NBCKC Monitoring Practices for Boreal Caribou

INDIRECT MONITORING METHODS IN CANADA

National Boreal Caribou Knowledge Consortium

Front Cover Photo Credit: Cole Burton

Indirect Monitoring Methods

Contents

INDIRECT METHODS

Photo Credit: Cole Burton

Introduction to Indirect Methods

Indirect monitoring – where population size, trend or other metrics are inferred from photos of animals or counts of animal scats or tracks – is well suited to population studies when direct observation methods may be challenging (e.g. Taberlet *et al*. 1999, O'Connell *et al*. 2011, New Zealand Department of Conservation 2012). Indirect methods can therefore be particularly beneficial for rare, shy or elusive creatures (e.g. Stanley & Royle 2005, Kuhl *et al*. 2008, McFarlane *et al*. 2020a), and are also effective for multi-species or community-level monitoring (e.g. Cromsigt *et al*. 2009, Burgar *et al*. 2019, Wittische *et al*. 2020).

Traditional approaches to boreal caribou monitoring may be limited by small sample sizes and often require intensive aerial sampling or direct handling (e.g. telemetry collaring, physical marking, tagging, and/or tissue collection; Carroll *et al*. 2018). DeMars *et al*. (2015) highlight indirect methods appropriate for caribou monitoring, including mark-resight, mark-recapture fecal DNA, or demographic models, though recommend that in some cases the results of indirect studies should be corroborated with direct methods (e.g. aerial studies; Kuhl *et al*. 2008, DeMars *et al*. 2015). Sources of error can be addressed through training, suitable sampling design, and use of appropriate statistical tests and inferences (e.g. Stanley & Royle 2005).

Two methods used in boreal caribou monitoring programs that use an indirect approach are camera trapping and fecal sampling. In camera trapping programs, weather-proof cameras with motion-sensors can be mounted in caribou habitat to record photos or videos of any animals passing by. This passive monitoring approach reduces wildlife disturbance and can record the presence not only of caribou but also of any other co-habiting species. Cameras can be left for long time periods in severe weather, and footage provides insight into distribution and habitat use, as well as indices of health and behaviour. Ongoing improvements to camera technology and the establishment of new camera-trapping networks are expanding the applications of camera-trap data to additional parameters (e.g. abundance) and broader spatial scales. In fecal sampling programs, genetic sampling of animal tissues provides a valuable source of DNA for use in wildlife research and monitoring, and when combined with good survey design and careful genetic and capture-recapture (CR) analysis provide a powerful and robust means of monitoring wildlife populations. This approach has been applied to caribou monitoring in Ontario (Carr *et al*. 2010), Manitoba (Hettinga *et al*. 2012), Saskatchewan (McFarlane *et al*. 2021) and Alberta (McFarlane *et al*. 2018, McFarlane *et al*. 2020a). Spatial capture-recapture (SCR) models of genetic data are an increasingly popular method for estimation of both population size and trend. SCR models are robust to small sample sizes, produce precise density and abundance estimates, and can accommodate low capture probabilities (Borchers and Efford 2008, Royle *et al*. 2014). Spatially-explicit non-invasive genetic sampling also generates ancillary data for population genetic structure analysis (Ball *et al*. 2010, Priadka *et al*. 2018, Thompson *et al*. 2019) and landscape genetic analysis (Galpern *et al*. 2012b, 2014) that can detect early signs of fragmentation, decline, or other ecological information (Bruggeman *et al*. 2010). While genetic samples may derive from hair, tissue, or blood, sampling of fecal DNA has been the most common method applied to caribou.

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 (dedicating time, energy, and resources) to include both capacity building, and compensation for time, in the monitoring program.

Photo Credit: Lorne Gould

6. Camera Traps

6.1 AT A GLANCE

Camera traps (also known as 'trail cameras') consist of a camera, typically mounted on a tree or other immovable structure, along with an infrared sensor or other motion detector (Silveira *et al*. 2003; Steenweg *et al*. 2017). When a moving object with a temperature differential (i.e. typically higher than ambient temperature) is detected by the sensor, the camera begins to record data, in the form of either pictures or videos. As such, these cameras are useful for wildlife surveillance, as the researcher does not need to be physically present, and there is minimal disruption to the animal's behaviour compared to direct observation. Images (or videos) are stamped with the date, time, and location, as well as other environmental data such as temperature (Steenweg *et al*. 2017).

Camera traps are ideally suited for multi-species monitoring, which can include both alternate prey and predators of caribou (e.g. Burgar *et al*. 2019, Tattersall *et al*. 2020b, Wittische *et al*. 2020). For caribou specifically, camera traps can provide considerable information on distribution/occupancy, and may also be valuable for estimation of a number of other parameters including habitat/site use or activity patterns (e.g. Frey *et al*. 2017), population density (e.g. Efford 2004, Burgar *et al*. 2018), migratory movements (e.g. Blagdon & Johnson 2021), foraging and other behaviours (e.g. Caravaggi *et al*. 2017, 2020). They can also provide some indications of body condition, disease, or other health concerns. Survival could be estimated if cameras are combined with individual marking of animals, and camera traps may allow estimation of a relative index of abundance (under the assumption of no density-dependent movement; Broadley *et al*. 2019). Burton *et al*. (2015) provide a review of camera trap applications and suggest ways that camera sampling can be tailored to the ecological processes of interest.

