.

Study area

The study area is a ~3200 km² area of northern Alaska between the communities of Wainwright (~population = 550) and Atqasuk (~population = 248) along the Chukchi Sea coast (NSB, 2016; Fig. 1). The area is characterized by low topographic relief (<40 m elevation), abundant small lakes, and tundra vegetation. The dominant vegetation communities are wet sedge meadow and moist tussock tundra. The area has a short growing season ranging from June to September (Stone *et al.,* 2002) and a mean annual temperature of -11.2° C (Wendler *et al.,* 2014).

The TCH typically winters on the coastal plain in northern Alaska, but the herd displays multiple wintering strategies with a portion of the herd, including a disproportionate proportion of males, wintering in the Brooks Range (Kelleyhouse, 2001; Person *et al.,* 2007; Wilson *et al.,* 2012; Parrett, 2015). The highest density calving occurs near Teshekpuk Lake. Following mosquito emergence, typically in late June, the herd uses coastal areas, especially the area north of Teshekpuk Lake for mosquito (*Aedes* spp.) harassment avoidance (Parrett, 2007; Person *et al.,* 2007; Yokel *et al.,* 2011; Wilson *et al.,* 2012).

The TCH increased substantially in size from the mid-1970s to its peak size of 64 106 animals in July 2008 (Parrett, 2015) but was estimated to be at 55 614 in 2017 (Klimstra, 2018). The study area is west of the traditional high density calving area near Teshekpuk Lake (Fig. 1; Davis & Valkenburg, 1978; Kelleyhouse, 2001; Person *et al.,* 2007; Wilson, 2012; Parrett, 2015), but the area is consistently used by the TCH during winter and by non-calving females during June, and the calving distribution of the TCH may have become less concentrated in recent years (Person *et al.,* 2007; Parrett, 2015). TCH caribou are collared over a large portion of their summer range with some collars deployed as far west as Atqasuk. Collaring is typically conducted approximately three weeks post calving in late June (Parrett, 2015).

The WAH typically winters in western Alaska on or east of the Seward Peninsula and primarily calves on the Utukok Uplands in the northern foothills of the Brooks Range to the south of the study area (Fig. 1; Dau, 2015; Joly & Cameron, 2017). The WAH is currently thought to be the largest herd in Alaska; it peaked at ~490 000 animals in 2003 (Dau, 2015), but was estimated to have a size of 259 000 in 2017 (Hansen, 2018). Prior to 2019, WAH caribou were collared by boat while crossing the Kobuk River at Onion Portage during fall migration (Prichard *et al.,* 2012; Dau, 2015; Joly & Cameron, 2017).

Material and methods

Aerial surveys

Surveys of the calving distribution were conducted on 8-10 June 2013, 13-15 June 2014 and 12-14 June 2015 in an area between Wainwright and Atqasuk, Alaska (Fig. 1). Caribou were counted by two observers, looking on opposite sides of a Cessna 206 airplane using similar methods as surveys of the Teshekpuk and Central Arctic Herds conducted near existing oilfield infrastructure since 1993 (Prichard *et al.,* 2018). During each survey, the pilot navigated along 26 east/west-oriented transect lines using route coordinates loaded into a GPS receiver. Transect length varied between 18 and 71 km to account for the variable northern boundary along the Chukchi Sea Coast. The pilot maintained the aircraft at an altitude of ~90 m above ground level (agl) using a radar altimeter. Transect lines were spaced at intervals of 1.6 km and observers counted caribou within a 400-m-wide strip on each side of the flight line to maintain 50% survey coverage. Based on the observed distribution of caribou, there was no indication that flying these east-west transects would result in a systematic bias at this level of survey coverage. During the first day of the 2013 survey (8 June), the survey was flown at ~150 m agl, but it was determined that sightability was low at that altitude and the remainder of that survey and subsequent surveys were flown at 90 m agl.

For each caribou group observed, we recorded airplane location, number of adults and calves, and estimated distance of the centroid of the group north or south of the airplane. The distance from the airplane was visually estimated based on comparisons of surface landmarks to maps on handheld GPSs. Caribou group locations were then shifted from the GPS location by the recorded distance from the airplane. A small section (~38.4 km²) in the western study area could not be surveyed in 2014, due to fog (Supplemental material 1).

