



Fate of the Caribou Project

2023 NSF Annual Report

Reporting Period: 11-01-2022 to 11-01-2023

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ACCOMPLISHMENTS

What are the major goals of the project?

Caribou (*Rangifer tarandus*) are the most widespread large mammal of the Arctic and consequently play an integral role in the culture and lifeways of Indigenous and settler peoples of the north. Climate change threatens the ecological, cultural, and economic role of caribou. The goal of the Fate of the Caribou project is to advance understanding of the coupled human-natural system of the Arctic to inform the adaptations of our collaborating communities to climate-induced changes in caribou distributions. Led by the concerns and observations of local communities and Indigenous governing bodies, and using shared datasets that are unprecedented in scale and scope, 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:

1. 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;
2. 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;
3. Identify continental-scale and herd-specific processes that control the dynamics and distributions of caribou populations;
4. Link environmental change, especially human development, directly to demographic processes and population dynamics using caribou movement and behavioral mechanisms;
5. Assemble and synthesize spatially-explicit environmental layers of vegetation change, fire dynamics, snow quality, and human infrastructure;
6. Make significant methodological advances in ecological, behavioral, habitat, and population modeling and in frameworks for the co-production of knowledge with Indigenous partners;
7. Generate new spatial data products and dynamic data visualizations that can be used by resource management organizations and the scientific community;
8. Develop a web application that allows managers, community members, and scientists to dynamically select, view, and interact with our data products at 30 m resolution;
9. 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: Building on the relationships established during the first year of the project, we began implementing the research plans and questions developed with our partners and rolled out and improved several research products that were in development last year. Many of our team members spent considerable time travelling to partner communities in northern Canada to meet with collaborators, learn

about the real-life impacts of caribou populations on communities, and deploying research equipment. We also participated in several conferences and community meetings to share preliminary results.

Two additional post-doctoral researchers and one PhD student were recruited, and the project is now fully staffed. To date, the project has directly and indirectly supported the publication of 15 scientific papers and book chapters, with several more under review or in press, as well as several popular articles, podcast and radio news segments, and a project website and Twitter account to disseminate results.

Specific Objectives: Our partnerships with Indigenous governments and caribou co-management boards have led to the development of an online storymap (an interactive storytelling and data visualization platform) outlining our recent movement analysis and Indigenous knowledge about the Bathurst Caribou Herd in northern Canada (see attached project proposal). This project is well underway, incorporating partners from the Wek'èezhii Renewable Resources Board, Tłıchq Government, Government of the Northwest Territories, and the Wyoming Migration Initiative/Global Initiative on Ungulate Migration. Building on previous collaboration with these partners, our group is providing spatial analysis of Bathurst caribou migration shifts and leading the design and development process for the storymap. This project has gone through many iterations of review by Indigenous partners and was presented to the Bathurst Caribou Advisory Committee (BCAC) in January 2023. The BCAC members were excited about the storymap's potential to showcase the multi-faceted threats to the declining Bathurst herd. The storymap project will be completed by the end of 2023 and disseminated to our partners, Bathurst caribou managers, and other relevant parties.

The Bathurst storymap project has led to an additional effort, at the request of the Tłıchq Government, to create an animation of caribou movements around mines and mining roads in the Bathurst herd's range. This animation will help Tłıchq demonstrate the negative impacts of infrastructure and will build technical skills for our team as we learn how to refine the animation process.

We have strengthened and expanded our working partnerships with Indigenous groups this year. In addition to our ongoing work with the Tłıchq Government and Wek'èezhii Renewable Resources Board, we have established relationships with the North Slave Métis Alliance, Kugluktuk Hunters and Trappers Association, and other Indigenous governments and co-management groups. Team members conducted interviews with two members of the North Slave Métis Alliance this year, and other team members traveled to Kugluktuk, Nunavut to meet with community members and discuss their observations and concerns about caribou. Several of our team members have been invited to present at the Western Arctic Caribou Herd working group meeting in Anchorage, Alaska in December 2023.

Several Indigenous partners have expressed frustration that they are repeatedly asked by different research groups to share knowledge on caribou, which takes up significant time. There is a plethora of traditional knowledge that has been shared at caribou management meetings, public hearings, and research interviews. However, most of that knowledge is buried in disparate text documents. Recognizing this, our team launched a new initiative this year to consolidate traditional knowledge and local observations from Indigenous knowledge holders into a searchable database. We have partnered with the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) to establish best practices on data sovereignty and sharing, and hired a computer developer to guide the technical build-out of a database. Several undergraduate interns at SUNY-ESF have spent hours reading through meeting notes for the Western Arctic Herd Working Group, pulling out individual observations and entering them in a prototype database, and are leading the troubleshooting process on how to enter observations with varying levels of detail and structure into a database. The goal of this project is to provide the technical

skills and human power to make existing records of caribou observations accessible to alleviate the information requests to our partners.

We continue to develop digital resources that can be used by researchers and communities to assess climate change impacts on caribou habitat. Our team at Northern Arizona University published two datasets of vegetation biomass and cover estimates over large areas of northern Alaska and northwest Canada. Both datasets are open-access and available through the NSF Arctic Data Center. These datasets are unprecedented in their spatial and temporal scale for this region and will accelerate our understanding of caribou-vegetation interactions, as well as benefiting other Arctic researchers.