The use of camera traps has increased dramatically in recent years, due to improvements in the technology, and decreased costs of units (e.g. Steenweg *et al*. 2017). For example, novel 'blackout cameras' or 'invisible flash' camera traps may be less disruptive (Trailcampro 2020) though they are likely still detected by the animals (Meek *et al*. 2014b). General guidelines for designing and reporting on camera-trapping are available (e.g. Meek *et al*. 2014a, Wearn & Glover-Kapfer 2017), and this method is continuing to prove effective as a monitoring tool (e.g. Wearn & Glover-Kapfer 2019). Remaining uncertainties about behavioural responses to cameras (Caravaggi *et al*. 2020) and study design for camera-trapping (Kays *et al*. 2020) are being actively researched.

Photo Credit: Fort McKay First Nation

6. Camera Traps

6.2 SUITABILITY FOR MONITORING

6.2.1 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
Indirect Methods	Trail Cameras	✓✓	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.*

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

- Presence of, or interactions with other species (Burgar *et al*. 2019, Keim *et al*. 2019, Tattersall *et al*. 2020b, Wittische *et al*. 2020)
- Response to specific landscape features (e.g. restored seismic lines; see Tattersall *et al*. 2020a, Wittische *et al*. 2020) or disturbance (Brodie *et al*. 2015a; Keim *et al*. 2019)
- Landscape connectivity (Barrueto *et al*. 2014, Brodie *et al*. 2015b)
- Plant/habitat conditions and phenology (Morisette *et al*. 2008, Fisher & Burton 2018, Hofmeester *et al*. 2019b)
- Spatial and temporal movement patterns in relation to environmental variables and co-occurring species (Blagdon & Johnson 2021)
- Habitat use at different life stages (Fisher *et al*. 2014)
- Camera trapping of individually identifiable animals (i.e. via natural markings or tags) provides information on movement
- Spatial capture-recapture modelling can be used to derive an index of abundance based on density estimates (e.g. Burgar *et al*. 2018)
- Parasites, body condition or signs of illness/disease may be observed opportunistically
- Vigilance and other behaviour/activity patterns (e.g. Caravaggi *et al*. 2017)

6.2.3 IMPLEMENTATION

- Best suited to medium- to large-bodied terrestrial animals (Steenweg *et al*. 2017)
- Well-suited to elusive or low-density species (Karanth & Nichols 1998)
- Camera traps can be used to monitor both nocturnal and diurnal species, as photographs can be taken during both day and night (Rowcliffe *et al*. 2008)
- May be well-suited to remote areas as cameras can be left in the field for several months at a time before being checked (O'Brien *et al*. 2003)
- Less suitable for small animals that may not be visible in the field of view of the camera or may not consistently activate the trigger (Villette *et al*. 2016, 2017)
- Caution should be exercised when calculating abundance from camera data: to obtain accurate estimates, statistical analysis of camera trap data should factor in imperfect detection rates, and methodology should be explicitly reported to allow for data to be scaled-up and compared (Rowcliffe *et al*. 2008, Burton *et al*. 2015, Forrester *et al*. 2016). As with any method, camera trap inferences are sensitive to model assumptions, but there is evidence that detection rates can provide a useful index of abundance (e.g. Neilson *et al*. 2018, Broadley *et al*. 2019).
- Relative to other monitoring methods (e.g. GPS collars), camera-trapping may not provide sufficiently fine-resolution data on infrequent movements of caribou at low densities (Blagdon & Johnson 2021).

6.2.4 ADVANTAGES

- Cameras can provide data over long temporal scales (e.g. Tattersall *et al*. 2020a), and also detect nocturnal activity (Silveira *et al*. 2003)
- The resulting photos and videos can facilitate public interest about biodiversity (Steenweg *et al*. 2017). Camera photographs and videos are very useful in engaging the community and stimulating conversation and information exchange.
- If properly set up, cameras operate in most weather conditions, including those that would normally impede field work (Silveira *et al*. 2003). For instance, the Fort McKay First Nations camera-trapping work has used cameras in rain and snow, in temperatures ranging from -40 to +30°C (L. Gould, *pers. comm*.)
- Multiple species can be monitored, including predators and competitors of the target species (Burgar *et al*. 2019).
- Camera traps can be effectively combined with other methods to obtain more accurate information, such as partially marked models with telemetry data (e.g. Sollmann *et al*. 2013, Royle *et al*. 2014), and integrated population models with DNA mark-recapture (Chandler and Clark 2014).
- Cameras are relatively easy to set and check following standardized protocols, and image processing is relatively straightforward
- There are emerging camera trap networks promoting data standardization and synthesis (e.g. Forrester *et al*. 2016, RISC 2019, WildCams 2020); without these, comparison of results across scales can be challenging (Steenweg *et al*. 2017).