Population estimates for total caribou and for calves in the entire study area were extrapolated from their respective counts of the ~50% of the area that was surveyed each year. Because the transect lengths were variable, we calculated 95% confidence intervals using bootstrap resampling of transects. We did not attempt to correct counts for missed observations, but believe sightability of caribou is high at the flight

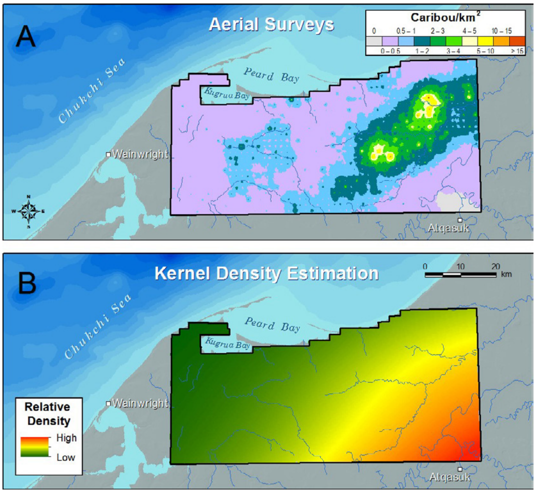

Figure 2. The estimated density of caribou based on aerial surveys conducted in mid-June 2013–2015 (A) and the relative density utilization distribution from kernel density estimation of telemetry data from Teshekpuk female caribou 2013–2015 (B).

altitude, transect width, and survey timing used for these surveys. The survey area is open tundra and light-colored caribou contrast well with the brown tundra after most snow melts in the spring. We do acknowledge that some caribou, especially calves, may have been missed and the reported numbers may underestimate the true numbers.

To summarize calving distribution and abundance data, we used the inverse distance-weighted (IDW) interpolation technique calculated with the 'gstat' package in R (Pebesma, 2004) to map caribou densities across the study area. This analysis produced color maps showing surface models of the estimated density of caribou to create an easily understood visual portrayal of the observed caribou distribution (Fig. 2A).

Kernel density estimation

We used existing telemetry data from WAH and TCH to identify the typical distribution of those herds during the survey period and to assess the probable herd affiliation of caribou observed during the surveys. We obtained GPS and satellite (PTT) telemetry data for the WAH from the ADFG and the National Park Service (NPS) for 1988-2016. GPS and PTT data for the TCH were obtained from the ADFG, NSB, and the U.S. Bureau of Land Management (BLM) for 1990-2016. After filtering to remove erroneous locations (Prichard *et al.,* 2014), we selected one location from each individual collared animal for each year by selecting the location nearest in time to 11 June. We used these locations to run KDE for females from each herd using data from the period of the study (2013-2015). Sample sizes were inadequate to run KDE for each year individually (Table 2; Seaman *et al.,* 1999). Because caribou are often sexually segregated during calving, we ran separate kernel densities for male caribou. Because the sample sizes available were inadequate to run kernel density estimation for males from just the years 2013-2015, we ran kernels for males using available data from males during all years (WAH = 2003-2016; TCH = 2001-2016). Kernel densities were calculated with the R package ks (Duong, 2017) using the plug-in method to determine the smoothing parameter (Wand & Jones, 1994; Duong & Hazelton, 2003).

After running these four kernel density calculations, we clipped the resulting UDs to remove areas in the ocean and Teshekpuk Lake. We then calculated the proportion of the clipped UD that was in the study area as an estimate of the proportion of the herd that was expected to be in the study area based on a typical herd distribution pattern. We then calculated the number of total males and females predicted to be in the study area based on the herd sizes. We used estimated herd sizes of 235 000 for the WAH and 41 542 for the TCH and estimated that 25% of both herds were adult males based on typical results of composition counts (Dau, 2015; Parrett, 2015). For example, if 10% of a herd's UD for females is in the study area and there are 30 000 females in

Table 1. Number and density of caribou in the caribou study area in 8-10 June 2013, 13-15 June 2014, and 12-14 June 2015. Survey coverage was 50% of the study area.

