



Fate of the Caribou Project

2025 NSF Annual Report

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ACCOMPLISHMENTS

What are the major goals of the project?

Caribou (*Rangifer tarandus*) are the most widespread and abundant large mammal in the Arctic and therefore both an ecological keystone species, and of profound importance to the culture and lifeways of Indigenous and settler peoples of the north. Climate change is rapid in the Arctic, and a warmer climate threatens the ecological, cultural, and economic role of caribou. The goal of the Fate of the Caribou project is to advance understanding of the inter-connected mechanisms driving changes in caribou distribution, habitat use, and abundance to inform management decisions by local caribou stewards and policy decision-makers. Led by the concerns and observations of local communities and Indigenous governing bodies and using shared datasets that are unprecedented in scale, we are implementing a large-scale, comparative suite of analyses across multiple caribou herds in North America, developing novel ecological modeling and environmental sensing tools at a near-continental scale.

Our objectives are to:

- O1. Build on new and existing partnerships with local communities and Indigenous, state, territorial, and federal governments in Alaska and Canada to share data and tools, and to guide research questions.
- O2. Identify near-continental-scale and herd-specific processes that control the dynamics and distributions of caribou populations.
 - O2a. Link environmental change, especially human development, directly to demographic processes and population dynamics using caribou movement and behavioral mechanisms;
 - O2b. Assemble and synthesize spatially-explicit environmental layers of vegetation change, fire dynamics, snow quality, and human infrastructure;
 - O2c. Develop dynamic field, remote sensing, and community-derived environmental datasets at a near-continental scale to measure the effects of human development and climate change on caribou and their habitat;
 - O2d. Develop analysis tools, data visualizations, and storytelling products that can be used by resource management organizations, local communities, and scientists to share the population dynamics, distributions, and importance of caribou;
 - O2e. Make significant methodological advances in ecological, behavioral, habitat, and population modeling, in framework of co-production of knowledge with Indigenous partners.
- O3. Support three postdoctoral researchers, three PhD students, and several undergraduate technicians in the fields of wildlife ecology, environmental informatics, and natural resource management.

What was accomplished under these goals and objectives?

Major Activities (8000 characters): Working with our established partners, we conducted data collection, analysis, and synthesis on all major research questions, while also exploring new areas of interest and

concern brought up by collaborators. This included development and deployment of new caribou audio recording equipment, completion a collaborative camera-trap pilot survey, refinement of remote-sensing methods to detect snow and ice, and more. Half of our team traveled to communities in Alaska and northern Canada throughout this year to participate in research and policy meetings, meet with community members, and deploy research equipment. Additionally, we published and improved several ground-breaking and publicly-available datasets and analysis tools. We shared our progress and findings through multiple communication pathways, including scientific papers, graphical summaries, reports, multi-media essays, and community presentations.

Specific Objectives:

- O1. Building on new and existing partnerships:** We have strengthened and expanded our existing partnerships with Indigenous co-management groups this year, particularly Tłıchq Government, Wek'èezhìi Renewable Resources Board, North Slave Métis Alliance (NSMA), and Kugluktuk Angoniatit Association. Community members from Lutsel'ke First Nation, NSMA, and the Tłıchq Government assisted PhD candidate Perra in retrieving acoustic recording equipment that had detached from caribou tracking collars at a scheduled time. Perra is also working with NSMA to analyze acoustic recording collected by NSMA along roads in the Bathurst caribou herd's range to measure caribou response to traffic noise, a primary concern of NSMA Caribou Guardians.

Team members presented at the 2024 Western Arctic Caribou Herd Working Group meeting in Anchorage, Alaska, our third time attending the meeting. The Working Group – which consists of representatives from 15 communities in northwest Alaska and five non-Indigenous interests – is the co-management authority on the Western Arctic herd and has a direct impact on policy. We shared a proposal for collaborative research in the Western Arctic Herd range and gave an update on our efforts to build a database to catalog traditional and local ecological knowledge of caribou.

- O2a.  Linking environmental change and caribou:** We continue to use GPS collar data, remote sensing, and cutting-edge analytical and modeling techniques to explore drivers of caribou survival, migration, and space-use in a dynamic and heterogeneous environment across our team's many areas of expertise. For example:

Barren-ground caribou are known to experience long-term and large-scale increases and decreases in numbers. PhD student McConnell built a series of mathematical models of caribou population cycles incorporating cohort effects (how conditions of birth and early life impact future adulthood survival and reproduction) along with density-dependence and environmental variation.

PhD candidate Liao continued analysis of caribou movement and lake ice conditions. Without lake ice, caribou must swim across or circumnavigate large lakes, both of which are energetically costly. Liao refined remote sensing tools to detect lake ice at fine spatial and temporal scales, then compared ice status with caribou movement data.

PhD candidate Salganek completed analysis and prepared a manuscript describing the relationship between snow and ice events and the distribution of caribou in the Western Arctic herd.

- O2b. Assembling spatial datasets:** This year, our team at Northern Arizona University published the first 30-m resolution maps of plant and woody plant biomass across the entire Arctic biome. These are the highest resolution maps of vegetation biomass ever produced across the Pan-Arctic and are over 70,000 times higher resolution than previous products. The maps are free and available on the Arctic Data Center.

Avoiding biting insects (i.e., mosquitoes, bot flies) is a driver of caribou summer habitat selection. PhD candidate Perra has developed updated insect activity thresholds for the summer ranges of the Bathurst, Porcupine, and Central Arctic caribou herds based on acoustic detections from monitoring grids on each of those herds' calving grounds. These thresholds will be used to provide dynamic interannual rasters of insect relief habitats (areas caribou congregate to avoid insects) to assist in land-use planning within these herds' ranges.

PhD candidate Salganek is working to publish a dataset on the National Park Service Integrated Resource Management Applications Portal that includes caribou resource selection data and associated resource variables extracted for those locations. These resource variables include plant functional type cover data and SnowModel snow cover covariates: snow depth, snow density, cumulative rain-on-snow ice crust, cumulative wind ice crust, and cumulative melt-freeze ice crust.

- O2c. Developing near-continental-scale datasets:** Our team is working to consolidate traditional knowledge and local observations that have been shared at caribou management meetings, public hearings, and research interviews into a searchable database ("Knowledge of the Caribou database"). The goal is to provide the technical skills and human power to make existing records of caribou observations accessible to alleviate the information requests to Indigenous partners. We now have a working database prototype that has been shared with our partners. This year we tested the data entry process and solicited feedback from our partners. The database is not yet public as we continue to address concerns about data sovereignty and long-term maintenance of the database.

- O2d. Analysis tools, data visualizations, and communication products:** The willingness and ability of caribou and other species to cross linear barriers, both human-made and natural, is important for conservation practitioners and land stewards. Post-doc Barbour therefore developed and published a straightforward method to estimate the permeability of linear barriers to animal movement, available in the computer program "R" package *permeability*. The package takes animal movement data and measures how likely animals are to cross the barrier of interest, assigning a permeability value to the barrier.

At the request of the Tłıchǫ Government, we are creating an animation of caribou movements around mines and mining roads in the Bathurst Caribou Herd's range, which will help them demonstrate how caribou respond to roads and traffic. This animation will be completed and distributed this autumn in collaboration with the Wyoming Migration Initiative, Wek'èezhii Renewable Resources Board, and North Slave Métis Alliance.

Our team published numerous papers, articles, visual research briefs, and other communication products this year in a wide variety of outlets. We continue working with our partners to make research findings accessible and relevant to local communities.

O2e. Methodological advances: Our team is using acoustic recording and machine learning tools to investigate Arctic acoustic ecology, especially with respect to caribou. PhD student Perra has made significant strides in building and testing animal-borne acoustic recorders, successfully recording and documenting different behaviors on captive reindeer and wild caribou. Her recorders and data analysis tools provide new levels of detail in our understanding of caribou behavior and habitat choices.

Gurarie, Couriot, Beaupré, and Barbour continue work on new analysis methods based on cognitive movement ecology (how choice and collective memory drive caribou movement and survival), leading to insights into a range shift in the Western Arctic Caribou Herd and development of tools to delineate calving areas. Gurarie led a class of graduate students and post-docs in exploring applications and limitations of the analysis tools.

O3. Supporting early career scientists: Our team includes four post-doctoral researchers, six PhD students/candidates, a program and communications manager, and several undergraduate research associates. Undergraduate computer science intern Morey was instrumental in developing the Knowledge of the Caribou database infrastructure; she has secured a full-time software development position starting after her imminent graduation. Communications manager Brose is launching a freelance scientific illustration business using skills she has developed on this project. Post-doc Couriot started full-time assistant professorship University of Alaska Fairbanks. Post-doc Barbour started a full-time assistant professorship at Towson University. Post-doc Larue was recently awarded the highly prestigious Liber Ero Fellowship to continue his work on predation and industrial threats to caribou.

Significant Results (8000):

O2a. Linking environmental change and caribou: PhD student Beaupré's continued analysis and reassessment of the Canadian Boreal Caribou Recovery Strategy. Beaupré's preliminary results indicate that the habitat disturbance thresholds identified in the Recovery Strategy are insufficient in capturing the nuanced impacts of disturbance on caribou survival and recruitment; she is now proposing updated disturbance guidelines to better guide boreal caribou habitat protections.

Beaupré also completed analysis of caribou winter survival relative to their access to lichen (an important winter food resource) and snow depth; Snow can impede access to lichen. She found that caribou survival was nine times higher in areas with high lichen abundance when snow depth was moderate. However, as snow depth increased, the benefits of high lichen abundance diminished: caribou survival was similar across low, moderate, and high lichen abundance when snow depth was high. These findings suggest that Arctic-wide lichen declines could threaten caribou populations by reducing overwinter survival, particularly as the benefit of lichen-rich habitat is critically dependent on snow conditions remaining moderate enough for caribou to access their food.

Beaupré is also performing a deep analytical dive into the causes of adult barren-ground caribou mortality and comparing mortality patterns across herds using multi-decadal tracking data from the Bathurst, Beverly, Bluenose East, Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose West Western Arctic, Porcupine Herds and landscape variables, including remotely-sensed and modeled data. Preliminary results show that male caribou have a higher risk of mortality, which peaks in late

summer and early autumn. Before 2014, female caribou mortality risk was greatest in the late summer; however, since 2014, female mortality risk is greatest in late winter and early spring, suggesting a shift in their habitat or lifecycle is putting more physical stress on them during the winter and early spring.

