APPENDIX B - Results of the 2020 boreal caribou abundance survey in the North Slave Region – Tłı̨chǫ all-season road study area

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Abstract

GNWT-ECC conducted an aerial survey to estimate the population abundance of boreal caribou within the Tłı̨chǫ ASR-NSR study area between February 19 and March 2, 2020. This survey was a requirement of the Tłı̨chǫ ASR WMMP and was timed to occur during the construction phase of the Tłı̨chǫ ASR. The two-phase survey method used a fixed-wing aircraft and equally spaced transects to locate caribou and caribou tracks (phase 1) and followed up with a helicopter to count and classify (cow, calf, bull) caribou associated with those track networks (phase 2). During phase 2, collared boreal caribou that were not detected via the survey methods were radio-tracked to include in the classification survey. Sightability rates of boreal caribou were based both on the collared caribou or their track networks that were detected in phase 1, and the proportion of those collared caribou from phase 1 that were available to be detected in phase 2 and observed without radio-tracking. Sightability correction factors for phase 2 were estimated using two methods: a ratio-based method and a sightability model developed using additional covariates for sightability. The minimum density of boreal caribou across the study area was 2.74 caribou/100 km^2 (based on 577 observed caribou) and the final abundance estimates of boreal caribou, after phase 1 and phase 2 sightability corrections, were 965 (SE = 327, CI = 506-1842, CV = 0.34) caribou using the sightability model and 1,725 (SE = 467, CI = 1,023-2,908, CV=0.27) caribou using the ratio-based method. These corrected abundance estimates provide a mean density estimate of 4.6 – 8.2 caribou per 100 km^2 within the 21,071 km^2 study area. Based on all the boreal caribou counted and classified, the calf:cow ratio was 28:100, and the bull:cow ratio was 49:100. We offer recommendations for future boreal caribou survey methods and data analysis. This survey provides baseline information for understanding the impact of the Tłı̨chǫ ASR on boreal caribou.

Introduction

A boreal caribou abundance survey in the North Slave portion of the boreal caribou range was required under Measure 6-1, Part 2 of the Report of EA (MVEIRB 2018). This survey was completed in February-March 2020 under wildlife research permit WL500813. A summary of the boreal caribou abundance survey along with other 2019-2020 field work under the same permit was published in September 2020 (Nietfeld and Hodson 2020).

Boreal caribou are challenging to census (or estimate population size) because they occur at low densities across large landscapes, are cryptic in their colouring, and are naturally secretive (often remaining stationary under survey aircraft), which makes them less likely to be observed during surveys (DeMars et al. 2014). Large survey areas also require a lot of survey effort to detect small groups of animals. Because of this, collar-based population monitoring is often used to monitor population trends in boreal caribou across Canada (including in this study area), instead of periodic abundance surveys used for other species like moose and bison. However, while collar-based population monitoring provides a measure of whether the population has increased, decreased, or remained stable over time, it does not provide any information about the number of animals in the study area, which is important information for some management questions (e.g., understanding potential impacts of harvest, or understanding if a population size is small enough to be vulnerable to stochastic events). The need for management information on population size makes it necessary to estimate abundance as reference points for connecting population trends to population size.

Methods

Study Area

The study area was delineated by the boreal caribou range within the North Slave Region, from Great Slave Lake northwest to encompass La Martre Lake (it did not include the farthest north part of boreal caribou range in the North Slave Region) (Figure B-1). The Tłı̨chǫ ASR alignment was in the center of the study area. The planned study area was 26,300 km^2 and included 13,000 km of transects. The study area was divided into five survey blocks to facilitate the survey using two fixed-wing planes and to reduce observer fatigue by dividing long transects up between the two aircraft (Figure B-1). Note that aircraft and weather issues resulted in the study area being reduced to 21,071 km^2 (see *Results* section and Figure B-3).

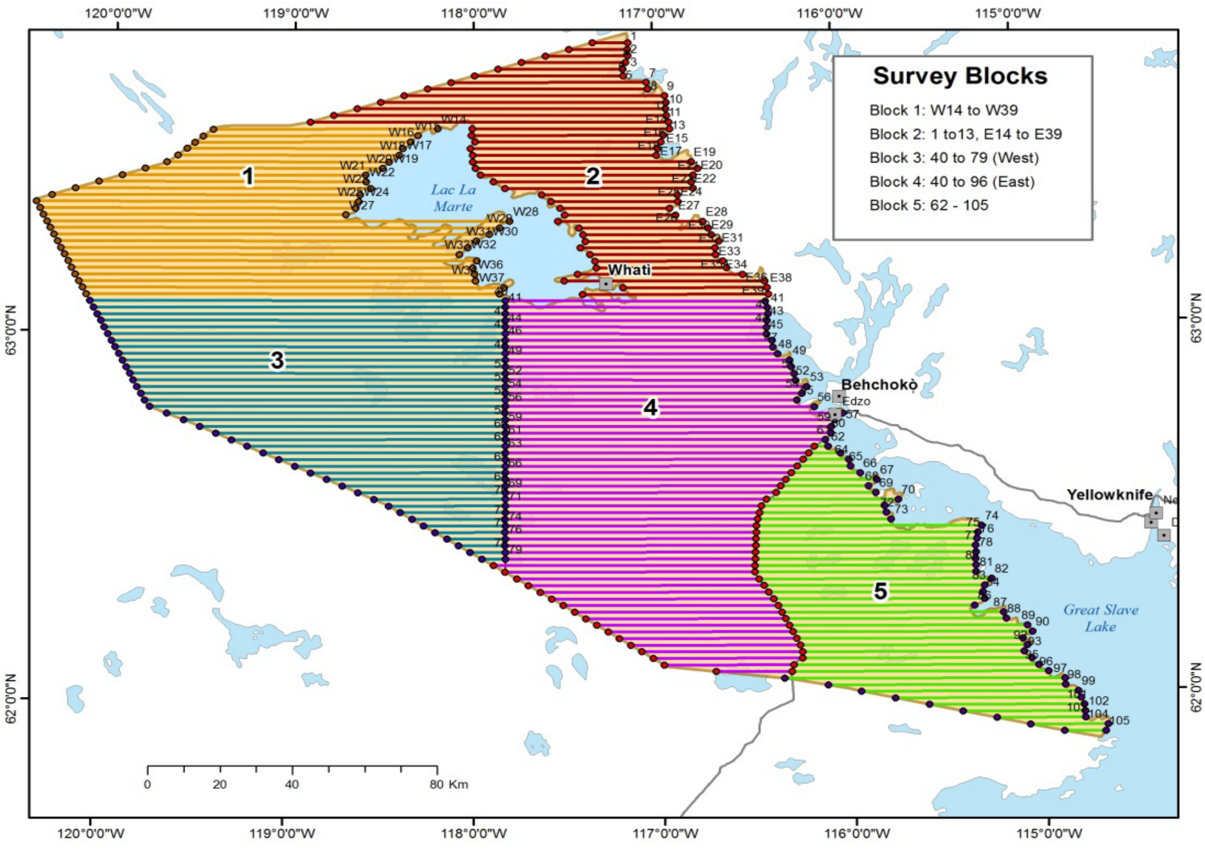


Figure B-1. Original Tłı̨chǫ ASR-NSR study area with survey blocks 1-5.

Survey Design

A two-phase aerial survey was used to estimate population abundance of boreal caribou within the Tłı̨chǫ ASR-NSR study area. This survey method, developed in Québec (Courtois et al. 2003), has been used estimate the population abundance of boreal caribou in Québec as well as other provinces.

Phase 1

Two fixed-wing aircraft were used to fly survey lines spaced 2 km part, at altitudes of 97 to 172 m AGL and a planned speed of 90 knots (167 km/hour). Each survey crew consisted of two community observers, a GNWT-ECC navigator, and a pilot. The objective of phase 1 of the survey was to locate and GPS mark caribou track networks, visual sightings of caribou, and unidentified ungulate tracks along equally spaced transects. The locations of the recorded observations were then revisited during phase 2 and associated caribou were located, counted, and classified. Observations of other ungulates (moose and bison), and carnivores (wolf, fox, lynx, wolverine) were recorded and locations marked during both phases of the survey. Other wildlife observations were also noted.

Phase 2

Each day, following the phase 1 surveys, the locations of tracks and sightings of boreal caribou and unidentified ungulates made by the phase 1 survey crews were investigated by helicopter (A-Star-350 B2). The phase 2 helicopter survey crew consisted of two GNWT-ECC staff (one caribou spotter/classifier/navigator and one radio telemetry operator/caribou spotter/data recorder), one Tłı̨chǫ Government staff member (caribou spotter/data recorder), and the pilot. The phase 2 survey crew tried to locate, count, and classify groups of boreal caribou by intensively searching the areas where boreal caribou groups or tracks had been sighted by the phase 1 survey crews. When groups of boreal caribou were located by helicopter, they were classified into adult females (cows), adult males (bulls), and calves to estimate cow:calf ratios and bull:cow ratios. The caribou classifier also looked for the presence of GPS collars on adult females in each group. The proportion of collared adult females visually located by the classifier was used to estimate a detection (sightability) correction factor. The telemetry operator had prior knowledge of the location of collared adult female caribou but did not share the locations with the other crew members in the helicopter. The telemetry operator used the telemetry gear to scan for the very high frequency (VHF) signals of collared caribou throughout the survey. When collared female caribou were not visually located by the classifier, the telemetry operator instructed the helicopter to circle back to locate the group using radio telemetry. While searching for groups containing one or more collared caribou, other groups of boreal caribou were incidentally located that would otherwise have been missed by the first pass phase 2 visual survey. These caribou were recorded but treated differently in subsequent analyses (as were collared caribou located with radio telemetry versus without).

Data Analysis

Sightability Rates and Correction Factors

Sightability rates were used to adjust the raw counts of caribou observed during a survey and account for potential bias in caribou detectability. Using the Courtois et al. (2003) method, there are two sources of detection error that could result in underestimating the total number of caribou in the study area: 1) failing to detect groups of caribou that occur in the study area and 2) failing to count all the caribou in each of the groups that is detected during the survey. The first source of error is calculated for phase 1 of the survey, while the second source of error is calculated for phase 2 of the survey, and the two detectability rates are then multiplied together to provide the "global" detection rate.

Phase 1

The phase 1 sightability rate is an estimate of occupied sites, using the ratio between the occupation sites including collared caribou that were observed during the flight and the total number of occupation sites including collared caribou that occurred during the survey (Equation B-1). An occupation site is defined as a location along the survey transect corresponding to the movement path of one or more collared caribou that either crossed or was within 1 km of a survey transect within one day prior to or on the same day the transect was surveyed. Thus, any cratering or tracks that were recorded during a flight that likely corresponded to the movement path of a collared caribou, as well as a sighting of a caribou group that would have contained one or more collared individuals, would be considered an "observed" occupation site. The phase 1 sightability rate accounts for a detection bias because its purpose is to determine how effective the fixed-wing observers were at detecting caribou and/or their tracks.

$\hat{p}_{phase1} = \frac{S_1}{S_2}$ (Eq. B-1)

S_1 = number of occupations sites detected

S_2 = total number of occupation sites available to be detected in the study area

The phase 1 sightability rate can vary between 1 and 0. A "1" suggests that all occupation sites were observed that included a collared caribou. A "0" suggests that no occupation sites were found where they should have been detected.

Phase 2

The phase 2 sightability rate used in Courtois et al. (2003) is the ratio between the number of collared caribou visually observed during the phase 2 survey flights and the total number of unique collared caribou that occurred at "found" occupation sites during phase 1 (Equation B-2). It is meant to represent the observer's capacity to detect all individuals in a group. The phase 2 sightability rate accounts for a counting bias because its purpose is to determine how effective the observer is at counting caribou once a group of caribou has been detected.

$\hat{p}_{phase\ 2} = \frac{n_1}{m_2}$ (Eq. B-2)

n_1 = number of collared caribou observed

m_2 = number of unique collared caribou at occupation sites found in phase 1

Similar to phase 1, a phase 2 rate can also vary between 1 and 0. A "1" suggests that all collared caribou were identified at occupation sites found in phase 1. A "0" suggests that no collared caribou were identified at occupation sites found in phase 1. We note that this formula assumes that collared caribou are independent, although caribou often occur in the same group. Detection for phase 2 was estimated differently for sightability models (explained later) where caribou groups rather than individual caribou were the sample units used to estimate detection probabilities.

Global Sightability

The global sightability rate is calculated by multiplying the phase 1 sightability rate by the phase 2 sightability rate (Equation B-3).

$\hat{p}_{global} = \hat{p}_{phase\ 1} \times \hat{p}_{phase\ 2}$ (Eq. B-3)

The purpose of the global sightability rate is to correct for imperfect detection of occupation sites and collared individuals within the detected occupation sites.

