TRIAD ZONING IN NORTHERN ONTARIO AND WOODLAND CARIBOU CONSERVATION: A CRITICAL REVIEW

by

Hailey Orchard

1162244

FACULTY OF NATURAL RESOURCES MANAGEMENT

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO

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Hailey Orchard

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Dr. Dzhamal Amishev
Major Advisor

Mr. Robert Glover
Second Reader

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ABSTRACT

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Woodland caribou in Ontario are threatened, posing a conflict between habitat and timber supply for forest areas. The current management practices with Dynamic Caribou Habitat Schedules (DCHS) address long-term habitat supply, relying on caribou to reinhabit harvested areas while lacking evidence of this and failing to address current demand for critical habitat protection. Meanwhile, Ontario's forest industry has been experiencing various other challenges including decreasing wood supply, increasing road distances and costs, decreasing wood quality, greater public pressure to provide a wide array of ecosystem services, and more. Ontario's shift to a sustainable forest management paradigm has continued to consider wood supply above environmental and social values. Cumulatively, these have caused pressure to apply an alternative management solution to current extensive practices that can better meet multiple objectives. Triad forest management divides the forest into three zones with designated uses and objectives with a wood production, ecosystem management, and conservation zone. This has the potential when properly planned to improve wood supply and quality, reduce road distances and costs, maintain ecosystem services, provide critical caribou habitat, and more. Though there are various challenges with employing a zoning method, a balanced approach between current management by using a DCHS with triad zoning could alleviate these while improving environmental, economic, and social sustainability.

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1.0 INTRODUCTION

Forest ecosystems provide a diverse range of ecological, cultural, recreational, and economic values (Binkley 1997), as forests are currently managed for a broader extent of values than ever before (Park and Wilson 2007). Meanwhile, the forest industry is currently facing various forest management challenges involving wood supply, increasing access distances and costs, decreasing wood quality, and providing ecosystem services. In addition, criticism of forest management from the public of negative impacts on the forest has been increasing with greater pressure to provide various environmental values (Côté *et al.* 2010). Managing the threatened woodland caribou has become of increasing importance in northern Ontario, presenting even greater complexities in forest management as they require large areas of suitable habitat (OMECP 2020). A major challenge that forest managers must solve when practicing extensive management is how to balance these conflicting values across the landscape (Binkley 1997). As a result, there has been increased public pressure to implement a new method of forest management, that better provides environmental, economic, and social sustainability (Côté *et al.* 2010). Recently, requirements for caribou management and to dedicate areas for conservation have increased, further reducing the amount of area available for harvest. This exemplifies the importance of an alternative solution to extensive management, that can derive a greater wood supply from a smaller portion of the landscape.

Forest management in Ontario has evolved in recent years with the implementation of sustainable forest management (SFM) (Robson and Davis 2014), applying extensive management to the entire forest to meet multiple objectives (Park and Wilson 2007). Caribou habitat management is incorporated into forest management, with the use of Dynamic Caribou Habitat Schedules (DCHS) to ensure a sustainable supply of suitable habitat (Armstrong *et al.* 2012). Triad zoning is an alternative method of forest management that aims to better address all stakeholder concerns, conserving biodiversity and natural habitats, while improving wood supply and quality, reducing road networks, and maintaining public and traditional forest uses. Rather than extensive management of all values across the landscape, the triad approach designates areas to three different zones that employ different management techniques to provide unique, designated objectives (Seymour and Hunter 1992). This zoning method poses a potential opportunity to dedicate area for caribou conservation in northern Ontario, while meeting other objectives and improving various issues the industry is facing. Though each management method has benefits and challenges, exploring the implementation of a balanced approach between the two methods could solve current management challenges and more efficiently meet environmental, economic, and social objectives.

1.1 OBJECTIVES

The objective of this undergraduate thesis is to evaluate the current SFM and DCHS compared to triad zoning in regards to caribou conservation, with consideration of impacts on other environmental, economic, and social values. This assessment of triad zone forest management hopes to determine whether it has the potential to be implemented in northern Ontario by efficiently providing multiple values and conserving caribou habitat. To do so, the benefits and challenges of current SFM and DCHSs will be compared to those of triad zoning. Future direction will be given for how zoning could be implemented in northern Ontario to meet multiple objectives, including caribou habitat conservation. To guide the literature review, the following research questions will be explored:

- What are the benefits and challenges of current forest management in Ontario?
- What are the benefits and challenges of triad zone forest management?
- How are woodland caribou managed and protected in Ontario?
- How would triad zoning impact woodland caribou habitat conservation while effectively providing multiple values?