PhD candidate McConnell found that cohort effects impacting caribou survival were the strongest driver of population cycles across a variety of demographic and environmental scenarios. McConnell's model predictions of population cycle characteristics (such as duration of the cycle and average period) agreed with cycle descriptions documented by Indigenous knowledge holders. This work provides new insight into how complex demographic and environmental interactions drive population cycles in large and long-lived animals like caribou.

PhD candidate Liao found that the factors affecting caribou's decision to cross or circumnavigate a large lake varied by season: In spring, caribou crossed the lake if the ice was strong enough; In autumn when lakes were ice-free, the decision of whether to swim across or go around were better predicted by other movement characteristics such as the speed at which caribou were migrating.

Post-doc Larue's initial analysis of camera trap data on the Bathurst caribou herd's calving grounds showed that grizzlies and newborn caribou calves do overlap on the calving grounds, as was hypothesized by local members of the Kugluktuk Angoniatit Association (Inuit Hunters and Trappers), and that grizzlies were detected five times more frequently than wolves during the calving season. While wolf predation of caribou is often cited as a contributing factor for caribou population declines, Larue's work indicates that grizzlies are a greater predatory threat to caribou calves on the Bathurst herd's range.

Preliminary assessment of PhD candidate Perra's animal-borne acoustic recording data shows success in detecting caribou cow-calf interactions, mosquito harassment, fine-scale foraging patterns, and rumination. Perra is now working on identifying infestation by nasal bot flies (a parasitic larva) by detecting excessive snorting in the recording data. Excessive snorting may indicate the caribou has nasal irritation caused by the growing larvae. This method provides unprecedented fine-scale measurement of nasal bot fly infestation prevalence in caribou.

Post-doc Orndahl and other team members published work detailing the relationship between shifting and expanding ranges in a sub-Arctic caribou herd and linking these changes to remotely sensed estimates of vegetation change. They found that as the Fortymile caribou herd's population grew from 1992-2017, population density increased dramatically across the herd's calving range. Over this same period, lichen cover declined and deciduous shrub cover increased across the entire Fortymile herd's range. However, these changes were more acute where caribou density was highest. Forage reduction in the herd's preferred range might therefore have played a role in the herd's subsequent population decline from 2017 through present.

PhD candidate Salganek found that caribou in the Western Arctic herd chose areas with high lichen abundance and avoided deep snow and ice. The herd's recent shift away from its traditional southern winter ranges occurred during several consecutive years of severe icing, suggesting that these events were a key driver of the change in the herd's winter range.

O2e. Methodological advances: PhD student Perra has designed innovative animal-borne acoustic recording devices, using 3D printing to build recorders that are lightweight enough to be attached to caribou tracking collars without negatively affecting the caribou. Perra deployed 30 animal-borne acoustic recorders attached to caribou GPS tracking collars last year. The recorders were scheduled to record several periods of interest (i.e., spring calving, winter foraging) then release from the collars. Twenty-one of the recorders were successfully retrieved and their recording data downloaded. Perra's development of these recorders addresses challenges unique to work in the Arctic: finding batteries that are lightweight but also robust to cold temperatures; mechanisms to detach from caribou collars without damaging equipment; adding radio telemetry emitters and flagging so the small devices can be recovered in the vast landscape after they detach from collars. Her methods will be instrumental to future animal-borne acoustic research in the Arctic and beyond.

Additionally, Perra's analysis of audio data from stationary audio recording devices has narrowed down the temperature and wind thresholds necessary for alleviating biting insect harassment on caribou. Biting insects cause blood loss, prevent caribou from foraging, and increase movements to escape the insect pests, and the warming climate allows insects to be active for longer periods. Perra can detect insects in audio data and is tying insect activity levels to local temperature and wind data, improving previously established thresholds for modeling insect harassment. This analysis supports Inuit and Dene knowledge that Contwoyto Lake is critical insect-relief habitat for the threatened Bathurst Caribou Herd. Contwoyto Lake is being considered for several new infrastructure projects, making her results more important than ever.

Post-doc Barbour and PI Gurarie developed a new model for quantifying the "barrier effects" of linear landscape features (i.e., roads, rivers). Linear features are known to alter animal movement, and can either accelerate movement or deter it. Barbour's permeability model estimates animal behavioral responses to a linear feature and assigns a "permeability level" to the feature where $k = 0$ is completely impermeable (tracked animals do not cross the linear feature); $0 < k < 1$ is semi-permeable; and $k \leq 1$ is hyperpermeable. Barbour continues building functions on the model to incorporate environmental covariates and characteristics of the barrier being analyzed, which will help wildlife managers better understand the effects of linear barriers under different conditions. This model is being used to inform land planning decisions.

Key outcomes or other achievements (8000):

O1. Building on new and existing partnerships: Following a successful pilot project on the Bathurst herd's calving grounds, post-doc Larue is co-leading an expanded effort to deploy camera trap grids on the calving grounds of the Bluenose East caribou herds; camera traps are deployed and maintained by community volunteers from the Kugluktuk Angoniatit Association.

We are working on a new partnership with the Beverly and Qamanirjuaq Caribou Management Board (BQCMB) this year. The BQCMB and the communities they represent are concerned about the potential impacts on caribou of a proposed all-season road that would cross much of the Northwest Territories and Nunavut. They recently designated a sub-award for PI Gurarie and PhD student Nandy to quantify potential impacts of the road based, in part, on the analysis tools our team has developed to measure the "permeability" of roads and other linear barriers to animal movement. This analysis will inform the review of the Environmental Impact Statement and BQCMB's position on the proposed road.

O2a. Linking environmental change and caribou: Post-doc Larue's analysis of camera trap data on the Bathurst Caribou Herd's calving range reaffirmed the observations of local Indigenous observers that grizzlies were active on the calving range and were likely targeting calves for predation. He and his collaborators are now expanding their community-led camera trapping efforts to cover larger areas and the calving grounds of a neighboring caribou herd. Their insights into grizzly activity are helping wildlife management boards make informed decisions about caribou population recovery and predator tolerance.

PhD candidate Perra successfully deployed 30 animal-borne acoustic recording devices on caribou fitted with GPS tracking collars, in collaboration with the Government of Northwest Territories. The devices were mostly successful in recording targeted time periods in the caribou's annual life cycle, though we still faced challenges with the batteries dying due to especially cold temperatures last spring. Perra and her collaborators retrieved 21 of the 30 devices after their scheduled "drop-off" from the GPS collars. The recording units are about four inches long and were retrieved across a >500-km² area. From the audio data, we were able to identify calving events and cow-calf interactions, as well as fine-scale foraging patterns and rumination. We have not yet identified any calf mortalities but are confident this tool could be used to identify calf mortalities by tracking cow-calf interactions through time.

Perra also processed and modeled audio data of road noise collected by stationary acoustic recording units deployed the North Slave Métis Alliance (NSMA). The purpose of this was to generate a sound occurrence map of road noise that could be used as a covariate within an integrated step selection function of caribou movement data. Perra plans to approximate sound attenuation at increasing distances from the road prior to receiving 2026 data from NSMA and evaluate whether there is any response within the caribou movement data.

We co-authored a study demonstrating significant survival consequences for caribou whose autumn migration is impeded by an industrial road in western Alaska. Of the caribou who were unable to cross or circumnavigate the road, only 58% survived until the following spring; 79% of caribou who were able to cross survived. We estimate the absolute number of additional mortalities associated with road impermeability to be >1,100 caribou/year, on average. Given our results, we posit that enhancing the permeability of roads by limiting traffic levels, road dust, and noise, among other things, could improve the survival of caribou in the region.

O2b. Assembling spatial datasets: Our remote sensing team's publication of the "Gridded 30-m resolution estimates of aboveground plant biomass, woody plant biomass, and woody plant dominance across the Arctic tundra" is a significant resource for the entire Arctic research community. When applied to caribou space-use models like those published by PhD candidate Salganek and other Fate of the Caribou team members, it will provide insight at a much larger spatial scale than existing datasets.

Orndahl et al. also published "Fortymile caribou herd range isopleths, occurrence distributions, and associated vegetation change data, Alaska and Yukon Territory (1991 - 2021)", an extensive dataset that is publicly available on the Arctic Data Center. The dataset includes population size estimates for the herd from 1920 to 2022; range isopleths (georeferenced outlines) for every year from 1992-2020 and seasons within each year; heat maps of animal spatial density, which highlights heavily-used habitat areas; and changes in vegetation communities over the same time period, correlated with caribou density and land-cover types.

O2d. Analysis tools, data visualizations, and communication products: Over the past three years, we have published four packages for the computing system *R*, which is widely used in the environmental sciences. This year, Post-doc Barbour published the *permeability* package, providing straightforward tools for managers to estimate the level of impact that roads and other linear barriers are having on animal movements. Barbour is revising a manuscript describing the package for *Ecological Monographs*. The package is already being employed by wildlife scientists in the public and non-profit sectors. Post-doc Orndahl also published a package that streamlines the process of moving data between Google Earth Engine (GEE) and *R*, a significant hurdle for researchers trying to capitalize on the remote-sensing data in GEE and the statistical modeling capabilities of *R*.

PI Gurarie developed an interactive mapping tool, *Tuktu Explorer*, which visualizes, animates, sorts, and searches movement tracks from over 1,900 individual caribou, collected from 1995 to present. While *Tuktu Explorer* is not publicly available due to data sensitivity, it is being used by caribou biologists at GNWT and WRRB. Potential applications include visualizing long-term changes in caribou migration, planning field work, and identifying critical habitat.

Communications manager Brose and coauthors have published a number of plain-language articles and research briefs this year, including several pieces featured in the NSF NNA Community Office Nuna Zine. Brose developed several visual research briefs, which present some of our major findings using artistic interpretation, graphic design, and accessible language.

O2e. Methodological advances: PhD candidate Liao developed a robust method for linking albedo (light reflectance from satellite imagery) to surface ice conditions on Arctic lakes. This technique has far-reaching applications across the Arctic sciences.