Currently, there are operating, planned, or proposed large-scale mines in several caribou ranges that we study. These mines are often supported by long, raised roads with huge trucks that cut across caribou migration routes and calf-rearing habitats. These mines are of utmost concern to many Indigenous communities because of their potential detrimental effects on caribou. We are working on developing tools to quantify permeability (and impermeability) of barriers to movement. In particular, the role of new highway construction in fragmenting populations, and the impact of intensive open-pit mining infrastructure and related seasonal road networks in perturbing traditional migratory routes. These analysis tools are of great relevance to caribou but are also an identified global need. Thus, we are working with the Global Initiative on Ungulate Migration (GIUM), an international IUCN-sponsored effort to map and quantify connectivity of migratory corridors for the benefit of communities and managers.

The concept of using behavioral indicators from GPS collar data is an emerging field. We are developing tools to detect short-term dramatic fluctuations in social aggregations from relatively coarse movement data. These aggregations are often a consequence of difficult-to-detect but extremely important processes, like insect avoidance or the reproductive rut season. This year, we published a suite of these tools through our TuktTools R package and taught a workshop at the 2023 North American Caribou Workshop and Arctic Ungulate Conference teaching other caribou researchers how to use them. We have also published several applications for movement analysis on open-source code repositories.

We continue to use GPS collar data to explore drivers of adult caribou survival with respect to migration patterns in a dynamic and heterogeneous environment. We have a paper very close to submission that reports on fascinating novel results indicating that large-scale behavioral shifts in migratory caribou in Alaska may, in part, reflect strategies to mitigate poor survival under climate change. Broadly, survival and demographics are the focus of Chloe Beaupré's Ph.D. work, which also involves a reassessment of boreal caribou demography and impacts of disturbance analysis in the Northwest Territories, work that has been essentially commissioned to revise how Canada addresses concerns about boreal woodland caribou in light of the Species at Risk Act (SARA).

Combining our ecological expertise with emerging technology, our team is using acoustic recording and machine learning tools to understand and investigate Arctic acoustic ecology, especially with respect to caribou. One of the main goals of this project is to obtain direct evidence of the effects of human disturbance and insect disturbance on caribou with audio recording units that are directly mounted on animal collars. This work involves (a) the development of a novel field data collection tool (animal-borne acoustic collars), (b) novel approaches to analyzing the data in the form of rapidly-developing large-scale Arctic acoustic labeling tools, all (c) in the service of fundamental ecological questions, in particular, "What are the direct impacts of climate change-driven increases in insect harassment and human industrial disturbance on our caribou herds of interest, all of which are greatly depleted?".

Further analysis is underway to build a synthetic population model for caribou using the demographic and environmental indicators we are developing. Team members and a PhD students at the University of Maryland have built the foundational models and are exploring ways to incorporate stochasticity and complex environmental variables. Ultimately, this mathematical model will lend insight to caribou population dynamics at a large spatial and temporal scale.

We have recruited several post-doctoral researchers and PhD students to map vegetation changes and snow and fire impacts in northern Canada using remote sensing, building on previous mapping of northern Alaska conducted by our team members. PhD students at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) have begun field work in northern Canada, deploying acoustic recorders and GPS collars on caribou to assess the effects of environmental factors and human infrastructure on declining caribou populations.

Our team was heavily involved in the first-ever joint meeting of the North American Caribou Workshop and Arctic Ungulate Conference, held in May in Anchorage, Alaska. The conference brought together over 600 Arctic ungulate researchers, Indigenous knowledge holders, and resource managers for a week of research talks and knowledge sharing. Our team members were involved at every level: on the organizing committee, leading an all-day workshop, presenting research talks and posters, facilitating sessions, and attending conference events.

Significant Results: Analysis conducted by team members at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) has revealed previously unknown patterns in the timing and synchrony of caribou calving at a continental scale. By bringing together collaborators from across northern Alaska and Canada, we compiled a near-complete dataset of caribou GPS collar data from the 11 herds of migratory tundra caribou in North America. Employing our behavioral analysis tools, our team showed that the synchrony of calving is strong within each herd and between neighboring herds, likely driven by local environmental conditions. However, herds that were geographically further from one another showed less synchrony in calving, indicating that local conditions, rather than continental climatic conditions, are driving calving timing.

To further explore behaviors associated with resource selection, co-PIs Fagan and Gurarie and their co-authors built synthetic models comparing several theories of animal movement relative to resource gradients. They found that models where animals tracked gradients of resource availability across space and/or time were more effective than models where animals tracked resource density alone. By incorporating more complex behavioral traits into the models, such as allowing animals to switch between resource searching modes (e.g., random searching versus following a resource gradient) and between movement modes as a function of their spatial context, this analysis brings a new level of sophistication to the resource selection discussion. These results will help us better understand how caribou make choices about where to go on the landscape as they attempt to maximize their resource intake while also navigating complex social, ecological, and spatial environments.

We have several papers in revision built on a novel dataset from video camera-equipped tracking collars, which allowed researchers to investigate caribou foraging ecology at an extremely fine scale, identifying forage species down to the number of bites taken. These papers link this fine-scale foraging ecology to juvenile caribou survival and provide caribou managers critical insight to the density dependence of an abundant caribou herd.

Our remote sensing team produced several major datasets this year and published results showing significant changes in the plant communities across Arctic Alaska and northwest Canada, mapping an area of approximately 500,000 km². Between 1985 and 2020, these models show a 37% increase in deciduous plant cover and decreases in graminoid and lichen biomass – two key forages for caribou. The largest changes in plant cover type were associated with wildfire and increased shrub (deciduous and coniferous) biomass was associated with decreased lichen and graminoid biomass. These changes have major implications not only for caribou, but all Arctic species and the Arctic/boreal ecosystems at large. We also presented results showing that migratory caribou can influence these rates of change at large scales.

