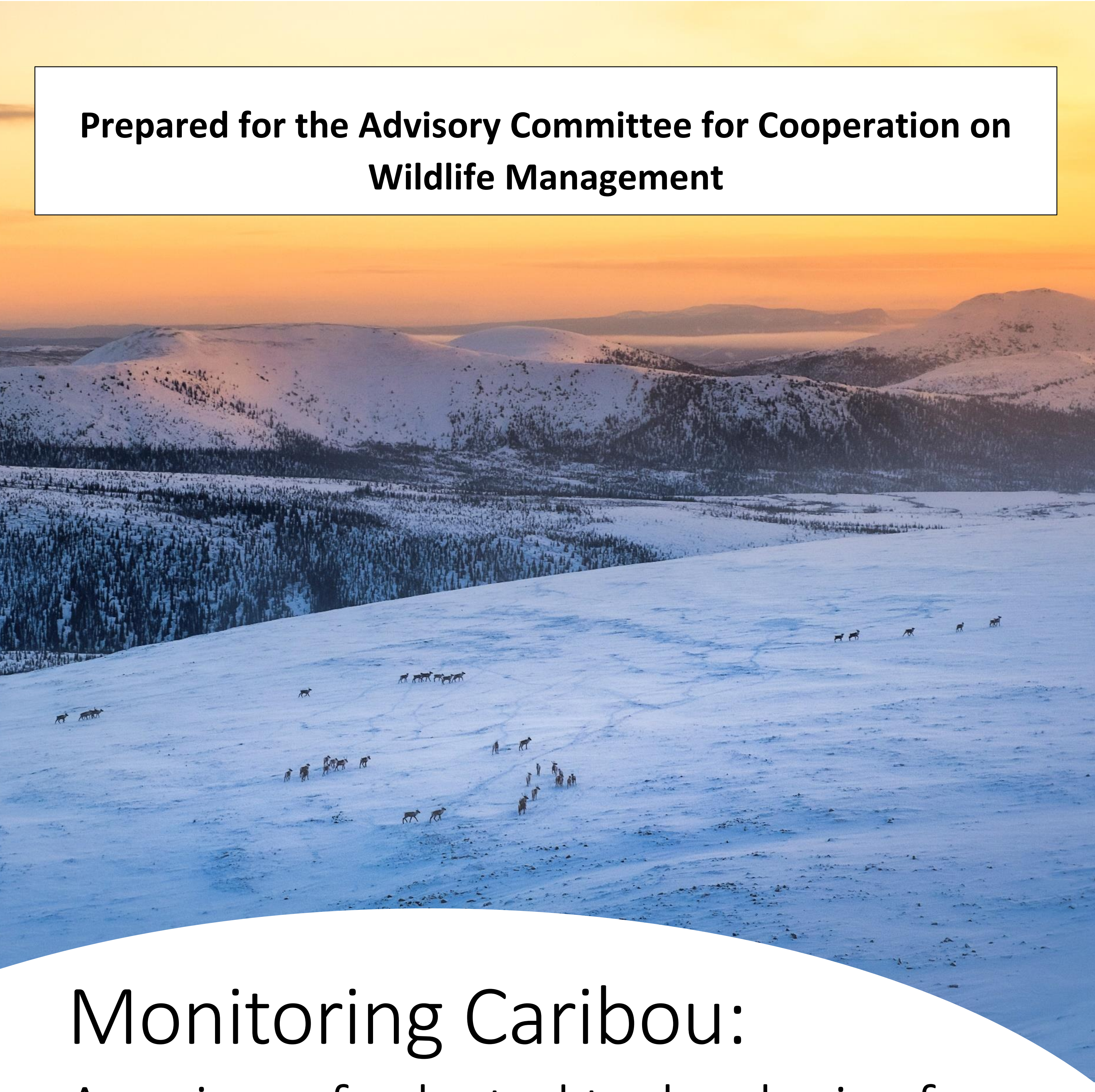
Prepared for the Advisory Committee for Cooperation on Wildlife Management



Monitoring Caribou:

A review of selected technologies for tracking barren-ground caribou

February 2022

Photo credit: Pierre Chaillon

Contents

Introduction

The Taking Care of Caribou Management Plan (ACCWM, 2014) identifies key information areas that are used in assessing the status and appropriate management actions for the Cape Bathurst, Bluenose-West, and Bluenose-East barren-ground caribou herds (see Table 1). The plan identifies both community-based and technical information sources. Currently, collaring of barren-ground caribou is one of the primary tools utilized for monitoring of barren-ground caribou. Collars are considered essential for current population estimate survey methodologies (calving and post-calving methods) but are also used during survival, productivity, recruitment, and adult composition surveys. Collar data inform range use and movement patterns, provide information on herd fidelity, and are used to identify habitat selection conditions and human disturbance effects. All this empirical information feeds into the management decision-making process by the Advisory Committee of the Cooperation of Wildlife Management (ACCWM) alongside the community-based knowledge.

Barren-ground caribou, unlike other caribou ecotypes, travel over large areas during their yearly migrations to their calving grounds. Their ranges are large and remote, making monitoring difficult. Indigenous groups involved in the Taking Care of Caribou Plan have identified cultural concerns with touching caribou, yet collaring is currently one of the key tools used. Collaring is an invasive, high-risk procedure involving the handling of individual caribou. It is recognized that collaring is risky to the crew and the caribou. Caribou mortalities do occur during collaring. The need for information about the caribou must be balanced with the cultural sensitivities around caribou and potential impacts to individual animals. This has always been a hot topic that needs reassessment. With that in mind, the ACCWM is undertaking a review of the monitoring methodologies currently available for barren-ground caribou.

There is a lot of excitement about new developments in wildlife monitoring technology. These advancements have the potential to transform the way researchers follow and learn from the movements of species all over the world. Huge datasets of high-resolution movement and location observations (largely produced with tracking devices) are now being combined with ever more detailed environmental data, providing insights into how and why animals move through their habitats.

Improvements in sensors at all levels (on-animal, aerial, satellite, etc.) may open entire new branches of potential research possibilities in the fields of ecology and wildlife behaviour. In some cases, sensors are fitted with solar panels, which enable the tracking of individual animals for much longer periods, reducing the number of captures needed. This individualized data may be paired with data from other sources providing population-spanning sampling across large study areas.

The resolution of some methodologies allows researchers to observe both inter- and intraspecific interactions. In the context of the barren-ground caribou, this can provide a glimpse into things like predator-prey dynamics relationships with species such as muskoxen, both of which have been highlighted as areas of special interest at the ACCWM annual status meetings.

This review identifies the information currently obtained using collars and examines some possible other methodologies to obtain this knowledge. Methods include both well-tested and utilized survey methods and emerging technologies such as satellite imagery and drones. There are recognized areas for improvement in current methods and opportunities to adopt new technologies, as well as to implement effective community-based monitoring.

Background of collaring

The technique that may have had the largest impact on wildlife research over the last half-century is wildlife tracking using radio or GPS tracking systems. The potential for learning new information with these systems is almost endless. Yet, these techniques require that animals be captured and fitted with a tracking device. Consequently, many people have expressed concerns about the potential negative impacts of radio-tracking studies and the ethical dilemma of interfering with animals. The following sections describe the development of this tool and some of the concerns related to its use on species like barren-ground caribou.

