

How alternative landscapes in the boreal forest impact woodland caribou using a model of animal movement, perception and memory

by

Brianna Collis

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ABSTRACT

HOW ALTERNATIVE LANDSCAPES IN THE BOREAL FOREST IMPACT WOODLAND CARIBOU USING A MODEL OF ANIMAL MOVEMENT, PERCEPTION AND MEMORY

Brianna Collis
University of Guelph, 2018

Advisor:
Robert Corry
Committee member:
John Fryxell

The boreal ecotype of woodland caribou, *Rangifer tarandus caribou*, is a threatened species in Canada. Their decline is complex, but cumulative effects of anthropogenic activity - including habitat alteration and loss from economic activities are implicated. This study investigates how a projection of current trends impacts caribou using alternative landscapes in northern Ontario. Landscapes are compared with an empirically-parameterized individual-based movement model to identify how landscape change impacts boreal woodland caribou. Results indicate that a business-as-usual landscape will continue to negatively impact woodland caribou persistence and population growth, as well as affect how caribou use the landscape with respect to movement and landcover occupation. Neither the existing landscape nor a business-as-usual projection stopped caribou decline, and caribou searched more-disturbed landcover types in the business-as-usual landscape. Results have implications for species conservation, landscape planning, boreal land-use practices, spatial ecology, and applied landscape ecology's role in the recovery of imperiled species.

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TABLE OF CONTENTS

Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	vi
List of Figures	vii
List of Appendices	ix
1 Introduction	1
2 Literature Review	6
2.1 The role of spatial planning and landscape pattern in habitat rehabilitation	6
2.2 Concept of landscape projection, design and alternative futures	7
2.3 Broad scales and animal movement	11
2.4 Status of boreal woodland caribou (<i>Rangifer tarandus caribou</i>) in Canada	14
2.5 Boreal woodland caribou (<i>Rangifer tarandus caribou</i>) habitat structure and selection ..	16
2.6 Spatial pattern of habitat matters for boreal woodland caribou	18
2.7 Landscape ecology and conservation challenges in mixed-ownership landscapes	19
2.8 Ecological landscape planning and habitat connectivity	20
2.9 Habitat rehabilitation importance for boreal woodland caribou	22
2.10 Using an individual-based movement model considering boreal woodland caribou perception and memory	23
2.11 Conclusion	24
3 Methods	25
3.1 Study Area	25
3.2 Landscape Representation	28
3.2.1 Land cover	28
3.2.2 Roads	30
3.2.3 Mines	30
3.2.4 Normalized difference vegetation index	30
3.2.5 Snow-depth	31
3.3 Alternative future scenario landscape development	31
3.4 Map creation in ArcGIS	32
3.4.1 Baseline landscape	32
3.4.2 Business-as-usual landscape	32
3.4.2.1 Mine creation	34

	3.4.2.2 Road creation	35
	3.4.2.3 Forestry Management Plan Unit analysis and FNLC reclassification	35
	3.4.2.4 Normalized difference vegetation index reclassification	37
	3.4.2.5 Snow-depth	38
3.5	Landscape modelling workflow	38
	3.5.1 Forage availability and wolf density	39
	3.5.2 Movement trajectories	39
	3.5.3 Likelihood of persistence	40
4	Results and Analysis	41
	4.1 Caribou persistence, population growth, forage, and wolf density and moose resource selection function	41
	4.2 Trajectory Landcover	41
	4.2.2 Baseline landscape	43
	4.2.3 Business-as-usual landscape	43
	4.3 Trajectory distribution	45
	4.4 Optimized Hot Spot Analysis	49
	4.4.1 Hotspot Analysis	50
	4.4.2 Coldspot Analysis	52
	4.5 Conclusion	53
5	Discussion and Conclusion	55
	5.1 Probability Viability Analysis, population growth rate, wolf density, caribou forage, and moose resource selection function	55
	5.2 Model Caribou Trajectory Landcover	56
	5.3 Trajectory distributions	58
	5.4 Optimized Hot Spot Analysis	59
	5.5 Limitations and future work	66
	5.6 Conclusion	68
6	Literature cited	70
7	Appendix 1	83

LIST OF TABLES

Table 1. Landcover proportions in the Baseline landscape occurring within the study boundary area ...	29
Table 2. Data required in the landscapes to receive modelling output results related to caribou viability	31
Table 3. Landcover proportions in the Business-as-usual landscape occurring within the study boundary area	33
Table 4. MDI deposits listed as most to least likely to become active in the study area in the BAU landscape	35
Table 5. Far North Land Cover categories in the baseline landscape and associated reclassified Far North Land Cover categories for the business-as-usual landscape	37
Table 6. Model results for caribou persistence, caribou population growth rate, wolf density, caribou forage and moose for baseline and business as usual landscapes	41
Table 7. Area of each Far North Land Cover category in hectares occurring in the model caribou trajectories in both the baseline landscape and business-as-usual landscape	42
Table 8. Far North Land Cover types associated with land-use hotspots (95% confidence interval) in randomly-selected model caribou trajectories in both business-as-usual and the baseline landscape ...	51
Table 9. Far North Land Cover types associated with land-use coldspots (95% confidence interval) in randomly-selected model caribou trajectories in both business-as-usual and the baseline landscape	53

LIST OF FIGURES

Figure 1. Kesagami herd range area in northern Ontario, adapted from <i>Woodland caribou (Rangifer tarandus caribou), boreal population: critical habitat fact sheet</i> (Environment Canada 2012)	15
Figure 2. Kesagami management unit (black outline) situated in northern Ontario. Inset with dotted line is study area	26
Figure 3. Baseline landscape indicating study boundary area within the Kesagami range in Northern Ontario	27
Figure 4. Landcover proportions (%) in the baseline based on 30x30m pixel counts	29
Figure 5. Landcover proportions (%) in the Business-as-usual landscape based on 30x30m pixel counts	33
Figure 6. Business-as-usual landscape, after land cover changes occurred following an explicit, replicable rules-based approach	34
Figure 7. Forest Management Unit Plan harvest blocks with landcover changes occurring within the study boundary	37
Figure 8. Far North Land Cover categories occurring in 25 randomly-selected caribou trajectories in the baseline and business-as-usual landscapes, represented in hectares. (FNLC categories 1= Clear Open Water, 2= Turbid Water, 3= Thicket Swamp, 4=Coniferous Swamp, 5=Open Fen, 6=Treed Fen, 7=Open Bog, 8=Treed Bog, 9=Sparse Treed, 10= Deciduous Treed, 11=Mixed Treed, 12=Coniferous Treed, 13=Disturbance-Non and Sparse Woody, 14=Disturbance- Treed and/or Shrub, 15=Community/Infrastructure)	43
Figure 9. Far North Land Cover category shifts, in hectares, in the business-as-usual landscape compared to the baseline landscape in 25 randomly-selected model caribou trajectories	45
Figure 10a. Trajectory distributions of randomly-selected model caribou in the baseline landscape	46
Figure 10b. Trajectory distributions of randomly-selected model caribou in the business-as-usual landscape	47
Figure 11. Spread for randomly-selected model caribou in the baseline and business-as-usual landscapes indicating the North-South and East-West distributions	48
Figure 12a. Optimized Hotspot analysis in the baseline landscape- Results for 25 randomly-selected model caribou trajectories in the study area indicating areas in each landscape that had significant usage highlighted in dark red	49
Figure 12b. Optimized Hotspot analysis in the business-as-usual landscape- Results for 25 randomly-selected model caribou trajectories in the study area indicating areas in each landscape that had significant usage highlighted in dark red	50
Figure 13. Difference in hectares of Far North Land Cover types associated with land-use hotspots (95% confidence interval) in randomly-selected model caribou trajectories in the business-as-usual landscape compared to the baseline landscape	52

Figure 14. Difference in hectares of Far North Land Cover types associated with land-use coldspots(95% confidence interval) in randomly-selected model caribou trajectories in the business-as-usual landscape compared to the baseline landscape. 53

Figure 15. Patterning of hotspots (left) and coldspots (right) in the landscape 60

Figure 16. Hotspots in relation to pre-existing forest disturbance in baseline (left, red) and BAU (right, pink). 'Disturbance- Non and Sparse Woody' and 'Disturbance- Treed and/or Shrub' in yellow. 'Mixed Treed' and 'Deciduous Treed' forest types not associated with caribou habitat in lime green 62

LIST OF APPENDICES

Appendix 1. Design Rules for Scenario Development	83
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1 INTRODUCTION

Ecological landscape design and planning is a process well suited to investigate how the landscape might best fulfill multiple objectives with contrasting needs in a multi-use setting. This process is needed to understand how the landscape is currently functioning and being used, and how these trends might play out in the future if current land-use practices continue at the present rate (Dale and Haeuber, 2001). Effective and thoughtful planning of desired landscapes requires understanding how past processes and decisions have impacted and influenced the present landscape conditions (Dale and Haeuber, 2001; Ahern, 2006). Better land-use decisions can be made by assessing the impacts of multiple drivers through the process of creating alternative landscape scenarios and evaluating how different decision-making frameworks influenced the subject of investigation (Dale and Haeuber, 2001). Landscape architecture and environmental landscape planning is an interdisciplinary participant in the application of this process, integrating forecasting and design with landscape processes and empirical evidence to problem-solve complex landscape and land-use problems. Landscape design can assist in identifying solutions to minimize adverse effects of current and future land-use and potential habitat loss and species decline associated with this change (Opdam et al. 2009).

Understanding the spatial patterns from land-use change and their impact on species is influential for species persistence. The complexity of land-use demands close attention to understanding the spatial aspects of habitat and how landscape change impacts species suffering from habitat loss which in Canada includes boreal woodland caribou (Environment Canada 2012), badgers (COSEWIC 2000), wolverines (Bowman et al. 2010), turtles (Millennium Ecosystem Assessment 2005) and birds (Bayne et al. 2005) among others. Understanding future landscapes allows scientists, practitioners and policy-makers to consider if connectivity and functional habitat rehabilitation efforts should be implemented. These efforts are intended to be geospatially appropriate based on life history traits, forest type, adjacent land-use, future land-use and lifestyle of

predator and prey and competitor, and how these forces interact in multi-use landscapes.

Anthropogenic landscape-change and degradation has led to decreased landscape integrity, loss of important habitat, reduced ecological function, and negative impacts on wildlife. Habitat loss from landscape-change and subsequent effects on species has been well documented, and is the primary factor influencing endangerment and loss of wildlife (Wilcove et al. 1998; Venter et al. 2006). Ceballos and Ehrlich (2002) found that an average of 44% of the historic range was lost for 18 medium-to-large mammals in North America which included bison, wolves, elk and brown bears.

Caribou are hoofed ruminant mammals of the deer family (Cervidae). The boreal woodland caribou *Rangifer tarandus caribou* is indigenous to the boreal forests of Ontario and is both threatened and experiencing habitat loss. Boreal woodland caribou is the largest subspecies of caribou and is distinguished from barren-ground caribou and porcupine herd by being mostly sedentary and non-migratory. The historic range of this ungulate covered over half of Canada, from Newfoundland and Labrador to Alaska, and down into the northern United States, but their range has since receded. Boreal woodland caribou are more dispersed than their migratory counterparts, and do not form large aggregations. They have thick fur coats and large, rounded hooves that assist in procuring food such as lichen from the ground in winter. Female caribou have one calf per year, unlike moose and deer. There are 9 designated boreal woodland caribou herds in Ontario, which have been formally compiled into designatable units—ON1 Sydney, ON2 Berens, ON3 Churchill, ON4 Brightsand, ON5 Nipigon, ON6 Coastal (a small, isolated local population), ON7 Pagwachuan, ON8 Kesagami and ON9 Far North, which is further subdivided into the ranges of Swan, Spirit, Kinloch, Ozhiski, Missisa, and James Bay. It is estimated that there are around 5,000 boreal caribou in Ontario.

Studies investigating landscape change to increase boreal woodland caribou habitat are often focused at the site scale; however, considering the ecological context and landscape at the regional or range-scale for such a large-ranging mammal is crucial (OMNRF, 2009; Environment Canada, 2011; Environment Canada, 2012; Ray, 2014). Landscape context identified at the regional, range and landscape-scale are paramount and strongly influence presence of species (Arkle et al. 2014). Site-scale details can become negligible, redundant, or simply not useful when considering the larger landscape matrix, patterns and connectivity at a scale at which caribou range and move. Rehabilitative efforts to increase and preserve existing habitat have become of utmost importance when considering how to increase caribou persistence in the boreal forests across Canada and in Ontario (Ray, 2014). Since linear features such as roads and other disturbed sites often increase moose forage and associated habitat types (Wasser et al. 2011; Environment Canada 2012), careful consideration of integrating these disturbances in the landscape, as well as rehabilitation of disturbed forest features such as forestry cutblocks, mine sites and associated industry features, is crucial to enhance boreal woodland caribou habitat, population stability and species persistence. While not always directly influencing caribou viability in a positive direction, forecasting future trends in landscapes is one way to assess the concept of future landscapes and modelled assessments, and is a future landscape often investigated in landscape planning.

The Committee on the Status of Endangered Wildlife in Canada, COSEWIC (2002) identifies six distinct populations of forest-dwelling woodland caribou in Canada: Northern Mountain population, Southern Mountain population, Boreal population, Forest-tundra population, Atlantic-Gaspésie population, and the Newfoundland population. The boreal woodland caribou, endemic to Canada and listed as threatened (COSEWIC 2002), is the population addressed in this thesis. Threatened species are likely to become endangered if steps are not taken to address the factors leading to population declines (Environment Canada, 2012). Boreal woodland caribou are distributed in boreal forest regions across British Columbia, Alberta, Saskatchewan,

Manitoba, Ontario, Quebec, Newfoundland and Labrador, the Northwest Territories, and the Yukon (Environment Canada, 2012). In Ontario, between 40-50% of boreal woodland caribou range has been lost since the late 1800's, receding northwards towards James Bay (Schaefer 2003).

In Ontario, caribou from two boreal caribou ranges, Sydney and Kesagami, are currently not self-sustaining, and are indicated as being unlikely and very unlikely, respectively, to become "self-sustaining"; therefore, efforts to increase habitat and connectivity have been identified as critical (Environment Canada 2012). Co-ordination of activities for rehabilitation that build large tracts of habitat with levels of landscape connectivity should be prioritized, as boreal woodland caribou individual ranges are in the thousands of kilometres (OMNRF, 2009; Environment Canada, 2012; Ray, 2014).

Habitat alteration has negatively impacted boreal woodland caribou that rely on large tracts of habitat for their persistence across Canada and in Ontario (Brown et al. 2007; Environment Canada, 2012; Ray, 2014; OMNRF 2014), and approximately half of their historic range remains (Schaefer 2003). The boreal forest landscape has seen a steady increase in human land-use and landscape-change and this change geographically mirrors the decline in boreal woodland caribou populations in Ontario (Schaefer, 2003). Boreal woodland caribou decline is complex, but cumulative effects of anthropogenic activity in the boreal region seem to be contributing to this decline, including habitat alteration from activities related to human settlement, mining and forestry (Seip 1992; Environment Canada, 2012; Ray 2014; Hervieux et al. 2013; Schaefer 2003). Landscape-change has also impacted how alternate prey (*Alces alces*) and predators (*Canis lupis*) utilize the landscape, with negative impacts for caribou (Bergerud & Elliot 1986; Seip 1992; Rettie & Messier 2000; McLoughlin et al. 2003; Festa-Bianchet et al. 2011). Disturbance and habitat alteration are changing older, later-seral forests into early-seral forests; this early-seral forest type is not a habitat type associated with boreal woodland caribou, but rather moose and their predators, wolves (Courtois et al. 2004; Wittmer et al. 2007; Seip, 1992). The primary cause of caribou

mortality is assumed to be predation caused by habitat alteration (Environment Canada, 2012) and thus it is paramount that landscape-change activities that alter habitats are investigated to assist in caribou recovery in the boreal forest.

Animal movement is integral to flows in an ecosystem and may support vital ecosystem functions (Lundberg and Moberg, 2003; Massol et al. 2011), and understanding space-use of species is important as anthropogenic landscape alteration increases (Bradshaw, Warkentin and Sodhi, 2009; Potapov et al. 2017; Venter et al. 2016). Animal movement may increase or decrease based on habitat fragmentation and changes to resources (Sawyer et al. 2013; Said and Servanty 2005; Prange et al. 2004; Jedrzejewska et al. 1994). Intentional landscape change that considers animal movement and habitat fragmentation might be an important link in recovery plans for species at risk.

This research uses an empirically-parameterized caribou movement model to understand how the landscape in the Kesagami region impacts boreal woodland caribou movement considering likely changes. Boreal woodland caribou may use the landscape differently in the future based on how current trends in development alter habitat and landcover in this specific range, which may have consequences for their future persistence in Ontario's boreal forest. By envisioning future landscapes and evaluating them with an empirically-parameterized model based on animal movement, perception and memory, this research can assess how future land-use and landscape patterns impact boreal woodland caribou forage, movement and persistence. By evaluating caribou movement trajectories in a future landscape, results can then be used for research in conservation and habitat rehabilitation to envision future landscape patterns that might positively impact the threatened boreal woodland caribou in Ontario.

2 LITERATURE REVIEW

2.1 The role of spatial planning and landscape pattern in habitat rehabilitation

The design of landscapes to provide multiple benefits simultaneously (i.e. resource extraction as well as habitat and wildlife conservation) is a key concept looking forward to sustainable landscapes and development (Termorshuizen and Opdam, 2009; O'farrell and Anderson, 2010). There is abundant evidence that the spatial configuration and amount of habitat at the landscape scale is critical from a species recovery perspective (Fahrig 2003; Lindenmayer et al. 2016). The size and configuration of habitat patches influence boreal woodland caribou population stability (Arsenault and Manseau 2011; Nagy 2011); however, metrics to understand these attributes are elusive (Ray, 2014). Landscape characteristics associated with a species' habitat selection and avoidance, and the spatial arrangement of these, are integral for habitat connectivity and recovery. Landscape design and projection is a unique area that considers this spatial patterning and how it can impede or restore habitat connectivity in the landscape.

There is evidence that some areas in the Kesagami region of northern Ontario could have caribou re-occupation based on forest stand age, after being cleared for forestry (stands >95 years of age). These areas, however, are potentially unable to serve as habitat due to severe habitat fragmentation from forestry and other anthropogenic disturbance despite being an age of forest class associated with boreal woodland caribou (OMNRF, 2014). The spatial position is such that caribou are unlikely to use this habitat, indicating a need for spatial design and planning that incorporates connectivity and habitat patterns for caribou conservation, an area that has yet to be reconciled. Boreal woodland caribou persistence may depend on separation from human incursion (Schaefer, 2003), indicating that this may ultimately be a problem of spatial design of the landscape where multiple landscape activities are co-occurring. This research seeks to understand how exploring future landscapes could lend to

caribou conservation in a fragmented landscape that continues to have intensive, economic land-uses.