Key outcomes or other achievements: Nothing to report

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

To date, the Fate of the Caribou project has recruited three post-doctoral researchers (at SUNY-ESF, University of Montana, and Northern Arizona University) and five PhD students (two at SUNY-ESF, one at Northern Arizona University, and two at University of Maryland). Co-PI Gurarie at the SUNY-ESF has also supported three undergraduate researchers who are assisting in camera trap data processing and in the development of the Knowledge of the Caribou database. These undergraduates have presented their work to other researchers and are being supported and encouraged to submit their work to conferences. Several of our team members participated in workshops at the 2023 North American Caribou Workshop and Arctic Ungulate Conference, including workshops on storytelling in science communication, structured decision making, and Google Earth Engine.

We also continue to grow our team's technical skillset through interdisciplinary partnerships. For example, PhD student Megan Perra has worked with the SUNY-ESF computer science department this year to develop prototype caribou collars. Program and communications manager Anna Brose and PI Elie Gurarie are working with SUNY-ESF's Digital Storytelling Studio to learn how to produce professional-level animations of caribou movement data. PI Bill Fagan is supporting an undergraduate computer science major who is working on the technical build-out of the Knowledge of the Caribou database.

Team members at SUNY-ESF completed the Collaborative Institutional Training Initiative Human Subjects Research Certificate in June of 2023. PhD student Chloe Beaupré also completed the Government of Northwest Territories Indigenous Cultural Awareness and Sensitivity Training.

Have the results been disseminated to communities of interest?

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 Kugluktuk, Nunavut, to meet with partners and Indigenous knowledge holders. The focus of these trips was to listen and learn, rather than disseminate results: we spent extensive time with caribou specialists and local knowledge holders out "on the land", learning about the ways wildfire is changing vegetation regimes, how caribou are responding to mining infrastructure, and how Indigenous groups are leading the way in caribou research, monitoring, and protection through their Caribou Guardians programs. During this time, 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.

In several cases during travel to northern Canada, we presented data visualizations and preliminary results to community members and caribou advisory groups to demonstrate our in-progress work and

facilitate feedback. Post-doctoral researcher Larue shared data on calving ground camera-trap surveys in Kugluktuk, Nunavut; PI Gurarie and Program Manager Brose shared progress on the Bathurst caribou storymap project and an animation of caribou movement around mining infrastructure to the Bathurst Caribou Advisory Committee; PhD Student Perra presented her plan to use acoustic recorders to monitor human and insect disturbance on caribou to community members in several Tłıchʔ communities. These meetings have led to several new and emerging partnerships with Indigenous groups, including the North Slave Métis Alliance and Kugluktuk Hunters and Trappers Association.

PhD Student Beaupré spent the summer in Yellowknife, Northwest Territories, working in the Government of Northwest Territories Regional Office alongside local wildlife biologists and managers. She engaged in community activities, discussed research and perspectives on caribou with locals, volunteered at the North Slave Métis Alliance Annual Fish Fry on Canada's Indigenous Peoples Day, and spent ten days in the field at the Tundra Ecological Research Station at Daring Lake.

PhD Students Perra and Beaupré conducted two interviews with members of the North Slave Métis Alliance to discuss caribou and the NSMA Guardianship program, which monitors caribou populations, health, and harvest. These interviews led to the formation of several focus groups in NSMA communities, where Perra and Beaupré will be interviewing additional knowledge keepers in the coming months.

Co-PI Couriot and PI Gurarie generated Canada-wide caribou calving ground maps and provided methods and R code for NatureServe Canada's Ecosystem-Based Automated Range mapping project. These maps and methods will be used to inform policy efforts to protect calving grounds.

PhD Student Perra was interviewed by Cabin Radio and CBC Radio's Quirks and Quarks show on her work using acoustic recorders to monitor caribou. Both of these radio segments have broad audiences across Canada and beyond.

Our website reached 231 new users in the past 12 months. The website introduces the project but also hosts many resources related to our work and Arctic caribou ecology. We have phased down our activity on Twitter due to changes in Twitter policy. We realized that, while Twitter was an excellent way to disseminate our results to other researchers, it was not reaching the communities most impacted by the changes in caribou ecology we are investigating.

We presented our research at numerous conferences and workshops this year, including at the Arctic Science Summit Week, the Global Initiative on Ungulate Migration Conference, the Gordon Research Conference, and other invited talks. By far our greatest outreach effort this year was participation in the 2023 North American Caribou Workshop and Arctic Ungulate Conference. In all, our team presented five research talks and one poster, and were coauthors on six others. Co-PI Anne Gunn gave the plenary talk on the opening day of the conference, "What have we missed?: A commentary on the status and trends of migratory tundra caribou", to an audience of over 500 conference attendees, including Indigenous community leaders, caribou co-management board members, researchers, and natural resource agency specialists.

Several team members attended the Global Initiative on Ungulate Migration conference in Jackson, Wyoming. PI Gurarie facilitated a panel titled "Social importance of conserving migration", which included panelists from collaborating Tłıchʔ communities in northern Canada. The panel had over 60 participants, most of whom were large ungulate migration researchers, Indigenous scholars, and policy experts. We also collaborated on a poster presented at the conference by the cartographer who has partnered with us

on the Bathurst caribou storymap project. His poster displayed several of the detailed Bathurst caribou migration maps he created for the storymap project.

Co-PI Gunn co-authored a book chapter, "Optimism for Caribou" in *Lines in the Snow: Thoughts on the past and future of Northern Canada Policy Issues*, which is freely available online. This book was published by the Canadian Arctic Resources Committee.

