Population characteristics, space use and habitat selection of two non-migratory caribou herds in central Alaska, 1994 - 2009

Jon S. Horne[1], Tim Craig[2], Kyle Joly[3], Glenn W. Stout[4], Merben R. Cebrian[5] & Edward O Garton[1]

[1] University of Idaho, Department of Fish and Wildlife, Moscow, Idaho, 83844, USA (Corresponding author: jhorne@uidaho.edu).
[2] US Fish and Wildlife Service, Kanuti National Wildlife Refuge, 101 12th Avenue, Fairbanks, Alaska, 99701, USA.
[3] National Park Service, Gates of the Arctic National Park & Preserve, 4175 Geist Road, Fairbanks, Alaska, 99709, USA.
[4] Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska, 99701, USA.
[5] Bureau of Land Management, Central Yukon Field Office, 1150 University Avenue, Fairbanks, Alaska, 99709, USA.

Abstract: Conservation and management of Alaska's caribou (*Rangifer tarandus granti)* herds are important for ecological, cultural, social, and economic reasons. While most research is directed towards the large migratory herds, smaller herds that may or may not be migratory can be an equally valuable component of the state's faunal resources; but for many of these smaller herds, basic information on herd size, demographics, space use and movements is lacking. We compiled Very High Frequency (VHF) telemetry data collected from 1994 - 2009 on 2 such herds in central Alaska, the Hodzana Hills Herd (HHH) and the Ray Mountain Herd (RMH) and estimated abundance, survival, resource selection and seasonal home ranges to inform future management of these herds. We found that both herds were relatively small and stable with approximately 1000 – 1500 individuals; annual survivorship of adult females was high (93% and 94% for RMH and HHH, respectively) and comparable to other stable or increasing herds in Alaska. Both herds were non-migratory maintaining seasonal ranges with substantial overlap. Additionally, despite their close proximity, we did not document any exchange of individuals between the 2 herds. Their spatial separation may be partly due to a strip of non-preferred habitat that somewhat parallels the Dalton Highway. While the telemetry data we used were not originally collected for the purpose of this study, careful compilation and application of appropriate analytical techniques allowed us to glean important characteristics of these herds that will be of value to regulatory and management agencies in the future.

Key words: Alaska; demographics; habitat selection; herd fidelity; management; *Rangifer tarandus granti.*

Rangifer, 34, (1), 2014: 1-20

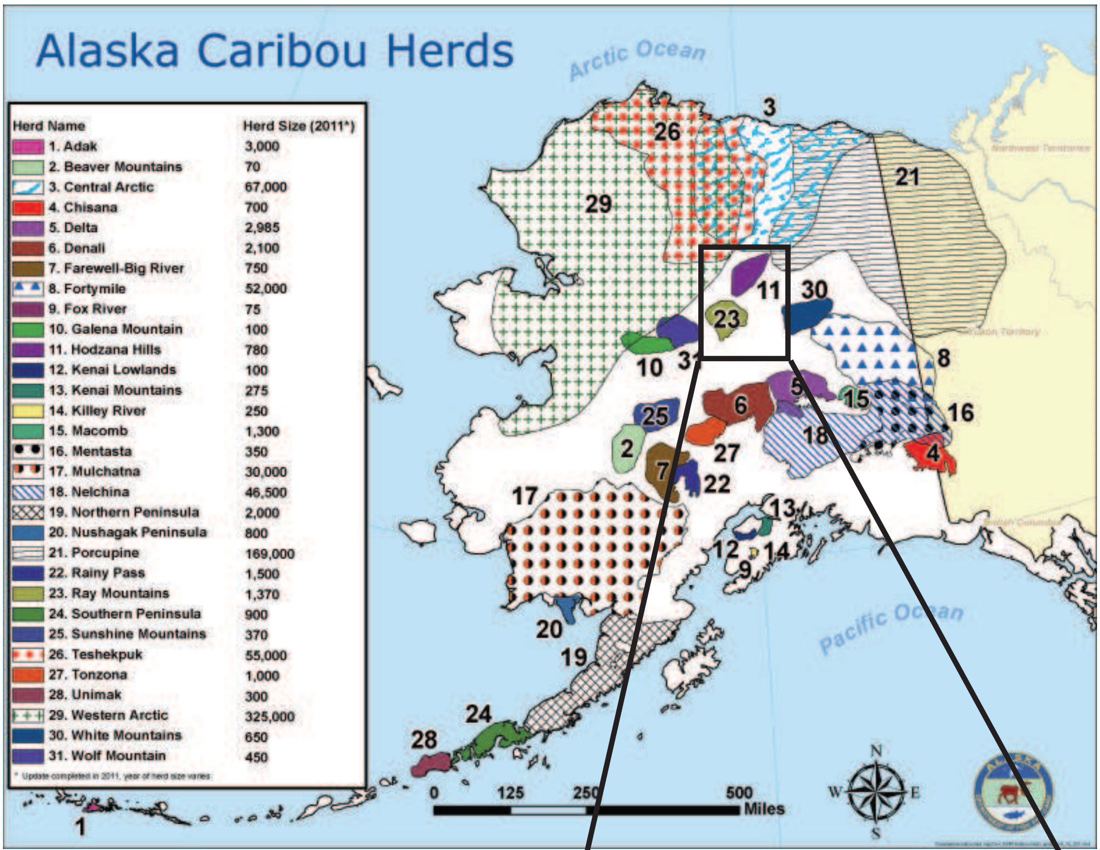
Introduction

It has been suggested that caribou (*Rangifer tarandus granti*) be considered a keystone species in the Arctic because the influence they have on Arctic ecosystems is disproportional to their biomass (Johnson *et al.,* 2005). Unfortunately, many caribou populations in parts of North America are undergoing declines with human activities implicated as a contributing factor in many of these declines (Vors & Boyce, 2009; Festa-Bianchet *et al.,* 2011). Because much of interior Alaska is de facto wilderness, caribou and their habitat have largely escaped major human-caused perturbations. However, this may change as infrastructure and resource development increase in the near future. For populations that are not of conservation concern, caribou provide an important opportunity for recreation and subsistence hunting in many parts of their range. Effective strategies for conservation and management of caribou rely on knowledge of distribution, abundance, movements and habitat selection.

The Alaska Department of Fish and Game (ADFG) has identified 32 caribou herds in Alaska (ADFG, 2009). Even though the large and migratory caribou herds garner the most research and public attention in Alaska, > 75 % of Alaska herds are smaller than 3500 caribou and do not exhibit obviously habitual seasonal movements. One of these small herds, the Ray Mountain Herd (RMH), occupies the geographically isolated highlands north of the Yukon River, just west of the Dalton Highway (Alaska Route 11; Fig. 1), and was first identified as a distinct herd in the 1970s (Robinson, 1985). Based on mitochondrial DNA analysis of genetic relationships, Cronin et al. (1995) suggested the RMH was most similar to the Galena and Central Arctic caribou herds; though more recent work has revealed genetic similarities across northern North America, especially within herds in interior Alaska (Mager, 2012; Weckworth *et al.,* 2012). Early observational studies suggested the herd size to be 500-1000 animals, with little information on distribution, seasonal use areas or habitat selection (Robinson, 1985; Jandt, 1998). To better describe population characteristics of the RMH, biologists with the ADFG and Bureau of Land Management (BLM) began a long-term study by capturing and radio-collaring 20 female calves with VHF transmitters in 1994 (Jandt, 1998; Hollis, 2007).

During routine aerial surveys of the RMH, caribou were periodically sighted in the nearby Hodzana Hills, which are east of the Dalton Highway and further north (Fig. 1). Although Jandt (1998) speculated these animals could be from a separate caribou herd, no systematic attempts were made to confirm this and, until recently, it was assumed these animals were from the RMH (Hollis, 2007). In 2005 researchers with ADFG and BLM began a radio-telemetry study of caribou in the Hodzana Hills. After 2 years of work, biologists observed that the caribou radio-collared in the Hodzana Hills remained there year around and detected no interchange with the RMH. Based on these observations, caribou in the Hodzana Hills were identified as a distinct herd (Hodzana Hills Herd; HHH) in 2007 (Hollis, 2007). Historically, the Hodzana Hills were identified as the "center of abundance" of caribou north of the Yukon River in the 1920's (Murie, 1935), so this recently designated herd may be a remnant population of that era.