2.2 Concept of landscape projection, design and alternative futures

Landscape design in the context of habitat conservation, as defined by Bartuszevige et al. (2016), is a conservation planning process that integrates societal goals and values with biological conservation goals using landscape ecology-based science to describe future scenarios where specific and measurable biological goals can be attained. Landscape design can be a powerful tool by providing a framework for ensuring that landscape planning does not occur in a vacuum: societal, cultural, and economic needs are considered alongside conservation goals (Bartuszevige et al. 2016). However, knowing about environmental processes and attributes is not sufficient on its own and must be integrated with the knowledge of understanding human behavior, values and trends (Opdam et al. 2013.) Landscape design as a conservation planning process including societal values (Nassauer and Opdam, 2008; Opdam et al. 2013) is one solution to create situations in which conservation goals can be met within the greater social and economic fabric of landscapes.

A key challenge to creating positive landscape change and management results from the accumulation of changes and alterations to ecological systems and the landscape through many land-use changes and decisions over time. Cumulative impacts arise from multiple sources and activities that overlap spatially in a region or create multiple perturbations over time from a single repeated activity (Beanlands 1995; Lane 1998). Boreal woodland caribou are a species that suffer from the cumulative impacts on the landscape (Hervieux et al. 2013; Faille et al. 2010; Environment Canada 2011; Beauchesne et al. 2014) and thus addressing the region holistically considering all landscape drivers is essential for determining conservation design for this species at risk. Understanding the consequences of landscape-change today through exploring possible future states of the landscape based on how it is currently used and exploited

is one way to assess where planning needs to be focused, where it needs to be malleable, how challenges of the future could be mitigated today.

Alternative landscape futures have been used by many researchers to produce simulated landscapes or landscape trajectories of which the resultant landscapes are used to assess the outcome of different policy, management or other land-based decision making (Hulse and Gregory, 2001). The alternative futures framework originated in land conservation and development work in the United States, as well as rural scenario development in Europe (Steinitz 1990; Montgomery et al. 1995; Schoonenboom, 1995). Written descriptions of possible future conditions of the landscape or whatever future scenario is being investigated have a key role in guiding assumptions about the future, as well as creating the designs for alternative spatial futures (Dale and Haeuber, 2001). These futures often consist of i) projections, based on trends that would describe the future landscape, and ii) prospective landscapes, anticipating change that importantly varies from the past (Harms et al. 1993; Ahern 1999). The narratives of these scenarios are created and mapped, providing a platform for investigating how the landscapes impact numerous variables or whether any goals set out have been met through this design process. The impacts of a specific project can be viewed in context with the effects of multiple drivers through the process of creating alternative futures so that better land-use decisions can be made (Dale and Haeuber, 2001).

In future scenario development, creating a baseline landscape is critical to understand how change is occurring relative to the current landscape attributes. Alternative future scenarios can be an effective way to test how future landscape states impact species when coupled with an evaluative tool such as a model. Alternative future scenarios of landscape change aid in visualizing and evaluating land-use consequences and decision-making choices in a specific situation temporally and spatially (Harms et al. 1993; Steinitz et al. 1994; Ahern, 1999; Bolte et al. 2006; Nassauer et al. 2007). Models assist in the evaluation of these alternative scenarios and can be effective for

understanding how species and ecosystems are impacted (Donigian and Huber, 1991; Pulliam and Danielson, 1991; Dunning et al. 1995; Holt et al. 1995; White et al. 1997), especially for large-scale landscape changes that cannot be readily evaluated (Ahern, 1999). Future scenarios can allow for economic impact assessment as well as including human perception of the future alternative landscape choices (Nassauer 1998). Alternative future scenarios can be evaluated with models to indicate how each landscape alternative impacts species and then methods can be developed to summarize and compare resultant landscapes for future planning, management and decision making.

Thoughtful planning of desired landscapes also requires an understanding how past processes and choices have influenced present conditions in the landscape (Dale and Haeuber, 2001). Landscape rehabilitation projects, for example, are more likely to be successful if they explicitly acknowledge and address connections between the ecological processes and dynamics, the local demography and land use, as well as economic and institutional dynamics (Dale and Haeuber, 2001), complemented with an understanding of how current land-use will play out in the future through business-as-usual projections.

Future scenarios coupled with Geographic Information System (GIS) based evaluative models as a methodology for land-use planning have been effective for evaluating effects on water quality and biodiversity in Oregon (Hulse et al. 2000), future land-use patterns in Monroe County from alternative policy/plan action (Steinitz et al. 1994), and biodiversity risk assessment from landscape change (White et al. 1997; ALT 2009). Alternative landscape futures have been used to guide land-use decisions for agricultural watersheds in the U.S. Corn Belt (Nassauer et al. 2007) and to determine restoration, protection and appropriate management practices for the Willamette River basin (Hulse and Gregory, 2001). Through their work, Hulse and Gregory (2001) sought to balance ecological needs for restoration with the social bindings on where investments in restoration should take place and how, and to efficiently use resources to

accomplish both economic and ecological goals in the area. Alternative landscape futures indicated how future land-development patterns impacted species richness of birds, mammals, reptiles and amphibians in Monroe County, USA (White et al. 1997). The risks to biodiversity are greater in landscapes extrapolated from current trends and zoning patterns when compared to landscapes where development was more spatially constrained (White et al. 1997). Landscape futures analysis is an effective tool for policy and planning decisions at the regional level to obtain or evaluate environmental objectives at the regional scale (Bryan et al. 2011; ALT 2009).

Comparing spatially explicit alternative scenarios with models and other assessment tools is a first step in quantifying the economic and ecological costs of continuing current trends and practices, as well as identifying the benefits of potential landscape changes (Dale and Haeuber, 2001).

Achieving connectivity is often required for effective conservation within fragmented landscapes to evaluate the effects of landscape change and to identify conservation goals and activities (Worboys et al. 2009). Landscapes often consist of dynamic, complex, heterogeneous habitats that make up a matrix where ecological processes influencing species and their environment occur (Risser, Karr & Forman, 1983; Stevenson-Holt et al. 2014). Assessing species connectivity by evaluating dispersal and potential movement across the landscape is a common method to identify areas of constraint for species and opportunities for conservation (Ferrerias 2001; Epps et al. 2007; Watts et al. 2010). Using alternative landscape futures coupled with a model provides a platform for decision making by envisioning how change will impact future animal movement in areas that are highly fragmented and resource rich that co-occur with sensitive species.

Alternative future studies on the impacts of boreal woodland caribou management scenarios at the regional level in the Athabasca Landscape area in Alberta, Canada, indicated that coordination of rehabilitation techniques and predation

control alone would not be sufficient to restore functional habitat, and that reducing the future land-use footprint would be required (Athabasca Landscape Team, 2009). Projected landscapes of the continuation of current land use trends assist in understanding how anthropogenic landscape impacts might affect species at risk, and potentially in what timeline this may occur.

Caribou were not predicted to persist past two to four decades without immediate management intervention in a scenario of continuing land-use trends (Athabasca Landscape Team, 2009), indicating that choices need to be made between boreal woodland caribou recovery efforts and plans for ongoing and continued development and forest harvesting. Current best practices in the region, based on the modelling, will not maintain or restore caribou populations, indicating a need to re-assess what practices are truly useful for the recovery of imperiled species. In all future scenario landscapes there was insufficient habitat to maintain and increase the current distributions and population growth rates within the study area for boreal woodland caribou (ALT 2009). The ALCES model was useful for identifying combinations of variables that positively contributed to caribou persistence by simulating effects of natural and land-use changes on boreal woodland caribou. It might also be used with spatially designed landscape patterns.

2.3 Broad scales and animal movement

Broad spatial areas are often paramount for maintaining wide-ranging species and for supporting important ecosystem processes in the landscape (Brown, 1978; Newmark, 1995; Tucker et al. 2018; Lundberg and Moberg, 2003; Bauer and Hove, 2014). Working at a fine-scale over short temporal steps, as is often done for land-use planning, may result in negative impacts in the surrounding landscape and contribute to a negative ecological condition in the future that could have been mitigated if decision making considered the broader spatial scale.

Understanding space-use of dispersing species is important as human disturbance on the landscape increases (Bradshaw, Warkentin, & Sodhi, 2009; Potapov et al. 2017; Venter et al. 2016), and when species experience habitat loss (Tucker et al. 2018). Body mass, dietary guild, and availability of resources are related to mammal movement distances (Tucker et al. 2018). Animal movement is integral to ecosystems, and movement patterns may be vital to support ecosystem processes as well as species interactions, including healthy predator-prey relationships (Lundberg and Moberg, 2003; Massol et al. 2011). The presence of animals on the landscape can be predicted by their home range size, and ability to traverse inhospitable habitat (Dale et al. 1994; Mladenoff et al. 1995).

Animal movement, such as that associated with the home range, has been shown to decrease as the result of habitat fragmentation, changes in resources or barrier effects (Sawyer et al. 2013; Said and Servanty, 2005; Prange et al. 2004; Jedrzejewska et al. 1994). Animal movement can also determine habitat preference in species, as well as habitat suitability (Chetkiewicz and Boyce, 2009; Lu et al. 2012).

Negative effects of human landscape alteration on long-distance movement of terrestrial mammals is observed globally (Tucker et al. 2018). Mammals living in areas of high human footprint had shorter movements compared to those living in areas of lower human footprint (Tucker et al. 2018). It is also possible that some species move farther into lower-quality environments expanding their range to find sufficient resources (Mueller et al. 2011). Species may also confine their movements in the landscape as well as their home-range in response human-induced disturbance (Beauchesne et al. 2014; Donovan, Brown, & Mallory, 2017; Ewacha, Roth, Anderson, Brannen, & Dupont, 2017; MacNearney et al. 2016; Smith, Ficht, Hobson, Sorensen, & Hervieux, 2000). Some female boreal woodland caribou in Canada experience smaller home ranges where human-caused disturbance is high (Wilson et al. 2018).

Alternatively, there is evidence that human-caused disturbance increases caribou home-ranges as a potential avoidance tactic (Beauchesne et al. 2014; Courtois, Ouellet, Breton, Gingras, & Dussault, 2007; Donovan et al. 2017; Smith et al. 2000).

Evidence suggests that changing movement behavior and land-use by species is significant over longer time scales compared to short term scales (Tucker et al. 2018). Future landscape management needs to include permeability to facilitate movement by including animal movement as a key life history attribute (Tucker et al. 2018), as movement can assist managers of landscapes to identify threats to species such as loss of habitat or important sites (Iwamura et al. 2013), or where there are barriers to movement (Seidler et al. 2015).

Successful landscape planning and conservation requires approaches that address broad spatial and temporal scales (Hulse and Gregory, 2001; Haeuber and Hobbs, 2001). The importance of addressing broad spatial scales is a central theme in conservation science (Noss 1983; Grumbine 1994, 1997; Christensen et al. 1996; Committee of Scientists, 1999). Regional-scale ecological systems are often broader than the established jurisdictional or administrative boundaries that govern decision making for landscape management and land use, creating a situation that seldom allows planning and power to reconcile land-use for ecological issues and broad-ranging species (Wuichet, 1995). Regional-scale spatial design and assessment of landscape attributes are paramount to understanding broad-ranging species at risk such as boreal woodland caribou, as well as to address ecological questions that impact species, people, and the economy. Investigating aspects of movement ecology and understanding specific population movements may determine the type of management needed and assist in the recovery of large ranging mammals facing accelerated habitat loss such as the boreal woodland caribou (Runge, Martin, Possingham, Willis, & Fuller, 2014; Tucker et al. 2018). As the discipline of movement ecology evolves, strengthening the relationship to land management is crucial to improve decision

making with practitioners and landscape stewards and managers (Allen and Singh, 2016).

2.4 Status of boreal woodland caribou (*Rangifer tarandus caribou*) in Canada

Boreal woodland caribou (*Rangifer tarandus caribou*) are protected under Canadian federal and provincial government law; the federal strategy for boreal woodland caribou recovery indicates that 65% of boreal woodland caribou habitat is to be left undisturbed, with a minimum 500m buffer from any anthropogenic disturbance (Environment Canada, 2012). Habitat rehabilitation for boreal woodland caribou is to achieve the recovery goal of “self-sustaining” local populations in a healthy boreal forest (Environment Canada, 2012; OMNRF, 2014). The Range Management Approach undertaken by the Government of Ontario provides information required to identify risks to boreal woodland caribou within their range and supports management decisions related to boreal woodland caribou conservation efforts (OMNRF, 2014).

This research investigates the landscape where the Kesagami boreal woodland caribou (DU6) herd resides in Northern Ontario, adjacent to the Quebec border. Currently, the Kesagami population mostly reside in a management area of approximated 47,400 km² (OMNRF, 2014), but also move into adjacent Québec. It is uncertain whether or not the Kesagami herd is capable of being self-sustaining, likely due to habitat alteration and predation (OMNRF, 2014), and therefore research into their recovery is paramount.

The Kesagami herd resides in the James Bay Lowlands, with wetland complexes in the north, and boreal forest in the south (OMNRF, 2014; Figure 1).

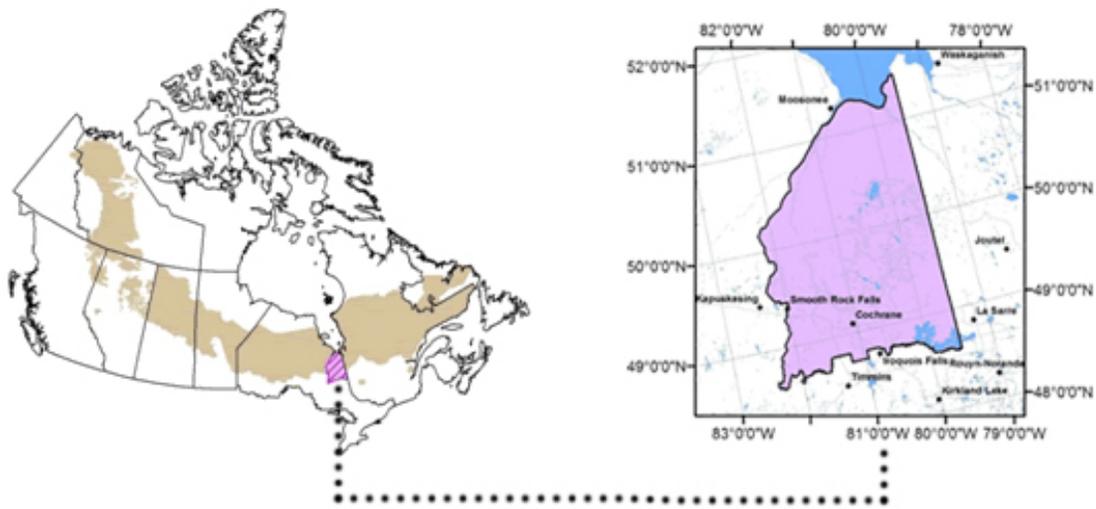


Figure 1. Kesagami herd range area in northern Ontario, adapted from *Woodland caribou (Rangifer tarandus caribou), boreal population: critical habitat fact sheet* (Environment Canada 2012).

Quality habitat in the northern extent provides refuge and there is a higher occurrence of boreal woodland caribou in this portion of the range in contrast to the south, which has seen extensive landscape alteration from forestry, settlement, extractive activities, and other anthropogenic activities (OMNRF, 2014). Geospatial analysis indicates that 43.8% of the range is characterized as disturbed from both natural and anthropogenic forces (OMNRF, 2014). The recession of woodland caribou in a consistent, northerly direction—in contrast to retraction toward the center of the range—implies an anthropogenic agent of decline (Channell & Lomolino 2000; Rodríguez 2002). This leaves 56.2% of potential habitat at the range scale, less than the required 65% required in the federal boreal woodland caribou recovery plan, indicating a need for habitat planning and rehabilitation to assist in meeting this requirement (OMNRF, 2014; Environment Canada, 2012).

2.5 Boreal woodland caribou (*Rangifer tarandus caribou*) habitat structure and selection

Boreal woodland caribou occur at low densities over very large areas and are associated with large tracts of old coniferous forest (OMNRF 2014; Brown et al. 2007), peatland complexes and treed bogs (OMNRF 2014; Brown et al. 2007; Rettie and Messier, 1998), upland conifer-dominated lichen-rich areas (Ray, 2014; Rettie and Messier, 1998; Brown et al. 2003) and areas with low densities of wolves (*Canis lupus*), white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*) (OMNRF, 2014). Boreal woodland caribou are known to occur in the landscape in places where they can seek refuge to forage, avoid predation, and avoid moose habitats (Environment Canada, 2012). Landscapes that provide sufficient food and opportunities to escape predators are critical for species persistence.

Boreal woodland caribou select for habitats high in dietary digestible biomass at the local and range scales, avoid areas with high wolf density and areas near roads in summer and winter (McGreer et al. 2015). Boreal woodland caribou in many studies show selective behaviour for mature forests (Hins et al. 2006; Rettie and Messier, 2001; Mahoney and Virgl, 2003; Ferguson and Elkie, 2004). 90-120-year-old forests were the most sought-after habitat type at the study area scale (~7,000 km²) in eastern Quebec (Hins et al. 2009), and open lichen woodlands and peatlands were also selected. 6-20-year-old forest cuts were avoided during calving (Hins et al. 2009), indicating avoidance of disturbed early-seral vegetation consistent with others' findings (Ray, 2013; Briand, 2009).

Boreal woodland caribou in the Kesagami area specifically are associated with large tracts of old coniferous forest, peatland complexes and treed bogs, and areas with low densities of wolves, deer and moose (OMNRF, 2014). Occupancy rates of boreal woodland caribou in the southern extent of their range in Ontario are negatively correlated to the amount of anthropogenic disturbance that exists in this area (OMNRF,

2014). This is consistent with Schaefer's (2003) findings that range contraction mirrors the geography of human activity in Ontario.

A number of studies suggest negative impacts of disturbed landscapes on population dynamics and habitat usage of boreal woodland caribou (Schaefer, 2003; Courtois et al. 2007; Schaefer and Mahoney, 2007). Boreal woodland caribou are known to avoid roads and other linear disturbance features (Leclerc et al. 2012; Leblond et al. 2013; Lesmerises et al. 2013; Beauchesne et al. 2013; Imbeau et al. 2015; Johnson et al. 2015) as well as other anthropogenic and natural disturbances (Johnson et al. 2015). Boreal woodland caribou shift their range following natural fire disturbance (Schaefer and Pruitt, 1991) and avoid deciduous shrub layers (Ray, 2014; Briand et al. 2009), industrial developments (Smith et al. 2000; Dyer et al. 2001; Nellemann et al. 2003; Cameron et al. 2005; Schaefer and Mahoney 2007) and habitats that are abundant with moose (Rettie and Messier, 1998) and associated with moose forage (Briand et al. 2009).