PI Gurarie organized a screening of nature documentary "Pleistocene Park", hosting the filmmaker at SUNY-ESF. Gurarie moderated a panel with several prominent members of the SUNY-ESF community to discuss the content of the movie and perspectives on landscape restoration through rewilding. This event was attended by over 100 students and faculty.

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

At SUNY-ESF, PhD student Megan Perra will continue her research on the auditory sensitivity of caribou, exploring 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, which she is currently testing on captive reindeer, and deploying acoustic recorders in northern Canada. PhD student Chloe Beaupré will continue developing behavioral analysis methods to detect rut timing and biting insect harassment, which both have potential impacts on caribou reproductive success and long-term population trends. She is also working on analysis of caribou survival and adaptations related to human infrastructure and climate change. PI Gurarie and Postdoctoral Researcher Couriot will be leading an effort to use behavioral analysis to detect the timing and duration of the rut, or caribou mating period, which has impacts on the timing of calving. They will explore a) whether Indigenous and local knowledges indicate a pattern or environmental trigger for the rut, b) whether the rut can be detected using behavioral cues, and c) how environmental variables impact rut timing and duration, focusing first on the neighboring Bathurst, Bluenose East, and Beverly-Ahiak caribou herds in north-central Canada. They will also focus on those herds in an ongoing analysis of how those herds' winter ranges are shifting and overlapping, which has critical management implications for First Nations, Métis, and Inuit harvesters. After identifying behavioral cues for the rut, Gurarie and Couriot plan to extend their analysis to compare behavioral differences between male and female caribou during critical periods of the year such as the rut, calving, and winter survival.

At the University of Maryland, PhD student McConnell just advanced to PhD Candidacy and in the coming year will develop her first dissertation chapter, which will focus on analysis of a synthetic population dynamics model for caribou demography. PhD student Liao will progress to PhD Candidacy this year and develop her first dissertation chapter, which will focus on methods development for determining influence of ice dynamics on migratory water-crossing events. Fagan has initiated a new collaboration with Dr. Dominique Berteaux (Canada Research Chair in Northern Biodiversity, Centre for Northern Studies and Quebec Centre for Biodiversity Science, Université du Québec à Rimouski, Rimouski, QC G5L 3A1, Canada) investigating the movement ecology of Arctic foxes and snowshoe hares at high latitudes in Canada, providing opportunities to investigate ecological responses of other Arctic mammals species to aspects of the same processes of climate change and land-use change affecting caribou.

At the University of Montana, Post-doctoral Researcher Larue 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. Larue and Research Associate Sarah Straughan will lead the publication of a data paper describing and making publicly available the GPS video-collar data from the Fortymile caribou herd. Larue will also lead the publication of a methods paper validating the accuracy of Hidden Markov Models for inferencing behavioral states from GPS-collar location data. Validation of the behavioral states will be done from known states from video-collars. 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. Larue also plans to advance a project which will integrate Inuit, Tłı̨chǫ, and Western knowledge in maps documenting temporal changes in caribou abundance, caribou range, and ancestral hunting grounds/trails. These maps will help preserve important Traditional Knowledge. By integrating three ways of knowing, this project will help better understand caribou abundance and space use across a large timescale which western science cannot alone. PI Hebblewhite and PhD student Tara Meyer will submit their book chapter on effects of climate change on arctic and temperate ungulates and caribou to the forthcoming book on ungulate nutritional ecology and management by John Hopkins Press.

At Northern Arizona University, PI Berner will finalize and publicly archive the *Arctic tundra biomass synthesis dataset*, as well as submit for publication a journal article that describes the new dataset. Post-doc Orndahl will (1) finalize and publicly archive spatial datasets of tundra biomass and woody biomass for the Arctic in the years 2000 and 2020; (2) analyze spatial patterns and changes in biomass; and (3) submit for publication a journal article that describes spatial patterns of biomass in 2020. Post-doc Orndahl will also finalize and submit for publication a journal article that describes how caribou spatial density affected changes in plant functional type cover from 1992-2020 across the Fortymile caribou herd in interior Alaska and the Yukon. PhD student Salganek will (1) finalize a winter resource selection model for the Western Arctic caribou herd, (2) submit for publication an associated journal article, and (3) begin research on the influence of habitat quality on individual winter range fidelity.

Across our team, we have many manuscripts in preparation, revision, or press that will be published this year. Topics include remote sensing methods, Arctic plant community changes, density dependence and calf survival from video-equipped caribou tracking collars, methods for defining caribou calving grounds, and migratory adaptations to climate change. These papers will be published in a wide range of peer-reviewed journals, including submissions to *Journal of Animal Ecology*, *Landscape Ecology*, and *Frontiers in Ecology and Evolution*. Co-PIs Gunn and Hebblewhite are also authoring book chapters and PI Gurarie's work will be featured in German magazine *Mondberge Magazin*. CO-PI Gunn provided technical advice and expertise on caribou ecology and mapping for a special issue of *National Geographic*, set to be published in December 2023.

As we complete analyses and our work is peer-reviewed, we plan to greatly increase our outreach efforts and broader impacts. A primary objective for the upcoming reporting period is to engage more directly with caribou co-management boards, including presenting our project at the Western Arctic Caribou Herd Working Group meeting in December 2023. We anticipate completion of the Bathurst caribou storymap and brochure in partnership with the Wek'èezhìi Renewable Resources Board, Tłı̨chǫ Government, Government of the Northwest Territories, which will be distributed to communities within the Bathurst herd's range. Team members at SUNY-ESF have begun publishing blog posts on their work, and we are exploring the possibility of sending email or print newsletters to update partnering communities on our progress.