In Canada, caribou were fitted with some of the earliest iterations of this technology. In 1992, the Ontario Ministry of Natural Resources (OMNR) contracted Lotek Engineering Inc. to develop a telemetry system using GPS technology. In cooperation with Hydro Québec and the Québec government, these prototype units were deployed on caribou at the La Grande River Reservoir in March 1993. In February 1994, the first commercial GPS collars were again deployed on caribou in northern Québec (Sibbald, 2001). The Government of the Northwest Territories (GNWT) began using satellite radio collars to track barren-ground caribou movement shortly afterwards in 1996.

New collar, left, weighs about a third less than older collar, right, due to a smaller, lighter battery

Figure 1: Many collars used today weigh 0.8 kg, much less than older collars, which weighed well over a kilogram. A snowmobile helmet, for comparison, weighs as much as 2 kg. (adapted from GNWT-ENR, n.d.)

The system works as long as four GPS satellites are in view of the receiver, which is located on the collar. At any given time and place on the planet, this should allow for three-dimensional position recording. When the receiver only has a line-of-sight to three satellites due to an obstructed view of the sky, a 2D position can be obtained (Rodgers et al., 1996).

GPS tracking can be expensive. However, per data point or for large ongoing studies in remote areas, the costs of GPS tracking have historically been cheaper than other options. This is because, for each unit of labour, GPS tracking can gather many more location data points. On the other hand, studies based on GPS tracking frequently use fewer individual animals because of the expense per GPS unit. If the animals themselves are considered the study unit, this reduced sample size can cause data analysis problems when generalizing about a population (Rodgers et al., 1996; Otis and White, 1999).

A single GPS collar can cost thousands of dollars; however, a single collar can be used on many different animals over the years. Therefore, the cost of fitting additional animals with GPS collars gets less over time. It is also important to note that GPS collars can be refurbished and reused, though some parts, such as the release, need replacement.[1] At the same time, there are considerable costs involved with deploying the collars, including helicopters and specialized crews.

Although start-up costs for GPS systems may seem high, this does not necessarily mean they are uneconomical. When cost per data point is considered, as opposed to cost per animal, GPS collars can be the cheaper alternative and save personnel costs since the study may be less labour intensive. In the mid-90s, Rodgers et al. (1996) found that GPS-based telemetry was the most economical and logistically feasible method to track moose even in relatively accessible parts of northwestern Ontario. Had Rodgers and coauthors done their comparison of VHF and GPS collars in the range of the barren-ground caribou, they would have found an even greater price differential due to the higher cost of labour and travel to remote monitoring locations.

Collaring process

There are standard operating procedures that are followed for collaring caribou in the NWT (Cattet, 2018). Nets launched from helicopters are generally used to catch caribou for the collaring process. Net-gunning is typically preferred in the NWT as there are concerns that residues of immobilizing drugs may have negative health effects on subsistence harvesters that rely on the caribou and that the effects from the immobilizing drugs will increase the potential for illnesses and predation on the affected caribou (Lian et al., 2018). Immobilization via net-gunning does entail some risk of injury or mortality but it provides a lower-level of stress (indicated by both physiological and biochemical parameters and the lowest morbidity and mortality rates when compared to other forms of immobilization (Jessup et al., 1988; Valkenburg et al., 1983).

Once the caribou are caught in the net, they are blindfolded to relieve stress, hobbled, and their heart rate monitored to ensure it goes down to normal levels. A collar is quickly placed on the animal, some health-related observations are recorded (this may include biological samples such as blood or hair) before the animal is released as quickly as possible. A major plus when compared to darting, netting can be extremely fast. Not only does this reduce stress time on

[1] Collar releases (also called drop-off mechanisms) are designed to reduce the cost associated with recapture, as well as the stress on the animal. The mechanism can be set to drop off the animal with a timer or triggered with a radio device. Additionally, a low voltage trigger will release the collar once the battery on the collar drops below a certain voltage.

the animal but it also lowers costs. On the other hand, researchers have less time to collect data and some data collection is not possible without the animal being sedated.

Still, mortality from capture-related injuries is a concern. The impact from the net-gun may lead to fractured legs, puncture wounds, broken bones, or even mortality (Cattet, 2018; Ferguson, 2015). In discussions with biologists specializing in net-gunning ungulates, mortality rates were considered to be very low but no actual mortality information was available.

Concerns and potential effects on caribou health

Since the time of the earliest studies where animals were fitted with an electronic tracking device, there has been an important ongoing discussion about ethical standards for this method of research (Benson, 2010). There is an inherent risk to each study animal whenever a device is attached. Reducing the negative impacts of these devices is a priority not only for ethical reasons, but also to ensure that the data collected accurately reflects the behaviour of the species being studied. It can be challenging to determine the effects of the collars, as in many cases the only way to get the data is with animals with collars. The effects of the tracking device on animals are generally undetectable or low, although there are some examples where tracking devices have been shown to have a noticeable effect on the study animal (Boitani & Fuller, 2000; Rasiulis et al., 2014). Animal tracking research is typically regulated to maintain high standards of animal care, which help drive constant methodological refinements to reduce the risks to the animals being studied. In the NWT, the Wildlife Care Committee maintains a Standard Operating Procedure (SOP) manual for capture, handling, and collaring of caribou (Cattet, 2018).

The continued miniaturization of tracking devices supports this goal, as adding weight to animals is a primary concern. However, the continued refinement of the actual collaring process is also a priority. The ethics of animal tracking are part of a cost/benefit analysis, and researchers need to consider how they can offset the inherent costs of capture and collaring by extending the benefits of their studies. This includes designing systems that maximize the long-term utility and availability of the data collected, such that they can be used in novel ways to enable conservation of barren-ground caribou. At the same time, solar charging and longer-lasting batteries (4+ years) may reduce the number of captures needed in order to keep a sufficient number of collars deployed at a given time. Currently, one of the biggest challenges for collar-based taking is battery size and longevity. Adding complexity to the collar (GPS, virtual fencing, additional sensors such as activity counters, etc.) uses more battery power. VHF-only collars, which are limited by needing to be tracked with telemetry gear, run extremely long times on the same battery size, especially if the pulse rate is set low. All these parameters can be adjusted to optimize the life of the collar. Selecting and setting up the proper collar for the data needed is another way of refining the current technology. From the discussions which formed the basis of this paper, it is apparent that many researchers are already trying to optimize efficiencies with respect to collar technologies, and there is abundant interest in improving these efficiencies with new technologies.

Potential effects on an animal's normal behaviour should be considered any time a tracking device is attached. Researchers work to minimize any effects since the goal of tracking is to obtain data most closely indicative of the individual's normal behaviour (Paton et al., 1991). Studies rely on the assumption that there are enough collars deployed to be representative of the population and that wearing the device does not impact the behaviour being studied (Murray, 2006). However, there are numerous studies indicating this is not always the case. Some studies have demonstrated abnormal behaviour[2] of collared individuals (C. Brooks et al., 2008; Ferguson, 2015; Murray, 2006) or even potentially reduced predator avoidance abilities (Rasiulis et al., 2014).

The range of potential adverse effects from capturing and collaring an animal can range from short- to long-term and from tolerable to severe or fatal. Animals may display behavioural and energetic deviations as a result of capture, handling, or collaring (Cattet, 2018). Generally, if a study animal maintains its weight, produces offspring, or otherwise appears to look and behave normally, the effects are considered to be of minimal impact (White & Garrott, 2012).