Boreal woodland caribou generally avoid landscape types with high predator encounter risk, such as mixed and deciduous forests (Hornseth and Rempel, 2015). Boreal woodland caribou avoid habitats with high wolf density and areas near roads in the northern Ontario boreal forest (McGreer et al. 2015). Predator avoidance is likely the main driving force behind habitat selection during the timeframe when calves are most vulnerable, in late spring/summer (Hins et al. 2006; Lantin, 2003). However, due to the spatial associations in relation to mature forests, young forest cuts were selected in some instances, indicating the importance of spatial analysis and pattern at the range scale, and the association of forestry planning to age of stands and spatial arrangement of stands (Hins et al. 2006). Wolf predation is an important factor contributing to boreal woodland caribou mortality and their population declines (Bergerud & Elliot 1986; Seip 1992; Rettie & Messier 2000; McLoughlin et al. 2003; Festa-Bianchet et al. 2011) and activities associated with forestry and energy exploration have created greater spatial

overlap between boreal woodland caribou and wolves, altered hunting efficiency, and resulted in higher wolf populations (Latham et al. 2011; Hervieux et al. 2013).

In a study of radio-collared wolves, moose and boreal woodland caribou, caribou increased their selection of conifer stands with lichen following a wolf's passage (Latombe et al. 2014), indicating the recent passage of a wolf informs boreal woodland caribou behaviour of landscape usage. Dickie et al. (2016) found that wolves travel two to three times faster on linear features, such as roads and seismic lines, compared to the natural forest and had an increased proportion of steps travelling along these features. These results indicate how and why refuge habitats, such as treed bogs, are important land cover types to boreal woodland caribou in a region that is altered with linear features.

Boreal woodland caribou's habitat selection driver is to decrease the risk of predation from wolves and bears, and as such they are dispersed widely across the landscape (Rettie & Messier 2000; Bowman et al. 2010; Whittington et al. 2011). These habitat types confirm the importance of considering land cover types and species relationships and spatial relationships for landscape planning and conservation design.

2.6 Spatial pattern of habitat matters for boreal woodland caribou

Many authors indicate that viable species populations in disturbed landscapes do not solely rely on a minimal amount (area) of habitat types but suggest that the spatial arrangement and organization of the habitat types could be integral to the distribution of populations (Rempel et al. 1997; Lindenmayer and Franklin, 2002; O'Brien et al. 2006). Considering habitat selection at multiple spatial scales is imperative to understand fully the selection patterns that reflect the survival and reproductive requirements of boreal woodland caribou (Matthiopoulos et al. 2011). Spatial configuration of mature forest and clear-cuts can force boreal woodland caribou into lower quality habitats where there is a greater risk of predation, permitting the forestry harvesting strategy to act as an

ecological trap (Battin, 2004). Northern range recession could be reduced through strategies that consider spatial arrangement in creating larger, > 250 km² block units (Courtois, 2003). Spatial pattern for conservation needs to provide connectivity for a broad ranging species in a fragmented landscape where area and arrangement of habitat are considered for rehabilitation to ensure that habitat types not only exist in the landscape but occur in locations, compositional amounts, and configurations that are useful for boreal woodland caribou.

2.7 Landscape ecology and conservation challenges in mixed-ownership landscapes

Unique challenges arise in landscapes where mixed ownership and land-use exists, which is common at broad spatial scales such as the regional-scale, and in resource-rich areas such as in the Kesagami region of Ontario. Knowing about environmental processes is not sufficient on its own when understanding coupled human and natural systems; it must be integrated with the knowledge of understanding human behaviour, values and trends (Opdam et al. 2013).

Forest harvesting and management strategies impact boreal woodland caribou and are frequently cited as having negative impacts on wildlife due to habitat fragmentation (Saunders et al. 1991; Fahrig 2003). Forest management strategies may include activities such as adjusting the organizational pattern of harvests to obtain greater connectivity and patch size, but response of wildlife to such measures is unclear. It will likely take decades for landscape recovery efforts to become effective for boreal woodland caribou, as proximity to harvest blocks at the population range scale did not decrease through time in a 20-year study by Donovan et al. (2017). Forests need to be better integrated within the surrounding context and recommendations to improve forest condition include considering the surrounding land-uses to be place-specific so that appropriate forest functions- that is, as habitat- are also actively sought (Ribeiro and Lovett, 2009). Challenges include identifying compatible land-uses in areas

and avoiding highly conflicted landscapes occurring adjacent to each other as to avoid a situation where their function is reduced (Ribeiro and Lovett, 2009).

The variance in attitudes and goals with landscape use and management make this a challenging situation when landscape planning, use and management are engaged to integrate ecological, social, and economic goals and objectives (Kaufmann et al. 1994). Challenges exist when trying to meet conservation and biodiversity objectives and enhance ecosystem integrity, while also considering the economic objectives of the landscape and societal needs (Dale and Haeuber, 2001). All of these intersections are important to consider in the landscape design and planning process; realistic concerns and landscape issues need to be addressed early in the design phase. Goals are more likely to be met if the reality of the landscape, with its challenges and opportunities, is properly considered when investigating landscape planning for conservation. Failure to integrate the social and economic objectives that exist within the landscape often result in unsustainable landscapes either socially, economically or ecologically (Dale and Haeuber, 2001). Coarse-filter approaches to analyzing landscapes allow ecosystem integrity to be considered (Schwartz, 1999), as this approach will focus on ecosystems and their processes for a threatened species in a fragmented landscape.

2.8 Ecological landscape planning and habitat connectivity

Ecological rehabilitation is integral to species persistence in landscapes where there has been a reduction in habitat and ecosystem integrity that now renders the species unable to fulfill its life processes due to reduced habitat (SER, 2004). The cumulative impacts of landscape fragmentation, combined with a higher incidence of predation due to the associations of wolves and moose in disturbed areas, have created a situation for boreal woodland caribou that is only contributing to their status as a threatened species. Habitat rehabilitation for boreal woodland caribou is especially needed in areas where local populations are small and declining and where cumulative

disturbances are high (Hervieux et al. 2013). Ecosystem integrity, a quality associated with the restorative landscape, addresses the ecological processes that are essential to ecosystem function; ecosystem integrity allows communities to function properly to support species and their genetic levels of biological diversity (Dale and Haeuber, 2001). When landscapes are degraded, ecosystem function is often compromised, and rehabilitation through landscape planning and design is one way to attempt to restore integrity to this system (SER, 2004). Effective habitat rehabilitation for boreal woodland caribou as noted by Ray (2014) will require linking site-specific action to range-level effectiveness evaluation (for example, through modeled landscape effects), underscoring the importance of planning restorative efforts at the range-scale first to prioritize the most likely areas for habitat rehabilitation activities.

Habitat connectivity impacts the spatial distribution of species through accessibility and can constrain species by making some areas inaccessible (Burgess and Sharpe, 1981; Pulliam et al. 1992). Land-cover change, for example from habitats such as treed coniferous forests to forest of sparse trees and shrubs, is likely to have substantial effects on species in areas where habitat is in a state of low-to-intermediate abundance (Pearson et al. 1996).

Since connectivity is a threshold dynamic, a reduction in habitat after a certain compositional amount will lead to more dramatic effects compared to changes in compositional amounts before this threshold is reached (Andren, 1997). The threshold of connectivity varies among species and is related to the abundance and spatial arrangement of habitat, and the movement or dispersal abilities of the organism (Gardner et al. 1989; Pearson et al. 1996). The ecological importance of a patch of habitat may be greater than its spatial extent, where the patch's contribution to the compositional and surrounding configuration has farther-reaching spatial benefits or consequences (Dale and Haeuber, 2001). Since individual sites are linked biologically to the landscapes in which they occur, there is functional interdependence, and individual rehabilitative efforts as well as exploitative landscape activities cannot occur

in isolation (Bedford, 1999). Landscape context identified at scales above the site-scale, such as the regional, range and landscape scale, are paramount and strongly influence presence of species occupation (Arkle et al. 2014).

Boreal woodland caribou are a far-ranging species, where 10,000-15,000 km² of sufficient habitat may be required for populations to be self-sustaining (Environment Canada, 2011). As such, their habitat requirements include large tracts of old-growth conifer-dominated forest that is becoming increasingly fragmented in the boreal region (Environment Canada, 2011). Conserving caribou habitat must include metrics to assess connectivity to assist in understanding future boreal woodland caribou occupation in the region. Environment Canada (2012) identifies that the local population range scale is the most appropriate scale at which critical boreal woodland caribou habitat should be characterized. This scale is consistent with the regional scale.

2.9 Habitat rehabilitation importance for boreal woodland caribou

Habitat rehabilitation is highlighted as a key component of boreal woodland caribou recovery plans (Environment Canada 2012). Co-ordination of rehabilitation activities that build large tracts of habitat that result in high levels of landscape connectivity should be prioritized (Ray, 2014; Environment Canada, 2012; OMNRF, 2009). Ecological landscape planning and habitat rehabilitation for boreal woodland caribou are especially needed in areas where local populations are small and declining (Ray 2014; Environment Canada 2011; OMNRF, 2009). Landscape-scale factors must influence site-scale habitat rehabilitation activities as outcomes of success include multiple scales of landscape context (Brudvig 2011; Kouki et al. 2011). Landscape context is linked to rehabilitation success where high quality habitat sites must be implemented in spatial areas that are accessible in high quality landscapes (Arkle et al. 2014). Ray (2014) summarizes that habitat rehabilitation at the range-scale should include i) prioritizing areas for landscape rehabilitation, ii) undertaking strategic coordination of rehabilitation activities that build large tracts of habitat, iii) building large

tracts of habitat with high levels of landscape connectivity, and iv) monitoring the progress of rehabilitation, including monitoring predators and alternate prey. This approach is opportunistic towards ameliorating conditions; however, a preventative approach may also be needed for species conservation. In either approach, evaluating alternative landscape patterns for habitat outcomes is useful to understanding ecological effects.

2.10 Using an individual-based movement model considering boreal woodland caribou perception and memory

The application of evaluative models with alternative landscape futures has the capacity to facilitate further collaboration and discussion among policy makers, ecologists, landscape planners, land and wildlife managers, landscape architects and other envisioners and stewards of the land (Santelmann et al. 2001). By evaluating a broad set of alternatives, experimental research can be focused on the most important aspects that hold the greatest promise to obtain desired outcomes (Santelmann et al. 2001).

Using an animal movement model that indicates forage, movement trajectory and population persistence is appropriate for evaluating landscape connectivity for a species at risk as it can evaluate how species might disperse throughout the landscape based on habitat requirements, land-cover and available forage. Understanding population persistence is an important task in conservation biology, and certainly with threatened species (Beissinger and Westpaul, 1998). The model's ability to assign each location in the landscape a value that corresponds to boreal woodland caribou's ability to transverse all land cover types that occur within the study boundary assists in understanding how landscape change impacts boreal woodland caribou. A movement model that considers the animal's perception and memory provides robustness to the decision-making process where modelled movement results are based on more

than one area and one moment of cognition. Coupling this with landscape characteristics to produce paths where many landscape factors impact model caribou movement decisions can assist in land management decision-making. Evaluating how landscape alterations impact model boreal woodland caribou's ability to move through alternative landscapes allows us to better understand how boreal woodland caribou might be impacted by landscape change at the regional/range scale through multiple measures.

2.11 Conclusion

Ongoing landscape fragmentation has significantly contributed to boreal woodland caribou declines in the boreal forest (Festa-Bianchet et al. 2011; Ray, 2014). Ecological landscape planning and evaluation are especially important in areas where boreal woodland caribou are in decline and have suffered severe landscape change, such as in the Kesagami region in northern Ontario. Understanding how future landscape alteration from current trends impacts species that are threatened allows us to quantify consequences from landscape change. Envisioning future management and landscape scenarios where spatially-specific interventions can then be implemented to assist in the recovery of boreal woodland caribou. Alternative scenario projection and design can be an effective strategy for envisioning future states based on different land-based goals and objectives and evaluating the resulting landscape changes with a robust model for caribou persistence merits investigation. Ecological landscape planning that considers the forage availability, movement trajectory and persistence of caribou with predator-prey relationships in the landscapes they inhabit through projections of future land-use, evaluated with an empirically tested agent-based movement model, could be opportune for understanding how our landscapes could facilitate or hinder caribou persistence and recovery and contribute to future policy and management of this threatened species.

3 METHODS

This chapter describes the methods utilized to execute this research project. The project required selection of a study area boundary, representation of the landscape, intentional alterations of landscape conditions by replicable means, and assessment of the outcomes for distinct landscapes. These outcomes are limited to the boreal woodland caribou and include multiple factors that affect caribou viability, such as predator and alternate-prey relationships. The landscape was represented at a scale that was appropriate to the boreal woodland caribou (the home-range scale).

3.1 Study area

The area selected for this project was based on an existing caribou range in Ontario and the availability of spatial data and applicable evaluation models. The study area is situated within the Kesagami management unit in northern Ontario, along the Quebec border and south of James Bay and is approximately 47,000 km² in size (Figure 2).



Figure 2. Kesagami management unit (black outline) situated in northern Ontario. Inset with dotted line is study area.

A smaller portion of the range was selected for landscape alteration in this study as the more-southerly extents exceed recommended disturbance proportions (more than 61% disturbed) making their likelihood as caribou habitat low (OMNRF 2014; Figure 2). The northern portion of the range, sub-arctic lowlands (2E-2 classified land identified from Ontario Eco district data) was clipped from the study area as this part of the landscape was not part of the parameterization process for modelling.

The study boundary within this region is central and 17,686 km² (roughly 37% of the Kesagami range area) and was delineated from habitat and anthropogenic disturbance data. This multi-use landscape includes boreal forest, boreal lowlands, forestry cutblocks, active and legacy mines, conservation areas, and some regions of settlement (Figure 3). Ownership of this landscape belongs to forestry companies, government, mining companies, First Nations peoples, and small landholders.

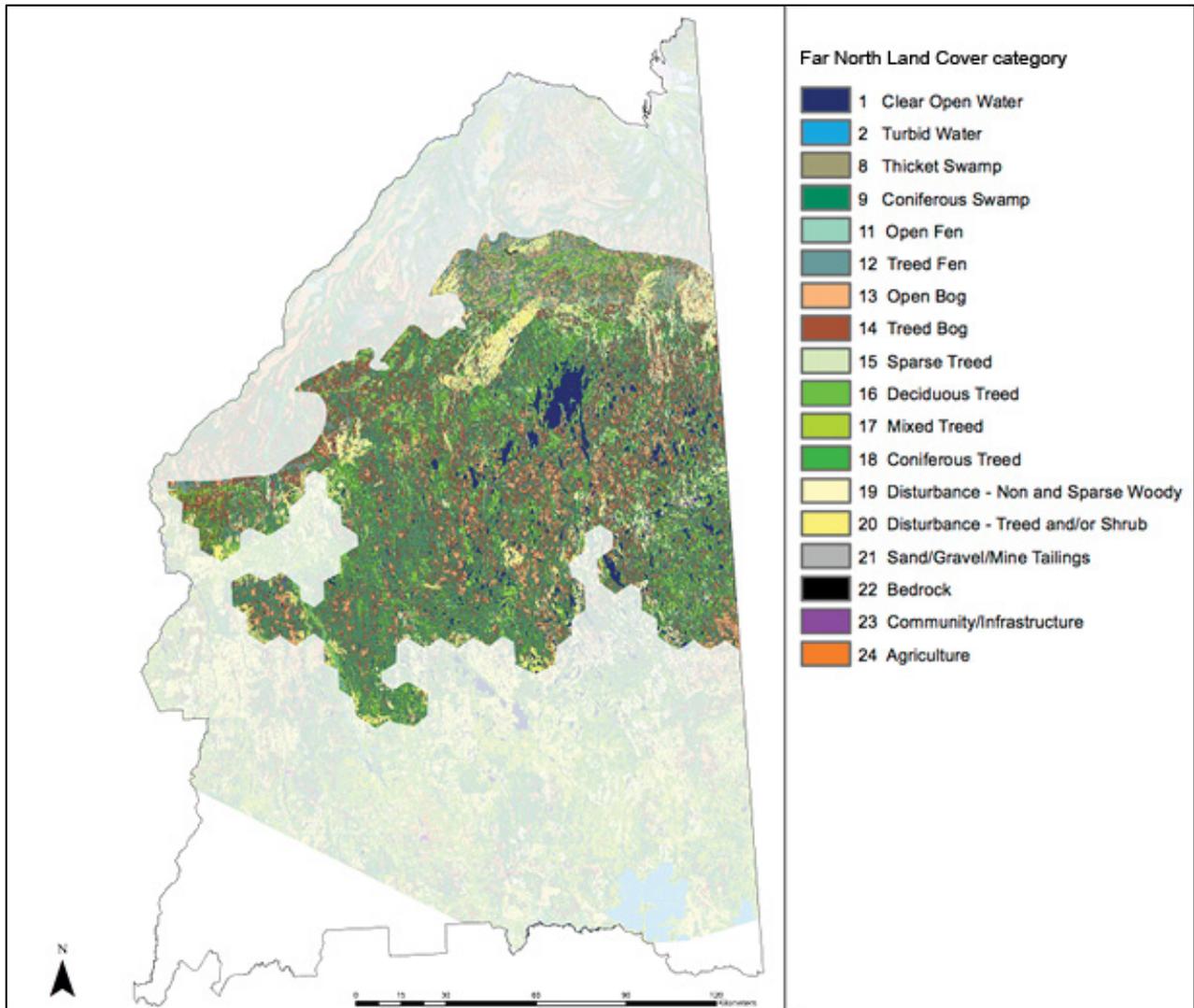


Figure 3. Baseline landscape indicating study boundary area within the Kesagami range in Northern Ontario.

3.2 Landscape representation

The landscape was represented in a geographic information system (GIS) using publicly-available data. Some data were digitized from reports, most-notably because the boreal woodland caribou are an at-risk species and some range and location data are not explicitly specified for at-risk species in Canada to protect them. This section describes how the landscape was represented and prepared for assessment. All landscapes were created in ArcMap 10.5. with Universal Transverse Mercator (UTM Zone 17N) projection based on NAD83 datum.

3.2.1 Land cover

2011 Far North Land Cover (FNLC) data, from Land Information Ontario (LIO) which represents information from 2005-2011, were used for this study. Representation in raster format used a cell size of 30m x 30m. 18 FNLC classes exist in the study boundary after the region was clipped (Table 1). Two categories, “Cloud” and “Other” were changed to “no data” as they did not represent any meaningful category in the analysis and might interfere with modelling. Table 1 and Figure 4 indicate land cover categories in the study boundary and their proportions. Figure 5 visualizes the baseline landscape.

Table 1. Landcover proportions in the Baseline landscape occurring within the study boundary area.

