NBCKC Monitoring Practices for Boreal Caribou

AERIAL SURVEYS IN CANADA

National Boreal Caribou Knowledge Consortium

Front Cover Photo Credit: Agnes Pelletier

Aerial Surveys in Canada

Contents

AERIAL SURVEYS

Photo Credit: Laura Finnegan

Introduction to Aerial Surveys

Aerial surveys are a population monitoring tool where a predetermined area is flown over with an aircraft, animals are surveyed (counted and classified), and population metrics such as coarse-scale distribution (e.g. range scale), occupancy, abundance, sex ratio, and recruitment can be determined simultaneously (Gauthier 1985, Courtois *et al*., 2003). In Canada, aerial surveys are a caribou monitoring method with a long history; most provinces and territories have relied heavily on aerial survey methods for their baseline population data, providing the foundation of most boreal caribou population datasets (NBCKC 2019).

Challenges associated with aerial surveys

A critical challenge with aerial surveys of wildlife is poor detectability of animals. Specific sightability challenges for boreal caribou include: low density and spatial clustering of animals, cryptic colouration of individuals, a tendency to remain motionless when approached by aircraft, observer experience and fatigue, dense canopy cover, and poor snow conditions (BC RIC 2002, Courtois *et al*. 2003, ASRD 2010, De Mars *et al*. 2017, MFFP 2019). Such sightability challenges can lead to low accuracy and low precision in estimates of population metrics such as size and density. Datasets with low accuracy and low precision may be unsuitable or inadequate to inform management actions (Thomas 1996, BC RIC 2002, DeMars *et al*. 2017).

To increase the robustness of aerial survey datasets, it has been recommended that "survey results consist of an estimate, confidence limits, probability level, and sample size" (Thomas 1996). Precision of these datasets can be improved by establishing a unique sightability correction factor for each survey (e.g. Buckland 2001, Courtois *et al*. 2003, Thomas *et al*. 2010, De Mars *et al*. 2017). Recent developments in the use of sightability correction factors include software creation and statistical analysis advancements (e.g. Thomas *et al*. 2010, Miller *et al*. 2019).

A second and inter-related challenge to low sightability is small sample sizes, because sightability correction is statistically inappropriate if sample sizes are too small (e.g. Thomas 1996, DeMars *et al*. 2017). Small sample sizes are an inherent problem with most approaches to boreal caribou surveying, thus prompting many current practices to combine mark-recapture or mark-resight studies with aerial surveys (see for example, BC RIC 2002, ASRD 2010, MNRF 2014, DeMars *et al*. 2017, MFFP 2019). An additional advantage to this practice is that data obtained from mark-recapture or mark-resight studies may be combined with Indigenous Knowledge and previous aerial study results, to guide the pre-flight stratification patterns (e.g. Siniff and Skoog 1964, Gasaway 1986, Thomas *et al*. 2010). Stratification is the process of breaking up the survey area into smaller, relatively homogeneous sampling units. This technique is effective for animals that display clumped distribution (BC RIC 2002), and groups sampling units based on expectations of caribou density. Stratification of the survey area can increase project efficiency, increase confidence in estimates, and reduce the number of sampling units to be flown. Nonetheless, pre-survey stratification flights typically require increased aircraft rental time, and thus incur increased rental costs, fuel costs, and personnel costs (BC RIC 2002, ASRD 2010).

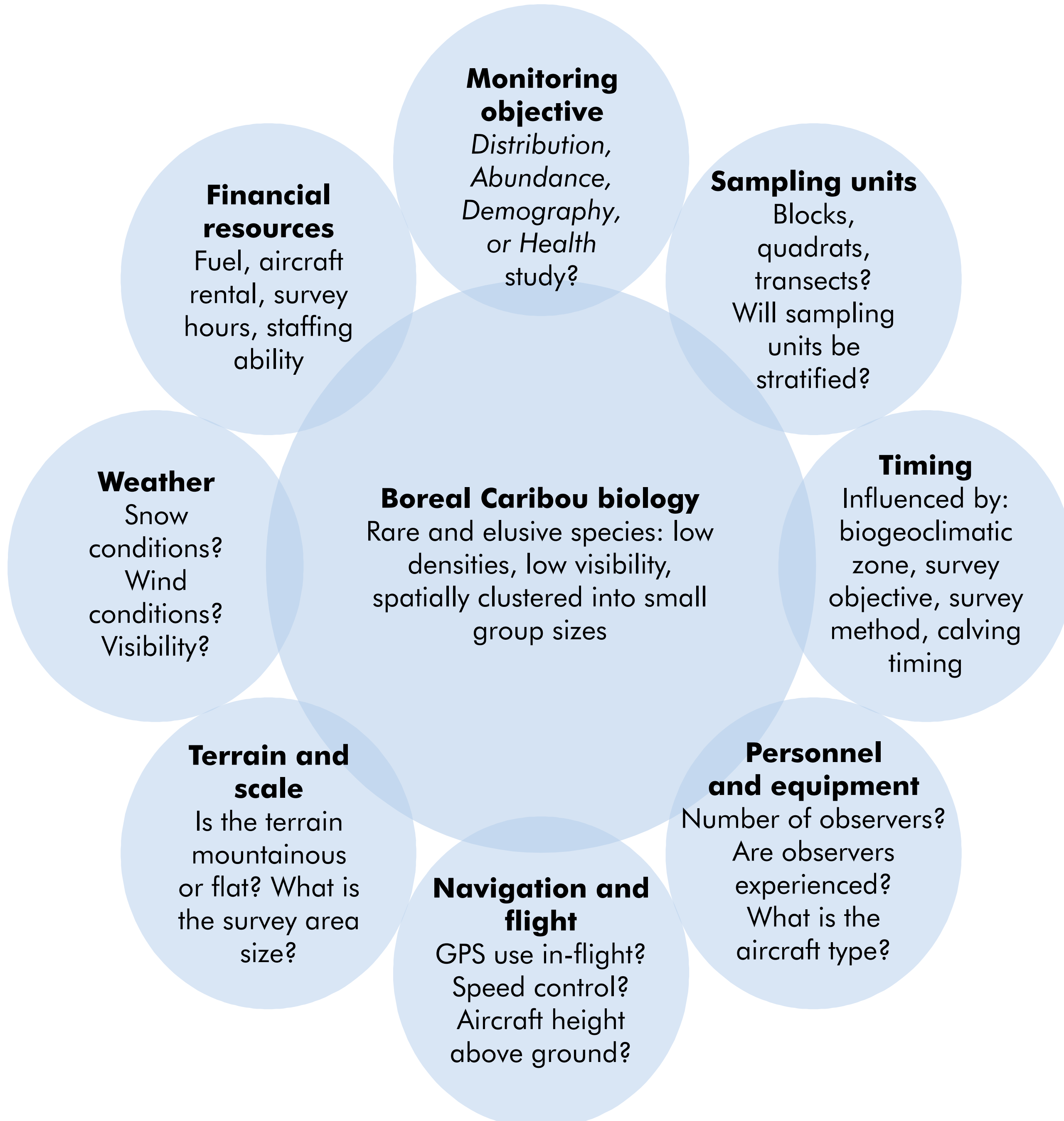
AERIAL SURVEYS

Common study designs

Aerial surveys may use either direct and/or indirect methods. *Direct methods* are based on observation of caribou individuals, whereas *indirect methods* are based on observations of signs (e.g. tracks or feeding craters). There exists a variety of study designs for aerial surveys, the choice of which is influenced by factors including those outlined in Figure 1.

Alternative study designs used for aerial surveys of boreal caribou in Canada are provided below, including advantages and disadvantages of each, as well as specific examples of when/where a particular method has been used. For more in-depth descriptions of each method, as well as how to integrate the factors listed in Figure 1 in the study design of future projects, we invite the reader to refer to the primary literature.

Figure 1 (right) : *Factors such as data needs, spatial scale, as well as financial and personnel resources, will guide the selection of the most appropriate method for aerial surveys of boreal caribou. Figure content is based on: BC RIC 2002, ASRD 2010, MNRF 2014, De Mars et al. 2017, and MFFP 2019.*



AERIAL SURVEYS

Block (or grid) based surveys: searches conducted systematically, flying an area in "sampling units"

Approaches

1. Grid-based sampling: Sampling units are a series of equally-sized polygons of identical shape arranged in a grid-like pattern on the landscape. The pattern may be any repeating polygon (hexagon, square, triangle, etc.), depending on survey design.
   - The province of Ontario is conducting integrated range assessments for boreal caribou using a two-stage survey method where "the first stage is a hexagon-based (approx. 100 km^2 cell size) fixed-wing survey [grid]" (MNRF 2014). The flight path of the aircraft intersects each cell in the grid, and subsequent analyses translate observations within the cell to represent the cell as a whole.
2. Stratified random block sampling: sampling units are variable-sized survey blocks (typically based on observable features like topography, or delineated using uniformly sized blocks using GPS technology) and are stratified (see discussion above) prior to being surveyed.
   - The province of British Columbia has used stratified random block sampling as a provincial standard protocol for surveying boreal caribou (BC RIC 2002), however this method is currently not the optimal methodology (A. Pelletier, *pers. comm.*)
   - Alberta "strives to implement aerial survey approaches that allow statistically rigorous estimates of ungulate population numbers and density within Wilderness Mass Units". Typically, this involves implementing counts in a random selection of survey blocks within WMUs. (ASRD 2010)

Photo Credit: OMNRF

Advantages to block based surveys

- Useful in areas with rugged terrain or variable terrain
- Local knowledge holders and experts can be involved in fieldwork planning. Specifically, insight into general caribou locations, flight paths, habitat conditions and refuel locations can greatly assist in increasing survey efficiency (ASRD 2010, Couturier *et al*. 2018).