Tracking devices have been reported to be responsible for overall decreased survival and body condition on a wide range of species such as zebras, grouse, and badgers (C. Brooks et al., 2008; Severson et al., 2019; Tuyttens et al., 2002). For example, animals partaking in sustained high-energy activities such as migration can also have their survival impacted by the presence of a GPS collar (Rasiulis et al., 2014). Rasiulis et al. (2014) note that "in addition to the detrimental effect of weight, the size or shape of the collar may contribute to the cumulative effect of wearing a heavier radio collar."

In a study of collared reindeer in Svalbard, Borquet (2020) found that there was a non-statistically significant increase in mortality for the collared reindeer. He suggests that further research may show impacts to collared individuals during high-stress situations such as icing events which impact the animal's ability to forage or contact with predators, two factors that did not impact the individuals in his study but may provide a tipping point for animals that are already exerting energy to carry the collars.

Borquet notes that modern GPS collars used on Svalbard reindeer are less than 2% of the bodyweight of the reindeer. In previous studies, such as Rasiulis et al. (2014), caribou were fitted with collars that were much heavier (1,630 g), and a number of negative effects were reported including increased predation when compared to individuals fitted with lighter (514 g) VHF collars. In the NWT, the Standard Operating Procedure (SOP) for collars notes the findings in Rasiulis et al. (2014) and states, "telemetry collars should be as light in weight as possible" (Cattet, 2018). The TGW-4680-3 GPS/Argos collars used on caribou weigh about 1,200 g. While this is an improvement on the units used by Rasiulis et al. (2014), it is unclear if this enough to

[2] Examples of abnormal behaviours can include but are not limited changes in movement patterns or reduced predator avoidance.

avoid the decrease in adult female survival during a population decline that they observed in their GPS-collared animals.

While researchers work to minimize any potential effects from tracking devices on the animals being studied, there remains the fact that handling these animals in any manner is both too invasive and disrespectful for some people to accept. The following section looks at what data are currently used to assess the status of caribou in the NWT and whether these data can be obtained with minimal reliance on collars or if the data can be obtained without the use of collars at all.

What data do we use to assess the status of the caribou?[3]

Section 8 of Taking Care of Caribou (ACCWM 2014) outlines the different questions that management authorities have asked in order to understand the status of the herds, summarizes the ways that information can be gained to answer those questions, and suggests how that information can be fed into the current management regime. In the sections below, descriptions of how each of the criteria is monitored are provided. Criteria that do not currently rely on data collected through collars are included in the section as the other methods and technologies being discussed below may either build on or replace these monitoring methods as well. The text in the following sections covers much of the same ground as the *Taking Care of Caribou management plan*[4] but has been condensed and does not include the figures used in the management plan. Please refer to the original management plan for the complete descriptions of these criteria and their respective monitoring methods.

It should be noted that the management plan utilizes two types of data: community-based and technical. The management plan clearly shows that both types of data can provide information on all the monitoring criteria. In the absence of data from one of the sources, management decisions can still be made.

Collar-based research methods are fundamental to the scientific approach to estimating the following monitoring criteria:

- Population size - number of animals
- Population trend and rate of change
- Productivity and recruitment - how calves are doing
- Adult composition - how bulls and cows are doing

[3] During preliminary discussions for this report, it was noted that collar data have many uses that are not touched upon in the Management Plan and may not be discussed during the annual status meetings. As such, there are numerous stakeholders that may be affected by a move away from collars. The breadth of uses for collar data beyond what is needed for the monitoring criteria is beyond the scope of this paper, but it should be noted that there may be other collar data users that are interested in partnering in the use of alternatives and the data provided by those alternatives.

[4] https://accwm.com/management-plan

- Caribou range and movement patterns
- Environment and habitat conditions

Utilizing collars during the assessment of these monitoring criteria allows researchers to provide a real-time snapshot of the state of herds that may not be possible with other methods. Additionally, the use of collars increases the efficiency of data collection for some of the criteria.

These criteria and associated monitoring methods are discussed below and are followed by monitoring criteria that do not currently require methods which include collaring. These additional monitoring criteria are:

- Body condition and health
- Harvest levels and practices
- Predator population
- Human disturbance
- Competitors

Population Size - number of animals

Collars are used during population surveys to help biologists improve the design and execution of aerial surveys, including the photo-censuses of calving grounds and post-calving aggregations, by directing survey planes to areas of high caribou densities, delineating the calving ground, and timing the peak calving periods (Gunn et al., 1997).

A major factor used to assess how well the herds are doing, and a key consideration when recommending the harvest for a herd is the estimated number of animals in a herd (population size). Currently, biologists conduct aerial surveys of these herds by conducting visual surveys and taking photographs either during or soon after the calving period when the caribou are found close together or aggregated. The location data from the collared caribou are used to find the caribou. The number of caribou are counted by observers and used with the collar distribution to estimate the total number of cows and calves in the herd. A composition survey is conducted in October, during the rut, to determine the proportion of bulls to cows. The results of the October and June surveys are used to calculate a population estimate for the herd. While photo surveys are commonly used, there are also other methods of counting caribou, as it is difficult to capture the entire herd in the photos. New methods of counting caribou using remote sensing are also currently being explored; these are referenced in the section *Remote sensing* (see page 13).

Population trend and rate of change

The trend or the rate of increase or decrease (decline) is also a key indicator of herd status. Trends can be determined by comparing herd size estimates over many years. For post-calving surveys and to some extent calving ground surveys, this currently needs collars. When a population estimate is not possible, we can look at other data to help determine the herd status, such as recruitment, body condition and health, and bull-to-cow ratio. Information on the trend of a caribou herd over the long term can also be provided by traditional knowledge as observations of changes in abundance and distribution, which are often linked. For example, when caribou are at low numbers, they often do not occupy all the same areas as when they are abundant.

Survival estimates can also help determine population trends and are important in interpreting recruitment and bull-to-cow ratios. Survival estimates are produced by assessing the survival rate of collared individuals (including hunting and natural death as determined by consecutive stationary locations or confirmed deaths; Boulanger et al., 2011).

Productivity and recruitment - how calves are doing

Productivity is the number of calves that are born. Scientists can look at the numbers of calves relative to the number of breeding cows on calving grounds using aerial or ground-based surveys. They can also collect information on pregnancy rates from blood samples either taken by hunters or during capture work that is part of collaring. Each of the methods tends to have small samples sizes and may provide no data on this monitoring criterion during bull-only harvests. As noted in the previous section, collars are used to improve the efficiency and design of the calving ground surveys. If collar data were not available, biologists would potentially waste valuable flying time trying to locate the herd.

Recruitment refers to the number of calves that survive to one year of age and is evaluated in the spring based on the number of calves per 100 cows. These ratios, while informative, are often difficult to interpret as they are influenced by changes in cow mortality (death rates including harvest) from year to year. Calf:cow ratios in late winter are best interpreted in combination with estimates of adult female survival (DeCesare et al., 2012). Calf abundance may be monitored relative to the number of breeding females. Typically, recruitment rates are low before the number of animals in a herd begins to decline, whereas high recruitment rates, particularly several years in a row, may indicate an increase in herd size. Monitoring can also be done by scientists and by harvesters who can provide information on the number of calves observed in relation to the number of cows.