Survey Year	Animal Demographic	Observed Caribou	Estimated Caribou [a]	95% CI Caribou [b]	Estimated Density [c]	95% CI Density [d]
2013	Adults	1239	2478	2096–2867	0.78	0.66–0.90
	Calf	65	130	78–187	0.04	0.02–0.06
	Total [e]	1304	2608	2209–3012	0.82	0.69–0.95
2014	Adults	456	935	639–1191	0.29	0.21–0.38
	Calf	97	199	108–301	0.06	0.03–0.10
	Total [e]	553	1133	758–1469	0.36	0.24–0.47
2015	Adults	1284	2568	1747–3502	0.81	0.55–1.10
	Calf	405	810	436–1256	0.25	0.14–0.39
	Total [e]	1689	3378	2208–4749	1.06	0.69–1.49

[a] Observed caribou × 2 (to adjust for 50% sampling coverage) and adjusted for unsurveyed area in 2014.

[c] 95% confidence interval of estimated number of caribou calculated by bootstrapping.

[c] Estimated caribou ÷ study area (3186 km²).

[d] 95% confidence interval of estimated caribou density calculated by bootstrapping.

[e] Large caribou + calves

the herd, we then estimated that 3000 females from that herd would be projected to be in that area during that time of year.

To assess the possibility that caribou moved from the core calving area to our survey area after calving occurred, we calculated the distance between caribou locations on 4 June (during calving) and 14 June (near the end of our aerial survey window) for 37 TCH females outfitted with GPS collars during 2013–2015.

We also characterized the relative timing of snowmelt during the survey years by calculating the median date of snowmelt in the study area for the period 2001-2015 using the continuous snow season metric from Lindsay et al. (2015).

Results

After doubling observed counts for the ~50% survey coverage, there were an estimated 2608 total caribou in the study area in 2013, 1133 total caribou in the study area in 2014, and 3378 total caribou in the study area in 2015 (Table 1), this included an estimated 130 calves in 2013, 199 calves in 2014, and 810 calves in 2015. Densities of 0.82, 0.36, and 1.06 total caribou/km² and 0.04, 0.06, and 0.25 calves/km² were observed in 2013, 2014, and 2015, respectively (Table 1). Caribou were widely distributed in a southwest to northeast swath across the eastern study area in all three years (Supplemental Material 1-2), a pattern clearly shown in the maps of average density across all three years (Fig. 2A).

There were an estimated 5.2 calves:100 adults in 2013, 21.3 calves:100 adults in 2014, and 31.5 calves:100 adults in 2015. Because calves are more difficult to see than adults during aerial surveys, these ratios represent minimum values.

Only five of the telemetry locations used in the kernel density analyses were in the study area, all were TCH females and they were in the study area during different years (1991, 2010, 2012, 2013, and 2015). Based on KDE from the WAH and TCH, the caribou in the area were predicted to be almost entirely TCH, with only one WAH female and zero males predicted to be in the study area during early to mid-June (Table 2; Fig. 3). TCH females are more

Table 2. Estimated number of caribou expected to be in the study area based on kernel density estimation of telemetry data from the Western Arctic Herd (WAH) and the Teshekpuk Herd (TCH).

Herd	Animal Demographic	Year Range	*n*	Proportion of UD	Estimated Number [a]	Estimated Density [b]
WAH	Females	1988–2016	719	<0.0001	0	0
	Females	2013–2015	204	<0.0001	1	<0.001
	Males	2003–2016	97	<0.0001	0	0
TCH	Females	1991–2016	269	0.0209	652	0.20
	Females	2013–2015	53	0.0410	1278	0.40
	Males	2001–2016	55	<0.0001	1	<0.001

[a] Based on an estimated herd size of 235 000 for the WAH and 41 542 for the TCH and 25% adult males.

[b] Caribou per km^2, based on a survey area size of 3186 km^2.

common in the study area during early to mid-June, but the study area was outside the typical distribution of TCH males during early June based on the collared sample (Table 2; Fig. 3).