To calculate the phase 1 sightability rates, movement paths of collared caribou were broken down by date and overlain by the flight track-log of the Bushawk and Beaver aircraft. Movement paths were created by connecting points of collared caribou positions (coordinates) over time (the surveying days). GPS collars were programmed to record locations every four hours, or every hour when caribou were within the 10 km geofence around the Tłı̨chǫ ASR alignment and Highway 3. A point (star symbology shown in Figure B-2) was placed along each individual's daily movement path at the collar location time that most closely corresponded to the time the aircraft flew within 1 km of that collared individual. The following information was considered when determining whether an occupation site from a collared caribou was detected by the phase 1 survey:

- The direction (right or left side of the plane) in which the caribou track, cratering site or group was observed.
- The time of the day the tracks were observed had to be comparable to the time the caribou was at the occupation site (one day before or same day as the plane passed over or beside it).
- If the caribou movement path was >1 km away from the flight line, it was considered to have been missed, as tracks and individuals are difficult to observe at distances greater than 1 km from the plane.

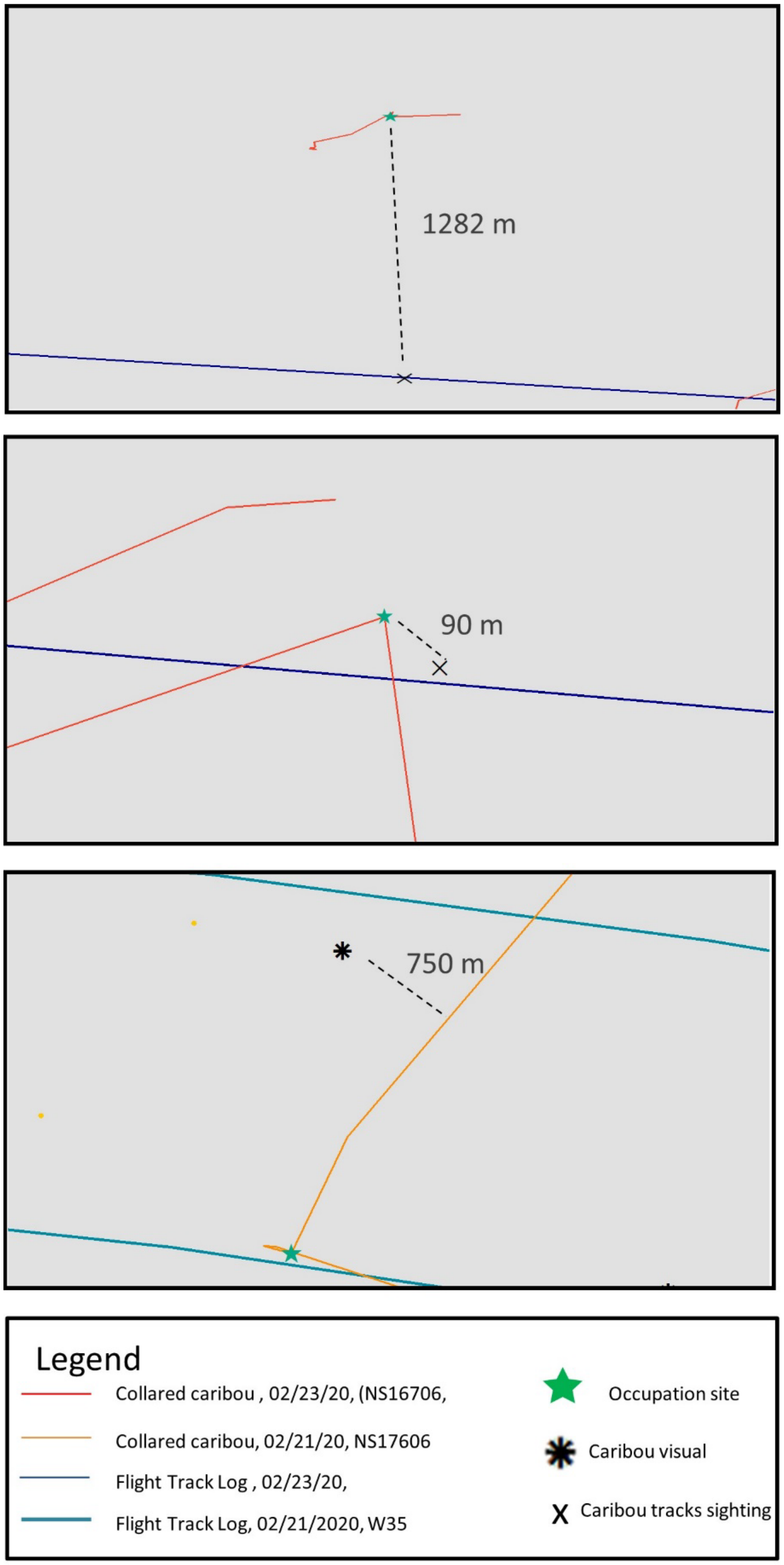
Table B-1 describes the variables considered in calculating the phase 1 sightability rates.

Figure B-2(a)-(c) illustrate the process of determining whether occupation sites were detected during the phase 1 survey. Each panel of Figure B-2 illustrates one of three scenarios:

a) The aircraft flew over a collared caribou or its tracks, but no occupation site was documented (detection = 0).
b) The aircraft flew over or within 1 km of a collared caribou's movement path, and caribou tracks were observed and documented (detection = 1).
c) The aircraft flew over or within 1 km of a collared caribou's movement path, and a group of caribou was observed during flight (detection = 1).

Table B-1. Description of variables listed in Appendix B-2 defining parameters used to calculate phase 1 sightability rates.

Variable	**Description**
Site number	The unique identifier of the site.
Latitude	Latitude coordinate of the occupation site.
Longitude	Longitude coordinate of the occupation site.
Collar identity	Identities of the collars present on site, populated after the flight based on collar data.
Site found	Yes (1), if tracks and/or caribou/s were observed during the flight. No (0), if no tracks nor caribou were observed during the flight, but the data suggests an occupation site should have been observed.
# of caribou marked on site	# of collared caribou on site populated after the flight based on flight lines and collar data.
# of caribou observed on site	# of caribou observed on site, filled during the flight.
Flight line	The unique identifier of the flight line.
Date	Date of the flight.
Team	Aircraft used; Beaver or Bushawk.



a) Caribou tracks observation was >1 km away from the midpoint of the collared caribou's movement path, and are therefore likely unrelated to the collared caribou and the occupation site was considered undetected ("0").

b) Caribou tracks were observed within <1 km from the movement path of the collared caribou, so it is assumed the tracks observed correspond to the group the collared caribou was in, and the occupation site is considered detected ("1").

c) Visual sighting of a group of caribou observed less than 1 km away from a collared individual's movement path. Occupation site of the collared caribou is considered detected ("1").

Figure B-2. Three possible scenarios for detection or non-detection of caribou occupation sites during phase 1 of the boreal caribou abundance survey. All detections/non-detections of occupation sites are documented in Appendix B-2.

Modelling of Survey Detection Rates and Application of Sightability Models

In this part of the analyses, we partially test the assumption that collared caribou detectability rates are representative of the entire population of caribou in the sampling area. We then develop sightability models to describe likely variation in sightability and produce alternative abundance estimates.

Test of Distributions of Collared Caribou Relative to Non-collared Caribou

A critical assumption of phase 2 of the Courtois et al. (2003) method is that radio collared caribou groups are a random sample of caribou targeted from phase 1 so that the proportion of collared caribou sighted is an unbiased estimate of phase 2 caribou sightability. We first assessed this assumption by comparing the distribution of collared groups to non-collared groups to assess if collared groups were more likely to occur in areas of higher tree cover. The actual mechanisms that would cause this difference could be past capture experience, or differences in age/sex class of collared caribou causing them to be distributed differently than other caribou observed in the population. Chi-square contingency tests (Zar 1996) were used for this analysis.

Analysis of Factors Influencing Sightability in Phase 2

The second part of our analysis involved assessing what factors might influence sightability and the building of a sightability model based on tree cover classes, groups size and other covariates that might influence sightability. Two approaches were used. First, data from collared groups were used to assess sightability based on detection and non-detection of these groups. Second, we used data from the collared caribou groups as well as other groups that were not initially observed visually but later detected using tracks and other cues. This allowed a larger sample size of detected/not detected data than one based entirely on collared caribou. The main covariates considered were percent of “closed” canopy land cover classes (crown closure of forest >55%) within 200 m, 500 m, and 1,000 m buffers around observations (Figure B-3, using 1,000 m buffer), group size, log group size, and mid-winter RSF score within a 1,000 m buffer (Figure B-4).

The percent of “closed” canopy land cover classes within a 1,000 m radius around each caribou observation was calculated using a multisource vegetation inventory (MVI) for the NWT (Castilla et al. 2022). Land cover classes of *Coniferous – Dense*, *Broadleaf – Dense*, and *Mixed Wood – Dense* were considered “closed” and all other classes were considered “open”. Land cover classes in the MVI were considered Dense when crown closure (percent tree cover) was 56-100%.

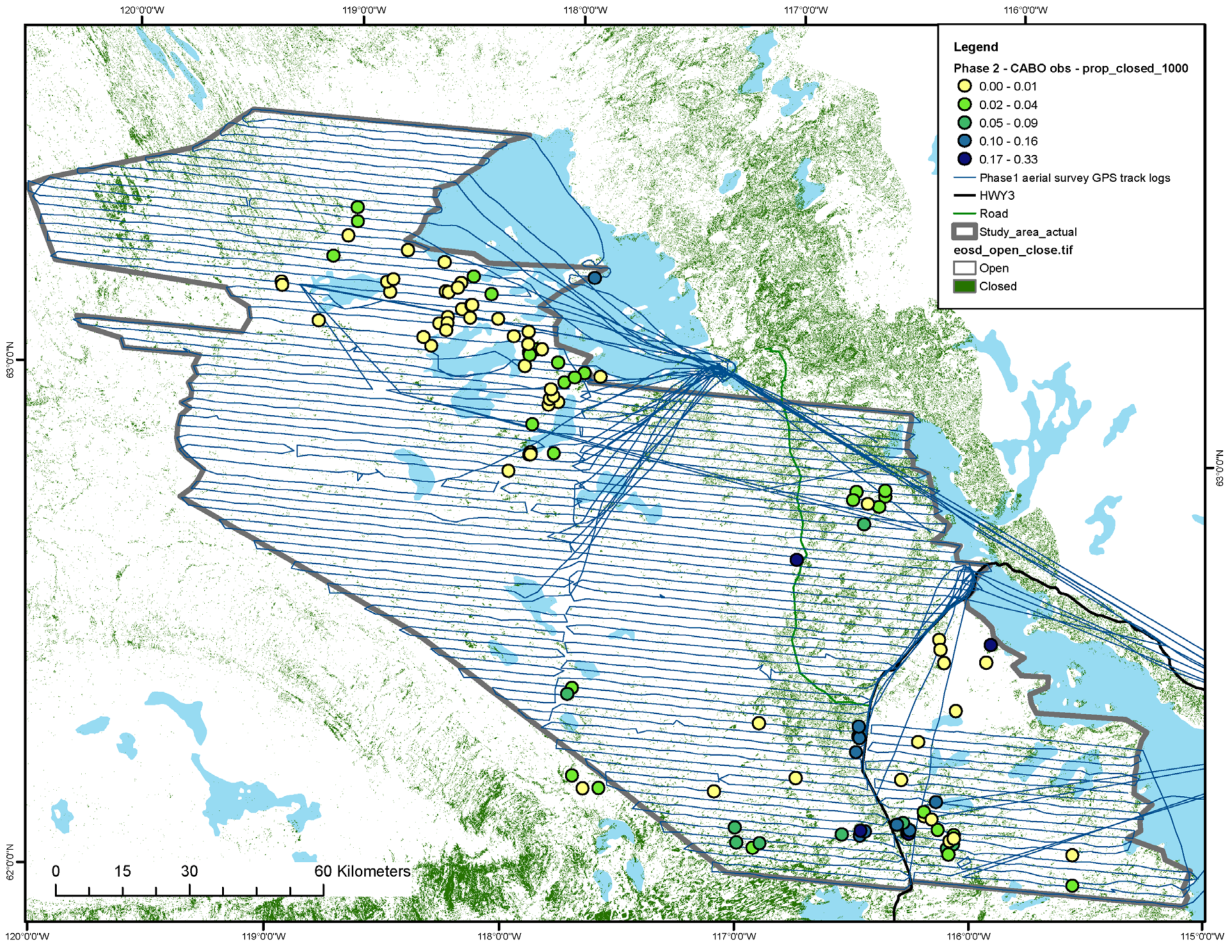


Figure B-3. Open- and closed-canopy land cover classes across the study area with the percent of closed canopy land cover classes in a 1,000 m buffer around each group of caribou observed during phase 2 of the boreal caribou abundance survey between February 20-March 02, 2020.

The RSF score was derived from a 30-m resolution raster of the relative likelihood of boreal caribou habitat selection predicted from a mid-winter RSF model (DeMars et al. 2020). Predicted RSF values were binned into 10 categories with 1 representing areas most likely to be avoided, and 10 representing areas most likely to be selected. The RSF model included land cover types, binned by upland versus lowland and further broken down into different age categories (years post-wildfire) by decade. The RSF model also included covariates for proximity to human disturbances including roads, settlements, and other polygonal disturbances, and a covariate for the density of linear features. The mid-winter mean RSF value was calculated for the area within a 1,000 m radius around caribou observations.