PhD candidate Perra successfully deployed 30 animal-borne acoustic recording devices on wild caribou. Perra developed these recorders through an iterative testing process on captive and wild reindeer and caribou over the last three years. Perra tested different materials for the drop-off mechanism, recorder housing, sealant, and batteries that could function in extreme Arctic conditions. Her work significantly advances the feasibility of using animal-borne acoustic recorders in remote and extreme environments.

Post-doc Couriot is revising a manuscript detailing her technique for delineating calving grounds and calf-rearing areas. This paper is a major milestone for caribou conservation and industrial development planning and mitigation. Historic inconsistencies and disagreements about which areas are defined as calving grounds have convoluted mitigation and conservation efforts. Couriot's method is both ecologically-sound and reproducible, addressing those historic inconsistencies.

What opportunities for training and professional development has the project provided? (8000)

To date, the Fate of the Caribou project has recruited four post-doctoral researchers (at SUNY-ESF, University of Montana, and Northern Arizona University) and six PhD students (three at SUNY-ESF, one at Northern Arizona University, and two at University of Maryland) and has supported paid work for several undergraduate researchers. Post-doc Couriot recently started an assistant professor position at the University of Alaska Fairbanks Department of Biology and Wildlife. Post-doc Barbour recently started an

assistant professor position at Towson University. PI Berner recently started an assistant professor position at University of Alaska Southeast. Post-doc Larue was awarded the Liber Ero Fellowship and has started a new post-doc position at Université Laval. Both Perra and Beaupré successfully defended their PhD proposals this year and became PhD candidates.

We also continue to grow our team's technical skillset through interdisciplinary partnerships. For example, PI Fagan is supporting an undergraduate computer science major who is working on the technical build-out of the Knowledge of the Caribou database and Program Manager Brose is working with cartographers at the Wyoming Migration Initiative to animate maps of caribou movement around mining roads.

PhD candidate Liao received the 2025 *New Phytologist* Innovation Award at the annual Ecological Society of America (ESA) conference for her talk, "Decision-making during migration: How lake melting and freezing affect the water crossing of caribou in the High Arctic". Liao also received the 2025 Best Poster Award from the Marine, Estuarine, and Environmental Science Graduate Program of the University System of Maryland for her poster on the same topic. Both Liao and McConnell gave talks at the ESA conference, one of the largest gatherings of environmental professionals in the country. Liao, Barbour, Larue, Fagan, and Gurarie participated in the Gordon Research Seminar on Animal Movement, which specifically invites movement ecologists to share in-progress and cutting-edge research to facilitate feedback and collaboration. Gurarie, Larue, Beaupré, and Perra attended The Wildlife Society annual conference, presenting research findings and networking with other wildlife professionals. McConnell presented her synthetic caribou population models at the Mathematical Congress of the Americas, a quadrennial meeting of leading mathematicians of the Western Hemisphere. Liao presented at the American Geophysical Union annual meeting, interacting with other geographers across a wide range of experience and topics of expertise. Post-doc Orndahl presented at both the European Geophysical Union Annual Meeting and the Arctic Science Summit Week, presenting her team's Pan-Arctic vegetation map products to a broad, international audience of Arctic researchers and geographers. Orndahl and her team also attended numerous other workshops and seminars this year to leverage their work and expand their technical skills in scalable, reproducible Arctic research.

To highlight the contribution of undergraduate students: one (Wright) is leading a manuscript using camera trap data, collected under the leadership of the Kugluktuk Angoniatit Association, to analyze parasite loads on caribou and female fecundity and health, applying non-invasive methods consistent with Indigenous values. Another (Morey) is leading the technical development of the Knowledge of the Caribou project. A third affiliated student (Matias, Lehigh University) was the first author on an analysis of caribou migration and remotely sensed snow quality.

Over the four-year lifespan of this award, Perra, Beaupre, and Brose continued their professional duties and cutting-edge research while collectively having four babies: Ansel, David, Anderson, and Larsen. Multiple team members have balanced research with parenting responsibilities, major life changes, immigration roadblocks, and cross-country moves. Our research has benefited from having a well-rounded, diverse, and grounded team.

Have the results been disseminated to communities of interest? (8000)

Our progress and results have been communicated primarily through in-person meetings and presentations this year. We have spent considerable time traveling to our collaborating communities, including Yellowknife, Northwest Territories, and surrounding communities, to meet with partners and

Indigenous knowledge holders. During those trips, we shared information about our work and technical skills as a tool for collaborative research to address concerns and questions posed by the people who are living alongside the caribou we study. PI Gurarie had several especially productive in-person meetings with collaborators from GNWT, WRRB, and Tłıchq Government. Gurarie also met with representatives of the Yellowknife Dene, who have, in the past, been resistant to working with us due to local politics.

Notably, Gurarie presented research findings and discussed ongoing concerns for caribou with the Bathurst Caribou Management Board (BCMB) at their annual meeting. The BCMB is the main governing body charged with making management decisions for the Bathurst Caribou Herd. Similarly, Couriot and Brose presented at the Western Arctic Caribou Herd Working Group annual meeting in Anchorage, Alaska. We shared updates on the Knowledge of the Caribou database project and presented a funding proposal to conduct further interdisciplinary research on the Western Arctic Herd's range. PI Gunn served on the Wek'èezhii Renewable Resources Board technical committee and attended Technical Advisory Committee meetings for mining operations on behalf of the Kivalliq Inuit Association, including sharing relevant results and tools from the Fate of the Caribou project.

We presented our research at numerous conferences, workshops, and community meetings this year, including at the NNA Community Meeting, ArcticNet's Arctic Change Conference, The Wildlife Society Annual Meeting, the Gordon Research Conference on the Movement Ecology of Animals, the European Geophysical Union Annual Meeting, Arctic Science Summit Week, American Geophysical Union Annual Meeting, and more. PI Gurarie was an invited speaker at the Smithsonian's National Zoo and Conservation Biology Institute, University of Minnesota Saint Paul Department of Ecology, Evolution, and Behavior, and Université de Grenoble, all of which were geared toward early career conservation professionals and students. PI Fagan was invited to speak at the Mathematical Congress of the Americas as part of a symposium on mathematical ecology and evolution.

Post-doc Larue and coauthors wrote and distributed "Bluenose East calving ground camera trapping: Start guide and field methodology". This guide was developed to help sustain long-term monitoring of caribou spatiotemporal overlap with predators during calving and was shared with local communities and co-management partners including the Government of Nunavut, GNWT, Tłıchq Government, and WRRB.

Following guidance from Navigating the New Arctic's 2022 Broader Impacts Network training on social media and feedback from our research partners, we launched a Facebook page in February 2024 (<https://www.facebook.com/FateOfCaribou>). Growth on the page has been slow, and the page will likely be closed down as this award, and, consequently, Brose's communications manager position, comes to an end.

In addition to numerous scientific papers published, in revision, or in development, we published work in several community-focused outlets this year. Brose and Beaupré both published poems on the movement ecology of caribou in the NSF NNA Community Office *Nuna* zine, bridging our ecological knowledge with creative writing. Brose, Gunn, and Larue also published an article on Larue's research on predator occurrence on calving grounds in *Nuna*. Printed copies of the zine were distributed to Alaska Native Village Council offices and schools; the zine's target audiences are, "Indigenous community members, Tribal administrators and practitioners, youth, Elders, NNA community" (NNA-CO website). PhD candidate Liao was interviewed by Yale Climate Connections, a news service focused on fact-based climate change reporting. We also have articles published or in progress in IUCN's Deer Specialist Group newsletter, World Wildlife Fund's *The Circle* magazine (which focuses on Arctic issues), *High Country News* (an

independent magazine highlighting land issues in the American West), and National Park Service News, among others.

We are working with the Global Initiative on Ungulate Migration (GIUM), part of the UN Convention on the Conservation of Migratory Species of Wild Animals, to add the Bathurst Caribou Herd to GIUM's "Atlas of Ungulate Migration". The Atlas presents interactive visuals of diverse ungulate migrations from around the world. We have worked with GIUM to develop maps of the Bathurst herd's complex migration, and to write an accompanying fact sheet that summarizes the migration, threats to the migration, and caribou spatial ecology. Once published, the Atlas entry will have global reach as well as being a useful visual storytelling tool for Bathurst caribou stewards.

PhD candidate Perra published the "Caribou Sound Library", a digital repository of caribou vocalizations, behaviors, and environments. The Sound Library includes downloadable recordings which can be used to enhance outreach materials and demonstrate sounds caribou make and experience in their environment.

The visual research briefs developed by Brose and coauthors have been shared with relevant communities. Printed copies of "Migration and Memory", a visual summary of Gurarie et al.'s study of behavioral adaptation by the Western Arctic Caribou Herd, were distributed at the Western Arctic Caribou Herd Working Group annual meeting and the PDF is available online. Additional copies were distributed at National Park Service, U.S. Fish and Wildlife Service, and Alaska Department of Fish and Game offices within the Western Arctic Herd's range. Another graphic summary, "Grizzlies on the Calving Grounds" summarizes Larue et al.'s camera trap study on the Bathurst Herd's calving grounds. Once the final design is approved by his collaborators, we plan to work with an interpreter to translate the graphic to Inuinnaqtun to be more accessible to community members in Nunavut, many of whom were directly involved in the inception, planning, and completion of the research.

What do you plan to do during the next reporting period to accomplish the goals? (8000)

At SUNY-ESF, PhD candidate Perra will continue her research on the acoustic ecology of barren-ground caribou, especially in relation to human development and infrastructure, which is a key concern for our Indigenous partners. This involves continued development of a novel animal-borne acoustic recorder and deploying both animal-borne and stationary acoustic recorders in northern Canada. PhD student Beaupré is working on analysis of caribou survival and adaptations related to human infrastructure and climate change. PhD student Nandy will be directly analyzing impacts of infrastructure on migrations and landscape-level connectivity and forecasting impacts on demographic rates. PI Gurarie will continue developing behavioral and demographic analysis tools including improvements on the *TuktuTools*, *TuktuMigration*, and *Permeability R* packages.