There are important opportunities to collaborate with hunters and community-based monitoring systems to develop robust datasets for understanding caribou population dynamics. Harvesters or other community members on the land can make observations of relative numbers of young caribou seen as compared to other years in the spring. They also notice the occurrence of twin fetuses or dry cows. These observations are another helpful way to gauge changing proportions of young caribou to adult caribou from year to year, especially when such information is shared across the distribution of the caribou's range.

Adult composition - how bulls and cows are doing

Part of monitoring overall herd structure is to look at adult composition, or the number of bulls and cows. It is important to establish a baseline and monitor when the herd is low and if a bulldominated harvest is implemented. The natural death rate for male caribou is higher than that for females, so even in non-harvested herds, there are usually fewer bulls than cows. This is not usually a concern, as bulls can mate with many cows within the same season.

Scientists do aerial and ground-based surveys during the rut to collect information on the numbers of bulls and cows. As with the other surveys, collar data are used to locate the herds and reduce the amount of flying time needed for a survey. Harvesters or other community members make observations of relative numbers of bull and cow caribou seen as compared to other years, mostly during the fall.

Caribou range and movement patterns

Barren-ground caribou use different geographic areas to meet their seasonal requirements. These are referred to as *seasonal ranges*. In winter, the preferred habitat of the Bluenose-West and Bluenose-East herds is boreal forest, where snowpack is not as deep, and lichen is easier to get at. The forest also provides some protection from predators and wind. The Cape Bathurst herd winters near the treeline, with many animals staying on the tundra all winter, pawing through snow to find lichen.

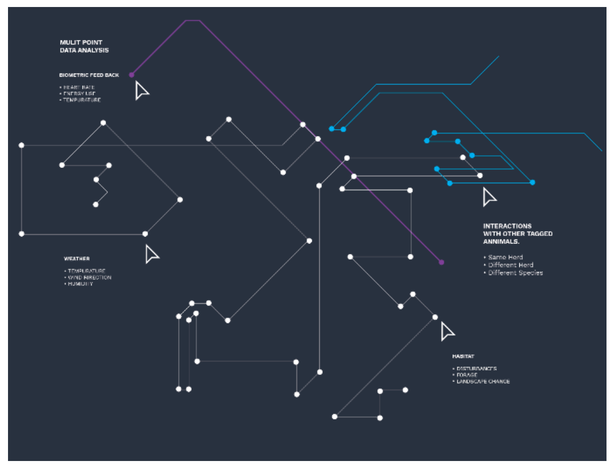


Figure 2: Researchers can now track animals with unprecedented detail, allowing researchers to predict the causes and consequences of movements, and animals to become environmental sensors (adapted from Kays et al. 2015).

In spring, barren-ground caribou usually migrate towards their calving grounds. These are typically open areas of tundra where cows can see predators approaching and where there is abundant feed for young calves and cows. Bulls and cows that are not calving also go to open areas of tundra at this time of year but might not travel all the way to the calving grounds. In the summer, caribou are influenced greatly by insects, seeking windy, cooler places as insect relief. Later in the summer, caribou begin to migrate back towards the winter range. Some other factors that influence habitat selection are fire and human disturbance. More information on caribou habitat is included in the Technical Report.[5]

Monitoring where caribou are present and absent as well as how and when they move across their range helps to make linkages between habitat conditions and what kind of habitat caribou require. Collars allow researchers to monitor movement and determine the peak of calving, which helps researchers time aerial surveys.

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[5] https://www.enr.gov.nt.ca/sites/enr/files/150_file.pdf

Additionally, such information is helpful for better understanding how caribou herds interact over time, filling in gaps in understanding relating to exchange rates between herds, for example. Communities may report throughout the year where and when they are seeing caribou, as well as when and where they are absent. The use of collar data as well as observations made during scientific studies, such as surveys, contribute to this understanding. "Life-tracks" (see Figure 1) are made possible by GPS collars with long life spans, or animals that can be located in near real-time and recaptured. This gives researchers a direct view into the daily life of the collared animal (Kays et al., 2015).

Environment and habitat conditions

Community members have observed changes in the climate and on the land that may have a positive or negative effect on caribou movements and condition. Scientists also predict increased variations in temperatures, more rain and snow, and more severe weather events as a result of climate change. During the summer, shifts in temperatures and precipitation can lead to changes in insect harassment of caribou or the timing of "green-up." During the winter, variation in temperature or precipitation can affect caribou energy use through changes in access to food or vulnerability to predation (see also the Technical Report[6] and the Community Report[7]).

Changes in habitat conditions (e.g., fires on winter range, levels of rain or snowfall, icing events, shifts in vegetation composition and/or other species presence) can provide insight into the stresses impacting caribou and the availability of habitat to caribou. These conditions are monitored through a combination of community and scientific observation. Collars may be used to determine areas caribou are most likely to encounter these changes.

Body condition and health

The health and condition of individual caribou can affect productivity and survival of calves and adults. The CircumArctic Rangifer Monitoring and Assessment Network (CARMA) has developed protocols for measuring body condition and health of caribou. The least intensive (Level 1) measurements can be done easily in the field. Sample kits may be provided to harvesters to measure or collect pregnancy information (presence of fetus); backfat thickness; left kidney and fat to assess contaminant levels and condition; body condition score; lower front teeth for age determination; and location, date, and sex of the animal harvested. It is most useful to collect Level 1 measurements on an annual basis. Harvesters may also submit samples for disease and parasite testing at any time to the responsible government agency. More intensive measurements (Level 2 or 3 protocols) of body condition and health, including disease and parasites, should be done by scientists and harvesters during a community hunt but on a less frequent basis (every three or five years; ACCWM, 2014).

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[6] https://www.enr.gov.nt.ca/sites/enr/files/150_file.pdf
[7] https://accwm.com/s/TCOC-Community-Report.pdf

Community members typically have an overall impression of the condition of caribou (body condition score) through harvesting, field dressing (skinning, gutting, etc.), and preparing or fixing the meat. Body condition information collected by community members, harvesters, and scientists provides information about caribou health, which can be used as supporting evidence when predicting or confirming changes to the herd size and trend. The challenge for scientists has been how to best integrate hunters' overall impression of the condition of caribou into a structure that provides a repeatable empirical basis that anchors these impressions and can be used to track trends over time.

Harvest levels and practices

Harvesting has a direct impact on caribou numbers, and accurate information on the harvest levels of all user groups is particularly important for making decisions and justifying management actions. Estimating how many animals are being taken out of a herd (e.g., through harvest and predation) is as critical as understanding how many animals are coming into a herd (e.g., through recruitment). In addition to knowing the total number harvested, it is also important to know the proportions of animals harvested—how many cows, calves, or bulls are taken.

There is a strong desire amongst wildlife managers, as well as harvesters, to have continued harvest monitoring programs and to establish (or re-establish) programs in each region. Efforts to make these programs as effective as possible are ongoing.

An effective overall monitoring program requires good communication and sharing of information between regions and wildlife managers. Analyses of both population data and harvest data can then be used to develop sustainable harvest recommendations.

Harvest monitoring has been done in a number of ways including the use of tags/authorization cards, voluntary stops at check stations, harvester surveys, and reporting directly to ENR.[8]

Predator populations

Predators affect caribou behaviour and mortality. Some predators take caribou only during the calving period (e.g., eagles) and some only during the spring to fall period (e.g., grizzly and black bears). Wolves prey on all age classes of caribou, and the rates may vary by season.