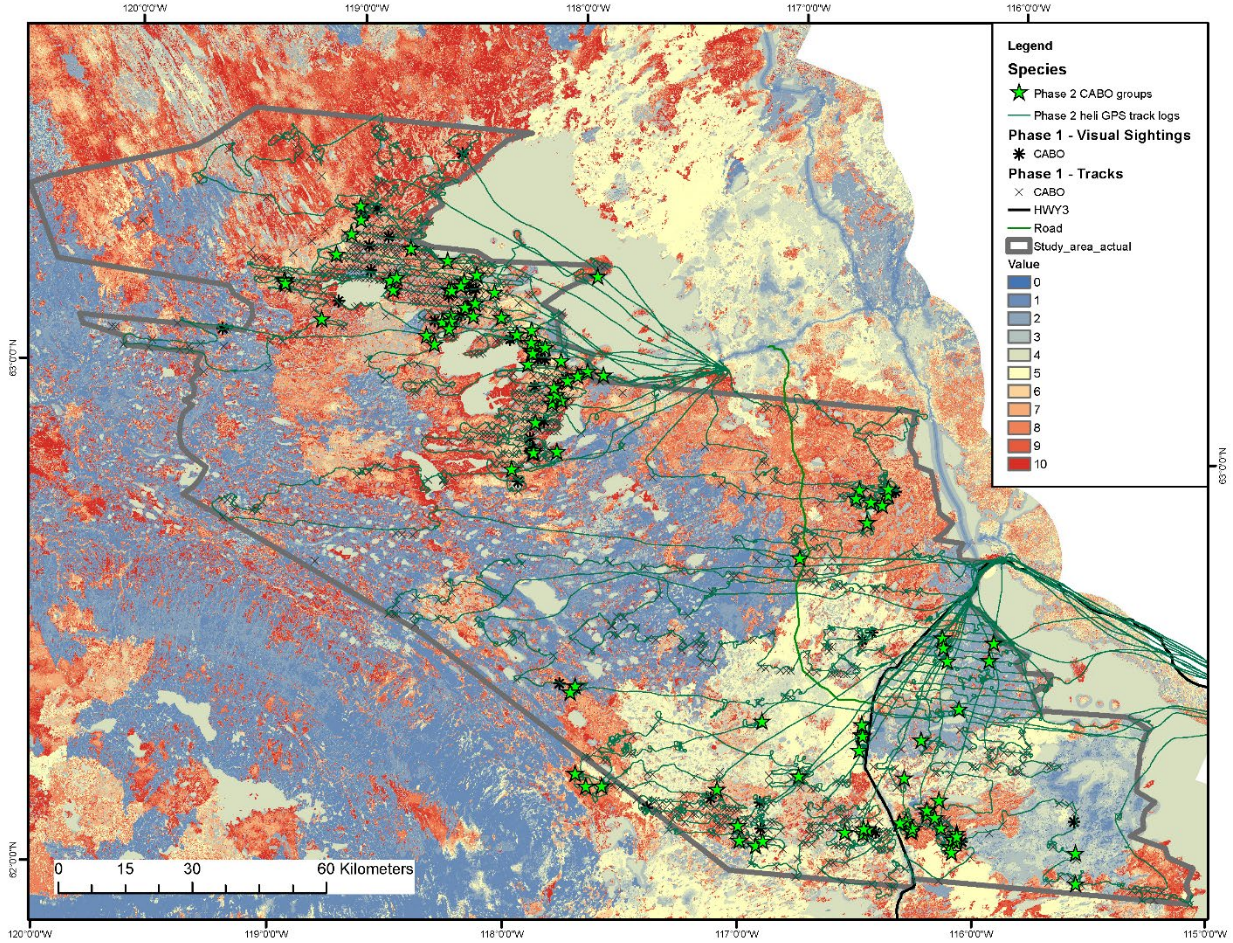


Figure B-4. Predicted RSF values across the study area (red is more preferred habitat; blue is less preferred habitat) with the flight paths and caribou tracks from phase 1, and observations of caribou groups from phase 2 of the boreal caribou abundance survey between February 20-March 02, 2020.

Logistic regression (Hosmer and Lemeshow 2000) was used for this analysis, which provided an estimate of sightability for each observation in the dataset. Information theoretic methods (Burnham and Anderson 1998) were used to determine the most parsimonious logistic regression model. Receiver operation characteristic curves (ROC) were used to asses overall model fit (Boyce et al. 2002).

We note that the logistic approach uses caribou groups rather than individual collared caribou as the sample unit (so it differs from the Courtois et al. (2003) approach in that it uses the ratio of collared caribou to estimate sightability). This approach is more statistically appropriate since it is likely caribou within a group are non-independent.

Sightability Model to Estimate Phase 2 Abundance

We then applied a sightability model to provide an alternative estimate of abundance for phase 2. Abundance was estimated approximately as the summation of each group size divided by the estimated detection probability for observations that were to be used in the survey. This is the standard Horvitz-Thompson (HT) estimator of abundance that is used in abundance estimation. This HT estimator is used to estimate abundance in distance sampling (i.e., double observer methods), mark-recapture estimation (McDonald and Amstrup 2001), and sightability models (Steinhorst and Samuel 1989, Fieberg 2012).

We used the R *SightabilityModel* package (Fieberg 2012) for the analysis, which uses a modified HT estimator to estimate abundance that accounts for covariances between logistic regression parameters. A bootstrap method was then used to provide standard error of phase 2 abundance estimates. Additional analyses were conducted using the *ggplot* (Wickham 2009), *ddply* (Wickham 2011), *pROC* (Robin et al. 2014), *AICmodavg* (Mazerolle 2016), and base statistical functions in *R* statistical package (R Development Core Team 2009). Data was plotted using QGIS software (QGIS Foundation 2020).

Estimation of Total Abundance and Variance using Courtois et al. (2003) or Sightability Model Methods
Formulas for estimation of variance for the Courtois et al. (2003) method were not presented in the original manuscript on the method (Courtois et al. 2003). We therefore derived estimates of variance for phase 2 using the Courtois et al. (2003) method and the total estimate that combines phase 1 and 2.

Phase 1 can be conceptualized as a series of binomial trials of the 35 available collars where the tracks of a subset are detected. Using this approach, we derived an estimate of binomial variance and associated standard error. We believe this was the method used by Courtois et al. (2003).

For the Courtois et al. (2003) method, we note that estimation of phase 2 abundance can be thought of as a two-sample mark-recapture estimate where m_2 collars are available for detection with n_1 collars being observed along with non-collared caribou observed during the survey. Using this approach allows a variance estimate for the phase 2 portion of the survey using the Lincoln Petersen mark-recapture estimator (Thompson 1992).

The sightability model approach provides an estimate of abundance for phase 2 using the R sightability model package and associated bootstrap estimator as described previously.

To obtain a total estimate using the estimate of global sightability, estimates from phase 2 using the Courtois et al. (2003) or sightability model were then divided by $\hat{p}_{phase1}$. Variance for the combined phase 1 and 2 survey was then derived using the delta method (Buckland et al. 1993). Log-normal confidence limits were then estimated.

Results

Survey Overview

The survey was conducted between February 19 and March 2, 2020. An incident with of one of the fixed-wing aircraft just prior the start of the survey and limited availability of a replacement aircraft resulted in the study area being reduced to 21,071 km^2 (Figure B-5). Areas eliminated from the survey were Block 2 in the northeast portion of the study area (east of Lac la Martre) where a relatively recent fire had occurred and based on previous surveys and radio-collar data, the likelihood of finding caribou was considered to be low. There were also portions of some survey transects that could not be completed due to poor weather and visibility associated with ice fog (in Blocks 1 and 3), and due to time constraints for completing the survey (southern portion of Block 5; see Figures B-1 and B-2). Fourteen transects in the northern part of survey Block 5 were completed by the helicopter, and only visual sightings of wildlife (not tracks) were recorded in this area (compare Figures B-3 and B-4). Daily flights, weather conditions, and crews are detailed in Supplementary Material B-1.

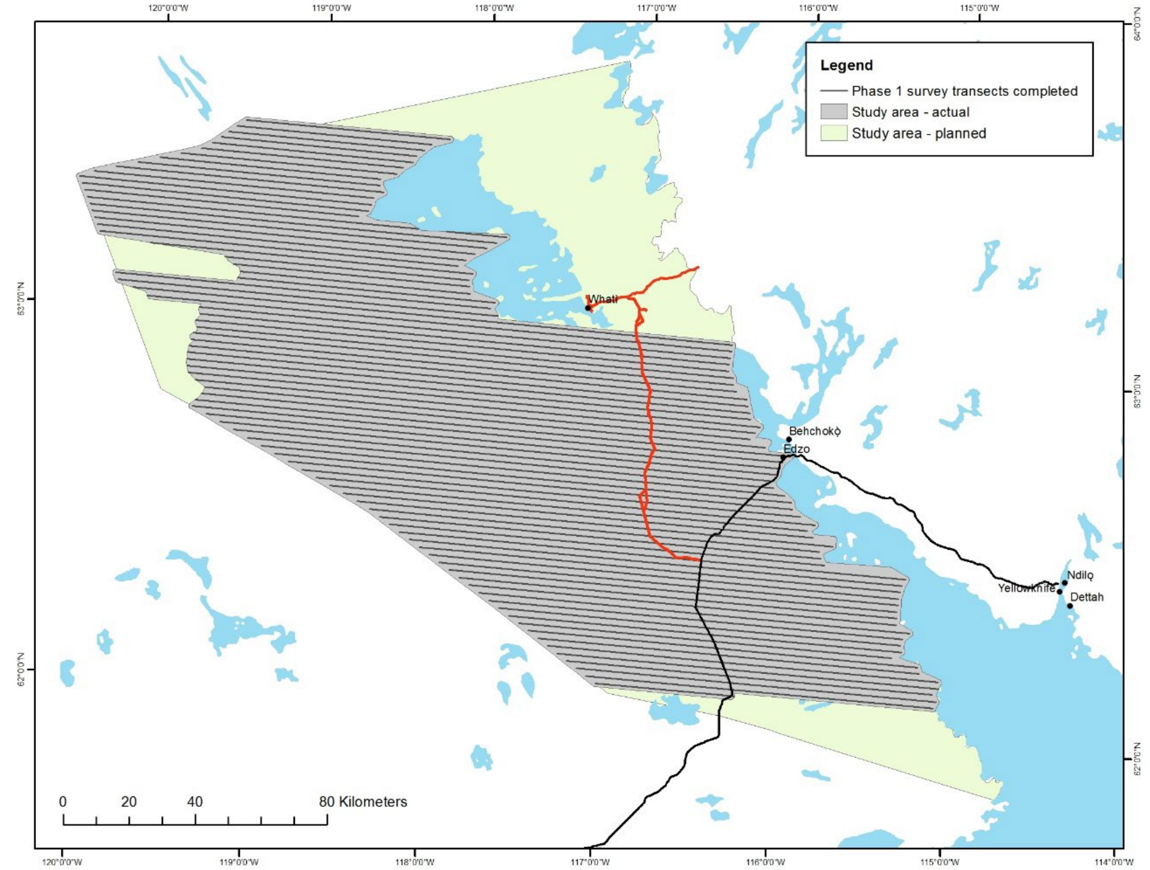


Figure B-5. Actual study area (grey polygon) and transects (lines) surveyed between February 19-28, 2020, by two fixed-wing aircraft for sightings and tracks of boreal caribou, other ungulate and carnivore species.

Phase 1

The phase 1 survey was flown with a Bush Hawk and DHC-2 Beaver (when available) along survey lines spaced 2 km apart, at altitudes ranging from 97 to 172 m and a speed of approximately 90 knots (167 km/hr; ranging from 124 to 212 km/hr). Community observers included Tłı̨chǫ community members from Whatì and Behchokǫ, and members of the YKDFN and NSMA. Crews and dates of participation are detailed in Supplementary Material B-1. The survey was flown on nine days and took 82.6 hrs total to complete. The Bush Hawk flew on February 19-25, 27 and 28. The DHC-2 Beaver flew on February 22, 23, 27 and 28. The DHC-2 Beaver also flew some lines at the southern end of the planned study area on February 25, but data from these lines has not been included in this report as the helicopter was not able to cover that area during phase 2 due to time constraints. February 27 and 28 were partial survey days and no survey was flown on February 26, due to poor weather (Supplementary Material B-1). Weather and observing conditions ranged from fair to excellent and were considered adequate for detecting wildlife and tracks.

A total of 10,109 km were flown along 154 transects that ranged from 1 km to 122 km in length (including those transects flown by the helicopter, not shown in Figure B-6). We observed 172 caribou in 39 groups ranging in size from 1-12 individuals and recorded a total of 910 tracks/sightings (Table B-2, Figure B-6). In addition, we recorded 189 wood bison in 25 groups (1-23 individuals/group), and 58 moose in 41 groups (1-3 individuals/group). Seven grey wolves were observed in five groups of 1-2 individuals/group, and wolves were the most common carnivore species in the area based on tracks. Fox, lynx, and wolverine tracks were also recorded (Table B-2). Forty-three unidentified tracks were mainly ungulate, however, of the two unidentified predator tracks one may have been cougar. All tracks were counted, regardless of proximity to another set, so tracks of one individual/group may have been counted several times. It should be noted that during phase 2, where the helicopter could fly slower, lower and could follow the tracks, it became evident that some of the tracks had been misidentified during phase 1 (e.g., several tracks marked as caribou turned out to be moose tracks). However, it is difficult to determine the degree of this error, as the phase 2 helicopter did not visit all observation locations for species other than caribou. Other wildlife or signs noted during the survey included snowshoe hare, spruce grouse, ptarmigan, and great grey owl.