At the University of Maryland, PhD candidate Liao is working on the final chapter of her dissertation, which investigates the network structure and long-term temporal dynamics of caribou migration paths using ~30 years of tracking data. This work aims to identify how migratory route structure evolves over time in response to environmental change. She expects to complete her PhD by May 2026.

PhD candidate McConnell is working on the final chapter of her dissertation, which involves building a mathematical model of the ecological stoichiometry of Arctic vegetation relevant to consumption by caribou. She expects to complete her PhD by May 2026.

At Université Laval, affiliated post-doc Larue (formerly U. Montana and SUNY-ESF) will co-lead with Indigenous partners the publication of a manuscript on the predator-prey spatiotemporal dynamics of

grizzlies and caribou on the calving grounds of the Bathurst herd in the Northwest Territories and Nunavut. This study will help inform communities on the mostly unknown role of grizzlies on caribou survival. This study will thus potentially be critical for predator control which has historically been mostly focused on wolves. The Montana team plans to publish and publicly archive the GPS video-collar data from the Fortymile caribou herd on MoveBank and Scientific Data. Larue will also lead the publication of a methods paper validating the accuracy of Hidden Markov Models for inferring behavioral states from GPS-collar location data. Results from this study will potentially open the door to wide-use of Hidden Markov Models to infer behavior and the use of video-collars for validation. Following the successful collaboration to document grizzly activity on caribou calving grounds, Larue will lead fieldwork to expand his study of grizzlies to the Bluenose East Caribou Herd calving grounds, complete outreach about the project, and present initial results at the ArcticNet Arctic Change conference. He also plans to publish an analysis on the effects of wind speed and direction on caribou movement patterns over periods of insect harassment during summer, and perform data gathering and initial analysis on a broad-scale caribou-road ecology project.

PI Gunn has co-authored several technical reports, including reports on caribou population responses to a proposed all-weather road and a second report on a warmer climate. She is writing a journal publication integrating the effects of climate change with the energetics and demography of migratory tundra caribou, and a manuscript on dispersal between neighboring caribou herds. She will also continue serving on various technical and advisory committees for co-management agencies and Inuit associations in Canada.

At Northern Arizona University, the team plans to publish a manuscript detailing changes in Pan-Arctic vegetation biomass over the past two decades and perform outreach activities related to Pan-Arctic biomass change results, including presenting the results at scientific conferences, media interviews, invited articles, and blog and social media posts.

PI Gurarie (SUNY-ESF) and post-doc Orndahl (NAU) are co-leading a high-level, high-impact synthesis, targeted as a “Perspective” in *Nature Communications* of the state of migratory caribou research and outlining future directions building in large part on the combined efforts, results and experiences of the Fate of the Caribou project.

We plan to have several team members present at the 2026 North American Caribou Workshop in Yellowknife, NWT, Canada. The NACW is a major gathering of caribou researchers, Indigenous Guardians and Knowledge Holders, policy makers, and other interested parties. PI Gurarie has been invited to be a plenary speaker for the event, and we anticipate excellent reach since the conference is being held in Yellowknife, which is the epicenter of much of our research.

A primary objective for the upcoming reporting period is to continue engaging directly with caribou co-management boards, including once again presenting at the Western Arctic Caribou Herd Working Group annual meeting in Anchorage, Alaska. Various segments of our teams will travel to Alaska and northern Canada in the coming year to participate in research updates, conduct field work, and continue building relationships with communities.

Communications Manager Brose is finishing development on several communications products that will be disseminated to relevant audiences. In particular, we are in the final stages of developing an animation of Bathurst caribou movement tracks around the Tibbit-to-Contwoyto Winter Road, a seasonal ice road

that supplies several large diamond mines in the Bathurst herd's range. Given the precipitous decline in the herd's population over the last several decades, many Indigenous people are concerned the winter road and the mines are having negative effects on the caribou. We are developing the animation at the request of the Tłıchǫ Government and it will be used as a visual aid to demonstrate how the winter road impacts the spring migration of Bathurst caribou.

The "Knowledge of the Caribou" database project is now being overseen by O. Couriot in her new role as an assistant professor at University of Alaska Fairbanks. Couriot plans to engage several undergraduate interns in entering data into the database, with the goal of testing the data entry process at a larger scale. We will also be seeking new funding sources to continue software development on the database and outreach/feedback efforts to make sure the database is as useful as possible to caribou co-management and advisory groups within Alaska.

Across our teams, we have multiple manuscripts in review, revision, or preparation. Gurarie and coauthors will submit a paper on caribou social memory to *Ecology*; Larue, Gurarie, Beaupré, Couriot, Orndahl, and Barbour all have papers in review or major revision. Topics range from validating Hidden Markov Models (a common statistical method in ecology) to caribou survival dynamics to road permeability and beyond.

As the funding for this award winds down, we are preparing to wrap up "Phase I" of the Fate of the Caribou project. Brose is working with the PIs, post-docs, and graduate students to compile a plain-language summary of each of our major research projects, which will be disseminated to our collaborators and will be available on our project website. Orndahl and Gurarie are leading an academic manuscript summarizing our cross-disciplinary findings and lessons learned, which should be submitted in 2026. All of the research conducted under this award will continue through other funding sources; this project has been a substantial jumping-off point for ongoing, innovative research across our teams.

PRODUCTS

Books:

E. Gurarie, N. Barbour, O. Couriot. Techniques and Concepts in Movement Ecology with applications in R. Open-source eBook. <https://eligurarie.github.io/MovementEcologyBook/>

Book Chapters:

Fleming, C.H., W.F. Fagan, J. M. Alston, G. Anand, N. Hiram, E.Y. Lin, M.J. Noonan, J.M. Calabrese. 2025. Spatial Distributions for Animal Movement Processes, in *The Mathematics of Movement: An Interdisciplinary Approach to Mutual Challenges in Animal Ecology and Cell Biology*. L. Giuggioli and P. Maini, ed.

Tyler, N.J.C., M. C. Forchhammer, D. Fortin, A. Gunn, M. Leblond, D. Panchenko. 2024. Reindeer/Caribou (*Rangifer tarandus* L. 1758). Chapt. 51. In: *Deer of the World: Ecology, Conservation and Management*. Editors: Mario Melletti, Stefano Focardi. Springer Cham.

Inventions: None

Journals or Juried Conference Papers:

Barbour, N., E. Gurarie, A. Kelly, and J. Hodson. The permeability R package: A maximum-likelihood tool to quantify the permeability of linear barriers to animal movement. In revision for *Methods in Ecology and Evolution*. Audience: Wildlife ecologists and biometricians.

Beaupré, C., K. Joly, M.D. Cameron, O. Couriot, W.F. Fagan, and E. Gurarie. Winter survival positively associated with forage abundance for a long-distance migratory ungulate. In revision for *Polar Biology*. NSF support acknowledged. Audience: Arctic wildlife ecologists and policy makers.

Brose, A., A. Gunn, O. Couriot, M. Perra, C. Beaupré, and E. Gurarie. 2025. Practicalities of co-production of knowledge in conserving caribou. *International Union for Conservation of Nature Deer Specialist Group Newsletter* (36). ISSN 2312-4644. deerspecialistgroup.org/newsletters/. NSF support acknowledged. Audience: Research scientists working with Indigenous communities.

Clark-Wolf TJ, St. John J, Rajesh CA, & Hebblewhite M. (2025). Caribou and Reindeer Population Cycles Are Driven by Top-Down and Bottom-Up Mechanisms Across Space and Time. *Ecology and Evolution*, 15(5), e71348. NSF support acknowledged. Audience: Wildlife ecologists and policy makers.

Couriot, O., Gurarie, E., Cosby, O., Leblond, M., and Campbell, M. What is a calving ground? Matching modern tools with ecological definitions. *Journal of Wildlife Management*. In revision. Audience: caribou researchers, policy makers, and stakeholders.

Ehlers L, Palm E, Herriges J, Bentzen T, Sutor M, Joly K, ... & Hebblewhite M. (2024). A taste of space: Remote animal observations and discrete-choice models provide new insights into foraging and density dynamics for a large subarctic herbivore. *Journal of Animal Ecology*, 93(7), 891-905. NSF support acknowledged. Audience: Wildlife ecologists and policy makers.

Ehlers, L.P.W., Bentzen, T., Gross, J., Wells, J., Sutor, M., Herriges, J., Joly, K., Palm, E. and Hebblewhite, M. In revision at *Wildlife Biology* (Nordic Society Oikos). Linking foraging ecology to juvenile survival for a subarctic ungulate. NSF support acknowledged. Audience: caribou researchers and policy makers.

Gurarie, E., Couriot, O., Beaupré, C., Barbour, N., Khadonova, E., Wehr, N., Opel, S., Cameron, M., & Joly, K. Remembering the good times, with friends: Collective behaviors and spatial memory inform seasonal range selection. In prep for *Ecology*. NSF support acknowledged. Audience: Wildlife ecologists and policy makers.

Joly, K., C. Beaupré, T.J. Fullman, M.D. Cameron, N. Barbour, and E. Gurarie. Barrier impermeability is associated with migratory ungulate survival rates. In review at *Scientific Reports*. NSF support acknowledged. Audience: Wildlife ecologists, land managers, Caribou Guardians, and policy makers.

Kolzsch, A., K. Safi, M.M. Armfield, C. Beaupré, et al. 2025. Citizen scientists for MoveApps: Innovations and insights from volunteer coders in wildlife conservation. *Methods in Ecology and Evolution* 16(8), pp 1550-1563. Doi: 10.1111/2041-210X.70101. NSF support not acknowledged. Audience: Wildlife ecologists, coders, and biometricians.

Larue B, Farr J, Ehlers L, Herriges J, Bentzen T, Sutor M, Joly K, Michelot T, Vuillaume B, Côté SD, Gurarie E, & Hebblewhite M. Inferring caribou behavioral states from tracking data with hidden Markov models — A validation study using GPS video-camera collars. In revision at *Movement Ecology*. NSF support acknowledged. Audience: Wildlife ecologists and biometricians.