Predator numbers decline as herds decline, but usually, there is a delay of one or two years. If other prey species are available, predator numbers may not decline at all. When caribou numbers begin to decline, the impact of predation may become proportionately greater.

Caribou users have requested increased monitoring of predator populations, measurements of predation, and assessments of the impact of that predation on the herds. Predator conditions

[8] Harvest monitoring is key and has been beset by multiple challenges. Recent experience with community-based monitoring in Nunavut sheds light on possible future directions for NWT communities (Etiendem et al., 2020).

may be monitored in the NWT and Nunavut through carcass collection programs, and predator abundance and predation rates can be monitored through community and/or scientific research programs.

In 2018, an enhanced Wolf Harvest Incentive Area was created in the North Slave region. Increased incentives, above what was already offered to harvesters throughout the territory, are offered for wolves harvested in this area. It is hoped that this program will lead to more samples being collected from harvested wolves. Submitted wolf carcasses can be used to determine the nutritional condition, age distribution, and diet of harvested wolves.

Human disturbance

Disturbance of caribou from human activities such as resource exploration and development, aircraft over-flights, and recreational activities can influence caribou behaviour and energy use, which in turn can affect the condition and health of the caribou. Indirect effects can also include a reduction in quality and quantity of habitat or access to quality habitat. Particularly when caribou numbers are low, human activities have the potential to alter the rate and extent of the decline or how long it takes the herd to recover (ACCWM, 2014).

Multiple sources of disturbance, and disturbance over a long period of time, can have cumulative effects on herd health. Because of this, the GNWT's current Barren-ground Caribou Management Strategy has identified a need to develop models to assess cumulative effects and to identify, monitor, and mitigate impacts of exploration and development activities and improve understanding of mechanisms of impacts.

Threshold levels of sensory disturbance are unknown for barren-ground caribou. Quantifying levels of disturbance to caribou could help establish how disturbance changes over time and how it influences caribou movements and behaviour. Location and levels of disturbances could then be related to habitat availability and accessibility. Currently, much of this work includes the use of collars.

Competitors

Species competing for food and space were added as a monitoring criterion by the ACCWM after the 2019 annual status meeting. This means that in future annual status meetings, members of the ACCWM will provide any available data on competitors and may use this data in the process of determining a status for each herd.

Competition between caribou and other ungulate species has been observed by community members and has been a topic of research for caribou in general. In the North, muskox, reindeer, and moose are potential competitors to barren-ground caribou. They are often found in the same areas and can consume similar resources. Currently, interactions between caribou and competitors are reported through community and harvester observations. Scientific studies on this topic are occurring in some areas, such as the Porcupine caribou range on the Yukon North Slope and northern Richardson Mountains, and other studies or surveys are planned in the region covered by this management plan.

Minimally invasive monitoring methods

The following section explores the tools that show some promise for potentially reducing the need for invasive monitoring methods. The goal here is to identify, as Lamb et al. (2019, p. 3) call it, “a more efficient and information-rich approach” to answering the critical questions regarding a species’ status, “adopting minimally invasive approaches that are cost-effective to initiate over vast areas.”

Remote sensing

Possibly the most promising technological replacement for the current population size estimation methodologies is the use of *remote sensing*, the process of monitoring physical characteristics, vegetation, or animals by measuring their reflected and emitted radiation at a distance (typically from satellite or aircraft). Most of the research to date applies these technologies to larger mammals that are easily spotted and are not spread over a large range. It is possible that they could be used to monitor caribou, but there does not seem to be much in the available literature indicating this yet. Increased resolution and coverage of the imagery provided by remote sensors may soon lead to the adoption of this technology. It is likely that until the cost of remote sensing data comes down, that collars would still need to be used in order to narrow the study area. Even then, the path of the imagery needs to capture the entire study area at one time. This level of coverage may be difficult to achieve with currently available systems. Remotely sensed imagery has several potential benefits over traditional animal survey techniques, including a large spatial coverage and faster data procurement (Pettorelli et al., 2014; Terletzky & Ramsey, 2014).

Spotting individual animals

Individual animals have been successfully spotted using remote sensing data, but to date, studies have generally been on small areas or confined to relatively uniform environments which provide a high contrast with animals (Laliberte & Ripple, 2003; Terletzky & Ramsey, 2014; Xue et al., 2017). Accurate animal detection over large areas has until recently only been successful in comparatively stark polar regions, and even then there were a significant number of false positives, thus requiring the researchers to confirm each sighting (LaRue et al., 2015). With the rapid development of AI-supported image recognition, it is possible to count animals such as wildebeest in aerial photos within 1% of expert counts with less processing time, demonstrating that the “combination of remote sensing and deep learning techniques can enable automatic/semiautomatic, accurate, inexpensive, and efficient wild animal surveys" (Peng et al., 2020, p. 1).

Another promising development in this field is the use of spectral signatures[9] for animals. Recently, spectral/thermal profiles have distinguished large mammals across a range of landscapes (Hollings et al., 2018) Spectral signatures of species can be used as training data and applied to new imagery. One study was able to generate accurate correlations (>90%) between estimated population sizes and animal surveys for livestock, even with image resolutions of two metres (Hollings et al., 2018).

Despite many studies using a variety of methods for detecting animals from remotely sensed imagery, this technology remains in its early stages. Studies demonstrated reasonably high accuracy on small spatial scales relative to the geographical range of the species of interest in homogenous environments. The main limitations are the accuracy of automated detection techniques, the cost of high-resolution data, and the ability to acquire images of the entire study area at the same time.

How is it done?

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. The types of remote sensing that are most relevant to caribou monitoring come from a variety of platforms including satellites, manned aircraft, and drones. Each of these platforms has its own advantages and disadvantages related to the cost, scale, and resolution of the data produced.

Which monitoring criteria can be measured?

- Population size
- Population trends
- Predator populations
- Environment and habitat conditions
- Human disturbance
- Competitors

Challenges and feasibility

Currently, remote sensing data is relatively expensive, especially when one considers the scale of barren-ground caribou ranges. Also, the timing of satellite overflights and the potential for clouds may mean that there are significant gaps in the data provided.

What is required?

The costs and logistics can vary widely depending on the platform. Satellite-based remote sensing can be done anywhere and by anyone, but the costs per image can add up very quickly. The resulting data needs to be stored and analyzed. Given the number of images that would

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[9] Some remote sensing systems can measure the reflection and absorption of various wavelengths of light by different objects. Each object (landform, plant, animal, etc.) may reflect/absorb an identifiable portion of the spectrum leading to the development of individual spectral signatures that may be utilized in identifying those objects.

typically need to be used for a population estimate, an automated system is generally needed to extract the data from the imagery.

Remote sensing using aerial platforms is more labour intensive in the data collection process, but due to its more focused nature, it may be simpler to analyze. Additionally, prices have come down significantly in recent years to the point where it is feasible to survey large areas. For example, the United States Geological Survey produces 1-metre resolution orthoimagery of one-third of the United States every year. In areas where higher resolution is needed, they are able to provide resolutions of ~30 cm per pixel (Mauck et al., 2009).

Case study: *Testing methods for using high-resolution satellite imagery to monitor polar bear abundance and distribution* (LaRue et al., 2015).

In previous studies, satellite imagery was shown to be a potential tool for providing information about species abundance and distribution. With polar bears (*Ursus maritimus*), this tool had only been effectively utilized on landscapes with little topographic relief and which contrasted with the white fur of the bears. Even then, a time-consuming manual review of imagery is required to confirm the sighting of the bears.