Far North Land Cover Category	Proportion in Baseline Landscape (%)	Baseline Hectares (ha)
Clear Open Water	7.708	136322.64
Turbid water	0.091	1611.81
Thicket Swamp	0.334	5903.91
Coniferous Swamp	35.406	626202.18
Open Fen	0.801	14172.93
Treed Fen	7.013	124027.47
Open Bog	6.093	107767.08
Treed Bog	19.925	352391.85
Sparse Treed	5.486	97028.55
Deciduous Treed	0.211	3731.31
Mixed Treed	1.038	18365.13
Coniferous Treed	9.421	166628.88
Disturbance-Non and Sparse Woody	3.022	53444.7
Disturbance-Treed and/or Shrub	3.076	54410.4
Sand/Gravel/Mine tailings	0.020	352.53
Bedrock	0.062	1090.8
Community Infrastructure	0.289	5106.6
Agriculture	0.003	51.93

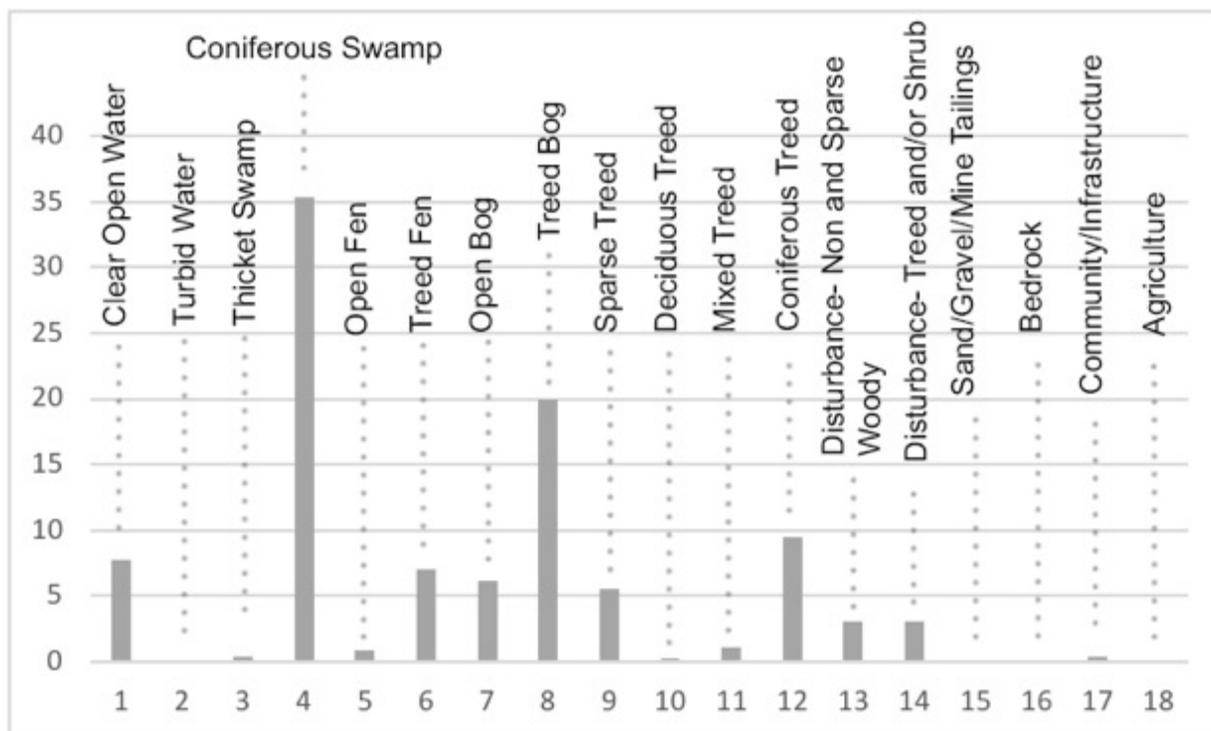


Figure 4. Landcover proportions (%) in the baseline based on 30m-resolution pixel counts.

3.2.2 Roads

Roads were synthesized from multiple datasets. Data sources for the road layer include Ministry of Natural Resources (MNR) road segments, Ontario Road Network, Ontario Railway Network and Forestry Roads from MNR which was previously compiled and provided by Boyan Liu (MSc and Research Assistant, Fryxell Lab, University of Guelph). Primary roads and secondary/tertiary roads were identified and split into two different categories. Roads were rasterized and reclassified as FNLC disturbance category 'Community/Infrastructure'. Primary roads were buffered 500m for use with wolf density analysis and classified as 'Community/Infrastructure'.

3.2.3 Mines

Mines and mineral deposits were identified from Mineral Deposit Inventory data from 2013 and clipped to the study region. Mines in the study region identified from this dataset were buffered 100m, rasterized to 30m cell resolution, and reclassified as FNLC disturbance category 'Community/Infrastructure.'

3.2.4 Normalized difference vegetation index

Normalized difference vegetation index (NDVI) quantifies vegetation in the landscape by measuring near-infrared and red light. Near-infrared light is highly reflected by vegetation, and red light conversely is absorbed, normalized to produce values between -1 and 1. NDVI data were used to infer forage as dietary digestible biomass estimates for caribou, Resource Selection Function Probability (RSFP) for moose, as well as density of wolves. NDVI data representation used a cell size of 381.6575462 metres x 381.6575462 metres, dated from May 25th, 2010 – Oct 15th, 2010, and then Nov 1st, 2010– Oct 31st, 2011. 2010 summer data was used, only for modelling wolf density. The dataset used is MOD13Q1 V006 (MODIS/Terra Vegetation Indices 16-Day L3 Global 250m Grid SIN V006, given in 16-day windows).

3.2.5 Snow-depth

Snow-depth data were downloaded from National Centers for Environmental Prediction, North American Regional Reanalysis (NARR), clipped to the region's extent, and normalized for each layer based on global minimum and maximum values of all snow-depth layers. Cell size 32km x 32km and date range is 1 Nov 2010- 31 Oct 2011. Summer months are set to zero (10 June 2011- 29 Sept 2011). Previous studies indicated that caribou response in this model to elevation was negligible and as such elevation data were not used in this project. Table 2 describes final data inputs for modelling submission.

Table 2. Data required in the landscapes to receive modelling output results related to caribou viability.

Data input	Source
Landcover	Far North Land Cover (2011) from Ontario Land Information
Road layers	Ministry of Natural Resources and Forestry, Ontario Road Network, Ontario Railway Network, Forestry Roads
Mining layers	Mineral Deposit Inventory 2013
Normalized difference vegetation index	MODIS/Terra Vegetation Indices, 2010-2011
Snow-depth	Nation Centers for Environmental Prediction, 2011

3.3 Alternative future scenario landscape development

Drivers of landscape change in the region were compiled from assessing the literature and policy documents for current trends within the area related to forestry, mining, settlement, road network, and other land covers. This information was used to create an explicit rules-based approach for extrapolating how the business-as-usual (BAU) landscape would be created conceptually and designed geospatially in a GIS. Key drivers of landscape change were identified to create replicable design rules and the resulting four landcover categories were identified: mining, forestry, infrastructure/settlement and conservation-based landcovers. These categories were then translated into geospatial rules for designing each landscape (Appendix 1).

3.4 Map creation in ArcGIS

3.4.1 Baseline landscape

A baseline landscape was created to assess current landscape conditions and was used as a control against the BAU landscape. The baseline represented – as closely as possible – the existing landscape conditions and includes the data described in section 3.2. Land covers were derived from existing data, with accompanying NDVI and snow-depth values. Roads and mines were based on current mapping ranging from 2005-2013 and described in 3.2.2.

3.4.2 Business-as-usual landscape

A business-as-usual (BAU) landscape (Table 3, Figure 6 and 7) was created to project landscape change approximately 20-years into the future based on development trends in the region with respect to forest harvesting, mineral exploration, infrastructure changes, and any activities associated with these including building new roads. Assumptions about this landscape and design rules associated with it can be found in Appendix 1.

This project used a timeline of 20 years into the future as this is the caribou generation time as well as a length of time that aligns with planning cycles.

Table 3. Landcover proportions in the Business-as-usual landscape occurring within the study boundary area.

Far North Land Cover Category	BAU Proportion (%)	BAU Hectares (ha)
Clear Open Water	7.708	136322.64
Turbid water	0.091	1611.81
Thicket Swamp	6.468	114384.87
Coniferous Swamp	29.273	517721.22
Open Fen	1.590	28125.36
Treed Fen	6.224	110075.04
Open Bog	8.755	154849.68
Treed Bog	17.263	305307.18
Sparse Treed	5.486	97028.55
Deciduous Treed	0.164	2902.95
Mixed Treed	0.867	15341.67
Coniferous Treed	7.502	132676.74
Disturbance-Non and Sparse Woody	5.159	91248.66
Disturbance-Treed and/or Shrub	3.076	54410.4
Sand/Gravel/Mine tailings	0.020	352.53
Bedrock	0.062	1090.8
Community Infrastructure	0.289	5106.6
Agriculture	0.003	51.93

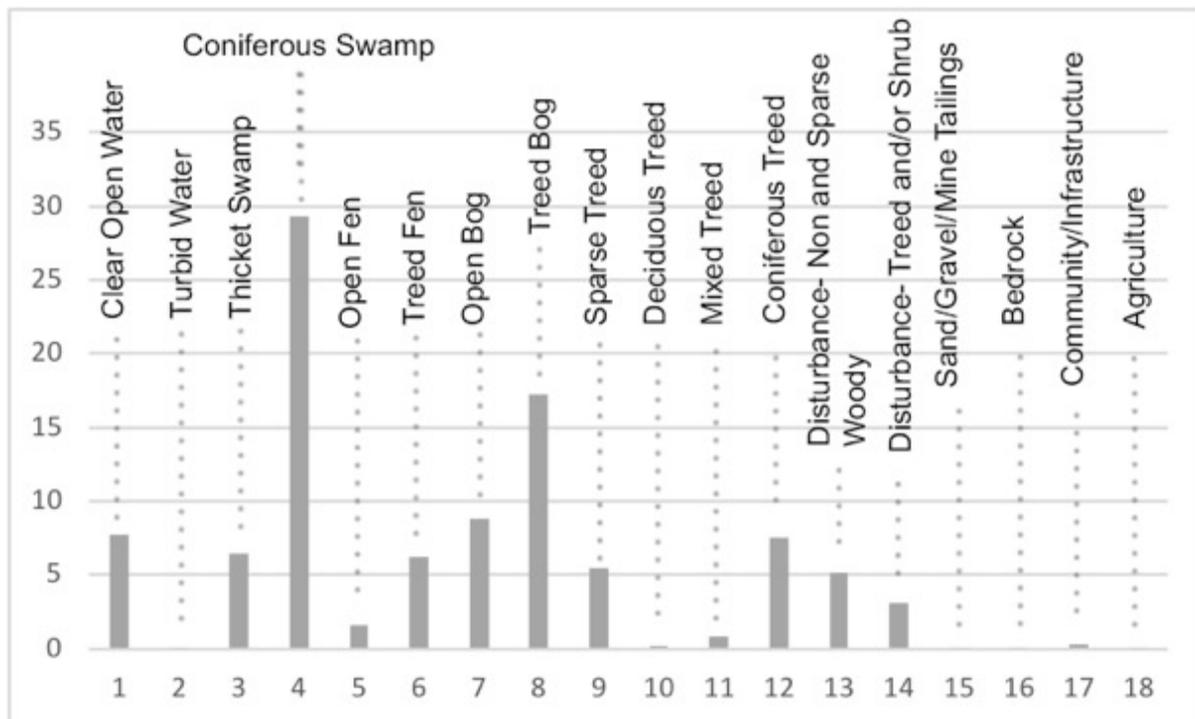


Figure 5. Landcover proportions (%) in the Business-as-usual landscape based on 30x30m pixel counts.

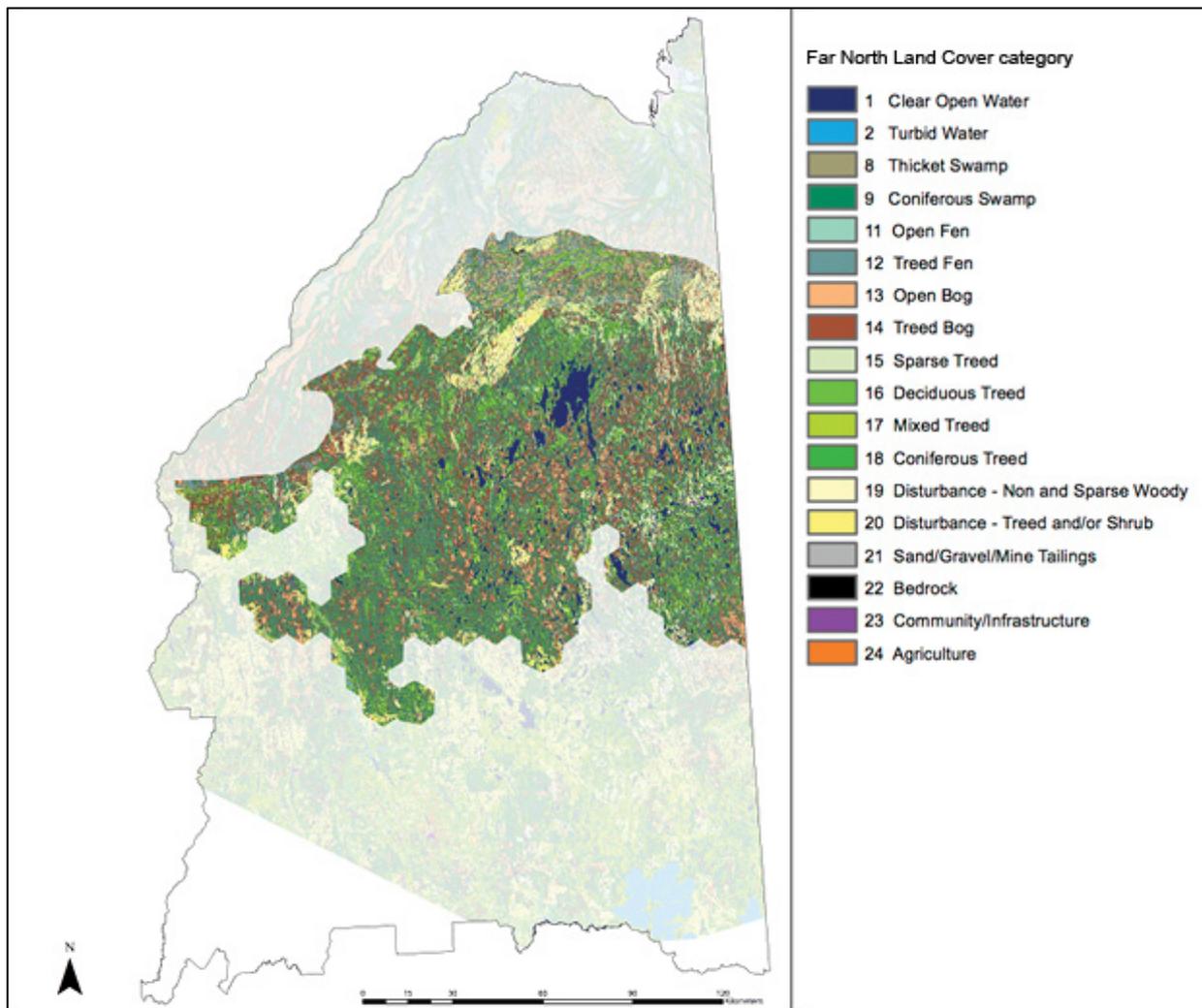


Figure 6. Business-as-usual landscape, after land cover changes occurred following an explicit, replicable rules-based approach.

3.4.2.1 Mine creation

Categories from the Mineral Deposit Inventory (MDI) definitions data sheet with MDI 2013 point data that occurred within the study boundary were ranked from most to least likely to become active in the next 20 years, based on the description in the mineral occurrence data set (Table 4). Within the study boundary, MDI data points that are present include (1) Prospect, (2) Developed Prospect with Reserves, (3) Occurrence and (4) Discretionary Occurrence. I assume (1) and (2) are most likely to become active, and that (3) is more likely to become active compared to (4). Based on

these definitions, I assume (1) Prospect and (2) Developed Prospect with Reserves to become active, I assume (3) Occurrence to become active 1/10th of the time and (4) Discretionary Occurrence becomes active 1/20th of the time (Table 4).

Table 4. MDI deposits listed as most to least likely to become active in the study area in the BAU landscape.

MDI 2013 category	Definition	Likelihood of becoming active in 20 years	Number of mine points in BAU
Prospect	Mineralization is present in 3 dimensions, indicated by diamond-drill intersections ± surface rock sampling. Mineralization occurs for significant distances along strike and down dip with a minimum of 3 intersections that meet the minimum requirements for a prospect.	1/1	7
Developed Prospect with Reserves	Mineralization is present and defined in 3 dimensions as outlined by a delineation diamond-drilling program. Mineralization occurs for significant distances along strike and down dip with multiple intersections that meet the minimum requirements for a Prospect. Reserves must meet the minimum requirements for a Producing Mine, a Past-Producing Mine or a Developed Prospect with Reserves.	1/1	10
Occurrence	Mineralization is present in 2 dimensions as indicated by surface rock sampling (channel or grab) and/or isolated diamond-drill intersection(s). At least one sample must meet the minimum requirements for a mineral occurrence.	1/10	3
Discretionary Occurrence	An occurrence or deposit that does not meet any of the defined criteria but is entered into the MDI database based upon a subjective decision by a MNDM geologist.	1/20	8

A Python (programming language) script tool was used to select a random sample of mining data points from (3) Occurrence and (4) Discretionary Occurrence. The script generated 8 random Occurrence points (1/10) and 3 random Discretionary Occurrence points (1/20). These selected mines were then buffered 100m and classified as disturbance 'Community/Infrastructure' in the FNLC based on model requirements.

3.4.2.2 Road creation

The same road data from the baseline landscape and described in 3.2.2 were used in the BAU landscape. However, new roads were created to new mineral deposit areas identified in the previous step, and forest management units slated to be harvested based on projected mining and forestry related activities were also created. These roads were created by connecting them to the nearest existing road feature by a simple, straight line using a 'near' function tool in ArcMap. Roads were then rasterized and integrated into the final FNLC category as 'Community/Infrastructure' in the FNLC based on model requirements.

3.4.2.3 Forestry Management Plan Unit analysis and FNLC reclassification

Forestry Management Plan (FMP) units indicating harvest schedule were used to delineate forest age and were created from the Ontario Ministry of Natural Resources and Forestry (OMNRF) 2014 maps and converted into rasters in ArcMap. Rasters were combined and classed with the FNLC to create age-classed land cover vegetation types from the seven cutblock types in the FMP. I inferred which blocks would be cut based on the harvesting schedule in the region (Forest cutblock G would have been cut, followed by cutblock A twenty years later) provided in the OMNRF 2014 document.

FMP units designated as harvested and to-be-harvested within the timespan of twenty years had land cover class changes to reflect this harvest schedule. FMP areas labelled A and G were "harvested" within the 20-year time change and associated FNLC class changes occurred (Table 5, Figure 8). These changes were based on the most-likely land cover type in the FNLC data set to match these spatial areas in 20 years after harvest cuts. These changes occurred via a 'reclassification' tool in ArcMap.