Photo Credit: Sarah Schmid

6. Camera Traps

6.2.5 DISADVANTAGES

- It can be difficult to assess population metrics using camera trap data, often requiring complex statistical models and high computing power, although this is an active area of methodological research (e.g. Rowcliffe *et al*. 2008; Burgar *et al*. 2018)
- Image and video files are often large, which may create difficulties with storage and sharing; digital storage may also fill quickly due to false triggers (e.g. wind, branches, leaf growth) unless camera sites are carefully prepared.
- Ethical concerns may arise regarding the photography of people
- Camera placement needs to avoid areas of direct sunlight or flooding, which could damage the camera and its sensors (Valdez 2018)
- Behaviour of photographed animals may be affected by noise, odor or light from the cameras (Caravaggi *et al*. 2020)
- Heavy-duty casing may be required to protect the camera from being chewed by carnivores (Valdez 2018) or from theft or vandalism in areas with greater human activity (Meek *et al*. 2019).

6.3 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
Indirect Methods	Trail Cameras	✓✓✓	✓	variable (see text)	Med	High	P, D, A, R	Low/ Med	Low	Med	No	None	Low

* *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*

6. Camera Traps

6.3.1 SPATIAL SCALE

- Camera traps are best suited to collecting data at a sub-population scale, as each camera is considered a point sample and therefore many cameras would be needed to cover a large area.
- The scale of study is typically determined by the program and the desired outcomes, e.g. inference at the level of an individual population vs. smaller unit of management. Spacing between cameras can have important implications for their treatment as independent (e.g. occupancy) vs. dependent (e.g. spatial capture-recapture) samples. Study design is an active area of research (e.g. Kays *et al*. 2020).
- Recent reviews demonstrate the ability to combine camera data from multiple sources to scale up to a regional perspective, but only with standardization of methodology and reporting, or statistical correction to account for differences between studies (Burton *et al*. 2015; Forrester *et al*. 2016; Scotson *et al*. 2017, Steenweg *et al*. 2017, Hofmeester *et al*. 2019a). Emerging camera-trapping networks are facilitating the standardization and collation of data from cameras across larger scales (e.g. McShea *et al*. 2015, Forrester *et al*. 2016).

Photo Credit: Fort McKay First Nation

6.3.2 DATA NEEDS AND CONFIDENCE

- Moderate ability to assess data confidence - Non-detections (individuals that are missed by the cameras) may be problematic. Low detections are likely more of a concern for surveys of short duration or with few cameras, and there are several methods for dealing with non-detection, e.g. the use of multiple sampling approaches, careful site location, and lures/attractants (e.g. Holinda *et al*. 2020).

6.3.3 COMMUNITY INVOLVEMENT

Opportunity for Local Community Involvement

- Camera traps are widely used in industry applications; Industry could contribute their own survey data to the broader database
- Using standardized metadata and protocols (e.g. Forrester *et al*. 2016; Hofmeester *et al*. 2019a, RISC 2019), camera data can be combined across multiple surveys and users.

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
    - 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.
    - Indigenous Knowledge can be used to inform camera placements. For example, Fort McKay First Nation held a community meeting to identify areas for camera placement, and camera protocols were monitored according to community feedback.

6. Camera Traps

- Data collection
    - Knowledge holders and local community members can be trained on how to install, operate, and maintain camera trap equipment, including the collection of data cards. For instance, two members of the Fort McKay First Nation have been employed as the Environmental Guardians camera team, and are in charge of camera installation.
- Analysis
    - Indigenous Knowledge can be used to inform data analysis and interpretation. For example, the two members of the Fort McKay First Nation employed as the Environmental Guardians camera team, and are in charge of photo sorting.
- Reporting
    - The two members of the Fort McKay First Nation employed as the Environmental Guardians camera team, and are in charge of report writing and knowledge sharing to local communities.

Cost: $$

6.3.4 RESOURCES

Equipment Costs

- Overall, camera traps are a relatively cost-effective monitoring method (Silveira *et al*. 2003). Initial equipment costs can be high but cost-effectiveness increases with repeated use of cameras over time.
- Camera prices are continually falling, with some models available for as little as US$100 (Steenweg *et al*. 2017), though inexpensive models may not be as reliable (see Newey *et al*. 2015).
- Other costs include supplies (e.g. batteries, SD cards), access (can be costly in remote boreal landscape, some of which can be reached only by helicopter), and skilled labour for analyses.