Disadvantages to block based surveys

- Increased flight time, fuel consumption, and personnel time for the pre-survey stratification flights lead to overall increased costs (Courtois *et al*. 2003).
- With grid-based surveys, resolution or precision of the data is limited, in part, to the size of the sampled polygon. In other words, the larger the cell sizes surveyed, the more opportunities there are to miss differences across the landscape as a whole.

Parallel transect-based surveys: searches conducted systematically, flying an area in "strips"

Approaches:

1. Distance sampling using line transects: A form of transect sampling where the perpendicular distance between observed animals and the survey line is measured and a detection function* is estimated to determine the size of the area sampled. This means that strip width is dependent upon sightability, rather than determining a strip width in advance, as with traditional strip transect surveys. Strip survey width is not held constant. All observable animals are recorded no matter their distance from transect; a covariate (like group size or landcover) can be included to account for some of the variation in sightability and therefore, can be used to improve the precision of the estimate. It is assumed, however, that animals directly on the transect line are not overlooked. (Quang and Becker 1996, Buckland 2001, Thomas *et al*. 2010).

**A 'detection function' is similar to the 'sightability correction factor' used in other experimental designs, except that assumptions must be met. See eg: Buckland 2001 for more information.*

- The Torngat Mountain caribou of Quebec and Labrador were recently surveyed using distance sampling, with transects spaced either three or four kilometers apart, depending on expectations of caribou density. This effectively stratified the survey area based on previous survey results as well as local knowledge of caribou distribution (Couturier *et al*. 2018).

2. Variable-width strip sampling: A form of transect sampling where the perpendicular distance between observed animals and survey line is not recorded, and strip survey width is not held constant.
   - A recent aerial survey of the Basse Cote-Nord region (Quebec) used variable-width strips in a two-stage survey, to count and classify boreal caribou in the area. In this survey, the sightability correction factor was based on the ratio between the number of collared individuals observed and the total number of collared individuals available on the survey area (MFFP 2019).
3. Fixed-width strip sampling: A form of transect sampling where all animals seen are recorded and contribute to survey findings, but only caribou seen within a defined survey area (thus within a predetermined strip width) contribute to density or abundance estimates (Bergerud 1963).
   - In fixed-width strip sampling, a constant strip width is maintained by flying the aircraft at a specific altitude (BC RIC 2002). On-board observers are trained to define animals as "on" or "off" transect, based on their maintained position, and distance markers on their aircraft window. Correction for sightability can be estimated by using double blind observers. This method has been used to survey boreal caribou in Labrador. It is worth noting that in British Columbia, due to rugged terrain, this method has only been used to survey moose (BC RIC 2002).

Advantages to parallel transect-based surveys

- If aircraft time (and financial resources) permit, transect surveys can be designed to include a second stage of flights where population composition can be assessed (this practice is called "two-stage flights": e.g. MPPF 2019). To be clear, in two-stage flights, animals are classified *during* the aerial survey, not in a subsequent flight.
- This approach to aerial surveys, known as "the strip census" has a history in Canada (Bergerud 1963), and is still used to compare results across years.
- Density can be estimated with either fixed-width strip sampling (where area surveyed is known) or distance-based sampling (where area surveyed is mathematically calculated using softwares following fieldwork)

Considerations for parallel transect-based surveys

- Transect sampling works best when animals are randomly distributed over large areas of homogeneous habitat (e.g. BC RIC 2002). However, boreal caribou are typically in clumped distribution, especially in the winter when most surveys take place. Boreal caribou also are not usually found in homogeneous habitat. Faced with this challenge, a possible study design adaptation is to stratify the sampling area (pre-survey) based on expected caribou densities (e.g. Couturier *et al*. 2018, MFFP 2019).

Disadvantages to parallel transect-based surveys

- In variable-width sampling, there is no measure of the area surveyed, and consequently density cannot be estimated.

Targeted sampling: searches conducted in areas where animals are known to be present

Approaches:

1. Composition studies
   - Alberta, Newfoundland and Labrador, and the Northwest Territories conduct composition surveys for woodland boreal caribou. These composition surveys begin by flying to radio-collared herds, and subsequently counting and classifying the total number of individuals encountered. (e.g. ASRD 2010, DeMars 2017). In these composition studies, the priority is the relocation of collared individuals. Hot-spot searching in areas of suitable habitat also occurs if time permits.

- When conducted in the winter, composition studies are usually aimed at obtaining recruitment numbers, as calves should be 9-10 months old for these studies.
- When conducted in the fall, composition studies are usually aimed at determining the number of legal bulls, and obtaining recruitment numbers are a secondary objective. These fall "rut counts" generally allow observers to have better counts because animals gather in larger groups, as compared to in the winter.

Advantages to targeted sampling surveys

- Saves time by only sampling areas where caribou are known to occur; useful for small study sites (Courtois et al. 2003)

Considerations for targeted sampling surveys

- If the goal of the survey is to obtain a population estimate, targeted sampling would need to be combined with extensive radio-telemetry collaring (done prior to sampling). Use of radio-telemetry collars allows for the calculation of a sightability probability, which is then applied to provide a population estimate.
- If the goal of the survey is to obtain composition information (and not a robust population estimate) then it is not absolutely required to use radio telemetry collars. In this case, targeted sampling could be carried out by flying to known areas of good habitat quality, or local observations of high density.

Disadvantages to targeted sampling surveys

- Potentially avoids sampling areas where caribou density is unknowingly increasing
- Targeted searches are usually based on telemetry data, thus, as with all telemetry-based monitoring, hot spot searching potentially neglects sampling for individual males or all-male groups, as usually only female caribou are collared.
- This method avoids sampling areas where 'absence' vs 'lack of detection' can be confused.

Indigenous Knowledge in monitoring programs

Through the production of Boreal Caribou Monitoring in Canada Part 1: Perspectives from the NBCKC Monitoring Working Group, a number of field methods were identified as being commonly used in Canada for monitoring boreal caribou, yet these are often conducted without being grounded in Indigenous methodologies. However, applying both Indigenous and non-Indigenous ways of knowing to caribou monitoring programs has numerous benefits (e.g. Raygorodetsky and Chetkiewicz, 2017). As such, opportunities for how Indigenous Peoples and their knowledge could benefit a monitoring program have been identified throughout the text of the toolkit. In addition, the Practical Aspects to Reconciling Indigenous and non-Indigenous Ways of Knowing toolkit (*in prep*) will highlight practical guidance for using multiple ways of knowing caribou and will help readers understand the characteristics of meaningful collaboration with Indigenous communities. For example, such characteristics include (but are not limited to): Indigenous people co-coordinating the program from the onset of planning; equitable sharing of decision-making as it pertains to the monitoring program; frequent communication throughout all phases of a program; dedication to relationship-building and mutual learning; agreement on ethical principles surrounding project design and implementation; transparency in collection, use, and storage of data (e.g. OCAP principles); adherence to protocols established by local governance and co-management boards, and making “space” to include both capacity building, and compensation for time, in the monitoring program.

Photo Credit: NL Wildlife Division

AERIAL SURVEYS

1. Aerial Counts

1.1 AT A GLANCE

Aerial counts are a specific type of aerial survey, suitable for monitoring where the objectives are to obtain minimum population counts, determine population size and/or density, or gain information about the distribution, growth trend, and recruitment rates of a population.
Aerial counts are typically conducted during the early to late winter months because this is when calves are less likely to be unduly stressed by aircraft (Arsenault 2019). Sampling in the winter also allows for the observers to make use of the snowfall: tracks in the snow can be used to stratify an area prior to flight, and can also be used to guide observers to locate caribou groups. Finally, the snow provides increased visual contrast between the colour of the caribou and the ground (e.g. BC RIC 2002, ASRD 2010, Arsenault 2019).