We have several trips planned to participate in research and management activities. Gurarie, Couriot, Perra, McConnell, and Beaupré will travel to Yellowknife, Northwest Territories in November 2023 to discuss ongoing collaboration with the Government of Northwest Territories and North Slave Métis Alliance. PI Gurarie, PhD student Beaupré, and Program manager Brose will travel to Anchorage, Alaska to present at the Western Arctic Caribou Herd Working Group meeting. Co-PI Couriot and PhD student Beaupré will travel to Yellowknife, Northwest Territories in February to participate in winter road monitoring with the North Slave Métis Alliance.

PRODUCTS

Books: None

Book Chapters:

N. J. C. Tyler, M. C. Forchhammer, D. Fortin, A. Gunn, M. Leblond, D. Panchenko. In press. Reindeer/Caribou (*Rangifer tarandus* L. 1758). Chapt. XX. In: *Deer of the World: Ecology, Conservation and Management*. Editors: Mario Melletti, Stefano Focardi. Springer Cham. 1) NSF support was not acknowledged.

A. Gunn, A. Guile, L. Meinert, J. Pellissey. Optimism for Caribou. Pp. 81 – 92 in: *Lines in the Snow: Thoughts on the Past and Future of Northern Canadian Policy Issues*. Editors: Clive Tesar and P. Whitney Lackenbauer. Canadian Arctic Resources Committee. NSF support was not acknowledged.

Inventions: None

Journals or Juried Conference Papers:

Berner, L. T., J. J. Assmann, S. Normand, and S. J. Goetz (2023). LandsatTS: an R package to facilitate retrieval, cleaning, cross-calibration, and phenological modeling of Landsat time-series data. *Ecography* 9, e06768. doi:10.1111/ecog.06768. (NSF support acknowledged)

Couriot, O.H., M.D. Cameron, K. Joly, J. Adamczewski, M.W. Campbell, T. Davison, A. Gunn, A.P. Kelly, M. Leblond, J. Williams, W.F. Fagan, A. Brose, and E. Gurarie. 2023. Continental synchrony and local responses: climatic effects on spatiotemporal patterns of calving in a social ungulate. *Ecosphere* 14(1). doi.org/10.1002/ecs2.4399 (NSF support acknowledged)

Ehlers, L.P.W., Palm, E., Herriges, J., Bentzen, T., Sutor, M., Joly, K., Millpaugh, J., Donnelly, P., Gross, J., Wells, J., Larue, B. and Hebblewhite. 2023. Discrete-Choice Models Reveal Density-Dependence Tradeoffs in Summer Foraging Choices for a Large Subarctic Herbivore. *Journal of Animal Ecology*

Ehlers, L.P.W., Bentzen, T., Gross, J., Wells, J., Sutor, M., Herriges, J., Joly, K., Palm, E. and Hebblewhite, M. 2023. Linking Foraging Ecology to Juvenile Survival for a Subarctic Ungulate. *Wildlife Biology*. In revision.

Fagan, W.F., C. Saborio, T.D. Hoffman, E. Gurarie, R.S. Cantrell, and C. Cosner. What's in a resource gradient? Comparing alternative cues for foraging in dynamic environments via movement, perception, and memory. 2022. *Theoretical Ecology* 15(pp. 267-282). doi: 10.1007/s12080-022-00542-0. (NSF support acknowledged)

Frost, G. V., M. J. Macander, U. S. Bhatt, L. T. Berner, J. W. Bjerke, H. E. Epstein, B. C. Forbes, S. J. Goetz, M. J. Lara, G. K. Phoenix, S. P. Serbin, H. Tømmervik, D. A. Walker, and D. Yang. Tundra greenness. NOAA Arctic Report Card 2022. (NSF support not acknowledged)

Orndahl, K. M. 2022. Mapping tundra ecosystem plant functional type cover, height and aboveground biomass in Alaska and northwest Canada using unmanned aerial vehicles, 2018-2019. Arctic Data Center. doi:10.18739/A2R785Q5B. (NSF support not acknowledged)

Orndahl, K. M., M. J. Macander, L. T. Berner, and S. Goetz. 2022. Plant functional type aboveground biomass change within Alaska and northwest Canada mapped using a 35-year satellite time series from 1985-2020. Environmental Research Letters(17), 115010. doi:10.1088/1748-9326/ac9d50. (NSF support acknowledged)

Licenses: None

Other Conference Presentations / Papers:

Beaupré, C. 2023. Migratory ungulates: from the intermountain west up to the Arctic. Invited speaker, Onondaga Audubon Society. Syracuse, New York.

Beaupré, C. 2023. Comparative analysis of caribou survival patterns. Invited speaker, SUNY-ESF Environmental Biology Spotlight on Grads Seminar. Syracuse, New York.

Carter, L., É. Bélanger, E. Gurarie, T. Davison, M. Sutor, D. Tavares, and M. Humphries. 2023. Muskox habitat association and interaction with caribou. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Couriot, O., E. Gurarie, and A. Gunn. 2023. Spatial aggregations of satellite-collared migratory caribou, an indicator of insect harassment in the Arctic. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Earls, J. 2023. Caribou research and data analysis. Poster. Central New York LSAMP Alliance Symposium at Ithaca College. Ithaca, New York.

Fagan, W. 2023. Spatial memory, hunting strategies, and preferred travel routes in mammalian carnivores. Invited speaker, University of Maryland Center for Environmental Studies – Appalachian Laboratory. Frostburg, Maryland.