Personnel Costs

- It can be fairly straightforward to train personnel to monitor and maintain cameras, and even to analyse videos/photos (depending on the desired outcomes; Steenweg *et al*. 2017)
- Software is available (or becoming available) to reduce the amount of time spent processing images, even for personnel with little training (e.g. Wildlife Insights 2020)
- Some projects rely on crowdsourcing to process images and perform identification in order to reduce costs (e.g. eMammal 2017, Zooniverse 2020)

Photo Credit: Fort McKay First Nation

6. Camera Traps

Logistical Complexity: MODERATE

Skills required

- New software enables minimally trained personnel to process and analyse images, however advanced analysis of data may demand expertise or specialized software
- Although often time consuming, methods are emerging for automated species identification (e.g. Wildlife Insights 2020) and crowdsourcing (Zooniverse 2020), which can speed up processing times, though this is still a work in progress (Schneider *et al*. 2020)
- Basic data summaries can be easily obtained using software like camtrapR or Wildlife Insights (Niedballa *et al*. 2020, Wildlife Insights 2020)

Capture/Handling: NO

6.3.5 ETHICAL CONCERNS

Capture/handling

- None

Potential Stress From Monitoring

- None

Carbon/environmental Footprint

- Variable – cameras are easily transported by car or on foot, and can be left to record for several months at a time. However, because cameras can be deployed easily (set and forget) they can also be used to sample very remote sites, requiring skidoo or ATV (habitat disturbance) or helicopter (carbon footprint) access.

Photo Credit: Cole Burton

6.4 EXAMPLES

FORT MCKAY FIRST NATION, ALBERTA In early 2019 Fort McKay First Nation's Environmental Guardians started using wildlife cameras to monitor wildlife in their Traditional Territory. Guardians have installed over 40 cameras in the Traditional Territory. Cameras deployment is a deliberately-biased placement at focal points to maximize the detection of target species; in this case, caribou. Camera deployment areas were selected based on information obtained from Community members during workshop discussions. In the field, specific locations were selected based on habitat (open fens and bogs or near trees with abundant lichen), evidence of wildlife use (e.g., tracks), and suitability for camera set up (e.g., tree size, the openness of habitat, security). It was also crucial that these locations were relatively near roads and cut lines for future access. The wildlife camera monitoring program is using Reconyx Hyperfire 2 cameras powered with lithium batteries with 32 GB SD cards. These cameras detect mid and large-sized mammals in a target area approximately 5 metres in front of the camera. Cameras are attached to trees at the height of roughly one metre above ground using wood screws and a metal bracket secured with a cable lock. Environmental Guardians then clear branches and shrubs obstructing the camera field and photograph the surrounding habitat. The Guardians record the camera number, SD card, and camera location (latitude and longitude) on a data sheet and a handheld GPS unit. The Environmental Guardians check cameras at 3- 6 months (batteries and SD cards are changed as needed). The Environmental Guardians then sort and categorize photographs on their computers at the office. Photograph and video data is analyzed, and results are reported annually to the Community. The Community and leadership have enthusiastically received the results and the program.

EAST SIDE ATHABASCA RIVER RANGE, NORTHEASTERN ALBERTA Between November 2015-2019, a camera trapping project was initiated to monitor the use of seismic lines by caribou, wolves, black bears, moose, and white-tailed deer following seismic line restoration. Restoration had been completed in the area between 2012 and 2015, and the cameras allowed comparison of mammals' use of these lines relative to their use of naturally regenerating lines and non-restored lines. Mammal co-occurrences (specifically predators: wolves, black bears, coyotes, and lynx) on seismic lines were also measured to investigate how they shared the landscape, and environmental data were also collected (seasonal snow accumulation and green-up). A related study involved setting up a camera array in the Richardson caribou range northeast of Fort McMurray, to collect data on mammals on and off seismic lines and within areas historically affected by wildfire. In short, cameras were beneficial in this case as a non-invasive, relatively cost-efficient method to collect data on mammal community responses to disturbance over long-term periods. Due to logistical constraints, the study only observed mammal responses after seismic line restoration; stronger inference of wildlife responses to change could result from use of camera traps in a Before-After-Control-Impact (BACI) design, where data are collected both before and after restoration. See Tattersall *et al*. (2020a) for additional details on this study.