1.2 SUITABILITY FOR MONITORING

1.2.1 CARIBOU POPULATION PARAMETERS THAT CAN BE MONITORED

From Suitability Table 1: Selecting a monitoring method that suits your objectives

x	Method is not appropriate for estimating this parameter
✓	Method provides some information or can be combined with other methods for inference
✓✓	Method provides considerable information and is appropriate for estimation
✓✓✓	Method is most appropriate and/or intended specifically for estimation of this parameter

Note: table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone

		Distribution			Abundance				Demography			Health			
		Distribution/ Occupancy	Dispersal/ Movement	Habitat use	Population density	Population size	Effective population size	Minimum counts	Population growth trend	Survival/ Mortality	Recruitment/ Reproduction	Body condition	Disease	Other health indices	Foraging/ Nutrition
Aerial Survey	Aerial counts	✓✓	x	✓	✓✓✓	✓✓✓	x	✓✓✓	✓✓	x	✓✓	x	x	x	x

***Note that the only parameters listed here are the primary population metrics that are explored in detail in Comparative Table 1 to allow for standardized comparison among monitoring approaches; all other information that can be obtained from this method is detailed in following "Additional parameters and information" section.*

1. Aerial Counts

1.2.2 ADDITIONAL PARAMETERS AND INFORMATION THAT CAN BE MONITORED (BEYOND THOSE LISTED IN TABLE 1)

- Classification surveys and/or recruitment assessments can be done during aerial counts surveys, to determine population demographics (such as sex ratio and recruitment).
- Environmental or habitat data can be incorporated into analyses to account for variation in sightability (e.g. observer, snow cover, slope, group size).
- Aerial counts can also assist in noting new changes to the landscape (e.g. natural disturbances such as a forest fire or human land use such as a new ATV trail), but would not be appropriate for documenting as part of total area disturbance.
- Aerial counts directed at caribou can in some cases also provide observational data on relative abundance of other large land-based animals. This may include gaining an index of human occupation on the land.

1.2.3 IMPLEMENTATION

- As with most aerial survey studies, aerial counts are best suited to estimating population size, density, and trend when the range, seasonal habitat, and local abundance are somewhat understood so that survey effort can be allocated appropriately.
- There must be sufficient funding to survey an adequate proportion of the area to narrow the confidence interval of the estimate. For example, pre-survey stratification of the survey area into high, medium, and low density categories may assist with this. Please see discussion of stratification under Chapter introduction.
- Aerial counts are not intended as a means to gather information on occupancy or seasonal distribution and habitat use. As most aerial counts are conducted in winter, winter use of an area may be noted during an aerial count survey, though only anecdotally. (Consider, for example, that aerial count surveys only provide a "snapshot" of distribution in time, and that caribou are a mobile species.)

1.2.4 ADVANTAGES

- Can be planned, implemented and analyzed in a short time.
- Do not require repeated annual funding, so can be implemented when funds are available.
- This method is not restricted to provincial monitoring programs. For example, wildlife co-management boards may lead the monitoring (e.g. Couturier *et al*. 2018). Further, this method also provides an opportunity for local groups (Indigenous Knowledge holders, ENGOs, etc.) to participate in planning and field work, and to acquire first-hand experience.
- Can be combined with population structure assessment (recruitment, sex ratio, etc.) through the use of two-stage survey flights. For example, this technique was recently used in the province of Quebec (MFFP 2019), where the objective of the first stage flight was to conduct a population count, and the objective of the second stage flights was to conduct a population composition assessment. Aerial classifications can be conducted simultaneously to aerial count surveys. In these instances, the helicopter departs from transect to classify individuals once a group is observed, as is done during aerial surveys of boreal caribou herds in Labrador.

1.2.5 DISADVANTAGES

- Flight costs are significant, and thus the budget is spent rapidly at time of surveying.
- Habitat use varies by season (as boreal caribou cover a broader area during calving season), and thus aerial counts conducted in the winter may not be representative of distribution in other seasons besides winter.
- Success is dependent on weather conditions. Requires enough good weather days to survey the entire range before caribou can move enough to expect double sampling.

AERIAL SURVEYS

1. Aerial Counts

1.3 CONSIDERATIONS AND REQUIREMENTS

From Suitability Table 2: Comparing suitability and requirements of monitoring methods

Spatial Scale

- ✓ Method provides some information at this spatial scale
- ✓✓ Method is appropriate for application at this spatial scale
- ✓✓✓ Method is most appropriate for application at this spatial scale

Co-application of Indigenous Knowledge:
P – Planning D – Data collection
A – Analysis R – Reporting

Note: *Table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone*

		Spatial Scale		Data Needs **		Community Involvement		Resources			Ethical Considerations		
		Local/study area	Regional/range	Minimum sampling requirements	Ability to assess data confidence	Local opportunity	Co-application of IK	Equipment costs	Personnel costs	Skills required	Capture/ handling	Potential stress from monitoring	Carbon footprint
Aerial Surveys	Aerial counts	✓	✓✓✓	≥1 yr pop size / ≥2 yr trend	High	Med	P, D	High	Med/ High	Med	No	Med/ High	High

** Two spatial scale scores for Aerial imagery represent Manned and Unmanned aircraft, respectively // ** These are general guidelines only; refer to text for details of sampling requirements*

1.3.1 SPATIAL SCALE

- Spatial scale should cover the entire winter range, as informed by collar locations, local/Indigenous knowledge, and historical habitat/range use.
- If winter ranges are unknown, aerial counts should be conducted at a regional or range scale. For instance, this was implemented in the Torngat Mountains area of Labrador (>30,000 km^2) and across areas of Quebec where detailed information on caribou locations was unavailable, but local knowledge could guide approximate survey area boundaries (Couturier *et al*. 2018).

1. Aerial Counts

1.3.2 DATA NEEDS AND CONFIDENCE

- Requires one concerted effort over several consecutive field days to obtain an estimate of population size or density over the winter range. Any level of sampling can be used as a minimum count.
- If study design involves distance sampling, a minimum of 60-80 groups must be observed for the detection function to be properly fitted, and ensure accuracy in the dataset (e.g. Buckland *et. al* 2001). However, more than 80 observations may be needed to attain abundance estimates that are precise (CV <20%) and minimally biased (<10%; Glass *et al*. 2016).
- Requires two or more years of data to inform population trend from abundance estimates.
- As with all aerial surveys, corrections should be made for sightability errors. This can be done as discussed above under "Challenges associated with aerial surveys".

Photo Credit: NL Wildlife Division

- Precision regarding the population abundance estimate can be expressed using the chosen statistical method and expressed as a confidence interval or error percentage.

1.3.3 COMMUNITY INVOLVEMENT

Opportunity for Local Community Involvement

- Local community members can provide knowledge on past and present caribou distribution/occupancy; Community members can help design the sampling plan prior to fieldwork by identifying specific areas of interest so that survey effort can be allocated appropriately (Couturier *et al*., 2018).
- Local community members often serve an important role as observers during survey execution because of their extensive life-long experience with tracking wildlife on the land in which an aerial survey is being conducted.

Potential for Co-application of Indigenous Knowledge

Note that any application of Indigenous Knowledge must be conducted in a manner which is agreed upon by all parties, is transparent, serves the local communities where the information originated from, and adheres to local Indigenous data governance and sovereignty.

- Planning
  - o Indigenous Knowledge can be used in survey area delineation in the absence of other caribou distribution data, or can be used to supplement overall caribou distribution knowledge in areas that are data deficient, or can be used to verify knowledge of caribou historical distribution (as described with Barren ground caribou in Campbell *et al*. 2015).
- Data collection
  - o Community members can conduct exploratory flights to search for animals and, if telemetry relocation is being used, facilitate the distribution of collars in zones that have low levels of monitoring.
  - o Indigenous Knowledge holders can also participate on the flights. Inexperienced observers can influence survey success due to missing significantly more animals than experienced observers (Gasaway *et al*. 1986). Local harvesters have extensive experience in tracking animals in the area in which a survey is being conducted, and have great insight into where caribou are likely to be.
- Analysis
  - o The authors note that though no examples have been provided for this section to date, there is an opportunity to learn more about how Indigenous Knowledge can inform analysis of aerial survey data. Should the reader know of information which may resolve this knowledge gap, kindly contact the NBCKC Secretariat.

AERIAL SURVEYS

1. Aerial Counts

- Reporting
  - o The authors note that though no specific examples have been provided for this section to date, lessons learned through community-based monitoring programs highlight an opportunity for collaboration in reporting and knowledge-sharing of monitoring program results. For example, while western scientists could lead in the development of academic papers or journal publications, local community members (notably youth) may collaborate in the interpretation of program results, and subsequently lead in knowledge sharing within their communities. As noted by Raygorodetsky and Chetkiewicz (2017) this practice has been applied when Community Based Monitoring programs are rooted in Multiple Evidence Based principles.

Cost: $$$

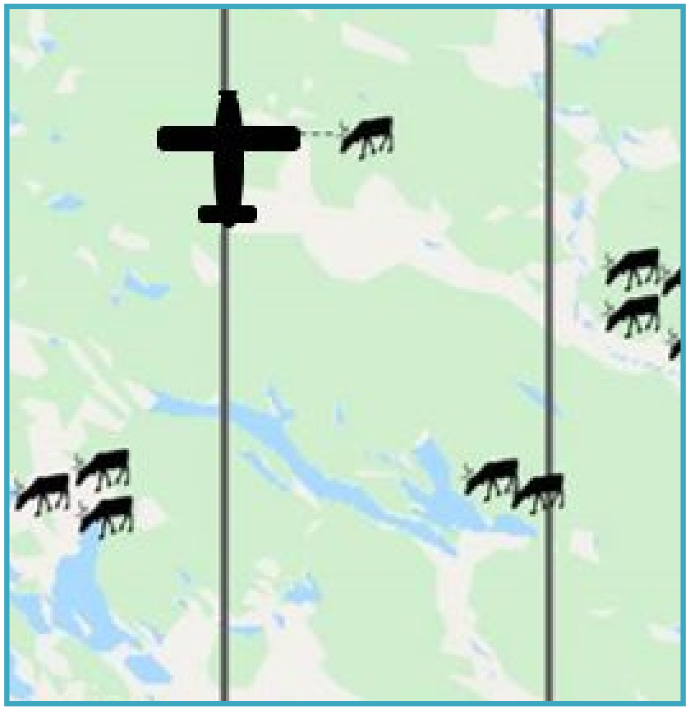
1.3.4 RESOURCES

Equipment Costs

- Expenses to consider in aerial count monitoring programs will vary, based on: aircraft fees, aircraft fuel, deployment of fuel to remote locations, and the extent of the study area.
- The costs of an aerial count survey will increase if a pre-survey flight is needed to help inform stratification (due to increased time in the air).