Larue B, Roberto-Charron A, Dumond A, Adamczewski J, Winter R, Hedlin E, Perra M, Gunn A, Gurarie E, & Hebblewhite M. Predators at the Nursery: Are Grizzly Bears Reducing Calf Survival in a Declining Caribou Herd? In revision at Biological Conservation. NSF support acknowledged. Audience: Wildlife ecologists and policy makers, local communities and Indigenous Caribou Guardians.

Liao, Q., Gurarie, E., & Fagan, W. F. Dynamic Lake Ice Conditions Shape Caribou Water-Crossing Behavior in the Arctic. *Global Change Biology* (under review). NSF support acknowledged.

McConnell, M., and W.F. Fagan. Drivers of periodicity in population dynamic models of long-lived, large mammals. In review *American Naturalist*, preprint on arXiv.org under reference number arXiv:2508.09037, NSF support acknowledged.

Orndahl, K.M., Bentzen, T.W., Berner, L.T., Ehlers, L.P.W., Hebblewhite, M., Herriges, J.H., Joly, K., Macander M.J., Palm, E.C., Sutor, M.J., Goetz, S.J., 2025. Shifting and expanding ranges of a sub-Arctic caribou herd and associated changes in vegetation. *Ecological Applications*, 35(4), e70038. <https://doi.org/10.1002/eap.70038>. NSF support acknowledged. Audience: wildlife ecologists and policy makers.

Orndahl, K.M., Berner, L.T., Macander, M.J., Arndal, M.F., Alexander, H.D., Humphreys, E.R., ... Goetz, S.J., 2025. Next generation Arctic vegetation maps: Aboveground plant biomass and woody dominance mapped at 30 m resolution across the tundra biome. *Remote Sensing of Environment*, 323, 114717. <https://doi.org/10.1016/j.rse.2025.114717>. NSF support acknowledged. Audience: Arctic researchers, wildlife ecologists, botanists, land managers, and policy makers.

Salganek, S., Gura, K.B., Joly, K., Orndahl, K.M., Berner, L.T., Liston, G.E., Macander, M.J., Cameron, M.D., Goetz, S.J. Caribou winter habitat selection of snow, ice conditions, and lichens across long- and short-distance migration strategies. In review at *Ecosphere*. NSF support acknowledged. Audience: Wildlife ecologists and policy makers.

Licenses: None

Other Conference Presentations / Papers:

Barbour, N., A. Kelly, E. Gurarie. 2025. Quantifying the Permeability of Linear Barriers to Animal Movement. August, 2025. Gordon Research Conference on the Movement Ecology of Animals. Ventura, CA.

Beaupré, C., A. Kelly, J. Hodson, E. Gurarie. 2025. Linking Caribou Movement and Mortality: A Dynamic Hazard Approach to Survival Modeling. Poster. The Wildlife Society Annual Conference. Edmonton, Canada.

Couriot, O., J. Ware, M. Sutor. November 2024. Workshop with Aklavik and Fort McPherson village members (Northwest Territories, Canada). Changes in fall migration corridors and winter distribution of the Porcupine Caribou Herd.

Couriot, O. and A. Brose. 2024. Compiling Knowledge and Long-term Observations and Investigating Threats to Caribou in a Rapidly Changing Arctic. Oral Presentation. Western Arctic Caribou Herd Working Group. Anchorage, AK.

Gurarie, E. 2025. Animals are social, cognitive, decision-makers and should be treated thusly in our models. Invited talk. Gordon Institute Research Seminar on Movement Ecology of Animals. Ventura, California.

Gurarie, E. 2025. Fate of the Caribou: Movements, memories, and co-production of knowledge. Invited seminar speaker (remote). Smithsonian's National Zoo and Conservation Biology Institute. September 9 2025. Audience: Smithsonian biologists and staff (post-docs, PhDs).

Gurarie, E. 2025. Fate of the Caribou: Movements, memories, and co-production of knowledge. Invited seminar speaker (in person). University of Minnesota Saint Paul Ecology, Evolution, and Behavior weekly department seminar.

Gurarie, E. 2025. Fate of the Caribou: Movements, memories, and co-production of knowledge. Invited seminar speaker (in person). Université de Grenoble. February 2025.

Larue, B., J. Farr, L. Ehlers, J. Herriges, T. Bentzen, M. Sutor, K. Joly, T. Michelot, B. Vuillaume, S.D. Côté, E. Gurarie, & M. Hebblewhite. (30-31 July 2025). HMMs in Movement Ecology: Behavioural Truth or Statistical Fiction? Poster Presentation and flash oral presentation (runner-up award). Movement Ecology of Animals Gordon Research Conference. Ventura, California.

Larue B. (26 July 2025) Invited introductory speaker and discussion leader for the topic: Applied Movement Ecology in Conservation and Policy, Movement Ecology of Animals Gordon Research Seminar, Ventura California.

Larue, B., J. Farr, L. Ehlers, J. Herriges, R. Bentzen, M. Sutor, K. Joly, T. Michelot, B. Vuillaume, S.D. Côté, E. Gurarie, & M. Hebblewhite. (26-27 July 2025). HMMs in Movement Ecology: Behavioural Truth or Statistical Fiction? Poster Presentation. Movement Ecology of Animals Gordon Research Seminar. Ventura California.

Larue, B., & J. Farr. (12 March 2025). Hidden Markov models – retaining biological inference with big data. iSSa Guild, online (Zoom).

Larue, B., A. Roberto-Charron, A. Dumond, J. Adamczewski, R. Winter, E. Hedlin, M. Perra, A. Gunn, E. Gurarie, & M. Hebblewhite. (12 December 2024). Community-led monitoring of predator-prey dynamics on caribou calving-grounds in Nunavut. ArcticNet's Arctic Change conference. Ottawa, Ontario, Canada.

Larue, B., A. Roberto-Charron, A. Dumond, A. Niptanatiak, A. Gunn, J. Adamczewski, E. Hedlin, R. Winter, M. Perra, E. Gurarie, M. Hebblewhite. 2025. Understanding predator-prey dynamics to inform caribou recovery in the central Canadian Arctic. The Wildlife Society Annual Conference. Edmonton, Canada.

Liao, Q. 2024. Water-Crossing Behaviours of Caribou Affected by Ice Melting and Freezing During Migrations in the High Arctic Areas. December 2024. American Geophysical Union Annual Meeting. Washington DC.

Liao, Q. 2025. Decision-making During Migration: How Lake Melting and Freezing Affect the Water Crossing of Caribou in the High Arctic. July 2025. Gordon Research Conference. Ventura, CA.

Liao, Q. 2025. Decision-making During Migration: How Lake Melting and Freezing Affect the Water Crossing of Caribou in the High Arctic. August 2025. Ecological Society of America Annual Meeting. Baltimore, MD

McConnell, M. 2025. Caribou, Caribou People and the Anthropocene. Invited guest lecture. University of Maryland Department of Teaching and Learning, Politics and Leadership 285, "Decolonizing Climate Change Education: Fostering Inclusivity, Equity, and Holistic Understandings". April 1st 2025. College Park, MD.

McConnell, M. and W.F. Fagan. 2025. Understanding conditions for long-period cycles in biological populations. July 2025. Mathematical Congress of the Americas. Miami, FL.

McConnell, M. 2025. Understanding the factors favoring periodicity in population dynamic models with biologically inspired complexities. August 2025. Ecological Society of America Annual Conference. Baltimore, MD

McConnell, M. 2025. Understanding conditions for long-period cycles in biological populations. September 2025. University of Maryland BEES Annual Retreat. Camp Misty Mount, Catoctin MD.

Orndahl, K.M. 2025. Next generation maps of plant aboveground biomass for the Arctic tundra biome. European Geophysical Union Annual Meeting. Oral Presentation. Vienna, Austria.

Orndahl, K.M. 2025. Next generation maps of plant aboveground biomass for the Arctic tundra biome. Arctic Science Summit Week. Oral Presentation. Boulder, CO.

Perra, M., A. Kelly, S. Chamaillé-Jammes, E. Çoban, E. Gurarie. 2025. Listening to Barren-Ground Caribou (Ekwò, Tuktu): Using Animal-Borne Audio to Monitor Fine Scale Behavior. The Wildlife Society Annual Conference. Edmonton, Canada.

Other Products:

Brose, A., Gurarie, E., Rodgers, P., and Freeman, I. Animating Bathurst caribou movements around winter roads in Northwest Territories. Video. In development. NSF support acknowledged.

Orndahl, K.M., Berner, L.T., Macander, M.J., Arndal, M.F., Alexander, H.D., Humphreys, E.R., ... Goetz, S.J., 2025. Gridded 30-meter resolution estimates of aboveground plant biomass, woody plant biomass and woody plant dominance across the Arctic tundra biome (2020). Arctic Data Center. <https://doi.org/10.18739/A2NS0M06B>.

Orndahl, K.M., Bentzen, T., Macander, M., Palm, E., 2025. Fortymile caribou herd range isopleths, occurrence distributions, and associated vegetation change data, Alaska and Yukon Territory (1991 - 2021). Arctic Data Center. <https://doi.org/10.18739/A2C824G8W>.

Other Publications:

Beaupré, C. 2025. Collective movement. Poem on caribou behavior. Navigating the New Arctic Nuna Zine. NSF support acknowledged. Audience: Arctic research community; Residents of Arctic Alaska.

Brose, A., Larue, B., and Gunn, A. 2025. Caribou and grizzlies in a New Arctic: an interview with researcher Benjamin Larue. Navigating the New Arctic Nuna Zine. NSF support acknowledged. Audience: Arctic research community; Residents of Arctic Alaska.

Brose, A. 2025. The way is changing. Poem on caribou migration. Navigating the New Arctic Nuna Zine. NSF support acknowledged. Audience: Arctic research community; Residents of Arctic Alaska.

Brose, A., B. Larue, A. Roberto-Charron, A. Dumond, J. Adamczewski, R. Winter, E. Hedlin, M. Perra, A. Gunn, E. Gurarie, and M. Hebblewhite. Grizzlies on the calving grounds: Are grizzly bears a major predator on the calving grounds of the imperiled Bathurst Caribou Herd? NSF support acknowledged. Graphical research summary. In review. Audience: Residents of the Bathurst Caribou Herd range; Policy makers and stakeholders in northern Canada.