The RMH and HHH ranges lie in close proximity to the Dalton Highway corridor (Fig. 1). The Dalton Highway is an industrial highway servicing the oil and gas fields on the North Slope. With increasing interests in resource development, the Dalton Highway may become even busier in the future. Understanding the population characteristics and habitat use of the RMH and the HHH is important in light of potential increased disturbance in the Dalton Highway corridor. Here, we present the results of cooperative research between Federal and State agencies on the seasonal ranges, habitat use, abundance and demography of these 2 herds. Of particular interest was the degree to which, if any, these 2 herds interact demographically or in their spatial distribution and habitat selection patterns.



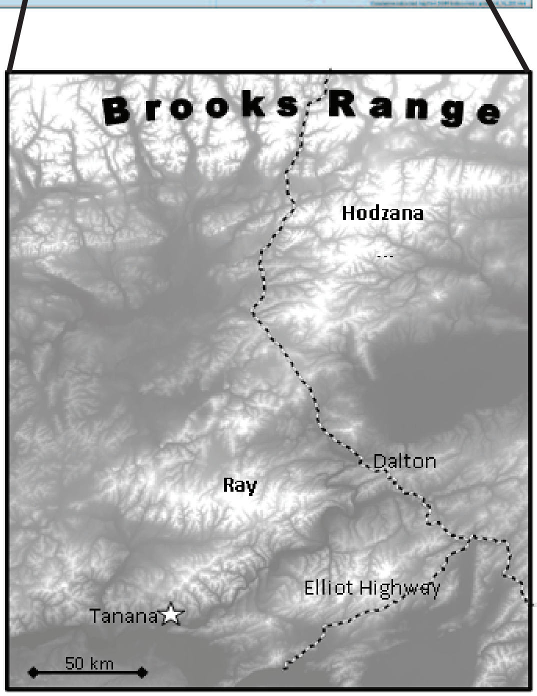


Figure 1. Map of caribou herds in Alaska (reproduced courtesy of Alaska Department of Fish and Game; http://www.adfg.alaska.gov/index.cfm?adfg=caribou.main) and our study area for studying population characteristics, distribution, and habitat selection of 2 non-migratory caribou herds in the Hodzana Hills and Ray Mountains. Lighter shading indicates higher elevation.

Material and methods

Study Area

In The 77,000 km^2 study area included areas surrounding the Hodzana Hills (66.3 - 67.0º N 149.0 - 150.6º W) and Ray Mountains (65.3 - 66.1º N 150.5 - 152.3º W) in north-central Alaska (Fig. 1). The study area was bounded to the north by the Brooks Range Mountains. The village of Tanana on the banks of the Yukon River was in the southern portion of the study area and the Dalton Highway ran north-south through the study area between the Ray Mountains and Hodzana Hills.

Farquhar and Schubert (1980) described the Ray Mountains as an ecological island of subarctic tundra within central interior Alaska's taiga. Even though the Hodzana Hills straddle the Arctic Circle, this area shares many physiographic and ecological characteristics with the Ray Mountains. The majority of the study area was comprised of the Intermontane Boreal Ecoregion (Nowacki *et al.,* 2001) in the Yukon-Tanana Uplands physiographic province (Wahrhaftig, 1965), with elevation ranging 150 – 1500 m. About 10% of the study area was characterized as boreal herbaceous wetlands, with the remainder split approximately equal between boreal forest, alpine rock-lichen barrens in the upper elevations, and low arctic shrub-tussock tundra in the lower slopes. The study area includes the full complement of naturally occurring wildlife species, however robust estimates of predatory species are not available.

The climate in this area was strongly continental (Hartman & Johnson, 1978) and characterized by short, warm summers and long, dry, cold winters. The 30-year average temperature at nearby Prospect Creek weather station (66.5° N, 150.4° W) for the warmest month of the year (July) was 21°C and the average temperature in the coldest (February) was - 31°C (Western Climate Data Center; http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak7778; accessed 16 October 2012). Average annual precipitation at this station during the same period was approximately 33.5 cm with an average annual snow depth of 28 cm. The study area was subject to high winds that scour snow from the summits during winter.

Capture and Tracking

To capture individual caribou, we located groups of caribou with a fixed-wing aircraft, and radioed their location to a pre-positioned helicopter (Robinson R44). The helicopter then approached the caribou, maneuvered to within close proximity and either darted or net-gunned individuals (Barrett *et al.,* 1982; Eagan, 1993; Hinkes *et al.,* 2005). Captured individuals were immobilized using general procedures reported in Valkenburg *et al.* (1999). We collected a blood sample and took morphometric measurements from each animal we captured. We fitted individuals with VHF radio-transmitter collars equipped with a mortality sensor (Telonics, Inc. Mesa, Arizona).

We tracked radio-collared caribou using a fixed-wing aircraft (Piper PA-18 or similar aircraft) equipped with 2 element antennas and a scanner/receiver (Telonics, Inc. Mesa, Arizona). We located animals by continuously searching for animals when in proximity to their capture sites or last known locations. Between 1994 and 1999 radio-telemetry flights were attempted at least monthly in the Ray Mountains. From 1999 to 2010 we conducted flights opportunistically (*i. e.,* when funds were available or when other work allowed us to economize by combining efforts) in both the Ray Mountains and the Hodzana Hills. Two exceptions were that we relocated radio-collared animals in both herds in fall (*i.e.*, late September to mid-October) to conduct herd composition counts via helicopter and when we located bands of caribou to capture and radio-tag animals. During most relocation flights, we were able to cover most of the study areas because of the insular nature of the appropriate habitat for caribou in these isolated highlands.

Estimates of Abundance and Survival

We estimated the abundance of each herd using a method JSH developed to make use of the typical telemetry data collected during this study: After locating individual caribou with radio collars, researchers recorded the size of the group and the number of individuals in the group with a radio-collar. Using these types of data, abundance can be estimated via maximum likelihood of a probability model based on the hypergeometric distribution (Horne *et al., in prep.*). Given there are a total of X radio-collared individuals in a population of size N, the probability of having x radio-collars in *any* group of size n is:

$$Prob\{x \mid N,X,n\} = \binom{X}{x}\binom{N-X}{n-x} \Big/ \binom{N}{n}$$

Taking into account that only groups with radio-collars are observed, the probability of observing x radio-collars in a group of size n, given that the group has 1 radio-collar is:

$$Prob\{x \mid x \geq 1,N,X,n\} = \frac{Prob\{x \mid N,X,n\}}{1-Prob\{x=0 \mid N,X,n\}}$$

For i = 1 to k^1 observed groups seen on a typical telemetry flight, we assume each x_i is independent. Thus, the joint probability is:

$$\prod_{i=1}^{k'} Prob\{x_i \mid x_i \geq 1,N,X,n_i\}$$

leading to the following log-likelihood for N:

$$L(N) = \sum_{i=1}^{k} log\left\{\frac{\binom{X}{x_i}\binom{N-X}{n_i-x_i} \Big/ \binom{N}{n_i}}{1-\binom{N-X}{n_i} \Big/ \binom{N}{n_i}}\right\}$$

which is numerically maximized over values N to find the maximum likelihood estimate of abundance. We calculated 90% confidence intervals for these estimates using a parametric bootstrap procedure. Based on an evaluation of this method via simulations (Horne *et al.,* in prep.), we estimated abundance only for surveys in which the mean number of radio-collars per observed group was >1.5. For each herd and year, we estimated abundance for 2 time periods, 1 that encompassed surveys from August of 1 year to April of the next year (*i. e.,* 'winter') and from May to July ('summer'). To increase the number of groups observed for a particular estimate we combined data when there were multiple flights during a period within the same year.