Personnel Costs

- The cost of fieldwork planning will be influenced by the degree of incorporation of local knowledge holders and experts into the survey design and execution. Personnel may need to travel to gather this information, and knowledge holders need to be compensated for their contributions.
- Survey pilots who are most useful to the project are those with high levels of both experience and interest (BC RIC 2002), which may come at an increased cost.
- Fieldwork costs will be influenced by staff salaries and travel to survey location, meals, accommodation and gear. Operationally speaking, personnel costs during fieldwork might be minimized by collaborating across jurisdictional boundaries by sharing resources (e.g. BC RIC 2002, ASRD 2010).
- Subsequent to field sampling, there are significant analytical steps required, for which technician time must also be budgeted.



AERIAL SURVEYS

1. Aerial Counts

Logistical Complexity: MODERATE

Capture/Handling: NO

Skills Required

- An aerial count sampling survey is made more efficient with previous knowledge of herd range and seasonal distribution. This can be obtained through local or Indigenous knowledge of the area, or through a review of previous survey results, resource selection functions, or occupancy models.
- Staff must be familiar with spotting caribou track or sign from an aircraft, measuring/estimating distance, and classifying animals (if estimating recruitment). "In addition to safety, maximizing the quality of the data collected while simultaneously minimizing stress to the animals should be the primary goals of every survey; this requires that experienced personnel are involved with all aspects of survey planning and delivery" (ASRD 2010). Simply put, the key is to choose observers who have experience looking for caribou/tracks, flight experience, and who will remain invested for a long time so that the experience grows.

- Survey design and analysis of data collected requires familiarity with statistics, GIS, and sometimes requires familiarization with additional software.

Photo Credit: OMNRF

1.3.5 ETHICAL CONCERNS

Capture/handling

- Caribou are not* directly captured for aerial counts.

**As mentioned in the introduction, aerial count studies are often combined with telemetry-studies to account for sightability challenges, improve data accuracy, and to derive recruitment estimates. If this is the case, caribou must be handled for the installation of the telemetry collars.*

Potential Stress From Monitoring

- Flying over caribou in any form of motorized aircraft could create disturbance; "aerial surveys should be timed […] to minimize the stress imposed on the animals due to harassment by the survey aircraft" (BC RIC 2002, ASRD 2010). Of particular importance is the calving period when stress should be minimized at all costs (Larter and Allaire 2018, Arsenault 2019).
- A flight altitude must be established that balances minimal disturbance and maximal sightability, which is often guided by animal care protocols outlined in permitting.
- If classifications are to be conducted from the aircraft, maximum chase time limits should be respected and staff should be familiar with indicators of caribou fatigue.This is often guided by animal care protocols outlined in permitting. For example,Wood Environmental and Infrastructure Solutions' survey protocol instructs to "abandon the classification if pursuit will extend beyond 2 minutes of caribou running" (Arsenault 2019).
- Photo-classifications have also been used to reduce pursuit time, and may allow for in-depth classification of caribou after the fact (e.g. Couturier *et al.*, 2018).

AERIAL SURVEYS

1. Aerial Counts

Carbon/environmental Footprint

- High: As with all aerial surveys, considerable fuel is consumed during flight time. For example, in Labrador, two commonly-used aircrafts are the Bell206 LR helicopter which consumes 123 L/hr (https://summithelicopters.ca/fleet/bell-206-lr/), and the Astar350 B2 helicopter which consumes 180 L/hr (https://www.yhl.ca/astar-as350-b2-helicopter/), where typical big game surveys range from 40-100 hours of flight time.

1.4 EXAMPLES

LABRADOR The Torngat Mountains caribou herd belongs to its own designatable unit (DU 10) and is currently listed as endangered (COSEWIC 2017). This small herd of mountain caribou lies across a vast range that spans the Ungava Peninsula in northern Labrador and Quebec, from Killiniq in the north and Okak Bay in the south. Shared goals and mutual interest in monitoring this herd brought multiple organizations together to form the Torngat Caribou Technical Committee, which included two parks, two provincial and three regional governments, and a co-management board. Monitoring using aerial surveys and classifications aimed to address the initial research questions regarding abundance and demography of the herd. The committee planned and executed the first strategic aerial population and classification surveys of the herd using distance-based sampling (Couturier *et al*. 2015). Although the population size was expected to be relatively small, it was believed that this method would be the most effective for this herd, given the large area and open tundra landscape that would need to be surveyed. There was little past information that could be used to determine the survey area, so the entirety of the known historical range of Torngat caribou was included. This plan was reviewed by community members prior to each survey to validate that no important areas were excluded from the design (Couturier *et al*. 2015, 2018). This method was used in 2014 to estimate the abundance and demography of the herd, and again with modifications in 2017 to establish initial population trends. Transects were distributed across this survey area, the spacing of which has varied across survey years. Most recently, this was three kilometers in the north, where the highest density of caribou occurs, and four kilometers along the southern periphery of the range, where fewer caribou groups are expected to be found. The surveys were flown for three to four weeks in late-March through early April, when day length was sufficient for surveying in the north, and using trained crew members proficient in detecting caribou and their tracks. In 2014, 269 caribou were observed in 50 groups and the population was estimated to be 930 caribou (90% CI: 616-1,453) distributed across 29,390 km^2 (Couturier *et al*. 2015). In 2017, with slightly increased coverage of the survey area (30,625 km^2), 610 caribou were observed in 58 groups and the population was estimated to be 1,326 caribou (90% CI: 912-1,986), a 13% increase in population size per year between 2014 and 2017 (Couturier *et al*. 2018). Calf recruitment also increased during this time, from 17.2% in 2014 to 23.1 in 2017 (Couturier *et al*. 2015, 2018). Despite this positive trend in caribou abundance, it is still too soon to know whether this increasing population trend has continued in recent years. With only two systematic surveys completed on this herd, the long-term trends are still unknown. Continued monitoring is expected to continue on a three-year cycle to further develop and distinguish meaningful trends.

AERIAL SURVEYS

1. Aerial Counts

ALBERTA The Government of Alberta monitors both the Narraway (NAR) and Redrock-Prairie Creek (RPC) mountain ecotype populations of boreal caribou which spend the majority of their winters at high elevations in the Canadian Rockies. These herds have ranges in west-central Alberta and east-central British Columbia. Given the reliance of finding both these herds over the winter months in the mountains, it is time and resource efficient to perform aerial transect surveys in these caribou ranges to gather information such as estimates of population density and age structure. Moreover, in order to maximize helicopter fly time investment, an aerial count can be paired quite well with a DNA survey, that is the scanning on transects of the presence of caribou (tracks or animals) and the landing at these sites to estimate caribou numbers and collect fecal material for DNA analysis. Caribou scat is then sent to one of many labs across the country for analysis, such as Wildlife Genetics in Nelson, B.C. When it comes to caribou surveys, regardless of the objective of the flight, aircraft time is typically the limitation as hours and overall cost of a project add up quickly. Therefore, the benefit of flying transects in a caribou's winter range to collect data which serves multiple project objectives (e.g. population estimates through aerial count surveys along with DNA from scat), increases efficiency while also enhancing the predictive power of both project datasets. Particularly in small mountain boreal caribou herds like NAR and RPC, the more population specific data one can gather during an aerial survey, the quicker it is to mobilize afterwards in terms of developing caribou recovery strategies based on the latest trends.

Photo Credit: Sonja Leverkus

2. Aerial Occupancy Surveys

2.1 AT A GLANCE

Aerial occupancy surveys are a specific type of aerial survey, most suitable for monitoring where the objectives are related to occupancy and habitat use. Aerial* occupancy surveys are used to collect presence /not detected data as well as additional variables (e.g., habitat) that may be included in models as predictors of occupancy. Multiple surveys through time are required at each study site to collect these data. Following collection in the field, data are analysed using occupancy models, which are based on the relationship between abundance and proportion of sites occupied within a species range. Note that aerial occupancy surveys are conducted in the field, and are the subject of this section, while aerial occupancy models use the field data to determine population persistence.