7. Fecal Sampling

7.1 AT A GLANCE

In lieu of physical tags or natural marking to identify individuals, diagnostic molecular markers or genetic tags (e.g. microsatellites) derived from fecal DNA can be combined with modern analytical methods to assess population abundance and to monitor population trend and demographics (e.g. survival and reproduction; Ball *et al*. 2010, Hettinga *et al*. 2012, Galpern *et al*. 2012b, McFarlane *et al*. 2019, 2020, 2021, Moeller *et al*. 2021). Genetic tags are unique sequences of DNA used to identify individuals and their species, sex, and lineage (Lamb *et al*. 2019). In addition to population monitoring through the identification of individuals (described in more detail below), genetic data derived from fecal DNA can also be used to estimate additional population parameters and processes such as diet, individual fitness, inbreeding, genetic diversity, dispersal, and genetic connectivity (e.g. Schwartz *et al*. 2007, McFarlane *et al*. 2018, Lamb *et al*. 2019). Additional parameters can be simultaneously assessed from the fecal pellets (e.g. reproductive status and population age structure; Morden *et al*. 2011, Flasko *et al*. 2017). Winter collected fecal pellets provide a high quality source of DNA (from embedded intestinal epithelial cells) for use in genetic population assessment and monitoring studies of caribou (Ball *et al*. 2007, 2010, Petersen *et al*. 2010, Arsenault & Manseau 2011, Hettinga *et al*. 2012). Genetic tags derived from fecal DNA provide a cost-efficient and information-rich approach to monitoring with the power and flexibility to assess numerous population parameters (Schwartz *et al*. 2006, Lamb *et al*. 2019). Genetic tags derived from fecal DNA are particularly useful for monitoring rare, elusive and low-density species such as boreal caribou, because fecal pellets: (i) can be collected without any animal contact (i.e. non-invasive), over vast areas; (ii) are well-preserved in the snow (DNA does not degrade rapidly); (iii) can be collected in large numbers in winter cratering sites (where caribou dig under the snow to get to lichen; see Hettinga *et al*. 2012); and (iv) can be collected by local community members such as Indigenous Guardians or citizen scientists.

Photo Credit: Samanta McFarlane and Govt of AB

Note that we focus mainly on the use of fecal DNA in CR/SCR sampling designs in this chapter, though other uses of genetic data for caribou monitoring are also discussed.

Capture-mark-recapture population monitoring through fecal DNA identification of individuals

For monitoring population demographic parameters using genetic data, non-spatial CR analyses have been the standard method used to estimate abundance of many vertebrate species, but spatially-explicit (SCR) models are an increasingly popular method for robust estimation of ecological parameters, as they are robust to small sample sizes and can

7. Fecal Sampling

accommodate low capture probabilities. By including spatial information of captured individuals directly into the analysis, SCR models resolve issues surrounding the effective trapping area and are robust to assumptions about geographic closure that are common issues in non-spatial CR studies.

Non-invasive genetic sampling techniques can be applied at the range/population scale (Ball *et al*. 2007) and have been used monitor a variety of population demographics. These include abundance (Arsenault & Manseau 2011, Harris *et al*. 2010, Hettinga *et al*. 2012, McFarlane *et al*. 2018, 2020a), population growth trend through robust-design mark-recapture models (e.g. Hettinga *et al*. 2012, McFarlane *et al*. 2018), sex ratio (e.g. Goode *et al*. 2014), pregnancy rates (Messier *et al*. 1990, Flasko *et al*. 2017), and familial relationships (McFarlane *et al*. 2021).

Individual identification based on fecal DNA is used as a substitute for the direct capture and recapture of animals in traditional CR studies. The genetic signal within the feces represents the individual, and thus the 'capturing' and 'recapturing' is only confirmed once the samples are analysed in the lab and the individual is identified.

Capture-mark-recapture via fecal DNA analysis requires a systematic sampling effort involving rotary or fixed-wing aircraft, or a combination of both. Aerial transects are systematically flown at set intervals (e.g. 3-km intervals, Hettinga *et al*. 2012) across the entire caribou population range. Observers search for and record all confirmed observations of caribou animals or signs (e.g. tracks, cratering), and record whether signs are fresh (cratering) or old (tracks melted out, windblown, lacking definition). Fecal pellets are collected on the ground as they are encountered during the systematic search. Sites may be revisited by helicopter if fixed-wing reconnaissance flights were used to initially locate caribou activity areas. Protocols to ensure the collection of high quality samples include: collecting a minimum of 10 pellets/sample, and choosing pellets frozen together over single pellets (see Hettinga *et al*. 2012). To ensure fecal DNA integrity, samples should be kept frozen at -20°C until DNA extraction.

This CR process occurs over two main phases:

- **The 'Capture' phase** is conducted in early winter (December-February) once sufficient snow cover (>30 cm) is present, preferably no later than 3-4 days after fresh significant (track obliterating) snowfall. Potential sampling sites vary within a season: in early winter, caribou feed on arboreal lichens, sedges and bog ericoids in treed muskegs (O'Brien *et al*. 2006, Arsenault & Manseau 2011), while in late winter they shift to mature upland jack pine dominated stands where ground lichens are abundant and snow conditions are more favorable for foraging (O'Brien *et al*. 2006).

Photo Credit: Sara McCarthy

7. Fecal Sampling

- **The 'Recapture' Phase** is conducted a minimum of 3 weeks after the capture phase, preferably 3-4 days after fresh significant snowfall. A threshold recapture rate of >20% is required for adequate precision of estimates from CR models (White *et al*. 1982), but the 'recapture' of an individual is not confirmed until fecal samples have been analyzed in the laboratory. It is therefore important to maximize sample collection at each sampling site (typically ~ 1.5 times the estimated number of individuals; Micheline Manseau, *personal communications*).