We estimated survival from caribou cows that were captured and equipped with radio collars on 3 occasions at Ray Mountain and 5 occasions at Hodzana Hills between 20 August 1994 and 18 April 2006. Individuals were relocated during 36 irregularly spaced aerial surveys through 20 September 2009. Therefore, we used staggered entry Kaplan-Meier (Kaplan & Meier, 1958; Pollock *et al.,* 1989) and Cox's proportional hazards (Cox & Oakes, 1984) models to estimate age-specific survival rates for 6 annual age classes (0 consisting of calves marked at 4 months of age through > 5 years of age). Survival rates were estimated throughout the entire period separately for each population and tested for significant differences between populations using Wilcoxon and log-rank chi-squared statistics in Lifetest (SAS 9.2, Statistical Analysis System 2011). Estimates of overall annual survival rates and additional tests for differences between populations and age classes were obtained using Cox's proportional hazards models in Phreg (SAS 9.2, Statistical Analysis System 2011).

Estimates of Seasonal Distribution, Habitat Selection and Home Range

To describe general seasonal distributions for each herd, we first pooled location data across years and then partitioned these data into 4 seasons: (1) calving, 1 May – 7 June; (2) summer, 8 June – 31 August; (3) fall, 1 September – 31 October; and (4) winter, 1 November – 30 April. Then, for each herd and season, location data from all individuals were combined and a kernel density (Worton, 1989) was fit to these data with likelihood cross-validation method to choose the smoothing parameter (Horne & Garton, 2006a). We assessed the degree to which these herds demonstrate migratory behavior by comparing overlap and location of seasonal ranges assuming that migratory behavior would be characterized at the population-level by movements between discrete seasonal ranges (Fryxell and Sinclair 1988).

For individual caribou with sufficient data (*i. e.,* >17 locations), we estimated individual home ranges and habitat selection using the synoptic model of space use (Horne *et al.,* 2008). The synoptic model is analogous to using a weighted distribution (Lele & Keim, 2006; Johnson *et al.,* 2008; Forester *et al.,* 2009) to simultaneously model an individual's space use (*i. e.,* home range) and the habitat selection that influences their space use. Under this approach, the probability density of being at spatial location **x**, a vector of *x* and *y* coordinates, is:

$$f_u(\mathbf{x}) = \frac{w(\mathbf{x}) \times f_0(\mathbf{x})}{\int_{\mathbf{x}} \left[w(\mathbf{x}) \times f_0(\mathbf{x}) \right]}$$

where $f_0(\mathbf{x})$ is the null distribution of space use which models the probability of use in the absence of habitat selection, and $w(\mathbf{x})$ is a selection function that transforms $f_0(\mathbf{x})$ to $f_u(\mathbf{x})$ by selectively weighting areas based on habitat conditions. We defined the resource selection function as:

$$w(\mathbf{x}) = Exp\left[\mathbf{H}(\mathbf{x})' \boldsymbol{\beta} \right]$$

where $\mathbf{H}(\mathbf{x})$ is a vector of covariate values describing the habitat or environmental conditions at location **x** and β is a vector of parameters (*i. e.,* selection coefficients) to be estimated. We defined $f_0(\mathbf{x}) = BVN(\Theta)$ to be a stationary (*i. e.,* time invariant) bivariate normal distribution with parameters Θ describing the means and variances in the *x* and *y* dimensions and the covariance. We used maximum likelihood (via numerical optimization) to estimate the parameters governing the null model of home range (Θ) and the selection coefficients (β) with a program written in R.

Because our location data on individuals were taken throughout the year (see Results), we included 3 general classes of covariates that we believed would influence year-round space use in including those derived from dominant vegetation types, elevation, and roads. Fire history can be an important consideration when evaluating habitat selection of caribou (Schaefer & Pruitt 1991, Joly *et al.,* 2003). However, we did not include the spatial distribution of previous fire events in our analysis because burned areas have the greatest influence on winter space use, whereas we were interested in more general associations with habitat that could be used to predict year-round space use. Furthermore, the temporally dynamic nature of burns and regrowth suggested a more in-depth analysis beyond the scope of our telemetry data. To investigate the influence of vegetation type on caribou space use, we aggregated digital landcover classifications provided by LANDFIRE (NatureServe, 2001) into 2 categorical covariates. These included (1) deciduous dwarf (<1 m) shrublands (*Shrub*), suspected as being selected for foraging (White & Trudell, 1980; Boertje, 1984), which was composed of Boreal Mesic Scrub Birch-Willow Shrubland, Boreal Alpine Dwarf-Shrub Summit, Boreal Alpine Dryas Dwarf-Shrubland, Boreal Alpine Ericaceous Dwarf-Shrubland, Boreal Alpine Dwarf-Shrub-Lichen Shrubland, and Boreal Shrub-Tussock Tundra; and (2) wetlands (*Wet*), suspected as being selected against, which included Sub-boreal Mesic Bluejoint Meadow, Boreal Aquatic Beds, Boreal Herbaceous Wetlands, Boreal Coniferous-Deciduous Woody Wetland, Boreal Dwarf Shrub Wetland, and Boreal Shrub Swamp. We created 2 additional covariates from digital elevation models including elevation (*Elev*) and percent slope (*Slope*). Because caribou in this area tend to avoid both low elevations and very high elevations, we also created a covariate for elevation squared (*Elev*^{2}) to allow for a parabolic relationship. Lastly, to investigate the effect of roads, we created a covariate for road density (Rd_Dens) calculated using the "Line Density" command in ArcGIS Version 10.0 with a radius set to 20 km. Because there was effectively only a single road affecting space use of the caribou we studied (*i.e.*, the Dalton Highway), this variable essentially characterized a non-linear (*i.e.*, half parabola) response of distance to road. To aid in likelihood calculations, all continuous-valued covariates were standardized to range 0 – 1.

We used information theoretic approach for synoptic model construction and selection (Horne & Garton, 2006b; Horne *et al.,* 2008). To reduce the number of candidate models, we took a 2-step approach. First, we created 8 candidate models to describe home range and habitat selection for individual caribou (Table 1).

Table 1. Initial candidate models for analyzing individual habitat selection and estimating home ranges of 21 caribou in central Alaska.

Model	***w(x)***	***K***
Null: bivariate normal distribution	0	5
elevation	β_1*Elev+β_2*Elev^2	
elevation and slope	β_1*Elev+β_2*Elev^2+β_3*Slope	8
elevation and shrub	β_1*Elev+β_2*Elev^2+β_4*Shrub	8
elevation and wet	β_1*Elev+β_2*Elev^2+β_5*Wet	8
elevation, slope, and shrub	β_1*Elev+β_2*Elev^2+β_3*Slope+β_4*Shrub	9
elevation, slope, and wet	β_1*Elev+β_2*Elev^2+β_3*Slope+β_5*Wet	9
elevation, slope, shrub, and wet	β_1*Elev+β_2*Elev^2+β_3*Slope+β_4*Shrub+β_5*Wet	10

These included a null model of space use in which no habitat covariates were included and 7 additional models with various combinations of the covariates described previously but excluding road density. After fitting these candidate models to each individual's location data, we selected the best model using Akaike's Information Criteria corrected for small sample bias (AICc; Burnham & Anderson, 2002). Due to management implications, we were particularly interested in whether roads affected space use. Therefore, once a best model was selected based on vegetation and topography covariates, we tested whether this model was improved by fitting one additional model based on each individual's AIC-best model with the covariate *Rd_Dens* added. Thus, a total of 9 candidate models were fit for each individual.

For each individual, we averaged selection coefficients ($\hat{\beta}_{\bar{w}}$) across all 9 candidate models based on Akaike weights (Burnham & Anderson, 2002). We tested for overall differences in individual selection coefficients between the 2 herds with multivariate analysis of variance (MANOVA) using the Pillai–Bartlett statistic (Hand & Taylor 1987). Following detection of an overall difference from the MANOVA, we tested for differences between each covariate using univariate analysis of variance (ANOVA). For population-level inference of habitat selection, we averaged selection coefficients ($\bar{\hat{\beta}}_{\bar{w}}$), across all individuals when there were no significant differences (*P<0.05*) between herds and for each herd when there were significant differences, and used the standard error of this mean as a conservative measure of precision (Fieberg *et al.,* 2010).

