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OCCUPANCY AND ACTIVITY PATTERNS OF SNOWSHOE HARES, MARTENS, FISHERS, AND BOBCATS WITHIN THE LEECH LAKE BAND OF OJIBWE RESERVATION

by

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OCCUPANCY AND ACTIVITY PATTERNS OF SNOWSHOE HARE, MARTEN, FISHER, AND BOBCAT WITHIN THE LEECH LAKE BAND OF OJIBWE RESERVATION

Kimberly Shelton

Snowshoe hare (*waabooz; Lepus americanus*) are a culturally significant animal and an important source of food and fur for the Leech Lake Band of Ojibwe. Snowshoe hare populations within the Leech Lake Reservation have declined, primarily due to changes in forest structure resulting in reduced dense vegetative cover used to escape predators. Primary mammalian predators are American martens (*waabizheshiwag; Martes americana*), fishers (*ojiigag; Pekania pennanti*), and bobcats (*gidigaa-bizhiwag; Lynx rufus*). Snowshoe hares, martens, and fishers are currently listed as species of management concern on the LLBO's *Threatened, Endangered, Sensitive and Management Concern Species* list. Research using culturally appropriate techniques is crucial to the future management and conservation of wildlife on tribal lands. I used two non-invasive monitoring techniques to assess species-habitat relationships for snowshoe hares and their mammalian predators. Sampling methods examined both spatial occupancy (snow-tracking surveys) and temporal activity patterns (remote camera traps) during the winters of 2020–2021 and 2021–2022. Both sampling methods and subsequent analysis incorporated northern white cedar (*giizhik; Thuja occidentalis*) stands, one of the few remaining cover types within the Reservation to provide dense vegetative refugia for snowshoe hares. Occupancy analysis revealed unique habitat relationships for each species; however, snowshoe hare, marten and fisher occupancy were all negatively related to the presence of roads and positively related to vegetative cover such as cedar stands, conifer cover or canopy cover. Snowshoe hare occupancy was positively correlated with predator species diversity, and fisher occupancy was negatively correlated with the presence of bobcats. Results from this research will further inform the use of forest management practices as a tool to support culturally significant species.

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Introduction

The documented integration and implementation of Indigenous Science (*e.g.* Traditional Ecological Knowledge [TEK]) and Western Science within natural resource management is growing (Johnson et al. 2016, Kutz and Tomaselli 2019, Popp et al. 2019, Henri et al. 2020). This increasing interest stems in part from an awareness that losses in biodiversity and extinctions are happening at unprecedented rates around the world, but that declines are happening slower on lands owned and managed by Indigenous peoples (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBS] 2019). The IPBS (2019) global assessment report stated that Indigenous knowledge is critical in protecting biodiversity and ecosystem health (IPBS 2019). In North America alone, tribally directed conservation initiatives have brought one of the rarest mammals in the continent, the black footed ferret (*Mustela nigripes*), back from the brink of extinction (Kraniak 2015) and made landscapes more resilient to natural disasters such as extreme wildfire (Roos et al. 2021). Increasing interest in the TEK of Indigenous communities within historically Eurocentric western-based institutions however, reinforces the importance of implementing culturally appropriate research and decolonization strategies to ensure that disrespectful practices are not perpetuated, and that research is conducted *with* rather than *on* Indigenous communities (Chalmers 2017, Kovach 2021). Use of decolonization strategies are critical to researchers wishing to engage in ethical and equitable cross-cultural collaboration with Indigenous communities that respects their unique epistemologies, independent governments, and culture (Ramos 2018).

The Leech Lake Band of Ojibwe's (LLBO) Division of Resource Management (DRM) have been conducting research on *waaboozoog* (snowshoe hare; *Lepus americanus*), a culturally significant species, since 2016. This tribally directed research was spurred by Band members who had been observing a long-term decline in *waabooz* populations. The LLBO DRM and Bemidji State University (BSU) collaborated in 2020 to create a project that would be the focus of my graduate research. The main goal of my research would be to answer questions regarding activity patterns and habitat use of three main mammalian predators of *waaboozoog/*snowshoe hare: *waabizheshiwag* (American marten; *Martes americana*), *ojiigag* (fisher; *Pekania pennanti*) and *gidagaa-bizhiwag* (bobcat; *Lynx rufus*), using camera trapping and snow-tracking.

From the onset of this research project, I was interested in relational accountability with the LLBO community as well as with the non-human beings that I was to engage in research with. To fulfill this goal, it was imperative to engage in methods that not only align with the research, but also with the specific values and interests of the community (Kovach 2021). Misunderstandings arising from inadequate consultation with Indigenous communities can negatively affect the research itself, such as misidentification of species (Bussey et al. 2016), or use of potentially inappropriate invasive research techniques (Salmon 2000). Many Indigenous cultures recognize the natural elements of an ecosystem as non-human person relatives (Salmon 2000, Bhattacharyya and Slocombe 2017), indicating that especially while on tribal land a kincentric perspective guide researchers' interactions with wildlife, including avoiding methods that cause destruction of wildlife or unnecessary pain or discomfort which may be viewed as unethical. My research did not involve unnecessary invasive handling or destruction of wildlife, nor was I personally subject to any official consultation requirements with LLBO community members regarding culturally sensitive research practices. It is possible that had I chosen not to hold myself accountable in conducting my research in a culturally sensitive way, this chapter could have easily been omitted. This statement is said without blame, indeed I received nothing but support for writing the subject matter of this chapter from the onset. This statement is meant as a signpost and suggestion to other professionals in the natural resources field engaged in work alongside Indigenous agencies or on Indigenous land: you must hold your-self accountable.

My objective in this chapter is multi-faceted. First, I intend to explore and illustrate recommended decolonization strategies and culturally sensitive research methodologies through my personal experience conducting wildlife research in collaboration with a tribal agency on reservation land. Within this intention, I hope to contribute to the broader conversation of weaving together Indigenous and Western Sciences. Secondly, I intend to give an historical overview of the political and cultural forces contributing to the contemporary land management practices of the LLBO within the Reservation, to both abide by recommended culturally sensitive considerations and provide context for the following chapters of this thesis.

Terminology. TEK has no universal definition but refers broadly to the knowledge of the relationship between people and the environment, is generated and disseminated through place-based ecological and cultural practices and beliefs, and is generally transmitted through oral tradition. TEK can be considered a branch of Indigenous Science which is generated through observation, theory, experimentation, and replication necessary for continued survival dependent on correct interpretations of natural phenomena, while maintaining a distinct spiritual component (Kawagley et al. 1998, Ramos 2018).

'Western Science' is a broad term used in reference to knowledge that is generated using the scientific method typical of universities and scientific journals utilizing tenets such as positivism, falsifiable hypothesis, experimentation, replication, and standardization. The roots of the Western Scientific paradigm originate in post-renaissance Europe, from which it derives and perpetuates much of its character (Iaccarino 2003, Ramos 2018).

Within this chapter, I interchangeably use the words Ojibwe and Anishinaabe, which refer to the same people. Ojibwe is derived from a European word and is used most often in legal or political contexts. The LLBO are one of many culturally related Indigenous tribal nations inhabiting the Great Lakes area who collectively refer to themselves as Anishinaabe. Anishinaabemowin is the word for the language of the Anishinaabe. I interchangeably use both Anishinaabemowin and English words for species names. In Anishinaabemowin, to pluralize a noun, '*oog*', '*ag*' or '*wag*' is added to the end of the word (Lucio 2023).

Prologue

Guided by the actions, research, and recommendations of Indigenous scholars and scientists (Kimmerer 2015, Kovach 2021, Ramos 2022), I introduce myself, my intentions, and my position as a researcher. *Boozhoo, Kimberly Shelton indizhinikaaz,* *Makade Binesish Giniw indigoo, wazhashk indoodem, Gaa-Zagaskwaajimekaag and northern Europe indoonjiba, Gaa-miskwaawaakokaag indanakii. Miigwech.* My name is Kimberly Shelton, my Anishinaabe name is Black Young Golden-Eagle. I am muskrat clan, I am from Leech Lake and northern Europe, I live in Cass Lake. Thank you.

I am the multi-cultural child of a settler-American multi-generational military family whose ancestors are mostly from northern Europe. I spent most of my childhood living over-seas but came home to Boy Bay on Leech Lake in northern Minnesota every year. On my father's side I am descended from mostly English ancestors who settled in the Smoky Mountains. On my mother's side I descend mostly from Norwegian ancestors who settled in the town of Boy River, on the edge of the LLBO Reservation multiple generations ago. I do not have Ojibwe ancestry, my connections to the LLBO community are through socio-cultural and family ties. After having my mother and her siblings, my grandparents divorced and my grandma re-married my grandpa Leroy Fairbanks (*Ogima Ogichidaa,* Leech Lake Ojibwe), fully embracing his culture. Mary Lee (*Bayezhigo Ma'iinganikwe*) and Leroy were prominent and respected elders of the community, and in my life. They lived a traditional lifestyle, attending and hosting gatherings and ceremonies frequently. I stayed with them often, learning from the constant revolving door of community members visiting their home. They, along with other tribal members, are buried on the land of their home, which my family still lives on and stewards. My grandma role-modeled to me what it looks like to be fiercely allied with her chosen family and community against oppressive settler colonialism.

I was received into the w*azhashk/*muskrat clan through my grandma. In the Anishinaabe creation story*, wazhashk* sacrifices their life to retrieve soil from the bottom of the waters so that turtle island can grow and hold all of creation. I'm honored to be of a clan named for *wazhashk*, who teaches me to reach for the edge of my comfort zone, and to be in service to others.

Throughout this project, I have aimed to be in service to my community, the land, and especially *waabooz*/snowshoe hare. I recognize my position within the academic institution of graduate studies, and that privileges have no doubt been granted to me on the basis of my whiteness. As Kovach (2021) explains: "supporting Indigenous methodologies means exploring one's own beliefs and values about knowledge and how these shape practices. For White scholars it is about examining whiteness. It is about examining power." With this prescription, I endeavor to challenge complacency, hesitancy, and dismissal of Indigenous Science within the academy. To resist tokenism, appropriation, and the urge to "add Indigenous and stir" and to instead strive to act as what Kovach calls a 'bridge scholar', bridging the divide between the academy and the Indigenous community (Kovach 2021).

Considerations for Culturally Sensitive Research

Ideally, every professional in the natural resource related fields would have a basic knowledge of the Indigenous history of at least the local area in which they live and work. Some natural resource agencies may even be federally mandated to engage with and consult with local Indigenous communities (Executive Office of the President 2000). The resources exist to become educated, and the considerations for how to do so mindfully and within context are outlined by multiple scholars and Indigenous scientists (Charmers 2017, Ramos 2018, Kovach 2021). Using my research to illustrate, I explore culturally sensitive considerations in wildlife conservation as outlined by Ramos (2018) through three contexts: 1) Historical Context: How the application of Federal Indian Law has affected the experience of the LLBO community; 2) Contemporary Context: How contemporary legal and social structures affect how the LLBO must operate; 3) Cultural and Spiritual Context: How practicing TEK may contribute to resilience and cultural revitalization.

Historical context: How the LLBO experienced colonization through application of Federal Indian Law. The application of Federal Indian Law on Indigenous communities has left a multidimensional legacy of biological and cultural genocide, fragmentation, theft, desperation, determination, and resilience in its wake (Jaeger 2007). This legacy can be understood through a timeline distinguished by distinct eras outlined by Getches et al. (2011): Treaty Making (1789–1871), Allotment and Assimilation (1871–1928), Reorganization (1928–1945), Termination (1945–1961) and finally the era of Self-Determination (1961–present).

The initial legal contact between the United States (US) federal government and tribal nations were in the form of treaties. These treaties were and still are international diplomacy, which the United States Constitution refers to as the “supreme law of the land” (U.S.C. VI). The first treaty between the US government and the people of what is now the Leech Lake Band of Ojibwe was signed in 1855 (Getches et al. 2011). Sixteen years later, the Indian Appropriations Act was passed, which shifted the government-to-government relationship of treaties to a government-to-individual relationship by defining Indigenous people as wards of the US government. This made theft of land through allotments possible, by declaring that any allotted land not belonging to individuals was unclaimed.

The most infamous and continent-wide allotment act was the Dawes Act of 1887 and was followed two years later by the Nelson Act which was specific to Minnesota (Getches et al. 2011). The Nelson Act dictated that tribal members of the Leech Lake Reservation (LLR) only receive allotments that were non-pine land, allowing the sale of the vast and coveted pine forests to the timber baron with the highest bid (LLBO 2023a). This act also illegally claimed that tribal members could no longer exercise treaty rights to hunt, fish and gather within the Reservation, and instead must follow state laws.

The effects and aftermath of the Nelson Act where so destructive and unjust against the Leech Lake Ojibwe people that the rising tensions culminated in the last battle between a tribe and the US government: the 1898 Battle of Sugar Point on Leech Lake (Duoos 2020). The Ojibwe people won this battle, which garnered nationwide attention, some of which was sympathetic to their struggle. The Federation of Women's Clubs in Minneapolis adopted the cause and, in an attempt to protect what was left of the pine forests of the LLR, helped establish the land as a national forest through the passing of the Minnesota National Forest Act of 1908. The land designated in this act would eventually become known as the Chippewa National Forest (CPF). Unfortunately, persistent lobbying from timber barons, negligence on the part of politicians and subsequent passing of multiple different laws eventually resulted in the loss of over 2,630 km^2 of land, theft of timber sales money from the LLBO and loss of over 95% of the red pine (w*enda-zhingwaak*; *Pinus resinosa*) and white pine (*biisaandago-zhingwaak; Pinus strobus*) forests that still existed when the CPF was established (LLBO 2023a). It wasn't until 1934 that the Indian Reorganization Act halted the sale of allotment land within reservations and restored all un-sold land back to the tribes (Getches et al. 2011).

The LLBO not only battled injustices from federal government, but also from the Minnesota state Department of Natural Resources, who had been illegally enforcing state hunting and fishing laws on tribal members since the passing of the 1889 Nelson Act. In 1971, the LLBO took MN DNR Commissioner Robert Herbst to federal court. The LLBO won this case in part because the US constitution maintains that the treaty contract between the US government and the sovereign government of the LLBO are not and never have been subject to state law. This ruling recognized the LLBO's treaty rights as property rights which eventually resulted in a settlement requiring that the state of Minnesota pay the government of the LLBO 5% of all hunting and fishing license sales (LLBO 2023b). In order to continue receiving this payment, the LLBO must restrain from the commercial harvest of fish and game and must fairly and uniformly enforce a conservation code within LLR boundaries.

Finally, in 1975, the US government granted tribes the authority and autonomy to govern their own affairs with the passage of The Indian Self Determination and Education Assistance Act (Getches 2011). By the following year the LLBO established their Division of Resource Management (DRM), who's current duties are to "enforce fish and game laws, regulate logging, wild rice harvesting, and plant resources, and generally protect the Band's many resources for the use of future generations." The immediacy with which the Leech Lake Band of Ojibwe created this division as soon as they were legally able is a testament to the immense value they place on caring for the land.

Contemporary context: How contemporary legal and social structures affect how LLBO must operate. Within the context of the land and wildlife related to my research, the most prominent contemporary structure affecting how the LLBO must operate is the United States Forest Service (USFS) CPF. The CPF is the largest landholder within the LLR and its borders overlap approximately 90% of the Reservation (LLBO 2023b). Since its inception, the CPF's history of management priorities and relationship with the LLBO and DRM employees have been constantly evolving. The history of this relationship has deeply affected the forests, lands, wildlife, and human community of the LLR, and has been the source of multiple studies (McEvoy et al. 2004, Bussey et al. 2016).

The CPF is managed under the larger USFS, which is an agency of the US federal government. All federal agencies are mandated by executive order to engage in government-to-government relationships with tribes and adhere to criteria that honors treaty rights, defers to tribes in establishing standards, and engages in meaningful consultation with regards to decisions that have tribal implications (Executive Office of the President 2000). Beyond adhering to this order, litigation has guaranteed that 1855 treaty rights to hunt, fish and gather on lands that the CPF hold title to within the borders of the LLR are property rights of LLBO tribal members (LLBO vs. Herbst 1973). Legal obligation does not always result in meaningful consultation, however. LLBO tribal members have expressed that the forests seem to be managed solely for the benefit of timber harvesting and not for tribal members to exercise treaty rights (McEvoy et al. 2004). Indeed, allowable sale quantities of timber harvest (ASQ) that the USFS has listed for the CPF is at a higher rate than most other forests in the US, and substantially higher than any other in the region (USFS 2010, LLBO 2023b).

There exists a legacy of unequal power dynamics between Indigenous communities and natural resource agencies (Nadasdy 1999, Riddell et al. 2017, Hernandez 2022). Despite a plethora of research defending the rigor of TEK (Baker 1996, Kawagley et al. 1998, Housty et al 2014, Hernandez 2022), collaborative suggestions offered by the Indigenous community are often dismissed if they do not conform to the Western Scientific paradigm (Bengston 2004, Bussey 2016). A series of interviews conducted with CPF and LLBO DRM employees in 2016 (Bussey) quote anonymously affiliated employees as saying: “We consult with the elders and the forest service has ignored advice from elders because the elders are not giving scientific advice”, and “What [species] are [tribal members] gathering? We look at a map and we know what is out there. That’s a difference. [Tribal members] assume what’s out there. We know. We have GIS [geographical information systems] and do inventory.” The Interviewees admit that despite energy put towards incorporating TEK into management decisions, the reality seems to be that the ultimate goal of the CPF is to “get the timber out” (Bussey 2016).

In 2016 LLBO Chairwoman Carri Jones wrote a letter to the US Forest Service Chief Tom Tidwell declaring that the current timber harvest levels are “unsustainable and are having significant negative effects on Tribal Trust Resources”, describing how USFS overharvesting has transformed much of the forest of the Reservation into biologically simple monotypic red pine plantations and aspen (*azaadiwag; Populus spp.*) stands that don’t support the diversity of wildlife and plants “that have been important to our culture” (LLBO 2023b). She made a point to state that the CPF staff that they work directly with are conscientious and “want to do the right thing” but that they struggle to provide for the interest of the LLBO members because of the USFS’s pressure on them to meet unrealistic timber harvest targets laid out in the Forest Management Plan (USFS

2004). The letter requested the creation of a new management plan, stating that the high harvest goals within the current plan are not sustainable (LLBO 2023b).

Tidwell, however, responded by declining this request and instead recommended the creation of a Memorandum of Understanding (MOU; 2018) between the CPF and the LLBO that laid out objectives for future consultation. Tidwell explicitly listed within these objectives that the CPF was to achieve the appropriate balance of resources on national forest land within the LLR to sustain Ojibwe lifeways, and that the CPF was to "use any TEK offered by the [LLBO]", but only in the context of achieving "desired forest conditions described in the [Forest Management Plan]" (USFS 2004, LLBO 2023b).

In 2019, the Leech Lake Band of Ojibwe Reservation Restoration Act, mandated by congress, transferred 47.6 km^2 back to the LLBO from the CPF, placing the management of these lands solely in the hands of the LLBO. Over time, the LLBO continues to increase their influence on managing the forest in a more holistic manner to meet tribal needs and concerns, this has resulted in increased consultation with the USFS and CPF to better meet treaty obligations.

Cultural context: How to contribute to resilience and cultural revitalization of the community. Revitalizing Indigenous Science and knowledge systems requires us to utilize strategies that aim to dismantle the damaging and lasting effects of colonization on Indigenous communities and knowledge (Chalmers 2017, Ramos 2018). This is especially true in the context of academia. Decolonization strategies include the support of Indigenous language revitalization, the use of equitable terminology, and the use of mixed-method research (Ramos 2018), such as Indigenous research methodologies (IRM). IRM's are general protocols for research conduction within an Indigenous conceptual framework that are unique to place, community, culture, and researcher (Kovach 2021). I explore the decolonization strategies of language revitalization and use of equitable terminology, as well as how I implemented five IRMs: 1) Self locating and positionality, 2) Following tribal protocols, 3) Giving data/results to the community, 4) Building a lasting relationship with the community, 5) Reciprocity and giving back to the community (Lavallee 2009, Kovach 2021, Ramos 2022).

Indigenous language revitalization. It is essential to remember that one of the main reasons for loss of Indigenous languages across north America was the theft of children by settler-colonial missionaries to be put in boarding schools and forced to speak English under threat of abuse (McCarty 2013). Because of this form of cultural genocide, generations of Indigenous language speakers were lost. This is part of why the use of Indigenous language can be seen as a decolonization strategy. Language influences how we observe and interpret the world which in turn influences the structures and cultures of our society (Whorf 1956, Trudgill 2000). The origins of languages are specific to and interactive with their local environments and are therefore reflective of the detailed minutia of those ecosystems (Loh et al. 2005). Indeed, where linguistic and cultural diversity occurs, so too does biological diversity (Maffi 2005, Toledo 2014). A broad perceptual scope translates to a broad scope of use, with Indigenous communities tending to use, value and protect more species than non-Indigenous communities (Battiste and Youngblood Henderson 2000).

As the English language has dominated the linguistic landscape of North America, so too has it dominated what the predominant society perceives and values. Despite English being my first language and the language through which I feel I can best express myself and my thoughts, there remain aspects of the English language that are conceptually limiting not only to me personally, but also through an Indigenous kincentric worldview (Salmon 2000, Kimmerer 2014, Bhattacharyya 2017). In English it is proper to objectify all non-human beings using pronouns such as 'it', or names such as 'natural resource', effectively robbing them of their animacy and distancing ourselves from them in our psyches. This language enables a positivist approach to knowledge generation that privileges objectivity and neutrality in the relationship between researched (object) and researcher (subject). The Western epistemology perceives the positivist approach as the universal method of generating knowledge (Elshakry 2010, Shipley and Williams 2019), the credibility of which stems from its reliance on objectively observing and measuring the physical world while dismissing subjective experiences and values. The concept of objectivity still permeates the practices of Western Science generation despite research finding that it is a social construct rather than an attainable position (Daston 1992).

In many Indigenous languages, pronouns are either animate or inanimate, rather than gender-specific. In Anishinaabemowin, *waabooz* is animate, and cannot be referred to as 'it' (Lucio 2023). Animate pronouns are used often to refer to non-human living beings as well as other non-living things. As Potawatomi scholar Kimmerer (2014) explains, using animate pronouns requires the speaker to perceive much of the world around them as not only alive, but as relatives, as kin. This relationship fosters ethical reciprocity on the part of the researcher which holds them accountable to and requires that they acknowledge a responsibility to care for and give back to those (human and non-human) involved in the research (Bhattacharyya and Slocombe 2017). I am reminded of my grandma who often referred to non-human beings as ‘she’. Despite her use of the English language, her use of terminology that wasn’t necessarily gender specific, but life-affirming, contributed to a perceptual shift in both her worldview and that of whomever was listening.

In my research project, I often battled with where and how to use Anishinaabemowin. Like many Indigenous languages, Anishinaabemowin is a verb-based language, rather than a noun-based language such as English, it is therefore difficult to directly translate concepts. I also have a very limited grasp of Anishinaabemowin, and I function within an institution and society which is dominated by the English language. Most LLBO Band members, including the DRM employees whom I worked with, speak English as their dominant language. However, Anishinaabemowin is spoken fluently by many Band members, for some of whom it is their first language. Anishinaabemowin is also spoken frequently at community events such as powwows, gatherings, and ceremonies. Anishinaabemowin is taught in schools throughout the LLR and surrounding area and Anishinaabemowin words and phrases are used often on signs, in greeting, and for names throughout the community. With this in mind, I chose to use English as the dominant language of my writing but to use Anishinaabemowin interchangeably for names. I also chose to use Anishinaabemowin to introduce myself, to show respect to the ancestors and to establish trust by allowing the community to locate me through name, kinship and place (Kovach 2021).