Following sample collection, laboratory analysis involves thawing samples and removing the mucosal coat surrounding the pellets for DNA analysis; extraction and amplification protocol is outlined in Ball *et al*. (2007). Samples are genotyped (and sex is identified) following a protocol documented (e.g. Flasko *et al*. 2017, McFarlane *et al*. 2018), and individuals are identified (Galpern *et al*. 2012a).

Note that there is a new project underway (P. Wilson, Trent University and M. Manseau, Environment and Climate Change Canada; funded by the Genomic Applications Partnership Program) to develop and implement cost-effective highly standardized genotyping methods, to improve data sharing for caribou conservation (ensuring cross-compatibility among laboratories) and to develop best practices for estimating a range of population parameters. Project objectives include the reliable extraction of unique genotypes using new sequencing technologies, diet and microbiome data using metabarcoding methods and the development of best practices (sample size, frequency of sampling) to maximize the cost-effectiveness of monitoring efforts. All data produced under this project are managed on a web-based database.
See http://www.ecogenomicscanada.ca/ for more information.

Photo Credit: Mark Bradley

7.2 SUITABILITY FOR MONITORING

7.2.1 CARIBOU POPULATION PARAMETERS THAT CAN BE MONITORED

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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

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Indirect Methods	Fecal sampling	✓✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓✓✓	✓✓

***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.*

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

**Note that the majority of the parameters listed below are possible due to genetic data contained within fecal samples and do not necessarily require a Capture Mark Recapture/Spatially Explicit Capture Recapture approach to analysing these data*

- Individual fitness level, pedigrees and kinship relations (Kalinowski *et al*. 2007, McFarlane *et al*. 2018, McFarlane *et al*. 2021)
- Genetic diversity levels (inbreeding coefficient/Fst value) and population structure inference via assignment of ancestry to a genetic cluster characterized by a set of allele frequencies (Weir & Cockerham 1984, Ball *et al*. 2010, Priadka *et al*. 2018, Thompson *et al*. 2019)
- Landscape parameters affecting patterns of gene flow and population structure (Galpern *et al*. 2012b, 2014, Priadka *et al*. 2018; Thompson *et al*. 2019)
- Diet can be analysed through metabarcoding (Newmaster *et al*. 2013)
- Hormone analyses of fecal samples have been used to determine

7. Fecal Sampling

pregnancy rates and to assess physiological and nutritional stress (Morden *et al*. 2011, Joly *et al*. 2015, Flasko *et al*. 2017). *Note, however, that fecal hormone concentrations are impacted by various factors, including diet, environmental conditions (e.g. humidity), and fecal pellet consistency (fresh or dried), which must be carefully considered and accounted for (Palme, 2005). As well, the use of progesterone concentrations for the confirmation of pregnancy is most accurate (>95%; Morden et al., 2011; Messier et al., 1990) once the breeding season has ended and progesterone levels in pregnant females are significantly elevated compared to non-pregnant/non-ovulatory females.*.

- Full genome and Single Nucleotide Polymorphism (SNP) genotyping can allow study of potentially functional variation and adaptive differences between ecotypes (Flanagan *et al*. 2018, Horn *et al*. 2018, Taylor *et al*. 2019, 2020, 2021a,b)
- Pellet samples can be tested for parasite burden (Turgeon *et al*. 2018)
- Habitat data can be recorded during sampling surveys, e.g. to distinguish anthropogenic (cutovers, trails/roads) vs. natural disturbance (wildfires, blowdown)

Photo Credit: Mark Bradley

7.2.3 IMPLEMENTATION

- Suitable for abundance estimation at sub-population scales (via CR/SCR), and also applicable to landscape-level studies of connectivity or gene flow.
- Suitable for estimation of distribution/occupancy (e.g. Steenweg *et al*. 2018), provided the survey design samples at a landscape scale and covers a significant portion of winter core use area.
- Applicable to estimates of population size if capture and recapture events are conducted in the same winter to allow use of closed population estimators (e.g. Hettinga *et al*. 2012, McFarlane *et al*. 2020a)
- Allows estimation of population trend with a minimum of three primary surveys occurring at one or two year intervals, with secondary surveys occurring three to four weeks later (Hettinga *et al*. 2012)
- Transect sampling design to detect groups and activity allows for collection of population demographic assessment metrics (Bulls/Cow, Calves/Cow, Calves/Adult, %Calves) to infer sex ratios and recruitment (Moeller *et al*. 2021)
- Helpful for studies of dispersal and movement, as it permits detection of changes in areas of winter activity across years, as well as identification of magnitude and directionality of gene flow through identification of migrants and relative seasonal movement networks. There are many studies now illustrating its applications to studies of dispersal (geneflow) and migration patterns within and among ranges (Berry *et al*. 2004, McLoughlin *et al*. 2004, Paetkau *et al*.