The majority of phase 1 observations (where estimated distance was recorded) were within 200 and 400 m horizontal distance from the aircraft, although some ungulates were observed up to approximately 1 km away. Qualitatively, the vast majority of actual sightings/tracks of caribou and other wildlife were in open to semi-open areas; relatively few observations were associated with densely forested habitat.

Table B-2. Wildlife observations recorded during the boreal caribou abundance phase 1 survey in the Tłı̨chǫ ASR-NSR study area, February 19 to February 28, 2020.

Species	**Number of observations tracks/visuals**	**Number of individuals observed**	**Number of groups**	**Group size range**
Boreal caribou	910	172	39	1-12
Wood bison	288	189	25	1-23
Moose	467	58	41	1-3
Wolf	281	7	5	1-2
Fox	6			
Lynx	5			
Wolverine	6			
Unidentified tracks	43			

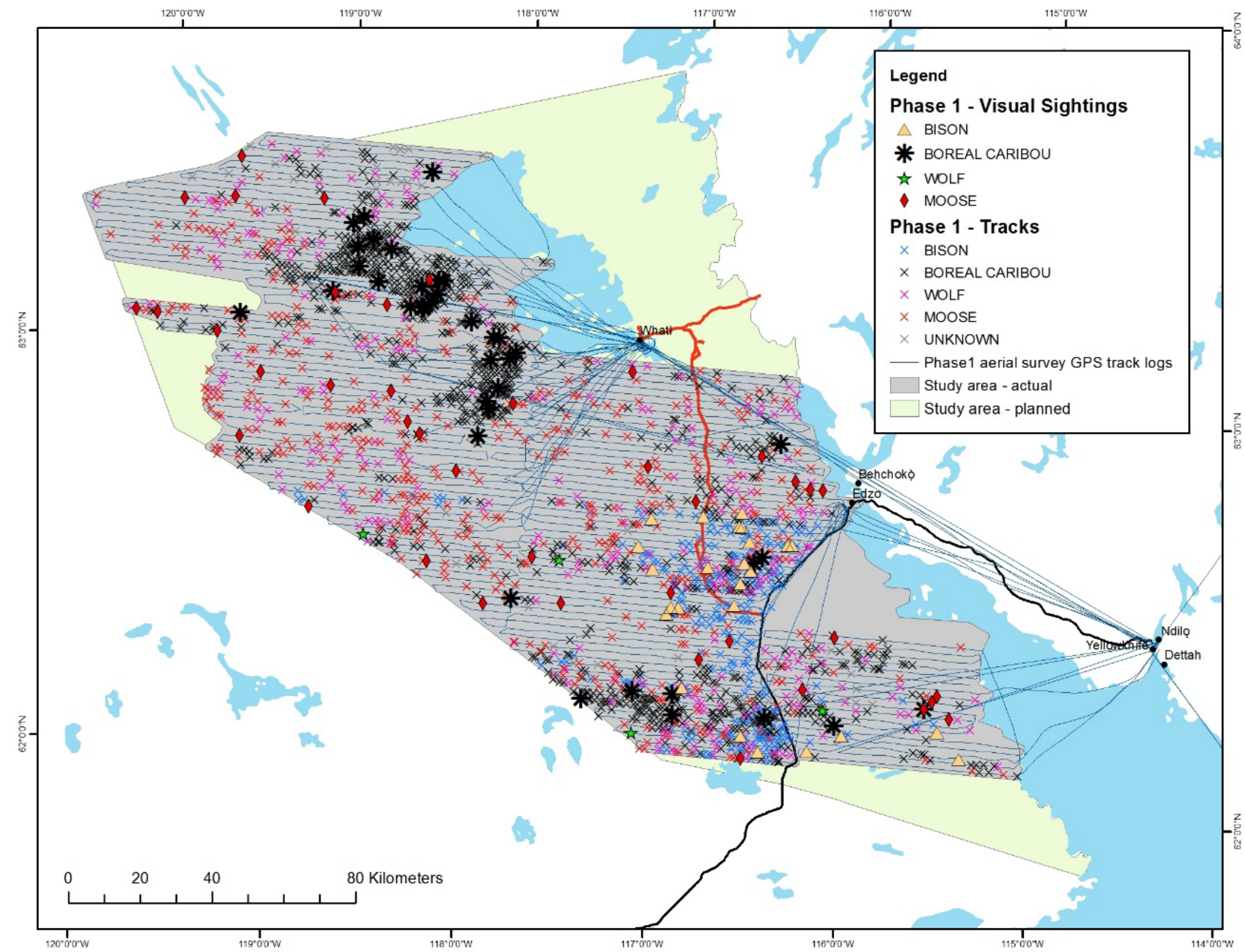


Figure B-6. Species observations (tracks and visual sightings made during phase 1 (fixed-wing) of the boreal caribou abundance survey between February 19-28, 2020.

Phase 2

Phase 2 surveys were conducted between February 20, 2020, and March 02, 2020, with no survey on February 26 due to poor weather. A total of 414 boreal caribou (218 cows, 122 bulls, and 66 calves) in 73 different groups were recorded visually by flying to the location of boreal caribou sightings and tracks recorded by the phase 1 survey crew and intensively searching the area (Table B-3, Figure B-7). Initially, flying in phase 2 focused on following the tracks identified by phase 1, but without much success. We then switched to a strategy of re-flying the portions of transects covered in phase 1 that had caribou tracks recorded on them and flew additional lines in between the 2 km spaced lines in areas where there were a lot of caribou tracks recorded in phase 1. We seemed to have more success at encountering caribou groups this way then breaking off the line to follow every track that looked reasonably fresh.

Eight collared boreal caribou were located visually within these groups without the aid of telemetry. An additional 163 boreal caribou (97 cows, 37 bulls, and 26 calves) were counted inside the study area by locating groups with collared boreal caribou (n = 26) by telemetry as well as other groups (n=5) found incidentally while searching for the collars that would have otherwise been missed by the visual surveys. The total number of boreal caribou counted within the study area was 577, resulting in a minimum density estimate of 2.74 caribou/100 km^2. Fifteen additional caribou were counted in three groups, each containing one collared female, which were located by telemetry just outside of the western study area boundary, in an area that was not covered by the phase 1 surveys (Figure B-7). These caribou were not included in the minimum density estimate.

Based on all of the boreal caribou counted and classified, the calf: cow ratio was 28:100, and the bull: cow ratio was 49:100. Group sizes of caribou varied between 1 and 16, with a mean group size of 5.5. The phase 2 survey crew also recorded 219 bison in 28 groups, 61 moose in 43 groups, one wolverine, and nine wolves in two packs (two and seven individuals), one of which was on a moose kill site (Figure B-7). One lynx and one great grey owl were also recorded, as were numerous spruce grouse (not counted).

Table B-3. Summary of phase 2 aerial survey results for boreal caribou conducted within the Tłı̨chǫ ASR-NSR study area between February 20 - March 02, 2020.

	Boreal caribou observations					
	Total number of groups	Total number of individuals	Cows	Bulls	Calves	Number of collared adult females
Detected visually	73	414	218	122	66	8 (7 groups)
Detected by telemetry*	31	163	97	37	26	26 (23 groups)
Total	**104**	**577**	**315**	**159**	**92**	**34 (30 groups)**

*Including caribou groups (n=5) found incidentally while searching for collared caribou using telemetry.

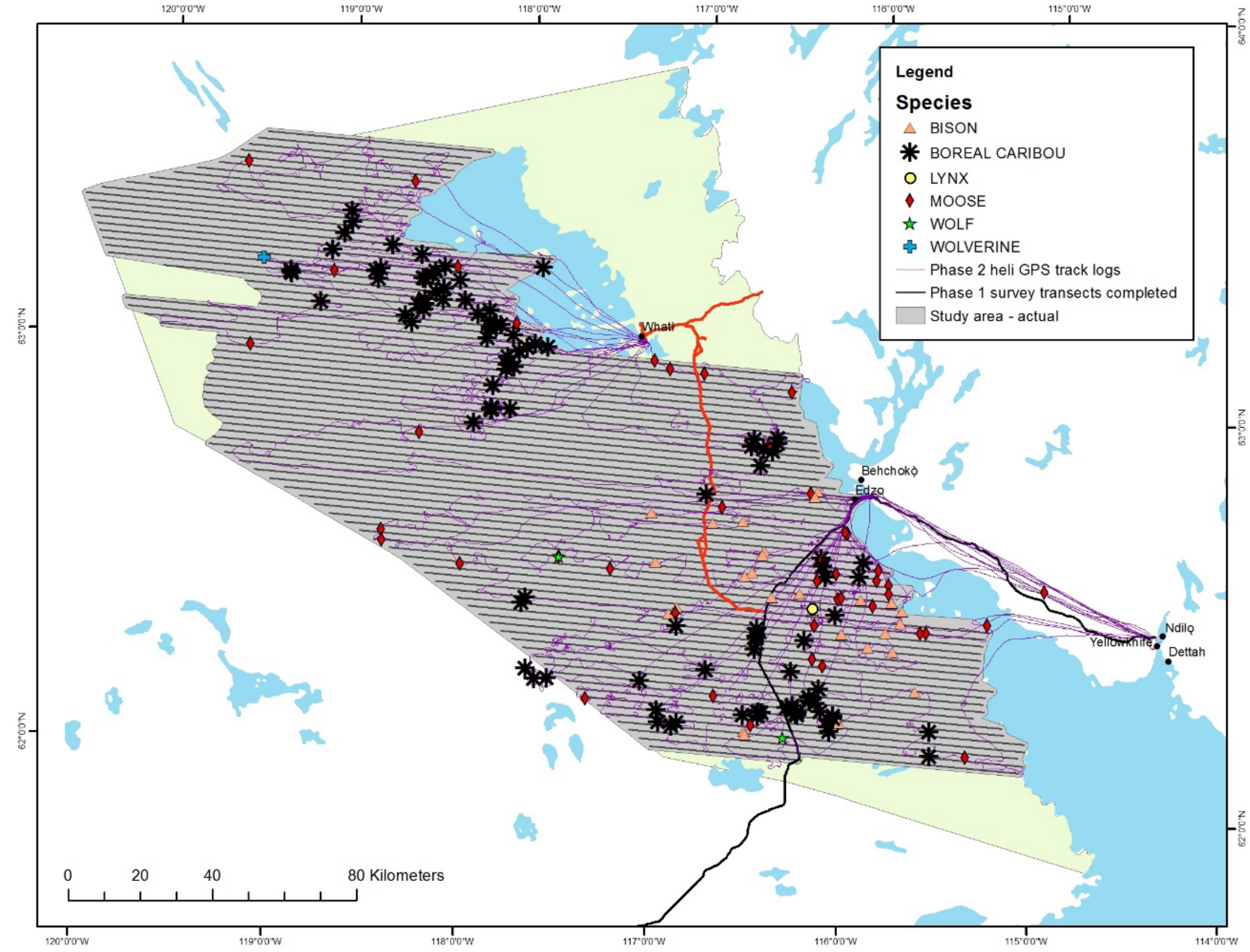


Figure B-7. Species observations made during phase 2 (helicopter) of the boreal caribou abundance survey between February 20-March 02, 2020.

Data analysis

Sightability Correction Factor using Courtois et al. (2003) Methods

A total of 35 occupation sites corresponding to movement paths of collared caribou occurred in the study area between February 20 and 28, 2020 (Table B-4, Supplementary Material B-2). Some occupation sites represent more than one occasion where a collared caribou was available to be detected. For example, if a collared caribou's movement path crossed more than one survey line that was surveyed on the same day, or consecutive daily movement path crossed several lines that were surveyed on consecutive days, it was deemed available to be detected at more than one occupation site (Supplementary Material B-2). Six of the 35 occupation sites with potential to be found during phase 1 contained two collared caribou. Twenty-one sites of the 35 were determined to be found during the phase 1 survey, suggesting a 60% detection rate. Fifteen of the 21 found sites were found based caribou tracks or cratering and six were found based on visual sightings of groups of caribou. Of the occupation sites that were not found during the phase 1, one was found visually during phase 2. Twenty collared caribou occurred at the 21 occupation sites that were found. During the phase 2 survey, we were able to locate and count groups of boreal caribou at 6 of the 15 occupation sites that were detected based on tracks during phase 1. Of the six occupation sites that were identified during the phase 1 based on sightings of groups of caribou observed, two were relocated visually in the phase 2 survey and the collared individuals in both of the groups were visually detected. Therefore, groups of caribou at 8 of the 21 occupation sites (i.e., 38%) identified in the phase 1 were found visually during the phase 2 (6/15 track sightings and 2/6 visual sightings). A visual detection of eight collared caribou out of the 20 unique collared caribou at the occupation sites found in phase 1, yielded a phase 2 sightability rate of 40% (8/20). Thus, the global sightability rate is estimated at 24% (0.6 x 0.4).

Table B-4. Phase 1 and 2 sightability survey results.