Fagan, W. 2023. How non-Markovian stochastic processes and probability ridges can inform our understanding of movement in wild animals. University of Maryland Department of Mathematics. College Park, Maryland.

Fagan, W. 2023. Contributions of perception, learning, and memory to animal movement. Invited speaker, Texas Technological University Department of Mathematics. Lubbock, Texas.

Fagan, W. 2023. Perception and species interactions. Invited speaker, Isaac Newton Institute for Mathematics, Cambridge University, UK.

Freeman, I. 2023. Bathurst Caribou: Range shrinkage. Poster, Global Initiative on Ungulate Migration conference. Jackson Hole, Wyoming.

Guile, A., L. Meinert, J. Pellissey, and A. Gunn. 2023. An adaptive co-management framework for Bathurst and Bluenose-East barren-ground caribou. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Gunn, A., and D. Russell. 2023. Plenary: What have we missed?: A commentary on the status and trends of migratory tundra caribou. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Gurarie, E. and A. Brose. 2023. Fate of the Caribou and Knowledge of the Caribou: Transcending boundaries. Arctic Science Summit Week Navigating the New Arctic special session. Vienna, Austria.

Gurarie, E. 2023. Fate of the Caribou Project: Modeling movements, behaviors, and demography in the changing Arctic. Invited speaker, Biology Department of the Université de Sherbrooke. Québec, Canada.

Gurarie, E., N. Barbour, A. Kelly, and A. Gunn. 2023. Measuring the (im)permeability of landscape features for highly mobile caribou. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Gurarie, E., O. Couriot, C. Beaupré, D.A. Hansen, M. Cameron. 2023. Differential impacts of environmental conditions and movement behavior on Arctic ungulate survival across seasons. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Gurarie, E. 2023. Knowledge of the Caribou: Collaboration, co-production, and co-management. Invited speaker, University of New Hampshire Convergent Arctic Research Perspectives and Education program. Durham, New Hampshire.

Hebblewhite, M. 2023. Cues to decide when and where to move. Discussion leader using caribou examples. Gordon Research Conference, Movement Ecology of Animals: Proximate and Ultimate Drivers of Animal Movement. Barga, Italy.

Hebblewhite, M., A. Gunn, E. Gurarie, J. Adamczewski, S. Cote, and O. Couriot. 2023. Arctic group update. Global Initiative on Ungulate Migration global atlas mapping workshop. Jackson Hole, Wyoming.

Kelly, A., E. Gurarie, E. Palm, E. Whitman, and J. Hodson. 2023. Boreal caribou response to wildfire burn severity varies across seasons. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Orndahl, K.M. 2023. Migratory caribou influence rates of vegetation change across Alaska and northwest Canada. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Orndahl, K.M. 2023. Mapping vegetation biomass and tracking herbivory from space. Toolik All Scientists Meeting. Santa Barbara, California.

Perra, M., E. Çoban, T. Brinkman, M. Mandel, and E. Gurarie. 2023. Emerging tools for processing audio data from animal-borne recorders. Poster. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Perra, M., S. Crimmins, O. Couriot, T. Brinkman, L. Glen, A. Reinking, E. Çoban, M. Mandel, N. Boelman, and E. Gurarie. 2023. Using auditory recording units to monitor insect activity and infer harassment intensity. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Perra, M. 2023. The value of bioacoustics in caribou research. Invited speaker, SUNY-ESF Environmental Biology Spotlight on Grads Seminar. Syracuse, New York.

Russell, D., R. White, and A. Gunn. 2023. Understanding productivity of migratory tundra caribou: Role of vital rates and climate. Poster. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Shamon, H., O. Couriot, and E. Gurarie. 2023. The current state of research on Determining the social components of ungulate migration. American Society of Mammalogists. Anchorage, Alaska.

Tulugak, J., L. Manzio, K. Poole, and A. Gunn. 2023. Looking after caribou: The Kivalliq Inuit Association (Nunavut) approach to caribou and mining. Poster. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

White, R., D. Russell, L. Fri, Colin D., A. Gunn, and D. Spalinger. 2023. Simulation of ruminal microbial protein synthesis in *Rangifer*. Poster. North American Caribou Workshop and Arctic Ungulate Conference. Anchorage, Alaska.

Other Products: None

Other Publications: None

Patent Applications: None

Technologies or Techniques:

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

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. Additional tools are being added to the package as it is developed.

Berner, L.T., Assmann, J.J., Normand, S., and Goetz, S.J. IsatTS - an R package for deriving vegetation greenness time series using Landsat satellite data. <https://github.com/logan-berner/IsatTS>

This package enables users to extract nearly four decades of Landsat satellite surface reflectance measurements for sample locations anywhere on Earth and then generate high-quality time series of vegetation greenness for ecosystem monitoring.

Couriot, O. Caribou calving ground mapping code for NatureServe Canada Ecosystem-Based Automated Range mapping. Publicly available at <https://ocouriot.github.io/IdentifyingCalvingGrounds.html>

Beaupré, C. Home Range (Kernel Utilization Distribution). Version v1.5 (5). MoveApps.
<https://github.com/chlobeau/moveAppHomeRange.git>

Couriot, O. Estimating parturition using movement rate. Version v1.0 (1). MoveApps.
<https://github.com/ocouriot/parturition-movement-rate>

Thesis / Dissertations: None

Websites or Other Internet Sites: FateOfTheCaribou.esf.edu, twitter.com/FateOfCaribou,
<https://arcg.is/1e0j1i0>

PARTICIPANTS

What individuals have worked on the project?