For a more detailed description of space use that incorporates habitat selection, as opposed to the kernel density estimates we used for seasonal range descriptions, we averaged individual utilization distributions (*i. e.,* home ranges) from their AIC-best synoptic model for each herd. Finally, we used the mean selection coefficients across all individuals from both herds to calculate a habitat suitability index (HSI) for the study area,

$$HSI = \frac{Exp\left[\mathbf{H}(\mathbf{x})'\,\bar{\hat{\boldsymbol{\beta}}}_{\bar{w}}\right]}{\max\left(Exp\left[\mathbf{H}(\mathbf{x})'\,\bar{\hat{\boldsymbol{\beta}}}_{\bar{w}}\right]\right)}$$

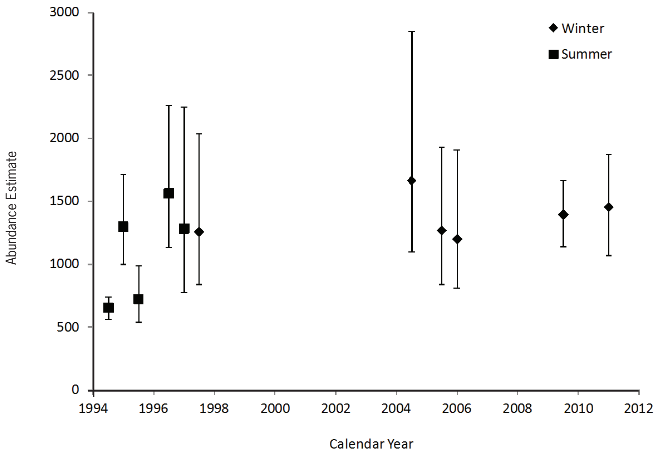


Figure 2. Abundance estimates for the RMH in central Alaska. Error bars represent 90% confidence intervals. Winter estimates are from surveys conducted from August of 1 year to April of the next year and summer estimates are from surveys conducted from May to July of the same year.

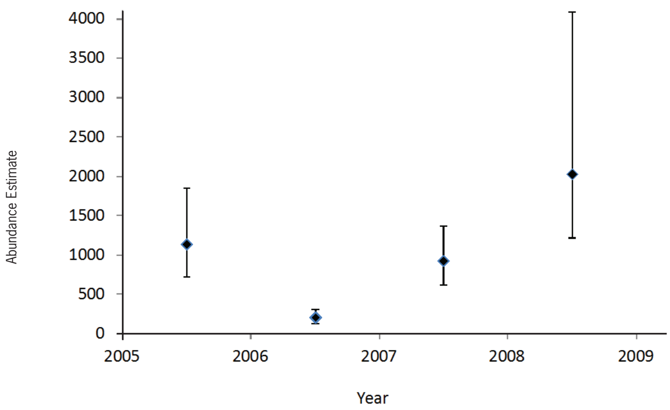


Figure 3. Abundance estimates for the HHH in central Alaska. Error bars represent 90% confidence intervals. Due to insufficient data during summer, all estimates are from winter which includes surveys conducted from August of one year to April of the next year. Note, the estimate during the winter of 2006 – 2007 is likely unreliable because it is from 1 flight in March when all telemetered individuals were seen in 2 groups (i. e, 4 collars in a group of 150 and 2 collars in a group of 7).

where the denominator is simply the maximum value of the numerator which standardizes the HSI to range 0 to 1.

Results

Seventy-one female caribou (45 RMH and 26 HHH) were captured from 1994 – 2009. For the RMH, capture occasions occurred in August 1994 (20 individuals); March 2002 (18 individuals); and April 2006 (7 individuals). For the HHH, capture occasions occurred in October 2003 (4 individuals); April 2005 (5 individuals); April 2007 (5 individuals); September 2007 (8 individuals); and September 2009 (4 individuals). Most of the animals we captured for radio-collaring were calves (<11 months old) or long yearlings (<22 month old) that were captured in the spring. Individual caribou were located via telemetry from 10 December 1994 to 29 September 2009 except for 2001 and 2002 when no telemetry flights were conducted. During this time, we recorded 829 locations (660 for RMH and 169 for HHH). Average number of locations per individual was 17.3 with most (67%) having 10 – 35 locations.

Abundance, Survival and Herd Composition

For abundance estimates, we used observations of group size and number of radio-collars per group recorded during 13 surveys of the RMH from the winter of 1994 to the fall of 2009 and 8 surveys for the HHH from the summer of 2005 to the fall of 2008 (see Table; Supplement 1). However, the mean number of radio-collars per observed group was too small (*i. e.,* < 1.5) for 2 of the RMH surveys and 4 of the HHH surveys to be reliable. Thus, based on 11 surveys, average abundance of the RMH was 1250 and ranged 656 – 1564 with no discernible trend over time (Fig. 2). For the HHH, there was insufficient data for a reliable summer estimate of abundance and only 4 estimates of winter abundance. One of these 4 estimates (*i.e.*, winter 2006 – 2007) was likely an inaccurate estimate due to insufficient number of collared individuals as this estimate is based on a single flight in March when all telemetered individuals were seen in 2 groups (*i. e.,* 4 collars in a group of 150, and 2 collars in a group of 7). The remaining 3 estimates suggest a population abundance of approximately 1000 – 1500 individuals (Fig. 3).

For survival, we monitored 41 female caribou from RMH, of which 15 died by 29 September 2009, yielding an estimated survivorship of 31.8% (SE 8.3%) over the 15.2 year period (Fig. 4). Four of 14 female caribou monitored from the HHH died by 9 September 2009, yielding an estimated survivorship of 69.2% (SE 13.6%) over the 5.9 year period (Fig. 4). Kaplan-Meier estimates of annual survival rates for RMH and HHH were 92.7% and 94.0%, respectively. Survival rates of the 2 populations were very similar and not significantly different (early Wilcoxon X^2= 2.64, 1 df, P = 0.104; late log-rank X^2 = 0.882, 1 df, P = 0.348; Cox's likelihood ratio X^2 = 0.787, 1 df, P = 0.38). Annual survival rates of females were generally high (> 0.85) and similar across age classes (Table 2).

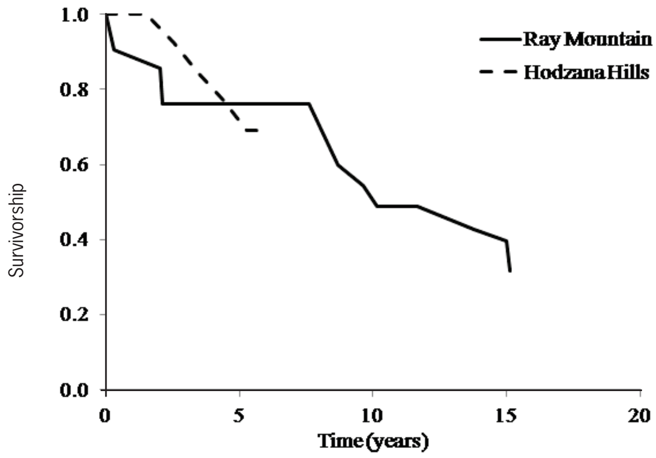


Figure 4. Staggered entry Kaplan-Meier survival functions for female caribou of the Ray Mountain (1994-2009) and Hodzana Hills (2003-2009) herds in central Alaska.

We estimated bull:cow and calf:cow ratios from 1994 to 2009 (14 surveys) for the RMH and from 2003 to 2009 (4 surveys) for the HHH (Table 3). Sample sizes (*i.e.*, number of individuals counted) were relatively large, resulting in precise estimates (*i.e.*, 95% confidence intervals were generally within 15% of the estimate). Herd composition was similar between RMH and HHH with a slightly lower ratio of number of bulls per 100 cows in the RMH versus the HHH (average equaled 34 and 44, respectively). Bull:cow

Table 2. Age-specific annual survival rates for Ray Mountain and Hodzana Hills female caribou.