Brose, A., Matias, M.T., Ramage, J.M., Brodzik, M.J., and Gurarie, E. Does spring snow melt trigger caribou migration? Graphical research summary. In development. Audience: Residents of caribou range in Alaska and Canada; Policy makers responsible for caribou and climate action.

Brose, A. 2025. Mic'd Up: Reindeer Edition. Blog post. eliguarie.github.io/Micd-Up-Reindeer-Edition/

Brose, A., E. Gurarie, C. Beaupré, O. Couriot, M.D. Cameron, W.F. Fagan, & K. Joly. 2024. Migration and memory. Graphic summary and research brief. https://fateofthecaribou.github.io/files/WACH_MigrationShift_web.pdf

Brose, A. and E. Gurarie. 2025. Caribou: Bathurst, Northwest Territories, Canada. Global Initiative on Ungulate Migration, editors. Atlas of Ungulate Migration. Convention on the Conservation of Migratory Species of Wild Animals. In review.

Gunn, A., D. Russell, K. Joly, L. Manzo, J. Pellissey, J. Tulagak and A. Whiting. 2024. NOAA Arctic Report Card 2024 : Migratory Tundra Caribou in a Warmer Climate. United States. National Oceanic and Atmospheric Administration. NOAA technical report OAR ARC; 24-10 (Arctic Report Card). DOI : <https://doi.org/10.25923/qn4a-td90>

Gurarie, E. and A. Brose. 2025. The caribou remember: Collective memory and survival. The Circle. World Wildlife Fund. <https://www.arcticwwf.org/the-circle/stories/collective-memory-and-survival/>

Larue, B., A. Dumond, A. Niptanatiak, Kugluktuk Angoniatit Association. 2025. Bluenose East Calving Grounds Camera Trapping: Start Guide and Field Methodology. Report delivered to the Government of Nunavut, Government of Northwest Territories, Tłı̨chǫ Government, and the Wek'èezhii Renewable Resource Board.

Liao, Q. for Yale Climate Connections. 2025. Climate change is forcing pregnant caribou to make dangerous decisions. 03 Mar 2025. <https://yaleclimateconnections.org/2025/03/Climate-change-is-forcing-pregnant-caribou-to-make-dangerous-decisions/>

National Park Service. 2025. Increasing caribou leads to expanded ranges and impacts on vegetation. NPS News. <http://nps.gov/articles/000/caribou-expanded-range.htm>

National Science Foundation. Migration and memory: How caribou adapt to changing winter conditions. NSF Stories. January 14, 2025. <https://www.nsf.gov/news/migration-memory-how-caribou-adapt-changing-winter>

Russell, D.E., A. Gunn and A. Frid. 2024a. Vulnerability Assessment of the Bathurst Caribou Herd for the proposed Slave Geological Province Road, NWT. GNWT Department of Environment and Natural Resources, Yellowknife, Northwest Territories, Canada. Manuscript Report 323, 83p.

Russell, D., R. White, and A. Gunn. 2024b. Understanding Productivity of North American Migratory Tundra Caribou (*Rangifer tarandus*): Role of vital rates and climate. Government of Northwest Territories, Department of Environment and Natural Resources, Yellowknife, Northwest Territories, Canada. Manuscript Report 312, 55p.

Russell, D. and A. Gunn. 2025. Caribou Futures: Assessing vulnerability of migratory tundra caribou to climate change. CARMA Network and Shadow Lake Environmental Inc., unpublished technical report for WWF Global Arctic Programme.

Toth, H. 2025. Mapping Carbon in the Arctic. The NAU Review. 5 May 2025. <https://news.nau.edu/arctic-carbon-mapping/>

Patent Applications: None

Technologies or Techniques:

Barbour, N., Kelly, A., and Gurarie, E. 2025. “permeability” R package. <https://github.com/NickiBarbour/permeability>

A maximum-likelihood based tool to quantify the permeability of linear barriers to animal movement, designed to help policymakers and researchers assess the impacts of natural and anthropogenic barriers to animal movement. Developed in partnership with Government of Northwest Territories.

Beaupré, C., Couriot, O., Brose, A., Gurarie, E., Billingsley, B., Morey, J., Druckenmiller, M., Gunn, A., Zaproshyan, A., Cheshire, M., and Earls, J. Knowledge of the Caribou database prototype.

A database designed to compile Traditional and Local Ecological Knowledge (TLEK) observations of caribou from existing reports and documents recorded at caribou workshops and herd-specific working group meetings. These observations provide an important local record of the past and present state of the Arctic environment and caribou, but participation and knowledge sharing in these meetings represents a significant time burden on local community members. The goal of this database is to alleviate repeated requests for information while compiling community-based observations of caribou ecology for posterity.

Gurarie, E., Couriot, O., and Brandão Biebuhr, B. Tuktutools: a package of tools for studying tuktut (caribou) spatial patterns. <https://github.com/ocouriot/Tuktutools>

The Tuktut Tools R package is a set of tools developed by the Fate of the Caribou team that allows researchers to analyze caribou spatial and behavioral patterns. To date, the package includes functions to estimate individual calving times using movement rate analysis, identify migration timing, compute sociality indices (how often individuals are interacting with each other), estimate calving and early rearing areas, delineate overall seasonal and daily ranges, and partition behavior into transient and residential stages using GPS collar data. The package also includes tools to map and animate location data to visualize animal movements more easily. Efforts this year were focused on debugging and fixing issues identified by researchers who are actively using it. To date, we know researchers at Government of Northwest Territories and elsewhere are using the package.

Gurarie, E. 2024. TuktutMigration: an R package for estimating individual and collective migration behavior. <https://github.com/EliGurarie/TuktutMigration>

An R package for estimating collective migration behavior the hierarchical migration model developed in [Gurarie et al. \(2019\)](#) to estimate migration timing for barren-ground caribou across North America. This package uses a Bayesian MCMC sampler using [RStan](#). To date, we know researchers at Government of Northwest Territories and elsewhere are using the package.

Orndahl, K.M., Burns, P., 2024. rf_r_to_gee. <https://doi.org/10.5281/ZENODO.13871352>.

An R package with tools to convert random forest models generated in R to data formats accepted by Google Earth Engine (GEE). Researchers often find themselves needing to move between R and GEE over the course of a modeling workflow. For example, a researcher might capitalize on GEE's raster processing power to extract predictor variables across a set of training data, then bring the extracted data into R to train and validate a series of models. Ideally, these models could then be applied in GEE across the full raster domain. However, a common sticking point is formatting R-based models in a way that is readable by GEE's javascript based interface. This repository includes scripts and sample data to take random forest models fitted via the ranger or randomForest package in R and convert them into the 'tree' based string format required for import into GEE. The code presented here is modified from the 'reprtree' package.

Thesis / Dissertations: None completed, but several forthcoming from multiple labs.

Websites or Other Internet Sites:

Project homepage: <https://FateOfTheCaribou.esf.edu>
Storymap on Bathurst caribou herd range shifts: shiftingtrails.caribou.esf.edu
Project Facebook page: <https://www.facebook.com/FateOfCaribou>
TuktutTools repository: <https://github.com/ocouriot/Tuktutools>
TuktutMigration repository: <https://github.com/EliGurarie/TuktutMigration>
Arctic Plant Aboveground Biomass Synthesis Dataset:
<https://arcticdata.io/catalog/view/doi%3A10.18739%2FA2QJ78081>

Gridded 30-meter resolution estimates of aboveground plant biomass, woody plant biomass and woody plant dominance across the Arctic tundra biome: <https://doi.org/10.18739/A2NS0M06B>
Fortymile caribou herd range isopleths, occurrence distributions, and associated vegetation change data, Alaska and Yukon Territory (1991 - 2021): <https://doi.org/10.18739/A2C824G8W>.
Permeability repository: <https://github.com/NickiBarbour/permeability>
Caribou Sound Library: <https://www.caribousoundlibrary.com/about>

PARTICIPANTS

What individuals have worked on the project?

Name	Most senior project role	Nearest person month worked	Describe contribution
Eliezer Gurarie	PI	6	Co-authored several papers and posters. Presented results and research progress at various forums. Developed analytical tools presented in the TuktTools, TuktMigration, and Permeability R packages. Completed several analyses of caribou sociality and habitat use and led collaboration with Indigenous and local partners in the Arctic.
William Fagan	Co-PI	1	Oversaw PhD students and undergraduates involved in grant-related research. Contributed to manuscripts developed both in his lab and in collaboration with other members of the research team.
Anne Gunn	Co-PI	2	Provided subject matter expertise during development of project research questions and outreach materials. Reviewed research proposals and manuscripts for post-docs and graduates. Co-authored outreach materials. Served on the Wek'ëezhii Renewable Resources Board technical committee and attended Technical Advisory Committee meetings for mining operations on behalf of the Kivalliq Inuit Association.
Scott Goetz	Co-PI	1	Participated in project planning meetings, guided remote sensing work
Logan Berner	Co-PI	1	Co-led pan-Arctic tundra biomass mapping. Participated in project planning meetings, guided remote sensing work
Katie Orndahl	Post-doc	3	Led pan-Arctic tundra biomass mapping, prepared manuscript, conducted outreach.
Skye Salganek	PhD Student	1	Developed habitat models for Western Arctic Caribou Herd, prepared manuscript.