Name	Most senior project role	Nearest person month worked	Describe contribution
Eliezer Gurarie	PI	3	Led the Fate of the Caribou team, organized PI meetings. Co-authored several in-progress papers and one poster presentation. Presented results and research progress at various forums. Developed analytical tools presented in the TuktuTools R package. 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	Led papers developing mathematical representations of perception and memory in the context of animal movement data.
Anne Gunn	Co-PI	2	Provided subject matter expertise during development of project research questions and outreach materials. Conducted outreach on the status of and threats to caribou in a book chapter and via a National Geographic special issue. Made introductions and connections between project PIs and Indigenous and governmental partners. Shared research results at the North

			American Caribou Workshop and Arctic Ungulate Conference, including giving the plenary talk.
Scott Goetz	Co-PI	1	Participated in project planning meetings, guided remote sensing work
Logan Berner	Co-PI	3	Worked on creating tundra biomass synthesis dataset and associated manuscript
Kathleen Orndahl	Post-doctoral researcher	3	Worked on mapping tundra biomass across the Arctic using satellite and field datasets
Skye Salganek	PhD student	9	Worked on winter resource selection modeling for the Western Arctic Caribou Herd
Mark Hebblewhite	Co-PI	1	Co-authored two papers, recruited a Post-Doctoral Researcher, participated in project planning meetings, and gave several outreach presentations.
Benjamin Larue	Post-doctoral researcher	6	Helped revise and improve Ehlers et al. manuscript for resubmission to JAE. Initiating a predator-prey dynamics study on Bathurst caribou. Initiating a project on integrative mapping of Indigenous knowledge and caribou range. Initiating a methodology project to validate behavioral inference from GPS-collars.
Tara Meyer	PhD student	4	Worked part-time on managing spatial caribou and remote sensing data and synthesizing effects of climate change on caribou and other ungulates for a forthcoming book chapter.
Sarah Straughan	Research associate	4	Worked part-time on managing caribou spatial data, analyses code and writing.
Ophélie Couriot	Post doc	12	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	4	Worked on a synthetic model of caribou demography, including gathering information on caribou demography, sociality, and behavior
Qianru Liao	PhD Student	4	Influence of ice melting and freezing on caribou migration across rivers and lakes
Alman Talreja	Undergraduate researcher	1	Caribou data scraping for demographic modeling
Megan Perra	PhD Student	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-doctoral researcher	7	Developed code to estimate permeability of linear barriers to caribou.
Chloe Beaupré	PhD Student	12	Research on sociality and migration memory of caribou, effects of climate change on migration and demographics. Presented research findings in several venues. Traveled to partnering communities and conducted field work with collaborators. Wrote and published kernel density app for MoveApps. Mentored undergraduate research associates.
Anna Brose	Other Professional	5	Communications and program management. Lead efforts to generate and design outreach materials (storymap, brochure, etc.), administrative support, proofreading publications, and writing project outreach and reporting materials. Sat on the Organizing Committee for the 2023 North American Caribou Workshop and Arctic Ungulate Conference and provided outreach and graphic design support.
Megan Cheshire	Undergraduate	1	Consulted on development of Knowledge of the Caribou database. Reviewed documents and entered observations and knowledge about caribou into a test database. Participated in planning meetings.
Jaylen Earls	Undergraduate	1	Consulted on development of Knowledge of the Caribou database. Reviewed documents and entered observations and knowledge about caribou into a test database. Participated in planning meetings.
Celebrity Wright	Undergraduate	1	Gathered peer-reviewed articles on camera trap data. Analyze camera trap photos for the Bathurst caribou camera project.
Aram Zaproshyan	Undergraduate	1	Consulted on technical build-out of the Knowledge of the Caribou database.

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?

Global Initiative on Ungulate Migration

Research group
Laramie, WY
Consultation and production of maps for the Bathurst Caribou storymap project

Wek'èezhìi Renewable Resources Board
Governmental
Yellowknife, NWT, Canada
Consultation on Bathurst Caribou storymap project and in identifying research priorities

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

North Slave Métis Alliance

Exchange for Local Observations and Knowledge of the Arctic

Have other collaborators or contacts been involved?

Yes

No

Tłıchǵ Government, Government of the Northwest Territories Environment and Resources, 2023 North American Caribou Workshop & Arctic Ungulate Conference, Wyoming Migration Initiative, Government of Yukon, Kivalliq Inuit Association, Alaska Department of Fish and Game, National Park Service, Bureau of Land Management, Yukon Department of Environment, Kugluktuk Hunters and Trappers Association

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 student 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 collar to release off the animal at a given time). She is also using machine learning to process the thousands of hours of acoustic recordings. Co-PI Ophelie, PI Gurarie, and PhD student 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. We then developed maps of tundra biomass by functional type from 1985 to 2020 for part of Alaska and northwest Canada, which showed a ~44% increase in shrub biomass and declines in graminoid and lichen biomass during this period. In addition to important findings about large-scale tundra vegetation changes, this work also generated novel methods and data products that can be used by a broad research and wildlife management community.

Our research investigating spatial foraging and juvenile survival of the Fortymile Caribou Herd produced important results for caribou population management and caribou ecology more generally. Using state-of-the-art GPS video collars that, for the first time, allowed fine-scale data collection of behavior and food choice in wild caribou, we found that density-dependence theory on foraging behavior scales down from the habitat selection all the way to the bite. This research highlighted a spatial foraging tradeoff between shrubs and lichen in summer. Our results support the idea of increased resilience of shrubs to density-dependent effects of caribou grazing and highlight potential risks of overgrazing to sensitive species, like lichens, in a changing global climate. In our second in-revision paper, we show that neonate caribou survival increased in areas with earlier snowmelt, showing evidence of the bottom-up effects of early spring vegetation on juvenile survival.