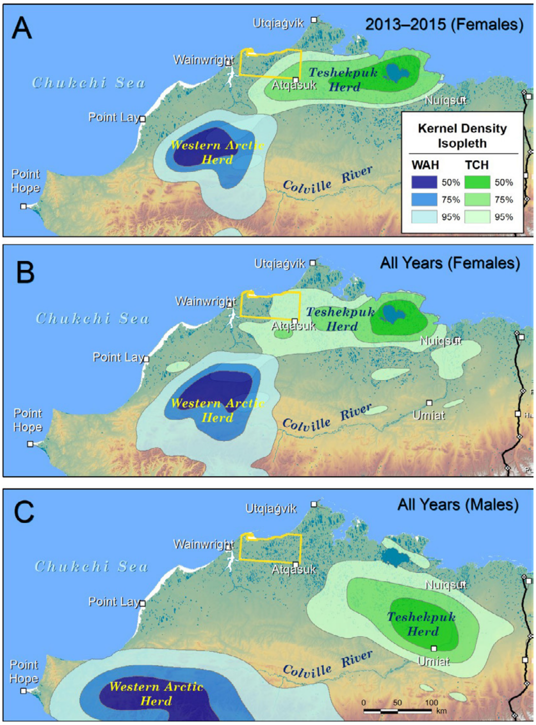

Figure 3. The predicted herd ranges for the Western Arctic (WAH) and Teshekpuk Herd (TCH) during early June based on kernel density estimation of telemetry data from females during the years 2013–2015 only (A), females during all years (B), and males during all years (C). The aerial survey study area is designated with a yellow polygon.

The overall predicted number of TCH plus WAH caribou in the study area based on KDE from telemetry data was 1279. This was close to the number of caribou estimated to be in the study area based on aerial surveys results in 2014, but just 49% and 38% of the number of caribou estimated to be in the study area based on aerial survey results in 2013 and 2015 respectively (Table 1). The UD of TCH females from KDE provided little specific information on the use of the study area but suggested that the highest densities of caribou in the study area should be in the southeast corner of the study area with declining densities farther north and west (Fig. 2B). The more detailed aerial survey results show that the highest densities were consistently in a southwest to northeast band on the east side of the survey area (Fig. 2A).

Median date of snowmelt in the study area was slightly earlier than average for this period in 2013 (3.5 days) although it was a late spring in much of Alaska (Verbyla *et al.*, 2017) Median date of snowmelt was slightly later than average in 2014 (2.5 days), and was much earlier than average in 2015 (11.5 days).

Discussion

This study provides new information for assessing potential impacts of oil and gas leasing in this specific study area, but it also provides additional insight into the limitations of assessing caribou distribution in remote regions of the Arctic in general. The use of telemetry data provides a convenient method to map the seasonal distribution and movements of caribou and is often used as the primary data source for impact analysis in northern Alaska, but the sample sizes are generally very low relative to the number of animals in the herd. Without close attention to where collars are deployed, there is no guarantee that KDE analysis will represent the entire herd, and it is likely to miss small localized concentrations of animals. Aerial surveys provide detailed local information for one time period, but they lack information on herd identity and movements, are expensive, raise safety concerns, and may be discouraged by local residents (Stinchcomb, 2017).

Although there was large annual variability in caribou density over the three years of our study, the precise distribution data from aerial surveys could provide useful information for designing and locating infrastructure as well as assessing impacts in the area if future development does occur. A change in density may be detectable with multiple years of pre- and post-construction data if a large change does occur, but a relative change in density near infrastructure (e.g., Dau & Cameron, 1986) would likely be a more sensitive indicator of impacts.