Mark Hebblewhite	Co-PI	1	Project management & mentorship. Co-led camera-trapping project design, HMM methods paper, and revision of Ehler et al. papers.
Benjamin Larue	Post-doc	12	Lead author on two publications in revision, presented work at an international arctic science conference, led fieldwork preparation for deploying a broad array of camera-traps on remote calving grounds, and advanced conceptual thinking and drafting of a third manuscript under work.
Ophélie Couriot	Post doc	5	Met with collaborators, analyzed data, wrote papers, communicated results through oral presentations, co-mentored PhD students, built and disseminated analysis tools
Marron McConnell	PhD Student	2	Submitted a manuscript to American Naturalist investigating the mechanisms that could drive long-period cycles in populations of large, long-lived mammals like caribou. Worked on development of a mathematical model of the ecological stoichiometry of Arctic vegetation relevant to consumption by caribou. She expects to complete her Ph.D. by May 2026.
Qianru Liao	PhD Student	2	Submitted a manuscript to Global Change Biology based on her dissertation research. Her work investigates how lake ice phenology influences migratory behavior in Arctic caribou by integrating two decades of GPS tracking data with MODIS daily albedo imagery. Specifically, she examines fine-scale lake ice dynamics and how they affect seasonal water-crossing decisions, distinguishing between direct crossings and circumnavigation around large glacial lakes. Her findings reveal how shifting ice connectivity can shape movement strategies and define climate-sensitive behavioral thresholds. She is currently working on the final chapter of her dissertation, which explores structural patterns in caribou migration routes and how these structures have evolved over time. Her work contributes broadly to the understanding of migratory connectivity and animal responses to environmental change in

			Arctic ecosystems. She expects to complete her Ph.D. by May 2026.
Stephanie Chia	PhD candidate	2	Assisted with methods development and informatics
Gayatri Anand	PhD student	2	Methods development for assessing the strength of landscape-level resource- or habitat-change wave tracking, with an emphasis on the role of interannual variability
Frank McBride	PhD candidate	1	Methods development for inferring evidence of interactions among individuals using movement data timeseries
Jessica Morey	Undergraduate	1	Developed and helped populate a database on scientific and cultural information pertaining to the migration of caribou in northern North America. Filtered and organized information obtained from Indigenous sources for the Knowledge of the Caribou database project.
Katherine Tootchen	Undergraduate	1	Computational analyses of trail establishment and trail following by animals in polar environments
Tekoa Sultan-Reisler	Undergraduate	1	Assisted with identification of spatial hotspots of caribou water-crossing activity and explored geographic and temporal patterns in these hotspots.
Megan Perra	PhD candidate	12	Developed animal-borne acoustic recording device. Deployed acoustic recorders with collaborators. Presented research findings in several venues. Mentored undergraduate research associates.
Nicole Barbour	Post-doc	7	Developed code to estimate permeability of linear barriers to caribou.
Chloe Beaupré	PhD candidate	9	Research on sociality and migration memory of caribou, spatiotemporal drivers of survival in barren-ground and boreal caribou. Presented research findings in several venues. Traveled to partnering communities and facilitated meetings with collaborators. Lead development of the Knowledge of the Caribou database.
Anna Brose	Other Professional	5	Communications and program management. Lead efforts to generate and design outreach materials (migration animation, graphical research summaries, etc.), administrative support, proofreading publications, and writing project outreach and reporting

			materials. Assisted in development of Knowledge of the Caribou database.
Brendan Billingsley	Contractor	1	Led software development on Knowledge of the Caribou database, mentored undergraduate computer science intern
Sagnik Nandy	PhD student	3	Began coursework and background research on linear barriers to animal movement and migration
Celebrity Wright	Undergraduate	1	Led analysis and manuscript development on using camera trap images to detect & estimate prevalence of bot fly infestations in caribou

Has there been a change in the active other support of the PI/PD(s) since the last reporting period?

Yes No

If Principal Investigators (PIs)/Project Directors (PDs) and co-PIs/co-PDs select “Yes,” they are required to upload their most up-to-date Current and Pending Support document in an NSF-approved format to notify NSF that active other support has changed since the award was made or since the most recent annual report. To access the NSF-Approved formats, you can find them here: <https://www.nsf.gov/bfa/dias/policy/cps.jsp>

What other organizations have been involved as partners?

Wyoming Migration Initiative
Research group
Laramie, WY
Supported development of research products

Wek'èezhì Renewable Resources Board
Governmental
Yellowknife, NWT, Canada
Shared data and commented on manuscripts

National Park Service
Governmental
Denver, Colorado
Data sharing and research co-authorship

North Slave Métis Alliance
Governmental
Yellowknife, NWT, Canada
Shared data, co-lead fieldwork, provided communication materials, and commented on manuscripts

Exchange for Local Observations and Knowledge of the Arctic
Academic
Boulder, CO
Provided guidance on development of Knowledge of the Caribou database

Tłıchǫ Government
Governmental
Yellowknife, NWT, Canada
Shared data and communication materials, reviewed research products

Kugluktuk Angoniatit Association
Indigenous co-management board
Kugluktuk, NU, Canada
Shared data, co-lead fieldwork, and commented on manuscripts

Kivalliq Inuit Association
Designated Inuit Organization
Rankin Inlet, Canada

Government of the Northwest Territories Environment and Resources
Governmental
Yellowknife, NWT, Canada
Provided data, commented on manuscripts

Cooperative Institute for Research in the Atmosphere, Colorado State University
Academic
Fort Collins, Colorado
Provided snow data and expertise in snow-wildlife ecology

Bureau of Land Management
Governmental
Alaska, USA
Shared data and commented on manuscripts

Alaska Department of Fish and Game
Governmental
Alaska, USA
Shared data and commented on manuscripts

Government of Nunavut
Governmental
Nunavut, Canada
Shared data and commented on manuscripts

Government of Yukon
Governmental
Yukon, Canada
Collaborated on projects focusing on examining changes in distribution of the Porcupine Caribou Herd

Porcupine Caribou Management Board
Advisory board
Yukon, Canada

Shared data and commented on manuscripts

Have other collaborators or contacts been involved?

Yes

No

Environmental Climate Change Canada, WWF Canada, Smithsonian Institute, Global Initiative on Ungulate Migration

IMPACTS

What is the impact on the development of the principal discipline(s) of the project?

We are combining cross-discipline technologies to develop new methods of studying wildlife, in addition to contributing to the understanding of caribou ecology. PhD candidate Perra is developing and testing novel animal-borne acoustic recording devices to directly measure the soundscape caribou experience. This has involved building and programming special drop-off devices (hardware that allows the recording device to release off the animal at a given time). She is also using machine learning to process the thousands of hours of acoustic recordings and accelerometer and magnetometer data-streams. Former post-doc Couriot, former post-doc Barbour, PI Gurarie and PhD candidate Beaupré are programming new analytical tools that use rate-change cues in animal movement data to detect life history events like calving, insect harassment, and social aggregation. These tools and others we are developing are already being used by other researchers and natural resource managers to inform policy decisions.

We developed novel methods to map tundra cover, height, and biomass using field surveys, uncrewed aerial vehicles, and satellite remote sensing, including publishing a dataset that maps Pan-Arctic vegetation at 70,000 times greater resolution than previously published datasets. Maps such as these provide a comprehensive view of conditions across the entire Arctic region, with the high resolution illustrating how fine-scale patterns in vegetation are shaped by local conditions such as topography, hydrology, and past disturbance. Our maps can be used to assess spatial patterns in caribou habitat suitability, understand environmental conditions driving caribou behavior and migration, and analyze the impacts of caribou on vegetation, especially as populations fluctuate in size, location, and density.

Post-doc Larue's research advances movement ecology and Arctic wildlife conservation through complementary studies that refine how we interpret and monitor caribou behavior and the spatiotemporal dynamics of predation. One study used GPS collars equipped with video cameras to empirically validate Hidden Markov Models (HMMs) of caribou behavior, revealing how the accuracy of inferred behavioral states depends strongly on GPS sampling resolution. Hidden Markov Models are an increasingly-popular method in wildlife ecology, so our sensitivity analysis could have far-reaching impacts. Another study used 96 motion-triggered cameras deployed across the Bathurst calving grounds to characterize predator-prey dynamics and estimate calving phenology non-invasively. Together, these studies bridge methodological and applied ecology by improving behavioral inference from tracking data and demonstrating how camera-based monitoring can support culturally appropriate, community-driven conservation in the rapidly changing Arctic. The findings strengthen theoretical understanding of animal movement and practical approaches to monitoring endangered caribou herds.

We have many ongoing analyses that will provide insight into caribou ecology, demography, and responses to human infrastructure and climate change. Our analysis of caribou survival relative to migratory behavior, caribou response to roads, reproductive success relative to environmental factors

and calving location, effects of changes to Arctic vegetation regimes, and impacts of freeze-thaw events to caribou water crossings during migration, to name a few, will increase understanding of the complex ways caribou, climate, and people interact. Our ongoing research is geared toward not only improving the scientific understanding of caribou, but producing results that on-the-ground caribou stewards can use to prioritize habitat protections, determine harvest quotas, and improve policy.

What is the impact on other disciplines?

PhD candidate Liao is contributing significantly to the fields of remote sensing and geography by developing a robust method for quantifying the albedo (light reflectance from snow and ice) of lake surfaces as a function of time (from totally frozen to completely open) based on the application of climatology methods to fill in the gaps in satellite timeseries. This has created a closer connection between remote sensing environmental data and fine-grained, biologically relevant ice conditions.

Post-doc Larue's integration of behavioral validation using video-collar data and large-scale camera-trapping bridges movement ecology, quantitative modeling, and social aspects of conservation science. The HMM validation study advances statistical and data sciences by demonstrating how GPS sampling frequency influences the accuracy of behavioral inference, offering insights relevant to bio-logging, animal physiology, and quantitative ecology. The camera-trapping work connects ecological research with Indigenous studies and conservation policy by establishing non-invasive, community-aligned approaches for monitoring wildlife. Together, these studies provide methodological foundations that can inform diverse fields, from behavioral ecology and environmental monitoring to participatory conservation planning and adaptive management.

PhD student Beaupré's innovations on linking movements in complex landscapes to survival via dynamic analysis will be widely applicable to the analysis of time-to-event processes that depend on dynamic covariates.

What is the impact on the development of human resources?

Our project has included four post-docs, six PhD students/candidates, a program and communications manager, and several undergraduate research associates, as well as contributing to the development of several other PhD students and early-career professionals. Two of our post-docs started assistant professorships at leading research universities this year; the third is continuing his research as a Liber Eros Fellow. At SUNY-ESF, two PhD students, both women, completed their qualifying exams and advanced to PhD candidacy. At the University of Maryland, two PhD students, both women, achieved doctoral candidacy status based on their efforts to date and research plans for the remaining period of the grant; one undergraduate, a woman, has gained experience working at the social-environmental interface through her efforts to develop a database on scientific and cultural information pertaining to the migration of caribou in northern North America; and one undergraduate, a woman, has gained experience in computational modeling of animal movement, focusing on trail establishment and trail following in polar environments. All of these early career professionals will go on to work in the fields of wildlife conservation and research, computer science and software development, resource management and planning, and more.