2.0 LITERATURE REVIEW

2.1 ONTARIO'S WOODLAND CARIBOU AND FORESTRY

The Ontario Ministry of Environment, Conservation, and Parks "Woodland Caribou Conservation Plan" (CCP) (OMECP 2020) provides extensive information on *Rangifer tarandus caribou* (woodland caribou) that are native to Ontario's northern boreal forest and classified as threatened in Ontario under the *Endangered Species Act* (2007). They are considered an indicator of a healthy boreal forest ecosystem, an important aspect of determining forest management sustainability. Caribou also hold significant cultural, spiritual, social, and subsistence value to Indigenous peoples, who have local knowledge valuable to their recovery. The CCP was developed with the goal to maintain self-sufficient and genetically connected caribou populations throughout their continuous distribution while improving connections with isolated, discontinuous populations. Figure 1 maps the continuous and discontinuous woodland caribou populations.

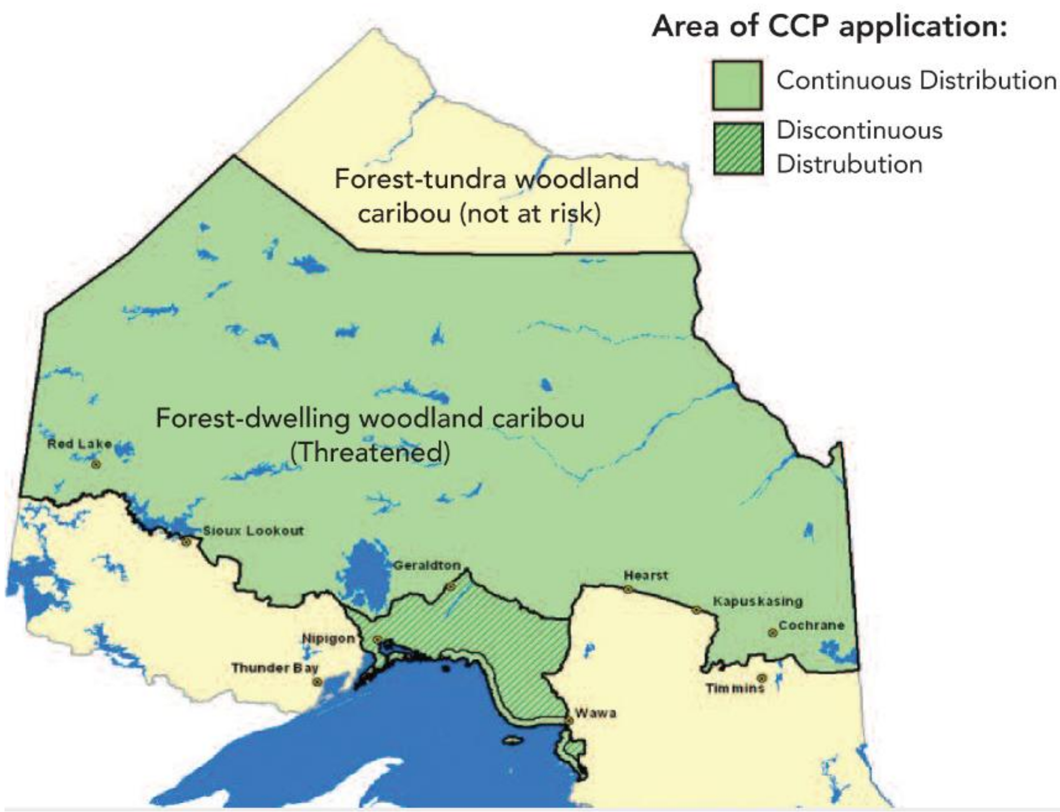

Figure 1. The area Ontario's woodland caribou conservation plan applies to, including the continuous and discontinuous forest-dwelling woodland caribou populations in Ontario (OMECP 2020).

The CCP (OMECP 2020) also explains that forest-dwelling woodland caribou used to inhabit most of Ontario north of Lake Huron and Lake Superior, though human development has significantly altered their habitat and fragmented the landscape, causing a reduction in 40-50% of their historic distribution to be lost since the late 1800s. Development including roads, communities, forestry, pipelines, and more are believed to be responsible for changing forest conditions and benefitting other species, damaging woodland caribou populations, and pushing their distribution further north.

As well the CCP (OMECP 2020) states that forest-dwelling woodland caribou do not migrate large distances like the forest-tundra woodland caribou, and thus inhabit the forest year-round. They have specific habitat needs and because the boreal is driven by disturbances to which caribou are adapted, patches of preferred habitat shift over time as stands age and fires or other disturbances occur. Thus, requiring the use of the entire landscape over time. Therefore, caribou require landscape and stand-level management to ensure continuously available large patches of preferred habitat, along with refuge and winter food areas within these. They require large patches of mature conifers, such as *Picea mariana* (black spruce) and *Pinus banksiana* (jack pine), with varying specific habitat preferences by region. To give perspective on woodland caribou needs, they have home ranges of 200-2000 km^2, while moose have home ranges smaller than 40 km^2. The CCP (OMECP 2020) also explains that they are also far less resilient to human disturbances than other ungulate species in Ontario, take longer to reproduce, and are more vulnerable to predators. Cumulatively these make managing woodland caribou complex, and their conservation and recovery in forest management pose a conflicting challenge. The boreal forest provides many important social and economic benefits that should be maintained, meanwhile, caribou are threatened by these very activities. Therefore, forest management must balance these values with caribou conservation.