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?

None to report

What is the impact on the development of human resources?

Our project is now fully staffed, including four post-doctoral researchers, five PhD students, a program and communications manager, and several undergraduate research associates. The three undergraduate research associates at SUNY-ESF are gaining experience in data cleaning and analysis of camera trap data and are full participants in the development of the Knowledge of the Caribou database project. This experience has positively impacted their careers as wildlife ecology majors. Undergraduate Jaylen Earls presented a poster on his caribou work at the Central New York LSAMP Alliance Symposium and plans to present it at additional conferences.

Our work has helped mentor our post-doctoral researchers, 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.

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-Doctoral Researchers and PhD students have had the opportunity to teach lectures or participate as teaching assistants in their fields of study.

Co-PI Goetz teaches a course on remote sensing missions and techniques during Spring semester, which includes a Google Earth Engine component for students' research applications. PI Berner and project participants Orndahl and Salganek both participated in the course.

What is the impact on physical resources that form infrastructure?

PhD student Perra is developing tracking collars that will carry acoustic recorders to measure the soundscape caribou experience. This has involved building and programming drop-off devices (mechanisms that allow the collar to fall off the animal after a set amount of time) and developing an acoustic recording device that has enough memory but a small enough battery to collect a sufficient sample size while not being cumbersome to the animal. She is currently testing her acoustic collar prototypes on captive research animals in partnership with the University of Alaska Fairbanks Large Animal Research Station. Once developed, 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 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 the storymap narrative of the Bathurst Caribou Herd and animation of caribou movements around mining roads will also become a useful tool for caribou stewards to illustrate the plight of the herd and its impacts on local communities. We are working with local partners, including the Wek'èezhì Renewable Resources Board, to create a storymap that not only summarizes our research and the local and Indigenous Knowledge about Bathurst caribou, but which can be used in meetings and outreach efforts to demonstrate the shifts in Bathurst caribou population size, range and migration patterns, and the resulting challenges faced by communities who rely on caribou for subsistence and cultural identity.

Our team published two large datasets mapping plant biomass and functional type cover across 500,000 km² of Alaska and northwestern Canada. These datasets, available through the Arctic Data Center, significantly increase the scale and resolution of vegetation estimates for the Arctic and boreal regions of North America. The potential applications for these datasets in ecological research are innumerable. We also published four peer-reviewed papers related to satellite remote sensing of tundra vegetation, including documenting changes in vegetation over time.

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. If successful, 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.

What is the impact on technology transfer?

This year we have continued honing our two R packages, TuktuTools and LandsatTS, and have added additional functions to the packages.

PhD student Beaupré wrote and published an application to estimate home range from a kernel utilization density in MoveApps, a platform compatible with the Movebank database. Beaupré's

application was selected as one of the top-ten applications in the EMAC23 Coding Challenge and she was invited to participate in the EMAC23 Workshop at the Max Planck Institute of Animal Behavior in Germany.

Post-doctoral researcher Couriot developed code to map caribou calving grounds across Canada for the NatureServe Canada Ecosystem-Based Automated Range mapping project. These methods and code are publicly available via Couriot's GitHub repository.

By formalizing some of our analytical methods into two R packages, we are making these methods readily available to other researchers. 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.

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. Indigenous people have been telling policy makers for years that mining infrastructure impacts caribou; now they will be able to demonstrate that visually.

Our scientific papers this year helped identify the key drivers from a forage and weather perspective that are affecting adult female and juvenile caribou survival and habitat in a changing Arctic. These results are being used to improve management of the Fortymile caribou herd in Alaska and the Yukon. Our results informed a decision by the Alaska Department of Fish and Game to increase caribou harvest to prevent overgrazing impacts, following the concerns of the main land management agencies (National Park Service and Bureau of Land Management).

Our contributions to the Global Initiative on Ungulate Migration (GIUM) are also showcasing the many challenges of expanding human development and climate change in the Arctic on barren-ground caribou for international conservation and policy agencies. By formally partnering with the Bonn Convention on Migratory Species (CMS), GIUM is showcasing globally-threatened ungulate migrations to world bodies such as IUCN, CMS, Global Economic Facility, World Wildlife Fund (WWF), Nature Conservancy, the IUCN connectivity working group, United Nations Environment Program (UNEP), and World Bank – all of which were attendees at the GIUM workshop. This translational work helps put maps of globally threatened ungulate migrations in these major international funding and environmental agencies to help influence changes to development policies at global levels. In particular, a highlight of the conference was hearing directly from two of our project partners: Tłıchǫ community members involved in caribou management participated in the conference remotely and educated all 120 conference attendees about the importance of caribou to traditional ways of life, culture, and livelihoods of northern communities.

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 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: We experienced significant delays in recruiting a post-doc well into the 2nd year of the project at University of Montana. Co-PI Hebblewhite conducted 2 formal searches – 1 in year 1 of the NSF-NNA project which ultimately failed to recruit a successful candidate. Only 5 qualified post-doctoral fellows applied. The second search led to only a marginally larger applicant pool, but it did lead to the successful hire of Dr. Ben Larue, who defended his PhD in January of 2023, and started in May 2023 at the University of Montana. This unexpected delay in recruitment has delayed progress scientifically on our project. Nonetheless, Dr. Larue has hit the ground running and has developed a number of independent collaborations linking Indigenous knowledge, quantitative methods, and conservation science together that are exciting.

Changes that have a significant impact on expenditures: Nothing to report

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