Phase 1	
Occupation sites found (S_1)	21
Occupation sites with potential to be found (S_2)	35
Sightability sate ($\hat{p}_{phase1}$)	0.60
	20
Phase 2	
# of collared caribou observed visually during flight (n_1)	8
Number of unique collared individuals at occupation sites found in phase 1	20
Total number of collared caribou in study area (m_2)	34
Sightability rate ($\hat{p}_{phase2}$)	0.4
Global sightability rate	
$\hat{p}_{phase1}$ x $\hat{p}_{phase2}$	0.24

Modelling of Survey Detection Rates and Application of Sightability Models

Test of Distributions of Collared Caribou Relative to Non-collared Caribou

We used contingency chi-square tests to formally test whether the distribution of groups relative to the percent of closed canopy land cover classes within a 1,000 m buffer (which influenced sightability) were independent of whether the groups had a collar in them. Figure B-8 shows observed versus expected values (assuming independence between groups with and without collars). Collared groups included phase 2 groups that were visually observed and groups that were detected by radio-tracking. It can be seen that observed values for collared groups increase with cover whereas they decrease for non-collared groups. Also, the expected values are higher for the lowest cover class bin for collared groups and lower for non-collared groups. The distribution of collared and non-collared groups were significantly non-independent using a chi-square test ($\chi^2 = 11.3$, df = 2, $p = 0.0035$) or a Fisher exact test ($p = 0.00234$). The Fisher exact test may be more appropriate given low expected values in the collar group.

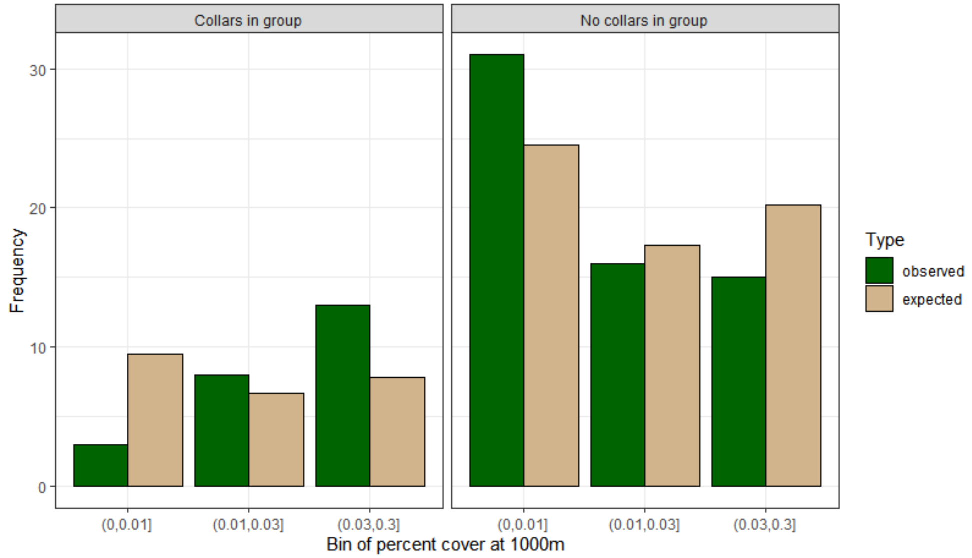


Figure B-8. Distribution of collared and non-collared groups relative to binned cover classes (based on the percent of closed canopy land cover classes within a 1,000 m buffer).

A similar test was conducted using mid-winter mean RSF values to see if collared groups were selecting habitat differently than non-collared groups (Figure B-9). Results suggested there was no difference using chi-square ($\chi^2 = 0.93$, df = 2, p = 0.6276) or a Fisher exact test (p = 0.6275) in habitat selection. Mid- and late-winter RSF values were closely correlated so the same result will occur using late-winter RSF.

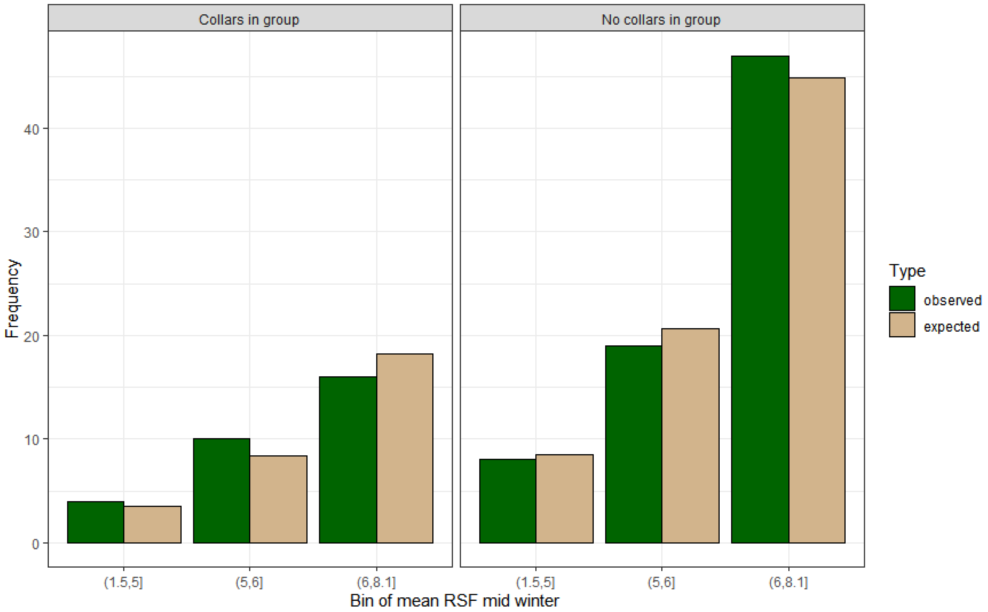


Figure B-9. Distribution of collared and non-collared groups relative to binned RSF values (based on mid-winter mean RSF values within a 1,000 m buffer).

A question was whether there was selection pressure for higher canopy cover classes, which may also have caused some groups to occur in areas of higher cover. There is not a strong relationship between percent cover and RSF score, suggesting that caribou were not detected in higher cover due to habitat preference. There is a wide range of land cover types that are present in the higher mid-winter RSF bins, and the higher mid- and late-winter RSF bins are more related to age class than to canopy closure.

A related question was whether collared and non-collared groups were more likely to be visually detected in areas with more open canopy cover or higher RSF scores (Figure B-10). Collared groups did not show a strong relationship between percent cover or RSF score. Non-collared groups were more likely to be detected in areas with more open canopy cover. Most caribou detections occurred in areas with mean RSF values of five and higher. Non-visually detected caribou in non-collared groups were located in areas with higher canopy cover than detected non-collared observations, but the sample size (8) is small.

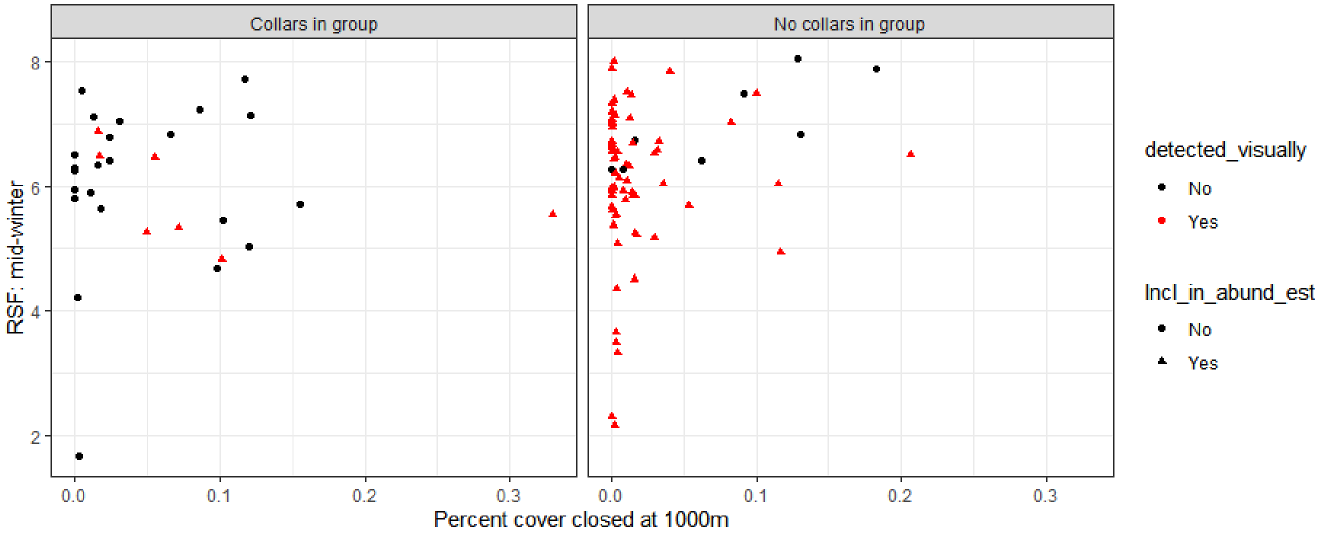


Figure B-10. Mean mid-winter RSF value within a 1,000 m buffer vs percent of closed canopy land cover classes within a 1,000 m buffer for collared and non-collared groups, that were detected visually or not detected visually (i.e., found via radio-tracking or while radio-tracking other groups).

In summary, these results indicated that collared and non-collared groups were similarly distributed based on habitat quality (RSF, Figure B-9), but sightability is influenced by canopy cover (Figure B-10). Non-collared groups were more likely to be observed in open habitat and observed values decreased with higher cover (Figure B-8), whereas the opposite was true for collared groups, where observations (including radio-tracked groups) increased with canopy cover class (Figure B-8). This result could partially be due to the detection of collared groups independent of canopy cover by using radio-tracking, whereas radio-tracking of non-collared groups in areas with lower sightability was not possible.

It is difficult to assess this issue completely especially given the relatively low sample size of collars. Regardless, estimates using a mean sightability based on collars could be biased if the distribution of collared groups relative to cover differed than non-collared groups. We therefore pursued sightability models to model variation in sightability due to differences in cover class to control for this potential source of bias and variation.

Analysis of Factors Influencing Sightability in Phase 2

Using only Collared Caribou Groups

For phase 2, there were 30 observations of groups with collared caribou with seven groups being sighted visually and 23 being found using telemetry. We included collars not seen in phase 1 (so that the total collars sum to 34).

Assessment of the distribution of collared groups by cover class suggests there are more observations in areas with lower canopy cover and the proportion detected is low suggesting low collar detection probability even when canopy cover is low (Figure B-11). We suspect this result could be due to low sample sizes of collared caribou groups, and because boreal caribou are challenging to detect on the landscape.

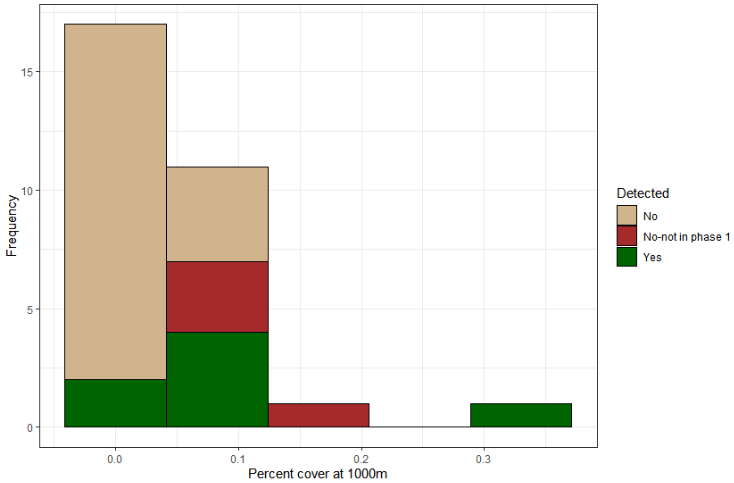


Figure B-11. Detection frequencies of collared groups as a function of percent closed canopy land cover classes within a 1,000 m radius around observations.

No significant relationships were detected in the logistic regression analysis.

Using Collars, Supplemental Observations, and Non-collared Groups

In the second analysis, we included additional groups that were not sighted to boost sample sizes. Therefore, the non-sighted groups included collared groups (23), groups seen while looking for collars or groups seen based on tracks (eight groups total). In addition, groups sighted without collars were included which amounted to 66 groups. Groups that were observed out of the study area or located only by telemetry (No2 and No3 in the database) were not included in the analysis.

We note this approach assumes that the sample of detection/non-detections still represents sightability; or, in other words, the non-detected caribou groups were adequately represented so that the relationship between percent cover or other covariates and sightability represents the larger population of caribou. To do this, we assumed that non-detected groups of non-collared caribou were adequately represented by the eight non-collared caribou groups that were detected when radio-tracking collared caribou. Given the low rate of detection of collared caribou, it is likely that many non-collared caribou were similarly not detected on the landscape, without (and with) the additional searching associated with radio-tracking. Although non-detected groups are obviously under-represented in our dataset, we took this approach to best present options for understanding the data. A plot of percent cover with detection type for this data set had higher frequencies in the open cover class in comparison to the collar-only data set (Figure B-12).