Equitable terminology. The use of language as well as equitable terminology reflects cultural sensitivity that begins to shift the worldview of the beholder in a more holistic and equitable way. There has been a hesitation within the Western Scientific community to use equitable terminology, born of epistemological differences that TEK does not constitute legitimate science (Warwick 2010, Bussey 2016). Indigenous scholar Hernandez (2022) argues that use of 'TEK' is suggestive of knowledge that is static and positioned in history and that we should instead use a term more representative of its adaptive rigor such as Indigenous Science. There is also growing research finding that natural resource managers are far more likely to make management decisions based on opinion, intuition, or inter-personal communications than they are to make decisions based on empirical evidence. (Forsythe 2003, Sutherland et al. 2004, Fabian et al. 2019). This kind of 'evidence complacency' (Kadykalo et al. 2021) is likely a result of socio-cultural or ethical values influencing decisions, contradicting the positivist positionality necessary to the practice of Western Science (Forsythe 2003). It would therefore be hypocritical of natural resource managers to deny the application of TEK based on its lack of adherence to positivism. On the other hand, at least within the natural resources field, perhaps a more appropriate term would be Western Ecological Knowledge (WEK), already in use by some scholars (Ramos 2016). We must also consider that much of what is considered legitimate science through the Western Scientific word-view was a result of 'helicopter science' that pirated the contributions of Indigenous peoples and lands without accreditation, consent or respect to data sovereignty (Kimsey 2012, Rochmyaningsih 2018, Haelewaters et al. 2021). Indigenous data sovereignty refers to the "right of Indigenous peoples to control data from and about their communities and lands, articulating both individual and collective rights to data access and to privacy" (Raine et al. 2019). The frequency of helicopter science exploitation has even resulted in some Indigenous governments issuing public statements against it (Cherokee Institutional Review Board 2023).

There is clearly a desire from the Western Science community to access the knowledge of Indigenous Scientists and TEK holders. Bridging Indigenous Science and Western Science in a way that is ethical and mutually beneficial requires the use of terminology that places them on equal footing. Using terminology such as 'braiding' or 'weaving' avoids exploitive connotations suggestive of Western Science being the dominant paradigm into which Indigenous Science is 'integrated' or 'incorporated' (Johnson et al. 2016, Reid et al. 2021). The equitable weaving together of knowledges must also present citations of unrecorded oral teachings from Indigenous Elders and Knowledge Keepers within Western academia alongside written publications in an equally valid way. Though templates have not yet been recommended for every institutional citation style, scholars have recently presented templates for proper and equitable citation of orally-transmitted knowledge within scholarly publications (MacLeod 2021). This recommended practice acknowledges that rigorously maintained oral teachings of Elders and Knowledge Keepers within Indigenous communities are unique from personal communications and should be referenced accordingly. I have adapted the recommended practice outlined by MacLeod (2021) to suit the citation style of this Thesis.

The power behind weaving together Indigenous Science and Western Science comes from recognizing both of their unique and legitimate strengths and limitations, sometimes referred to as 'two-eyed seeing' within the wildlife research community (Kutz 2019, Reid et al. 2021). *Niizhoo-gwayakochigewin* is an Anishinaabemowin term which refers to blending these ways of knowing together in a culturally specific way and translates closely to 'two ways of doing the right thing in the right way.' This name holds both ways of knowing equally, and firmly places them on a path and purpose of right-ness, but what is right remains undefined. *Niizhoo-gwayakochigewin* not only directed me as a researcher to do right*,* but to be right*.*

Mixed-method Research: Indigenous Research Methodologies & Implementation.

1) Self-locating & positionality. Presented in the Prologue at the beginning of this chapter – an introduction of self, intentions, and position as a researcher. This helps to maintain relational accountability. An introduction may also be considered a cultural protocol.

2) Following tribal protocols. All of my research was conducted in collaboration with the DRM, who issued me research permits for collecting data (Appendix B) that I carried with me while in the field. I followed cultural protocols in the field as instructed by elders and LLBO tribal community members to provide gifts of *asemaa* (tobacco) and food to the land, trees and animals, and to feast to the animals that I studied, to speak to them and tell them my intentions and to ask for their support in sharing their stories with me. *Asemaa* is considered sacred in many Indigenous communities and is given when intending to request knowledge in a good and respectful way (Lavalee 2009).

3) Giving of data to the community (human and non-human). All data and research will be placed on hard drives and shared privately with both BSU and the LLBO

DRM. The LLBO will have sole authority in disseminating culturally significant data to the community appropriately and with respect to data sovereignty. This thesis will be publicly published and shared physically/individually with any community members who request it. Where applicable and desired, credit will be given to contributing community members. I will also use the results of my research with *waaboozoog* and their needs to inform my decisions in stewarding my own land and creating habitat for them where I am able. In this way I intend to share my research with my non-human community.

4) Building a lasting relationship with the community (human and non-human). This research directly effects the land that I consider my home and the people I consider my community. In contrast to researchers engaging in extractive helicopter science, I am a resident of the LLBO Reservation and have been an active member of the local community for years before considering conducting this research. During my research I worked closely with DRM employees and consulted with tribal members, some of whom are life-long friends or family members. I have been and will continue to snare *waaboozoog* for food and fur, however, knowing what I know now will affect my decisions in when, where and how frequently I will set snares. Interacting in this way with *waaboozoog* helps me feel an ethical responsibility to care for them and the habitat they need. *Waaboozoog* helps me strengthen my human community when I share their fur and meat with others.

5) Reciprocity and giving back to the community (human and non-human). My intention is that through the inclusion of the decolonization strategies illustrated in this chapter, I have worked toward participating in a generation of knowledge that has been reciprocal rather than simply data driven and extractive. This collaborative and tribally directed research project began at the behest of the community, the results of which will be utilized by the LLBO DRM to use as they see fit in making management decisions that benefit *waaboozoog* and the ecosystems they are a part of, and in doing so will benefit tribal members and support treaty rights.

My Research

For the LLBO, *waabooz/*snowshoe hare have historically been, and continue to be, a culturally significant animal and an important food and fur source. A traditional Anishinaabe *aadizookaan* (legend) describes *waabooz* as saying "I will sense when the Anishinaabe is struggling to find food to eat. I will not go anywhere. Whenever I see a round snare, that is where I will put my head. That is how much I care about the Anishinaabe" (Panci et al. 2018). It is through honoring TEK that my research project exists at all; the observations of elders and community members that *waabooz* populations were declining below their normal cyclic variation was the impetus behind the DRM beginning their initial research, and consequently collaborating with BSU on the research outlined in this thesis (LLBO 2010). After multiple years of research, the DRM found that the most influential factor in snowshoe hare density was change in forest structure that resulted in a lack of adequate woody debris for cover from predators. They found that that 91% of all snowshoe hare mortalities were caused by predation (LLBO DRM 2018). Suspected predators of *waaboozoog* included *waabizheshiwag/*martens, *ojiigag*/fishers, and *gidagaa-bizhiwag/*bobcats, among others (unpublished data, LLBO DRM). The distribution and habitat use of *waabizheshiwag*, *ojiigag,* and *gidagaa-bizhiwag* were of particular interest to the LLBO because of their reliance on *waaboozoog.* In the Great Lakes Indian Fish & Wildlife Commission's 2018 Climate

Change and Vulnerability Assessment (Panci et al. 2018), *waaboozoog* are described as extremely vulnerable, and the LLBO DRM list *waaboozoog, waabizheshiwag* and *ojiigag* as species of management concern. Additionally, regional data from across northern Minnesota indicates low or declining populations for *waaboozoog*, *waabizheshiwag* and *ojiigag* (Erb 2019). Notably, *gidagaa-bizhiwag* were excluded from these lists. Of particular interest to the DRM was how *waaboozoog, waabizheshiwag, ojiigag,* and *gidagaa-bizhiwag* interacted with *giizhikag* (northern white cedar*; Thuga occidentalis*) stands, which the DRM had identified as being one of few habitats with enough cover for *waaboozoog* to escape predation.

My research objective was to assess spatial distribution, environmental interactions, and co-occupancy of *waaboozoog, waabizheshiwag, ojiigag* and *gidagaa-bizhiwag* through snow track surveys and camera trapping. Of particular interest to me was the use of wildlife tracking and its corresponding utilization of TEK. Wildlife tracking has been and still is utilized by Indigenous peoples across the world to expertly identify and interpret behavior of wildlife, notably down to the individual, with up to 100% accuracy (Stander et al. 1997, Zuercher et al. 2003). Practical applications of wildlife tracking continue to be through hunting and trapping, and my early lessons in wildlife tracking came from the trapping oriented TEK teachings of my grandpa Leroy and other community members. These teachings were primarily in the form of stories which included lessons about which furbearers lived around us, their habits, size, locomotion, how to successfully capture or kill them and how to process their meat and fur. Context clues such as habitat, micro-habitat, gait, and substrate as well as an understanding of animal behavior are essential pieces of information to consider when correctly identifying wildlife track and sign. Consequently, these early TEK teachings inspired me to grow and maintain a practice of wildlife tracking through trapping, hunting, and as an internationally recognized certified level IV wildlife tracker within northern Minnesota (Tracker Certification CyberTracker North America 2023). The non-invasive methodological nature of both snow-tracking and camera trapping felt vital to me as I collaborated in designing a research project that respected the non-human personhood of the beings I intended to study. Based on prescriptions from my community, I prepared myself to engage in this relationship by taking part in cultural protocols involving gifts and introducing myself and my intentions to the beings I was to engage with and ask for help from. To the best of my ability, I conducted my research with *nizhoo-gwayakochigewin*. To do the right thing in the right way involved many tangible and intangible elements that I have explored in this chapter, and some which I have intentionally omitted out of respect for Indigenous data sovereignty. The in-depth detailed quantitative results and analyses of this research are detailed in the following chapters of this thesis.

I found that *waaboozoog*/snowshoe hare depend heavily on the presence of *giizhikag*/cedar stands, which exist in small and scattered patches throughout the LLR, making up just 1.9% of the landcover. Despite the scarcity of *giizhikag* stands, I detected *waaboozoog* at camera traps located within *giizhikag* stands 84% of the time. Additionally, If the distance to a *giizhikag* stand was further than 2 km, the probability of *waaboozoog* occurrence dropped off precipitously, suggesting that *waaboozoog* populations are becoming isolated within pockets of high-quality habitat that they cannot expand out from. While I did not find any association between *giizhikag* stands and *waabizheshi/*marten*, ojiig/*fisher*,* or *gidagaa-bizhiw/*bobcat occupancy, I did detect substantial overlaps between the daily activity patterns of these predators and that of *waaboozoog;* indicating that *waaboozoog* is an important prey animal for these predator species (Brown et al. 2001, Barrull et al. 2013). I also found that *waaboozoog* occupancy and predator diversity were positively correlated, supporting previous studies finding *waaboozoog* have a disproportionate effect on the health and biodiversity of the ecosystems they inhabit (O'Donoghue et al. 1998, Krebs et al. 2001).

The historic management emphasis on timber production within the LLR and the resulting density and distribution of roads and vegetative cover were consistently important predictors of occurrence for *waaboozoog, waabizheshiwag, ojiigag,* and *gidagaa-bizhiwag.* I found that the occurrence of *waaboozoog, waabizheshiwag* and *ojiigag* were all negatively associated with road density and/or distance to snow-plowed roads and positively associated with dense vegetative or canopy cover, but that the occurrence of *gidagaa-bizhiwag* were positively associated with snow-plowed roads and open canopy cover. My research revealed patterns of avoidance between *gidagaa-bizhiwag* and other predator species, especially *ojiigag,* who *gidagaa-bizhiwag* will occasionally prey on (Erb and Sampson 2016). Unlike *waaboozoog/*snowshoe hares and *waabizheshiwag/*martens*,* neither *ojiigag/*fishers nor *gidagaa-bizhiwag/*bobcats are snow adapted species, which restricts the territories that they can easily travel through during winter. Snow adaption and unfragmented landscapes of deep snow facilitate spatial segregation between competitive species. However, the human activities of snow clearing and compaction may promote territorial expansion of lesser snow-adapted species into otherwise inaccessible areas while decreasing habitat for snow-adapted species (Marrotte et al. 2020).

I found *bizhiw/*Canada lynx tracks twice, both on the northernmost transect and within *giizhikag* stands. *Bizhiwag* are snow adapted specialist predators of *waaboozoog,* with large fur covered feet that can splay up to 14.3 cm wide. By comparison, *gidagaa-bizhiw/*bobcat tracks can splay up to 7.6 cm wide. *Bizhiwag* have historically been common throughout northern Minnesota, however their range has contracted by 40% within the last century (Laliberte and Ripple 2004), and are now rare within the LLR. *Bizhiwag* are federally endangered, threatened within the state of Minnesota, a culturally significant animal to the LLBO and listed as endangered on the LLBO's list of *Threatened, Endangered, Sensitive and Management Concern Species.* Research suggests that *bizhiwag* may actively avoid *gidagaa-bizhiwag* presence (Scully et al. 2018), however, spatial segregation exhibited between these species is most likely a result of *gidagaa-bizhiwag* expanding into areas already unoccupied by *bizhiwag* following the effects of human activity and climate change on forest structure, *waaboozoog* presence, and snow conditions (Parker et al. 1983, Marrotte et al. 2020). During an interview of both CPF and DRM employees in 2016, one interviewee expressed their awareness and disappointment for the reason why *bizhiw/*lynx populations were so low: "A [biologist] told me that there are no lynx here anymore. That's very disturbing because [the lynx] is a very important being for us spiritually. Why does the lynx have to be gone? So it's very complex to think about that and how to consider those values and spirituality and try to balance that with the economic drivers" (Bussey 2016). The historically dominant presence of *bizhiwag* and secondary presence of *gidagaa-bizhiwag* on this landscape is also evident in the Anishinaabemowin name for bobcat: *gidagaa-bizhiw,* which translates to ‘spotted lynx’.

Conclusion

Fundamentally, as humans, we are only capable of observing our reality at a scale (spatial, temporal, metaphysical) we can comprehend, which leads us to impose our perceptual bias to the greater reality (Levin 1992). And in this sense, we tend to arbitrarily impose domains of pre-conceived scale on the often-inconceivable complex variation in nature (Wiens 1989). We are aware that a forest’s temporal scale is centuries long, and yet we attempt to manage entire forested ecosystems within the temporal scale of our humanness: decades at the most. Theoretically, to mediate the problem of scale, Management Plans should be created at the scale of the forests, which would be over centuries, with an extent that encompasses the entire ecosystems, and with a scale of conceptual complexity capable of adaptation to constant change. However, this management scale likely doesn’t support the predominant infrastructure of human economic dependencies on natural resources. The ecosystems within the LLR that existed under the formation of contemporary Management Plans by federal, state and county agencies have changed, and so with them the needs of management. Constantly changing ecosystems need adaptive management plans reflective of their complexity (Rammel et al. 2006). However, the implementation of adaptive management requires relinquishing the ‘command and control’ pathology that has plagued the natural resource management field (Holling and Meffe 1996). As Holling and Meffe (1996) explain, “The purpose [of command and control management] is to turn an unpredictable and ‘inefficient’ natural system into one that produces products in a predictable and economically efficient way.”

The natural ecological controls that this pathology replaces however are largely unknown to us, but the results are clear: loss in biodiversity, genetic variation, and resiliency.

Indigenous societies are often able to successfully manage complex adaptive systems through simple prescriptions based on epistemologies that are typically excluded from Western Science such as spiritual or religious beliefs (Berkes 2009). It can be argued that it is the traditional moral prescriptions involved in human-wildlife relationships that are responsible for the resiliency informative to successful adaptive management (Berkes and Berkes 2009, Reo and Whyte 2012, Kutz and Tomaselli 2019). Inclusion of the metaphysical or intangible aspects of knowing serve to maintain that knowledge generation is reciprocal rather than extractive (Kovach 2021) and are not only appropriate to include within research methodologies but essential (Salmon 2000, Ramos 2018). These prescriptions may foster awareness (*e.g.* offering gifts, asking permission, seasonally aligned rituals) or serve to protect (*e.g*. taboos or prohibitions on harvesting, hunting, interacting with), thereby building, maintaining and generating both relationships with and knowledge of the natural world (Berkes 2009). For the Menominee Nation in Wisconsin, it is adherence to the traditional moral prescription to “keep all the pieces” that has influenced the health of the forests within the reservation to a degree that is now considered a model in sustainable forest management (Trosper 2007).

The contemporary management plans at work within the LLR, and indeed across much of the globe, which prioritize ecosystem control for economic gain at the cost of biodiversity have been succeeding. However, if we aim to sustain and grow biodiverse landscapes (capable of supporting subsistence practices defined in treaties) perhaps it would be more efficient to create new plans altogether, through ‘two-eyed seeing’ or *niizhoo-gwayakochigewin;* plans that weave together both Western Science and TEK of Indigenous peoples (4% of human population) who inhabit 18-22% of global land and maintain 80% of earth's biodiversity on that land (World Bank 2003; 2008).

References

Abouelezz, H. G., T. M. Donovan, R. T. Mickey, J. D. Murdoch, M. Freeman, and K. Royar. 2018. Landscape composition mediates movement and habitat selection in bobcats (*Lynx rufus*): implications for conservation planning. Landscape Ecology 33:1301–1318.

Baker, D. 1996. Does 'Indigenous Science' really exist? Australian Science Teachers Journal 42:18–20.

Barrull, J., I. Mate, J. Ruiz-Olmo, J. G. Casanovas, J. Gosàlbez, and M. Salicrú. 2013. Factors and mechanisms that explain coexistence in a Mediterranean carnivore assemblage: an integrated study based on camera trapping and diet. Mammalian Biology 79:123–131.

Battiste, M., and J. Youngblood Henderson. 2000. Protecting Indigenous knowledge and heritage: a global challenge. Purich Press, Saskatchewan, Canada.

Bengston, D. N. 2004. Listening to neglected voices: American Indian perspectives on natural resource management. Journal of Forestry 102:48–52.

Berkes, F., and M. K. Berkes. 2009. Ecological complexity, fuzzy logic, and holism in Indigenous knowledge. Futures 4:6–12.

Bhattacharyya, J., and S. Slocombe. 2017. Animal agency: wildlife management from a kincentric perspective. Ecosphere 8:e01978.

Brown, J. S., B. P. Kotler, and A. Bouskila. 2001. Ecology of fear: foraging games between predators and prey with pulsed resources. Annales Zoologici Fennici 38:71–87.

Bussey, J., M. A. Davenport, M. R. Emery, and C. Carroll. 2016. “A lot of it comes from the heart”: the nature and integration of ecological knowledge in tribal and nontribal forest management. Journal of Forestry 114:97–107.

Cherokee Institutional Review Board. 2023. Helicopter Research. https://irb.cherokee.org/media/rkknqeww/helicopter-research.pdf. Accessed 17 Feb 2023.

Chalmers, J. 2017. The transformation of academic knowledges: understanding the relationship between decolonizing and Indigenous research methodologies. Socialist Studies 12:97–116.

Cook, C. N., M. Hockings, and R. W. Carter. 2010. Conservation in the dark? The information used to support management decisions. Frontiers in Ecology and the Environment 8:181–186.

Daston, L. 1992. Objectivity and the escape from perspective. Social Studies of Science 22:597–618.

Duoos, K., 2020. On this day in history: the battle of sugar point. Leech Lake News. https://www.leechlakenews.com/2018/10/05/on-this-day-in-history-the-battle-of-sugar-point/. Accessed 17 Feb 2023.

Elshakry, M. 2010. When science became western: historiographical reflections. Isis 101:98–109.

Erb, J. 2019. Furbearer winter track survey summary. Minnesota Department of Natural Resources, Forest Wildlife Research Group, Minnesota, USA

Erb, J., P. Coy, and B. Sampson. 2016. Survival and causes of mortality for fishers and martens in Minnesota. Minnesota Department of Natural Resources, Minnesota, USA.

Executive Office of the President. 2000. Consultation and coordination with Indian tribal governments. Executive Order 13175 of Nov 6, 2000. https://www.federalregister.gov/documents/2000/11/09/00-29003/consultation-and-coordination-with-indian-tribal-governments. Accessed 17 Feb 2023.

Fabian, Y., K. Bollmann, P. Brang, C. Heiri, R. Olschewski, A. Rigling, S. Stofer, and R. Holderegger. 2019. How to close the science practice gap in nature conservation? Information sources used by practitioners. Biological Conservation 235:93–101.

Forsythe, T. 2003. Critical political ecology: The politics of environmental science. New York, NY: Routledge.

Fortmann, L., and H. Ballard. 2011. Sciences, knowledge, and the practice of forestry. European Journal of Forest Research 130:467–477.

Gadamus, L., J. Raymond-Yajoubian, R. Ashenfelter, A. Ahmasuk, V. Metcalf, and G. Noongwook. 2015. Building an Indigenous evidence-base for tribally-led habitat conservation policies. Marine Policy 62:116–124.

Getches, D., H. Wilkinson, F. Charles, R. A. Williams, and M. L. Fletcher. 2011. Cases and materials on federal Indian law. Sixth edition. West, St. Paul, Minnesota, USA.

Haelewaters, D., T. A. Hofmann, and A. L. Romero-Olivares 2021. Ten simple rules for Global North researchers to stop perpetuating helicopter research in the Global South. PLoS ONE 17:e1009277.

Hernandez, J. 2022. Fresh banana leaves: healing Indigenous landscapes through Indigenous science. North Atlantic Books, Berkeley, California, USA.

Housty, W. G., A. Noson, G. W. Scoville, J. Boulanger, R. M. Jeo, C. T. Darimont, and C. E. Filardi. 2014. Grizzly bear monitoring by the Heiltsuk people as a crucible for First Nation conservation practice. Ecology and Society 19:70.

Iccarino, M. 2003. Western science could learn a thing or two from the way science is done in other cultures. EMBO Reports 4:220–223.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES]. 2019. Global assessment report of the intergovernmental science policy platform on biodiversity and ecosystem services. IPBES secretariat, Bonn, Germany.

Jaeger, L. 2007. Tribal nations and the story of federal Indian law. Tanana Chiefs Conference, Fairbanks, AK.

Johnson, J. T., R. Howitt, G. Cajete, F. Berkes, R. P. Louis, and A. Kliskey. 2016. Weaving Indigenous and sustainability sciences to diversify our methods. Sustainability Science 11:1–11.

Kadykalo, A. N., S. J. Cooke, and N. Young. 2021. The role of western-based scientific, Indigenous and local knowledge in wildlife management conservation. People and Nature 3:610–626.

Kawagley, A. O., D. Norris-Tull, and R. A. Norris-Tull. 1998. The Indigenous worldview of Yupiaq culture: its scientific nature and relevance to the practice of teaching of science. Journal of Research in Science Teaching 35:133–144.

Kimmerer, R. W. 2015. Braiding Sweetgrass. Milkweed Editions, Minneapolis, Minnesota, USA.

Kimsey, L. S., and M. Ohl. 2012. *Megalara garuda*, a new genus and species of larrine wasps from Indonesia (*Larrinae, Crabronidae, Hymenoptera*). Zookeys 177:49.

Kraniak, D. 2015. Conserving endangered species in Indian country: the success and struggles of joint secretarial order 3206 nineteen years on. Colorado Natural Resources, Energy and Environmental Law Review 26:321–349.

Krebs, C. J., S. Boutin, and R. Boonstra. 2001. Ecosystem dynamics of the boreal forest: the Kluane project. Oxford University Press, New York, USA.

Kovach, M. 2021. Indigenous Methodologies. Second edition. University of Toronto Press, Ontario, Canada.

Kutz, S., and M. Tomaselli. 2019. "Two-eyed seeing" supports wildlife health. Science 364:1135–1137.

Laliberte, A. S., and W. J. Ripple. 2004. Range contractions of North American carnivores and ungulates. BioScience 54:123–138.

Lavallee, L. 2009. Practical application of an Indigenous research framework and two qualitative Indigenous research methods: sharing circles and Anishnaabe symbol-based reflection. International Journal of Qualitative Methods 8:21–40.

Leech Lake Band of Ojibwe. 2010. Leech Lake Reservation. Observations by multiple community members of snowshoe hare populations shared with me via the Leech Lake Band of Ojibwe Division of Resource Management, personal communication. 2010.

Leech Lake Band of Ojibwe Division of Resource Management. 2018. Influence of forest structure and composition on the space use and survival of snowshoe hare (Lepus americanus). Annual report. Leech Lake Band of Ojibwe, Cass Lake, Minnesota, USA.