7. Fecal Sampling

2004, Galpern *et al*. 2012b, 2014, Drake *et al*. 2018, Priadka *et al*. 2018, Thompson *et al*. 2019, McFarlane *et al* 2020a). Fecal sampling can also be used to monitor source-sink dynamics through identification of migrants among populations (i.e. genetic clusters) (Ball *et al*. 2010, Priadka *et al*. 2018, Thompson *et al*. 2019, McFarlane *et al*. 2021)

Photo Credit: Lorne Gould

- Currently the only monitoring method that allows estimation of effective population size (i.e. a genetic-based estimate of the size of an idealized population that would have the same degree of inbreeding as the population under consideration; see Frankham *et al*. 1995, Luikart *et al*. 2010, Garner *et al*. 2020).

- CR/SCR methods are not intended for fine-scale abundance studies over small survey areas because single-survey sampling is often sufficient for demographic estimation (M. Manseau, *personal communication*). *Note however that genetic surveys at the sub-populations scale can be valuable for estimating other parameters such as individual fitness, familial relationships or gene flow.*
- Less suitable for sampling during seasons without snow because it is much more difficult to find fecal samples without snow cover, and DNA in fecal pellets degrades more readily when not frozen.

7.2.4 ADVANTAGES
- No direct capture or handling of animals is required
- Efficient, information-rich approach to initiate at the range/population scale (relative to traditional monitoring methods, e.g. Lamb *et al*. 2019)
- Generates precise parameter estimates subject to sufficient sample size and survey area size (McFarlane *et al*. 2020a)

7.2.5 DISADVANTAGES
- Weather constraints can result in significant protraction (prolonging) of sample collection events
- Poor light conditions can significantly reduce detection of sign and activity
- Sampling cannot be conducted in locations that helicopter cannot safely land

7. Fecal Sampling

7.3 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
Indirect Methods	Fecal sampling	✓✓	✓✓✓	variable (see text)	High	Med	P, D, A, R	Med	Med	Med/ High	No	None	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*

7.3.1 SPATIAL SCALE

- Capture-recapture/spatial capture-recapture analysis for estimation of parameters such as population size and trend is most appropriate at the scale of a caribou range or significant portion of a local population range.
- Other applications of genetic data, such as measures of genetic relatedness, gene flow or pedigree analysis can be assessed at either sub-population or population scales (e.g. Priadka *et al*. 2018, Thompson *et al*. 2019, McFarlane *et al*. 2021).

7.3.2 DATA NEEDS AND CONFIDENCE

- Typically, ranges are surveyed once if population structure or landscape connectivity are the goal, or repeated 2-3 times in a single winter to derive estimates of population size, trend, or pedigree (M. Manseau, *personal communication*).
- A single static population estimate requires two sampling events (capture and re-capture), preferably in the same season (minimum of 3 weeks apart) to allow for the use of closed population estimators (Hettinga *et al*. 2012, McFarlane *et al*. 2018). Single-sampling approaches to estimation are under development (Ruzzante *et al*. 2019).

7. Fecal Sampling

- Aerial surveys are usually spaced at 3 km intervals to ensure adequate coverage, as it is critical to obtain enough recaptures of individuals between surveys to estimate abundance.
- A minimum of ten pellets/sample needs to be collected to collect high quality samples, selecting pellets frozen together over single pellets (Hettinga *et al*. 2012). At each cratering site, approximately 1.4 more samples than the number of caribou thought to be present should be collected to ensure all individuals will be sampled (Hettinga *et al*. 2012).
- Power analysis has been conducted using real and simulated data (McFarlane *et al*. 2020a) and initial results suggest that estimation power varies with population sizes and structure.

Photo Credit: Al Arsenault

- Accurate genotyping information is critical when collecting genetic data for use in capture-recapture analysis, as the inclusion of erroneous genotypes can result in the overestimation of population size (Creel *et al*. 2003, Hettinga *et al*. 2012).

7.3.3 COMMUNITY INVOLVEMENT

Opportunity for Local community involvement

- Fecal DNA collection and the subsequent analysis of genetic material are methods highly conducive to involvement of local community members throughout all stages of a project (e.g. Polfus *et al*. 2016).
- Local community members can be easily trained on sterile sample collection and preservation methods and can directly assist trained biologists. Involvement of local experts is particularly relevant in informing survey designs, and conducting field collection.