The CCP (OMECP 2020) describes their winter habitat needs including areas with an abundant lichen population for food and refuge areas found in mature conifer stands with low biodiversity. They disperse in these areas to avoid predators as these forest types do not support other ungulate species. Forestry plays an important role in impacting and managing caribou habitat because disturbances such as logging produce younger forests, often with more deciduous species, attracting moose and white-tailed deer. These species along with forest access roads in turn increase the number of predators and diseases in the area, causing a decrease in woodland caribou.

2.1.1 ONTARIO'S MANAGEMENT STRATEGY

Woodland caribou range recession and conservation have been a concern for decades in Ontario, with increased emphasis on their management emerging in the 1990s (Armstrong *et al.* 2012). A provincial Caribou Recovery Team was appointed to provide a provincial Caribou Recovery Strategy, the advice of which was used to inform the CCP (Armstrong *et al.* 2012). The CCP describes Ontario's actions to manage caribou populations including conservation and recovery strategies (Armstrong *et al.* 2012). The CCP outlines the goal "to maintain self-sustaining, genetically-connected local populations of woodland caribou (forest-dwelling boreal population) where they currently exist, strengthen security and connections among isolated mainland local populations, and facilitate the return of caribou to strategic areas near their current extent of occurrence" (OMECP 2020). This involves incorporating caribou management into land use planning at a landscape scale, using adaptive management. Adaptively managing caribou is practiced during forest management, as strategies are updated as the understanding of caribou and the boreal forest improves. Figure 2 displays the Ontario government's plan to apply adaptive management for caribou conservation.

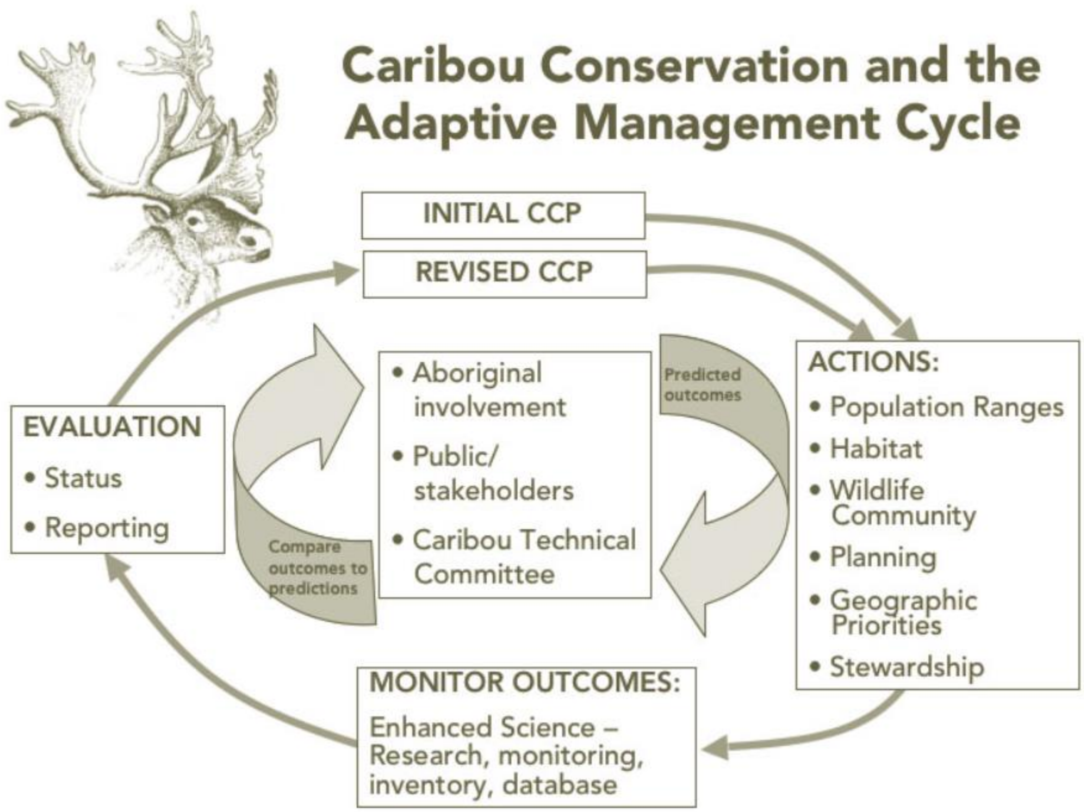

Figure 2. Caribou conservation and the adaptive management cycle in Ontario (OMECP 2020).