Leech Lake Band of Ojibwe [LLBO]. 2023a. History: Nelson Act 1889. https://www.llojibwe.org/aboutUs/history.html. Accessed 17 Feb 2023.

Leech Lake Band of Ojibwe [LLBO]. 2023b. Materials related to the co-management of the Chippewa National Forest. https://www.llojibwe.org/drm/ads/co_mgmt_booklet.pdf. Accessed 17 Feb 2023.

Leech Lake Band of Chippewa Indians vs. Robert L. Herbst. 1973. United States District Court District of Minnesota Third Division. https://www.llojibwe.org/drm/ordinances/LLBO%20VS.%20Herbst%20(June%201973)%20B-1.pdf. Accessed 17 Feb 2023.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology 73:1943–1967.

Loh, J., and D. Harmon. 2005. A global index of biocultural diversity. Ecological Indicators 5:231–241.

Lucio, V. 2023. Naicatchewanin First Nation. Treaty 3. Lives in the Leech Lake Reservation, Cass Lake, MN. First language speaker oral teaching. Personal communication. 24 March 2023.

MacLeod, L. 2021. More than personal communication: templates for citing Indigenous elders and knowledge keepers. KULA: Knowledge Creation, Dissemination, and Preservation Studies 5:1.

Maffi, L. 2005. Linguistic, cultural, and biological diversity. Annual Review of Anthropology 29:599–617.

Marrotte, R. R., J. Bowman, and S. J. Morin. 2020. Spatial segregation and habitat partitioning of bobcat and Canada lynx. FACETS 5:503–522.

McCarty, Teresa L. 2013. Language planning and policy in Native America. Multilingual Matters, Buffalo, New York, USA.

Memorandum of Understanding [MOU] Between the USDA Forest Service Chippewa National Forest And the Leech Lake Band of Ojibwe of the Minnesota Chippewa Tribe. 2018. Federal Register of July 23 83:34865.

Morin, S. J., J. Bowman, R. R. Marrotte, and M. Fortin. 2020. Fine-scale habitat selection by sympatric Canada lynx and bobcat. Ecology and Evolution 10:9396–9409.

Nadasdy, P. 1999. The politics of TEK: power and the ‘integration’ of knowledge. Arctic Anthropology 36:1–18.

McAvoy, L., P. Shirilla, and J. Flood. 2005. American Indian gathering and recreation uses of National Forests. Proceedings of the 2004 Northeastern Recreation Research Symposium. Gen. Tech. Rep. NE-326. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 81–87.

O’Donoghue, M., S. Boutin, C. J. Krebs, D. L. Murray, and E. J. Hofer. 1998. Behavioral responses of coyotes and lynx to the snowshoe hare cycle. Oikos 82:169–183

Panci, H., M. Montano, A. Schultz, T. Bartnick, and K. Stone. 2018. Climate change vulnerability assessment. Great Lakes Indian Fish and Wildlife Commission Version 1, Odanah, Wisconsin, USA.

Parker, G. R., J. W. Maxwell, L. D. Morton, and G. E. Smith. 1983. The ecology of the lynx (*Lynx canadensis*) on Cape Breton Island. Canadian Journal of Zoology 61:770–786.

Popp, J. N., P. Priadka, and C. Kozmik. 2019. The rise of moose co-management and integration of Indigenous knowledge. Human Dimensions of Wildlife 24:159–167.

Rainie, S. C., T. Kukutai, M. Walter, O. L. Figueroa-Rodríguez, J. Walker, and P. Axelsson. 2019. Issues in open data: Indigenous data sovereignty. Pages 300–319 *in* T. Davies, S. Walker, M. Rubinstein and F. Perini, editors. The state of open data: Histories and horizons. African Minds and International Development Research Centre, Cape Town, South Africa and Ottawa, Ontario, Canada.

Rammel, C., S. Stagl, and H. Wilfing. 2006. Managing complex adaptive systems – a co-evolutionary perspective on natural resource management. Ecological Economics 63:9–21.

Ramos, S. C. 2016. Hlkelonah ue meygeytohl: Traditional Ecological Knowledge in wildlife conservation and an interdisciplinary approach to culturally sensitive research with the Yurok Tribe. Dissertation, University of Arizona, Tucson, USA.

Ramos, S. C. 2018. Considerations for culturally sensitive traditional ecological knowledge research in wildlife conservation. Wildlife Society Bulletin 42:358–365.

Ramos, S. C. 2022. Understanding Yurok traditional ecological knowledge and wildlife management. The Journal of Wildlife Management 86:e22140.

Reid, A. J., L. E. Eckert, J. F. Lane, N. Young, S. G. Hinch, C. T. Darimont, S. J. Cooke, and N. C. Ban. 2021. 'Two-eyed seeing': An Indigenous framework to transform fisheries research and management. Fish and Fisheries 22:243–261.

Reo, N. J., and K. P. Whyte. 2012. Hunting and morality as elements of traditional ecological knowledge. Human Ecology 40:15–27.

Riddell, J. K., A. Salamanca, D. J. Pepler, S. Cardinal, and O. McIvor. 2017. Laying the groundwork a practical guide for ethical research with Indigenous communities. International Indigenous Policy Journal 8:6.

Rochmyaningsih, D. 2018. Study of 'sea nomads' under fire in Indonesia. Science 361:318–319.

Roos, C. I., T. W. Swetnam, T. J. Ferguson, M. J. Liebmann, R. A. Loehman, J. R. Welch, E. Q. Margolis, C. H. Guiterman, W. C. Hockaday, M. J. Aiuvalasit et al. 2021. Native American fire management at an ancient wildland-urban interface in the southwest United States. PNAS 118:4 e2018733118.

Salmon, E. 2000. Kincentric ecology: Indigenous perceptions of the human-nature relationship. Ecological Applications 5:1327–1332.

Scully, A. E., S. Fisher, D. A. Miller, and D. H. Thornton. 2018. Influence of biotic interactions on the distribution of Canada lynx (*Lynx canadensis*) at the southern edge of their range. Journal of Mammology 99:760–772.

Shipley, G. P., and D. H. Williams. 2019. Limitations of the western scientific worldview for the study of metaphysically inclusive peoples. Open Journal of Philosophy 9:295–317.

Stander, P. E., L. //. Ghau, D. Tsisaba, //. ≠Oma, and |.| Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Sutherland, W. J., A. S. Pullin, P. M. Dolman, and T. M. Knight. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution 19:305–308.

Tracker Certification CyberTracker North America. 2023. Tracker Certification home page. https://trackercertification.com/. Accessed 3 Mar 2023.

Toledo, V. M. 2013. Indigenous peoples and biodiversity. Pages 269–279 *in* S. A. Levin, editor. Encyclopedia of biodiversity. 2nd ed. Academic Press.

Trudgill, P., 2000. Sociolinguistics: An introduction to language and society. Penguin Books, London, United Kingdom.

The Constitution of the United States: A Transcription. Article VI [U.S.C. VI]. U.S. National Archives and Records Administration. https://www.archives.gov/founding-docs/constitution-transcript#6. Accessed 17 Feb 2023.

Why Treaties Matter. 2013. Why treaties matter: self-government in the Dakota and Ojibwe nations. Chippewa National Forest. Educator Guide for Grades 6–12. Appendix A. http://treatiesmatter.org/exhibit/wp-content/uploads/2017/09/The-Chippewa-National-Forest.pdf. Accessed 17 Feb 2023.

United States Forest Service [USFS]. 2010. Chippewa National Forest. Five year forest plan and monitoring and evaluation report. https://www.fs.usda.gov/detail/chippewa/landmanagement/planning/?cid=stelprd3793083. Accessed 15 Feb 2023

United States Forest Service [USFS]. 2004. Chippewa National Forest. 2004 Forest Plan. https://www.fs.usda.gov/detail/chippewa/landmanagement/planning/?cid=fsm9_016569. Accessed 17 Feb 2023.

Warwick, D. 2010. The titi project, traditional ecological knowledge and science: a critique. Journal of the Royal Society of New Zealand 40:39–43.

Whorf, B.L. 1956. Language, thought, and reality: selected writings. Technology Press of Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.

Wiens, J. A. 2009. Landscape ecology as a foundation for sustainable conservation. Landscape Ecology 24:1053–1065.

World Bank. 2003. Implementation of operational directive 4.20 on Indigenous peoples: an independent desk review. World Bank, Washington, DC, USA.

World Bank. 2008. Social dimensions of climate change: workshop report. World Bank, Washington, DC, USA.

Zuercher, G. L., P. S. Gipson, and G. C. Stewart. 2003. Identification of carnivore feces by local peoples and molecular analyses. Wildlife Society Bulletin 31:961–970.

Chapter 2: Occupancy Using Snow-tracking Survey Observations of Snowshoe Hare, American Marten, Fisher, Bobcat and Other Predators

Introduction

Snowshoe hares have a disproportionate effect on the ecosystems they inhabit, qualifying them as a keystone species (Keith and Cary 1991, Mills et al. 1993, O'Donoghue et al. 1998, Krebs et al. 2001). Their populations follow 9–11-year cycles which include periods of relatively low abundance persisting for 2–4 years (Keith 1963, Keith and Windberg 1978, Krebs et al. 2001). However, in northern Minnesota beginning in 1994, there have only been subtle signs of a cycle in the first few years of each decade (Erb 2019). For the Leech Lake Band of Ojibwe (LLBO), who's Reservation is located in north-central Minnesota, snowshoe hares (w*aaboozoog; Lepus americanus*) have historically been and continue to be a culturally significant animal and an important source of food and fur for tribal members. Snowshoe hares are also an important prey animal for multiple culturally significant mammalian predators within the Reservation including American martens (*waabizheshiwag; Martes americana*), fishers (*ojiigag; Pekania pennanti)* and bobcats (*gidigaa-bizhiwag; Lynx rufus*; Raine 1987, Litvaitis et al. 1986, Kuehn 1989, unpublished data, LLBO Division of Resource Management [DRM] 2018). Understanding the spatial distribution and habitat use of snowshoe hares, martens, fishers, and bobcats is critical to informing wildlife management and monitoring decisions. However, monitoring multiple species over a large geographic area can be challenging for agencies with limited resources (*e.g.* labor, finances, equipment; Noon et al. 2012), which in turn limit potential research methodologies.

Recognizing and utilizing culturally sensitive methodologies is essential for wildlife researchers wishing to engage in ethical and equitable collaboration with Indigenous communities in a manner that respects their unique epistemologies, independent governments, and culture (Ramos 2018). Many Indigenous cultures recognize the natural elements of an ecosystem as non-human person relatives (Salmon 2000, Bhattacharyya and Slocombe 2017), indicating that use of methodologies that are non-invasive, involve traditional ecological knowledge (TEK) and follow the specific cultural protocols of the community (*e.g.* asking permission, offering *asemaa*, feasting) should be applied whenever possible and with appropriate guidance from community members. Wildlife tracking has been and still is utilized by Indigenous communities across the world to expertly identify and interpret behavior of wildlife, notably down to the individual, with up to 100% accuracy (Stander et al. 1997, Zuercher et al. 2003). Especially in areas with reliable substrate such as persistent snow cover, tracking is a resource efficient and reliable method for detection of rare carnivores with detection probability rates comparable to that of other non-invasive monitoring techniques such as aerial surveying or camera trapping (Zielinksi and Kucera 1995, Stander et al. 1997, Pirie et al. 2016, Clare et al. 2017, Keeping et al. 2018). Snow-track surveys can be conducted on foot in terrain inaccessible by motor vehicles, which allows for surveys to be conducted in remote and/or rugged terrain while avoiding the potential of biasing observation data of species who avoid human disturbance.

Population trends for wide-ranging, cryptic species such as martens, fishers, and bobcats can be difficult to accurately monitor without accounting for low detection probability and the inability to completely survey a large study area. Occupancy modeling (MacKenzie et al. 2002) addresses such considerations by incorporating detection variables and repeated surveying of selected sites representative of the larger study area. Occupancy is the probability that a site is being used by a species and can reveal information about probability of occurrence and detection, distribution, and habitat selection (MacKenzie et al. 2002, MacKenzie and Royle 2005). Presence-absence data required for occupancy modelling can be collected through non-invasive, indirect observation indices of the species (*e.g.*, tracks and sign/spoor). I examined the unique ecologies of snowshoe hares, martens, fishers and bobcats when selecting site covariates to be considered within single-species occupancy models.

Snowshoe hares require habitat with areas of dense visual cover for protection from predators (Gigliotti and Diefenbach 2018, LLBO DRM 2018), and are less associated with vegetative species composition as they are with vegetative structure (Litvaitis et al. 1985, Fuller and Harrison 2013). As a result, their presence is negatively associated with canopy closure due to lack of forest floor light stimulating thick undergrowth (Orr and Dodds 1982, Fuller and Harrison 2013).

Martens exhibit a preference for mature conifer stands, lowland conifers, and canopy closure (Bull et al. 2005, Manlick et al. 2017), and will avoid areas of human activity such as logging roads (Robitaille and Aubry 2000). Martens are snow-adapted with large fur-covered feet which allow them to travel over deep snow (Krohn et al. 2005), but will also tunnel into the subnivean to hunt, rest, and evade predators (Bissonette et al. 1997, McCann et al. 2010, Pauli et al. 2013). In areas where snowshoe hares are common, they constitute a substantial portion of the diet of martens (Raine

1987). Martens may alter population demographics in response to food availability, even delaying breeding by up to a year (Thompson and Colgan 1987).

Similar to martens, fisher occupancy is associated with lowland and mixed conifer forest, canopy cover, and low road density (Fuller et al. 2016, Linden et al. 2017, Manlick et al. 2017). Snowshoe hares also make up a substantial portion of the diet of fishers where they are common, but fishers do not display numeric responses to snowshoe hare populations, relying on other sources of prey, such as squirrels, and maintaining body weight when snowshoe hare populations decline (Kuehn 1989). Unlike martens, fishers are less snow-adapted, with smaller feet in comparison to their body size, resulting in a heavier foot-fall (Krohn et al. 2005). Juvenile and adult fishers are occasionally preyed on by bobcats, with whom they compete for similar prey and habitat (Erb et al. 2016).

Bobcat occupancy is associated with areas of lowland forest, non-forested wetland, wetland edge, and snowshoe hare presence (Litvaitis et al. 1986, Preuss and Gehring 2007, Morin et al. 2020). Bobcats use paved and unpaved roads and streams disproportionately to their availability on the landscape (Abouelezz et al. 2018) but avoid traveling in areas of deep snow and sinking depth as they are not snow-adapted (Morin et al. 2020).

My objective was to assess spatial distribution, environmental interactions, and occupancy of snowshoe hares, martens, fishers, and bobcats using a single-species occupancy modeling framework. I developed several hypotheses for species-specific habitat/occupancy relationships: snowshoe hare occupancy would be positively correlated with dense vegetative cover and negatively correlated with human activity and predator presence; marten occupancy would be positively correlated with conifer forests, closed canopy, and snowshoe hare presence and negatively correlated with human affects and fisher presence; fisher occupancy would be positively correlated with conifer forests and closed canopy and negatively correlated with human affects and bobcat presence; bobcat occupancy would be positively correlated with conifer forests, wetland edge, and road density and would have no correlation with canopy cover density.

Study Area

I conducted my research within the boundaries of the 3,518 km^2 Leech Lake Reservation (LLR; *Gaa-zagaskwaajimekaag*) in northern Minnesota, covering portions of Beltrami, Cass, Hubbard and Itasca counties (47.3654, -94.3462; Figure 2.1). The LLR straddles the transition zone between the Great Lakes temperate deciduous forests and the Canadian taiga. It includes deciduous forest (25.6%), wetlands (26.4%), open water (29.1%), coniferous and mixed forest (11.8%), shrub/scrub (1.6%) and northern white cedar (g*iizhik; Thuja occidentalis*) stands (1.9%; Dewitz 2021) with a combined paved and unpaved road density of 0.82 km/km^2. Summers are hot and humid with mean temperatures between 12.4°C to 24.4°C and an annual mean of 68.6 cm of rainfall. Winters are cold and dry with mean temperatures between -18.5°C to -6°C accompanied by 113.5 cm of snowfall which is typically present from December to April (Cass Lake; National Oceanic and Atmospheric Administration 2021). The LLBO and the United States Federal Government established the LLR with the Treaty of 1855. Since its inception, land ownership within the LLR has become increasingly fragmented; <5% of the total land area belongs to the tribe (50.2 km^2 of allotted lands, 34.8 km^2 of Band land, and 54.14 km^2 of Minnesota Chippewa Tribe land), with the remaining area owned by private landowners and county, state, or federal agencies. The Chippewa National Forest (CPF), operated by the United States Forest Service (USFS) overlaps ~90% of the LLR and is the largest private landowner within the Reservation boundary.

Methods

Data collection. I established 8 5-km survey transects by randomly selecting start points along existing non-motorized trails across the study area. I divided each transect into 1-km segments for occupancy determination, for a total of 40 1-km segments. Previous research demonstrates transects >400 m in length are sufficient to achieve spatial independence (detection of the species at a segment is independent of detection of the species at all other segments) when modeling occupancy of meso-carnivores (McHenry et al. 2016, Kordosky et al. 2021). I surveyed transects a minimum of 3 times during the winters (15 January–30 March) of 2021 and 2022. I conducted surveys 1–3 days following snowfalls of >2.5 cm depth to ensure observation independence between repeat visits (Aing et al. 2011). For each species detection I recorded date, temperature (°C), time since last snowfall (hrs), snow depth (cm), snow sinking depth (cm), snow condition (Halfpenny et al. 1995), and dominant tree species. I measured snow sinking depth by dropping a spherical weight (450 g, 9.2 cm diameter) from 1 m into undisturbed snow and measured the penetration depth.

I recorded observations for snowshoe hares and all mammalian predators larger than and including long-tailed weasels *(zhingosag; Mustela frenata*). To maintain integrity of correctly identified observations, I limited track identification to one observer (myself) with professional certification in wildlife track and sign identification in the state of Minnesota (IV; Tracker Certification CyberTracker North America 2023). I recorded data used to support species identification for each observation such as snow track quality (Halfpenny 1995), percent confidence in identification (0–25%, 26–50%, 51–75%, 75–100%), and track/trail measurements (gait, trail width, stride length, track width, track length, step depth; Elbroch 2019). To reduce the probability of misidentification between marten and fisher tracks, I followed quantitative identification protocol outlined by McCann et al. (2017). Especially for mustelid species, and when confidence in identification was <75%, I recorded multiple sets of track measurements per observation to aid in species identification. For analysis, I reduced species observation counts to presence/absence across each 1-km transect segment. Repeated surveys informed estimations of detectability and occupancy, accounting for both detection covariates and site covariates (Table 2.1). Critical assumptions included closed occupancy, independence, consistent occupancy probability, and consistent detectability across sites (while maintaining that variations in occupancy and detection probabilities were described by observation and site covariates). I modeled occupancy for single species using the *occu* function within the package "unmarked" in program R 4.0.3 (Fiske and Chandler 2011). I conducted all sampling with approval and appropriate permitting (Appendix B) from the LLBO DRM.

Detection covariates. I modeled detection as a function of time since last snowfall, snow depth, snow sinking depth and temperature. For each species I tested 6 detection models, 4 single variable and 2 multi-variable, while setting occupancy probability constant (Table 2.2). I expected the increased additive effects of deep snow and deep sinking depth to negetively affect detection for all species, especially those less snow adapted, combining snow sinking depth and snow depth in one model.

Additionally, I expected the additive effects of low temperature and deep sinking depth to have a negetive effect on detectibility for all species due to a reduction in movement, combining snow sinking depth with temperature in one model. After running each of the 6 detection models for each species, I included the covariates of the models with the lowest AIC_c (Akaike's Information Criterion, corrected for small sample sizes; Burnham and Anderson 2002) score as the detection covariate in all proceeding occupancy models (Burnham et al. 2011) for that species.

Site covariates. I quantified 12 site level covariates for consideration in modeling occupancy for each target species (Table 2.1). I created a 500 m buffer around each survey segment to quantify landscape structure and composition. I chose this scale because it represents the lower end of female marten home range size (Dumyahn et al. 2007), while maintaining a scale at which spatial autocorrelation between segments is limited for meso-carnivores. (McKenry et al. 2016). I quantified landcover variables at a 30 m resolution using landcover classifications from the 2019 National Landcover Database (NLCD; Dewitz 2021) that I hypothesized would most influence target species' presence. I calculated percent conifer forest and shrub cover and aggregated all wetland cover types together to create a single wetland edge density value. Cedar stands were of special interest to the LLBO DRM as they provide critical refugia habitat for snowshoe hare (LLBO DRM 2018), I therefor calculated percent cedar stand cover using data provided by the LLBO DRM merged with data from the Minnesota Department of Natural Resources 2021 Forest Inventory Management System. I used the Minnesota Department of Transportation 2012 roads and streets data to calculate a combined road density value of both paved and unpaved roads (km/km^2). I calculated a major roads value by identifying only roads that remained snow-plowed. I also calculated 2 classes of canopy cover using the 2016 NLCD United States Forest Service Tree Canopy Cover Database: percent closed (>75% canopy closure), and percent non-forest (<10% canopy closure). For each buffered survey segment I created a centroid from which I calculated distance to the nearest major (snow-plowed) road and distance to the nearest cedar stand. Finally, I calculated values of snowshoe hare and bobcat presence/absence and predator richness per segment using transect observation data.

In order to select site level covaraites considered for occupancy modeling, I created a full set of single-covariate models for each species (Table 2.3). Of these, I only considered variables from models ranked above the null model with an ΔAIC_c score of <10, as models with ΔAIC_c's above ~9–11 have little support (Burnham and Anderson 2002). I then tested for correlation between the remaining covariates and removed any with correlation coefficients of $|r| > 0.7$ (Dormann et al. 2013). To aid in the selection process, I organised these covariates into 4 categories: human activity (road density, distance to major snow-plowed road), landcover (% conifer forest, % shrub cover, % cedar stands, distance to cedar stands), canopy cover (% non-forest, % closed), and species interaction (hare presence, bobcat presence, predator richness) and selected ~1 from each group, where possible, to be considered in the *a priori* model set. I considered the ecology and potential management implications for each species when creating the model set, refraining from adding more than 3 variables to a single model so as not to over-fit the data set. For each species, I created a suite of 10 *a priori* models containing both single variable and multi-variable models, a null model and a global model (Table 2.4).

Results

Transects were representative of the overall landcover of the LLR (Figure 2.1, Table 2.5). I surveyed each of the 5 8-km transects at least 3 times, for a minimum of 120 transect segment surveys conducted during the winters of 2020–21 and 2021–22. Out of 40 survey segments, I observed tracks of snowshoe hares at 31, martens at 13, fishers at 16, and bobcats at 13. I observed a total of 10 mammalian predators along transects: red foxes (*waagoshag; Vulpes vulpes* [26/40 sites]), long-tailed weasels (25/40 sites), gray wolves (*ma'iinganag; Canis lupus* [20/40 sites]), coyotes (*wiisagi-ma'iinganag; Canis latrans* [10/40 sites]), river otters (n*igigwag; Lontra canadensis* [6/40 sites]), minks (*zhaangweshiwag; Neovison vison* [4/40 sites]), and notably Canada lynx (*bizhiwag; Lynx canadensis* [2/40 sites]), who are a federally threatened species, of special concern within the state of Minnesota, a culturally significant animal for the LLBO, and listed as endandered on the LLBO's list of *Threatened, Endangered, Sensitive and Management Concern Species* (TES). Red pines (*wenda-zhingwaakwag; Pinus resinosa*) and aspens (*azaadiwag; Populus spp.*) were the 2 most common dominant tree species present at observation locations of snowshoe hares (21%; 26%), martens (30%; 44%), fishers (19%; 33%) and bobcats (35%; 29%). White cedars were the third most common dominant tree species at both snowshoe hare and fisher observation locations but were not present at any marten or bobcat observation locations.