LaRue and colleagues (2015) developed methods using satellite imagery by examining data from Rowley Island, Canada. They found the spectral signature of polar bears was not distinct enough to be automatically differentiated from other objects. On the other hand, using automated image differencing—or subtracting one image from another to show only objects that had moved—led to a 90% success rate in identifying polar bear locations. This method still required a manual review, as it did produce a lot of false positives.

They concluded “that satellite imagery may be an effective monitoring tool in certain areas, but large-scale applications remain limited because of the challenges in automation and the limited environments in which the method can be effectively applied” (LaRue et al., 2015). During discussions in the early phase of this paper, biologists expressed that this technology was the one that was most likely to be utilized in the near future, but they also echoed the assessment about the challenges with current feasibility.

Drones (UAV)

Drones, or unmanned aerial vehicles (UAVs), can provide remote sensing data similar to that which comes from other platforms (aerial and satellite). UAV technologies have significantly advanced and are becoming increasingly more available and affordable, making them a safer and more cost-effective option over traditional aerial surveys (Gonzalez et al., 2016) The software for UAVs is evolving just as quickly and can autonomously perform flight paths and acquire geo-referenced sensor data (ACUASI, n.d.; Gonzalez et al., 2016). Despite the benefits of UAV technologies, there are some issues, such as the extensive post-processing that can negate any convenience or time savings compared to traditional survey methods (Gonzalez et al., 2016).

How is it done?

UAVs are essentially a type of remote sensing. Sensors can be deployed on UAVs that do everything from taking simple pictures to multi-spectrum recordings that allow for a much deeper analysis of target parameters.

Which monitoring criteria can be measured?

- Population size
- Population trends
- Harvest levels
- Predator populations
- Environment and habitat conditions
- Human disturbance
- Competitors

Challenges and feasibility

Currently, there is limited availability of commercially produced UAVs that are capable of flying the distances required for surveying caribou populations. These UAVs are extremely expensive to purchase, but there are companies and research groups that provide UAV-based survey services.

For the smaller rotocopter UAVs, limited range is the greatest factor impacting the feasibility of their use. Additionally, there are concerns that lower-flying devices may disturb caribou, as they can be quite noisy. In this discussion, the term UAV will refer to the larger aircraft-based systems rather than small rotocopters unless it is specifically stated.

What is required?

UAVs tend to be more limited in range than other remote platforms, though there is some potential for longer or indefinite flights with lighter-than-air vehicles with onboard solar chargers. More commonly used are gas-powered, fixed-wing UAVs, which can have flying times up to 8 hours, and battery-powered quadcopters that have flying times that max out around 1 hour. Gas-powered UAVs can be deployed from community airstrips and may provide a level of flexibility that is not achievable through satellite-based remote sensing.

Case Study: *Wildlife multispecies remote sensing using visible and thermal infrared imagery acquired from an unmanned aerial vehicle* (Chrétien et al., 2015).

Aerial surveys require significant resources. Chrétien and colleagues sought to demonstrate how a UAV-based survey could reduce the cost of a multi-species census for species that coexist spatially. They note that traditional aerial survey methods require high levels of concentration from the observers and are not well suited to multi-species censuses. They used multi-spectral aerial imagery acquired from an unmanned aerial vehicle (UAV) as a solution for multi-species detection. The study used multi-criteria object-based image analysis on both visible and infrared imagery acquired from the UAV. The study area contained bison, wolves, deer, and elk located in separate enclosures with a known number of individuals. Results showed that all bison and elk were detected without errors, while for deer and wolves, some individuals went undetected.

The researchers concluded that their results show the potential of multispectral imagery acquired from UAVs for wildlife censuses. In the context of barren-ground caribou, this technology could have some use in limited situations. For example, there are currently Indigenous monitors that visit areas within the range of the caribou at various times of the year. The systematic deployment of UAVs by these monitors could add significantly to the data that they are able to provide.

Fecal sampling

Caribou fecal samples have been used as a source of DNA to estimate population demographics (Hettinga et al., 2012). Most of the available literature focuses on woodland populations in relatively small study areas, but it is possible that similar methodologies could be applied to barren-ground caribou. There would be logistical challenges, though, due to the fact that the herds are less easily accessed.

Collection of pellet samples takes place when snow is present to allow for tracking and location of caribou cratering areas and to obtain good quality DNA (Flasko et al., 2017). In most cases, fecal pellet samples are collected using systematic surveys of caribou ranges. Some studies have used a chance find methodology in conjunction with local community-based monitoring projects. Each of these methodologies can be labour intensive and may require expensive air charters. The relatively high cost of collecting the samples may be offset by the rich health and population data produced (Joly et al., 2015; Morden et al., 2011).

On top of the DNA data that is collected through fecal sampling, the pellets can provide valuable information on the winter diet of barren-ground caribou. The winter forage quality can affect adult survival, timing of parturition, neonatal survival, and postpartum mass. Studies in Alaskan barren-ground caribou have also used hormone levels in feces to determine sex-specific late-winter diets, pregnancy rates, group composition, and endocrine-based measures of physiological and nutritional stress (Joly et al., 2007).

How is it done?

Study areas are surveyed by fixed-wing aircraft to find signs of cratering (locations where caribou are spending time rather than just passing through). Researchers then collect fecal pellet samples by visiting the sites via helicopter. Typically, collars are used to delineate sampling areas with high potential for these studies, but habitat models developed using remote sensing data and TK can provide similar levels of efficiency.

Some surveys give sampling kits to land users so that they can submit samples they encounter while on the land.

Which monitoring criteria can be measured?

- Population size

- Population trend
- Range
- Population demographics (including age class; see Flasko et al., 2017)
- Health
- Productivity and recruitment

Challenges and feasibility

While this methodology has been effective for monitoring smaller, discrete populations, the feasibility of scaling this methodology up to barren-ground caribou still needs to be assessed. It is possible that there is an upper limit for reliably estimating large populations and, as such, it may not work for large migratory caribou herds.

What is required?

Sampling kits are relatively simple and low-cost. The main expense for this type of study comes from the flying time used to find cratering sites and then collect the samples. Sampling protocols and DNA analysis can be completed by community-based technicians.

Case Study: *Use of fecal DNA to estimate population demographics of the boreal and southern mountain ecotypes of woodland caribou* (Hettinga, 2010)

This study assessed the efficacy of using DNA from caribou fecal pellets to identify sampled animals and estimate population demographics.

Researchers flew transect lines 3 km apart over the study area. This amounted to 2,200 km flown. Observers recorded and mapped the location of tracks and cratering sites. Using a helicopter, a team of three researchers flew to the noted sites to collect pellets. Collection of pellet samples took place when snow was present to allow for tracking and location of caribou cratering areas and to obtain good quality DNA. Model assumptions were tested by stratifying available samples based on herd and gender information. The population sizes for the study area using this method were assessed to be comparable to the standard population estimates calculated over the same sampling periods.

Of particular interest to the researchers was the finding that samples showed considerable genetic admixture from other herds despite collar data showing strong herd fidelity.

This study demonstrated that fecal DNA sampling may be a reliable and non-invasive alternative to monitoring population sizes and trends of boreal and southern mountain caribou. Application to barren-ground caribou has not been attempted to date due to their much larger and more remote winter ranges.