Although the study area is on the periphery of the calving range for the TCH (Person *et al.,* 2007; Wilson *et al.,* 2012; Parrett, 2015), between 130 and 810 calves were estimated to be in the area annually during late calving 2013-2015 and local residents of Wainwright and Atqasuk report that caribou regularly calve in the area. The highest caribou density in this study occurred in 2015, when 1.06 caribou/km² and 0.25 calves/km², and 31.5 calves:100 adults were estimated to be in the area. Noel and George (2003) surveyed a 1401–2327 km² area of the high density TCH calving area east of Teshekpuk Lake during 1998–2000 using similar methods (although transects were twice as wide) and recorded total densities of 1.90, 1.45, and 0.45 total caribou/km², calf densities ranging of 0.39, 0.38, and 0.02 calves/km², and calf to adult ratios of 27.5, 38.1, and 6.6 calves: 100 adults. Similar surveys were conducted over a ~788 km² high density calving area for the Central Arctic Herd during 1995–2017 and recorded total densities ranging from 0.20–14.74 total caribou/km² (mean = 3.97 caribou/km²), calf densities ranging from 0.03–3.68 calves/km², and calf to adult ratios ranging from 16.5–36.2 calves: 100 adults (mean = 26.3 calves: 100 adults; Prichard *et al.,* 2018). Hence, although the densities were slightly lower than densities typically recorded in high density areas, the calves: adult ratios were similar, at least in 2015.

The densities of caribou observed on two of the three years of our surveys were considerably higher than predictions based on kernel distributions of the calving range of the WAH and TCH, although no variance for this prediction could be calculated due to low sample sizes among years. The area used by TCH females during calving extends west towards the study area, and female TCH caribou appeared to be more widely distributed during 2013-2015 than in previous years (Fig. 3A, 3B). Although the survey area is within the WAH range, and some WAH caribou do winter in this area in some years, the KDE analysis shows that few collared WAH females are found north of the herd's calving range during June (Fig. 3C).

The sex and age composition of adult caribou in the survey area is unknown. Non-parturient females are often located farther from the core calving area than parturient caribou during early June (Person *et al.,* 2007), but based on the adult:calf ratio of observed caribou, at least 31.5% of the adult caribou in the survey area in 2015 were parturient cows. These surveys took place shortly after the typical peak of calving, so caribou observed with calves likely calved in or near the study area. TCH caribou do not generally move far immediately following calving (Carroll *et al.,* 2005; Person *et al.,* 2007); we found that TCH females only moved a mean distance of 17.8 km (straight-line distance) between 4 June to 14 June during the years of our survey. The TCH primarily uses coastal areas between Teshekpuk Lake and the Beaufort Sea after the onset of mosquito harassment in late June (Parrett, 2007; Person *et al.,* 2007; Wilson *et al.,* 2012), so most TCH caribou are likely to move closer to the coast and Teshekpuk Lake as the mosquito season approaches.

The area is also used for winter range by the TCH (Person *et al.,* 2007), and some of the adult caribou observed in these surveys could be males. Telemetry data indicates that most TCH males wintered in the Brooks Range and were well to the east of the study area during June (Fig. 3C). Based on telemetry we would conclude that few bull caribou are present, but while there does appear to be a large degree of sexual segregation of the TCH during winter and calving as indicated by the telemetry data, many males do winter on the Coastal Plain and males are observed near the survey area during ADFG recruitment surveys (unpublished data). So, this appears to be an example where the small sample of collared males is not fully representing the wintering strategies of all male TCH caribou and therefore, underestimating the number of males in the study area.

Previously reported resource selection function (RSF) maps of the TCH summer range created for parturient and non-parturient TCH females during calving show the northeastern section of our study area having patches with predicted moderate and high probability of use, higher predicted use along the coast, and higher use for non-parturient caribou than parturient caribou (Wilson *et al.,* 2012). Although these maps identify areas of high quality habitat occurring within the study area, the areas they predicted would have the highest use were closer to the coast than the distribution of caribou that we observed. This RSF analysis was conducted when most collared females calved near Teshekpuk Lake, and did not appear to accurately predict all of the areas where calving occurred west of Teshekpuk Lake in subsequent years. Whether this was just a result of incomplete model specification or changing caribou selection of calving areas is unknown.

Both the RSF and KDE incorrectly identified different portions of the survey area that should contain the highest calving densities; the RSF identified the coastal area (Wilson *et al.,* 2012), while the KDE identified the southeast corner (Figure 2B), while the aerial surveys clearly indicated that the heaviest used area occurred in a band from southeast to northeast through the survey area (Figure 2A).