Our work has helped mentor our post-docs, PhD students, program manager, and undergraduate research associates in the use of statistical methods for spatial ecology and mapping, and helped them

gain experience working with diverse partners in Academia, NGOs, the government, and Indigenous communities. Our team members at all levels continue to benefit from knowledge sharing amongst our interdisciplinary group, and from our research partners.

In Nunavut and at University of Montana, Indigenous Guardians, graduate students, and research assistants were trained to annotate animal behavior from video footage and deploy and maintain camera traps under Arctic conditions. These experiences built technical capacity in wildlife monitoring, data management, and quantitative ecology while fostering cross-cultural collaboration.

What is the impact on teaching and educational experiences?

In addition to the regular faculty teaching responsibilities of several of the project's Primary Investigators, several of our Post-docs and PhD students have had the opportunity to teach lectures or participate as teaching assistants in their fields of study. The acoustic monitoring study led by Megan Perra has been used as an example in a lecture as part of the course WLF F301 – Design of Wildlife Studies, offered at the University of Alaska Fairbanks, AK, by Dr. Ophélie Couriot. Findings from the Hidden Markov Model validation and camera-trapping studies have been used as example case studies in a senior university course at the University of Montana (WILD 470). Students learned how to understand model limitations and design field studies. Camera-trap images from the Bathurst calving grounds have also been used in lectures to illustrate predator–prey dynamics and showcase non-invasive research methods. These educational uses have helped students connect quantitative modeling with real-world conservation applications.

What is the impact on physical resources that form infrastructure?

PhD student Perra has designed and developed novel acoustic recorders that have been mounted to GPS tracking collars to measure the soundscape caribou experience. This has involved building and programming drop-off devices (mechanisms that allow the recording device to fall off the animal after a set amount of time) and acoustic recording devices that have enough memory but a small enough battery to collect a sufficient sample size while not being cumbersome to the animal. She tested her acoustic collar prototypes on captive research animals in partnership with the University of Alaska Fairbanks Large Animal Research Station. The devices were deployed on 40 free-ranging caribou in partnership with Government of Northwest Territories in spring 2025, and the majority have been successfully recovered. These collars will allow researchers to gather extensive data on the daily experiences and behaviors of large ungulates. While collars have been used for several decades to track animal movements across the landscape, pairing that movement data with acoustic information will provide unprecedented and fine-scale insight into the drivers behind observed behaviors.

What is the impact on institutional resources that form infrastructure?

None to report

What is the impact on information resources that form infrastructure?

We have published several papers and articles detailing the methods and results of our research to date, which will inform future research and caribou management decisions. Development of graphical research summaries, and an animation of caribou movements around mining roads will also be useful tools for caribou stewards to illustrate challenges facing caribou and their impacts on local communities.

Post-doc Orndahl published a high-resolution dataset on Arctic plant aboveground biomass, available through the Arctic Data Center. The dataset significantly increases the scale and resolution of vegetation estimates across the Arctic, and has already led to new insights on relationships between vegetation, climate change, and caribou. The potential applications for this dataset in ecological research, land use planning, climate change monitoring, and other fields is immeasurable. Orndahl also published a highly-detailed and rigorous dataset on the population size, range dynamics, and associated vegetation communities for the Fortymile Caribou Herd, one of the only North American caribou herds to cross an international border. The dataset has already provided new insights to the interaction between caribou population density and their habitat, and will be a long-standing resource for biologists at the many state, federal, Indigenous, and territorial agencies and NGOs who manage the Fortymile herd.

We are working with the Exchange for Local Observations and Knowledge of the Arctic to build a searchable database of traditional knowledge and local observations of caribou from Indigenous knowledge keepers from existing meeting notes and public records. This database will increase access to knowledge while alleviating the time demands placed on knowledge keepers who are often asked repeatedly to share their knowledge with outside researchers.

Post-doc Larue's work with the Kugluktuk Angoniatit Association generated high-value datasets combining GPS tracks, behavioral HMM outputs, annotated video clips, and over 245,000 camera trap images from the Bathurst calving grounds. These data are being curated with comprehensive metadata, standardized processing workflows, and open analytical scripts to promote transparency and reproducibility. Together, they represent one of the few empirical linkages between modeled and observed behavior in a free-ranging Arctic herbivore, as well as the first community-driven visual dataset documenting predator-prey overlap on caribou calving grounds.

Between all our team members, we have several manuscripts in preparation, review, revision, or press. These papers provide not only ecological insight, but also new or improved techniques for analyzing data on highly-mobile animals and their habitat.

What is the impact on technology transfer?

We continued support and improvement on the TuktTools and LandsatTS packages for R, which were both published last year. R is an open-source coding language that allows for free access to software packages, encouraging collaboration and innovation. Our TuktTools and LandsatTS packages are publicly available, free to use, and continuously growing. This year, we also published three additional packages: TuktMigration, Permeability, and rf_r_to_gee. Among other things, the packages we have published have tools to delineate calving grounds in a reproducible way, identify behavioral states based on movement data, quantify how strongly linear barriers like roads affect animal movements, download and clean large amounts of animal movement and remote sensing data, and move data between computing programs. These packages increase access to ecologically sound and effective tools for estimating animal movement, detecting and tracking vegetation changes, processing and understanding environmental variables, and modeling population dynamics under various conditions.

What is the impact on society beyond science and technology?

Our ongoing partnerships and outreach efforts with caribou co-management boards and state and territorial governments have directed our research questions to ensure we are producing actionable results that are relevant to the local communities that rely on caribou. We are also using our technical skills to produce communication tools for caribou stewards to share the multi-faceted challenges caribou

face with their communities and policy makers. For example, PI Gurarie and Program manager Brose are using Gurarie's skills with movement data and Brose's knowledge of graphic design and the Adobe suite to build a detailed animation of caribou response to mining roads, at the request of the Tłıchǫ Government, and in partnership with the Wyoming Migration Initiative, North Slave Métis Alliance, and Government of Northwest Territories. Indigenous people have been telling policy makers for years that mining infrastructure impacts caribou; now they will be able to demonstrate that visually.

One of the research directions we have taken that has been of greatest interest to our partners in the North is the analysis of potential impacts of road infrastructure on caribou populations, and the fragmentation of large, overlapping herds in light of proposed all-season roads in the Arctic. PI Gurarie, PI Gunn, PhD student Nandy, Post-doc Barbour, and Post-doc Larue are addressing these issues, combining our expertise on behavioral and ecological modeling to parameterize and explore various scenarios of road infrastructure, and – together with Northern partners who have regulatory authority over construction – to inform design measures that might mitigate the effects of the roads.

We are collaborating with the Global Initiative on Ungulate Migration (GIUM) to add the Bathurst caribou to their Atlas of Ungulate Migration. The Atlas is an interactive map of diverse ungulate migrations from around the world. The Bathurst caribou entry will highlight the threats to an imperiled caribou herd, drawing attention to the impacts of climate change and industrial infrastructure. As part of the UN Convention on the Conservation of Migratory Species of Wild Animals, GIUM has a wide audience of wildlife professionals, and, more importantly, international policy makers.

A guiding principle of our research is to collaborate in full partnership with Arctic communities. Larue's camera trap project with the Kugluktuk Angoniatit Association is a perfect example of this: The project's community-driven approach has strengthened northern stewardship and public engagement with Arctic wildlife conservation. The Bathurst camera-trapping initiative was co-designed with Inuit partners to align with local values of minimizing disturbance and ensuring shared benefits from monitoring. The resulting imagery and findings have been used in community meetings, educational outreach, and media to communicate how climate change and predation affect caribou recovery. By linking advanced analytical methods with Indigenous participation and visual storytelling, this research promotes mutual learning and empowers local communities in decision-making. The work thus contributes not only to science but also to the social, cultural, and ethical foundations of Arctic conservation.

Caribou are critical to the culture, lifeways, food security, and well-being of Indigenous and non-Indigenous peoples of the Arctic. Our research is already helping local communities and caribou management boards make more informed decisions about the harvest and stewardship of caribou and their habitat. As we move forward, our primary goal is to continue producing results and tools that help inform on-the-ground caribou management.

What percentage of the award's budget was spent in a foreign country?

>1% of total budget spent on travel and supplies while in Canada.

CHANGES / PROBLEMS

Changes in approach and reason for change: Nothing to report

Actual or Anticipated problems or delays and actions or plans to resolve them: PI Hebblewhite sustained a serious accident while conducting field work for another NSF LTREB funded project. For that project,

Hebblewhite and staff and students use horses for field work in the remote study area. All our staff and students receive annual horse refresher training and have taken multiple advanced horsemanship career development trainings.

Mark was on a training ride with a Parks Canada horsemanship instructor when his horse became tangled in concealed barbed wire and started bucking to get loose. Project staff have ridden Buck for over a decade with no previous accidents. Mark also became tangled in it on his right foot and stirrup for almost 1 minute of frenzied bucking. Mark got loose, but then was knocked unconscious by the horse's head, bucked high in the air, and stepped on as the horse backed up.

Mark was hospitalized in the Calgary Foothills trauma unit with 5 bones broken in 7 places, including a broken sternum and many ribs, suffered a punctured lung, internal bleeding, and head and neck trauma including a moderate severity TBI/concussion. Mark was 100% medically off work until 7/1/2025 and has been working half-time since then as he recovers from the concussion and neurological damage. Accordingly, progress on manuscript submission and other research activities has been delayed and affected.

Changes that have a significant impact on expenditures: Post-doc Couriot has transitioned away from this project to start her assistant professorship at University of Alaska Fairbanks. Post-doc Barbour has transitioned to her assistant professorship at Towson University. Post-doc Larue has transitioned to his fellowship at Université Laval. All three will continue as collaborators on our ongoing research, but no longer directly report to this project.

Significant changes in use or care of human subjects: Nothing to report

Significant changes in use or care of vertebrate subjects: Nothing to report

Significant changes in use or care of biohazards: Nothing to report

Has there been a change in your primary performance site location from the originally proposed? If so, please provide the location of your new primary performance site and reason for the change in location.

Nothing to report