Antler shed and bone surveys

Antler shed and bone surveys have been utilized in the Porcupine caribou herd’s calving grounds. Both male and female caribou grow antlers. Bulls shed them after the rut, while pregnant females keep their antlers until they calve, losing them within a day or two of giving birth. Additionally, neonatal calves also suffer high mortality rates in the first couple of days after birth. The female antlers and newborn skeletal remains offer a unique biological signal for understanding calving activity. These types of surveys are able to provide historical data, as bones and antlers may be preserved for millennia in the cold conditions common to the calving grounds. At the same time, antlers and bones collected during the most recent calving period can provide insight into a number of the monitoring criteria (Brook & McLachlan, 2008; Miller et al., 2013).

As with the fecal sampling technique mentioned above, this type of survey is labour intensive and may be too expensive in areas where monitors require expensive charter flights to access the calving grounds.

How is it done?

For antler shed surveys, researchers walk transects through the calving grounds after the calving period, sampling any bones or antlers found. While the work is labour intensive, it can be done by local technicians with limited previous experience. Older bones and antlers may be collected, as these can provide data on historical ecological conditions.

In smaller calving grounds, transects may be completed systematically across the whole calving ground. For larger calving grounds, transects may only cover a small portion of the calving grounds, or research may target specific ecological features that are more likely to contain antlers and bones.

Which monitoring criteria can be measured?

- Range (can be used to delineate calving grounds and changes in landscape use over time)

Challenges and feasibility

This methodology is quite labour intensive and may not scale well to large and remote barren-ground caribou calving grounds.

What is required?

As with fecal sampling, the kits are quite simple and low-cost. The main expense for this type of study comes from the labour needed to walk transects through the study area and the cost of getting to the study area. Sample analyses are usually done in a laboratory.

Case study: *Antlers on the Arctic Refuge: Capturing multi-generational patterns of calving ground use from bones on the landscape* (Miller et al., 2013).

Just as tree rings faithfully record ecological data year after year, bone assemblages can be a vast storehouse of historical ecological data. In cold climates, bones can survive for millennia. Using accumulations of female antlers, which are shed within days of calving, and neonatal skeletons, Miller and colleagues (2013) sought to understand if caribou calving grounds develop measurable and characteristic bone accumulations and if skeletal data may be helpful in establishing a fuller, historically integrated understanding of landscape and habitat needs.

The continued integrity of the calving grounds of the Porcupine caribou is a fundamental concern in the region. However, climate change and human disturbances have been shown to increase the variability in calving ground geography. Miller and co-authors (2013) suggest that "future calving success could benefit from extended temporal perspectives."

In this study, abundant shed antlers and newborn skeletal were located. These were most likely to be found in vegetated riparian terraces (which compose less than 10% of landscape traditionally viewed as primary calving terrain). These assemblages offer invaluable historically integrated ecological data invaluable for the management and conservation of caribou across polar latitudes.

Traditional ecological knowledge (TEK) and community-based monitoring

Community-based monitors already provide a significant quantity of data that feeds into the yearly status assessment process. Traditional and local knowledge is a powerful tool that can be utilized in the collection of data in the Management Plan's monitoring criteria. Data from community-based monitoring programs can remarkably improve the knowledge base regarding the wildlife which sustain our communities (Gagnon et al., 2020; Prno et al., 2021).

Creating opportunities for a more equitable and substantive role of TEK in building an evidence and knowledge base for the status assessment and decision-making processes can create benefits for each stakeholder. It is still necessary to find even more meaningful ways to engage with local and community knowledge holders and ensure that their knowledge is transmitted through the whole assessment process. Despite the enthusiastic recognition of its value, more progress is required to fully realize the integration of TEK in decision-making (Prno et al., 2021; Romero Manrique et al., 2018).

Community-based monitoring programs draw on both traditional and western scientific approaches. The programs provide opportunities for contributing and analyzing observations and identifying monitoring priorities. Co-production approaches draw on local knowledge systems and scientific methods to develop novel questions and interpret data based on multiple ways of knowing.

With respect to the use of TEK and community-based monitoring as an alternative to collars, it has been repeatedly shown that local knowledge holders can provide high-quality data on the health and status of wildlife (Moller et al., 2004; Parlee et al., 2010; Peacock et al., 2020; Polfus et al., 2014). Status decisions can be made in years where there is limited, or no scientific data presented for some of the monitoring criteria. It is certainly possible that TEK could provide the bulk of the direct observations for the monitoring criteria.

It has generally been assumed that TEK provides data with a long temporal range but relatively small spatial scales (Moller et al., 2004; Usher, 2000). Polfus and colleagues (2014) found that TEK-based habitat models most closely resembled caribou habitat selection at the scale of the herd home range; as such, the data provided by local and traditional knowledge holders may be relevant at scales much larger than expected. In the same study, it was noted that there are examples from both Canada and Europe where local knowledge holders' information has been provided at a larger spatial scale than current scientific data and that habitat models developed with the local knowledge holders performed better than models developed with knowledge from scientific experts when validated against information from the local areas. For example, Doswald and others (2007) tested "expert models" as a possible alternative method. Their study developed an expert model and evaluated it against independent lynx data. They used two classes of experts: academic and local experts. When they evaluated the models against the local data, the local expert model was better than the academic model. When the models were evaluated against data from a different region, it was found that the local expert model performed worse than the academic model, suggesting that some local knowledge may not be applicable in a broader context.

Doswald and co-authors (2007) compared weights each expert group had used in their models, which highlighted the important place-based nature of knowledge and how personal experience and theoretical knowledge can lead to different answers.

How is it done?

TEK is often collected through interviews with knowledge holders, but this type of data is not always easy to elicit through standard interview methods. Direct participation in monitoring programs by knowledge holders is more likely to produce quality TEK. A good example of this is Ekwǫ̀ Nàxoèhdee K'è: Boots on the Ground.[10] The program utilizes interdisciplinary research techniques but is grounded in the traditional knowledge of Tłı̨chǫ harvesters and monitors. The result is a robust program that provides high-quality data on the status of caribou.

Which monitoring criteria can be measured?

- Population size
- Population trends
- Productivity and recruitment
- Adult composition
- Body condition and health
- Harvest levels and practices
- Predator populations
- Range and movement patterns
- Environment and habitat conditions
- Human disturbance
- Competitors

[10] https://research.tlicho.ca/research/bootsontheground

Challenges and feasibility

TEK and community-based monitoring have been shown to be feasible. The current challenge lies in the inconsistent funding of these programs and the ongoing need to improve how community-based knowledge is used in the management process. There is a lot of support for the inclusion of TEK in these processes, but there are still significant challenges involved in fitting community observations into frameworks that tend towards a reliance on empirical observations and may struggle with data that is communicated in such a varied manner.

What is required?

The key to acquiring good TEK is the development of strong relationships. These take time to develop and require mutual trust and understanding. Long term programs such as the Ekwǫ̀ Nàxoèhdee K'è: *Boots on the Ground* foster trust between researchers and knowledge holders by providing them opportunities to collaborate and share their unique understanding of the caribou.

Case study: *Comparing traditional ecological knowledge and western science woodland caribou habitat models* (Polfus *et. al* 2014).

Polfus and colleagues (2014) were one of the first to quantitatively compare TEK-based caribou habitat models with habitat models developed using western science approaches. They studied the strengths and weaknesses of predicting woodland caribou habitat selection with resource selection functions (RSF) based on western science and traditional knowledge-based models in northern British Columbia. They developed RSF models with data from collared caribou and generated TEK-based habitat suitability index models from interviews with local Elders. The high predictive ability of the models and correlations between western science-based model outputs showed that TEK can be an effective tool for wildlife monitoring and management.