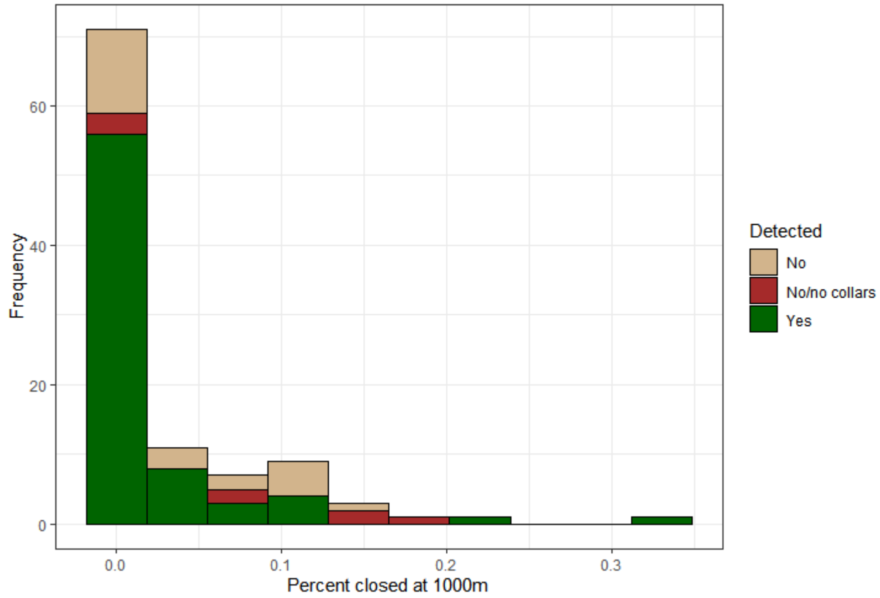


Figure B-12. Distribution of caribou (collared and non-collared group) as a function of percent of closed canopy land cover classes within a 1,000 m buffer. Whether caribou groups were detected is noted as sub-bars. Data includes caribou groups inside the study area, including collared and non-collared groups that were detected without radio-tracking ("yes"), groups that were collared but <u>not</u> visually detected (without radio-tracking; "no") and groups that were not collared but located using tracks when radio-tracking other groups ("no/no collars").

Logistic regression was then used to assess dominant factors influencing sightability. The most supported model had percent closed canopy land cover classes within a 1,000 m buffer as a significant predictor.

Table B-5. Model selection for sightability analysis using the full dataset. Sample size adjusted (AICc), the difference in AICc between the most supported model for each model (ΔAIC_c), AIC_c weight (w_i), number of model parameters (K) and log-likelihood.

Model	**AIC_c**	**AIC_c**	**w_i**	**K**	**LL**
pctcover1000	125.20	0.00	2	0.40	-60.54
pctcover1000+groupsize	127.30	2.10	3	0.14	-60.53
pctcover1000+loggroup	127.32	2.12	3	0.14	-60.54
pctcover500	128.09	2.89	2	0.09	-61.99
constant	128.76	3.56	1	0.07	-63.36
RSF	129.83	4.63	2	0.04	-62.85
pctcover1000^2	129.90	4.69	2	0.04	-62.89
groupsize	130.51	5.31	2	0.03	-63.20
pctcover200	130.62	5.42	2	0.03	-63.25
loggroup	130.64	5.44	2	0.03	-63.26

Parameter estimates for the percent cover model were significant at $\alpha = 0.05$ (Table B-6).

Table B-6. Parameter estimates for percent closed canopy land cover classes within a 1,000 m buffer.

Logistic regression model				
Term	**Estimate**	**SE**	**z value**	**Pr(>|z|)**
(Intercept)	1.19	0.27	4.44	0.0000
pctcover1000	-9.37	4.19	-2.24	0.0254

A plot of the predictions reveals a range of detection probabilities with the most confidence at lower cover classes (where most of the observations occurred) resulting in a mean detection probability of 0.71 (Figure B-13). The mean sightability is based on just collars (using proportion of collars detected was 0.4) so most observations have higher detection rates then this estimate.

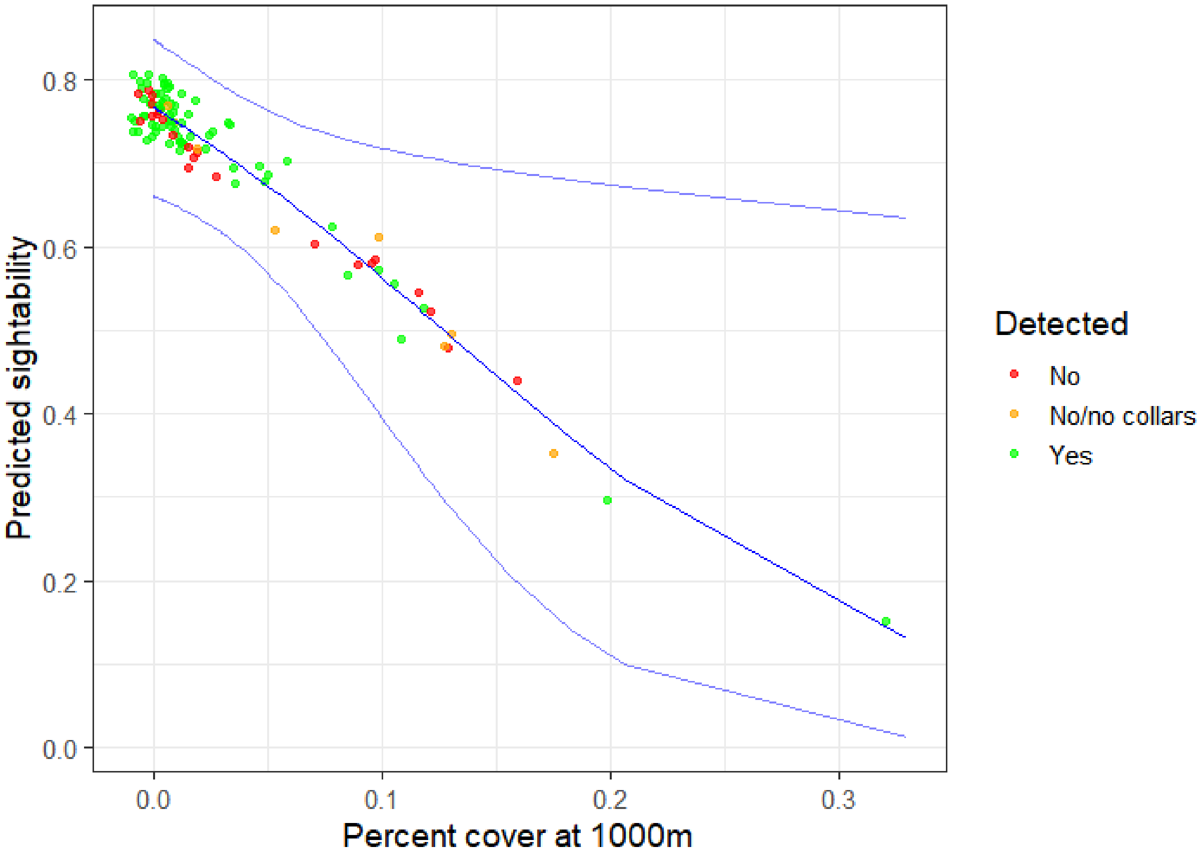


Figure B-13. Prediction plot for sightability as a function of percent closed canopy land cover classes within a 1,000 m buffer with detection type noted. The blue line is the predicted curve from logistic regression (with confidence limits denoted). Observation points are offset vertically from the prediction line to show spread of cluster prediction points.

The ROC score for the percentage cover model was 0.65 which suggests satisfactory but not optimal predictive ability of the logistic model. This was likely due to lack of data points at higher cover class values.

A map of predicted sighting probabilities with survey tracks and observations during phase 2 is shown below. Basically, each observation is assigned a sighting probability based on the percent cover that it occurred in. The dataset includes some observations where caribou were located using collars, etc. Only the yellow-highlighted observations (which are the include_in_abundance = yes) are used for estimates with the other observation used to model sightability.

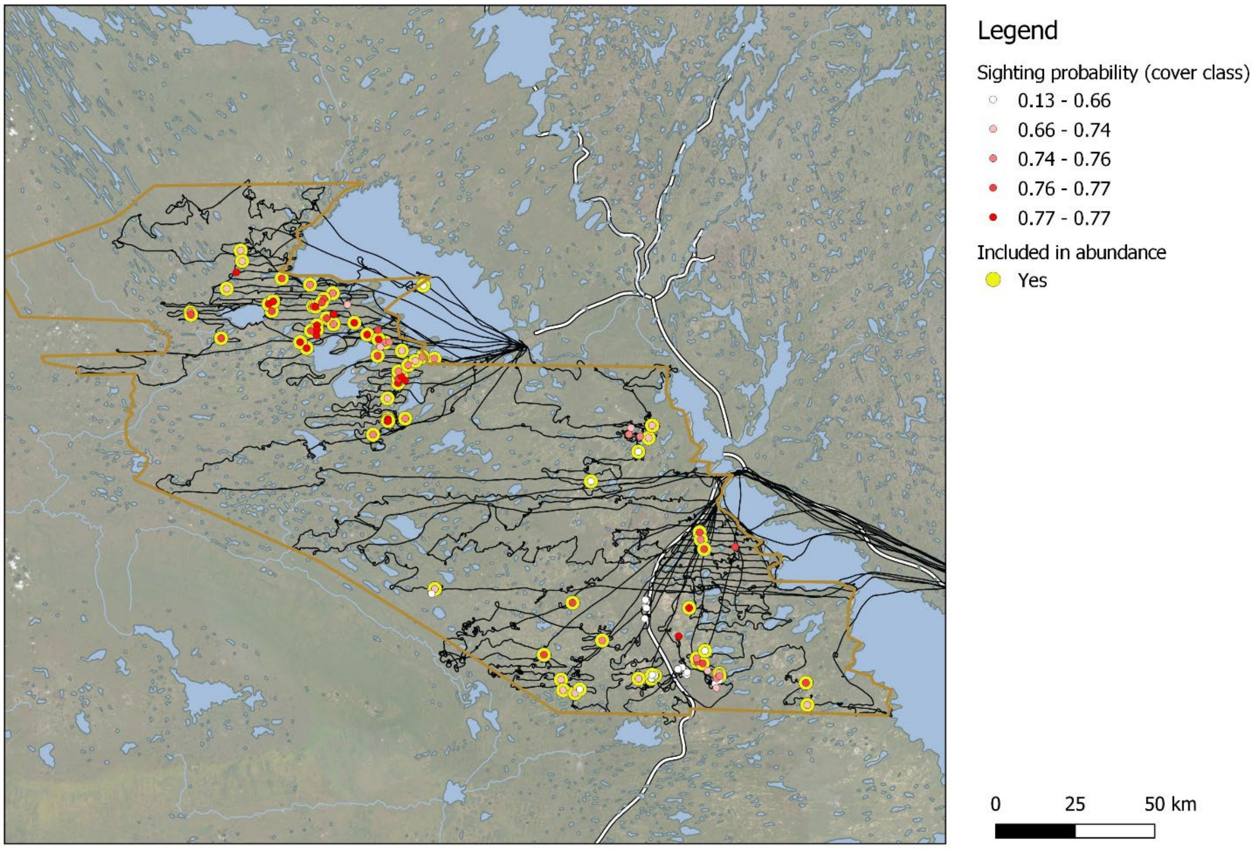


Figure B-14. Predicted sighting probabilities for each observation during phase 2. Also shown are the flight paths. Observations that were included in the abundance estimate are highlighted in yellow.

Abundance Estimates

Phase 1 Sightability

For both approaches, the phase 1 estimate of proportion units surveyed (based on proportion collars detected) was 0.6. This was based upon detecting 21 of 35 tracks of collared caribou groups. A binomial-based estimate of standard error was 0.083 (CV=0.138). Phase 2 abundance was then estimated using the Courtois et al. (2003) and sightability model approach.

Phase 2 Abundance Estimates

The total number of caribou observed visually "on survey" was 414 in phase 2. If caribou that were observed using telemetry are included the total is 577.

Courtois et al. (2003) / Lincoln-Petersen Estimate

The Lincoln-Petersen estimate of caribou was based on eight detections of 20 collared caribou total with 414 caribou observed visually in phase 2. The resulting estimate for phase 2 was 1,035 caribou (CV = 0.23).

Sightability Model Estimate

The estimate of abundance for phase 2 using the R *SightabilityModel* package (Fieberg 2012) and using percent cover as a sightability covariate was 579 (SE = 179, CI = 457-1,779). Precision was low (CV = 0.31), which was presumably due to uncertainty in detection when cover class was high.

Final Survey Abundance Estimates

Table B-7 provides total estimates using the Courtois et al. (2003) and sightability model approach. In each case the final estimate was the phase 2 abundance estimate divided by phase 1 sightability (0.6). As discussed later, the main reason for the large difference in estimates is that the Courtois et al. (2003) method estimates a single detection probability for phase 2 (of 0.4) based on the collar-only data set that was detected in areas of higher cover class compared to the visually detected caribou. In contrast, the sightability method used a broader dataset to estimate sightability based on percent of closed canopy cover class. However, the sightability estimate is based upon supplemental data sources, which may not be completely indicative of the range of sightability in the survey area. Considering the range of estimates provided by these methods, we provide a caribou abundance of 965-1,725 in the survey area. This provides a mean density estimate of 4.6 – 8.2 caribou per 100 km^2 within the 21,071 km^2 study area.