Ontario developed a Range Management Policy to include all caribou range guidance into one policy to promote consistency in management (OMECP 2019a, Armstrong *et al.* 2012). The Forest Management Guide for Boreal Landscapes follows the direction of Ontario's Range Management Policy, with requirements to manage for historically natural levels of woodland caribou habitat and include a Boreal Caribou Habitat Plan with a DCHS (GC 2022a). Overall, forest management aims to emulate natural disturbances, specifically, forest fires that woodland caribou are adapted to (OMECP 2020). A DCHS is a long-term plan incorporated into forest management to provide year-round caribou habitat through a system of large tracts of mature conifer forest that are interconnected, with usable areas alternating through a rotation cycle (Armstrong *et al.* 2012, OMECP 2019b). To resemble wildfire cycles and patterns the schedules alternate through numerous designated spatial areas for harvest, so there are always multiple large tracts in the forest at various ages. Essentially, harvesting is aggregated in large areas to mimic forest fires thus minimizing road densities and preventing many small, widely distributed clear-cuts (Yemshanov *et al.* 2021). Aggregated clear-cuts also help to maintain connectivity between large tracts of suitable caribou habitat (Yemshanov *et al.* 2021). Silviculture treatments are applied to renew harvested areas for future caribou use, ensuring there is always a sufficient supply and spatial arrangement of caribou habitat available over time (Armstrong *et al.* 2012). Figure 3 provides an example of a DCHS in the Wabadowgang Noopming Forest Management Unit (FMU) within northwestern Ontario.

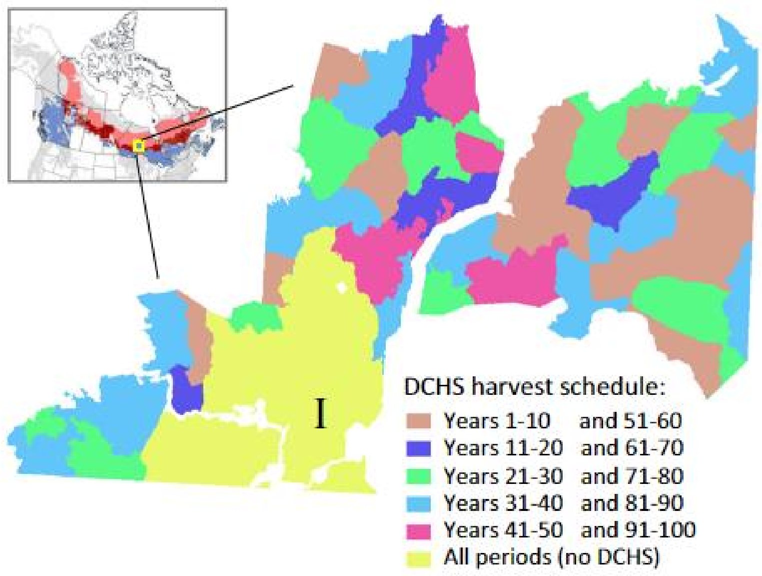

Figure 3. An example of a DCHS in the Wabadowgang Noopming FMU within northwestern Ontario (Yemshanov *et al.* 2021).

FMUs within the continuous distribution of caribou employ this DCHS technique. However, forestry is relatively recent in the current continuous distribution zone of woodland caribou which makes it very difficult to confirm whether areas impacted by commercial forestry have been successfully re-inhabited by caribou, as this can take 40 years or more (OMECP 2020). The public and Caribou Science Review Panel have expressed concern over the untested hypothesis that harvested forests can be successfully renewed to useable caribou habitat, that the methods of the CCP and the DCHS rely on (Armstrong *et al.* 2012). As a result, large efforts have gone into researching the re-occupancy of caribou into harvested habitats (Armstrong *et al.* 2012). Research results will take a long time, so it is difficult to confirm whether this method is working, though observations suggest there have been positive impacts to the southern extent of the continuous distribution (OMECP 2020).

Armstrong *et al.* explained the method of insurance for caribou habitat that was implemented to address this uncertainty (2012). Deferral areas allocated for harvest 20 years or more in the future are assigned and for harvest to proceed in these areas, specific criteria must be met. There must be enough caribou habitat area in an appropriate spatial arrangement, harvested areas must be able to provide future habitat confirmed with silviculture surveys, and local caribou populations must be stable or increasing. Silviculture is key to caribou habitat management and meeting the deferral area requirements. Effective treatments must be applied to renew suitable conifer habitat, avoiding succession to hardwood or mixedwood stands following harvest. As well, linear disturbances pose a risk to caribou, so a road management framework was proposed to manage road densities and decommissioning to support caribou populations. Forests are also managed to support relatively low moose populations, to maintain historically natural predator-prey relationships and reduce predation on caribou.