TCH caribou typically calve farther south in years of late snowmelt (Carroll *et al.,* 2005). Spring temperatures in Utqiaġvik (formerly Barrow), Alaska have increased 1.8° C from 1979-2012 (Wendler *et al.,* 2014) and the timing of snowmelt in northern Alaska has increased by 2.86 days/decade from 1975-2016 (Cox *et al.,* 2017), but there is large interannual variability in the timing of snowmelt. During our surveys, the median date of snowmelt ranged from 11.5 days earlier than normal in 2015 to 2.5 days later than normal in 2014. During the three years of our study, more caribou used the area during years with earlier snowmelt; however, more years of data would be required to verify this trend. If this trend continues, it would suggest that this area may be more important for calving caribou in the future as the Arctic warms.

Line transect aerial surveys of caribou calving grounds in northern Alaska are rare following the widespread adoption of telemetry collars for studying caribou, although surveys of the western segment of the CAH were conducted annually 1995-2017 (Prichard *et al.*, 2018). Telemetry collars are only deployed on a very small percentage of a herd; therefore localized areas of use may be underrepresented, especially if some animals had a lower probability of being collared due to an unusual or unknown distribution pattern. Our results suggest that aerial surveys should be conducted periodically in areas of concern, and continued effort should be taken to ensure collars are representative of the entire herd.

We analyzed these data using different data sets and analysis techniques which provided different, but complementary information and results. The telemetry data provided information on herd association and potential changes in calving distribution compared to previous years, and KDE did identify this as an area of use during calving, but KDE analysis did a poor job of predicting the spatial distribution and density of caribou within the finer scale of this small survey area. The aerial survey data provided fine-scale distribution of caribou within the survey area but lacked information on herd association or movements and distribution outside the timing of the surveys. By using both techniques, we were able to derive a more thorough understanding of the use of the area than would have been possible with any individual technique. We determined that the calving in this area was most likely comprised of TCH animals and not WAH as assumed by early researchers (Davis & Valkenburg, 1978) and some local residents. Telemetry suggests a recent increase in calving west of Teshekpuk Lake, although it is not known if densities in our survey area increased recently. We were able to collect three years of density information as well as the contextual information to explore herd associations and changes in distribution compared to the long-term telemetry data set.

Although offshore oil exploration is currently suspended in this region and there are no current onshore oil development plans in this area, there is continued interest in constructing roads across the Arctic Coastal Plain and the Integrated Activity Plan for NPRA, that will set stipulations for lease sales in the area, is currently being revised. If future development does occur, this additional information on caribou calving, from both aerial surveys and telemetry data, will be useful for assessing impacts on caribou numbers and subsistence hunting in this little-studied region. Because of the moderately high number of calving caribou in the area, long-term reports of calving occurring in this area, and the possibility that caribou in the area are not proportionally represented by collared caribou, we recommend additional study by deploying telemetry collars on caribou in this area to fully understand the annual movements of caribou using this area during calving. Our results point to the importance of supplementing telemetry data results with aerial survey data or other direct observations for assessing caribou distribution in remote areas prior to development.