Table B-7. Estimates of total caribou using the sightability model and Courtois et al. (2003) method based on phase 2 estimates divided by proportion sites with collars surveyed as estimated in phase 1.

Method	**Phase 2 estimates**			**Phases 1 and 2 estimate (N_{phase2}/p_{phase1})**				
	Caribou sighted	**N_{phase2}**	**CV**	**N**	**SE**	**Conf. Limits**		**CV**
Sightability model	414	579	0.31	965	326.7	506	1,842	0.34
Courtois/LP	414	1,035	0.23	1,725	467.4	1,023	2,908	0.27

<u>Discussion</u>

Field Survey Conditions

Field survey conditions in 2020 may have influenced the low detection rates of caribou. Based on weather station data from the Whatì airport, the last major snowfall (>1 cm) prior to the survey occurred on February 13, 2020 (six days before the survey started). With no recent snowfall, there were several days for caribou track networks to accumulate, and it was difficult to discern between fresh tracks and older tracks during both survey phases. The phase 1 survey did not consistently distinguish between old versus fresh tracks, and therefore the phase 2 survey investigated all caribou tracks recorded during phase 1. Considerable time was spent following tracks that may have already been a few days old at the time they were investigated, and in some cases there were considerable networks of tracks that had accumulated in a small area making it difficult to discern which were the most recent ones to focus and which direction the caribou may have been travelling.

NWT Conditions

Our global sightability rate (0.24) was much lower that the 0.85 sightability rate obtained by Courtois et al. (2003) in their development of this survey method. Based on a review of reports from five surveys conducted in Quebec that used the Courtois et al. (2003) method, phase 1 sightability rates ranged from 0.88 to 1.00, phase 2 sightability rates ranged from 0.6 to 0.81, and global sightability rates ranged from 0.58 to 0.85 (Courtois et al. 2001; Heppell 2019, 2020; Heppell and Boissonneault 2021; Brodeur et al. 2022). One notable difference between the results of the surveys in Quebec and our NWT survey is that caribou group sizes tended to be much larger than we observed. Fewer, larger groups of boreal caribou within a study area may be easier to detect than many small groups of caribou dispersed across the same area. Maximum group sizes reported from the surveys in Quebec ranged from 14 to 85 caribou (Heppell 2020; Brodeur et al. 2022), and average group sizes ranged between 5.4 and 17 (Heppell 2020; Heppell 2015). In our survey, caribou occurred in groups of 1 to 16 individuals, with a mean group size of 5.5.

Another factor that may have contributed to higher sightability rates in Quebec is the colour of belting used on GPS collars. Heppell et al. (2021) attributed the lower sightability rate (0.60) obtained in their 2021 surveys in the Manicougan study area when compared to a 0.81 sightability rate obtained in an adjacent area in 2019 to the use of paler-coloured belting on the colours (yellow and red) in the 2021 surveys compared to bright orange belting on collars used in the 2019 surveys. In the NWT, all of the GPS collars in the study area had beige belting. It is unlikely, however, that the colour of collar belting played a large role in our low detection rates of groups with collared caribou. For our survey, the main source of detection bias seemed to be whether a group of caribou containing a collared individual was detected visually or not, rather than the ability to count all of the caribou in a group once it was detected. Where a group of caribou containing a collar was detected visually, we always managed to see the collared caribou in the group as we were classifying individuals.

The number of collars present in our study area (n = 34) exceeded the number of collars used in the Quebec surveys referenced above (15 to 32 collars per study area) to estimate sightability rates, and some of those surveys covered much larger areas (up to 50,094 km^2) than the Tłı̨chǫ ASR-NSR study area (21,071 km^2). Therefore, our sample size of collared individuals available to estimate detection rates appeared to be reasonable, compared to the Quebec surveys.

Distributions of Caribou Relative to Cover Class (and Sightability)

The assumption of similar distributions of collared and non-collared groups relative to factors such as cover class that influence sightability is critical for unbiased estimates. For example, if collared caribou are distributed in areas of higher cover (and lower sightability) relative to other caribou then the mean detection probability for phase 2 will be low leading to a positive bias in estimates. Meeting this assumption becomes more problematic when sample sizes of collared caribou are low relative to population size. For example, in this study there were 34 collars within a population size varying from 965-1,725. In this case, only 1.9-3.5% of the population was collared. So, the Courtois et al. (2003) method is relying on these 34 caribou being distributed in a similar way to all other caribou in the population to obtain an unbiased estimate. It is for this reason that we tested similarity of distribution of collared caribou groups relative to other caribou and considered a sightability model to help control for the influence of cover class on sightability.

Comparison of distributions of collared and non-collared caribou (Figure B-8) suggests that collared groups were more likely to occur in areas of thicker cover. There are three explanations for these test results that are not mutually exclusive. First, collared groups may be more likely to occur in areas of high cover due to past capture history or capture bias towards certain age and sex classes that occur in forested areas. For example, bulls and yearlings that are not collared may occur in more open areas than collared cows with calves. In addition, past capture experience may make collared caribou more likely to seek cover due to airplane or helicopter noise associated with phase 1 and 2 of the survey. Second, it is possible that collared groups were more detected in these forested areas compared to non-collared groups due to sightability (because if not visually detected, they were radio-tracked) rather than distribution. So, the true distribution of caribou is better reflected by the collared groups than the visual only groups. Thirdly, the relatively low sample size of collars relative to overall population size could cause a given distribution of collars to be non-indicative of the population by chance alone. If explanation #2 is more likely, then estimates of sightability will not be biased. If explanation #1 is more likely, then mean estimates of sightability used by the Courtois et al. (2003) method will display a negative bias due to collared groups preferring areas of thicker cover. If explanation #3 is more likely, then a positive or negative bias may result. These conclusions also assume that there is a gradient of cover in the study area that will affect sightability. It might be that in some areas, such as Quebec, cover has less influence on sightability, in which case the mean estimate method will suffice.

Comparison of collared and non-collared groups by RSF habitat score suggests no difference in distribution of groups; both groups were more likely to be detected in locations with higher RSF habitat scores (Figure B-9). However, there were more detections of non-collared groups in areas with a higher percent of open canopy cover than areas with more closed canopy cover (Figure B-10). So, either collared caribou were more likely to occur in areas of higher cover class or there were many caribou in dense canopy cover that were missed by observers. Regardless, the Courtois et al. (2003) method assumes that the collared caribou detection/distribution relative to areas of higher cover reflects sightability of the population.

The Sightability Model (Horvitz-Thompson estimator) Approach to Estimation

The sightability model approach to estimation of abundance attempts to model the variation in sightability due to percent of closed canopy land cover classes within a 1,000 m buffer to reduce the reliance on the assumption that collars are distributed similar to non-collared groups. In addition, it considers groups rather than individual collared caribou as the sample unit, which is more statistically appropriate given likely non-independence of collared caribou within groups. When sample sizes of collars are low it is possible that the distribution of collared caribou relative to cover may not represent all caribou in the population due to simple random chance.

The main assumption and additional requirement of the sightability model approach is adequate sample sizes of caribou to estimate a sightability curve. In the case of this study, sample sizes using just the collar data set were insufficient to model detection. We brought in other survey data to bolster the sample size (i.e., inclusion of non-collared groups) but recognize the limitations to this approach. Sightability models can incorporate data from multiple studies, and sightability models that combine data from multiple studies would be able to obtain more robust estimates given the usual low sample sizes of collars from single studies. If results of additional studies can be added to allow a more robust sightability model, that model can be applied across multiple surveys. Although this is the first boreal caribou abundance survey in the NWT, if this method was repeated, the sightability approach can utilize data from multiple surveys to improve sightability corrections and abundance estimates. In addition, additional survey transects could be flown that are dedicated to obtaining sightability data by designing those transects to include collared caribou in different habitat characteristics. This data could further augment the datasets from existing studies.

In this study we used data from groups observed via tracks and groups located by telemetry under the assumption that searching behaviour for these groups was similar enough to other groups that they still represented the likely sightability of caribou groups during a survey. The main question becomes whether the relationship that was detected (Figure B-13) would change if the survey had a higher number of collared caribou (particularly in higher cover classes). It is likely that inclusion of the non-collared groups (which were all observed, i.e., we don't have information about the non-collared caribou that were not observed, as we do for collared caribou) caused estimated detection probabilities to be higher leading to a conservative (negatively biased) estimate. We also note that the predictive ability of the model was satisfactory (ROC score = 0.65) but not optimal, which would be indicated by ROC scores above 0.7 (ideally 0.8 or higher). For these reasons we suggest that results of the sightability model including the estimates *be treated cautiously and in the context of a "pilot study".* We suggest that any future surveys collect additional data that can be used to develop a more robust sightability curve preferably using just data from collared caribou groups observed during the survey. If further data is collected it would also be possible to reconsider estimates from this study with a more robust dataset.

Additional Assumptions of the Courtois Method

An assumption of the two-phase Courtois et al. (2003) approach (that also applies to an approach that uses the HT estimator) is that all groups identified in phase 1 are searched for in phase 2 so that the estimate of proportion sighted in phase 1 directly applies to phase 2. Bias might occur if these groups are not searched for (tracks identified in phase 1 cannot be re-identified in phase 2), or additional groups not identified in phase 1 are counted assuming they were detected in phase 1. We use a simple binomial estimator to estimate variance in the phase 1 estimate of proportion sites surveyed. This estimate assumes independence of collared caribou, which is potentially violated given that caribou occur in groups. In this case, binomial variance will be over dispersed leading to an optimistic estimate of variance.

A more systematic block approach to sampling might provide a more robust two-phase approach that would not require cross-referencing of groups/tracks identified in each phase. This design would divide the survey up into blocks perhaps stratified by habitat type. Phase 1 would identify blocks to be surveyed based on tracks. Phase 2 would then estimate caribou within sub-blocks with application of sightability models to provide robust estimates. This approach, which is often used in moose surveys, is implemented in the sightability model R package.

Finally, it is assumed that collared and non-collared caribou respond in a similar fashion to flight noise during the phase 1 and phase 2 surveys. Ungulate response to helicopter and flight noise has been documented in various studies (Starikowich 2008). If collared caribou are more likely to respond to flight noise (by seeking cover) then detection probabilities will exhibit a negative bias. Further analysis of collar movement data may allow a partial testing of this assumption.

Overall Estimates (incorporating phase 1 and 2)

The estimates for phase 2 from this study (579 to 1,035 caribou) likely present the range of possible estimates for phase 2. The estimate of 579, using the sightability model, is likely conservative due to the inclusion of non-collared groups in the sightability model. Based on comparison with the total number of caribou observed in phase 2 (577), the sightability estimate of 579 basically assumes that the majority of caribou in the phase 2 area were counted. The Courtois et al. (2003) estimate of 1,035 is likely positively biased due to the detection of collared groups in areas of higher cover compared to the rest of the caribou in the survey. Overall estimates (965-1,725) using the phase 1 detection probability of 0.6 assumes that 60% of the occupied sites in the survey were enumerated in phase 2. As discussed, violation of this assumption could lead to a positive or a negative bias.

Results Relative to Previous Estimates, and Estimates Elsewhere in Canada

The population of boreal caribou in the NWT has previously been estimated to be 6,000-7,000 boreal caribou, which has been reported on a national scale as an NWT-wide population estimate of 6,500 or 1.47 caribou/100 km^2 (Environment Canada 2012). This number was based on regional density estimates provided as a "best guess" by biologists and managers in circa 2010. A total of 577 caribou were counted during phase 2 of this survey, including animals found by telemetry and incidental groups found on the way to locate collars using telemetry. This 'minimum count', while not an abundance estimate, provides a minimum density of 2.74 caribou/100km^2, which alone is higher than the density previously estimated for this region (1.3 caribou/100km^2; ENR 2012). Surveys in the southern NWT, including bison control area surveys that record boreal caribou as incidental observations, have also suggested that boreal caribou densities may be higher than estimated previously in the NWT (A. Kelly 2023, pers. comm.).

The 2014 Committee on the Status of Wildlife in Canada (COSEWIC) status report compiled boreal caribou population estimates for local populations across Canada, of which population densities in Alberta and British Columbia (BC) are provided below (Table B-8). The range (depending on sightability correction method) of mean density estimated in this survey is 4.6 – 8.2 caribou per 100 km^2, is comparable to densities estimated for some of the local populations in Alberta and BC.

Table B-8. Population estimate and range size for local populations from Alberta and BC identified in the federal recovery strategy for boreal caribou (Environment Canada 2012) extracted from Table 2 in the “Caribou (Rangifer tarandus) specific populations: COSEWIC assessment and status report 2014, part 2” (COSEWIC 2014). Bolded rows highlight ranges with similar caribou densities to those observed in this study.