2.2 CURRENT FOREST MANAGEMENT IN ONTARIO & CANADA

Implementation of the Crown Forest Sustainability Act (CFSA) (1994) officially marked the shift from multiple use sustained yield to SFM in Ontario (Robson and Davis 2014). Sustainability is the main objective, managing for all forest values with legal requirements for public consultation (OMNRF 2020). Sustainability is defined as long-term crown forest health, and forest management plans are to have "regard for plant life, animal life, water, soil, air, and social and economic values, including recreational and heritage values" (OMNRF 2020). Sustainable forest management aims to equally balance social, environmental, and economic values rather than the prior multiple use sustained yield paradigm that considered other values while focusing on timber management (Robson and Davis 2014). This policy change occurred because of social pressures to improve forest management beyond sustained yield and manage for social and environmental values (Robson and Davis 2014). The Forest Management Planning Manual (FMPM) provides direction to achieve sustainability, where indicators for various values are measured to determine whether objectives are achieved (OMNRF 2020). The majority of Canada's forests have previously or currently been managed with a similar extensive method (Park and Wilson 2007).

2.2.1 BENEFITS

To improve public and Indigenous consultation in the forest management planning process, Local Citizen Committees (LCCs) were introduced in the CFSA, with members reflecting multiple stakeholders and their values (Robson and Davis 2014). In addition, there are multiple requirements for public and Indigenous participation opportunities during the planning process (OMNRF 2020). Crown forests are publicly owned, this ensures public interest and multiple values are considered. Forest Management Plans (FMPs) develop a Long-Term Management Direction (LTMD) for the forest to produce desired forest conditions and values, along with the associated management directions to achieve this (OMNRF 2020).

The OMNRF FMPM (2020) describes the current forest management techniques applied in Ontario, with the use of an adaptive management cycle to improve sustainability over time. FMPs are developed for 10-year periods and following year 5 the FMP's ability to provide for the long-term sustainability of the forest is assessed and recommendations are made for future planning. During the preparation of the next FMP, these recommendations are considered. Plans are then implemented according to the FMPM to provide designated objectives. Regular monitoring ensures compliance with FMPs and yearly annual work schedules (AWS), while contributing to adaptive management by evaluating the effectiveness of activities to guide future decisions. Reporting compares the current conditions and objectives to the LTMD to evaluate silviculture effectiveness, the spatial distribution of harvest, stand conditions, and more to provide recommendations for the next management plan. Figure 4 describes the adaptive management cycle in Ontario's current SFM regime.