**The authors of this report note that occupancy studies can also include non-aerial variants, where occupancy data are collected through survey methods such as wildlife cameras or genotyping DNA in fecal samples.*

2.2 SUITABILITY FOR MONITORING

2.2.1 CARIBOU POPULATION PARAMETERS THAT CAN BE MONITORED

From Suitability Table 1: Selecting a monitoring method that suits your objectives

- x — Method is not appropriate for estimating this parameter
- ✓ — Method provides some information or can be combined with other methods for inference
- ✓✓ — Method provides considerable information and is appropriate for estimation
- ✓✓✓ — Method is most appropriate and/or intended specifically for estimation of this parameter

Note: table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone

		Distribution			Abundance				Demography			Health			
		Distribution/ Occupancy	Dispersal/ Movement	Habitat use	Population density	Population size	Effective population size	Minimum counts	Population growth trend	Survival/ Mortality	Recruitment/ Reproduction	Body condition	Disease	Other health indices	Foraging/ Nutrition
Aerial Survey	Occupancy surveys	✓✓✓	x	✓✓✓	✓✓	✓	x	x	✓	x	x	x	x	x	x

***Note that the only parameters listed here are the primary population metrics that are explored in detail in Comparative Table 1 to allow for standardized comparison among monitoring approaches; all other information that can be obtained from this method is detailed in following "Additional parameters and information" section.*

2. Aerial Occupancy Surveys

2.2.2 ADDITIONAL PARAMETERS AND INFORMATION THAT CAN BE MONITORED (BEYOND THOSE LISTED IN TABLE 1)

- Aerial occupancy surveys are suitable for multi-species monitoring and assessment (Poley *et al*. 2014).
- As with most aerial surveying, aerial occupancy surveys may be opportunistically used to note new changes to the landscape, for example disturbances such as a forest fire or a new ATV trail, but would not be appropriate for documenting total area disturbed.

Photo Credit: Laura Finnegan

2.2.3 IMPLEMENTATION

- Aerial occupancy surveys are most appropriate and beneficial for long-term monitoring of species persistence at coarse scales (e.g. range scale). For example, such surveys may be particularly useful for examining potential changes in range and in persistence probabilities associated with climate change. Note that inference about changes in spatial distribution of a herd requires repeated aerial occupancy surveys.
- Can be used in situations where samples sizes are too small to use other forms of statistical analysis.
- As with most aerial surveys, canopy cover in the spring and summer months leads to reduced sightability. As such, aerial occupancy surveys are usually restricted to the winter months (e.g. Poley *et al.* 2014, Mackenzie and Nichols 2014). That said, DeMars *et al*. (2017) demonstrate that a "winter-based occupancy program may not reflect the full extent of annual caribou distribution". As such, inferences made from aerial occupancy studies must be made at the correct temporal sale.
- Population trend can be inferred from the number of occupied units; however, there is a risk that the number of individuals within each unit could decrease without an associated change in the number of occupied units (and vice versa). For example, McLellan *et al.* (2011) note that "for group-living species such as boreal caribou, initial population declines can be masked from occupancy monitoring when the number of individuals per group decreases while the number and distribution of groups on the landscape stays relatively constant". Further, DeMars *et al.* (2017) make the point that tracking changes in occupancy as a surrogate for population size and trend may result in limited power to detect smaller, short-term change. In brief, using aerial occupancy surveys to determine population trend should only be used as a coarse estimate, and should be corroborated with other methods of inference.
- Occupancy surveys are not sufficient if estimates of abundance, recruitment or survival are required (e.g., for demographic modelling) .

2.2.4 ADVANTAGES

- Presence/ not detected data obtained through occupancy surveys can be used as a coarse estimate to identify areas of potentially higher use, based on associations with habitat types (e.g. MacKenzie and Nichols 2004, DeMars *et al*. 2017). In addition, recent approaches explicitly incorporate detectability and spatial autocorrelation in occupancy models (e.g. Poley *et al*. 2014).
- Occupancy surveys only require searching for evidence of species presence (e.g., tracks, cratering), which is easier and less expensive

than direct observation or capture of animals. Evidently, the caveat to this practice is that tracks must be accurately identified, which is occasionally difficult. (Consider for example that in some areas, moose, deer, and caribou tracks in partially melted snow may appear quite similar in shape, especially when observed from an aircraft (Oswald 1998).

- Data can be combined from multiple sources including, for example: aerial surveys, fecal DNA, TEK/LEK/IK, and camera trapping (e.g. Noon *et al*. 2012).

2.2.5 DISADVANTAGES

- To meet sample size requirements for occupancy modelling, occupancy surveys may require more data than other Species Distribution Models (SDMs).

2.3 CONSIDERATIONS AND REQUIREMENTS

From Suitability Table 2: Comparing suitability and requirements of monitoring methods

Spatial Scale

✓ Method provides some information at this spatial scale

✓✓ Method is appropriate for application at this spatial scale

✓✓✓ Method is most appropriate for application at this spatial scale

Co-application of Indigenous Knowledge:

P – Planning D – Data collection
A – Analysis R – Reporting

Note: *Table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone*

		Spatial Scale		Data Needs **		Community Involvement		Resources			Ethical Considerations		
		Local/study area	Regional/range	Minimum sampling requirements	Ability to assess data confidence	Local opportunity	Co-application of IK	Equipment costs	Personnel costs	Skills required	Capture/ handling	Potential stress from monitoring	Carbon footprint
Aerial Surveys	Occupancy surveys	✓	✓✓✓	≥1 yr (≥3 samples events/yr)	High	Med	P, D	High	Med/ High	Med/ High	No	Med/ High	High

** Two spatial scale scores for Aerial imagery represent Manned and Unmanned aircraft, respectively // ** These are general guidelines only; refer to text for details of sampling requirements*

2. Aerial Occupancy Surveys

Photo Credit: OMNRF

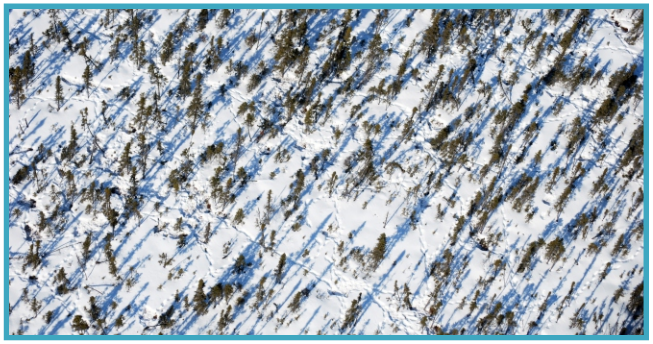


Photo Credit: OMNRF

2.3.1 SPATIAL SCALE

- Occupancy-based surveys are appropriate for inferences about coarse distribution, such as at the range or regional scale. (e.g. DeMars *et al*., 2017).
- For caribou, the most appropriate spatial scale for aerial occupancy surveys would likely be the defined caribou ranges (Environment Canada 2011).

2.3.2 DATA NEEDS AND CONFIDENCE

- Multiple surveys through time are required at individual sites to collect presence-not detected data as well as additional predictor variables (e.g., habitat) that may be included in occupancy models.
- Sample size (number of repeated surveys and total number of sites) is dependent on the sightability probability of the species (see "Challenges associated with aerial surveys" above) and the complexity of the occupancy model (i.e., number of covariates) in which the data will be used.
- Occupancy models produce inferential statistics, including mean values and standard errors from which confidence intervals can be calculated.
- In order to determine population size, an estimate of per unit abundance must be available.

2.3.3 COMMUNITY INVOLVEMENT

Opportunity for Local Community Involvement

- Local community members can provide knowledge on past and present caribou distribution/occupancy.
- Community members can provide information on known gathering sites (craters, licks) and on areas where preferred food sources may be found (lichen).
- Community members can conduct exploratory flights to search for animal signs.
- Local community members can participate as observers in the survey work, or gain experience to do so.

Potential for Co-application of Indigenous Knowledge

Note that any application of Indigenous Knowledge must be conducted in a manner which is agreed upon by all parties, is transparent, serves the local communities where the information originated from, and adheres to local Indigenous data governance and sovereignty.

- Planning
  - o Indigenous Knowledge can be used in survey area delineation in the absence of other caribou distribution data, or can be used to supplement overall caribou distribution knowledge in areas that are data deficient, or can be used to verify knowledge of caribou historical distribution.

2. Aerial Occupancy Surveys

- Data collection
  - Data used in occupancy surveys can be combined from multiple sources including current and historical TEK/LEK/IK.
  - Indigenous Knowledge holders can also participate on the flights. Inexperienced observers can influence survey success due to missing significantly more animals than experienced observers (Gasaway *et al*. 1986). Local harvesters have extensive experience in tracking animals in the area in which a survey is being conducted, and have great insight into where caribou are likely to be.
  - Once designed (i.e., where, when, and how to collect data), collection of occupancy data is fairly straightforward and there is definitely a role for community members and partners to define the area of interest and to collect data.
- Analysis
  - The authors note that though no examples have been provided for this section to date, there is an opportunity to learn more about how Indigenous Knowledge can inform analysis of aerial survey data. Should the reader know of information which may resolve this knowledge gap, kindly contact the NBCKC Secretariat.
- Reporting
  - The authors note that though no specific *examples have been provided for this section to date, lessons learned through community-based monitoring programs highlight an opportunity for collaboration in reporting and knowledge-sharing of monitoring program results. For example, while western scientists could lead in the development of academic papers or journal publications, local community members (notably youth) may collaborate in the interpretation of program results, and subsequently lead in knowledge sharing within their communities. As noted by Raygorodetsky and Chetkiewicz (2017) this practice has been applied when Community Based Monitoring programs are rooted in Multiple Evidence Based principles.*

Cost: $$$

Photo Credit: OMNRF

2.3.4 *RESOURCES*

Equipment Costs

- Expenses to consider in aerial occupancy monitoring programs will vary, based on: the extent of the study area (i.e. sample size), as well as data requirements for the variables (e.g., habitat) used for analysis in occupancy models.
- Since repeat visits to sites are required to estimate sightability correction factor, accessibility is a primary consideration.