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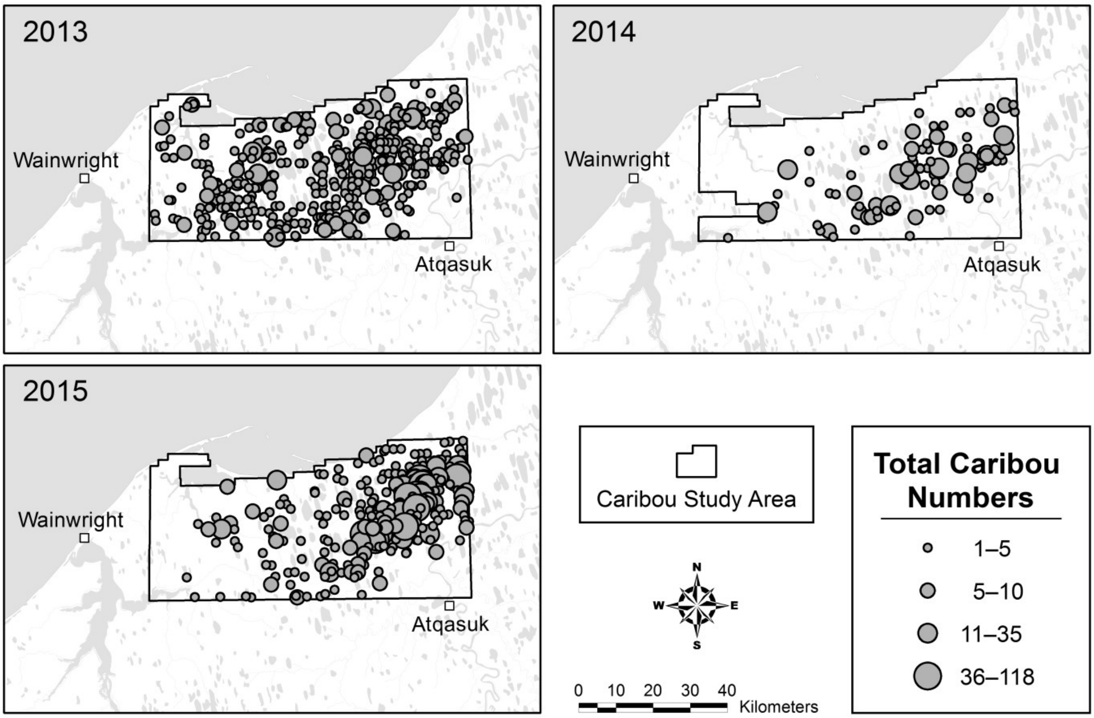
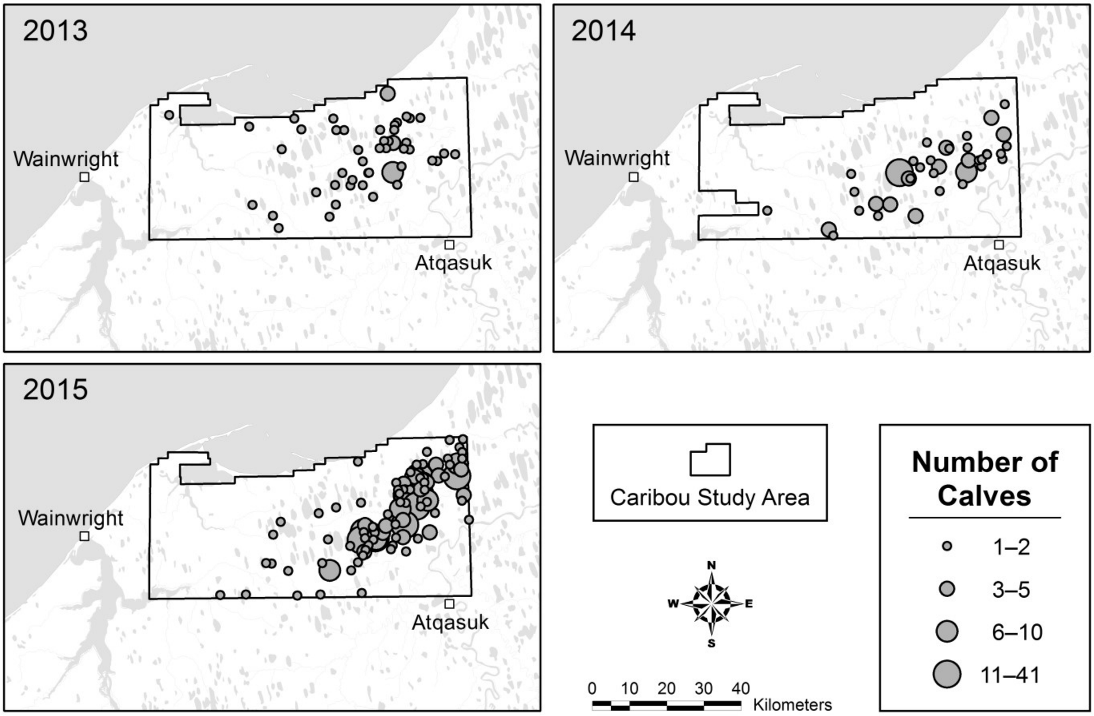
Appendix



Supplemental material 1. The location and number of caribou observed during aerial surveys conducted in mid-June 2013–2015.



Supplemental material 2. The location and number of calves in caribou groups with calves observed during aerial surveys conducted in mid-June 2013–2015.