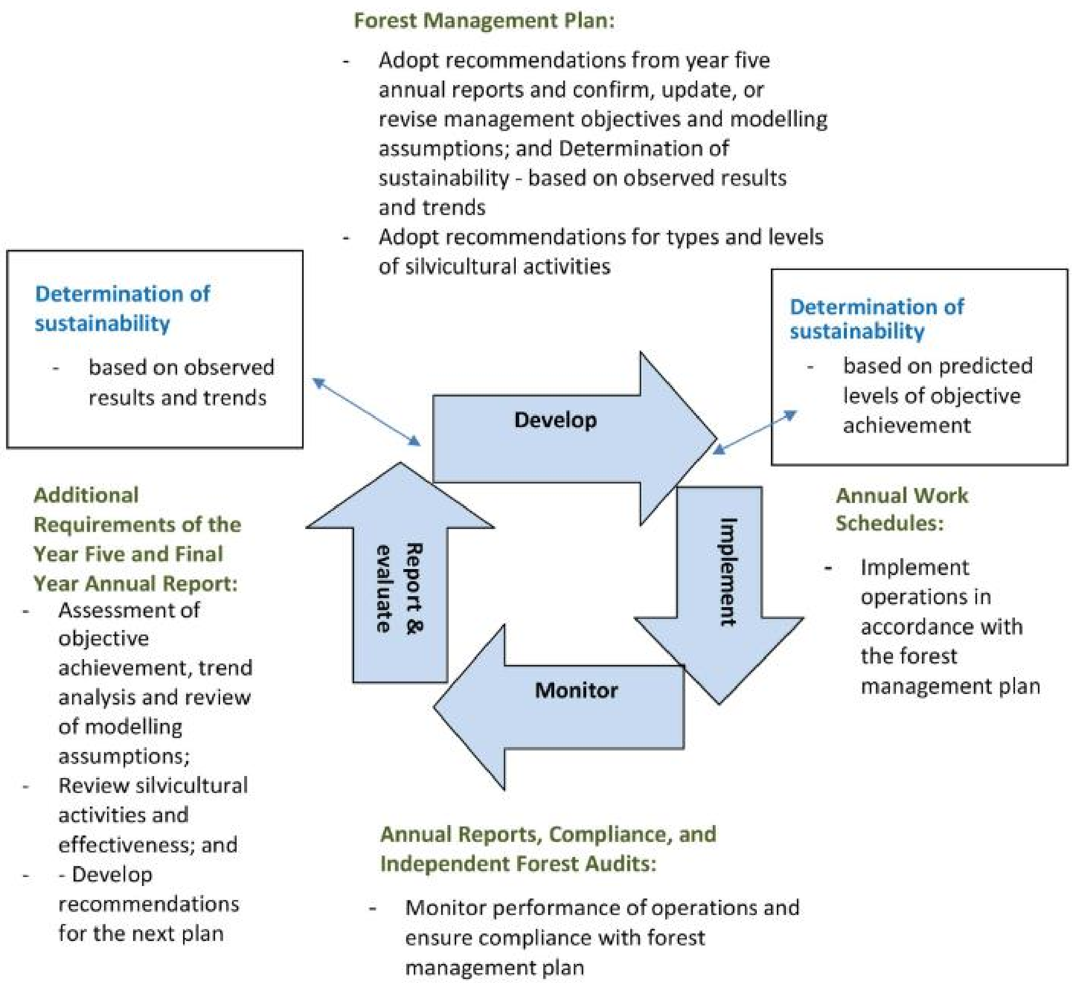

Figure 4. The adaptive management cycle in Ontario's forest management (OMNRF 2020).

The FMPM (OMNRF 2020) also describes how Ontario's SFM contributes to climate change efforts as the CFSA and FMPM provide direction to ensure a healthy, diverse forest that as a result should be more resilient to climate change. A healthy, sustainable forest should be less at risk of negative impacts from climate change and prepared to adapt to changing conditions. The FMPM also provides direction to manage and reduce carbon emissions, as forests' ability to store or release carbon is influenced by management activities.

A coarse and fine filter management approach is used to maintain biodiversity and manage species at risk (OMNRF 2020). The coarse filter aims to emulate forest conditions created by natural disturbances (forest fire, wind, insects) to sustain a variety of ecosystem conditions and thereby manage healthy populations of most plant and animal species, that are distributed across the landscape. The fine filter approach is applied when the coarse filter does not sufficiently provide a species' needs. For example, the fine filter approach is applied to caribou because they require the habitat compositions created through coarse filter management, but in a particular pattern that requires more detailed management (OMNRF 2020).

2.2.2 CHALLENGES

Canada's forest sector has gone through difficult transitions due to a high, fluctuating Canadian dollar, higher levels of global competition from southern, faster-growing plantations, rising energy costs, increasing public concern over biodiversity loss, areas lacking access to mature wood, and an over-dependence on the United States market paired with the softwood lumber disagreements (Messier *et al.* 2009). At the same time, conserving and restoring woodland caribou populations has increased the complexity of forest management. Climate change also poses significant uncertainty and management challenges for the boreal forest, with long-term ecological impacts

(OMECP 2020). This has the potential to further inhibit caribou persistence and complicate caribou and forest management (OMECP 2020).

Public pressure to truly manage forests sustainably with equal consideration of all stakeholder demands has been rising in Canada (Côté *et al.* 2010). There is increasing value being placed on recreation, tourism, and other forest values than timber supply by Canadians (Robson and Davis 2014). It is widely believed that in Canada and globally, previous and current forest management practices are responsible for the degradation of natural forest conditions including reduced old growth and biodiversity (Côté *et al.* 2010). There is increasing demand for the protection of environmental services such as air quality, water quality, habitat, and outdoor recreation which have been diminished by previously lax regulations, making it more difficult to meet this demand (Binkley 1997).

Forest policy paradigms have evolved in response to these pressures from exploitation, then sustained yield management, to current SFM. However, as Robson and Davis (2014) explained, concerns still exist under current management and it is very difficult for human organizations and industries to adapt to changing paradigms. When members of an organization share values, standards, and beliefs it is referred to as organizational structure, impacting the way members practice their work. Due to this, new policy often doesn't align with the current industry culture, thus changing paradigms are resisted and the industry is unable to keep up with changing social values. Robson and Davis (2014) state that while there has been evident policy responsiveness with the CFSA, increases in consultation requirements, and a greater emphasis on managing all forest values; overall the OMNR's policy response to the SFM paradigm shift has been minimal. Although there are a greater variety of values mentioned in policy and associated guidelines, timber values are mentioned disproportionately more frequently than other values, remaining the dominant consideration and failing to align with the true intent of SFM.

When managing for non-timber and timber across the entire landscape the non-timber objectives often are not entirely fulfilled while still causing reductions in annual harvest levels (Binkley 1997). Extensive management emulating natural disturbances has been found to reduce timber yields, producing significantly lower yields per area than intensive silviculture (Binkley 1997). As well as causing long-term reductions in wood quality (Park and Wilson 2007). While requiring a larger, extensive road system which has various negative environmental impacts and increases delivered wood costs (Binkley 1997). This can have negative impacts on landscape structures and various species, including species sensitive to less intensive silviculture (Himes *et al.* 2022). This method has resulted in harvesting increasingly occurring further into remote sites which is also driving up delivered wood costs (Binkley 1997). As these costs increase, it further reduces the profits for forest companies using extensive management (Binkley 1997), therefore being economically inefficient (Himes *et al.* 2022). As wood costs in Canada increase, it supports the expansion of timber sources from locations such as New Zealand, Chile, and Brazil, impeding Canada's global competitiveness (Binkley 1997). An increased involvement of intensive silviculture will be necessary for Canada to remain competitive in global markets (Parks and Wilson 2007). It is possible that the continued use of extensive management could result in forests producing lower yields and other values than Ontario's forests have the potential to (Carmean 2007). Further, the continued use of extensive management will lead to rises in carbon emissions because hauling distances and fuel consumption will unavoidably increase (Park and Wilson 2007).