Age (years)	*Total*	*Survivors*	*Survival Rate (%)*	*SE (%)*
0.3-1	56	55	98.2	1.79
1-2	55	49	89.1	4.24
2-3	49	44	89.8	4.37
3-4	44	37	84.1	5.58
4-5	37	34	91.9	4.55
5+	32	31	96.9	3.13

Table 3. Fall[1] herd composition for Ray Mountain and Hodzana Hills caribou.

Year	*Bulls:100 cows*[2]		*Calves:100 cows*[2]	
	RMH	*HHH*	*RMH*	*HHH*
1994	38 (33, 41)		19 (17, 20)	
1995	33 (30, 36)		12 (10, 13)	
1996	28 (25, 30)		15 (14, 16)	
1997	33 (30, 36)		13 (12, 14)	
1998	26 (24, 28)		32 (31, 33)	
2000	38 (36, 41)		19 (18, 20)	
2001	30 (28, 32)		15 (14, 16)	
2002	51 (42, 60)		31 (27, 36)	
2003	33 (30, 36)	52 (46, 58)	18 (16, 19)	25 (22, 28)
2005	35 (32, 39)	52 (49, 55)	10 (9, 12)	17 (15, 18)
2006	27 (24, 30)		10 (9, 11)	
2007	26 (23, 29)		25 (23, 27)	
2008	47 (43, 51)	43 (37, 48)	28 (26, 30)	28 (25, 30)
2009	36 (32, 39)	29 (26, 33)	29 (27, 30)	18 (16, 19)
Average	***34***	***44***	***20***	***22***

[1] Surveys were conducted in late September to mid-October.
[2] 95% confidence intervals based on the normal distribution are in parentheses

ratios were relatively stable during the observation period ranging between 26 and 38 in 12 of the 14 RMH surveys and ranging between 29 and 52 for the HHH surveys. Average number of calves per 100 cows was 20 and 22 for the RMH and HHH, respectively. Calf:cow ratios were also relatively stable (*i.e.*, no significant linear trend; $r^2 = 0.09$ RMH; $r^2 = 0.01$ HHH) during the observation period (RMH ranged 10 to 32, HHH ranged 18 to 28).

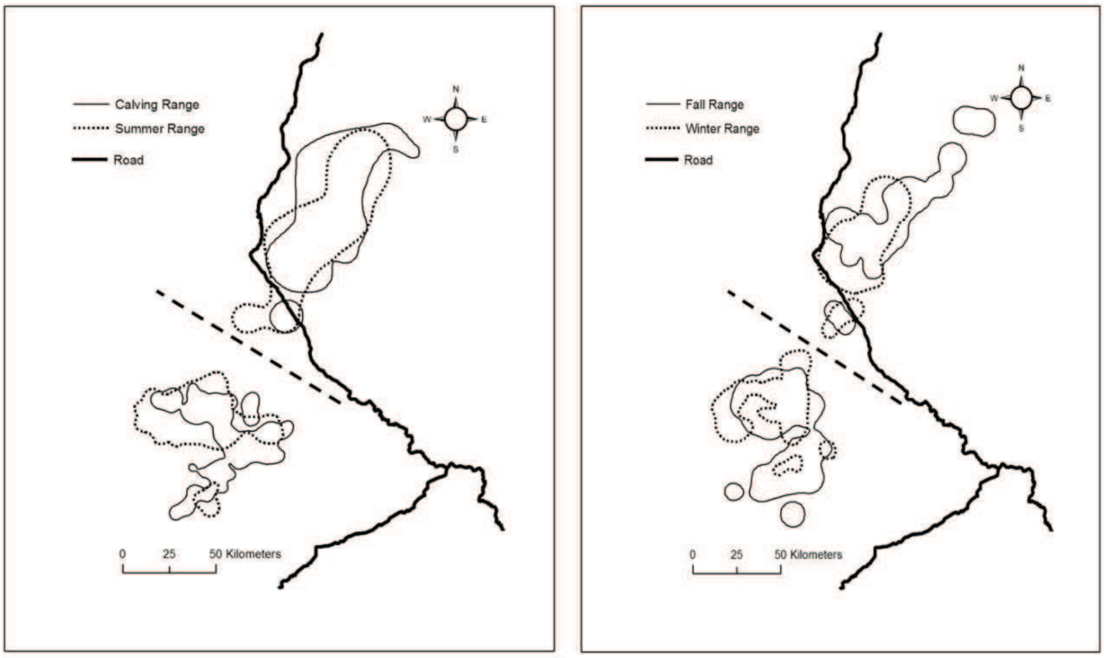


Figure 5. Seasonal ranges (90% cumulative probability contours) of RMH and HHH based on kernel density estimates. Dotted line represents an approximate line of separation between the RMH (southwest of line) and HHC H (northeast of line).

Seasonal Distribution, Habitat Selection and Home Range

The RMH and HHH occupied completely distinct ranges during our study. Of the 169 locations from 26 caribou radio-collared in the Hodzana Hills from 2003 to 2009, 9 (5%) locations from 3 individuals were obtained southwest of the Dalton Highway and none were obtained southwest of a line running approximately parallel to the highway but slightly southwest (Fig. 5). Of the 660 locations from 45 caribou radio-collared in the Ray Mountains from 1994 to 2009, none were relocated northeast of the line running approximately along the Dalton Highway (Fig. 5). Restricted movement was also evident in that there was substantial overlap (Table 4) and close proximity of seasonal ranges of both herds suggesting no large-scale migrations among calving, summer or winter ranges (Fig. 5).

Twenty-one individuals (15 from RMH and 6 from HHH) had sufficient number of locations (*i.e.*, > 17) to analyze habitat selection and estimate home ranges. Of these, the average number of locations per individual was 32.7 (range 29 – 35) for RMH and 20.7 (range 18 – 25) for HHH. Location data from 1994 – 2000 was used for the RMH and from 2003 – 2009 for the HHH. Due to timing of telemetry flights, approximately 30% of the locations were during May while the rest of the locations were generally spread equally among the remaining months. Thus, the models of individual habitat selection and home range represent year-round space use with slightly more weight given to areas used during calving. Of 189 models fit to data, 8 (4%) failed to converge during the optimization procedure and were excluded from the results.

Table 4. Percent overlap in seasonal ranges (constructed using 90% cumulative probability contour based on kernel density smoothing) of Ray Mountain and Hodzana Hills caribou herds.

Overlap between	*Ray Mountain Herd*	*Hodzana Hills Herd*
calving and summer	34	58
calving and fall	43	31
calving and winter	26	43
summer and fall	32	42
summer and winter	40	46
fall and winter	32	34

Variable importance, as measured by the percent of individuals for which a particular covariate was in at least 1 of their top ($\Delta AIC \leq 3$) models, was elevation (100%), slope (86%), deciduous dwarf shrublands (81%), wetlands (76%), and road density (43%). One individual from the RMH showed a strongly negative relationship with road density (*i. e.,* model-averaged selection coefficient equaled -51.3) and was deemed an outlier because selection coefficients of all other 19 caribou from both herds ranged -3.5 to 1.0. The following summary results exclude this individual. MANOVA results suggested an overall difference in mean selection coefficients between the 2 herds ($F_{6,14}$ = 3.15, P = 0.04). Univariate tests indicated a significant difference in mean coefficients between the 2 herds for slope (P = 0.003) while other variables did not show large differences (P > 0.09). Based on mean selection coefficients (Table 5), caribou from both herds preferred areas characterized by low slope (RMH showed a stronger negative relationship than caribou from the HHH) and elevations between ~500 to 1500 m (optimum = 951 m) with lower probability-of-occurrence as elevations deviated from this optimum (see Fig. in Supplement 2). Caribou from both herds also strongly selected against areas that were characterized as wetlands. To a lesser extent, caribou preferred areas with deciduous dwarf shrublands and low road density. Thus, using mean selection coefficients across all individuals, the final resource selection function used to calculate the *HSI* (Fig. 6) was:

$$w(\mathbf{x}) = Exp\left[23.06 * Elev - 23.40 * Elev^2 - 3.56 * Slope - 0.10 * Road\_Dens + 0.06 * Shrub - 5.52 * Wet\right]$$

To reiterate, this equation (*i.e.*, the selection coefficients) coincides with the standardized values (*i.e.*, range 0 to 1) of the covariates.