Range name	**Range area (ha)**	**Range area (km²)**	**Population size (min)**	**Population size (max)**	**Max. density (#/100 km²)**
Chinchaga (with BC)	3,162,612	31,626	250	250	0.79
Cold Lake	672,422	6,724	150	150	2.23
Nipisi	210,771	2,108	55	55	2.61
Slave Lake	**151,904**	**1,519**	**65**	**65**	**4.28**
Bistcho	1,436,555	14,366	195	195	1.36
Yates	**523,094**	**5,231**	**350**	**350**	**6.69**
Caribou Mountains	2,069,000	20,690	315	394	1.9
Little Smoky	308,606	3,086	78	78	2.53
Red Earth	2,473,729	24,737	172	206	0.83
West Side Athabasca	1,572,652	15,727	204	272	1.73
Richardson	707,350	7,074	150	150	2.12
East Side Athabasca	1,315,980	13,160	90	150	1.14
Maxhamish	**710,105**	**7,101**	**300**	**300**	**4.22**
Calendar	**496,393**	**4,964**	**290**	**290**	**5.84**
Snake-Sahtahneh	1,198,752	11,988	360	360	3.00
Parker	**75,222**	**752**	**40**	**60**	**7.98**
Prophet	**119,396**	**1,194**	**50**	**100**	**8.38**

Recommendations

In the current analysis we classified canopy cover based on remote sensing imagery. This could introduce error based on the remote sensing data, and in future surveys it would be beneficial for observers to classify and record canopy cover in the field. Other recommended field changes are to ensure that GPS waypoints are marked where the animal was first detected, and if possible, photos should also be taken of caribou groups (or the habitat around a group) to allow a secondary classification of cover that could be compared to remote sensing classification.

We suggest that if the two-phase Courtois et al. (2003) method is repeated, the use of additional data (e.g., dedicated sightability transects; data from multiple surveys (e.g., this one)) in developing more robust sightability models should be considered**.** This would help offset likely issues created by differential distributions of collared caribou relative to cover classes. As discussed earlier, this issue may make estimates of abundance based on mean sightability unreliable, especially when collar sample size is low compared to the size of caribou populations within study areas. In the future, if more survey data is available, the preliminary sightability model developed in this study should be re-assessed using only data from collared caribou groups to ensure a representative proportion of detected to non-detected caribou in the dataset.

We recommend carefully evaluating other survey methods to improve the survey design:

- Block survey methods: Another aerial survey method, which may offer potential improvement, is a block design where sample units in phase 1 are identified spatially rather than observation of tracks alone. This may offset the potential issue of re-identifying tracks from phase 1 in phase 2, especially in years of lower snow cover. This approach might also allow pre-stratification of areas to be surveyed based on RSF habitat value, with more survey effort dedicated to areas of preferred habitat.
- Distance sampling methods: If sightability models are developed it might be possible to obtain an estimate of abundance using phase 1 data alone and distance sampling as has been done with moose surveys (Peters et al. 2014). A double observer approach (Laake et al. 2008a, 2008b) could also be used to obtain a secondary estimate of detection probability near the plane based on observers. The challenge will be obtaining enough sightings in phase 1 to fit a detection curve. However, it is possible to use detection data from multiple surveys to model distance detection functions therefore offsetting low sample sizes in any one survey. We note that in this survey, 41 groups of caribou were observed during phase 1, and if the entire study area in phase 1 as planned had been flown in phase 1, the 60-group minimum needed to fit a detection function may have been met. Furthermore, if the phase 1 survey recorded the actual location of the caribou groups, then it might have been easier for the phase 2 survey to find them again to count and classify them, in addition to providing data to use with distance-sampling methods to estimate abundance.
- DNA-based methods: Non-invasive DNA-based sampling techniques have been applied to boreal caribou at the range/population scale for many years (Ball et al. 2007), and these methods (from the techniques to extract DNA, to gaining insight into familial relationships among sampled caribou) have continued to improve over time (e.g., McFarlane et al. 2021). DNA-based capture-mark-recapture surveys sample DNA from fecal pellets collected using a systematic sampling design across the study area. Aerial transects are systematically flown across the study area to detect observations of caribou animals or signs, and then sites are visited by helicopter to collect fecal pellets. Laboratory analyses obtain DNA from the mucosal coat surrounding the pellets, and individuals are identified via their DNA (Flasko et al. 2017; McFarlane et al. 2018; Galpern et al. 2012). A single abundance estimate requires two sampling events (capture and re-capture), preferably in the same season (minimum of three weeks apart) to allow for the use of population estimators (e.g., Hettinga et al. 2012; McFarlane et al. 2018), but approaches using a single sampling event are being developed (Ruzzante et al. 2019).

We compared the accuracy of DNA-based surveys to our Courtois et al. (2003) and sightability model-based estimates. The seven DNA-based surveys conducted in Alberta and reviewed in McFarlane et al. (2020; see Table 2 in that report) had coefficients of variation (CV) around the density estimate varying between 0.06 to 0.16, whereas our two estimates had CVs of 0.23 and 0.31. This is a good indicator that DNA-based surveys may provide much more accurate estimates than aerial surveys even with some of the suggested improvements above.

The flights designed to locate boreal caribou animals or tracks for a DNA-based survey (to follow up with fecal pellet collection) are similar to the phase 1 flights in this survey. These aerial transects could also be used to obtain sightability estimates of boreal caribou (using distance-sampling methods, if the distance from sighting to caribou location was recorded), or could potentially be done in conjunction with distance sampling abundance surveys of other species (e.g., moose). Given that mark-recapture surveys require surveying an area twice in the same season (although single-sampling approaches are under development; Ruzzante et al. 2019), this may help to reduce (or share) costs.

Despite the challenges inherent in surveying wildlife across large areas, this 2020 boreal caribou abundance survey provides new and valuable information about boreal caribou in the study area. The minimum-count density (2.77 caribou/100 km^2) is twice the previously-estimated density (1.3 caribou/100 km^2), with corrected abundance estimates between 4.6 – 8.2 caribou per 100 km^2. In addition, we have presented an alternate sightability model method that includes study area covariates (in addition to the detection of collared caribou) to adjust sightability methods, that can be further improved with more data collected in the future.

We recommend that for the next Tłı̨chǫ ASR boreal caribou abundance survey, to be completed during the operational phase, the above methods and any emerging methods should be carefully reviewed to determine the optimal survey design to obtain a robust estimate of boreal caribou in the study area. We suggest that DNA-based methods, which continue to evolve and improve rapidly, are likely the optimal way to estimate the abundance of boreal caribou with the most precision.

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Supplementary Material B-1. Summary of days surveyed and crew members for the phase 1 (fixed-wing) and phase 2 (helicopter) Tłı̨chǫ ASR boreal caribou abundance surveys. F = ferry flight, D = drive, S = survey, WD = weather day, PWD = partial Day, orange squares indicate days that a given crew member or aircraft did not fly.

		February												**March**	
Aircraft	**Crew**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**1**	**2**
Phase 1															
BushHawk	Dave Olesen (pilot)	F	S	S	S	S	S	S	S	WD	S-PWD	S-PWD	🟧	🟧	🟧
Hoarfrost River Huskies	Marie Nietfeld (ECC)	F	S	S	S	S	S	S	S	WD	S-PWD	S-PWD	🟧	🟧	🟧
Whatì section	Peter Nitsiza	🟧	S	S	🟧	S	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Frankie Nitsiza	🟧	S	🟧	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Louisa Nitsiza	🟧	🟧	🟧	S	S (1/2 day)	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	George Simpson	🟧	🟧	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Behchokǫ̀ section	Archie Black	🟧	🟧	🟧	🟧	🟧	🟧	S	S	WD	S-PWD	S-PWD	🟧	🟧	🟧
	Leon Ekendia	🟧	🟧	🟧	🟧	🟧	🟧	S	S	WD	S-PWD	S-PWD	🟧	🟧	🟧
Beaver Ahmic Air	Stephen Jefferies (pilot)	🟧	🟧	🟧	🟧	S	S	🟧	S	WD	S	S	🟧	🟧	🟧
	Lisa Worthington (ECC)	🟧	🟧	🟧	🟧	S	S	🟧	🟧	WD	S	S	🟧	🟧	🟧
	Kathy Unger (ECC)	🟧	🟧	🟧	🟧	🟧	🟧	🟧	S	WD	🟧	🟧	🟧	🟧	🟧
Whatì section	Frankie Nitsiza	🟧	🟧	🟧	🟧	S	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Richard Romie	🟧	🟧	🟧	🟧	S	S	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Yellowknife section	Stefany Bulmer (NSMA)	🟧	🟧	🟧	🟧	🟧	🟧	🟧	S	WD	S-PWD	S	🟧	🟧	🟧

	Henri Martin (YKDFN)								S	WD					
	Alex Martin (YKDFN)										S				
	Ricky Drygeese (YKDFN)											S-PWD			
Phase 2															
A-Star – Great Slave Hel.	Ryan Mutz (pilot)		F	S	S	S	S	S	S	WD	S-PWD	S-PWS	S	S	S
	James Hodson (ECC)		D	S	S	S	S	S	S	WD	S-PWD	S-PWD	S	S	
	Stefan Goodman (ECC)		D	S	S	S	S	S	S	WD	S-PWD	S-PWD	S	S	S
	Stephanie Behrens (TG)		D	S	S (1/2 day)	S	S	S		WD		S-PWD	S	S	
	Lisa Worthington (ECC)		S	S	S (1/2 day)	S	S	S		WD		S-PWD	S	S	
	Judy Williams (ECC)														S

Supplementary Material B-2. Phase 1 sightability rate results.

Site #	Latitude	Longitude	Collar ID	Site found (Yes = 1, No = 0)	# of caribou marked on site	Actual # of caribou observed on site	Flight line	Date	Team	Collar found during Phase 2? (visual/telemetry)
1	63.315499	-118.92316	NS17617	1	1	0	W28	2/20/2020	Bushawk	Telemetry
2	63.292818	-118.902253	NS17624	1	1	0	W30	2/20/2020	Bushawk	Telemetry
3	63.201726	-118.286909	NS17624	1	1	0	W34	2/21/2020	Bushawk	Telemetry
4	63.188087	-118.424323	NS17607	1	1	2	W35	2/21/2020	Bushawk	Telemetry
5	63.141028	-118.565436	NS17619	1	1	0	W38	2/21/2020	Bushawk	Telemetry
6	63.172127	-118.123826	NS17601	1	1	0	W36	2/21/2020	Bushawk	Telemetry
7	63.117641	-118.085017	NS17610	1	1	1	W39	2/21/2020	Bushawk	Telemetry
8	63.120981	-118.029547	NS17603	1	1	3	W29	2/21/2020	Bushawk	Telemetry
9	63.032411	-117.947855	NS17621	1	1	0	44	2/21/2020	Bushawk	Telemetry
10	62.893638	-116.620549	NS17618	1	1	0	51	2/23/2020	Beaver	Telemetry
11	62.905272	-116.657064	NS17606	0	1	0	51	2/23/2020	Beaver	Telemetry
12	62.885605	-116.564718	NS19603	1	1	0	51	2/23/2020	Beaver	Telemetry
13	62.874811	-116.521733	NS17622	1	1	0	52	2/23/2020	Beaver	Visual
14	62.893303	-116.545116	NS18603, NS19606	1	2	0	51	2/23/2020	Beaver	Visual
15	62.892436	-116.53159	NS19606	1	1	0	51	2/23/2020	Beaver	Visual
16	62.448843	-117.784308	NS17612	0	1	2	76	2/27/2020	Bushawk	Telemetry
17	62.423669	-116.535803	NS18600	0	1	0	77	2/27/2020	Bushawk	Telemetry
18	62.412477	-116.517376	NS19600	0	1	0	78	2/27/2020	Bushawk	Telemetry
19	62.415746	-116.494842	NS19602, NS18604	0	2	0	78	2/27/2020	Bushawk	Telemetry
20	62.414543	-116.494199	NS18604, NS19602	0	2	0	78	2/27/2020	Bushawk	Telemetry
21	62.316167	-116.531693	NS19604	0	1	0	83	2/27/2020	Bushawk	Visual
22	62.265908	-116.462516	NS19604	1	1	0	86	2/28/2020	Bushawk	Visual
23	62.232045	-116.417499	NS17623, NS19601	1	2	7	88	2/28/2020	Bushawk	Visual

24	62.217964	-116.90809	NS17605	1	1	8	89	2/28/2020	Bushawk	Visual
25	62.232247	-117.076219	NS17602	1	1	0	88	2/28/2020	Bushawk	Visual
26	62.228886	-116.384531	NS19601, NS17623	1	2	0	88	2/28/2020	Bushawk	Visual
27	62.214684	-116.067478	MK809	1	1	8	88	2/27/2020	Beaver	Telemetry
28	62.227994	-116.289701	MK18601	1	1	0	88	2/27/2020	Beaver	Telemetry
29	62.144905	-116.122306	MK734	0	1	0	93	2/28/2020	Beaver	Telemetry
30	62.321732	-116.30001	MK715	0	1	0	83	2/27/2020	Beaver	Telemetry
31	62.188417	-116.15759	MK2023	0	1	0	90	2/27/2020	Beaver	Telemetry
32	62.187013	-116.12157	MK734	0	1	0	90	2/27/2020	Beaver	Telemetry
33	62.171241	-116.139918	MK709, MK2021	0	2	0	91	2/27/2020	Beaver	Telemetry
34	62.171399	-116.143465	MK724	0	1	0	91	2/27/2020	Beaver	Telemetry
35	62.171245	-116.135077	MK2021, MK2023	0	3	0	91	2/27/2020	Beaver	Telemetry