Demand for wood production and conservation areas have both been increasing in northwestern Ontario (Carmean 2007). Although, Ontario's boreal forest wood supply is expected to decrease below the current demand in upcoming years (OMNRF 2019). This lack of supply is a result of imbalances in the forests' age classes and is considered to be one of the most critical issues Ontario's forest industry is facing (OMNRF 2019). Meanwhile, the amount of area dedicated to parks or conservation reserves had almost doubled in Ontario as part of the *Living Legacy Agreement* (1999), reducing 12% of the area available for timber harvest (Carmean 2007). More recently, Canada has developed targets that have been increased to dedicate 30% of the terrestrial area to conservation by 2030, an additional 16.5% than the terrestrial area conserved by 2021 (GC 2022b). While these parks and protected areas do provide important reserves for caribou habitat, they are typically not large enough to sustain caribou populations (Armstrong *et al.* 2012). This has created a problem where wood supply needs to be maintained or increased from a smaller available area (Carmean 2007). Though suggested mitigation measures for this dilemma include increased utilization, improved growth and yield data, and more efficiently harvesting small-diameter trees, intensive silviculture is also a viable recommendation (Carmean 2007).

Further, by 2050 over half the wood used globally is expected to come from plantations (Himes *et al.* 2022). Despite this, the current policy regime in Canada has limited incentives for intensive silviculture, research, and development. Canada is behind its major competitors regarding key forest management technologies and research (Binkley 1997). Forests are regenerated to the minimum free-to-grow standard, and the use of silviculture technology is far behind almost all competing countries (Binkley 1997). Minimal research efforts limit the ability of the forest industry to respond to changing conditions with different forest management strategies (Park and Wilson 2007).

2.3 TRIAD ZONE FOREST MANAGEMENT

The triad method was first introduced by Seymour and Hunter in 1992 and has since gained popularity as one of the most cited forest zoning strategies (Côté *et al.* 2010, Zhang 2003). The triad zoning approach to forest management aims to manage forests sustainably by minimizing negative impacts on the environment while at the same time improving timber supply (Côté *et al.* 2010). There are three different land use zones with unique objectives and priorities in this approach including conservation, wood production, and ecosystem management (Seymour and Hunter 1992, Côté *et al.* 2010, Himes *et al.* 2022). The conservation zone is typically protected with no operations permitted to preserve natural ecological characteristics (Seymour and Hunter 1992). In contrast, the wood production zone applies intensive management to increase productivity and yields, compensating for the other zones by maintaining a viable harvest level (Seymour and Hunter 1992). The ecosystem management zone involves forest operations that emulate natural disturbances using a coarse-filter management approach (Messier *et al.* 2009), current approaches used in SFM practices in Ontario resemble this and would be suitable for this zone (OMNR 2014). This zone does value wood supply, but not above ecosystem services (Himes *et al.* 2022). The trade-offs between these zones are effective because the loss of available harvest in the conservation zone is made up for in the wood production area (Côté *et al.* 2010).

2.3.1 BENEFITS

Typically, many believe extensive management is most suitable for northern Ontario's boreal forest because of the relatively poor site quality compared to southern forests, however, many question whether these practices will enable the forest to meet multiple objectives while maintaining timber supply (Carmean 2007). The use of intensively managed forest plantations with the triad strategy has the potential to solve conflicts between economic and environmental objectives by minimizing trade-offs between timber demand and ecosystem services (Binkley 1997, Himes *et al.* 2022). The UN Conference on the Environment and Development in Brazil discussed the important role intensively managed forest plantations can play, stating they should be recognized and promoted (UN 1992). They can provide sustainable sources of raw wood materials and renewable bioenergy while contributing to offsetting pressure on natural forests and increasing regional employment and development (UN 1992, Messier *et al.* 2009). They also have the potential to resolve demands for conservation areas by concentrating intensive silviculture in the wood production zone, allowing a greater area to be dedicated to other uses in the ecosystem management and conservation zones (Carmean 2007). Additionally, the use of intensively managed plantations can partially resolve long-term wood supply and accessibility challenges in Ontario (Messier *et al.* 2009), by producing better quality and an increased quantity of wood (Carmean 2007). Though wood production zones will have higher yields than ecosystem management zones, the ecosystem management zone will be the largest and still a significant source of fibre, which helps to reduce the size of the wood production zone (Himes *et al.* 2022). The ecosystem management zone also contributes to conservation efforts, with emphasis on providing ecosystem services while management activities lower the risk for catastrophic disturbances that exist in the conservation zone (Himes *et al.* 2022).