Discussion

The Arctic is experiencing far-reaching changes that are predicted to substantially impact its fauna (Lawler *et al.,* 2009). Many of these changes are tied to climate change and increased industrialization. Direct and indirect anthropogenic impacts (*e.g.,* roads, mining, oil and gas development, hunting, snowmachining, climate change, et.c.) have the potential to affect caribou populations (Reimers & Colman, 2006; Johnson *et al.,* 2005; Seip *et al.,* 2007; Vistnes & Nellemann 2008; Vors & Boyce 2009). Populations that are small and isolated are more vulnerable than large populations that commingle with other populations (Rabinowitz *et al.,* 1986). We found the RMH and HHH were both relatively small populations (1000 – 2000 individuals) that despite their close proximity (*i.e.* centers of core home ranges were approximately 100 km apart; see Fig. 6), were spatially disjunct with very little interaction. The apparent lack of female dispersal between these herds was somewhat surprising given their proximity and the fact that most of the individuals radio-collared for this study were calves, the age class most likely to disperse. However, it is also important to recognize that our analysis was restricted to the female portion of the population and male movements may allow for genetic exchange as has been documented in other caribou herds (Roffler *et al.,* 2012). Also, neither herd demonstrated growth in population abundance during this study; a characteristic that has been shown to increase dispersal rates in other caribou herds (Hinkes *et al.,* 2005). Despite these population characteristics, we do not believe that either herd is an immediate conservation concern under current conditions because their abundance and composition parameters are relatively stable, and both herds sustain low annual harvest. Furthermore, nearly 20 other small herds in Alaska with similar demographics have persisted for decades (ADFG, 2009) as have other relatively small populations Norway (Reimers & Colman, 2006). However, calf:cow and bull:cow ratios for RMH and HHH are low compared to composition values for most of the larger, stable or increasing, herds in Alaska (≥30 calves:100 cows, ≥50 bulls:100 cows; Valkenburg 1997; Boertje *et al.,* 1995; ADFG, 2009). Therefore, managers of these 2 herds must continue to be vigilant in monitoring environmental changes and anthropogenic activities that may affect population demographics. Furthermore, additional research into potential factors that limit these popu-

Table 5. Mean selection coefficients (90% confidence intervals in parentheses), across individual caribou[1] for population-level habitat selection functions in central Alaska, USA, 1994–2009.

Variable[2]	***RMH***	***HHH***	***RMH and HHH***
Elev	20.3 (19.2, 21.4)	31.6 (26.3, 36.9)	23.7 (22.6, 24.83)
Elev^2	-21.0 (-22.4, -19.7)	-31.3 (-37.3, -25.3)	-24.1 (-25.4, -22.82)
*Slope	-4.7 (-5.1, -4.4)	-0.7 (-0.9, -0.4)	-3.5 (-3.8, -3.25)
Road_Dens	-0.3 (-0.4, -0.2)	0.4 (0.3, 0.5)	-0.1 (-0.2, -0.02)
Shrub	0.1 (0.1, 0.1)	-0.01 (-0.03, 0.01)	0.07 (0.05, 0.09)
Wet	-5.2 (-5.6, -4.9)	-5.9 (-8.7, -3.1)	-5.4 (-5.9, -5.0)

1 Excludes one individual from the RMH that was deemed an outlier because the selection coefficient for Road_Dens (-51.3) deviated strongly from the other individuals.

2 Mean selection coefficients of variables with an asterisk (*) were significantly different (two-tailed t-test, P <.05) between RMH and HHH.

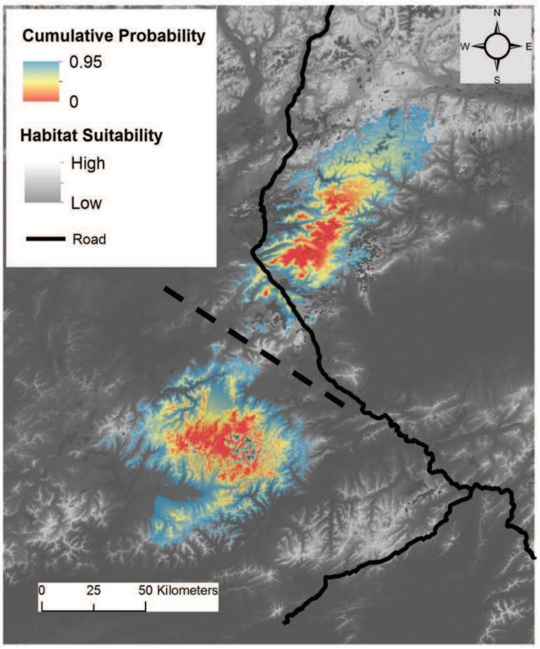


Figure 6. Habitat suitability index and cumulative probability (note: low cumulative probability translates to high probability of use) of aggregate home ranges (averaged individual utilization distributions) for RMH (southwest of dotted line) and HHH (northeast of dotted line) in central Alaska

lations (*e.g.*, reproduction, predation, immigration) would help to understand the mechanisms responsible for the apparent lack of population growth.

Based on the aggregate seasonal ranges and the average utilization distributions (*i.e.*, home range) across individual synoptic models, there was significant spatial separation in home ranges of individuals from the RMH versus the HHH along a line running approximately parallel to, but southwest of the Dalton Highway (Fig. 6). Although an ecological basis for the spatial separation of the 2 herds is abstruse, our analysis suggests that an area of unsuitable habitat and the negative association with the Dalton Highway may be contributing factors. Based on values from the *HSI*, the area along the line of separation was generally characterized by habitat with low suitability values (Fig. 6) which generally coincided with the area along the Dalton Highway. However, the Dalton Highway did not appear to be an impermeable barrier as high probability-of-use areas were predicted for home ranges of HHH individuals southwest of the Dalton Highway (Fig. 6) and 9 (5%) locations from 3 of the 21 HHH individuals were obtained in this area. Additionally, the effect of road density was relatively weak and somewhat ambiguous. In fact, road density was the least important predictor variable of those we investigated; it occurred in a top model in 43% of the individuals; the overall mean selection coefficient was close to zero (*i.e.,* -0.10); and mean selection coefficients for each herd indicated opposite preference (*i.e.,* -0.31 and 0.38 for RMH and HHH, respectively; but $P = 0.17$). Thus, our conclusion is not that space use of caribou from the RMH and HHH is unaffected by the presence of roads, but that in light of other more prominent drivers of space use (*e.g.,* elevation, slope, wetlands), there was insufficient data (*i.e.,* number of locations per individual) to robustly characterize the relationship. It is also important to note that due to the sporadic nature of our telemetry data, we were only able to analyze habitat selection at 1 scale (*i.e.*, home range scale). Future research conducted at a finer-scale (*i.e.*, individual movement paths) would be needed to further evaluate the effect of roads on space use of these herds.

Our main objective in modeling habitat selection was to provide a more accurate description of individual home ranges from each herd to inform our assessment of interactions. However, we were also able to provide general characteristics of habitat selection for RMH and HHH caribou. In general, these herds selected for habitat and topographic features similar to other caribou herds in Alaska. For example, our study found caribou selected for moderate elevations, similar to the Western Arctic Herd in northwest Alaska (Joly, 2011). Higher elevation areas tend to have little forage due to edaphic conditions and low elevations dominated by wetlands. RMH and HHH selected for dwarf shrub habitats, which are known to be important to caribou in Alaska (*e.g.*, Skoog, 1968; Joly, 2011). Similarly, the negative association we detected for RMH and HHH caribou with road density has been shown with the Central Arctic Herd, just to the north of our study area (*e.g.*, Nellemann & Cameron, 1998).