Table 5. Far North Land Cover categories in the baseline landscape and associated reclassified Far North Land Cover categories for the business-as-usual landscape.

Baseline FNLC category	Reclassified post-harvest FNLC category in BAU
Coniferous Swamp	Thicket swamp
Treed Fen	Open Fen
Treed Bog	Open Bog
Deciduous Treed	Disturbance-Non and Sparse Woody
Mixed Treed	Disturbance-Non and Sparse Woody
Coniferous Treed	Disturbance-Non and Sparse Woody

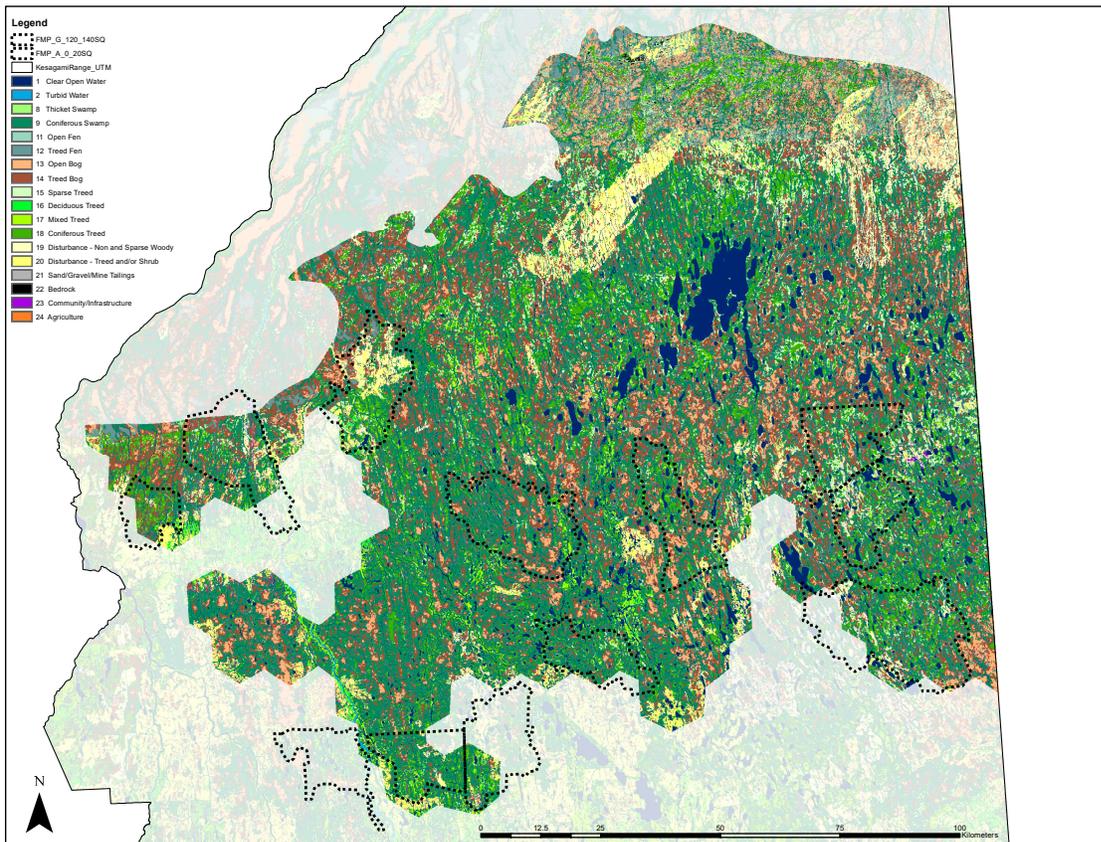


Figure 7. Forest Management Unit Plan harvest blocks with landcover changes occurring within the study boundary.

3.4.2.4 Normalized difference vegetation index reclassification

Normalized difference vegetation index (NDVI) data from 2010 and 2011 as described in the baseline landscape were used to infer dietary digestible biomass in the future projected landscape. NDVI values in the FMP unit cuts were changed to reflect

the land cover reclassification changes. Mean values for FNLC categories Disturbance-Non and Sparse Woody, Open Bog, Open Fen and Thicket Swamp within the study boundary were calculated in ArcMap 10.5 from original land cover classes for each NDVI layer. These means were used to reflect harvest cuts implemented in the BAU landscape of what the resulting landcover class would be at this timestep. Mean NDVI was used to create a new layer reflecting this change, which was then joined using a 'mosaic' function to the original NDVI layer in ArcMap. This resulted in an updated version of the NDVI with projected BAU changes. Spatial reference was MNR Lambert 1983, cell size was 381.6575462 metres.

3.4.2.5 Snow-depth

Snow-depth data were downloaded from NCEP, clipped to the study area extent, and normalized for each layer based on global minimum and maximum values of all snow-depth layers. Due to the coarse spatial resolution, snow-depth data were not modified and are unchanged from the baseline snow-depth data.

3.5 Landscape modelling workflow

The baseline and business-as-usual landscapes were run on a model created by Avgar et al. 2015 and described in Avgar et al. 2015 and Fryxell et al. [in prep.] to produce results related to caribou persistence and population growth using caribou forage, wolf density, moose resource selection probability (RSPF) values and model caribou movement trajectories. Data layers required to run the model included land cover classes in the form of FNLC (with associated road changes, mine additions, and land cover changes from FMP in the BAU landscape), NDVI data, and snow-depth data. Separated out road files with 500m buffers were used for calculating wolf density.

Described briefly, the model runs as a three-part module and produces

1. forage availability for moose and caribou, and wolf density,

2. movement trajectories for caribou, and
3. likelihood of caribou persistence based on results from steps 1 and 2.

3.5.1. Forage availability and wolf density

The first part of the module produces results related to caribou forage in the form of dietary digestible biomass (DDB). Caribou forage is calculated from NDVI and FNLC land cover class data. RSPF for moose is calculated from delta NDVI 2011 summer average – 2011 winter average, snow-depth, and land cover classes. RSPF values are calculated per hexagon unit in the landscape. Wolf density is calculated from elevation, land cover road types, dumps, settlement, and distance to water, and seasonal NDVI. Each hexagon is 500m from the centroid of one hexagon to the adjacent hexagon.

3.5.2 Movement trajectories

The movement model portion indicates where caribou are most likely to go on the landscape based on outputs from step 1 of wolf density, forage in the form of dietary digestible biomass, and moose occupancy. Movement trajectories can start anywhere within the range, and for this reason, I included a model boundary. The sub-alpine area and other portion of the Kesagami management unit range was, however, re-instated in an unaltered format prior to submission for modelling to alleviate truncation in the movement path simulations. Modelling was truncating when it came to movement trajectory formation of caribou, likely due to scale of study boundary with respect to how caribou were parameterized, or shape of study boundary. This challenge was overcome by introducing the rest of the landscape back and then running the model with a larger landscape.

3.5.3 Likelihood of persistence

The probability viability analysis (PVA) creates outputs from randomized movements of 1000 generated movement trajectories of individual caribou in a population of 300 caribou. Each year, if the caribou survives, the model then indicates if it reproduced. This occurs every year for 50 years, and each population is run 1000 times to produce an average lambda value of population growth related to caribou persistence. If output lambda is less than one, the population is decreasing.

4 RESULTS AND ANALYSIS

4.1 Caribou persistence, population growth, forage, and wolf density and moose resource selection function

Results from the model created by Avgar et al. 2015 and described in Avgar et al. 2015 and Fryxell et al. [in prep.] related to caribou persistence, population growth rate, wolf density, caribou forage and moose resource selection for both the baseline landscape and business-as-usual landscape are summarized in Table 6.

Table 6. Model results for caribou persistence, caribou population growth rate, wolf density, caribou forage and moose for baseline and business as usual landscapes.

Model output	Baseline landscape	Business-as-usual landscape
Population Persistence	20.70%	22.30%
Population growth rate (lambda)	0.9499	0.9501
Wolf density (mean, normalized)	0.2454	0.2470
Caribou forage (mean, normalized)	0.1472	0.0281
Moose (mean, normalized)	0.0273	0.1472

4.2 Trajectory Landcover

Far North Land Cover (FNLC) proportions in the baseline landscape and business-as-usual (BAU) were calculated from model caribou paths. The trajectory distributions of 25 randomly-selected model caribou were analyzed. Based on the time-intensive conversion of data from model outputs back into ArcMap for further analysis, all 1000 trajectories were not analyzed for this research. A random number generation with criteria to select between 1 and 1000 was used to select trajectory numbers for both the BAU and baseline model caribou. This tool was used to randomly select numbers until there was a total of 25 model caribou trajectories that met the criteria of being within 5km of the study boundary. Trajectories had to occur within the boundary as this was the part of the landscape with intentional landscape pattern changes. In the baseline landscape, three different model caribou selected had the same geospatial trajectory.

Each model caribou trajectory's landcover was analyzed by calculating the area of each landcover type that fell within each model caribou path, represented as a 250-meter radius buffered point in ArcMap (Table 7, Figure 8).

Table 7. Area of each Far North Land Cover category in hectares occurring in the model caribou trajectories in both the baseline landscape and business-as-usual landscape.

Far North Land Cover category	Sum of Baseline trajectories (ha)	Sum of BAU trajectories (ha)
Clear Open Water	34573.23	36882.9
Turbid water	35.82	18.54
Thicket Swamp	1147.59	35179.38
Coniferous Swamp	197412.75	157744.26
Open Fen	1243.26	4867.11
Treed Fen	17609.22	15173.01
Open Bog	24616.53	48613.32
Treed Bog	95081.4	81213.84
Sparse Treed	13806.18	14264.19
Deciduous Treed	589.23	282.87
Mixed Treed	5898.51	5016.51
Coniferous Treed	44406.09	35267.76
Disturbance-Non and Sparse Woody	3237.03	9959.4
Disturbance-Treed and/or Shrub	5384.61	4800.24
Community/Infrastructure	502.65	275.67

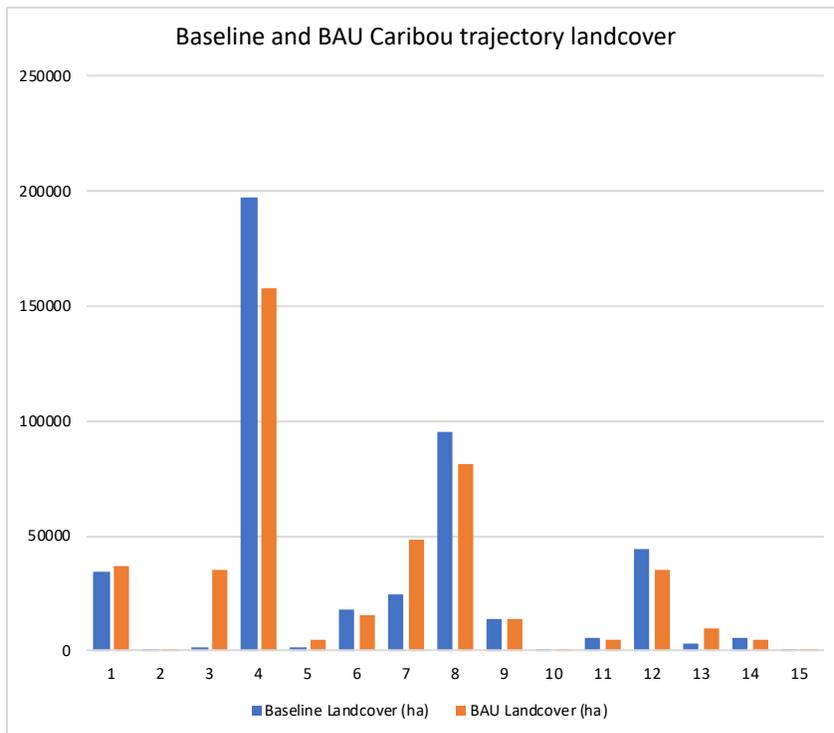


Figure 8. Far North Land Cover categories occurring in 25 randomly-selected caribou trajectories in the baseline and business-as-usual landscapes, represented in hectares.

(FNLC categories 1= Clear Open Water, 2= Turbid Water, 3= Thicket Swamp, 4=Coniferous Swamp, 5=Open Fen, 6=Treed Fen, 7=Open Bog, 8=Treed Bog, 9=Sparse Treed, 10= Deciduous Treed, 11=Mixed Treed, 12=Coniferous Treed, 13=Disturbance-Non and Sparse Woody, 14=Disturbance- Treed and/or Shrub, 15=Community/Infrastructure)

4.2.2 Baseline landscape

In the baseline landscape, caribou trajectories mostly occurred in FNLC categories coniferous swamp (44.31%), treed bog (21.34%) and coniferous treed (9.97%). Less than 1% of their time was spent in FNLC categories ‘Turbid Water’, ‘Thicket Swamp’, ‘Open Fen’, ‘Deciduous Treed’, ‘Disturbance-Non and Sparse Woody’, and ‘Community Infrastructure’.

4.2.3 Business-as-usual landscape

In the BAU landscape, caribou trajectories mostly occurred in FNLC categories ‘Coniferous Swamp’ (35.09%), ‘Treed Bog’ (18.07%) and ‘Open Bog’ (10.81%). Less

than 1% of model caribou trajectories were spent in 'Turbid Water', 'Deciduous Treed', and 'Community Infrastructure' in BAU.

'Thicket Swamp' consisted of nearly 8% of landcover trajectory cover compared to less than 1% in baseline. Caribou trajectories nearly doubled in 'Open Bog' in BAU and quadrupled in 'Open Fen' compared to the baseline landscape. Caribou in the BAU landscape occurred in 'Thicket Swamp' 30 times more than in the baseline landscape. Caribou in BAU spent 2.17% of their time in 'Disturbance-Non and Sparse Woody' compared to 0.74% in baseline.

Caribou in BAU spent less time in categories 'Turbid Water', 'Coniferous Swamp', 'Treed Fen', 'Treed Bog', 'Deciduous Treed', 'Mixed Treed', 'Coniferous Treed', 'Disturbance Treed and/or Shrub' and 'Community/Infrastructure' compared to baseline. Caribou spent more time in 'Open Bog', 'Clear Open Water', 'Thicket Swamp', 'Sparse Treed', 'Disturbance- Non and Sparse Woody' and 'Open Fen' compared to the baseline landscape (Figure 9).

Landcover types that increased in the BAU landscape included 'Disturbance-Non and Sparse Woody,' 'Community/Infrastructure,' 'Open Fen,' and 'Open Bog' and 'Thicket Swamp.' Landcover types that decreased from the baseline due to landscape change include 'Coniferous Swamp', 'Treed Fen', 'Treed Bog', 'Deciduous Treed', 'Mixed Treed', 'Coniferous Treed.'

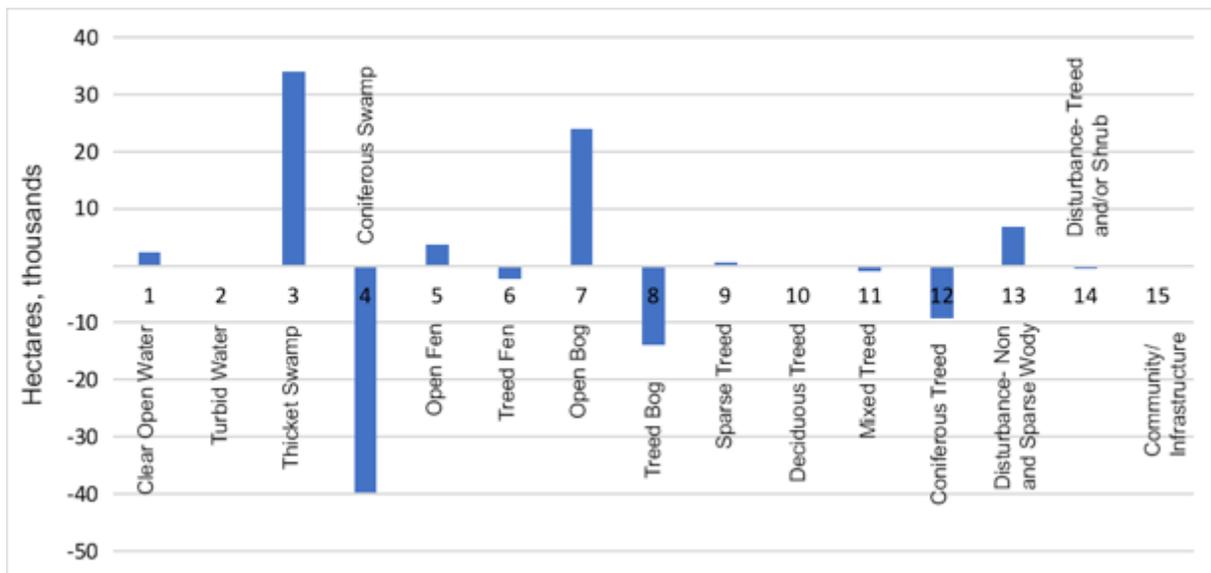


Figure 9. Far North Land Cover category shifts, in hectares, in the business-as-usual landscape compared to the baseline landscape in 25 randomly-selected model caribou trajectories.

4.3 Trajectory distribution

Trajectory distribution (North-South and East-West spread) was analyzed in ArcMap 10.5 for each randomly-selected caribou in both the baseline landscape and business-as-usual (Figures 10a and 10b). The average E-W distribution and N-S distribution values for baseline are 39542.72m and 37140.00m, respectively. The average E-W distribution and N-S distribution values for BAU are 35143.28m and 36990.00m, respectively (Figure 11). Max and min N-S values for baseline are 18500 and 57500 and for BAU, 13250 and 61250. Max and min E-W values for baseline are 22517 and 80541 and for BAU, 16887 and 58024. The BAU landscape extends further in the N-S direction; however, the baseline landscape extends further in the E-W direction.