Snowshoe hare. Probability of snowshoe hare occupancy and detection was 0.348, and 0.418 respectively. The top-ranking detection model for snowshoe hares included time since last snow, which was negatively correlated with the probability of detection ($\beta = -0.564$, SE = 0.234; Table 2.2), and was used as the detection covariate in all subsequent snowshoe hare occupancy models. The comprehensive single-covariate model set resulted in 6 covariates available for consideration when building *a priori* occupancy models (Table 2.3). Site covariates used in *a priori* occupancy models included predator richness which was positively correlated with probability of occupancy (β = 4.44, SE = 2.12), road density which was negatively correlated with probability of occupancy (β = -1.88, SE = 1.44), increased distance to cedar stands which was negatively correlated with probability of occupancy (β = -1.28, SE = 0.69), percent shrub cover which was positively correlated with probability of occupancy (β = 9.05, SE = 5.39) and percent non-forested canopy cover which was negatively correlated with probability of occupancy (β = -0.73, SE = 0.42; Figure 2.2, Table 2.3). Probability of snowshoe hare occupancy decreased as road density exceeded 1.5 km/km^2 and as distance to the nearest cedar stand exceeded 2 km. Probability of snowshoe hare occupancy increased as both predator richness per segment increased and as shrub cover within a buffered segment exceeded ~1% of the landcover.

The top 4 occupancy models for snowshoe hares were competitive with ΔAIC_c scores of <2 (Table 2.4). The top-ranking model included percent shrub cover which was positively correlated with probability of occupancy (β = 4.17, SE = 3.12), road density which was negatively correlated with probability of occupancy (β = -3.78, SE = 2.32), and increased distance to the nearest cedar stand which was positively correlated with probability of occupancy (β = -6.43, SE = 3.84).

Marten. The probability of marten occupancy and detection was 0.576 and 0.244, respectively. The top-ranking detection model for martens included temperature which was negatively correlated with probability of detection (β = -0.567, SE = 0.339) and was used as the detection covariate in all subsequent marten occupancy models (Table 2.2). The comprehensive single-covariate model set resulted in 5 covariates available for consideration in *a priori* occupancy models (Table 2.3). Site covariates used in *a priori* occupancy models included percent conifer cover which was positively correlated with probability of occupancy ($\beta = 1.11$, SE = 0.508), increased distance to major roads which was positively correlated with probability of occupancy ($\beta = 2.94$, SE = 1.69), percent closed canopy cover which was positively correlated with probability of occupancy ($\beta = 1.62$, SE 1.16) and percent cedar stands which was negatively correlated with probability of occupancy ($\beta = -2.78$, SE = 3.12), (Figure 2.3, Table 2.3).

The top 3 ranking models were competitive with ΔAIC_c scores of <2 (Table 2.4). The top-ranking occupancy model included percent conifer forest which was positively correlated with probability of occupancy ($\beta = 1.470$, SE = 0.728) and cedar stand density which was negatively correlated with probability of occupancy ($\beta = -2.20$, SE = 2.175).

Fisher. The probability of fisher occupancy and detection was 0.687 and 0.246, respectively. The only competetive detection model for fishers included snow sinking depth which was negatively correlated with probability of occupancy ($\beta = -0.94$, SE = 0.33) and snow depth which was positively correlated with probability of occupancy ($\beta = 0.73$, SE = 0.29), and were used as the detection covariates in all subsequent fisher occupancy models (Table 2.2).

The comprehensive single-covariate model set resulted in 5 covariates available for consideration in *a priori* occupancy models (Table 2.3). Site covariates used in *a priori* occupancy models included road density which was negatively correlated with probability of occupancy ($\beta = -62.9$, SE = 65.8), percent nonforest canopy cover which was negatively correlated with probability of occupancy (β = -40.9, SE = 99.4), bobcat presence which was negatively correlated with probability of occupancy (β = -2.13, SE = 1.13) and percent conifer forest cover which was negatively correlated with probability of occupancy (β = -0.70, SE = 0.45; Figure 2.3, Table 2.3). Notably, probability of fisher occupancy decreased as road density exceeded 1.5 km/km^2. I did not include 3 of the 10 models in the final ranked *a priori* model set because they did not converge (Table 2.4). Only 1 occupancy model scored an ΔAIC_c of <2, and included road density which was negatively correlated with probability of occupancy (β = -55.8, SE = 50.0) and bobcat presence which was negatively correlated with probability of occupancy (β = -71.7, SE = 62.6).

Bobcat. The probability of bobcat occupancy and detection was 0.999 and 0.113, respectively. The top-ranking detection model for bobcats included snow sinking depth which was negatively correlated with probability of occupancy (β = -0.87, SE = 0.45) and temperature which was negatively correlated with probability of occupancy (β = -1.42, SE = 0.53; Table 2.2), and were used as the detection covariates in all subsequent bobcat occupancy models. The comprehensive single-covariate model set resulted in 5 covariates available for consideration in *a priori* occupancy models (Table 2.3). Site covariates used in *a priori* occupancy models included percent cedar stands which was negatively correlated with probability of occupancy (β = -15.0, SE = 26.4), increased distance to major roads which was negatively correlated with probability of occupancy (β = -16.7, SE = 37.6), percent non-forest canopy cover which was positively correlated with probability of occupancy (β = 1.97, SE = 1.27) and percent wetland which was negatively correlated with probability of occupancy (β = -19.2, SE = 39.0; Figure 2.5, Table 2.3).

I did not include 5 of the 10 models, including the global model, in the final ranked *a priori* model set because they did not converge (Table 2.4). Three models including the null model proved to be competitive with ΔAIC_c scores of <2. The top model included only percent non-forest canopy cover which was positively correlated with probability of occupancy (β = 1.96, SE = 1.27).

Discussion

I found that the most important predictor variable for snowshoe hare occupancy was distance to cedar stands. As distance to cedar stands exceeded 2 km, snowshoe hare occupancy decreased sharply, dropping by >50% at 3 km. Cedar stands form high quality habitat for snowshoe hare who use the dense vegetative understory cover to escape predation (LLBO 2018). However, cedar stands exist in small, fragmented pockets across the LLR and make up just 1.9% of the landcover (Dewitz 2021). Additionally, these stands are unlikely to expand; white cedar's slow growth rate cannot keep up with heavy winter browsing by abundant white-tailed deer (*waawaashkeshi; Odocoileus virginianus*; Rooney et al. 2002).

Although cedar stands provide excellent cover from predators, cedar is not ideal food for snowshoe hares; when compared with deciduous species such as maple (*ininaatig; Acer spp.*) and aspen, cedar provided the lowest nutritional availability (Walski and Mautz 1977). Shrub cover however, which is characterized by early successional or stunted trees and shrubs (Dewitz 2021), is indicative of both dense vegetative cover and nutritionally valuable foraging habitat. I found that snowshoe hares use shrub cover disproportionately to what is available on the landscape, with the probability of snowshoe hare occupancy dropping off precipitously when shrub cover density fell below 1%. Similar to cedar stands, shrub cover is also patchy and fragmented, constituting just 1.6% of the landcover within the Reservation.

The accuracy of predator richness and snowshoe hare presence site covariates using presence/absence data collected in the field are dependent on the detectability of species. Low detection rates for most species indicate that segment calculations for predator richness and snowshoe hare presence underestimated actual presence/absence of these species. This must be taken into consideration when analyzing the effects of these site covariates in occupancy models. I found that predator diversity increased with snowshoe hare occupancy, but that snowshoe hare presence did not have any effect on marten, fisher, or bobcat occupancy. Despite marten, fisher or bobcat occurrence not individually exhibiting positive associations with snowshoe hare presence, these data indicate that areas of high-quality habitat capable of supporting increased predator richness are also areas of habitat that snowshoe hares select. In this sense, snowshoe hares act as an indicator for ecosystem health and as a keystone species, supporting previous studies finding that snowshoe hare have a disproportionate effect on the health and diversity of the ecosystems they inhabit (Keith and Cary 1991, Mills et al. 1993, O'Donoghue et al. 1998, Krebs et al. 2001).

Although positive correlations between snowshoe hares and conifer forests have been reported in the past (Buehler and Keith 1982), I found no evidence to suggest that snowshoe hare select for conifer forests within the LLR. Timber harvest levels within the CPF, which are of the highest percent of their annual maximum allowable sale quantity of any forest in the region (USFS 2010), have been described as having a negative and unsustainable effect on tribal trust resources (LLBO 2023). Historic prioritization of meeting timber harvest quotas has resulted in predominately homogenic forests dominated by red pine plantations and aspen stands across the LLR. The most common trees species that I observed at observation locations for all 4 species along transects were in fact red pine and aspen. The dense overstory canopies of planted red pines prevent sunlight from reaching the forest floor, resulting in open understories lacking in horizontal ground cover which negatively affect snowshoe hares (Orr 1982, Fuller and Harrison 2013).

Increased predator presence combined with scarce and fragmented habitat may have a compounding negative effect on snowshoe hare metapopulation dynamics over time. When predation risk is high, and when population numbers are low, snowshoe hares will consistently select for high-quality habitats that minimize predation over other habitats (Keith and Windberg 1978, Gigliotti 2017, Gigliotti and Diefenbach 2018). Decreased snowshoe hare occurrence in areas beyond 2 km from cedar stands suggests that snowshoe hares likely do not have sufficient cover for populations to persist between stands. Impeded by an inability to interact with neighboring fragmented populations, increasingly isolated snowshoe hare populations risk reduced demographic and fitness measures (Cheng et al. 2014). Additionally, as snowshoe hares become geographically isolated near cedar stand and shrub cover pockets, predators may regularly search them, creating a type of ecological trap. This sustained predation pressure induced stress may increase cortisol levels in snowshoe hares which have been found to decrease reproduction and population density (Sheriff et al. 2009).

The most important variable influencing bobcat occupancy was non-forested canopy cover, which may indicate areas of edge habitats and other open habitats characterized by greater prey density that bobcats select for (Preuss and Gehring 2007, Clare et al. 2015). Bobcat's positive association with major snow-plowed roads may indicate that they mitigate their lack of snow-adaption by travelling plowed roads during winter, coinciding with previous research finding that bobcat will use paved and unpaved roads for travel and will avoid areas of deep snow (Abouelezz et al. 2018, Morin et al. 2020). Fishers, who are occasionally preyed on by bobcats (Erb 2016), avoided paved and unpaved roads and areas of non-forested canopy cover as well as the direct presence of bobcats; indicating that fishers achieve niche partitioning with bobcats through spatial segregation. Sympatric carnivores who share prey and habitat resources must exhibit some form of niche-partitioning in order to avoid negative interactions. Lesser dominant carnivores may also actively avoid the presence of, or habitats frequently used by, more dominant carnivores. I found no evidence to suggest that marten occupancy decreased in areas that fishers or bobcats were present. However, marten may be avoiding fishers and bobcats through finer scale niche partitioning such as tunneling, a behavior used to access the subnivean zone beneath the snow surface to forage and escape predation (Bissonette et al. 1997). I found evidence of martens tunnelling under the snow on at least 2 occasions, but I suspect that there were more that I could not detect resulting in false negative detections. Detection rates for martens however, were negatively correlated with warmer temperatures, which facilitate the formation of crust on the snow surface. The formation of crust impedes martens' ability to tunnel, and it allows less snow adapted competitive species such as fishers and bobcats to travel over wider areas. Additionally, detection rates for fishers were positively associated with deep snow and low sinking depth, which also indicates possible crust formation. The most important predictor variables for marten occupancy included percent conifer forest and distance to major snow-plowed roads, with probability of occupancy being reduced by >50% within 1 km of a major road. Frozen ground during winter allows heavy equipment to operate in areas that would otherwise be inaccessible, as a result, areas that usually experience little human activity become high-traffic areas by way of plowed roads. During the first year of the study, I observed marten tracks frequently along a transect that was designated as a walking-only hunting trail. During the second winter field season half of this trail had become the site of a logging operation, after which marten observations dropped by 60%. Marten already occur in low densities within the LLR, which is located on the southern edge of their range (Erb 2021). Their snow adaption and dependence on coniferous forests make them susceptible to the effects of climate change which will continue to cause warmer winter temperatures, changes in winter precipitation patterns, and shifts in both competitive species' ranges and forest species composition from coniferous to deciduous (Fisichelli et al. 2013).

I observed Canada lynx tracks twice during my 2 winters of surveying. Lynx have historically been common throughout northern Minnesota, however their range has contracted by 40% within the last century (Laliberte and Ripple 2004), and are now rare within the LLR. This limited observation is noteworthy because lynx not only hold important spiritual value for the LLBO and are an endangered species on the LLBO's TES list, but are also a federally threatened species; under the Endangered Species Act, federal agencies such as the USFS are required to proactively use their authority to conserve threatened species (United States 1983). The CPF states within their Forest Management Plan their intention to err on the side of maintaining and restoring lynx habitat for lynx and their prey (USFS 2004). The Plan states that essential lynx habitat is snowshoe hare habitat, and that unsuitable lynx habitat is habitat that does not support snowshoe hare populations. Unsuitable snowshoe hare habitat includes clear-cut areas, which they will avoid for up to 4 years after logging (Ferron et al. 1998). Conversely, previous research has found increased presence of both lynx and snowshoe hares 22–28 years later in forest stands that received management action (*e.g.* clear cutting, planting, clearcutting with planting) after a wildfire (Olson et al. 2023). Lynx are snowshoe hare specialist predators who require large tracts of intact forests that remain undisturbed by land clearing and forestry. Bobcats on the other hand are habitat and prey generalists, with whom lynx exhibit spatial segregation (Marrotte et al. 2020). This spatial segregation is most likely a result of bobcats expanding into anthropologically disturbed areas that lynx have already vacated (Marrotte et al. 2020).

Within a landscape historically managed with an emphasis on timber production, the resulting density and distribution of both paved and unpaved roads and vegetative cover were consistently important predictors of occurrence for snowshoe hares, martens, fishers, and bobcats. Whereas snowshoe hare, marten, and fisher occupancy probabilities were consistently positively associated with increased vegetative cover and negatively associated with proximity to and density of roads, bobcat occupancy associations were the opposite. Landscape use and interactions among martens, fishers and bobcats within the LLR are complex and species-specific, with patterns of spatial avoidance cascading from the most dominant (bobcat) to the least dominant (marten). While I found no evidence to suggest that these predators are shifting their use of habitat around snowshoe hare presence, I did find evidence to suggest that snowshoe hares indicate areas of ecosystem health and biodiversity, including greater carnivore diversity. It is therefore critical to both protect and expand habitats that support snowshoe hares, thereby protecting and expanding habitats that support biodiversity.

Management Implications

Future decisions involving maintenance and development of both paved and unpaved roads within the Reservation must be scrutinized by managers as the presence of roads often associated with commercial timber harvest operations is a consistent limiting factor in the occupancy of snowshoe hare, marten and fisher. Managers must scrutinize any management actions that degrade high-quality snowshoe hare habitat such as cedar stands or shrub cover, as well as areas within 2–3 km of these locations. Managers may also consider decreasing the density and accessibility of historic logging roads currently open to vehicles, in addition to increasing dense woody and vegetative cover habitat (*e.g.* cedar stands, shrub cover). Considerations for achieving this may include filling in historic logging roads with dense woody debris, especially roads adjacent to or within 2–3 km of existing cedar stands or shrub cover, taking care to avoid roads used for traditional gathering activities by the LLBO community. Managers may consider evidence of lynx within the study area as motivation for management actions which support their continued existence under the Endangered Species Act. These management actions may include avoiding clear-cutting, increased use of prescribed burning, or other actions that create snowshoe hare habitat. I suggest managers be guided by the values of the community when making decisions that affect cultural legacy species in competition for prey and resources such as bobcat, fisher and lynx.

References

Abouelezz, H. G., T. M. Donovan, R. T. Mickey, J. D. Murdoch, M. Freeman, and K. Royar. 2018. Landscape composition mediates movement and habitat selection in bobcats (*Lynx rufus*): implications for conservation planning. Landscape Ecology 33:1301–1318.

Aing, C., S. Halls, K. Oken, R. Dobrow, and J. Fieberg. 2011. A Bayesian hierarchical occupancy model for track surveys conducted in a series of linear, spatially correlated, sites. Journal of Applied Ecology 48:1508 –1517.

Bhattacharyya, J., and S. Slocombe. 2017. Animal agency: wildlife management from a kincentric perspective. Ecosphere 8:e01978.

Bisonette, J. A., D. J. Harrison, C. D. Hargis, and T. G. Chapin. 1997. The influence of spatial scale and scale-sensitive properties on habitat selection by American marten. Pages 368–385 *in* J. A. Bissonette, editor. Wildlife and landscape ecology: effects of pattern and scale. Springer-Verlag, New York.

Buehler, D. A., and L. B. Keith. 1982. Snowshoe hare distribution and habitat use in Wisconsin. Canadian Field Naturalist 96:19–29.

Burnham K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer, New York, NY.

Burnham K. P., D. R. Anderson, and K. P. Huyvaert. 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observation, and comparisons. Behavioral Ecology and Sociobiology 65:23–35.

Bull E. L., T. W. Heater, and J. F. Shephard. 2005. Habitat selection by the American marten in northeastern Oregon. Northwest Science 79:37–43.

Cheng E., K. E. Hodges, J. Melo-Ferreira, P. C. Alves, and L. S. Mills. 2014. Conservation implications of the evolutionary history and genetic diversity hotspots of the snowshoe hare. Molecular Ecology 23:2929–2942.

Clare, J. D., E. M. Anderson, and D. M. MacFarland. 2015. Predicting bobcat abundance at a landscape scale and evaluating occupancy as a density index in central Wisconsin. Journal of Wildlife Management 79:469–480.

Clare J., S. T. McKinney, J. E. DePue, and C S. Loftin. 2017. Pairing field methods to improve inference in wildlife surveys while accommodating detection covariance. Ecological Applications 27:2031–2047.

Dewitz, J., and U.S. Geological Survey. 2021. National Land Cover Database 2019 Products (ver. 2.0, June 2021), U.S. Geological Survey data release.

Dormann C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carre, J. R. Garcia Marquez, B. Gruber, B. Lafourcade, P.J. Leitao, et al. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:027–046.

Dumyahn, J. B., P. A. Zollner, J. H. Gilbert.2007. Winter home-range characteristics of American marten (Martes americana) in northern Wisconsin. The American Midland Naturalist 158:382–394.

Elbroch, M. 2019. Mammal tracks and sign: a guide to North American species. Second edition. Stackpole, Mechanicsburg, Pennsylvania, USA.

Erb, J. 2019. Furbearer winter track survey summary. Minnesota Department of Natural Resources, Forest Wildlife Research Group, Minnesota, USA

Erb J. 2021. Furbearer winter track survey summary. Minnesota Department of Natural Resources, Forest Wildlife Research Group, Minnesota, USA

Erb, J., P. Coy, and B. Sampson. 2016. Survival and causes of mortality for fishers and martens in Minnesota. Minnesota Department of Natural Resources, Minnesota, USA.

Erb. J., P. Coy, and B. Sampson. 2009. Fisher and marten demography and habitat use in Minnesota. Minnesota Department of Natural Resources, Minnesota, USA.

Evans, J. W., C. A. Evans, J. M. Packard, G. Calkins, and M. Elbroch. 2009. Determining observer reliability in counts of river otter tracks. Journal of Wildlife Management 73:426–432.

Ferron, J., F. Potvin, C. Dussault. 1998. Short-term effects of logging on snowshoe hares in the boreal forest. Canadian Journal of Forest Research 28:1335–1343.

Fisichelli, N. A., L. E. Frelich, and P. B. Reich. 2013. Temperate tree expansion into adjacent boreal forest patches facilitated by warmer temperatures. Ecography 37:152–161.

Fiske, I., and R. Chandler. 2011. unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1–23.

Fuller, A. K., D. W. Linden, and J. A. Royle. 2016. Management decision making for fisher populations informed by occupancy modeling. Journal of Wildlife Management 80:794–802.

Fuller, A., and D. J. Harrison. 2013. Modeling the influence of forest structure on microsite habitat use by snowshoe hares. International Journal of Forestry Research 2013:892327

Gigliotti, L.C., D. R. Diefenbach, and M. J. Sheriff. 2017. Geographic variation in winter adaptations of snowshoe hares (Lepus americanus). Canadian Journal of Zoology 95:539–545.

Gigliotti, L. C., and D. R. Diefenbach. 2018. Risky behavior and its effect on survival: snowshoe hare behavior under varying moonlight conditions. Journal of Zoology 305:27–34

Halfpenny, J. C., R. W. Thompson, S. C. Morse, T. Holden, and P. Rezendes. 1995. Snow tracking. Pages 91–163 *in* J. Zielinski and T. E. Kucera, editors. American marten, fisher, lynx, and wolverine: survey methods for their detection. General Technical Report PSW-GTR-157, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.

Keeping, D., J. H. Burger, A. O. Keitsile, M. Gielen, E. Mudongo, M. Wallgren, C. Skarpe, and A. L. Foote. 2018. Can trackers count free-ranging wildlife as effectively and efficiently as conventional aerial survey and distance sampling? Implications for citizen science in the Kalahari, Botswana. Biological Conservation 223:156–169.

Keith, L. B. 1963. Wildlife's ten-year cycle. University of Wisconsin Press, Madison, USA.

Keith, L. B., and J. R. Cary. 1991. Mustelid, squirrel, and porcupine population trends during a snowshoe hare cycle. Journal of Mammalogy 72:373–378.

Keith, L. B., and L. A. Windberg. 1978. A demographic analysis of the snowshoe hare cycle. Wildlife Monographs 58:3–70.

Kordosky, J. R., E. M. Gese, C. M. Thompson, P. A. Terletzky, and K. L. Purcell. 2021. Landscape use by fishers (*Pekania pennanti*): core areas differ in habitat than the entire home range. Canadian Journal of Zoology 99:289–297.

Krebs, C. J., S. Boutin, and R. Boonstra. 2001. Ecosystem dynamics of the boreal forest: the Kluane project. Oxford University Press, New York, USA.

Krohn, W., C. Hoving, D. Harrison, D. Phillips, and H. Frost. 2005. Martes foot-loading and snowfall patterns in eastern North America. Pages 115–131 *in* D. J. Harrison, A. K. Fuller, and G. Proulx, editors. Martens and fishers (Martes) in human-altered environments. Springer, Boston, Massachusetts, USA.

Kuehn, D. 1989. Winter foods of fishers during a snowshoe hare decline. Journal of Wildlife Management 53:688–692.

Laliberte, A. S., and W. J. Ripple. 2004. Range contractions of North American carnivores and ungulates. BioScience 54: 123–138.

Leech Lake Band of Ojibwe [LLBO]. 2023. Materials related to the co-management of the Chippewa National Forest. https://www.llojibwe.org/drm/ads/co_mgmt_booklet.pdf. Accessed 17 Feb 2023.

Leech Lake Band of Ojibwe Division of Resource Management. 2018. Influence of forest structure and composition on the space use and survival of snowshoe hare (Lepus americanus). Annual report. Leech Lake Band of Ojibwe, Cass Lake, Minnesota, USA.

Lehner, P. N. 1996. Handbook of ethological methods. Second edition. Cambridge University Press, New York, New York, USA.

Linden, D. W., Fuller. A, Royle. J, and Hare. M. 2017. Examining the occupancy-density relationship for a low-density carnivore. Journal of Applied Ecology 54:2043–2052.

Litvaitis, J. A., J. A. Sherburne, and J. A. Bissonette. 1985. Influence of understory characteristics on snowshoe hare habitat use and density. Journal of Wildlife Management 49:886–873.

Litvaitis, J., J. Sherburne, and J. Bissonette. 1986. Bobcat habitat use and home range size in relation to prey density. Journal of Wildlife Management 50:110–117.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

MacKenzie, D. I., and J. A. Royle. 2005. Designing occupancy studies: general advice and allocating survey effort. Journal of Applied Ecology 42:1105–1114.

Manlick, P. J., J. E. Woodford, B. Zuckerberg, and J. N. Pauli. 2017. Niche compression intensifies competition between reintroduced American martens (*Martes americana*) and fishers (*Pekania pennanti*). Journal of Mammalogy 98:690–702.

Marrotte, R. R., J. Bowman, and S. J. Morin. 2020. Spatial segregation and habitat partitioning of bobcat and Canada lynx. FACETS 5:503–522.

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2010. Survival of adult martens in northern Wisconsin. Journal of Wildlife Management 74:1502–1507.