Currently, the Dalton Highway is the only road access to the Arctic in Alaska from the contiguous road system. However, there are plans to increase the number of roads north of the Arctic Circle in the future (http://www.dot.state.ak.us/roadstoresources/index.shtml; accessed 16 October 2012). Increased vehicular traffic on the Dalton Highway in and of itself will not jeopardize the viability of the RMH and HHH as there is already little use of this area; however, it may increase their isolation from each other. We believe a larger threat to these herds is the potential for off-highway vehicle use, which is currently restricted along the Dalton Highway by state and federal law. Sport hunters using firearms are currently required to walk 8 km from the road before they can hunt. If off-highway vehicle restrictions were lifted, these 2 herds would become more susceptible to hunting pressure, especially in spring when snow cover is extensive and daylight has returned. Given their small population sizes and the fact the RMH and HHH are the first herds hunters from the more populous south would encounter when traveling north of the Yukon River, we recommend that herd specific regulations be promulgated if the off-highway vehicle restrictions are removed.

In the past, active management of these 2 herds was limited, due to low harvest demand by hunters (Hodzana Hills and Ray Mountain herds combined 10 yr. avg. = 1.7 caribou harvested/yr.) and limited knowledge of the range used by these herds. Caribou harvest regulations affecting HHH are liberal (5 caribou/day with an open season from 1 July - 15 May), because those regulations were established for the large (>300,000; Dau, 2007) Western Arctic caribou herd prior to documenting the existence of the HHH. Although that management strategy worked adequately in the past, our study provides management agencies the information needed to manage these herds as independent populations with herd specific population and harvest objectives and to define accurate hunt area descriptions in regulations. For example, despite high (> 92%) annual adult survival rates, both herds are relatively small with low recruitment (*i.e.*, low calf:cow ratio) and thus harvest limits may need to be conservative. Furthermore, information related to seasonal range use and habitat selection may be important in developing management guidelines and guiding decisions about future industrial development in the region.

With respect to survey methodologies for these herds, historically, radio-collared caribou served only as beacons for economizing search effort for these small, widespread herds. Minimum herd counts and composition data were the only data obtained from those surveys. By diligently compiling these data and being careful not to extend analyses beyond the capability of the available data, we were able to provide additional insights into the population characteristics of these 2 herds. For example, abundance estimates based on the probability model used in this study, improved upon previous minimum counts and estimates of survival, space use, and habitat selection provided baseline information for comparison with future studies. However, due to data limitations, we were unable to provide information on seasonal range use and habitat selection of individuals or finer-scale movements among seasons. Additionally, while estimates of survival and herd composition (*i.e.*, ratio estimates) were relatively precise using the types of data collected during this study, estimates of abundance were generally much less precise. If intensified management of these herds becomes necessary and additional information is needed, the monitoring protocol will need to address these limitations by increasing the number of telemetered animals, increasing the frequency of survey flights, and improving the rigor of collecting relocation data.

Acknowledgments
We thank all the biologists and pilots that have contributed over many decades to our understanding of these 2 herds. Funding for this project was provided by ADFG and BLM. Naming of products in this paper is not necessarily an endorsement from any of the agencies involved with the project. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of their respective agencies.

References
Alaska Department of Fish & Game. 2009. *Caribou management report of survey-inventory activities 1 July 2006-30 June 2008.* P. Harper (ed.). Alaska Department of Fish and Game, Juneau, Alaska. 334pp.

Barrett, M.W., Nolan, J.W. & Roy, L.D. 1982. Evaluation of a hand-held net-gun to capture large mammals. – *Wildlife Society Bulletin* 10:108-114.

Boertje, R.D. 1984. Seasonal diets of the Denali Caribou Herd, Alaska. – *Arctic* 37:161-165.

Boertje, R.D., Gardner, C. L. & Valkenburg, P. 1995. Factors limiting the Fortymile caribou herd. Alaska Department of Fish and Game. Federal Aid in Wildlife Restoration. Research Progress Report. Grant W-24-3. Project 3.38. Juneau, Alaska. 26pp.

Burnham, K.P. & Anderson, D.R. 2002. Model Selection and multimodel Inference: a Practical Information-theoretic Approach. 2nd Edition. Springer-Verlag New York, Inc., New York. 488pp.

Cox, D.R. & Oakes, D. 1984. Analysis of survival data. Chapman & Hall/CRC Press. Boca Raton, Florida. 203pp.

Cronin, M.A., Renecker, L., Pierson, B.J. & Patton, J.C. 1995. Genetic variation in domestic reindeer and wild caribou in Alaska. – *Animal Genetics* 26:427-434.

Dau, J. 2007. Units 21D, 22A, 22B, 22C , 22D, 22E, 23, 24, 26A caribou management report. – *In:* P. Harper (ed.). *Caribou management report of survey and inventory activities 1July 2004 –30 June 2006.* Alaska Department of Fish and Game. Project 3.0. Juneau, Alaska. pp. 174-231

Eagan, R.M. 1993. Delta herd. – *In:* S. M. Abbott (ed.). *Caribou management report of survey and inventory activities1 July 1990 –30 June 1992.* Alaska Department of Fish and Game. Project 3.0. Juneau, Alaska. Pages 122-147

Farquhar, N. & Schubert, J. 1980. Ray Mountains, central Alaska: environmental analysis and resource statement. Middlebury College Press, Middlebury, Vermont. 390pp.

Festa-Bianchet, M., Ray, J.C., Boutin, S., Côté, S.D. & Gunn, A. 2011. Conservation of caribou *(Rangifer tarandus)* in Canada: an uncertain future. – *Canadian Journal of Zoology* 89:419–434

Fieberg, J., Matthiopoulos, J., Hebblewhite, M., Boyce, M.S. & Frair, J. L. 2010. Correlation and studies of habitat selection: problem, red herring or opportunity. – *Philosophical Transactions of the Royal Society B* 365:2233-2244.

Forester, J.D., Im, H.K. & Rathouz, P.J. 2009. Accounting for animal movement in estimation of resource selection functions: sampling and data analysis. – *Ecology* 90:3554-3565.

Fryxell, J.M. & Sinclair, A.R.E. 1988. Causes and consequences of migration by large herbivores. – *Trends in Ecology and Evolution* 3: 327-241.

Hand, D.J. & Taylor, C.C. 1987. Multivariate Analysis of Variance and Repeated Measures. Chapman and Hall, London, UK. 262pp.

Hartman, C.W. & Johnson, P.R. 1978. Environmental atlas of Alaska. Institute of Water Resources, University of Alaska, Fairbanks. USA. 103pp.

Hinkes, M.T., Collins, G.H., Van Daele, L.J., Kovach, S.D., Aderman, A.R., Woolington, J.D. & Seavoy, R.J. 2005. Influence of Population Growth on Caribou Herd Identity, Calving Ground Fidelity, and Behavior. – *Journal of Wildlife Management.* 69: 1147-1162.

Hollis, A.L. 2007. Units 20F, 21B, 21C, 21D, and 24 caribou. – *In:* P. Harper (ed.). *Caribou management report of survey and inventory activities 1 July 2004 - 30 June 2006.* Alaska Department of Fish and Game. Project 3.0. Juneau, Alaska. pp. 158-173.

Horne, J.S. & Garton, E.O. 2006a. Likelihood cross-validation vs. least squares cross-validation for choosing the smoothing parameter in kernel home range analysis. – *Journal of Wildlife Management* 70:641-648.

Horne, J.S. & Garton, E.O. 2006b. Selecting the best home range model: an information theoretic approach. – *Ecology* 87:1146-1152.

Horne, J.S., Garton, E.O. & Rachlow, J.L. 2008. A synoptic model of animal space use: simultaneous analysis of home range, habitat selection, and inter/intra-specific relationships. – *Ecological Modeling* 214:338-348.