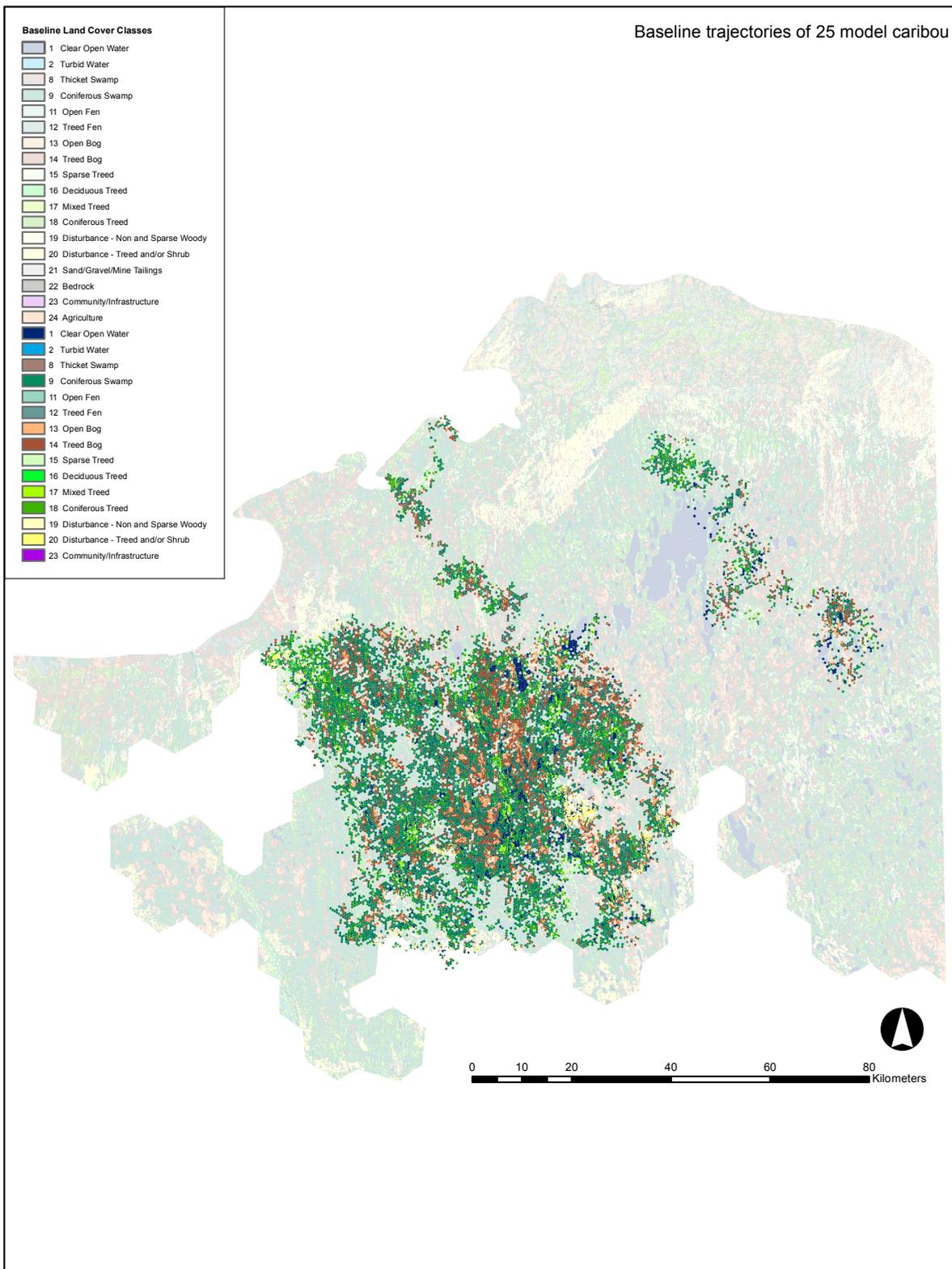


Figure 10a. Trajectory distributions of randomly-selected model caribou in the baseline landscape.

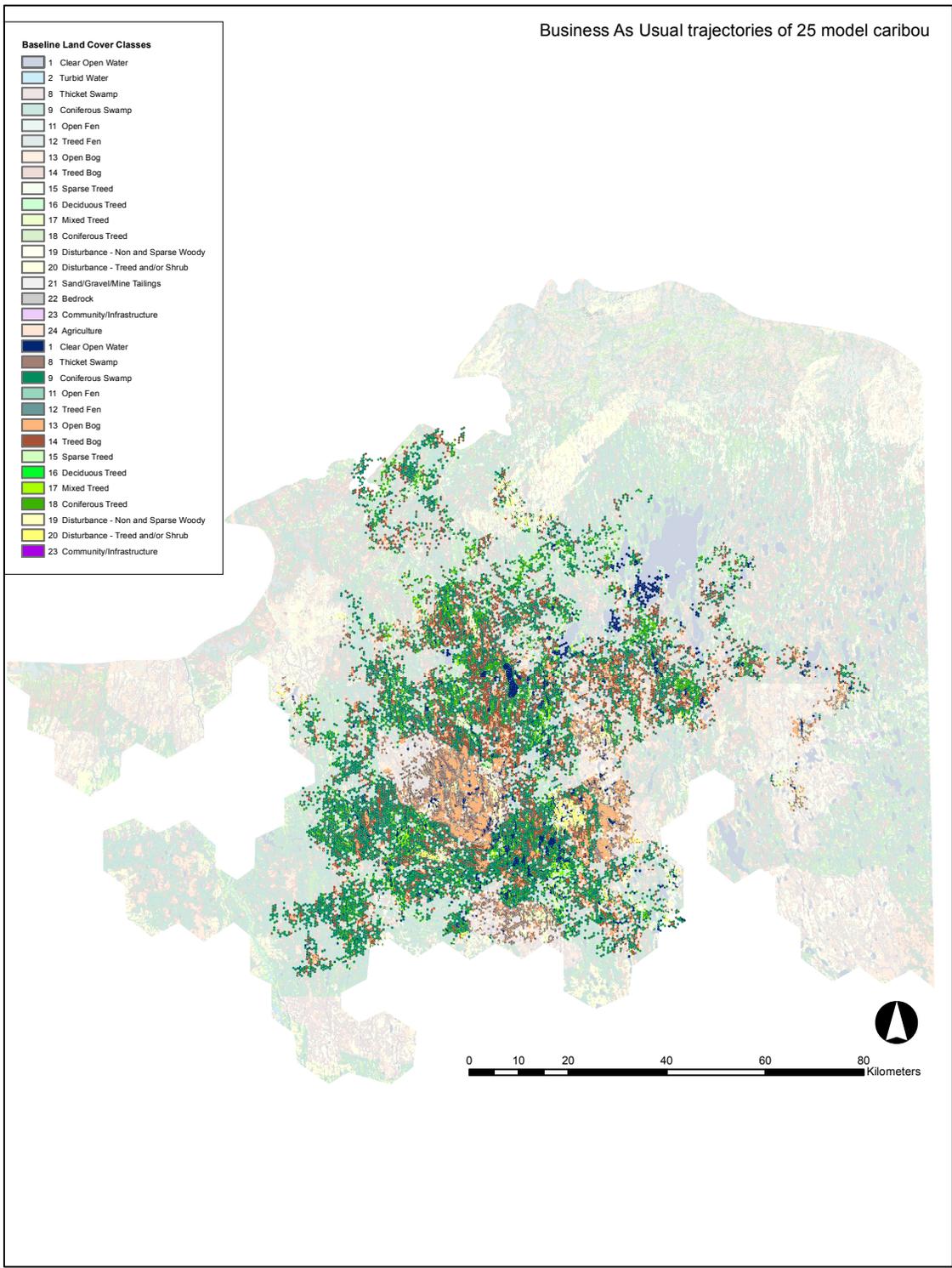


Figure 10b. Trajectory distributions of randomly-selected model caribou in the business-as-usual landscape.

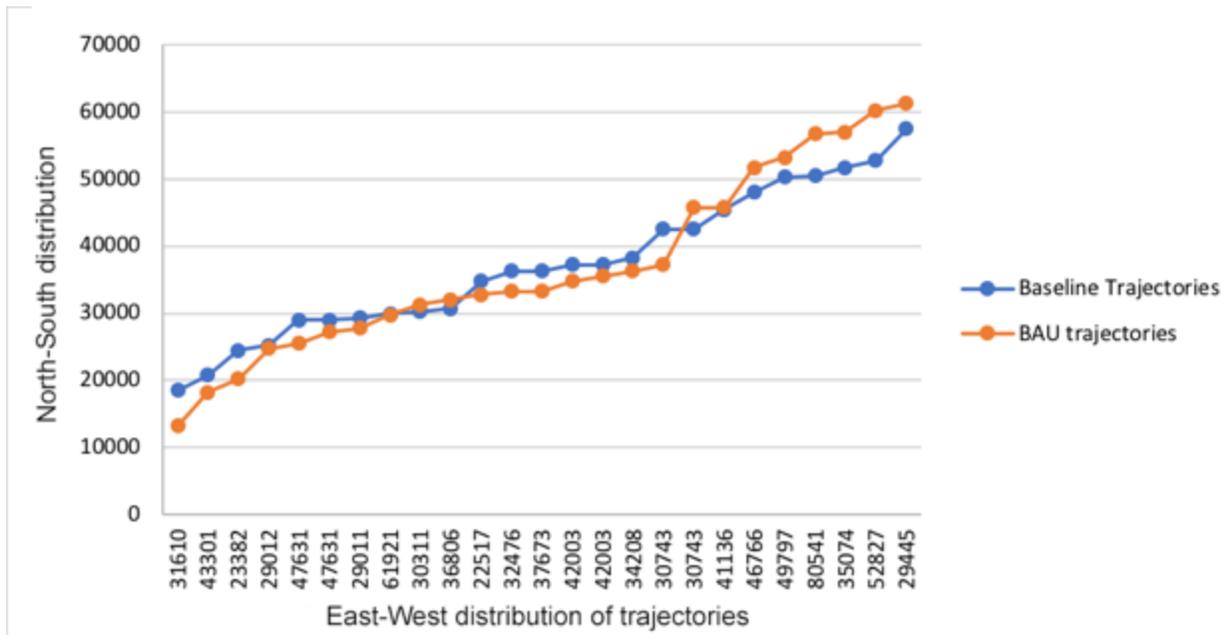


Figure 11. Spread for randomly-selected model caribou in the baseline and business-as-usual landscapes indicating the North-South and East-West distributions.

4.4 Optimized Hot Spot Analysis

An 'Optimized Hot Spot Analysis' was run in ArcMap 10.5 to determine which landcover category was preferred in the caribou trajectories for each. The 'Optimized Hotspot Analysis' creates a map of statistically significant hot and cold spots using the Getis-Ord-Gi* statistic. Spatially significant clusters of both high (hot) and low (cold) values are identified with this analysis using parameters derived from the characteristics of the input data (in this case- the trajectory points from model caribou paths). This tool indicates statistically significant spots where model caribou had high and low usage in the landscape. Detailed descriptions of how this tool is executed are described in ESRI (2018). To run this tool, randomly-selected caribou trajectories were merged in the baseline landscape and BAU landscape, respectively (Figures 12a and 12b).

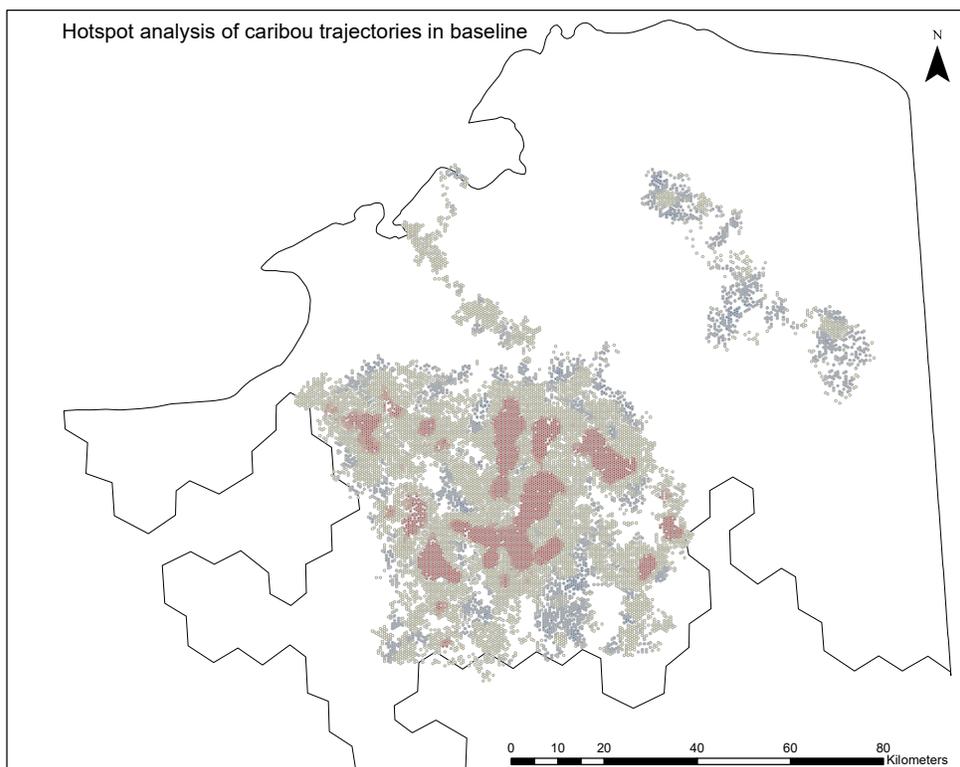


Figure 12a. Optimized Hotspot analysis in the baseline landscape- Results for 25 randomly-selected model caribou trajectories in the study area indicating areas in each landscape that had significant usage highlighted in dark red.

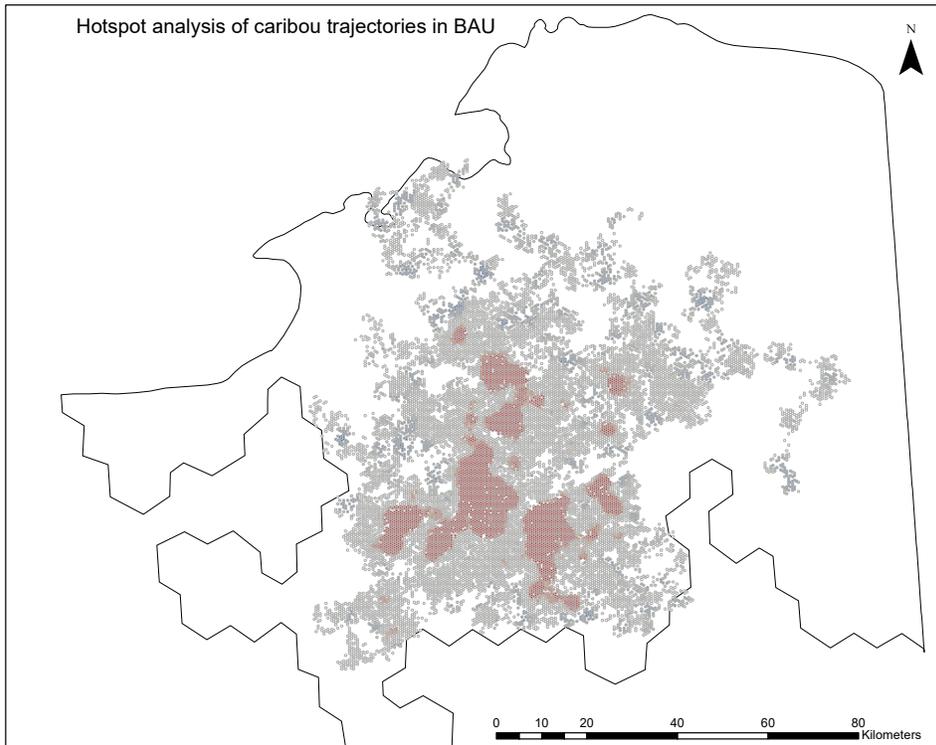


Figure 12b. Optimized Hotspot analysis in the business-as-usual landscape- Results for 25 randomly-selected model caribou trajectories in the study area indicating areas in each landscape that had significant usage highlighted in dark red.

Hotspot and coldspot areas were analyzed for landcover types associated with these areas in both the baseline and business-as-usual landscapes after merging randomly-selected model caribou trajectories in both landscapes, respectively (Table 8 and 9).

4.4.1 Hotspot Analysis

3244 of 16277 hotspot areas represented as 500m hexagons were significant in the business-as-usual landscape, and 2776 out of 13676 areas were significant in the baseline landscape at 95% confidence interval.

Hotspot landcover areas in BAU were less numerous in Far North Land Cover categories 'Turbid Water', 'Coniferous Swamp', 'Treed Fen', 'Treed Bog', 'Mixed Treed', 'Coniferous Treed', 'Disturbance- Treed and/or Shrub' and 'Community/Infrastructure' compared to the baseline landscape (Table 8, Figure 13).

Hotspot landcover areas were more numerous in Far North Land Cover categories 'Clear Open Water', 'Thicket Swamp', 'Open Fen', 'Open Bog', 'Sparse Treed', 'Deciduous Treed', and 'Disturbance- Non and Sparse Woody' in the BAU compared to the baseline landscape (Table 8, Figure 13).

Table 8. Far North Land Cover types associated with land-use hotspots (95% confidence interval) in randomly-selected model caribou trajectories in both business-as-usual and the baseline landscape.

FNL category	Baseline (ha)	BAU (ha)	Difference
Clear Open Water	4138.2	6172.74	2034.54
Turbid water	4.14	1.62	-2.52
Thicket Swamp	169.47	9038.43	8868.96
Coniferous Swamp	26704.89	21322.53	-5382.36
Open Fen	174.42	1139.13	964.71
Treed Fen	2273.22	1781.28	-491.94
Open Bog	3827.34	12269.16	8441.82
Treed Bog	14392.44	10525.5	-3866.94
Sparse Treed	1526.49	1644.57	118.08
Deciduous Treed	13.23	56.97	43.74
Mixed Treed	852.03	810.81	-41.22
Coniferous Treed	5722.65	4056.21	-1666.44
Disturbance-Non and Sparse Woody	315.54	1689.03	1373.49
Disturbance-Treed and/or Shrub	275.13	78.12	-197.01
Community/Infrastructure	28.44	0	-28.44

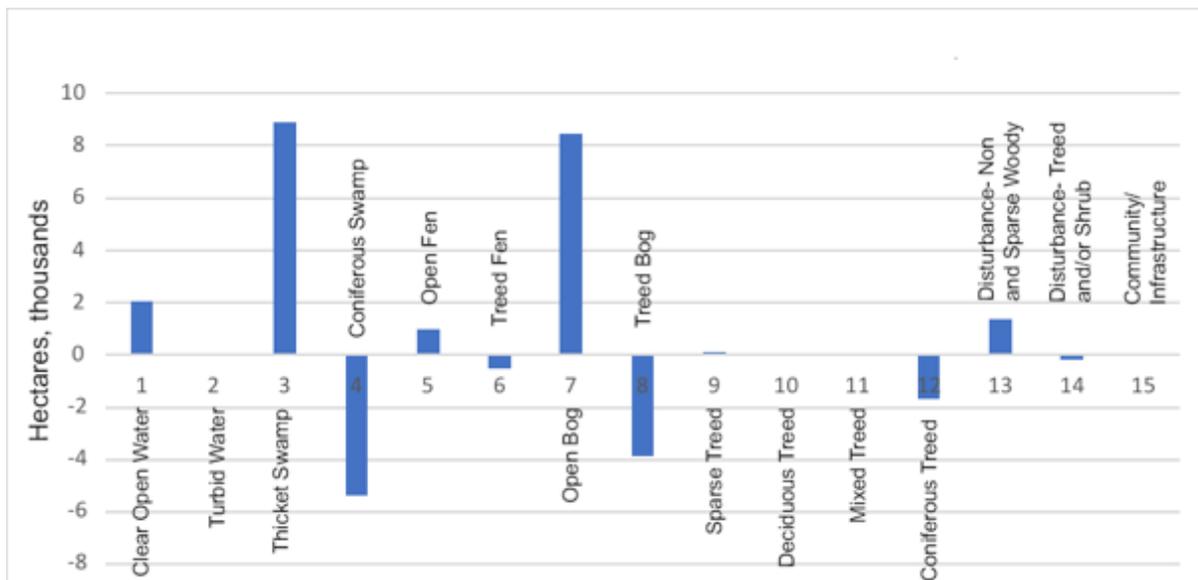


Figure 13. Difference in hectares of Far North Land Cover types associated with land-use hotspots (95% confidence interval) in randomly-selected model caribou trajectories in the business-as-usual landscape compared to the baseline landscape.