McCann, P. N., P. A. Zollner, and J. H. Gilbert. 2017. Classifying carnivore tracks using dimensions that control for snow conditions. Wildlife Society Bulletin 41:278–285.

McHenry, E., C. O’Reilly, E. Sheerin, K. Kortland, and X. Lambin. 2016. Strong inference from transect sign surveys: combining spatial autocorrelation and misclassification occupancy models to quantify the detectability of a recovering carnivore. Wildlife Biology 22:209–216.

Mills, L., M. Soulé, and D. Doak. 1993. The keystone-species concept in ecology and conservation. BioScience 43:219–224.

Morin, S. J., J. Bowman, R. R. Marrotte, and M. Fortin. 2020. Fine-scale habitat selection by sympatric Canada lynx and bobcat. Ecology and Evolution 10:9396–9409.

National Oceanic and Atmospheric Administration [NOAA]. 2005. National Weather Service internet services team. Climate Normals for Cass Lake, Minnesota. https://www.ncdc.noaa.gov/cdo-web/datatools/normals. Accessed 17 December 2020.

Noon, B. R., L. L. Bailey, T. D. Sisk, and K. S. McKelvey. 2012. Efficient species-level monitoring at the landscape scale. Conservation Biology 26:432–441.

O'Donoghue, M., S. Boutin, C. J. Krebs, D. L. Murray, and E. J. Hofer. 1998. Behavioral responses of coyotes and lynx to the snowshoe hare cycle. Oikos 82:169–183

Olson, L. E., J. S. Crotteau, S. Fox, G. Hanvey, J. D. Holbrook, S. Jackson, and J. R. Squires. 2023. Effects of compound disturbance on Canada lynx and snowshoe hare: wildfire and forest management influence timing and intensity of use. Forest Ecology and Management 530:120757.

Orr, C. D., and D. G. Dodds. 1982. Snowshoe hare habitat preferences in Nova Scotia spruce-fir forests. Wildlife Society Bulletin 10:147–150.

Pauli, J. N., B. Zuckerberg, J. P. Whiteman, and W. Porter. 2013. The subnivium: a deteriorating seasonal refugium. Frontiers in Ecology and the Environment 11:260–267.

Pirie, T. J., R. L. Thomas, and M. D. Fellowes. 2016. Limitations to recording larger mammalian predators in savannah using camera traps and spoor. Wildlife Biology 22:13–21.

Preuss, T. S., and T. M. Gehring. 2007. Landscape analysis of bobcat habitat in the northern lower peninsula of Michigan. Journal of Wildlife Management 71:2699–2706.

Raine, R. M. 1987. Winter food habits and foraging behavior of fishers (Martes pennanti) and martens (Martes americana) in southeastern Manitoba. Canadian Journal of Zoology 65: 745–747.

Ramos, S. C. 2018. Considerations for culturally sensitive traditional ecological knowledge research in wildlife conservation. Wildlife Society Bulletin 42:358–365.

Robitaille, J., and K. Aubry. 2000. Occurrence and activity of American martens *Martes americana* in relation to roads and other routes. Acta Theriologica 45:137–143.

Rooney, T. P., S. L. Solheim, and D. M. Waller. 2002. Factors affecting the regeneration of northern white cedar in lowland forests of the Upper Great Lakes region, USA. Forest Ecology and Management 163:119–130.

Salmon, E. 2000. Kincentric ecology: Indigenous perceptions of the human-nature relationship. Ecological Applications 5:1327–1332.

Sheriff, M.J., C. J. Krebs, and R. Boonstra. 2009. The sensitive hare: sublethal effects of predator stress on reproduction in snowshoe hares. Journal of Animal Ecology 78:1249–1258.

Stander, P. E., L. //. Ghau, D. Tsisaba, //. ≠Oma, and |.|. Ui. 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242:329–341.

Suffice, P., M. Chieveau, L. Imbeau, M. J. Mazerolle, H. Asselin, and P. Drapeau. 2020. Habitat, climate and fisher and marten distributions. Journal of Wildlife Management 84:277–292.

Sultaire, S. M., J. N. Pauli, K. J. Martin, M. W. Meyer, and B. Zuckerberg. 2016. Extensive forests and persistent snow cover promote snowshoe hare occupancy in Wisconsin. Journal of Wildlife Management 80:894–905.

Swanson, G., T. Surber, and T. S. Roberts. 1945. The mammals of Minnesota. Minnesota Department of Conservation Technical Bulletin No. 2.

Thompson, I., and P. Colgan. 1987. Numerical responses of martens to a food shortage in northcentral Ontario. Journal of Wildlife Management 51:824–835.

Tracker Certification CyberTracker North America. 2023. Tracker Certification home page. https://trackercertification.com/. Accessed 3 Mar 2023.

Whittington, J., K. Heuer, B. Hunt, M. Hebblewhite, and P. M. Lukacs. 2015. Estimating occupancy using spatially and temporally replicated snow surveys. Animal Conservation 18:92–101.

United States. 1983. The Endangered Species Act as amended by public law 97-304. Washington, U.S. G.P.O.

United States Forest Service [USFS]. 2004. Chippewa National Forest. 2004 Forest Plan. https://www.fs.usda.gov/detail/chippewa/landmanagement/planning/?cid=fsm9_016569. Accessed 17 Feb 2023.

United States Forest Service [USFS]. 2010. Chippewa National Forest. Five year forest plan and monitoring and evaluation report. https://www.fs.usda.gov/detail/chippewa/landmanagement/planning/?cid=stelprd3793083. Accessed 15 Feb 2023

United States Forest Service [USFS]. 2020. Chippewa National Forest. Monitoring and evaluation report fiscal years 2016–2017. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd702812.pdf. Accessed 15 Feb 2023

Zielinski. W. J, and T. E. Kucera. 1995. American marten, fisher, lynx, and wolverine: survey methods for their detection. General Technical Report PSW-GTR-157, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.

Zuercher, G. L., P. S. Gipson, and G. C. Stewart. 2003. Identification of carnivore feces by local peoples and molecular analyses. Wildlife Society Bulletin 31:961–970.

Tables

Table 2.1. Descriptions of covariates considered for the estimation of snowshoe hare, fisher, marten, and bobcat detection (p) and occupancy (ψ) within the Leech Lake Reservation during December-March 2019-2021.

Covariate Name	Covariate Abbreviation	Definition	Data Source
(*p*) Temperature	Temp	Temperature (C) taken at the start time of each transect survey	NA/Local thermometer
(p) Snow Depth	Depth	Snow depth (cm) measured at the beginning of each transect survey	NA
(*p*) Snow Sinking Depth	Sink	Snow density measured as the sinking depth (cm) of a croquet ball dropped from ~1m above snow surface.	NA
(*p*) Time of Last Snow	LastSnow	Time (hours) since the end of the last snow period to onset of transect survey.	NA/Local observation data
(*ψ*) Percent Conifer Forest	Conifer	Percentage of a segment buffer identified as Evergreen Forest by the 2016 National Land Cover Database (code 42, [*areas dominated by tress generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage*]).	https://www.mrlc.gov/data
(*ψ*) Percent Shrub/Scrub Cover	Shrub	Percentage of a segment buffer identified as Shrub/Scrub by the 2016 National Land Cover Database (code 52 [*areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions*]).	https://www.mrlc.gov/data
(*ψ*) Wetland Edge Density	EdgeWetland	Density (km/km²) of segment buffer identified as a perimeter edge of Wetlands (codes 90 and 95) by the 2016 National Land Cover Database (code 90 [*Woody Wetlands-areas where forest or shrubland vegetation accounts for greater then 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water*], code 95 [*Emergent Herbaceous Wetlands-areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated or covered with water*]).	https://www.mrlc.gov/data
(*ψ*) Distance to Major Road	RdDist	Distance to the nearest snow-plowed road from a centroid of each segment.	LLBO DRM

(ψ) Road Density	Rd	Density (km/km²) of all paved and unpaved roads and streets, including forest roads	https://gisdata.mn.gov/dataset/trans-roads-mndot-tis
(ψ) Distance to Cedar Stand	CedarDist	Distance to the nearest cedar stand from a centroid of each segment.	LLBO DRM, https://gisdata.mn.gov/dataset/biota-dnr-forest-stand-inventory
(ψ) Percent Cedar Stand	Cedar	Percentage of segment buffer identified as a cedar stand.	LLBO DRM, https://gisdata.mn.gov/dataset/biota-dnr-forest-stand-inventory
(ψ) Percent Closed Canopy	Closed	Percent of segment buffer identified as having a tree canopy closure of >75% by the 2016 NLCD USFS Tree Canopy Cover (CONUS) Database.	https://www.mrlc.gov/data
(ψ) Percent non-forest canopy	Nonforest	Percent of segment buffer identified as having a tree canopy closure of <10% by the 2016 NLCD USFS Tree Canopy Cover (CONUS) Database	https://www.mrlc.gov/data
(ψ) Predator Richness	Pred	Count of all predator species (larger than and including long tailed weasels) observed along transect segment.	NA
(ψ) Hare Presence	HarePres	Hare presence (0-1) observed along each transect segment	NA
(ψ) Fisher Presence	FisherPres	Fisher presence (0-1) observed along each transect segment	NA
(ψ)Bobcat Presence	BobcatPres	Bobcat presence (0-1) observed along each transect segment	NA

Table 2.2. AIC_c ranked models of detection probability (*p*) for snowshoe hare, marten, fisher and bobcat in the Leech Lake Reservation, Minnesota during December-March 2019-2021.

Models of detection probability (*p*)	ΔAIC_c	*w*
Snowshoe hare		
p (LastSnow)	0	0.433
p (Sink + Depth + Temp + LastSnow)	0.81	0.289
p (Depth)	3.00	0.097
P (Null)	4.37	0.049
p (Sink + Temp)	4.80	0.039
p (Sink)	4.97	0.036
p (Sink + Depth)	5.40	0.029
p (Temp)	5.51	0.028
Marten		
p (Temp)	0	0.328
p (Null)	0.93	0.206
p (Depth)	1.66	0.143
p (Sink + Temp)	2.19	0.110
p (Lastsnow)	2.65	0.087
p (Sink)	3.05	0.071
p (Sink + Depth)	4.10	0.042
p (Sink + Depth + Temp + Lastsnow)	6.34	0.014
Fisher		
p (Sink + Depth)	0	0.801
p (Sink + Depth + Temp + Lastsnow)	3.49	0.140
p (Sink)	6.90	0.025
p (Sink + Temp)	8.76	0.010
p (Temp)	9.06	0.009
p (Null)	9.46	0.007
p (Depth)	10.04	0.005
p (Lastsnow)	11.80	0.002
Bobcat		
p (Sink + Temp)	0	0.453
p (Temp)	0.12	0.427
p (Sink + Depth + Temp + Lastsnow)	3.85	0.066
p (Null)	5.80	0.025
p (Depth)	7.62	0.010
p (Lastsnow)	8.04	0.008
p (Sink)	8.10	0.008
p (Sink + Depth)	10.02	0.003

Table 2.3. Site covariate models for snowshoe hare, marten, fisher and bobcat ranked by ΔAIC_c. Only site covariates with ΔAIC_c scores of <10 and higher ranking than the null model were considered for *a priori* models, and include β estimates and standard errors values (SE).

Models of site covariates	ΔAIC_c	*w*	β	SE
Snowshoe hare				
ψ (Pred)	0.00	0.330	+ 4.44	2.12
ψ (Rd)	0.43	0.265	- 1.88	1.44
ψ (CedarDist)	1.86	0.130	- 1.28	0.69
ψ (Shrub)	2.59	0.090	+ 9.05	5.39
ψ (Cedar)	3.26	0.065	- 82.4	114.1
ψ (Nonforest)	4.21	0.040	- 0.73	0.42
ψ (**Null**)	**4.94**	**0.028**		
ψ (Conifer)	5.96	0.017		
ψ (EdgeWetland)	6.27	0.014		
ψ (Closed)	6.53	0.013		
ψ (RdDist)	7.21	0.009		
Marten				
ψ (Conifer)	0.00	0.248	+ 1.11	0.508
ψ (CedarDist)	0.48	0.238	- 63.0	83.5
ψ (RdDist)	1.57	0.138	+ 2.94	1.69
ψ (Cedar)	1.71	0.129	- 2.78	3.12
ψ (Closed)	2.02	0.111	+ 1.62	1.16
ψ (**Null**)	**4.39**	**0.034**		
ψ (EdgeWetland)	6.18	0.014		
ψ (Rd)	6.34	0.013		
ψ (Nonforest)	6.75	0.010		
ψ (FisherPres)	8.84	0.010		
ψ (HarePres)	6.84	0.010		
Fisher				
ψ (Rd)	0.00	0.637	- 62.9	65.8
ψ (Nonforest)	2.02	0.232	- 40.9	99.4
ψ (BobcatPres)	5.44	0.042	- 2.13	1.13
ψ (RdDist)	6.41	0.026	+ 0.93	0.63
ψ (Conifer)	6.86	0.021	- 0.70	0.45
ψ (**Null**)	**7.10**	**0.018**		
ψ (Cedar)	9.14	0.007		
ψ (HarePres)	9.27	0.006		
ψ (CedarDist)	9.39	0.006		
ψ (Closed)	9.41	0.006		
Bobcat				
ψ (Cedar)	0.00	0.352	- 15.0	26.4
ψ (CedarDist)	0.11	0.333	+ 60.4	73.6
ψ (RdDist)	2.26	0.113	- 16.7	37.6
ψ (Nonforest)	2.29	0.112	+ 1.97	1.27
ψ (Wetland)	3.78	0.047	- 19.2	39.0
ψ (**Null**)	**3.98**	**0.046**		
ψ (Shrub)	6.13	0.016		
ψ (Closed)	6.14	0.016		
ψ (Conifer)	6.36	0.014		
ψ (HarePres)	6.53	0.013		
ψ (EdgeWetland)	6.56	0.013		
ψ (Rd)	6.60	0.012		

Table 2.4. AIC_c ranked models of occupancy probability (ψ) for snowshoe hare, marten, fisher and bobcat within the Leech Lake Reservation during December-March 2019-2021. Models in bold font had ΔAIC_c values <2 and were considered competitive.

Models of occupancy probability (ψ)	ΔAIC_c	w
Snowshoe hare		
ψ (Rd + Shrub + CedarDist)	**0.00**	**0.279**
ψ (Rd + CedarDist)	**0.40**	**0.228**
ψ (Shrub + Pred)	**0.46**	**0.221**
ψ (Nonforest + Pred)	**0.53**	**0.213**
ψ (CedarDist + Pred)	5.17	0.021
ψ (Pred)	6.07	0.013
ψ (Rd + Shrub + CedarDist + Nonforest + Pred)	6.37	0.012
ψ (CedarDist)	7.93	0.005
ψ (Shrub)	8.66	0.004
ψ (Rd)	10.28	0.002
ψ (Nonforest)	10.28	0.002
ψ (Null)	11.02	0.001
Marten		
ψ (Conifer + Cedar)	**0.00**	**0.288**
ψ (Conifer + RdDist)	**0.09**	**0.275**
ψ (Conifer + Closed + RdDist)	**1.19**	**0.159**
ψ (Conifer + Closed)	2.52	0.082
ψ (Conifer + Closed + RdDist + Cedar)	3.06	0.063
ψ (Conifer)	3.68	0.046
ψ (RdDist)	5.25	0.021
ψ (Cedar)	5.39	0.019
ψ (Closed + Cedar)	5.68	0.017
ψ (Closed)	5.70	0.017
ψ (Closed + RdDist)	7.10	0.008
ψ (Null)	8.06	0.005
Fisher		
ψ (Rd + Bobcat)	**0.00**	**0.710**
ψ (Rd + Nonforest + Conifer)	3.50	0.123
ψ (Rd + Nonforest + Bobcat + Conifer)	4.66	0.069
ψ (Nonforest + Conifer)	4.72	0.067
ψ (Nonforest)	7.35	0.018
ψ (Nonforest + Bobcat)	9.59	0.006
ψ (Bobcat)	10.78	0.003
ψ (Conifer)	12.19	0.002
ψ (Null)	12.43	0.001
Bobcat		
ψ (Nonforest)	**0.00**	**0.306**
ψ (Cedar + Nonforest)	**0.88**	**0.197**
ψ (Wetland)	**1.49**	**0.145**
ψ (Null)	**1.69**	**0.132**
ψ (Wetland + Nonforest)	2.44	0.090
ψ (Wetland + RdDist)	2.92	0.071
ψ (Wetland + RdDist + Nonforest)	3.30	0.059

Table 2.5. Proportions of landcover variables within the Leech Lake Reservation (LLR) and within 500m buffered transects.

Landcover Type	LLR (%)	Transects (%)
Conifer	7.51	10.78
Deciduous	25.56	34.42
Wetland	26.38	30.19
Shrub	1.66	1.76
Cedar	1.91	9.8

Figures

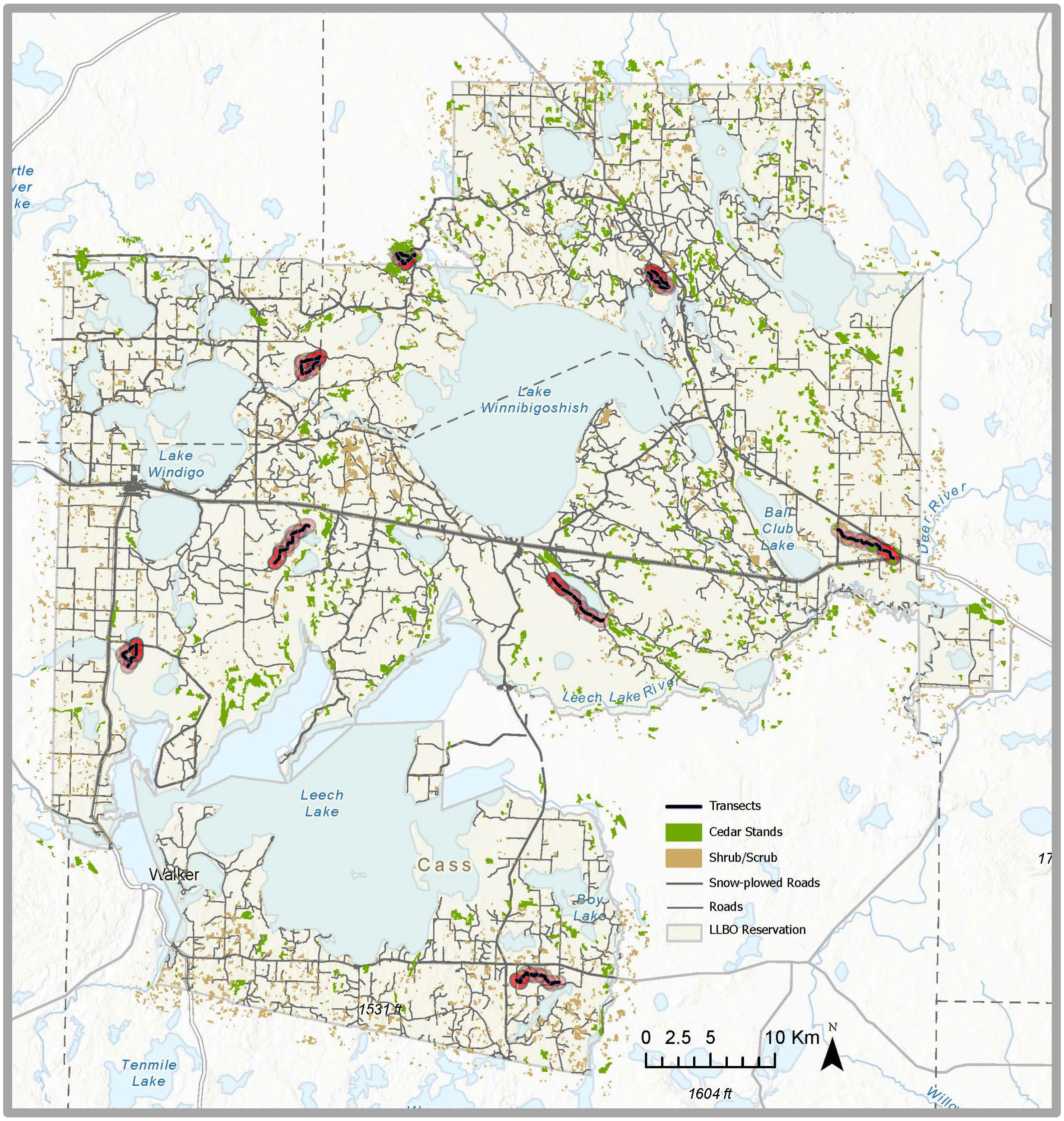

Figure 2.1. Leech Lake Reservation in northern Minnesota, USA. Transects with 500 m buffered segments ($0.8km^2$ – $2.4km^2$) and landcover symbolized according to the legend.

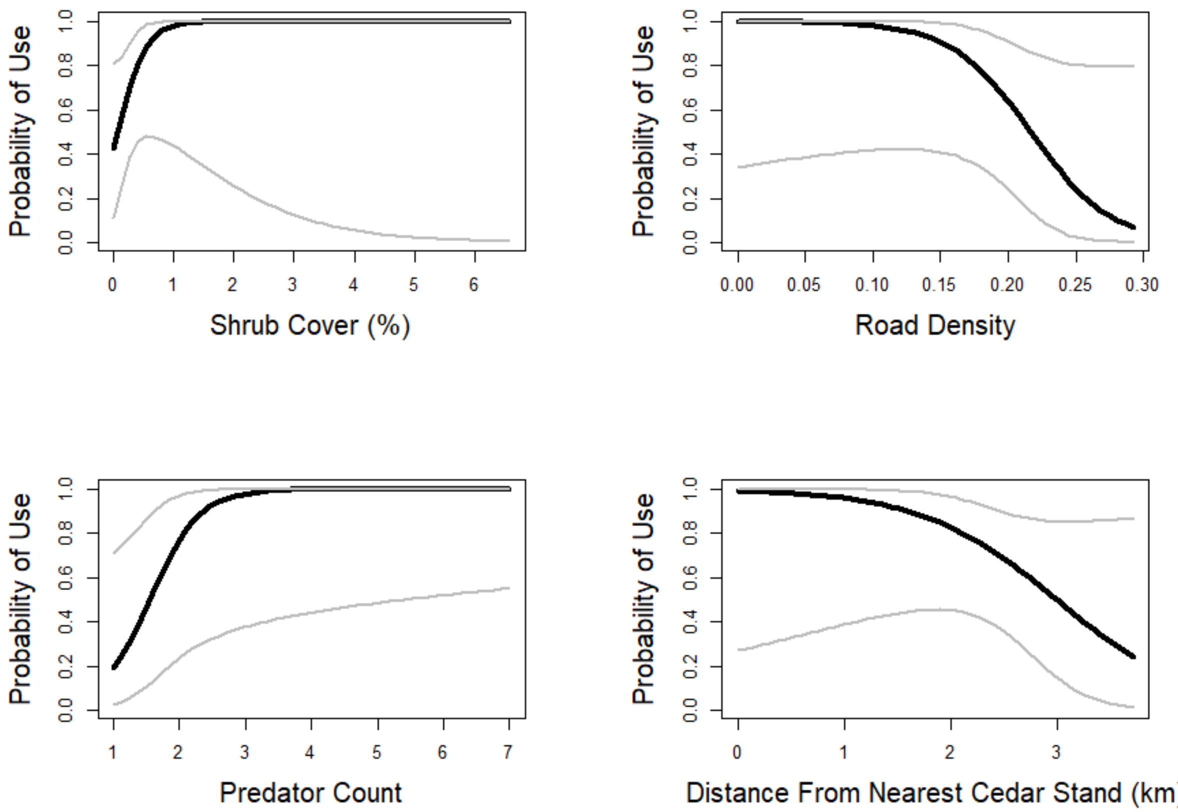

Figure 2.2. Probability of snowshoe hare occupancy (*ψ)* on the Leech Lake Band of Ojibwe Reservation as a function of landscape covariates from top AIC$_c$-ranked models.