Jandt, R.R. 1998. Ray Mountains caribou: distribution, movement and seasonal use areas, 1994-1997. *BLM-Alaska Open File Report* #67. Department of the Interior, Bureau of Land Management, Anchorage Alaska. 39pp.

Joly, K. 2011. Modeling influences on winter distribution of caribou in northwestern Alaska through use of satellite telemetry. – *Rangifer Special Issue* 19:75-85.

Joly, K., Dale, B. W., Collins, W. B. & Adams, L. G. 2003. Winter habitat use by female caribou in relation to wildland fires in interior Alaska. – *Canadian Journal of Zoology* 81:1192–1201.

Johnson, C.J., Boyce, M.S., Case, R., Cluff, L.H.D., Gau, R.J., Gunn, A. & Mulders, R. 2005. Cumulative Effects of Human Developments on Arctic Wildlife. – *Wildlife Monographs* No. 160. 36 pp.

Johnson, D.S., Thomas, D. L., VerHoef, J.M. & Christ, A. 2008. A general framework for the analysis of animal resource selection from telemetry data. – *Biometrics* 64:968-976.

Kaplan, E.L. & Meier, P. 1958. Nonparametric Estimation from Incomplete Observations. – *Journal of the American Statistical Association* 53:457-481.

Lawler, J.J., Shafer, S.L., White, D., Kareiva, P., Maurer, E.P., Blaustein, A.R. & Bartlein, P.J. 2009. Projected climate-induced faunal change in the western hemisphere. – *Ecology* 90: 588–597.

Lele, S.R. & J.L. Keim. 2006. Weighted distributions and estimation of resource selection probability functions. – *Ecology* 87:3021–3028

Mager, K.H. 2012. Population structure and hybridization of Alaskan caribou and reindeer: integrating genetics and local knowledge. Ph.D. thesis, University of Alaska, Fairbanks. 215 pp.

Murie, O. J. 1935. Alaska-Yukon Caribou. North America Fauna 54:1-90.

NatureServe. 2011. International Ecological Classification Standard: Terrestrial Ecological Classifications. NatureServe Central Databases. Arlington, VA, U.S.A. Data current as of 28 February 2011.

Nellemann, C. & Cameron, R.D. 1998. Cumulative impacts of an evolving oilfield complex on the distribution of calving caribou. –

Canadian Journal of Zoology 76:1425–1430.
Nowacki, G., Spencer, P., Fleming, M., Brock, T. & Jorgenson, T. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297.
Pollock, K.H., Winterstein, S. R., Bunck C.M. & Curtis, P.C. 1989. Survival analysis in telemetry studies: the staggered entry design. – *Journal Wildlife Management* 53:7-15.
Rabinowitz, D., Cairns, S. & Dillon, T. 1986. Seven forms of rarity and their frequency in the flora of the British Isles. – *In:* M.E. Soule. (ed.) *Conservation Biology: the science of scarcity and diversity.* Sineaur Associates, Sunderland, MA, USA, pp. 182-204.
Reimers, E. & Colman, J. E. 2006. Reindeer and caribou (*Rangifer*) response to human activity. – *Rangifer* 26: 55-71.
Reimers, E., Eftestøl, S. & Colman, J.E. 2003. Behavior responses of wild reindeer to direct provocation by a snowmobile or skier. – *Journal Wildlife Management* 67:747-754.
Robinson, S.R. 1985. Status of the Ray Mountains caribou herd. *BLM-AK Open File Report* 12. Department of the Interior, Bureau of Land Management, Anchorage, AK. 11 pp.
Roffler, G.H., Adams, L.G., Talbot, S.L. Sage, G.K. & Dale, B.W. 2012. Range overlap and individual movements during breeding season influence genetic relationships of caribou herds in sourth-central Alaska. – *Journal of Mammalogy* 93:1318-1330.
Schaefer, J. A. & Pruitt, W. O. 1991. Fire and woodland caribou in southeastern Manitoba. – *Wildlife Monographs* 116:1–39.
Seip, D.R., Johnson, C.J. & Watts, G.S. 2007. Displacement of mountain caribou from winter habitat by snowmobiles. – *Journal of Wildlife Management* 71:1539–1544.
Skoog, R.O. 1968. *Ecology of the caribou* (*Rangifer* tarandus granti) *in Alaska.* Ph. D. thesis, University of California, Berkeley. 699 pp.
Valkenburg, P. 1997. Investigation of regulating and limiting factors in the Delta caribou herd. Alaska Department of Fish and Game. Federal Aid in Wildlife Restoration. Research Final Report. Grants W-23-5, W-24-1 through 4. Study 3.37. Juneau, Alaska. 45pp.
Valkenburg, P., Tobey, R.W. & Kirk, D. 1999. Velocity of tranquilizer darts and capture mortality of caribou calves. – *Wildlife Society Bulletin* 27:984-896.
Vistnes, I. & Nellemann, C. 2008. The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. – *Polar Biology* 31:399-407.
Vors, L.S. & Boyce, M.S. 2009. Global declines of caribou and reindeer. – *Global Change Biology* 15:2626–2633.
Wahrhaftig, C. 1965. Physiographic divisions of Alaska. *US Geological Survey Professional Paper* 482, Department of Interior, US Geological Survey. 52 pp.
Weckworth, B.V., Musiani, M., McDevitt, A.D., Hebblewhite, M. & Mariani, S. 2012. Reconstruction of caribou evolutionary history in Western North America and its implications for conservation. – *Molecular Ecology* 21:3610-3624.
White, R.G. & Trudell, J. 1980. Habitat preference and forage consumption by reindeer and caribou near Atkasook, Alaska. – *Arctic and Alpine Research* 12:511-529.
Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. – *Ecology* 70:164-168.

Manuscript recieved 15 July, 2013
revision accepted 2 January, 2014

Supplement 1

Table 1. Survey characteristics used to estimate abundance for the RMH and HHH in central Alaska.

Herd	Survey Id[1]	Date of first survey	Date of last survey	Number of flights	Number of groups observed	Mean number of collars/group
RMH	1994_Winter	12/10/1994	3/9/1995	3	10	4.0
RMH	1995_Summer	5/4/1995	8/8/1995	5	26	2.3
RMH	1995_Winter	9/6/1995	3/18/1996	4	26	1.9
RMH	1996_Summer*	5/17/1996	8/27/1996	4	47	1.3
RMH	1996_Winter	10/5/1996	3/1/1997	3	23	1.7
RMH	1997_Summer	3/1/1997	7/1/1997	4	28	1.5
RMH	1997_Winter	9/5/1997	1/28/1998	3	24	1.6
RMH	1998_Summer*	5/21/1998	5/29/1998	2	22	1.1
RMH	2004_Winter	10/14/2004	4/5/2005	3	10	1.9
RMH	2005_Winter	10/2/2005	4/3/2006	2	7	1.9
RMH	2006_Summer	5/3/2006	5/31/2006	2	13	1.7
RMH	2009_Winter	9/29/2009	9/29/2009	1	2	4.0
RMH	2011_Summer	7/10/2011	7/10/2011	1	3	3.0
HHH	2004_Winter*	10/14/2004	10/14/2004	1	2	1.4
HHH	2005_Summer*	6/10/2005	6/10/2005	1	7	1.1
HHH	2005_Winter	10/2/2005	4/3/2006	2	9	1.8
HHH	2006_Summer*	6/20/2006	6/20/2006	1	5	1.4
HHH	2006_Winter	3/13/2007	3/13/2007	1	2	3.0
HHH	2007_Winter	10/18/2007	3/7/2008	2	11	1.8
HHH	2008_Summer*	5/29/2008	5/29/2008	1	7	1.1
HHH	2008_Winter	9/24/2008	1/21/2009	2	6	1.7

[1] Abundance estimates from surveys with asterisks (*) are not reported because the mean number of observed collars per group was too small (< 1.5) for reliable estimates.

Supplement 2