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
    - Indigenous Knowledge can be used in survey area delineation in the absence of other caribou distribution data, 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. Culturally sensitive approaches to knowledge sharing can facilitate communication and participation in genetic studies by Indigenous community members (see Polfus *et al*. 2017).
- Data collection
    - The indirect nature of this monitoring approach (i.e. involving no contact with the animals) is consistent with many Indigenous views where non-invasive methods are preferred (M. Manseau, *personal communication*; NBCKC 2019)

7. Fecal Sampling

- Analysis
  - o Indigenous knowledge can provide valuable context to the interpretation of genetic data (e.g. through an advisory group composed of Indigenous experts and knowledge holders; Polfus *et al*. 2016)
- Reporting
  - o Indigenous community members can and should be involved with dissemination and discussion of research results in their own language. For instance, ongoing collaborative research between Environment and Climate Change Canada (M. Manseau) and the Sahtu Renewable Resource Board explicitly provides opportunities for Indigenous research leadership, dissemination and validation throughout all steps of their fecal DNA work.

Cost: $-$$$

7.3.4 RESOURCES

Equipment costs

- Sampling kits, sterile sticks for sample manipulation, coolers to keep samples frozen until analyzed
- Laboratory analysis equipment purchase, or cost of sending out samples for analysis; note that new methods are in development to reduce analysis costs and maximize data quality (M. Manseau, *personal communication*/Genome Canada Project).
- Helicopter time; a 600 km^2 survey area will take ~3.5 days per sampling event (depending on travel time to survey area) if sampling at 12-14 feeding/cratering sites per event

Personnel costs

- Two trained observers on the helicopter
- Staff to run genotyping analysis in laboratory (included $60/sample estimate, though noting that price will vary over time and among lab facilities; M. Manseau, *personal communication*/Genome Canada Project; http://www.ecogenomicscanada.ca/)

Logistical Complexity: SIMPLE-COMPLEX*

*Logistical complexity is considered Simple for sample collection but Complex for data analysis

Skills required

- Field work requires time in a helicopter as well as on the ground to physically collect samples
- Expertise in genetic laboratory techniques and data analysis is required to process DNA samples and interpret the findings.

Photo Credit: Sarah Schmid

7. Fecal Sampling

Capture/Handling: NO

7.3.5 ETHICAL CONCERNS

Capture/handling

- No capture or handling required

Potential stress from monitoring

- There is no pursuit of animals for this monitoring method. Although fecal DNA collection may in some cases be conducted in combination with classification surveys, any pursuit of animals is not required to conduct fecal DNA studies.

Carbon/environmental footprint

- High, given the substantial helicopter time required to conduct surveys

Photo Credit: Bridget Redquest and Team Wilson Research (Trent University)

7.4 EXAMPLES

ALBERTA (COLD LAKE, EAST SIDE ATHABASCA RIVER, WEST SIDE ATHABASCA RIVER, RED EARTH, SLAVE LAKE, NIPISI, AND LITTLE SMOKY RANGES) Between 2014 and 2018, non-invasive genetic surveys were employed to accurately estimate abundance of seven Alberta boreal caribou populations. Accurately estimating abundance is a critical component of monitoring and recovery of rare and elusive species. Non-invasive genetic sampling approaches can alleviate the challenges associated with surveying rare and elusive species such as caribou, by constructing capture histories from DNA collected from feces, hair, or other noninvasively collected samples. McFarlane *et al*. (2020a) provided an analytical framework to assess results from empirical non-invasive SCR studies and to inform on SCR sampling design. The researchers used data from seven boreal caribou ranges (with populations varying in abundance and geographic size) to explore the influence of varied sampling intensity on the relative bias and precision of SCR density estimates. Results show that reduced sampling intensity had a greater impact on density estimates in smaller ranges, and the best sampling designs did not differ with estimated population density, but different between large and small ranges. The researchers provided an efficient R framework that can be used when designing a monitoring program to minimize effort and cost while maximizing effectiveness, which is critical for informing wildlife management and conservation. The combination of non-invasive genetic sampling together with SCR modeling is an effective, accurate and precise approach to monitoring caribou.

7. Fecal Sampling

7.4 EXAMPLES

NORTHWEST TERRITORIES Fecal sampling for DNA analyses was conducted between 2012-14 for a collaborative project among researchers, NWT government, industry, and five local Dene and Metis communities, to understand caribou differentiation and population structure. Community members were encouraged through public outreach efforts to help with sample collection, and hunters and trappers collected samples while traveling during normal on-the-land activities. Caribou fecal pellets were collected on the snow, placed in plastic bags, and kept frozen at -20°C until lab analysis. First, the outer mucous layer of the fecal pellets was swabbed with a sterile cotton-tipped applicator to obtain epithelial cells for DNA extraction. Subsequently, swabs were placed into a lysis buffer, digested during an incubation period of 12 h, and DNA was extracted; microsatellite loci were amplified for population-level analysis, and mitochondrial DNA were sequenced for analysis of ancestral lineages. This genetic analysis of microsatellites and mitochondrial DNA from caribou fecal pellets, collected in collaboration with community members during the winter, supported population differentiation that corresponded to the caribou types recognized by Dene people. See Polfus *et al*. 2016 for more details.

Photo Credit: Mark Bradley

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