4.4.2 Coldspot Analysis

In the coldspot analysis, 1139 out of 16277 areas represented as 500m hexagons were significant in the BAU landscape, and 1764 out of 13676 areas were significant in the baseline landscape at 95%.

Coldspot landcover areas in BAU were more numerous in Far North Land Cover categories 'Thicket Swamp', 'Open Fen', 'Open Bog', 'Deciduous Treed', 'Disturbance- Non and Sparse Woody', 'Disturbance- Treed and/or shrub', and 'Community/Infrastructure' compared to the baseline landscape (Table 9, Figure 15).

Coldspot landcover areas in BAU were less numerous in 'Clear Open Water', 'Turbid Water', 'Coniferous Swamp', 'Treed Fen', 'Treed Bog', 'Sparse Treed', 'Mixed Treed', and 'Coniferous Treed' compared to the baseline landscape (Table 9, Figure 14).

Table 9. Far North Land Cover types associated with land-use coldspots (95% confidence interval) in randomly-selected model caribou trajectories in both business-as-usual and the baseline landscape.

FNLC category	BAU (ha)	Baseline (ha)	Difference
Clear Open Water	2639.25	3528.9	-889.65
Turbid water	0.54	4.95	-4.41
Thicket Swamp	2116.17	66.78	2049.39
Coniferous Swamp	7914.42	16751.7	-8837.28
Open Fen	360.09	143.64	216.45
Treed Fen	871.29	1961.1	-1089.81
Open Bog	1882.26	1551.69	330.57
Treed Bog	4403.07	6843.15	-2440.08
Sparse Treed	1171.17	1694.43	-523.26
Deciduous Treed	12.78	7.74	5.04
Mixed Treed	188.64	411.21	-222.57
Coniferous Treed	2135.52	4742.01	-2606.49
Disturbance-Non and Sparse Woody	662.76	181.53	481.23
Disturbance-Treed and/or Shrub	393.48	347.58	45.9
Community Infrastructure	38.52	17.46	21.06

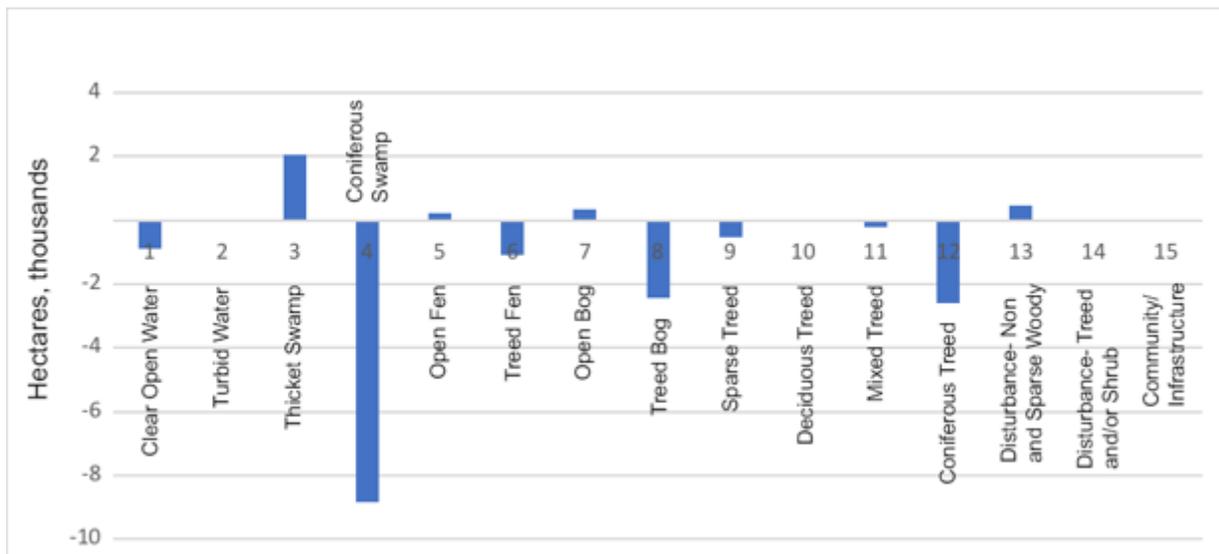


Figure 14. Difference in hectares of Far North Land Cover types associated with land-use coldspots (95% confidence interval) in randomly-selected model caribou trajectories in the business-as-usual landscape compared to the baseline landscape.

4.5 Conclusion

Population persistence, population growth rate and wolf density differed negligibly between the baseline and BAU landscapes. Caribou forage decreased, and

moose increased, but the results were not significant. Trajectory distribution or spread was negligibly different, with caribou occurring in a slightly more confined spatial dimension in the BAU. Landcover proportions in caribou trajectories differed between landscapes in some categories. The two most occupied landcovers did not differ, but subsequent landcover proportions did, most notably in 'Thicket Swamp', 'Open Bog' and 'Open Fen' and 'Disturbance- Non and Sparse Woody.'

Hotspots were more numerous in the BAU landscape in Far North Land Cover categories 'Clear Open Water', 'Thicket Swamp', 'Open Fen', 'Open Bog', 'Sparse Treed', 'Deciduous Treed', and 'Disturbance- Non and Sparse Woody', and less numerous in 'Turbid Water', 'Coniferous Swamp', 'Treed Fen', 'Treed Bog', 'Mixed Treed', 'Coniferous Treed', 'Disturbance- Treed and/or Shrub' and 'Community/Infrastructure' compared to the baseline landscape. Hotspot analysis also revealed more steps in the trajectories in BAU, as well as 10,349 ha more area of hotspots in BAU compared to baseline. Coldspot areas in BAU were more numerous in 'Thicket Swamp', 'Open Fen', 'Open Bog', 'Deciduous Treed', 'Disturbance- Non and Sparse Woody', 'Disturbance- Treed and/or shrub', and 'Community/Infrastructure' compared to baseline. Coldspot area was decreased in the BAU compared to baseline, at 24,659 ha compared to 38,191 ha.

These results and their implications for future research and management are discussed in Chapter 5: Discussion and Conclusion.

5 DISCUSSION AND CONCLUSION

Ecological landscape planning is a process that combines multidisciplinary information and data to assess how changes in the landscape impact other processes, such as wildlife movement. This project investigates how landscape change impacts boreal woodland caribou in a portion of the Kesagami region of northern Ontario by testing alternative landscapes with a model based on animal movement and cognition. By evaluating how business-as-usual (BAU) landscape change might impact boreal woodland caribou at the regional scale (and range scale for this species), future action and management can be taken that consider the landscape at this larger, less studied magnitude to consider landscape-level conservation needs for this threatened mammal. The assessment of alternative landscape patterns can lead to new ways of considering how different landscape patterns affect a species-of-interest, ultimately leading to better-informed choices among different landscape futures.

5.1 Probability Viability Analysis, population growth rate, wolf density, caribou forage, and moose resource selection function

Modelling results from the Probability Viability Analysis (PVA) indicated that caribou in the BAU landscape had slightly more population persistence (1.6%) compared to the baseline, but this result is not significant. In both landscapes, persistence was less than 1.0, indicating a declining population. Population growth rate for caribou and wolf density values were essentially unchanged, indicating that landscape changes did not impact wolves and did not have detectable differences for caribou population growth. This is contrary to what is expected, where an increase in caribou mortality is often linked to an increase in habitat alteration (Environment Canada, 2012). Mean normalized caribou forage was lower in the BAU landscape by 0.119, and the mean normalized moose RSF was higher in the BAU landscape by 0.120. This result is consistent with what we would expect based on an increase in disturbed forest types in the BAU landscape that are heavy in moose browse (Courtois

et al. 2004; Wittmer et al. 2007; Seip, 1992; Hornseth and Rempel, 2015) and a decrease in rich habitat areas such as coniferous forests and treed bogs that contain caribou forage (OMNRF 2014; Brown et al. 2007; Rettie and Messier, 1998).

The non-significance of the PVA results could be because i) none of the landscape alterations impacted woodland caribou enough to see a detectable difference due to the scale of the changes, or ii) due to model movement path truncation, the entire Kesagami range was used to run the model on as opposed to the study boundary. Unfortunately, the PVA and forage, moose and wolf density results are possibly less representative of the landscape changes this project sought to test due to this technical challenge, where modelled results are based on a much larger landscape than was altered.

5.2 Model Caribou Trajectory Landcover

Modelled caribou were parameterized based on caribou telemetry, moose habitat, snow-depth, wolf density, and forage abundance data (Avgar et al. 2015). Changes in land cover preference were detected between the two landscapes. In both landscapes, caribou occurred in 'Coniferous Swamp' and 'Treed Bog', and the third most used land cover was 'Open Bog' in BAU, whereas in baseline it was 'Coniferous Treed.' This is consistent with findings in the literature that indicate treed and coniferous landcover types are ideal habitat for boreal woodland caribou (OMNRF 2014; Brown et al. 2007; Rettie and Messier, 1998), possibly accounting for more occurrence in these areas in the modelled trajectory steps. Avgar et al. (2015) found that modelled caribou, using the same model run in this project, actively avoided young seral forests which could increase predation risk and may explain why the previously identified landcover categories were most used by caribou in this project.

Caribou in BAU might have used 'Open Bog' more than 'Coniferous Treed' due to a decrease in landcover associated with the latter habitat type, and a slight increase in 'Open Bog.' Bog landscapes are often used by caribou in the literature to avoid

predation from wolves and alternate prey, moose (OMNRF 2014; Brown et al. 2007; Rettie and Messier, 1998). Caribou might have used 'Open Bog' more after BAU changes due to the spatial areas they occurred in, habitat quality in adjacent cells, increased availability of the habitat type, and for predator avoidance.

Very few modelled caribou trajectory steps (<1%) occurred in each of the following land-cover categories: 'Turbid Water', 'Thicket Swamp', 'Open Fen', 'Deciduous Treed', 'Disturbance-Non and sparse woody' and 'Community/Infrastructure' in the baseline landscape. As caribou are unlikely to be attracted to areas of disturbance in the literature (Ray, 2013; Briand, 2009; Smith et al. 2000; Dyer et al. 2001; Nellemann et al. 2003; Cameron et al. 2005; Schaefer and Mahoney 2007; Johnson et al. 2015) and are moving in the model to avoid risk of predation and moose habitat, the findings for the latter three categories are not surprising.

Modelled caribou in BAU occurred in 'Thicket Swamp' nearly 30 times more than in the baseline landscape. Some of this change is likely due to the landcover differences between the landscape: BAU having eight times more area of 'Thicket Swamp' compared to the baseline landscape (5903.91 ha vs 114384.87 ha). This is likely a consequence of the land-cover change that occurred in 'Coniferous Swamp' where caribou then occurred in 'Thicket Swamp' at close to the inverse proportion of the number of steps lost in the land-cover alteration.

In my reclassification of Far North Land Cover (FNLC) categories based on forest harvesting schedules, 'Treed Bog' in certain spatial areas became 'Open Bog' in BAU. Caribou in BAU were more likely to encounter 'Open Bog' than in baseline (2.66% more land cover) but had double the trajectory points in this type in BAU compared to baseline, indicating higher usage in the BAU. This could be because there were less coniferous treed locations in the BAU compared to the baseline, and modelled caribou were then occurring in bog habitats more extensively to avoid potential predation and moose, as is noted in the literature (OMNRF 2014; Brown et al. 2007; Rettie and

Messier, 1998). Caribou occurred in 'Open Bog' more than 'Open Fen', also consistent with the literature on habitat preference (Stuart-Smith et al. 1997; Schneider et al. 2000; James et al. 2004).

While not being a landcover type that was used very much in the baseline, modelled caribou were more likely to occur in 'Disturbance- Non and sparse woody' in BAU compared to baseline (502.65 ha vs 275.67 ha). However, this land cover category was increased in the BAU at a rate that could explain this shift in trajectory occurrence. This is likely not due to modelled caribou preferring this land-cover category, but rather a consequence of the landscape change where some caribou spend time in less quality landscapes in highly disturbed environments (Chubbs et al. 1993; Smith et al. 2000; Courtois et al. 2007).

Caribou spent half the time in 'Community/Infrastructure' in the BAU compared to baseline, with no change in land-cover proportion detectable at this scale, indicating a potentially more pronounced avoidance to disturbed landscapes in BAU. The amount of trajectory occupancy was small, however, in both landscapes.

Model caribou occurred in 'Disturbance-Treed and/or Shrub' less in the BAU compared to baseline. Because this landcover category never changed, this shift is likely the result of the consequences of other landscape changes where caribou are spending less time in this disturbance category compared to the baseline landscape. This could be due to adjacent habitat quality in the model where predation risk could have changed or habitat suitability in adjacent areas decreased due to harvest cuts, or presence of roads or mines (Wasser et al. 2011; Environment Canada 2012).

5.3 Trajectory distributions

The trajectory distribution (North-South and East-West spread) across the landscape had few detectable differences between the baseline landscape and the BAU

when analyzing the randomly-selected caribou trajectories within the study boundary. If we remove one value that appears to be an outlier, the trajectory spread is less dispersed across the landscape in baseline compared to the BAU. With this value included in the analysis, the baseline trajectories have a larger N-S and E-W spread in the study boundary.

This distribution of trajectories shows that the BAU – apart from one unusual trajectory – has caribou movements with more dispersion than the baseline landscape. This would result when caribou are wider-roaming across the landscape, such as when searching for suitable habitat across a larger portion of the range. Courtois et al. (2007) note that in disturbed landscapes, mainly during calving, caribou increase their movements and seasonal home range size. Caribou home range size also increases with road density (Lablond et al. 2013).

5.4 Optimized Hot Spot Analysis

Optimized Hot Spot Analysis indicated which landcover categories were used the most and least based on movement path occurrence (significance of 95-99%). In the optimized hotspot analysis, behaviour of modelled caribou indicated affinity for certain landcover categories (hotspots) and negative affinity for others (coldspots). Some of these results corroborated what would be expected from the literature; however, other results were more perplexing. Limitations to this analysis include that there was lost information about individual modelled caribou land-cover occupation, as trajectories were merged to analyze this portion of data in the baseline and BAU, respectively. Caribou trajectories that occurred within the study boundary were merged in each landscape to analyze trajectory information about the caribou as a group, and therefore information about individual caribou land-cover use was not obtainable. This let me understand, for example, which land-cover types were more occupied by caribou in one landscape compared to the other but did not give me data to see if there was a difference between individual caribou within that landscape.

The BAU landscape had around 3000 more trajectory hexagons (steps) compared to baseline, indicating longer trajectory length. These steps were non-significant in terms of being assigned as a hotspot or coldspot (GiBin 0, 60% of the steps in BAU classified as this). This indicates more movement, with less selection for where the movement is occurring.

Pattern of hotspots and coldspots appear to be different in both landscapes. Coldspot patterns appear to occur in smaller, rounder, more dispersed clusters compared to hotspots which appear in larger, aggregated clumps (Figure 15).

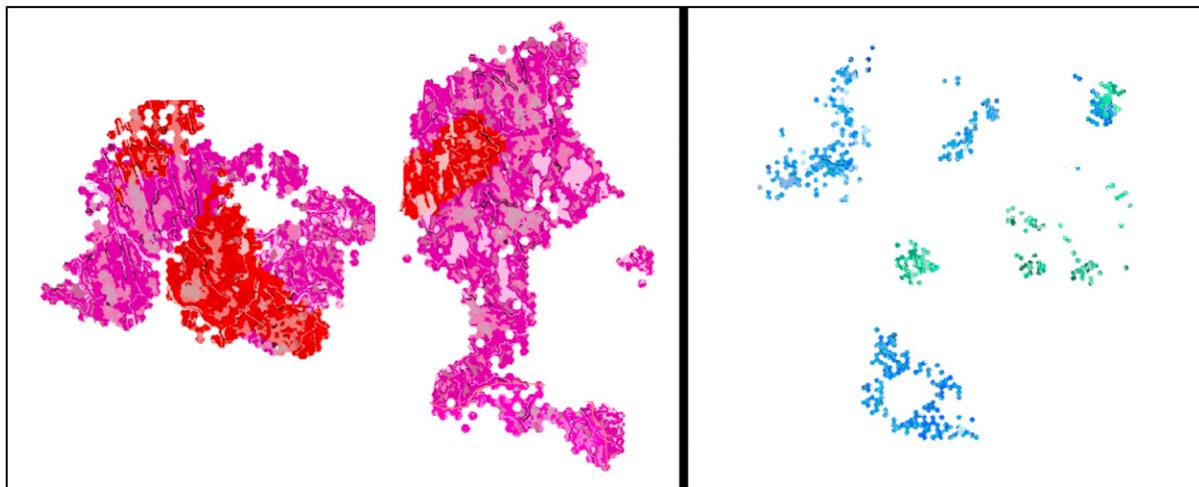


Figure 15. Patterning of hotspots (left) and coldspots (right) in the landscape.

As boreal woodland caribou's habitat selection in the literature is driven by avoiding predation (Rettie and Messier, 2000; Bowman et al. 2010; Whittington et al. 2011), it is possible modelled caribou in BAU were dispersing more in their steps, as they occurred more often in lesser quality landcovers such as 'Disturbance- Non and Sparse Woody'. In the model, this could be attributed to the movement motivated by the landscape in the adjacent habitats. There was variability in how caribou used the landscape for model parameterization, which could also contribute to some decision-making processes we would not expect based on risk of predation and lack of forage (Avgar et al. 2015). In the literature this behaviour has been seen in young, disturbed

forest stands where cows in some instances selected disturbed forest types in eastern Canada (Hins et al. 2009), indicating importance of understanding movement at the range scale. Selection of logged areas in the short -or long-term could also reflect a fidelity by caribou to their home ranges that were established before any disturbance which is observed in many caribou herds across Canada (Schaefer et al. 2000; Rettie and Messier, 2001; Wittmer et al. 2006).

Spatially, caribou hotspots in both landscapes that occurred adjacent to two cutblocks were clustered near- but not in- pre-existing disturbance categories (that is, disturbance that was not implemented in the BAU landscape). In BAU, these hotspots were closer to the disturbance, likely based on implemented harvest cuts; however, in both landscapes caribou were spatially trying to separate themselves from categories 'Disturbance- Non and Sparse Woody' and 'Disturbance- Treed and/or Shrub' that existed prior to BAU changes. This is consistent with caribou avoidance behaviour of early-seral forest disturbance, which is well documented in the literature (Ray, 2013; Briand, 2009). Model caribou hotspots are clustered in 'Coniferous Treed' and 'Treed Bog' in the landscape adjacent to this disturbance; however, the degree of separation in the BAU closer to the pre-existing disturbances (Figure 16) are likely due to harvest cuts increasing moose browse in the surrounding landscape.