Personnel Costs

- The cost of fieldwork planning will be influenced by the degree of incorporation of local knowledge holders and experts into the survey design and execution. Personnel may need to travel to gather this information, and knowledge holders need to be compensated for their contributions.
- Fieldwork costs will be influenced by staff salaries and travel to survey location, meals, accommodation and gear.

Logistical Complexity: MODERATE

Skills Required

- An aerial count sampling survey is made more efficient with previous knowledge of herd range and seasonal distribution. This can be obtained through local or Indigenous knowledge of the area, or through a review of previous survey results, resource selection functions, or occupancy models.

2. Aerial Occupancy Surveys

- Staff must be familiar with spotting caribou track or sign from an aircraft, measuring/estimating distance, and classifying animals (if estimating recruitment). "In addition to safety, maximizing the quality of the data collected while simultaneously minimizing stress to the animals should be the primary goals of every survey; this requires that experienced personnel are involved with all aspects of survey planning and delivery" (ASRD 2010). Simply put, the key is to choose observers who have experience looking for caribou/tracks, flight experience, and who will remain invested for a long time so that the experience grows.

Photo Credit: OMNRF

- Survey design and analysis of data collected requires familiarity with statistics, GIS, and sometimes requires familiarization with additional software.

Capture/Handling: NO*

* unless telemetry is combined in program

2.3.5 ETHICAL CONCERNS

Capture/handling

- Caribou are not directly captured for aerial occupancy surveys.

Potential Stress From Monitoring

- Although occupancy surveys involve no direct handling of animals, the method requires repeated visits to estimate sightability ; this may increase probability of animal stress.

Carbon/environmental Footprint

- High: As with all aerial surveys, considerable fuel is consumed during flight time. For example, in Labrador, two commonly-used aircrafts are the Bell206 LR helicopter which consumes 123 L/hr (https://summithelicopters.ca/fleet/bell-206-lr/), and the Astar350 B2 helicopter which consumes 180 L/hr (https://www.yhl.ca/astar-as350-b2-helicopter/), where typical big game surveys range from 40-100 hours of flight time.

2.4 EXAMPLE

NORTHERN ONTARIO Annual winter distribution surveys for boreal caribou in northern Ontario provide data to estimate occupancy probability and infer changes in population distribution: "Researchers from the Ministry of Natural Resources and Forestry applied new analytical techniques to caribou, moose and wolf observations collected during systematic aerial surveys that were conducted in the Far North of Ontario and used them to develop occupancy models for each species. The factors with the greatest impacts on animal detection, varied between species and ecozones (i.e. the Ontario Shield and the Hudson Bay Lowlands). In both ecozones, caribou were more likely to be detected when terrain openness was high. In the Hudson Bay Lowlands Ecozone, caribou detection was also influenced by time of year and time of day. Detection probability was highest earlier in the winter and at mid-day (vs. early or late in the day). Additionally, using an analytical technique that explicitly accounted for the lack of spatial independence between sampling locations improved the accuracy of occupancy models and the uncertainty associated with occupancy estimates." (MNRF, 2014)

3. Aerial Imagery

3.1 AT A GLANCE

Photo Credit: OMNRF

Aerial imagery is a wildlife monitoring technique based on camera technology. Cameras may be flown remotely (Unmanned Aerial Vehicle or UAV), or be controlled by an on-board pilot. Images are collected from the visible light (RGB imagery) or the infrared (e.g. Forward-Looking Infrared Radiometer or FLIR) portion of the electromagnetic spectrum. The flight path of the camera(s) covers the survey area, typically in a grid-based pattern of parallel transects. A "wide field of view" is used to search for caribou, while a "narrow field is view" is used to verify the object, as needed (Carr *et al*. 2012, Bernatas 2013). Video recordings (and sometimes still frame images) are collected throughout the flight. Subsequent to flight, footage is analyzed to inform on a variety of caribou population metrics. For example, survey results may be used to provide a baseline for density and distribution of animals within the survey area (Bernatas 2013). This monitoring method is said to be both cost and time efficient, especially for projects where a large geographical area is to be surveyed, or where herd-level assessments are required (Carr *et al*. 2012, Gillette *et al*. 2015).

A NOTE ON VOCABULARY:

Unmanned: Cameras flown remotely are referred to in the literature as Unmanned Aerial Vehicle (UAV)-mounted, Unmanned Aerial Systems (UAS)-mounted, or "drones". UAVs can be fitted with either visible light spectrum cameras, or infrared sensors, or both. In Canada, The use of UAVs falls under Transport Canada's Canadian Aviation Regulations, where regulations differ depending upon the weight of the device, the equipment attached, and its intended purpose. A restriction to note with the use of UAVs is the legal line-of-sight requirement. UAV's must be flown within a direct line of sight of the operator, meaning that use of UAV in caribou monitoring programs requires knowledge of herd location prior to UAV flight. Special permits are required to fly UAV devices beyo nd the line of sight of the observer (e.g. Patterson *et al.* 2016). For the purpose of this report, we refer to Unmanned Aerial Vehicles and their attached cameras as "Unmanned".

Manned: Cameras flown by an on-board pilot and survey crew may be mounted to fixed-wing or to rotary-wing aircrafts. Aerial imagery collected from a manned aircraft makes use of technology such as Forward-Looking Infrared Radiometer (FLIR) sensors. These are typically mounted with a gimbal (pivoted support) that allows vertical and horizontal panning, which is an advantage over vertical-looking infrared imaging. FLIRs make pictures from heat, not visible light (FLIR Systems Inc. 2019). Animal identification is sometimes challenging from thermal imagery alone (e.g. Carr *et al*. 2012), and a camera/sensor that can detect visible light won't detect thermal energy (FLIR Systems Inc. 2019). Therefore, FLIR sensors are often coupled with a high spatial resolution natural colour video camera. For the purpose of this report, we refer to these aircrafts and their attached cameras as "Manned".

RGB imagery: The visible light spectrum refers to the portion of the electromagnetic spectrum that is detectable by the human eye, daylight cameras, and some night vision cameras (FLIR Systems Inc. 2019). This includes white light and colors such as red, green, and blue (hence, "RGB"). On the electromagnetic spectrum, visible light is found at the 0.4 - 0.7 μm wavelength (Figure 2). The images detected in the human eye and in daylight and night vision cameras are based on the amount and strength of light that can be detected (e.g. sunlight, moonlight, starlight, artificial light)).

3. Aerial Imagery

Infrared imagery: Infrared imagery is unlike seeing along the visible light spectrum, because infrared imagery is taken from the infrared (IR) portion of the electromagnetic spectrum (not the visible light portion). The portion of the electromagnetic spectrum that refers to infrared energy is 0.7 - 1.0 μm wavelength (Figure 2). This energy is too low for the regular human eye to see. Infrared illuminated cameras (also known as "infrared night cameras") generate their own light by projecting a beam of near-infrared energy that their imager can see when it is reflected back by the object (JagerPro2015, FLIR Systems Inc. 2019). In other words, special sensors are required to be able to detect infrared energy. This is why we say "infrared sensors", and not "infrared cameras". Simply put, infrared images are produced based on the amount of infrared energy the sensors can detect.

Photo Credit: OMNRF

Thermal imagery: Thermal imaging cameras are devices that 'translate' the thermal imagery region of the infrared spectrum into visible light, in order to analyze a particular object or scene. In other words, these sensors translate heat (which is invisible to the human eye) into something visible for analysis. The "thermal imaging region" of the electromagnetic spectrum is from 8.0 – 15.0 μm (Figure 2). FLIR systems detect thermal energy in the 7.5 - 13.5 μm range of the electromagnetic spectrum. The images produced from FLIRs and other thermal imaging cameras are known as thermograms and are analyzed through a process called thermography (Grainger 2018). Simply put, thermal cameras detect differences in heat and display those differences (depending on the type of thermal imaging camera used) as black/white, iron, or rainbow (Grainger 2018, FLIR Systems Inc. 2019). This allows users to tell warm objects (e.g. caribou) from colder backgrounds (e.g. ground).

Photo Credit: OMNRF

3. Aerial Imagery

Photo Credit: OMNRF

Daylight cameras

- Passive imaging
- Based on visible light

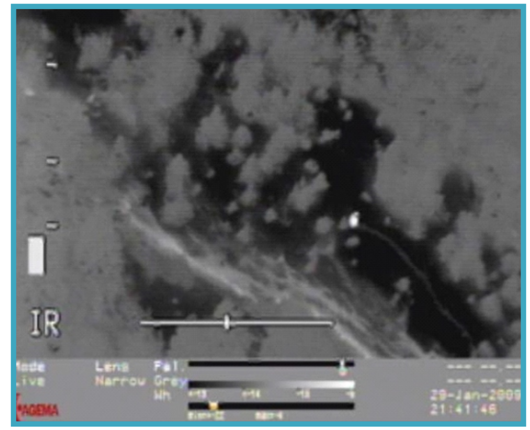


Photo Credit: OMNRF

Forward-Looking Infrared Radiometer

- Sensors obtain a completely passive image of subjects
- Requires that subjects have a higher temperature than the background
- Uses more complex sensors than those in daylight or infrared night vision cameras.