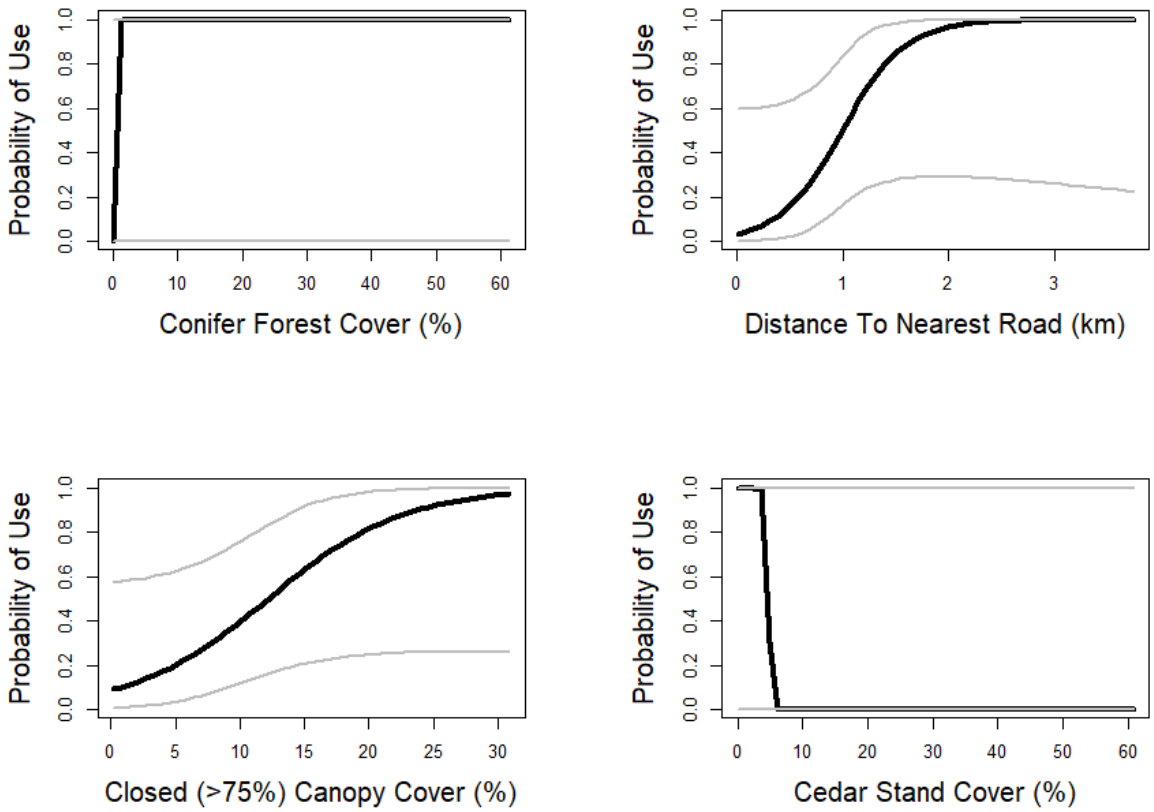

Figure 2.3. Probability of marten occupancy (*ψ)* on the Leech Lake Band of Ojibwe Reservation as a function of landscape covariates from top AIC$_c$-ranked models.

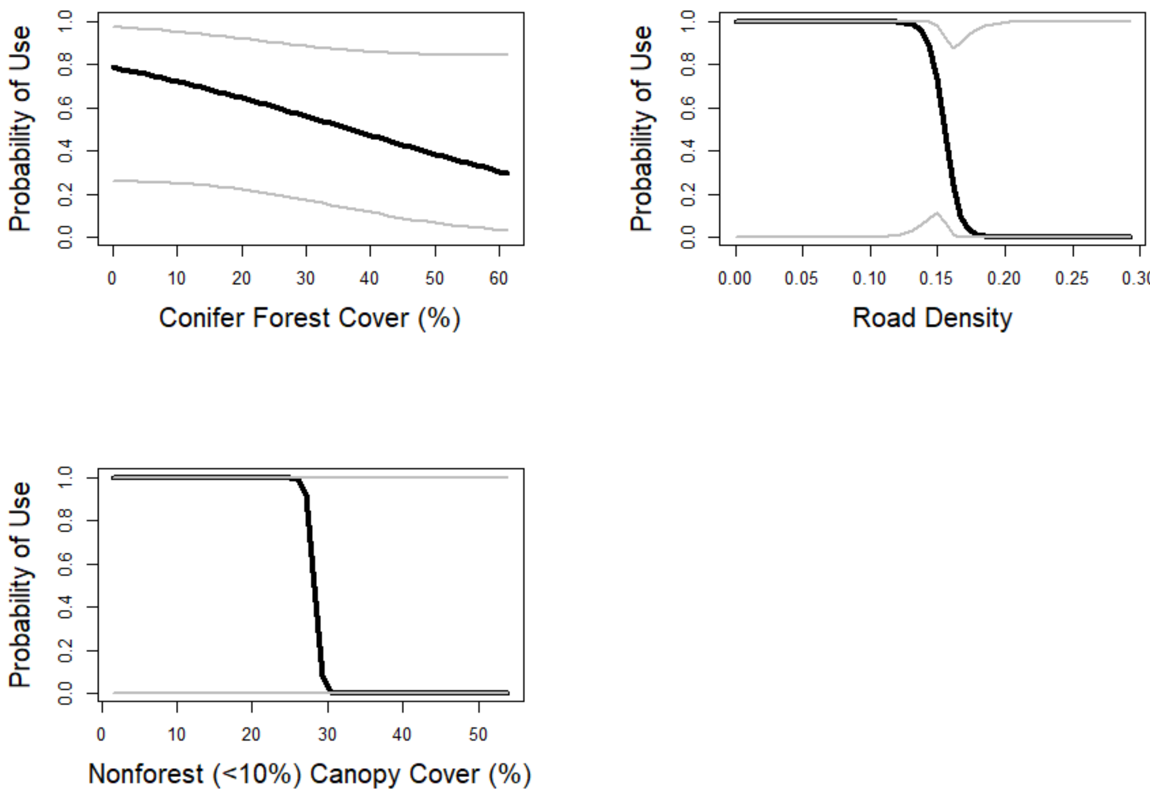

Figure 2.4. Probability of fisher occupancy (*ψ)* on the Leech Lake Band of Ojibwe Reservation as a function of landscape covariates from top AIC$_c$-ranked models.

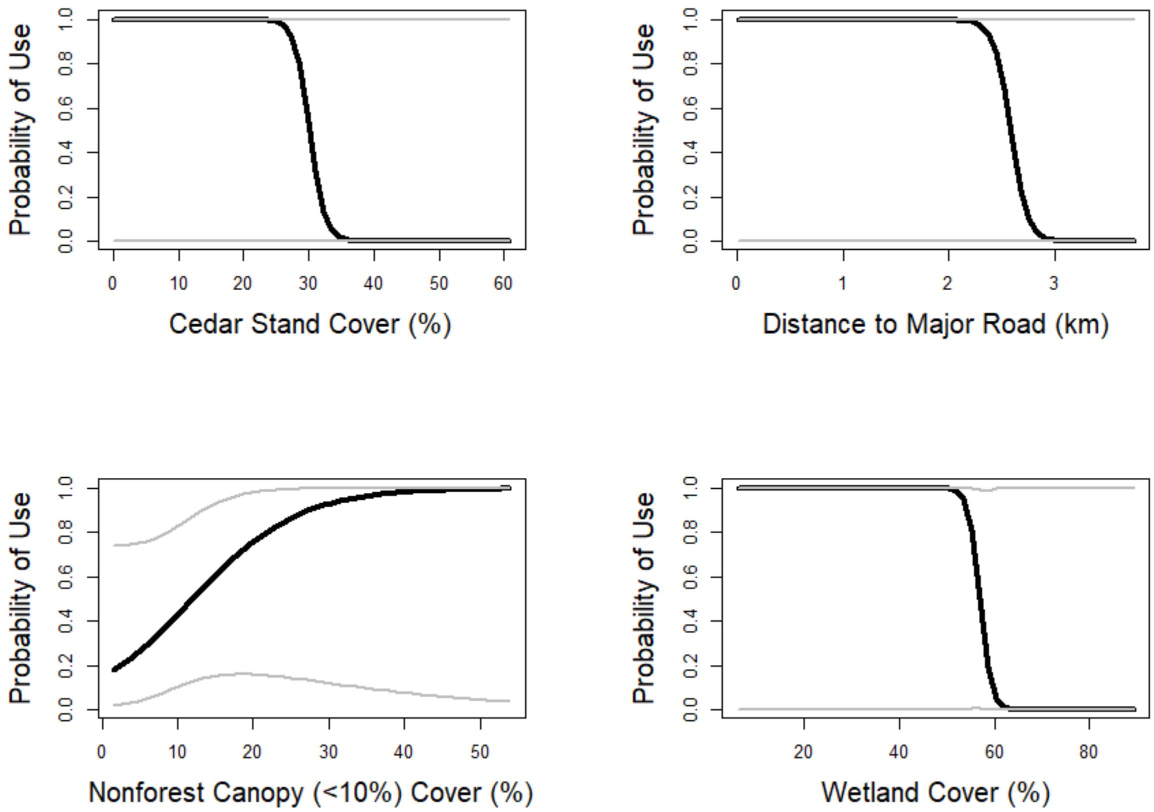

Figure 2.5. Probability of bobcat occupancy (*ψ)* on the Leech Lake Band of Ojibwe Reservation as a function of landscape covariates from top AIC$_c$-ranked models.

Chapter 3: Temporal Activity Patterns of Snowshoe Hare and Their Mammalian Predators on the Leech Lake Band of Ojibwe Reservation, Minnesota

Introduction

Reliable detection and monitoring of carnivores is essential to their management but, can prove difficult for agencies with limited resources (labor, finances, equipment, etc.; Noon et al. 2012). Low densities and elusive behaviors of cryptic carnivore species present challenges to conventional methods such as live-trapping which are often invasive, financially prohibitive over large geographic areas, and potentially culturally inappropriate (Ramos 2018, Miranda Paez et al. 2021). The relatively low cost and noninvasive nature of remote camera trapping, however, can remediate some of these challenges. Camera trapping is a precise, cost-effective, and less invasive method when compared to other techniques for monitoring mammals (Sirén et al. 2016, Miranda Paez et al. 2021). Photo data gathered from camera trapping are the basis for several methods to estimate metrics such as population abundance and distribution (Heilbrun et al. 2003, Alonso et al. 2015, Sirén et al. 2016). Precise date and time data for each photo also allows researchers to observe species temporal activity patterns and how they relate to external variables such as habitat, prey availability, or the presence of other sympatric carnivores (Bu et al. 2016, Vilella et al. 2020, Mori et al. 2021). These methods can be used to reveal patterns of activity avoidance or overlap, revealing insights into how sympatric carnivores competing for spatial and prey resources coexist. Temporal avoidance may be a type of niche partitioning that supports intra-guild carnivore co-existence by reducing the potential for negative interactions (Linnell and Strand 2000, Barrull et al. 2013, Vilella et al. 2020). Degree of temporal overlap may also indicate the dietary importance of prey species for predators; predators may synchronize their hunting activity to align with the activity patterns of a certain prey species, increasing activity overlap and thereby reducing energy output when foraging (Brown et al. 2001, Barrull et al. 2013). Understanding inter-species interactions is essential for research aiming to gain holistic insight into multiple sympatric species simultaneously.

Snowshoe hare (*waabooz; Lepus americanus*) is a species of cultural significance and management concern to the Leech Lake Band of Ojibwe (LLBO; LLBO Division of Resource Management [DRM] 2018). Historically abundant across the Leech Lake Reservation (LLR; *Gaa-zagaskwaajimekaag*), snowshoe hare populations have declined in recent years, raising concerns within the community. As a prey species, snowshoe hare mortalities are attributed mostly to predation (LLBO DRM 2018), and in order to sustain long-term population stability and growth, snowshoe hares must have access to habitats that provide high-quality cover from predators (Holbrook et al. 2017). Dense vegetative ground cover is lacking throughout most of the LLR due to historic timber harvest and fire suppression, however, some habitats such as northern white cedar (*giizhik; Thuja occidentalis*) stands provide this type of cover and as a result are used disproportionately by snowshoe hare (LLBO DRM 2018). Because snowshoe hares have a disproportionate effect on the ecosystems they inhabit (Krebs et al. 2001), long term population declines no doubt affect the carnivore species that prey on them. American martens (*waabizheshi; Martes americana*), fishers (*ojiig; Pekania pennanti*), bobcats (*gidigaa-bizhiw; Lynx rufus*), and red foxes (*waagosh; Vulpes vulpes*) are all regulated fur-bearing species within the LLR, with varying degrees of dietary reliance on snowshoe hare amongst them (Johnson 1970, Raine 1987, Newbury and Hodges 2018). Additionally, not only are martens and fishers culturally significant species to the LLBO, but population trends have also exhibited long-term declines across the region (Erb 2019).

The purpose of this research was to better understand the interactions between snowshoe hares, their predators, and cedar stands within the LLBO Reservation using camera trapping, and to use this information to inform management for the benefit of the LLBO community. My objectives were to evaluate the temporal activity patterns of snowshoe hares, martens, fishers, and bobcats and how these related to habitat classifications characterized by cedar stands (*e.g.* inside cedar stands vs outside of cedar stands), which are used disproportionately to their availability on the landscape by snowshoe hare. Additionally, I included red foxes in my analysis because I detected them frequently at camera traps and they are a common predator of snowshoe hare within the LLR. Specifically, I aimed to address the following questions; 1) do martens, fishers, bobcats, and red foxes exhibit temporal avoidance of each other, 2) do martens, fishers, bobcats and red foxes exhibit temporal overlap with snowshoe hares, and 3) do species exhibit differences in temporal activity between habitat classifications?

Study Area

I conducted my research within the boundaries of the 3,518 km^2 LLR in northern Minnesota, covering portions of Beltrami, Cass, Hubbard, and Itasca counties (47.3654, -94.3462; Figure 1). The LLR straddles the transition zone between the Great Lakes temperate deciduous forests and the Canadian taiga The LLR includes deciduous forest (25.6%), wetlands (26.4%), open water (29.1%), coniferous and mixed forest (11.8%), shrub/scrub (1.6%) and northern white cedar stands (1.9%; Dewitz 2021), with a combined paved and unpaved road density of 0.82 km/km^2. Summers are hot and humid with mean temperatures between 12.4°C to 24.4°C and an annual mean of 68.6 cm of rainfall. Winters are cold and dry with mean temperatures between -18.5°C to -6°C accompanied by 113.5 cm of snowfall, which is typically present from December to April (Cass Lake; National Oceanic and Atmospheric Administration 2021). The LLBO and the United States Federal Government established the LLR with the Treaty of 1855. Since its inception, land ownership within the LLR has become increasingly fragmented; <5% of the total land area belongs to the tribe (50.2 km^2 of allotted lands, 34.8 km^2 of Band land, and 54.14 km^2 of Minnesota Chippewa Tribe land), with the remaining area owned by private landowners and county, state, or federal agencies. The Chippewa National Forest (CPF), operated by the United States Forest Service (USFS) overlaps ~90% of the LLR and is the largest private landowner within the Reservation boundaries. I conducted all sampling with approval and appropriate permitting from Bemidji State University and the LLBO Division of Resource Management (DRM; Appendix A, Appendix B).

Methods

Camera Trapping. I set a total of 40 locations with camera traps during the winters of 2020–2021 and 2021–2022 (December–March) within the LLR. Cameras were active for 24 h/day for ~21 days for a total of 1,680 trap nights. I identified 2 spatial landcover classifications within the Reservation based on the presence of lowland northern white cedar stands (inside cedar stands [IC]; outside of cedar stands [OC]). I established camera sites using a paired stratified random design; 20 sites were randomly located inside of lowland cedar stands >50 m from the edge and 20 were randomly located outside of lowland cedar stands but within 0.5–2.5 km of a paired IC location, remaining within the lower spatial limit of marten home range size (Dumyahn et al. 2007, Linden et al. 2017). Two cameras were deployed at each camera trap site approximately 5 m apart, 1 infrared ground camera (Dark Ops Apex, Browning; Morgan, Utah, USA) positioned 15–30 cm above the ground to be triggered by the torso of an adult bobcat (Heilbrun et al. 2003), and 1 white-flash platform camera (NWF18, Covert; Superior, Wisconsin, USA) placed approximately 1.5 m above ground and 1.5 m from a bait station platform. Ground cameras were set to take a series of 3 photos per trigger with a 10 second pause between triggers. Platform cameras were set to take a single photo when triggered. I attached bait station platforms to a tree ~1.5 m above ground and baited with a sardine can secured with a hose-clamp above the standing platform. A log harvested from the nearby area rested on the bait station directly below the standing platform to act as a run pole allowing fisher/marten to access the bait (Figure 2). I set camera trap locations with a cotton ball soaked in skunk lure attractant (Gusto, Caven's Quality Animal Lures: Pennock, Minnesota, USA), placed inside a small plastic bottle and secured with wire to a nearby branch approximately 2 m above the ground. All camera trapping procedures were approved by the Bemidji State University Institutional Animal Care and Use Committee (protocol #21-1; Appendix A). I conducted all sampling with approval and appropriate permitting (Appendix B) from the LLBO Division of Resource Management (DRM).

Temporal Activity Analysis. I extracted camera trap location, species, and time metadata and compiled into a database using the *Camelot* application (Hendry and Mann 2018). To maximize independence between detections, I thinned data to 30-minute intervals so that photos of the same species captured at the same camera within a 30-

minute window were counted as a single detection (Bu et al. 2016). I then organized data by site (IC, OC) and species. Detections by both cameras at each site were combined into a single database and treated as one camera site and I pooled detections across years. Diel activity patterns were classified as predominantly diurnal, crepuscular, nocturnal, or irregular based on sunrise, sunset, and astronomical twilight times for the study area and season. Sunrise and sunset times varied by approximately 2 hours throughout the length of the winter field season, ranging from 06:00–08:00 for sunrise and 17:00–19:00 for sunset. I transformed time into radians (24 hr) and fitted detection data with a kernel density function using the *overlap* package in Program R (Ridout and Linkie 2009). I calculated activity overlap for 3 contexts with differing combinations of species detections and habitat types (inside cedar stands [IC], and outside of cedar stands [OC]): Context 1) a comparison of all detections for species A vs. species B; Context 2) a comparison for detections of species A vs. species B within habitat types (IC and OC); and Context 3) a comparison of detections for a singles species between habitats (IC vs. OC). To estimate the overlap between species activity curves without true density distributions, I used a general nonparametric estimator of coefficient of overlap ($\hat{\Delta}_1$; Meredith and Ridout 2021). $\hat{\Delta}_1$ estimates the coefficient of overlap for all data combinations with sample sizes of <50, ranging from 0 (no overlap of activity patterns) to 1 (100% overlap of activity patterns). I calculated confidence intervals (95%) around $\hat{\Delta}_1$ by adjusting the raw percentiles of 10,000 bootstrapped sample estimates to account for bootstrap bias (Meredith and Ridout 2021). Due to low detections of some species, I could not compare overlaps of all species for all 3 contexts.

Results

I recorded 95 combined independent detections (detection rate = 0.056/day) of snowshoe hares, martens, fishers, bobcats, and red foxes at 27 sites, the majority of which occurred within cedar stands (Table 3.1). At these sites, the average number of days until first detection was 13 days for bobcats (n=7 sites), 16 days for martens (n=2 sites), 18 days for both fishers (n=13 sites) and red foxes (n=7 sites) and 20 days for snowshoe hares (n=13 sites). Independent detection rates for sites across the entire trapping period were low (mean = 2.3 detections/site; IC mean = 3.2; OC ave = 1.6), with most detections concentrated at 2 IC sites, both exclusively hare (IC15 = 16; IC16 = 10). Species richness at sites was also generally low (Figure 3). Species detections varied between sites with more than 84% of both snowshoe hare and bobcat detections occurring in cedar stands, most marten and fisher detections occurring at OC sites, and 100% of red fox detections occurring at OC sites (Table 3.1). At sites where I detected hares, I detected fishers the most frequently out of the predator species, (n = 4), followed by red foxes (n = 3), and bobcats (n = 2). Notably, I did not detect marten at sites where I also detected snowshoe hares, but I did detect fishers at all sites where martens were also detected. Cameras captured a total of 6 (martens: n=1, fishers: n=3, bobcats: n=2) individuals with adequate unique markings to identify individually, and these data were insufficient to estimate abundance.

Activity Overlap. Each species exhibited some degree of either nocturnal or crepuscular activity patterns when both IC and OC site activity were combined (Figure 4). Snowshoe hares were distinctly nocturnal, displaying a unimodal activity peak between 20:00–0:500. Both martens and bobcats demonstrated characteristic crepuscular activity patterns, with 2 distinct peaks during pre-dawn twilight (04:12–06:11) and dusk twilight (18:47–20:34), both with minor activity peaks during nocturnal pre-dawn hours (~02:30). Red fox and fisher activity patterns were irregular, spanning more broadly throughout the 24-hour period than other species, but still exhibiting the greatest activity peaks around sunrise and sunset.

Only snowshoe hare and fisher detections yielded sufficient data to compare activity overlaps between habitat types for individual species. Fisher displayed substantially different activity patterns between habitat types ($\hat{\Delta}_1 = 0.45$, CI = 0.19–0.69; Table 3.1): distinctly crepuscular at IC sites with peaks occurring at sunrise (06:00–07:58) and sunset (16:58–18:49), and mainly nocturnal at OC sites (Figure 5). Hare activity was less variable between habitat types ($\hat{\Delta}_1 = 0.66$, CI = 0.40–0.87; Table 3.1) but was also characterized as nocturnal at OC sites, with activity broadening into daylight hours at IC sites (Figure 5). The combined detections for martens, fishers, bobcats, and red foxes as single 'predators' category also exhibited distinctly crepuscular patterns inside cedar stands and more nocturnal patterns outside of cedar stands (Figure 6). Predator vs. snowshoe hare activity overlaps by habitat type exhibited lower activity overlaps inside of cedar stands ($\hat{\Delta}_1 = 0.48$, CI = 0.28–0.68; Table 3.1) compared with outside of cedar stands ($\hat{\Delta}_1 = 0.59$, CI = 0.33–0.83; Table 3.1).

When activity at both OC and IC sites were combined for all species, martens and fishers exhibited the greatest degree of overlap with snowshoe hares (marten: $\hat{\Delta}_1 = 0.65$, CI = 0.29–0.98; fisher: $\hat{\Delta}_1 = 0.65$, CI = 0.46–0.82; Figure 4; Table 3.2). Overlap between red foxes and snowshoe hares was similar, ($\hat{\Delta}_1 = 0.62$, CI = 0.39–0.84), and bobcats activity overlapped with hares was the least of all the predators ($\hat{\Delta}_1 = 0.44$, CI = 0.19–0.69). When comparing predator species, red foxes and fishers had the greatest degree of overlap ($\hat{\Delta}_1 = 0.73$), greater also than all other activity overlaps for any other contexts of species interactions (Figure 4; Table 3.2). Bobcats and fishers displayed the lowest activity overlap ($\hat{\Delta}_1 = 0.41$, CI = 0.18–0.63), also the lowest of any other context. Activity overlap of bobcats with other species were also consistently lower than any other species combinations within this context. Other comparisons of activity overlap between predators displayed similar degrees of overlap ($\hat{\Delta}_1$ = 0.43–0.55; Figure 4, Table 2).

When analyzing OC and IC site detections separately, activity overlaps revealed more nocturnal patterns at OC sites and broader crepuscular patterns at IC sites for both snowshoe hare and predator species (Figure 6). However, low detections at IC sites limited overlap analysis within this context to just 3 target species: hares, fishers, and bobcats. Of these, all displayed relatively low degrees of overlap, the lowest of which was bobcat and hare ($\hat{\Delta}_1 = 0.45$, CI = 0.19–0.73; Figure 6). By comparison, the degree of activity overlap between species at OC sites was generally greater than the degree of activity overlap between species at IC sites, with fishers and hares overlapping the most ($\hat{\Delta}_1 = 0.66$, CI = 0.38–0.91; Figure 6). Red foxes, who were detected exclusively at OC sites and who's activity displayed the broadest activity patterns, overlapped the least of any species with both hares and other predators (Figure 6).