This study demonstrates how local knowledge can be utilized in ecological models and has shown not only that expert knowledge can be used when no other data exist, but also that local and community knowledge ought to be used more often in ecological models and conservation plans. Building on this research, biologists and local knowledge holders can feel confident that this type of knowledge can be used in the development of data for the monitoring criteria and for opening up new avenues for data collection. In both TEK studies discussed here (Polfus et al., 2014; Doswald et al., 2007), the strength of the local knowledge models dissipated when applied to unfamiliar landscapes. A possible remedy for this would be to support the Indigenous stewardship programs to visit more of the study region. In doing so, they could also be tasked with completing some of the other monitoring techniques discussed in this paper.

Comparing reviewed methods

Table 1: Monitoring Methods (below) provides a side-by-side comparison of the various methods reviewed in this paper. To date, the only projects that have been done at the scale of the barren-ground caribou range have all relied on collar-based telemetry. As such the data in each of the columns was sourced through conversations with subject matter experts and impressions from the available literature.

Table 1: Monitoring Methods

Method	*Scale*	*Resources (Cost)*	*Current Feasibility*	*Level of invasiveness*	*Monitoring Criteria Observed*	*Community Involvement*
Collars	Large	Equipment: high Personnel: medium Skills: high	High	High	Population size Population trends Range and movement patterns Productivity and recruitment Adult composition Population demographics Human disturbance – ZOI	Limited
Remote Sensing	Large	Equipment: high Personnel: medium Skills: med	Medium–High (for smaller areas)	Low	Population size Population trends Predator populations Environment and habitat conditions Human disturbance Competitors	No
Drones	Small-Medium	Equipment: high Personnel: medium Skills: medium	Low–Medium	Medium	Population size Population trends Predator populations Environment and habitat conditions Human disturbance	Possibly

					Competitors	
Fecal Sampling	Medium	Equipment: medium Personnel: medium Skills: medium	Medium–High	Low	Population size Population trend Range Population demographics Health Productivity and recruitment	Yes
Antler / Bone surveys	Small	Equipment: medium Personnel: medium Skills: medium	High	Low to medium	Range Productivity and recruitment	Yes
TEK/CBMP		Equipment: medium Personnel: medium Skills: medium	High	Medium, low-med	Harvest monitoring (total harvest and harvest effort for caribou and predators may provide information on relative abundance) Predator abundance Environmental conditions (weather and climate) Habitat conditions (fire, drought, biting insects) Productivity and recruitment Adult composition Body condition and health Harvest levels and practices Range and movement patterns Human disturbance Competitors	Yes

Discussion

The data collected on the monitoring criteria used in the Taking Care of Caribou Management Plan (ACCWM, 2014) are meant to provide the member boards with the information they need in order to make well-informed status decisions for the three herds. It is possible new monitoring methods will never be able to fully replace the data provided by collars. The question is, what is acceptable, recognizing that "acceptable" will be different for different people and organizations? Status decisions are made with the best available knowledge. It is possible that the first step towards reducing the reliance on collars will involve a deeper look into which elements of the monitoring criteria are needed to determine the status of the herds.

There is no perfect solution because everyone has different levels of intrusiveness tolerance, various techniques provide different amounts and qualities of information, and there is a wide range of costs, risks, and logistical challenges. With this in mind, this section will try to offer some solutions to improve current monitoring practices and to provide some direction for exploring new technologies.

During the last 60 years, the Three Rs (*Reduction*, *Refinement*, *Replacement*) suggested by Russell and Burch (1959) have steadily been adopted as a framework for ethical and scientific dilemmas faced during the use of animals in research. Recent calls to update or move away from the animal welfare focus of the Three Rs have favoured a wider concept of humanity and welfare. Balls (2020), in his assessment of the current validity of the Three Rs in the field of pharmaceutical research, argued that the aim should not be to directly replace animal-based methods with non-animal methods which have similar aims and which produce similar results but to lean into technological advancements, such as those being realized in computer science, to create novel research strategies that actually produce more reliable results.

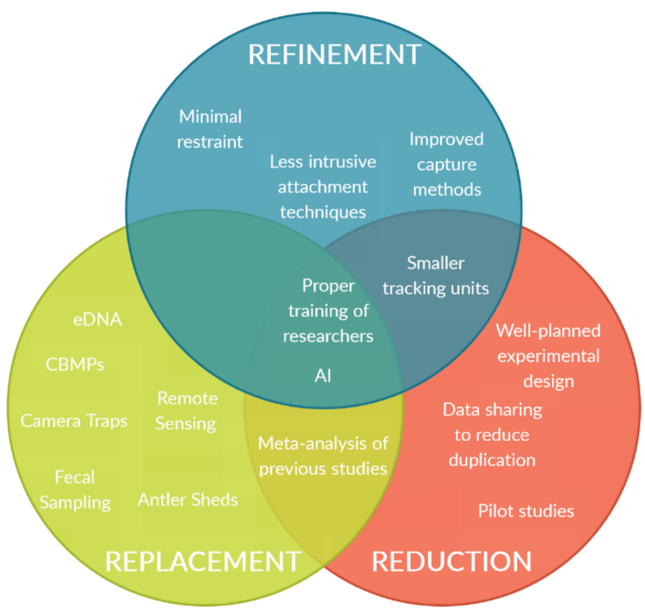

Figure 3: Some examples of the Three Rs applied to wildlife research adapted from Zemanova, 2020.

In the field of wildlife research and monitoring, similar discussions are occurring as obtaining information on population statuses often involves invasive sampling (Zemanova, 2020).

Replacement may not be immediately feasible when individual animals are the objects of the study or current logistical constraints limit the practicality of deploying new research methods. This would appear to be the case for at least some of the methods proposed as potential alternatives to the use of collaring caribou.

Reduction and refinement can come from several avenues. For example, the efficient design of monitoring programs combined with lighter collar-based systems can significantly reduce the stressful impacts on the subject animals.

Moving forward

Solutions which offer options and flexibility because things rarely go as planned and may change direction in the future are likely to have the most success. Collecting information and data which can be used for multiple studies and offer insight to many possible questions are a bonus. An immediate solution can come from the “Refine” part of the three Rs. Can we further refine capture and collaring techniques to ease the concerns being voiced?

As we look forward to replacing some techniques, can we start transitioning and overlapping techniques to allow correlations to be made so we can compare results appropriately? How can we improve upon our current coordination efforts between groups and stakeholders? How do we improve relations and trust? Many of these will be open-ended questions because there may be issues we currently don’t have solutions for.

Conclusion

Collars, such as those that are placed on large wildlife around the world, have been significantly improved over the past several years. The collars that are used on caribou are lighter, smaller and provide better-quality data then collars from previous decades. Nevertheless, it is important to acknowledge that the deployment of collars continues to cause stress on the individual being collared. These negative effects are a concern shared by many people. As such the alternatives to caribou collars will remain a priority for communities and researchers.

Unless there is a change in the consensus regarding the data needed to assess the status of the herds, collars appear, at present, to be the least harmful, best option currently available for acquiring the information needed to support the welfare of the caribou herds on which they have been installed, including the Cape Bathurst, Bluenose-West and Bluenose-East herds.

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