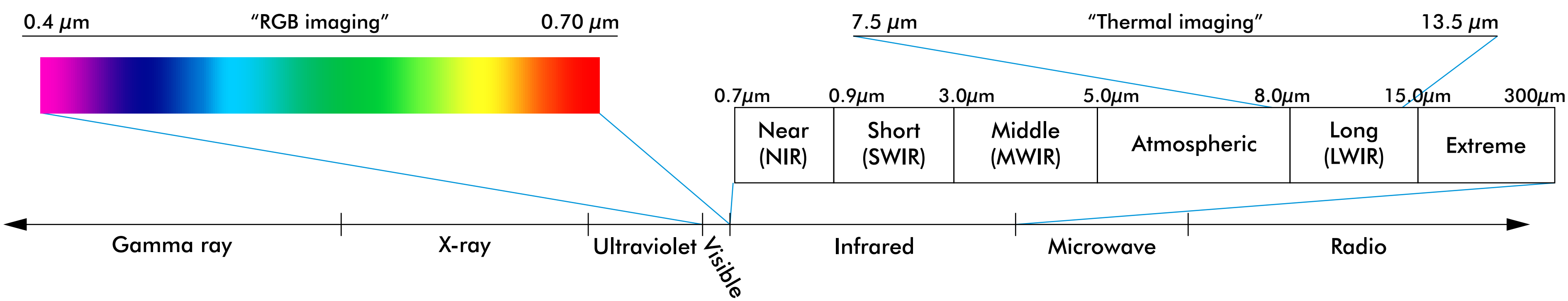


Figure 2: Where daylight cameras and Forward-Looking Infrared Radiometers(FLIRs) operate along the electromagnetic spectrum. Differences in properties of visible light and infrared light lead to differences in camera properties. Daylight cameras and FLIRs are both used for aerial imagery of boreal caribou in Canada. Figure content is based on: NASA 2013, Akhloufi and Bendada 2013, Pinkson 2015, Grainger 2018, FLIR Systems Inc. 2019.

3. Aerial Imagery

3.2 SUITABILITY FOR MONITORING

3.2.1 CARIBOU POPULATION PARAMETERS THAT CAN BE MONITORED

From Suitability Table 1: Selecting a monitoring method that suits your objectives

- x — Method is not appropriate for estimating this parameter
- ✓ — Method provides some information or can be combined with other methods for inference
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- ✓✓✓ — Method is most appropriate and/or intended specifically for estimation of this parameter

Note: table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone

		Distribution			Abundance				Demography			Health			
		Distribution/ Occupancy	Dispersal/ Movement	Habitat use	Population density	Population size	Effective population size	Minimum counts	Population growth trend	Survival/ Mortality	Recruitment/ Reproduction	Body condition	Disease	Other health indices	Foraging/ Nutrition
Aerial Survey	Aerial imagery	✓✓	x	✓✓	✓✓	✓✓	x	✓✓	✓✓	x	✓	x	x	x	x

***Note that the only parameters listed here are the primary population metrics that are explored in detail in Comparative Table 1 to allow for standardized comparison among monitoring approaches; all other information that can be obtained from this method is detailed in following "Additional parameters and information" section.*

3.2.2 ADDITIONAL PARAMETERS AND INFORMATION THAT CAN BE MONITORED (BEYOND THOSE LISTED IN TABLE 1)

- Habitat monitoring: UAV Thermal cameras as well as high-resolution RGB imagery can provide details of change over time.
- There is potential to use UAVs for assessing changes in vegetation due to climate change (Malenovský *et al*. 2017) and long-term forest monitoring following human (e.g., timber harvest) and natural (e.g., fire, insect) disturbance events at local and/or regional scales (Zhang *et al*. 2016).
- Aerial imagery surveys are suitable for multi-species monitoring and assessment (e.g. Bernatas 2010, Millette *et al*. 2011)
- Landscape level approaches can be used to note disturbance patterns in the area (e.g. Riccardo *et al*. 2017).
- In future, potential to measure body temperature as health index (Lavers 2009)

3.2.3 IMPLEMENTATION

- As with all aerial survey methods, this method is appropriate during the spring/fall seasons, when ground access to survey areas are not possible (mud, snow, private property, lack of road access) or cost prohibitive (Gillette *et al*. 2015).
- Most beneficial in remote areas where return visits are costly, especially if multiple species are surveyed.

3. Aerial Imagery

- Aerial imagery can support findings, and verify trends predicted through other monitoring programs. For example, Gillette *et al*. (2015) showed that counting grouse leks using aerial thermal imaging was statistically equivalent to counts from a ground-based survey. On the other hand, Carr *et al*. (2012) found that FLIR imagery detected more caribou than other survey methods.
- Aerial imagery can guide novel monitoring programs in areas when monitoring data are scarce or non-existent. For example, aerial imagery used to obtain an initial estimate on the size and distribution of a herd could guide the stratification patterns of subsequent aerial counts or aerial occupancy surveys (ref).
- Thermal imagery is inappropriate for use where age*, sex*, and health data are the main focus of the survey, due to risk of insufficient resolution of images.
- *It is worth noting that thermal and RGB footage have been used in combination in Ontario for age/sex stratification, though insufficient image resolution prohibits this from being a common practice.

Photo Credit: OMNRF

3.2.4 ADVANTAGES:

- Unmanned
    - UAV has the potential to provide imagery with high spatial and temporal resolutions (compared to traditional aerial surveys) including distinction of wildlife age/sex classes (e.g. Jones *et al*. 2006, Berger 2012, Whitehead et al. 2014, Chretien *et al*. 2016).
    - Carbon footprint is reduced (compared to manned surveys) because devices are small, lightweight, and often battery-powered.
- Manned
    - "Although FLIR surveys require an experienced sensor operator and specialized equipment, they are usually less expensive than conventional aerial surveys". (Carr *et. al* 2012)
    - There is a reduced safety risk to humans (as compared to traditional aerial surveys) because of reduced observer fatigue and airsickness, and thus potentially a reduction in observer bias.
    - There is a reduced risk of potential stress on caribou (as compared to traditional aerial surveys) because surveys are generally flown at higher altitude, often with fixed-wing aircraft, and spend less time directly above the animals.
- Aerial imagery generally
    - RGB and thermal footage can provide concrete visual data for future review and assessment. This digital survey can be reviewed forward, backward, and frame by frame at the observer's preferred speed.
    - RGB and thermal footage can help determine sources of sightability challenges. For example, a review of FLIR footage by Bernatas (2013) highlighted a surprise: bud break "glow" from deciduous trees made the glow of white tail deer on the ground less obvious.
- RGB footage
    - With RGB footage, animals with highly contrasting colors are easily counted, but there are limitations for more cryptic species (Chretien *et al*. 2016). For example, the potential for using UAVs with RGB cameras to survey caribou was tested in Labrador using plywood boards as surrogate targets, which showed an overall detection rate of 77.5% and elucidated the importance of habitat type as an important factor in detectability (Patterson *et al*. 2016).

3. Aerial Imagery

- Thermal footage
    - Thermal footage leads to more accurate detection rates, as compared to traditional aerial counts (e.g. Bernatas 2013, Gillette *et al*. 2015)
    - Regarding seasonal timing : "The window of opportunity for FLIR surveys is wider than for aerial surveys that require appropriate snow conditions in winter; an important consideration in a period of climate change that may produce short, mild winters with less snow." (Carr *et al*. 2012)
    - Thermal imaging is gaining popularity as a monitoring tool, because it does not require capture and handling of individuals (e.g. Carr *et al*. 2012).

3.2.5 DISADVANTAGES:

- Unmanned
    - The effects that UAV's have on caribou behavior and physiology need to be assessed (Ditmer *et al*. 2015).
    - Staging area suitable to launching and retrieval of UAV must be relatively close to the herd as UAV requires visual line of sight at all times.
    - Knowledge of the approximate location of a caribou herd is required before conducting the survey, unless a 'beyond line of sight permit' is acquired from Transport Canada.
    - Flight time is restricted to battery capacity (fuel capacity if larger UAV being used). Drones most commonly used have a battery life of 20-30 minutes.
    - Weather and temperature limitations create restriction periods (UAVs cannot fly below -10°C)
    - UAVs can only cover a relatively small area in a given day compared to manned aircraft.
- Manned
    - As with all manned aircraft operations, flights can be noisy, thus leading to potential stress of caribou (Patterson *et al.* 2016)
- Aerial imagery general
    - High start-up cost of equipment (camera or sensor), aircraft, and trained operator.
- RGB footage
    - Vegetation cover hinders detection of animals.
- Thermal footage
    - Determining animal sex is not possible, unless the FLIR unit is coupled with a high spatial resolution natural color camera.