Discussion

Snowshoe hare populations have been declining within this study area, largely due to loss of quality habitat which provides dense vegetative cover from predators. (LLBO DRM 2018, Erb 2019). During the low phase of the population cycle, and when predation risk is high, snowshoe hare will prioritize habitats with sufficient cover from predators (Keith and Windberg 1978, Majcharzak et al. 2022), which are characterized less by species composition than by dense horizontal ground cover (Sultaire et al. 2016). Cedar stands are one of the few landcover types to provide this habitat within the Reservation but make up just 1.9% of the landcover. I detected snowshoe hare in cedar stands 84% of the time, confirming that snowshoe hare occur in cedar stands disproportionately to what is available on the landscape. Although cedar stands provide excellent cover from predators, this habitat is not ideal foraging habitat for snowshoe hare; when compared with deciduous species such as maple (*Acer spp.*) and aspen, cedar provided the lowest nutritional availability (Walski and Mautz 1977). Despite low nutritional availability, hares consistently prioritize habitats with sufficient cover from predators such as lowland cedar stands over habitat with greater food availability (Majcharzak et al. 2022). When comparing temporal activity between habitat types (IC vs. OC), snowshoe hares exhibited broader activity patterns inside of cedar stands, and distinct nocturnal activity outside of cedar stands. In other words, snowshoe hare rarely travel outside of the safety of cedar stands unless under the cover of darkness, when it is easier to hide. This behavior suggests snowshoe hare adapt their temporal activity patterns to availability of cover, becoming more nocturnal in the absence of vegetative cover, consistent with the research of Gigliotti and Diefenbach (2018) who found during high-risk, high-visibility full moon nights, snowshoe hare balanced predation risk with foraging and thermo-regulation requirements by selecting for areas with denser cover. As white cedar stands become increasingly fragmented from each other and isolated from areas of high-quality foraging habitat, metapopulation dynamics of snowshoe hare will likely become degraded over time. Small, scattered pockets of cedar stands are essential refugia habitat for snowshoe hare but may act as ecological traps. Predators may regularly search these cedar pockets and hare must eventually leave cover to forage, hampering both movement between isolated cedar stands and population expansion of snowshoe hare outside of cedar stands. Indirect predation pressure induced stress may also cause increased cortisol levels in hares which have been found to decrease reproduction (Sheriff et al. 2009). Decreased reproduction combined with decreased interaction between meta-populations will likely cause declines in genetic variability and resiliency over time (Cheng et al. 2014).

Low prey densities may also influence predator diel activity, causing greater temporal overlaps among predator species. In areas of low prey density, predators may become more active throughout the diel cycle as opposed to displaying distinct daily activity patterns such as crepuscular or nocturnal (Karanth et al. 2017). While all predator species exhibited predominantly crepuscular activity patterns, both red foxes and fishers were markedly active more broadly during daylight hours, and also exhibited the greatest degree of temporal overlap of any species combination. During winter, food resources such as fruits and insects are less accessible for generalist predators, causing a dietary shift toward small mammals such as snowshoe hares (Raine 1981, Padial et al 2002, Dell'Arte et al. 2007). Predators who exhibit high degrees of temporal activity overlap despite sharing other resources such as habitat and diet may indicate other dimensions of niche partitioning (Karanth et al. 2017, Mori et al. 2021). Though fisher and red fox activity overlap was greatest when IC and OC site detections were combined, red foxes were detected exclusively at OC sites, while fisher detections were more evenly distributed between habitats, suggesting despite high temporal overlap, cedar stand micro-habitat use may be the driving factor of niche partitioning between these two species. Alternatively, the lowest degree of temporal overlap was between bobcats and fishers. Bobcats are known to prey on juvenile and adult fishers within the study area, indicating inter-species competition (Erb 2016). Low activity overlaps combined with high detections for both fishers and bobcats within IC sites suggests these two species actively avoid negative interactions by maintaining niche partitioning through temporal segregation. While intra-guild predation between sympatric fishers and martens has been documented (McCann et al. 2010, Manlick et al. 2017), I found no evidence indicating temporal avoidance to mitigate negative competitive interactions. This is consistent with Kautz et al. (2021) who found that coexistence between martens and fishers is facilitated by vigilance and short-term avoidance.

The degree of temporal activity overlap between all target species were comparable to that of similar studies (Foster et al. 2013, Bu et al. 2016). Activity overlaps between predator species and snowshoe hare indicated that predator species were synchronizing their activity patterns with that of snowshoe hare. I found that fishers and red foxes exhibited high degrees of temporal overlap with hares and were detected more often than martens or bobcats at sites that also detected snowshoe hares, suggesting that snowshoe hares are an important food source for these species (Brown et al. 2001, Barrull et al. 2013). Despite the high temporal overlaps between martens and snowshoe hares, detections rates for martens were generally low and martens were absent from sites that also detected snowshoe hares.

The detection rates I observed were sufficient for temporal activity analysis, but insufficient for spatial capture-recapture abundance estimates. When compared with similar studies, both detection and capture rates were low (Bu et al. 2016, Sirén et al.

2016, Robinson et al. 2017, Vilella et al. 2020). The recommended trap density for spatial capture-recapture density estimates is 4 camera traps per home range (Otis et al. 1978), though more recently Sun et al. (2014) demonstrated a clustered configuration with wider spacing between sites can accurately estimate abundance. The number of camera traps per cluster, however, should increase as expected detection rates decrease. The expected detection rates of species within my study area were unknown, and resources limited cluster sizes to 2 camera traps each, with an average distance between clusters of ~18 km. Initial detection latency was long compared to similar studies (Robinson et al. 2017), despite the use of both lure and bait. Latent detection rates may indicate trap shyness, however, based on comparisons with similar protocol (Sirén et al. 2016) as well as regional reports of decreasing numbers in recent years (Erb 2019), the latent and low detection rates I observed more likely indicate low densities of snowshoe hares, martens, fishers and bobcats across the LLR. The geographic range of the LLR, combined with low densities and small home range size of the smallest female carnivore species (marten; 2.5 km^2; Dumyahn et al. 2007, Linden et al. 2017), suggests that accurate abundance estimation would require either more camera trap sites spaced throughout the LLR or more cameras traps per cluster. Results of this study should be regarded with caution due to the low detection rates for most species. Sample sizes of less than 20 independent detections may produce activity curves that are unreliable (Lashley et al. 2018); independent detection of marten, red fox, and bobcat were less than the recommended minimum while the number of fisher and hare detections exceeded this threshold. Snowshoe hare detections exceeded recommended thresholds to estimate activity curves comparable to those obtained through more intensive radio-tracking methods (Lashley et al. 2018).

Management Implications

My results suggest temporal segregation contributes to co-existence within a sympatric carnivore guild and their shared prey; and that availability of high-quality habitat influences temporal activity of both prey and predator species on the LLR. Assuming similar logistical and financial constraints, managers may consider multiple changes to camera trap methodology to improve future detection of multiple carnivores across the LLR: 1) set camera traps for longer time periods without re-baiting, 2) abandon explicit use of white flash cameras, 3) consider camera locations based on other important research variables (*e.g.* recent clear cuts, red pine plantations, adjacent to low use road *etc.*). Setting cameras for longer periods of time may mitigate long detection latency for target species, while allocating resources away from re-baiting will likely have little effect on detection as most bait did not need replacing. Use of white flash cameras was important for identifying individuals for abundance estimations; however, they are unnecessary for simple detection indices which can be achieved with more commonly available camera traps.

The disproportionate use of cedar stands by snowshoe hare clearly indicates the importance of the habitat to hare survival. When managing for snowshoe hare, biologists should consider protection of cedar stands and other habitats with dense vegetative cover from destruction or further fragmentation. In areas where timber harvest is unavoidable, managers should consider harvest methods that avoid clear-cutting, as clear-cut habitats are avoided by snowshoe hare for up to 4 years after logging (Ferron et al. 1998).

Managers may consider identifying potential travel corridors between larger cedar stands and other high-quality habitat as areas of future habitat improvement or protection. Travel corridors and expansion of isolated high quality habitat islands will provide opportunities for population expansion and genetic diversity, which may in turn support predator diversity.

References

Alonso, R. S., B. T. McClintock, L. M. Lyren, E. E. Boydston, and K. R.Crooks. 2015. Mark–recapture and mark–resight methods for estimating abundance with remote cameras: a carnivore case study. PLoS ONE 10:1–13.

Barrull, J., I. Mate, J. Ruiz-Olmo, J. G. Casanovas, J. Gosàlbez, and M. Salicrú. 2013. Factors and mechanisms that explain coexistence in a Mediterranean carnivore assemblage: an integrated study based on camera trapping and diet. Mammalian Biology 79:123–131.

Brown, J. S., B. P. Kotler, and A. Bouskila. 2001. Ecology of fear: foraging games between predators and prey with pulsed resources. Annales Zoologici Fennici 38:71–87.

Bu, H., F. Wang, W. J. McShea, Z. Lu, D. Wang, and S. Li. 2016. Spatial co-occurance and activity patterns of mesocarnivores in the temperate forests of southwest China. PLoS ONE 11:10.

Cheng E., K. E. Hodges, J. Melo-Ferreira, P. C. Alves, and L. S. Mills. 2014. Conservation implications of the evolutionary history and genetic diversity hotspots of the snowshoe hare. Molecular Ecology 23:2929–2942.

Dell'Arte, G. L., T. Laaksoned, K. Norrdahl, and E. Korpimäki. 2007. Variation in the diet composition of a generalist predator, the red fox, in relation to season and density of main prey. Acta Oecologica 31:276–281.

Dewitz, J., and U.S. Geological Survey. 2021. National Land Cover Database 2019 Products (ver. 2.0, June 2021), U.S. Geological Survey data release.

Dumyahn, J. B., P. A. Zollner, and J. H. Gilbert. 2007. Winter home-range characteristics of American marten (*Martes americana*) in northern Wisconsin. The American Midland Naturalist 158:382–394.

Erb, J., P. Coy, and B. Sampson. 2016. Survival and causes of mortality for fishers and martens in Minnesota. Minnesota Department of Natural Resources, Minnesota, USA.

Erb, J. 2019. Furbearer winter track survey summary. Minnesota Department of Natural Resources, Forest Wildlife Research Group, Minnesota, USA

Ferron, J., F. Potvin, and C. Dussault. 1998. Short-term effects of logging on snowshoe hares in the boreal forest. Canadian Journal of Forest Research 28:1335–1343.

Foster, V. C., P. Sarmento, R. Sollmann, N. Torres, A. T. Jacomo, N. Negroes, C. Fonseca, and L. Silveira. 2013. Jaguar and puma activity patterns and predator-prey interactions in four Brazilian biomes. Biotropica 45:373–379.

Gigliotti, L. C., and D. R. Diefenbach. 2018. Risky behavior and its effect on survival: snowshoe hare behavior under varying moonlight conditions. Journal of Zoology 305:27–34

Heilbrun, R. D., N. J. Silvy, M. E. Tewes, and M. J. Peterson. 2003. Using automatically triggered cameras to individually identify bobcats. Wildlife Society Bulletin 31:748–755.

Hendry, H., and C. Mann. 2018. Camelot—intuitive software for camera-trap data management. Oryx 52:15–15.

Holbrook, J. D., J. R. Squires, L. E. Olson, R. L. Lawrence, and S. L. Savage. 2017. Multiscale habitat relationships of snowshoe hare (*Lepus americanus*) in the mixed conifer landscape of the Northern Rockies, USA: cross-scale effects of horizontal cover with implications for forest management. Ecology and Evolution 7:125–144.

Johnson, W. J. 1970. Food habits of the red fox in Isle Royale National Park, Lake Superior. The American Midland Naturalist 84:568–572.

Karanth, K. U., A. Srivathsa, D. Vasudev, M. Puri, R. Parameshwaran, and N. S. Kumar. 2017. Spatio-temporal interactions facilitate large carnivore sympatry across a resource gradient. Proceedings of the Royal Society B: Biological Sciences 284:20161860.

Kautz, T. M., D. E. Beyer Jr., Z. Farley, N. L. Fowler, K. F. Kellner III, A. L. Lutto, T. R. Petroelji, and J. L. Belant. 2021. American martens use vigilance and short-term avoidance to navigate a landscape of fear from fishers at artificial scavenging sites. Scientific Reports 11:12146.

Krebs, C. J., S. Boutin, and R. Boonstra. 2001. Ecosystem dynamics of the boreal forest: the Kluane project. Oxford University Press, New York, USA.

Lashley, M. A., M. V. Cove, M. C. Chitwood, G. Penido, B. Gardner, C. S. Deperno, and C. E. Moorman. 2018. Estimating wildlife activity curves: comparison of methods and sampling size. Scientific Reports 8:4173

Leech Lake Band of Ojibwe Division of Resource Management (LLBO DRM). 2018. Influence of forest structure and composition on the space use and survival of snowshoe hare (Lepus americanus). Annual report. Leech Lake Band of Ojibwe, Cass Lake, Minnesota, USA.

Linden, D. W., A. Fuller, J. Royle, and M. Hare. 2017. Examining the occupancy-density relationship for a low-density carnivore. Journal of Applied Ecology 54:2043–2052.

Linnell, J. D., and O. Strand. 2000. Interference interactions co-existence and conservation of mammalian carnivores. Diversity and Distributions 6:169–176.

Majcharzak, Y. N., M. J. Peers, E. K. Studd, A. K. Menzies, P. D. Walker, S. Shiratsuru, L. K. McCaw, R. Boonstra, M. Humphries, and T. S. Jung. 2022. Balancing food acquisition and predation risk drives demographic changes in snowshoe hare population cycles. Ecology Letters 00:1–11.

Manlick, P. J., J. E. Woodford, B. Zuckerberg, and J. N. Pauli. 2017. Niche compression intensifies competition between reintroduced American martens (*Martes americana*) and fishers (*Pekania pennanti*). Journal of Mammology 98:690–702

McCann, N. P., P. A. Zollner, and J. H. Gilbert. 2010. Survival of adult martens in northern Wisconsin. Jounral of Wildlife Management 74:1502–1507.

Meredith, M., and M. Ridout. 2021. Overview of the overlap package. https://cran.r-project.org/web/packages/overlap/vignettes/overlap.pdf. Accessed 31 Jan 2023.

Miranda Paez, A., M. Sundaram, and J. R. Willoghby. 2021. Comparison of minimally invasive monitoring methods and live trapping in mammals. Genes 12:1–10.

Mori, E., C. Paniccia, B. Munkhtsog, M. Cicero, and C. Augugliaro. 2021. Temporal overlap among small and medium sized mammals in grassland and forest-alpine meadow of central Asia. Mammalian Biology 101:153–162.

National Oceanic and Atmospheric Administration [NOAA]. 2021. National Weather Service internet services team. Climate normals for Cass Lake, Minnesota. https://www.ncdc.noaa.gov/cdo-web/datatools/normals. Accessed on 31 Jan 2023.

Newbury, R. K., and K. E. Hodges. 2018. Regional difference in winter diets of bobcats in their northern range. Ecology and Evolution 8:11100–11110.

Noon, B. R., L. L. Bailey, T. D. Sisk, and K. S. McKelvey. 2012. Efficient species-level monitoring at the landscape scale. Conservation Biology 26:432–441.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:3–135.

Padial, J. M., E. Ávila, and J. M. Gil-Sánchez. 2002. Feeding habits and overlap among red fox (*Vulpes vulpes*) and stone marten (*Martes foina*) in two Mediterranean mountain habitats. Mammalian Biology 67:137–146.

Raine, R. M. 1987. Winter food habits and foraging behavior of fishers (*Martes pennanti*) and martens (*Martes americana*) in southeastern Manitoba. Canadian Journal of Zoology 65: 745–747.

Ramos, S. C. 2018. Considerations for culturally sensitive traditional ecological knowledge research in wildlife conservation. Wildlife Society Bulletin 42:358–364

Ridout, M. S., and M. Linkie. 2009. Estimating overlap of daily activity patterns from camera trap data. Journal of Agricultural, Biological, and Environmental Statistics 14:322–337.

Robinson, L., S. A. Cushman, and M. K. Lucid. 2017. Winter bait stations as a multispecies survey tool. Ecology and Evolution 7:6826–6838.

Sheriff, M.J., C. J. Krebs, and R. Boonstra. 2009. The sensitive hare: sublethal effects of predator stress on reproduction in snowshoe hares. Journal of Animal Ecology 78:1249–1258.

Sirén, A. P. K., P. J. Pekins, P. L. Abdu, and M. J. Ducey. 2016. Identification and density estimation of American martens (*Martes americana*) using a novel camera-trap method. Diversity 8:3.

Sun, C. C., A. K. Fuller, and J. A. Royle. 2014. Trap configuration and spacing influences parameter estimates in spatial capture-recapture models. PLoS ONE 9:e88025.

Vilella, M., M. Ferrandiz-Rovira, and F. Sayol. 2020. Coexistance of predators in time: effects of season and prey availability on species activity within a Mediterranean carnivore guild. Ecology and Evolution 10:11408–11422.

Walski, T. W., and W. W. Mautz. 1977. Nutritional evaluation of three winter brose species of snowshoe hares. The Journal of Wildlife Management 41:144–147.

Tables

Table 3.1. Independent detections of species by habitat type.

Species	Inside Cedar	Outside Cedar	Total
Snowshoe hare	44	8	52
Marten	1	3	4
Fisher	6	7	20
Bobcat	8	1	9
Red fox	0	10	10

Table 3.2. Dhat1 ($\hat{\Delta}1$) activity overlap indiced with 95% confidence intervals (CI) for each overlap pair by combination context: All/Combined (IC + OC), Inside Cedar Stands (IC), and Outside Cedar Stands (OC).

	IC + OC		IC		OC	
Species	$\hat{\Delta}_1$	CI	$\hat{\Delta}_1$	CI	$\hat{\Delta}_1$	CI
Hare(IC)/Hare(OC)	0.66	0.40 – 0.87				
Fisher(IC)/Fisher(OC)	0.45	0.19 – 0.69				
Hare/Predators	0.67	0.52 – 0.81	0.48	0.28 – 0.68	0.59	0.33 – 0.83
Marten/Hare	0.65	0.2 – 0.98			0.54	0.17 – 0.91
Fisher/Hare	0.65	0.46 – 0.82	0.42	0.19 – 0.64	0.66	0.38 – 0.91
Bobcat/Hare	0.44	0.19 – 0.69	0.45	0.19 – 0.73		
Red fox/Hare	0.62	0.39 – 0.84			0.45	0.17 – 0.72
Fisher/Marten	0.55	0.25 – 0.84			0.62	0.29 – 0.95
Bobcat/Fisher	0.41	0.18 – 0.63	0.43	0.17 – 0.67		
Bobcat/Marten	0.433	0.15 – 0.74				
Redfox/Marten	0.55	0.25 – 0.85			0.62	0.33 – 0.95
Redfox/Fisher	0.727	0.5 – 0.93			0.61	0.35 – 0.84
Red fox/Bobcat	0.507	0.25 – 0.77				

Figures

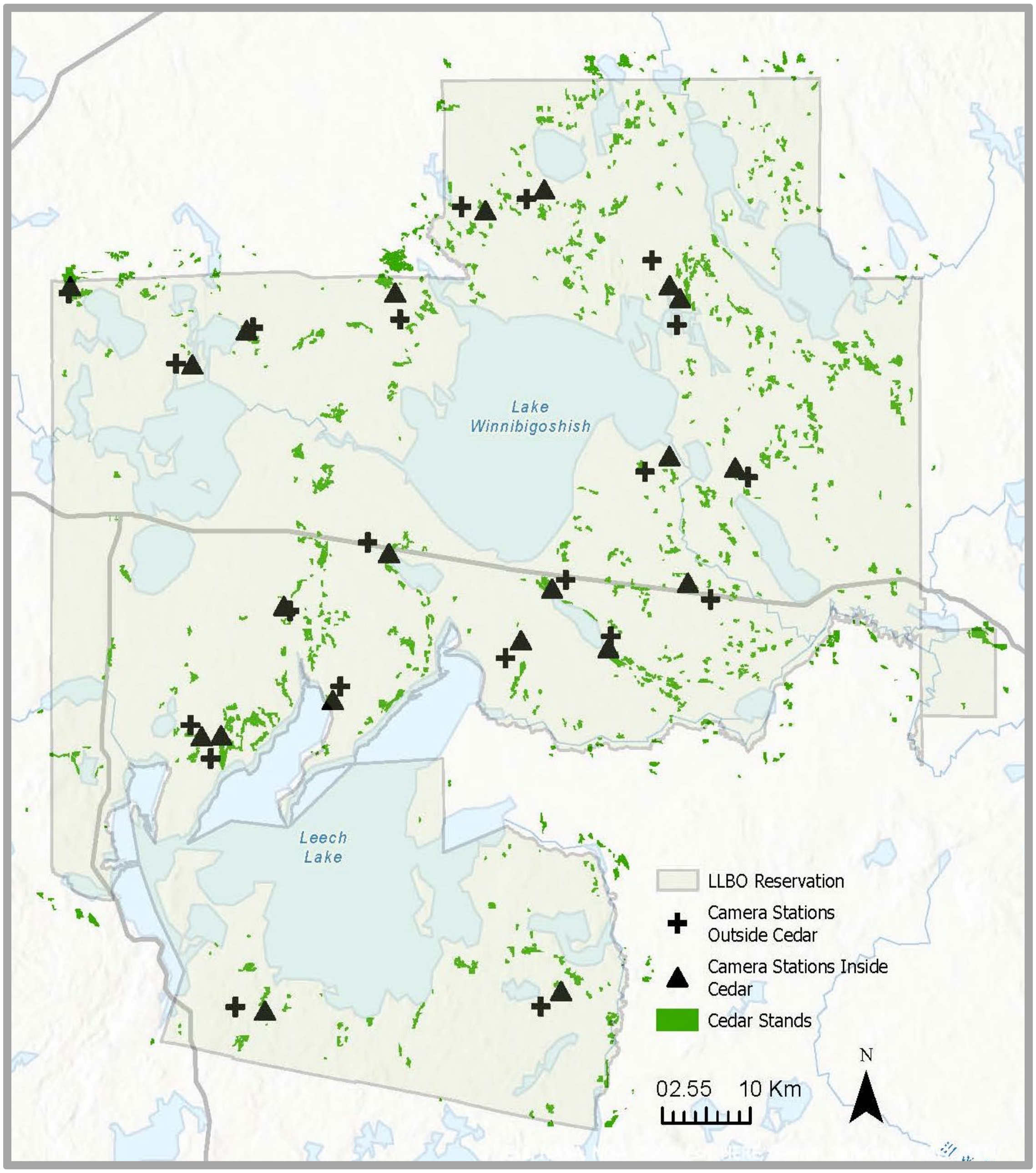

Figure 3.1. Leech Lake Band of Ojibwe (LLBO) reservation in northern Minnesota, USA. Location of camera trap sites distinguished by habitat type (inside cedar stands; IC/ outside of cedar stands; OC) are symbolized according to the legend.

Figure 3.2. Bait station stands were secured with run poles and cans of frozen sardines to encourage exposure of ventral patches on marten and fisher used for unique identification.