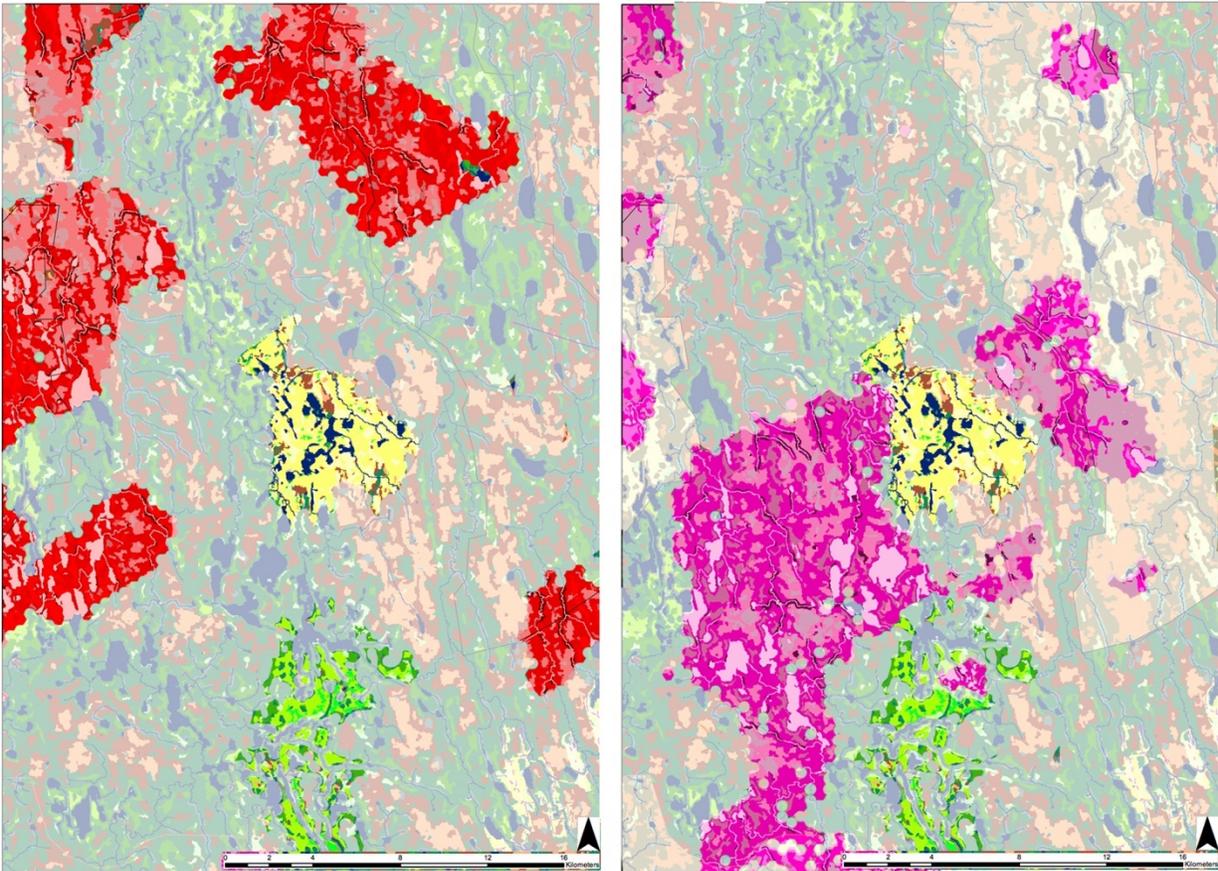


Figure 16. Hotspots in relation to pre-existing forest disturbance in baseline (left, red) and BAU (right, pink). 'Disturbance- Non and Sparse Woody' and 'Disturbance- Treed and/or Shrub' in yellow. 'Mixed Treed' and 'Deciduous Treed' forest types not associated with caribou habitat in lime green.

Where roads went into the landscape in BAU, there were no hotspots; however, in the baseline landscape before these roads were present, modelled caribou displayed hotspot affinity in this general area. Consistent with this result, more coldspots appear near new roads, whereas in the baseline landscape, modelled caribou displayed less coldspots in these areas. It appears the caribou are shifting their behaviour based on implementation of new road infrastructure in the landscape. It has been well documented in the literature how caribou behave near linear disturbances (Leclerc et al. 2012; Leblond et al. 2013; Lesmerises et al. 2013; Beauchesne et al. 2013; Imbeau et al. 2015; Johnson et al. 2015) and this research corroborates why landscape planning is paramount for conservation of large-ranging species in economically important landscapes (Nassauer and Opdam, 2008; Opdam et al. 2013).

'Community/Infrastructure' was 138% more likely to be a coldspot in BAU compared to baseline, despite the landcover difference area between landscapes not being very different. This could be due to the spatial areas where this shift occurred or due to other landscape changes that occurred in projecting the BAU. It was also directionally different; in baseline, 'Community/Infrastructure' occurred more as a hotspot. It is possible this is a subsampling issue, or this could reflect spatial changes where the baseline landscape caribou ended up spending more time in 'Community/Infrastructure' without preferring it based on some spatial patterning of adjacent landscape features, and then changed their affinity for it when landscape changes occurred in BAU. Modelled caribou's path decision making was partly shaped by the relative costs vs. benefits of nearby habitats (Avgar et al. 2015), which could also account for some of the movement into lesser quality habitats; perhaps there was no better landscape adjacent that modelled caribou could perceive and thus in baseline modelled caribou stayed in lesser quality habitat. The result makes more sense in BAU where 'Community/Infrastructure' was a coldspot with less trajectory steps, which is more consistent with what we would expect in the literature on avoidance of anthropogenic disturbance (OMNRF, 2014; Leclerc et al. 2012; Leblond et al. 2013; Lesmerises et al. 2013; Beauchesne et al. 2013; Imbeau et al. 2015; Johnson et al. 2015).

Directional differences between hot and coldspots were also observed in landcover categories 'Sparse Treed' and 'Turbid Water'; both were more likely to be hotspots in BAU, whereas in baseline they were coldspots. Modelled caribou could be spending more time in 'Sparse Treed' in the BAU due to an increase in lower-quality habitat in the modelled landscape: they could also have more affinity for this landcover type based on the quality of the landscape in adjacent landcovers in the modelled landscape space. Caribou have been known to frequent fewer desirable habitats in landscapes where quality habitat is difficult to get to as well as the spatial association of degraded habitat in relation to mature forests or higher quality habitat (Hins et al. 2009).

The 'Sparse Treed' landcover category had little difference between landscapes with respect to trajectory occurrence; however, in the BAU sparse treed became a hotspot, indicating an affinity for it not observed in the baseline landscape. It could have more forage compared to the adjacent land cover types after landscape change if the model follows the most likely avenue of how caribou moved in the model (Avgar et al. 2015), which may explain why it was a hotspot in the BAU. Naturally open, sparse areas have been known to be frequented by woodland caribou in summer as they represent a good trade-off between optimal foraging and predator avoidance (Lantin, 2003). It is possible that with increased disturbance in the surrounding landscape, Sparse Treed became a more reliable location to find food and avoid wolves.

'Disturbance-Treed and/or Shrub' was a significant coldspot in BAU compared to baseline, more than three-and-a-half times more likely to be a significant coldspot in BAU. Modelled caribou might have used this landcover differently as a consequence of other landscape changes, as the area of this landcover did not change between landscapes. It is possible that this landcover was more highly correlated with disturbance in adjacent hexagonal cells and/or increased rate of predation in the BAU.

'Open Fen' had more landcover area in the BAU, but the magnitude of caribou occurrence in this area is much more than would be explained by these changes. Modelled caribou used 'Open Fen' as a hotspot, but not 'Open Bog', which occurred more in the trajectories. This means caribou had less model path steps in 'Open Fen' but occurred there more with significance. This could mean that 'Open Fen' was preferred when caribou ended up in this landcover type, whereas they simply wandered around in 'Open Bog' without using it significantly. It is possible that 'Open Fen' provided better quality habitat in the BAU for reasons that could be related to adjacent cell conditions with respect to moose and wolf presence, or that 'Open Fen' contained better forage for caribou in the BAU. Regardless, it appears that Fen habitat should be considered an important landscape for conservation purposes when landscapes are increasingly disturbed and fragmented, as caribou were significantly more likely to occur in 'Open Fen' after modelled landscape disturbance.

'Clear Open Water' and 'Turbid Water' were the same in both landscapes; however, modelled caribou were 43.52% and 86%, respectively, more likely to be using these landcovers as hotspots in the BAU landscape. This direction and magnitude of change could be occurring due to adjacent landscape conditions, as the amount of landscape area in this category was constant in both landscapes. 'Turbid Water' hotspots occurred in cutblocks in both landscapes. The landscape adjacent to 'Turbid Water' hotspots in BAU was 'Open Bog', 'Thicket Swamp', and 'Open Fen', which were clustered inside 'Disturbance- Non and Sparse Woody,' indicating that perhaps adjacent habitat, based on this hotspot occurring in a new cutblock, explains the affinity observed for 'Turbid Water' in BAU, whereas in Baseline before harvest cuts, preferable landcover types existed in this area.

'Coniferous Treed', 'Treed Fen' and 'Coniferous Swamp' were all more likely to be hotspots than coldspots in both landscapes, indicating their importance as habitat, which is corroborated by the literature (OMNRF 2014; Brown et al. 2007; Rettie and Messier, 1998). These landcovers had area removed in the BAU, and had fewer trajectory steps, but higher model caribou affinity, indicating their importance as caribou habitat in a changing landscape. These results indicate the importance of conservation planning as noted by Opdam et al. 2013, where societal goals and conservation goals need to be considered in landscape planning to assess future impacts in the landscape.

'Open Bog', 'Thicket Swamp', and 'Disturbance- Non and Sparse Woody' had more trajectory steps but less hotspots and more coldspots, indicating lesser affinity compared to 'Coniferous Treed', 'Treed Fen' and 'Coniferous Swamp'. Based on the forage abundance portion of the model being the most likely explanation for movement (Avgar et al. 2015), this seems plausible. However, modelled use of disturbance is still likely due to the increase of it as a landcover and how it is spatially located in the range, as well as accounting for some variability in how caribou in model parameterization behaved. In the literature, male woodland caribou in Newfoundland do not avoid

cutblock disturbances in the way that female caribou do, where males occurred in proximity to harvest blocks with no incremental response to clearcutting (Schaefer and Mahoney, 2007).

5.5 Limitations and future work

Further work is warranted to infer whether the PVA results are related to how modelling the procedure occurred. The model ran at the scale of the entire Kesagami range, whereas for practical reasons landscape changes were limited within the study boundary to around 37% of the entire Kesagami range. Results from the PVA used data from the sub-range changed landscape and a border landscape (held constant) of much greater extent; therefore, it would be worth creating landscape changes at the scale the model is running by either creating a larger landscape for future scenario development or applying the model to a finer scale.

This research project analyzed a sub-sample of caribou movement path trajectories; however, it would give us a better indication of how landscape changes impacted model caribou by analyzing all modelled caribou paths that occurred within the study boundary. Because of some manual procedures this was not possible. Ideally, this model could be applied at the scale of the landscape changes, and then all modelled caribou trajectories could be compared. While the trajectory results analyzed only occurred within the study boundary, it would be important to analyze all trajectories that occurred in the study boundary, with the appropriate landscape scale to fit the model for more certainty in some of the results. This might implicate other landcovers and adjacency relationships for caribou trajectories and hotspots.

Future scenario development requires manipulating the landscape based on anticipated, projected trends as well as envisioning new ways of using landscapes. Increasing the ease of creating more landscapes within an accessible geospatial platform for data manipulation would enable an efficient way for researchers to test

more scenarios with this model. For example, manipulating NDVI data to new landcover patterns was time-consuming and there was no pre-existing method to get an indication of what a future NDVI would be for this region. The method used was based on time and resources but could be enhanced for future studies. Snow-depth data were not manipulated because of the broad scale at which they were interpreted. Some of the data occurred at multiple scales, and this can lead to alignment difficulties in a GIS for projected changes.

This study resulted in correlative findings, not causal findings. Further sub-projects that could explain variable differences and attribute them to a proximate cause with more controlled of variables would allow for a more rigorous understanding of why some of the changes occurred. While the work enables better understanding of some landscape changes, it cannot account for the variable(s) that would best explain some of these differences in how modelled caribou used different land-cover types, or why modelled caribou moved in certain ways. Future analysis of creating mini controlled variable situations would enhance our understanding of why modelled caribou made some of the decisions they did within the landscapes.

This work sets up the next step in alternative future scenarios to create future landscapes with alternate land use possibilities, notably conservation-designed landscapes based on spatial configurations to further investigation how landscape change impacts woodland caribou, and if future, alternative landscape design can mitigate some of the challenges caribou face by understanding habitat pattern importance and imagining alternative forms of forestry harvest blocks. This work is an important next step for caribou conservation in Ontario and in Canada.

Understanding further the impacts of landscape change on moose and wolves would also benefit this study, as the data that were mostly analyzed were related to caribou trajectory movement and how caribou were using the landscape. As caribou exist within an ecologically important predator-prey relationship with wolves and

alternate prey moose (Environment Canada, 2012), the changes that occur in the landscape are impacting all of these species, and many more, which future research could address. This would assist with future management of boreal forest landscapes both in the study area, and with implications for other boreal regions experiencing caribou decline and extensive landscape change.

Finally, collaboration with stakeholders of this landscape is an important part of scenario development; an ideal alternative futures process involves planners, scientists, and local citizens collaborating together (Theobald et al. 2005). This study could not accommodate such a process due to limitations in time and resources. Stakeholders of this particular landscape include forestry companies with leases within the region, all of the First Nations of this landscape, hunters, trappers, local citizens, MNR, Environment Canada, mining companies and the public in general. Consulting with more ecologists with expertise in the behaviour and habitat and landscape use of moose and wolves, and those with expertise in boreal forest health and climate change would enhance the design process and future landscape development to better understand how this landscape might look in a projected fashion, as well as how it could look through future scenario development that allows for all voices to be heard in the spirit of conservation science.

5.6 Conclusion

Understanding movement in animal populations helps determine what kind of management actions are required for population persistence; however, understanding more of the characteristics associated with movement is integral for planning, design and management implementation (Allen and Singh, 2016). Understanding what factors determine land uses, the scale at which they occur, and how these can be managed and implemented to simultaneously retain conservation and economic values is imperative to obtain desired, long-lasting conservation results (Weins et al. 2008). Creating alternative landscape futures coupled with a movement model can assist land

managers, conservation agencies, biologists, planners, and industry in the recovery of imperilled species through envisioning and projecting how landscape changes impact animal movement and their subsequent ability to thrive in multi-use landscapes.

This project investigated how landscape change impacts boreal woodland caribou movement with alternative landscapes by creating a BAU landscape and comparing it to a baseline landscape. Results from the PVA indicate that a BAU landscape negatively impacts woodland caribou, as does the baseline landscape. Neither landscape shows caribou persistence at a rate that would indicate a stable population, and neither landscape indicates positive population growth. It appears that the BAU landscape enhances the avoidance of some landcover types, such as 'Disturbance- Treed and/or Shrub' and 'Community/Infrastructure', which would be expected for woodland caribou from the literature and in the model. Caribou also, however, used some landcover types in ways we would not expect. It appears that landscape change impacts the way model caribou use 'Open Fen' and 'Sparse Treed', both being used with more magnitude and with more significant hotspots. With continued landscape change, Open Fen and Sparse Treed may be areas to consider as important in the spatial arrangement of the landscape and set aside for boreal woodland caribou along with treed habitat areas. Caribou may be more likely to use degraded landscapes when more are present in a BAU future, and planning should be focused on what habitats are most suitable for protection from further degradation as an utmost important step for this threatened species.

This research indicates that it is unlikely that boreal woodland caribou will persist in this landscape with continued economic trends; future planning should include designing the landscape at the range-scale with ecological integrity, prioritizing conservation areas of highest quality habitat for refuge and forage and identifying areas for habitat restoration.

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APPENDIX 1

Design Rules for Scenario Development

1.1 Baseline and business-as-usual design rules; all landscapes

Conservation/Landscape	Mining	Infrastructure/Settlement	Forestry-related
> 61% disturbance levels in the landscape not considered for habitat potential for designing	Mines buffered 100m	Forestry and mining are landscape activities in all scenarios	Forestry continues in an 'as-scheduled' fashion according to OMNRF reports for the region
Landcover type hierarchy for caribou habitat: Treed bog > Coniferous treed > Sparse treed>	Old and/or abandoned mines / active mines buffered 100m	Primary roads are buffered 500m	
Habitat initiatives can be in any jurisdiction (First Nations land, crownland, private land)	<i>MinDep Prospect</i> treated the same as <i>DMPWR</i>		
	<i>MinDep Discr. Occ < Min Occurrence</i> To become extracted		

1.2 Business-as-usual design rules

Conservation/Landscape	Mining	Infrastructure/Settlement	Forestry-related
No new conservation lands or reserves are added in the region	Assumes offset permitting allowed in the region <ul style="list-style-type: none"> - Disturbances can occur in caribou habitat, such as mine creation and road creation 	Areas of increased roads and infrastructure based on trends of where infrastructure needs would occur in 20 years <ul style="list-style-type: none"> - Based on forestry plans, mining plans (economic expansion dictates where this increase occurs and by how much) 	Forest harvesting and subsequent age class follows Abitibi River Forest Management Plan (spatially and compositionally) for 20 years into the future
Does not consider development impacts on landscape features or species	Likelihood of mine extraction ordered based on description of the mineral occurrence from the Mineral Deposit Inventory (2013) and used to determine most to least likely areas of mineral extraction in 20 years	Railroads and existing roads and linear features are left in the landscape	Disturbance from harvesting is related to a FNLC type for habitat suitability purposes

	<ul style="list-style-type: none"> - All prospective mines and DPWR mines weighted as 1/1 likelihood of becoming extracted - Assumes 1/10 Occurrence labelled mines developed - Assumes 1/20 Discretionary Occurrence mines developed - Developed Mineral Prospect without Reserves ignored because unlikely to be influential in this landscape in this timeline 		
Protection of existing conservation lands unless important economic opportunity arises		New roads are built to new infrastructure and development areas such as mines and cutblocks	Infrastructure associated with FMP execution occurs (forestry access roads and associated access infrastructure implemented into the landscape to nearest major road)
Does not follow ecological landscape principles		Roads are not designed <ul style="list-style-type: none"> - Drawn line from centroid (i.e. new mine) to nearest major road or linear feature 	