Photo Credit: Agnes Pelletier

3. Aerial Imagery

3.3 CONSIDERATIONS AND REQUIREMENTS

From Suitability Table 2: Comparing suitability and requirements of monitoring methods

Spatial Scale
- ✓ Method provides some information at this spatial scale
- ✓✓ Method is appropriate for application at this spatial scale
- ✓✓✓ Method is most appropriate for application at this spatial scale

Co-application of Indigenous Knowledge:
P – Planning D – Data collection
A – Analysis R – Reporting

***Note:** Table is meant to be used in combination with the other tools in the toolkit and may not reflect regional subtleties when used alone*

		Spatial Scale		Data Needs **		Community Involvement		Resources			Ethical Considerations		
		Local/study area	Regional/range	Minimum sampling requirements	Ability to assess data confidence	Local opportunity	Co-application of IK	Equipment costs	Personnel costs	Skills required	Capture/ handling	Potential stress from monitoring	Carbon footprint
Aerial Surveys	Aerial imagery *	✓ , ✓✓	✓✓✓ , ✓✓	≥1 yr pop size / ≥2 yr trend (≥2 samples/yr)	Low/ Med	Med/ High	P, D	Med/ High	Med/ High	Med/ High	No	Low/ Med	Med/ High

** Two spatial scale scores for Aerial imagery represent Manned and Unmanned aircraft, respectively // ** These are general guidelines only; refer to text for details of sampling requirements*

3.3.1 SPATIAL SCALE

- Aerial imagery is most effective when conducted at a coarse scale, or when used for herd-level assessments
- Relative to each other, unmanned surveys are more appropriate for studies conducted at finer spatial scales, while manned surveys are more appropriate at coarse spatial scales.
- With either camera survey method, photos can be aligned spatially in a manner that would provide good data over a broader area.

3.3.2 DATA NEEDS AND CONFIDENCE

- Requires two or more years of data to inform population trend from abundance estimates.
- As with all aerial surveys, corrections should be made for sightability errors. This can be done, for example, through calculation of a detection function, if the aerial imagery has been combined with distance sampling methods. Alternatively, mark-recapture protocols can be used if marked individuals (e.g., radio collars) are in the survey area, as discussed in the chapter introduction.

3. Aerial Imagery

3.3.3 COMMUNITY INVOLVEMENT

Opportunity For Local Community Involvement

- Could certainly involve any community members or partners that have knowledge of the areas where caribou spend time.

Potential For Co-application Of Indigenous Knowledge

Note that any application of Indigenous Knowledge must be conducted in a manner which is agreed upon by all parties, is transparent, serves the local communities where the information originated from, and adheres to local Indigenous data governance and sovereignty.

- Planning
  - o Indigenous Knowledge can be used in survey area delineation in the absence of other caribou distribution data, or can be used to supplement overall caribou distribution knowledge in areas that are data deficient, or can be used to verify knowledge of caribou historical distribution.
- Data collection
  - o The authors note that though no examples have been provided for this section to date, there is an opportunity to learn more about how Indigenous Knowledge can contribute to the collection of aerial imagery data. Should the reader know of information which may resolve this knowledge gap, kindly contact the NBCKC Secretariat.
- Analysis
  - o The authors note that though no examples have been provided for this section to date, there is an opportunity to learn more about how Indigenous Knowledge can inform analysis of aerial imagery data. Should the reader know of information which may resolve this knowledge gap, kindly contact the NBCKC Secretariat.
- Reporting
  - o The authors note that though no specific examples have been provided for this section to date, lessons learned through community-based monitoring programs highlight an opportunity for collaboration in reporting and knowledge-sharing of monitoring program results. For example, while western scientists could lead in the development of academic papers or journal publications, local community members (notably youth) may collaborate in the interpretation of program results, and subsequently lead in knowledge sharing within their communities. As noted by Raygorodetsky and Chetkiewicz (2017) this practice has been applied when Community Based Monitoring programs are rooted in Multiple Evidence Based principles.

Cost: $$

3.3.4 RESOURCES

Equipment Costs

- Expenses to consider in aerial imagery monitoring programs will vary, based on: whether flights are manned or unmanned, imagery type (RGB or Thermal), as well as duration and location of study
- Unmanned survey flight typical expenses include the UAV device itself, UAV charging equipment, and staff transportation to, and accommodations on, the potentially remote survey site.
- Manned survey flight typical expenses include: Aircraft (prices will vary based on whether fixed-wing or rotary-wing is being used, as well as length of time the aircraft is being used)
- Both RGB and thermal imagery costs are highly variable and depend on the quality of the imagery.

Photo Credit: NL Wildlife Division

3. Aerial Imagery

Personnel Costs

- The cost of fieldwork planning will be influenced by the degree of incorporation of local knowledge holders and experts into the survey design and execution. Personnel may need to travel to gather this information, and knowledge holders need to be compensated for their contributions.
- Staff would require some training in thermography, and suitable data storage and computer processing capabilities to handle both the high-resolution RGB video stream and the thermal camera video stream.
- Field survey work requires a minimum of two people; a pilot and system operator.
- Fieldwork costs will be influenced by staff salaries and travel to survey location, meals, accommodation and gear.
- Time investment for analysis of recorded video following the survey is considerable (~2 hrs review for each 1 hr recorded). This time requirement may be reduced in the future through machine learning algorithms under development for use with aerial surveys and camera traps (Schneider *et al*. 2019, Torney *et al*. 2019, Willi *et al*. 2019).

Logistical Complexity: MODERATE

Skills Required

- UAV pilot training (flight time, ground school, and basic thermography course).
- Sampling design and analysis are straightforward and similar to planning for typical aerial surveys.
- Fieldwork would require labour to move equipment (using amphibious or all-terrain vehicles).
- System operator requires specialized training to use equipment and identify wildlife, including age/sex where possible.

Photo Credit: NL Wildlife Division

Capture/Handling: NO*

* unless telemetry is combined in program

3.3.5 ETHICAL CONCERNS

Capture/handling

- Caribou are not captured or handled in aerial imagery monitoring programs

Potential Stress From Monitoring

- UAVs are battery-powered and therefore less disruptive than FLIR-based surveys.
- The amount of stress that aerial imagery aircrafts cause to caribou requires investigation. There is agreement that unmanned aircrafts are less noisy than manned aircrafts, due to smaller aircraft size. However, there is uncertainty as to what "level" of noise is acceptable, in terms of risk of disturbing caribou.

Carbon/environmental Footprint

- Unmanned: Low
- Manned: Moderate. Time to complete a FLIR survey is usually less (80%) than to complete a standard aerial survey because less time is spent circling individuals to confirm a sighting and to identify age/sex.

3. Aerial Imagery

3.4 EXAMPLE

SLATE ISLANDS, LAKE SUPERIOR, ONTARIO The Boreal woodland caribou on the Slate Islands in northern Lake Superior, Ontario, are the southernmost in Canada, with the population reaching as many as 600 individuals between 1975 and 1997 (Bergerud *et al*. 2007, Rangifer). A pilot study was undertaken in January 2009 to assess the feasibility of using Forward-Looking Infrared (FLIR) imagery to obtain an updated population estimate. The Slate Islands provided an ideal setting to test the FLIR technology because it represents an essentially closed system and lacks other ungulates (moose, deer) that could be misidentified as caribou in the aerial imagery. The results of the FLIR survey were subsequently compared to three other methods of population estimation (Carr *et al*. 2012, Rangifer). The FLIR survey of the Slate Islands was conducted by Vision Air Research Inc. (Boise, Idaho) on January 29-30, 2009. A PolyTech Kelvin 350 II gimbal (Eskilstuna, Sweden), which included a high resolution Agema Thermovision 1000 (FLIR Systems, Inc., Wilsonville, Oregon) infrared sensor with a spectral range of 8-12 microns and a Sony video camera (Sony Corporation, Minato, Tokyo, Japan), mounted under the left wing of a Cessna 206 "Stationair" was used for the survey. Survey flights took place between 1000 and 1400 hrs. along transects that were oriented to run northeast-southwest, parallel to the dominant terrain. Transects were spaced 200 m apart to give complete coverage of the area and were flown at an altitude of 305 m (1,000 ft.) above ground level of the highest point along each transect and the adjacent transect. The sensor operator scanned side to side to allow multiple fields of view and overlap with adjacent transects. Animals were initially sighted using the infrared sensor and verified using real time video imagery. Imagery was recorded along all transects. Following the survey, all video recordings were reviewed frame by frame to confirm caribou sightings and locations and to verify the number of individuals that may have occurred in groups. Perpendicular distances between caribou locations and transect lines were determined in ArcGIS (ESRI, Redlands CA). An estimate of the caribou population size and associated confidence intervals was then calculated using Distance 6.0 release 2 software (Thomas *et al*. 2010, Journal of Applied Ecology). The FLIR survey provided a population estimate that was comparable to other methods of population estimation but had narrower confidence intervals than two methods. However, the detection rate in the FLIR survey was only 60%, likely due to conifer canopy closure, and it is recommended that it be combined with other techniques such as genetic sampling to improve precision. It should be noted that significant advances have been made in FLIR technology since the time of the pilot study, including deployment on Unmanned Aerial Systems (UAS) (Beaver *et al*. 2020, Wildlife Society Bulletin).

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