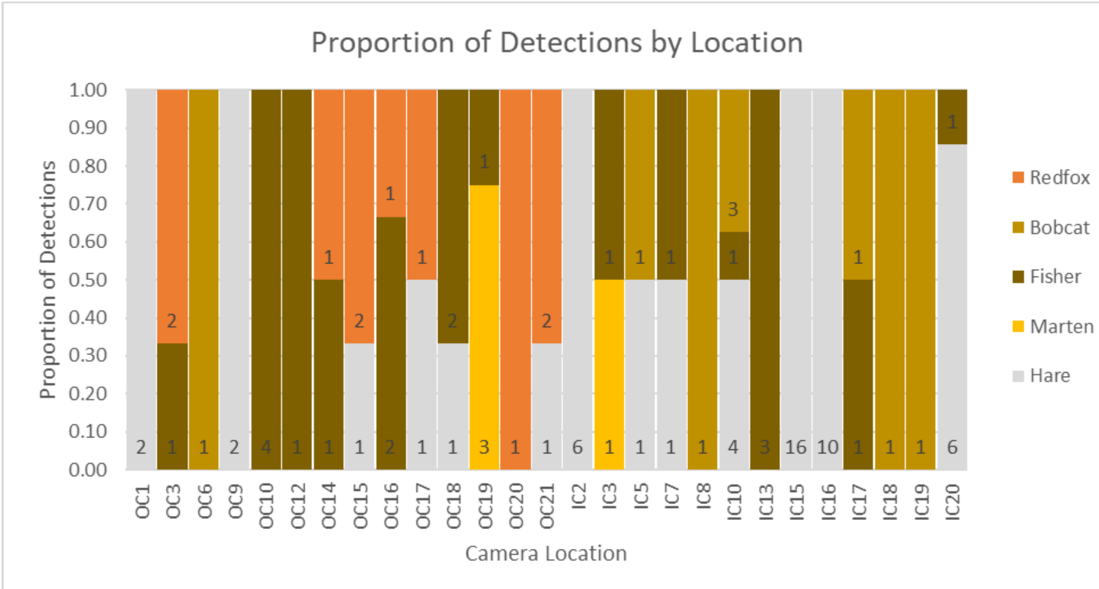

Figure 3.3. Proportion of independent detections of each species at each camera trap location. Detection counts are displayed within the bars for each species at that location.

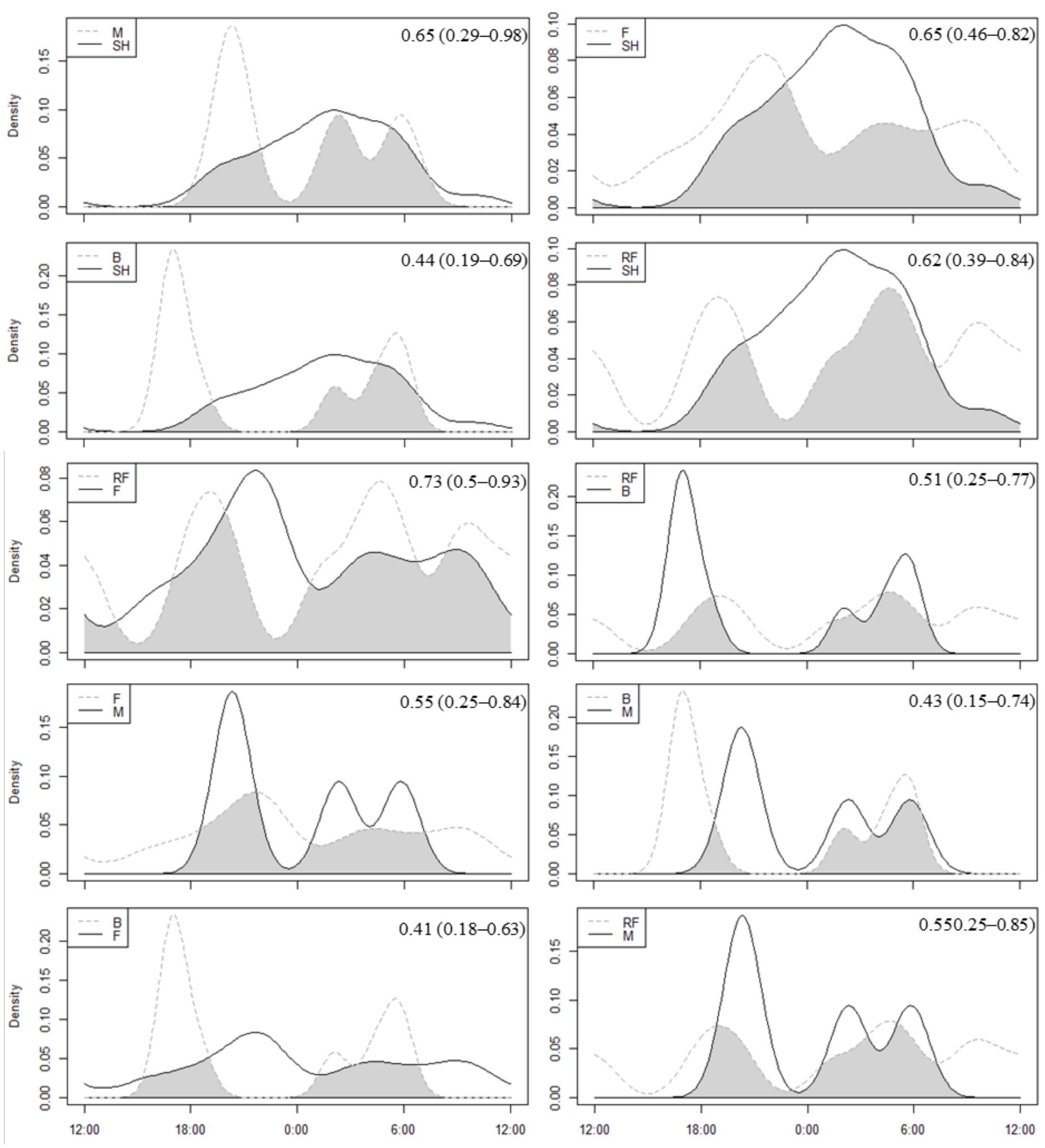

Figure 3.4. Diel activity patterns and temporal overlap of species from all sites (OC and IC combined). At the top right of each graph: Dhat1 activity overlap indiced with 95% confidence intervals. At the top left of each graph: legend with species abbreviations (SH-snowshoe hare; M-marten; F-fisher; B-bobcat; RF-redfox). Timing is centered on midnight (0:00).

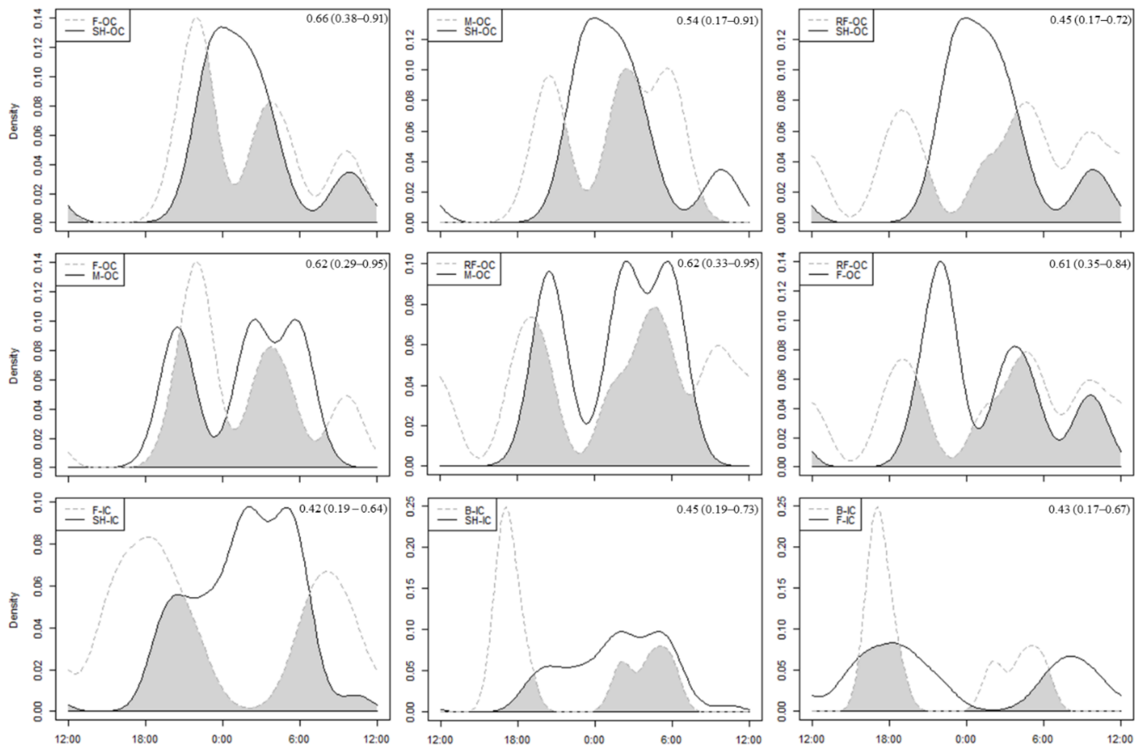

Figure 3.5. Diel activity patterns and temporal overlap of species by habitat type (OC, IC). At the top right of each graph: Dhat1 activity overlap indiced with 95% confidence intervals. At the top left of each graph: legend with species abbreviations (SH-snowshoe hare; M-marten; F-fisher; B-bobcat; RF-redfox) followed by habitat type abbreviations (IC-inside cedar stands; OC-outside of cedar stands). The top two rows are detections from only OC sites and the bottom row are detections from only IC sites. Timing is centered on midnight (0:00).

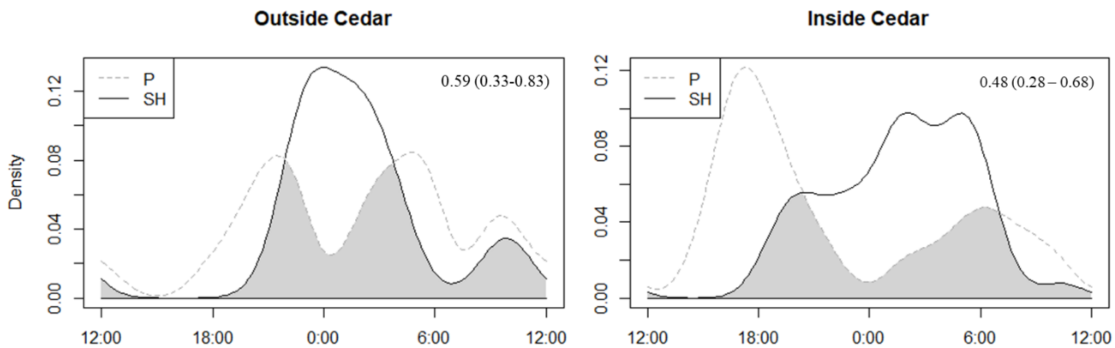

Figure 3.6. Diel activity patterns and temporal overlap of snowshoe hare and predators between habitat types (OC vs. IC). At the top right of each graph: Dhat1 activity overlap indiced with 95% confidence intervals. At the top left of each graph: legend with species abbreviations (SH-snowshoe hare; P-predators [marten, fisher, bobcat & red fox]).

APPENDIX A

Bemidji State University Institutional Animal Care and Use Committee approval of data collection protocols.

1

Office use only
Protocol Number___21-1______
Date Approved__11/22/2021_____
Date Expires___6/31/2022__

Bemidji State University
Animal Care and Use Review Form
Type all information into this form. Explain procedures as completely as possible for an evaluation of the proposal.

I. Investigator(s) and Protocol Title

Principal Investigator:
(include position and phone #)

Dr. Jacob Haus, Bemidji State University, Assistant Professor, 218-755-4372

Co-investigators:
(include position and phone #)

Tanya Roerick, Leech Lake Band of Ojibwe Division of Resource Management, Wildlife Biologist, 218-335-7428

Protocol Title:

Snowshoe hare (Waabooz; *Lepus americanus*) predator-prey dynamics on the Leech Lake Ojibwe Reservation

II. Type of project (check all that apply):

New project___x_____ Renewal________

Teaching project________ Research Project___x_____

III. Identify Species and Sources

Species	Source
snowshoe hare (*Lepus americanus*)	Leech Lake Band of Ojibwe Reservation
American marten (*Martes americana*)	Leech Lake Band of Ojibwe Reservation
fisher (*Pekania pennanti*)	Leech Lake Band of Ojibwe Reservation
bobcat (*Lynx rufus*)	Leech Lake Band of Ojibwe Reservation

IV. Purpose of Proposed Use

1. State rational for use of animals and for appropriateness of species used.

Snowshoe hare are a culturally important species for the Leech Lake Band of Ojibwe, and population abundance has remained lower than expected in the previous years. The relationship between hare and their mammalian predators is a poorly understood dynamic on the Leech Lake Band of Ojibwe reservation. In this study, we will examine survival and space use of snowshoe hares in relation to the habitat and presence of the primary mammalian predators of hares in the study area; American marten, fisher, and bobcat.

2. Can any of the research or teaching needs described be met without the use of live animals?

No__x___Explain why animals are required.
Yes_____Explain how animals are optional.

The complexity of the processes being studied cannot be duplicated or modeled in simpler or alternative systems. When investigating a species' ecology and natural history, it is essential to observe the animals in the wild and how they respond under natural conditions.

3. List any off-campus sites where animal use/monitoring is to be conducted. If the project requires the animals to be housed at a particular site, describe how the site is compliant with the Animal Welfare Act/IACUC guidelines.

Not Applicable

V. Describe all procedures to be performed on animals and their purpose. Surgical procedures must be fully described, including post-operative care where appropriate.

1. For each distinct procedure, describe the manipulations that will be performed in the order in which they will be performed. Procedures that will be performed after the animal has been killed need not be described.

Fisher, American Marten, and bobcat will not be captured or handled by researchers but will be photographed using motion-triggered remote cameras baited with cans of sardines. Camera and bait sites will be established in December 2021 and will remain in place until the loss of snow cover (approximately March 2022). Photographic data will be used to analyze the relationship between habitat characteristics and the probability of site occupancy for all 3 species (Shannon et al. 2014). The methodology is non-invasive but under strict interpretation of the Animal Welfare Act (9 C.F.R. § 1.1), surveys using bait can materially alter the behavior of the animals being studied. We anticipate no adverse effects of the research activities on any target or non-target species. Baited camera surveys are a common, safe, and effective methodology for our research objectives (Burton et al. 2015).

We will capture ≤ 25 snowshoe hare between December 2021 and March 2022 using Tomahawk wire live traps. We will place traps on or near hare runs and cover them with vegetation to camouflage the traps and provide a level of protection from the elements for the hare. We will bait traps with alfalfa biscuits and chunks of apple or set them in well used runs. Traps will remain closed (i.e., an animal cannot enter them or be trapped) during and preceding inclement weather (e.g., heavy snowfall, rain, or extreme cold). We will check traps daily and when a hare is trapped, we will collect data on their weight, length of their hind foot, and fit them with a very high frequency (VHF) or GPS collar equipped with a mortality sensor and weighing ≤ 45 grams. We will place hare in white plastic mesh sacks to reduce stress during handling. Hare will be released at the site of capture immediately following handling. Collared hare will be monitored at least weekly to record their habitat use, home range size, and mortality rates. The procedures described are consistent with best practice recommendations for the species (Sikes 2016, Silvy et al. 2020).

Literature cited

Burton, A. C., et al. 2015. Wildlife camera trapping; a review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology 52:675-685.

Shannon G., J. S. Lewis, and B. D. Gerber. 2014. Recommended survey design for occupancy modeling using motion-activated cameras: insights from empirical wildlife data. PeerJ 2:e532.

Sikes, R. S. 2016 Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663–688.

Silvy, N. J., R. R. Lopez, and T. A. Catanach. 2020. Capturing and Handling Wild Animals. Pages 65-106 *in* N. J. Silvy, editor, The Wildlife Techniques Manual: Volume 1 Research; 8th edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

2. Will the animals be subjected to any of the following?

Use in a previous study?	Yes____	No _x__
Use in a future study?	Yes____	No__x_
Transfer to another investigator?	Yes____	No__x__

If yes, please specify and note that prior Committee approval is required for each of the above.

3. List any building and room outside of the BSU animal quarters where animals will be housed longer than:

12 hours___________ 24 hours_________ If none: so state__None_______

VI. Describe the animal handling qualifications and training of the personnel who will be involved in this project.

Dr. Haus is a Certified Wildlife Biologist® with over 11 years of experience capturing and handling wildlife for research. He is certified through Safe-Capture International, Inc. (now 'Global Wildlife Resources, Inc.'), and regularly teaches workshops on animal capture methods for research purposes at the national conference for The Wildlife Society. He has captured and released >1,000 wild mammals for research purposes. Dr. Haus will be responsible for training all BSU personnel on this project.

Kim Shelton is a Bemidji State University graduate student responsible for coordinating field activities on the project. She holds a Bachelor of Science degree in Wildlife Biology. She will be trained in all aspects of animal capture and handling by Dr. Haus.

Tanya Roerick is a wildlife biologist with the Leech Lake Band of Ojibwe Division of Resource Management. She holds a B.S. and M.S. in Wildlife Biology and has extensive experience capturing and handling wild animals for research. She has overseen the ongoing hare research efforts on the reservation for the previous 5 years.

VII. Assurance that analgesic, anesthetic, and tranquilizing drugs will be used where indicated and appropriate to minimize discomfort and pain to animals.

1. Check a, b, or c below and give justification below:

__x___a. The procedures to be performed on animals do not involve pain or distress to the subject animals (excluding that caused by venipuncture).

_____b. The procedures to be performed do involve pain, and/or anesthetic, analgesic or tranquilizing drugs will be used throughout the entire course of the project to alleviate pain or distress including post-operative and post-procedure care. The drugs, dosages (drug amount/body weight) and routes of administration are as follows:

_____c. Pain and/or distress will be involved for subject animals but drugs will not be used because they interfere with protocol, and justification for non-use is described below.

2. Check each statement that applies to this project:

____a. Terminal (animals are killed under anesthesia without regaining consciousness).

______b. Survival (animals regain consciousness after anesthesia).
If checked, Federal law [AWA 2.31(d)] requires that aseptic technique be used. Please initial here_____.

____c. Multiple survival (individual animals may undergo more than one survival surgery). If checked, provide a detailed scientific justification as required by Federal Law.

3. Where will the surgery be performed?

Not applicable

4. Who will perform the surgery (training of this individual should be addressed in question VI)?

Not applicable

5. What post-procedural measures will be taken to minimize discomfort and what monitoring will be done? How will post-procedural events be humanely handled?

Not applicable

6.Will paralytics be employed? Yes___ No__x__.
If yes, how will the animals be monitored to insure adequate anesthesia

7. Where will the monitoring be performed?

Not applicable

8. Who will perform the monitoring?

Not applicable

9. Will food and/or water be withheld? Yes___ No__x__.

If yes, what will be the duration, how often will a single animal be restricted, and what will be the duration between restrictions? Describe the monitoring that will be done to assure that adverse effects do not occur.

10. Will the animals be restrained by chairs, tethers, stanchions, metabolism cages, etc.? No___ Yes_x__

a. Method of restraint:

Snowshoe hare will be captured using Tomahawk brand cage traps (model 202, 19"x6"x6"). Traps will be checked every 24 hours.

b. Duration of restraint:

From the time of capture until release, ≤ 24 hours.

c. Frequency of restraint:

Once, although the potential exists to capture an individual hare at multiple locations. Recaptured animals will be immediately released without handling.

d. How frequently will the animal be observed during restrain?

Once, upon release.

e. Where restraint will occur:

Capture sites will be spread out through the forests within the Leech Lake Ojibwe Reservation, and hare will be released at their capture site.

11. Will hazardous agents (i.e. infectious agents, carcinogens, toxic chemicals, etc.) or radioactive material be present in the animal facility?

No _x__ Yes___
a. Identify hazardous agent or material:
b. Exposure route:
c. Exposure dose:
d. Exposure duration:
e. Will the agent be excreted? No____ Yes____
in urine___ in feces___ exhaled___
f. Describe where the animals will be housed during and after exposure:
g. Probable animal health effects

NOTE: Radioactive materials are currently not allowed on the BSU campus, but may need to be detailed if working with an off-site collaborator.

VIII. Euthanasia techniques

List by species and describe method to be used, including drug, type, dose, and route of administration:

species	method
snowshoe hare	Manually applied blunt force trauma to the head
American marten	Will not be handled

fisher	Will not be handled
bobcat	Will not be handled

Snowshoe hare will be the only animals directly handled by researchers. If, at the discretion of the researcher, the condition of a captured hare would result in undue pain or distress to the animal upon release into the wild, the hare will be euthanized. The primary method of euthanasia will be manually applied blunt force trauma to the head, followed by secondary methods of mechanical decapitation and evisceration. The American Veterinary Medical Association approves of the listed methods for the humane euthanization of wild, non-domestic rabbits and small rodents. BSU personnel will be trained on the described methods by Dr. Haus. The carcass (skin and skull) of any euthanized animal will be prepared as study specimens for the Bemidji State University vertebrate museum collection.

IX. Claim of confidentiality

Contents of this report are available for public disclosure unless confidentiality is requested by the investigator and it is adequately shown by the investigator that the protocol discloses unpublished data or research procedures for which copyright or patent is being sought.

___x___I do not claim confidentiality

______I claim confidentiality; justification is attached

X. Assurance:

The undersigned is familiar with the AWA and the PHS Policy on Humane Care and Use of Laboratory Animals by Awardee Institutions, the NIH Guide for the Care and Use of Laboratory Animals and the University Guidelines and agrees to abide by the Principles for the Utilization and Care of Vertebrate Animals Use in Testing, Research, and Training contained in this document. I assure that I will obtain the institutional care and use committee (ICAUC) approval prior to significant changes in the protocol. I assure that students, staff, and faculty on the project are qualified or will be trained to conduct the project in a humane and scientific manner. Any change in the care and use of animals involved in this protocol that would affect their welfare will be promptly forwarded to the ICAUC for review. Such changes will not be implemented until the Committee's approval is obtained. Animals will not be transferred between investigators without prior approval.

Jacob M. Haug __11/22/21________
(Signature of Principal Investigator) (Date)

XI. Approval

APPROVAL NUMBER _21-1_
DATE_11/22/2021__
EXPIRATION DATE_6/31/2022__

APPROVAL CATEGORY: A___X___ (No pain or distress involved)

B______ (Drugs used to alleviate pain and/or distress)

C______ (No drugs used for pain and/or distress)

SPECIAL CONDITIONS: NONE____X____ REMARKS ATTACHED________

Randy Westhoff ____11/22/2021____
(Approval Signature for Committee) (Date)

ACADEMIC AFFAIRS
NOV 22 2021
BEMIDJI STATE UNIVERSITY

APPENDIX B

Special Use permits to conduct field research on Leech Lake Reservation

LEECH LAKE BAND OF OJIBWE
DIVISION OF RESOURCES MANAGEMENT
190 Sailstar Dr. NW, Cass Lake, MN 56633
218-335-7400

Special Permit

The Leech Lake Band of Ojibwe, Division of Resources Management (DRM), hereby authorizes Jacob Haus and associates from Bemidji State University to conduct snowshoe hare research on the Leech Lake Reservation, including entering onto non-housing parcels of tribal land to conduct this research.

Carry a copy of this letter while on the Reservation in the event you are stopped by one of our conservation officers. As with any survey or research that takes place within the Reservation boundary, where we have regulatory authority, it is mandatory that you provide us a copy of the final report as a condition of this permit. This permit can be revoked at any time by the DRM. This permit is good from January 15 - March 31, 2021.

I understand and agree to abide by the terms of this permit.

Jacob M. Haus ______ Date 1/6/21
Jacob Haus, Bemidji State University

Permit Approved by

______ Date 1/4/21
Rich Robinson, Director
Division of Resources Management
Leech Lake Band of Ojibwe

LEECH LAKE BAND OF OJIBWE
DIVISION OF RESOURCES MANAGEMENT
190 Sailstar Dr. NW, Cass Lake, MN 56633
218-335-7400

Special Permit

The Leech Lake Band of Ojibwe, Division of Resource Management (DRM), hereby authorizes Jacob Haus and associates from Bemidji State University to conduct snowshoe hare, fisher, marten, and bobcat research on the Leech Lake Reservation, including entering onto non-housing parcels of tribal land to conduct this research. Research includes setting up bait stations with trail cameras, winter track surveys, and trapping/collaring snowshoe hare.

Carry a copy of this letter while on the Reservation in the event you are stopped by one of our conservation officers. As with any survey or research that takes place within the Reservation boundary, where we have regulatory authority, it is mandatory that you provide us a copy of the final report as a condition of this permit. This permit can be revoked at any time by the DRM. This permit is good from November 1, 2021 – April 15, 2022.

I understand and agree to abide by the terms of this permit.

Jacob M. Haus Date 10/13/21
Jacob Haus, Bemidji State University

Permit Approved by

Rich Robinson lmj Date 10/12/21
Rich Robinson, Director
Division of Resources Management
Leech Lake Band of Ojibwe