On suitable sites, the use of site preparation, genetic tree improvement, herbicides, thinning, fertilization, and/or control of forest diseases can produce fully stocked stands with greater yields and wood quality (Carmean 2007). Native species that have been genetically improved or hybrids that are faster growing can be planted in the wood production zone to increase yields, however, caution must be executed to ensure they do not inhibit the function of natural species compositions (Messier *et al.* 2009). As well, good quality sites require effective and prompt silviculture treatments because while they produce desirable tree species, they also support vigorous growth of competing species (Carmean 2007).

By focusing intensive plantations on good quality sites, higher yields can be achieved of higher quality wood suitable for valuable products (Carmean 2007). This can improve global competition, as southern and tropical regions can grow wood much faster, but as a result, these regions produce lower-quality fibre unsuitable for valuable, high-quality products (Carmean 2007). By managing to produce higher quality wood, northern Ontario could better compete in global markets (Carmean 2007). Greater wood quality increases the amount of logs suitable for high-value products such as high-grade sawlogs and veneer logs (Carmean 2007). These bring the potential for growth in the value-added industry to support economic growth in Ontario's forest industry (Carmean 2007). As well, though there are high initial investments, they are offset by the long-term benefits to the Sustainable Forest License holder through increased revenue from higher yields and quality of wood (Carmean 2007, Park and Wilson 2007).

There are alternatives to mitigate public concerns about intensive silviculture. Mixed plantations are an alternative to monocultures that are typically more accepted by the public than monocultures, and if appropriately prescribed can mimic natural succession conditions (Messier *et al.* 2009). As well, mixed plantations have a lower risk of insect and disease outbreaks, higher biodiversity, more complex structures, and lower risks of depleting soil nutrients (Messier *et al.* 2009). However, it should be considered that native species to Ontario's boreal including jack pine and black spruce, are fire-origin, pure, even-aged stands, occurring as natural monocultures (Carmean 2007). Concerns about intensive plantations may also be mitigated by ensuring they occupy a small portion of the landscape as their likelihood to cause significant impacts on ecosystem connectivity increases as they occupy greater areas (Himes *et al.* 2022).

The triad method can produce much higher harvest volumes from a smaller portion of the landscape than current practices (Côté *et al.* 2010). A study modelling the benefits of triad zoning in an area of Quebec found that in the wood production zone, the annual yield rate was modelled as double that of other zones due to the benefits of intensive silvicultural treatments (Côté *et al.* 2010). This concentration of harvesting and silviculture activities on the landscape serves to benefit the economic aspect of forestry, as forest roads are less extensively spread across the landscape, therefore reducing road building, silviculture, and maintenance costs (Beese *et al.* 2003, Messier *et al.* 2009). Situating the wood production zone close to mills and existing main roads serves to further reduce road and transportation costs (Côté *et al.* 2010). As well, it helps to reduce emissions for climate change action (Himes *et al.* 2022). A study of the Revelstoke Forest District in British Columbia found that by only moderately increasing management intensity, 40% of the landscape could produce the same amount of timber as 100% of the landscape could produce under their integrated resource management (Sahajanathan 1994). This contributes to balancing the increased costs of silviculture activities in the wood production zone and the higher costs of roads and transportation in the ecosystem management zone (Côté *et al.* 2010).

Due to the wood production zones' ability to produce greater volumes over less area and concentration of the wood production zone near mills, impacts from harvesting and roads are less distributed across the landscape (Côté *et al.* 2010, Beese *et al.* 2003). This would reduce fragmentation by roads, harvesting, and other human disturbances (Beese *et al.* 2003). This spatially limits the impacts of forest activities on landscape structure, old growth, and other valuable forest types (Côté *et al.* 2010). The increased disturbance near mills is balanced out in the conservation zone where natural structures and functions of old-growth forests are preserved (Seymour and Hunter 1992).

Himes *et al.* emphasized that maintaining areas with sufficient habitat conditions for species highly sensitive to management and human disturbance is critical for the persistence of healthy populations (2022). As well, the conservation areas serve as an "ecological benchmark" to compare the impacts of human disturbances on natural ecosystems to. By monitoring ecosystem functions, services, biodiversity, and more in the conservation areas, a baseline for undisturbed areas can be determined and the other two zones can be compared to it. Conservation reserves also hold significant social and economic value through ecosystem services such as habitat and biodiversity (Himes *et al.* 2022, Messier *et al.* 2009)

It can be argued that as climate change and natural disturbances are posing increased risks and uncertainty, management that improves forest diversity rather than efficiency may be desired (Himes *et al.* 2022). Though it should be considered that by managing multiple species plantations in the wood production zone, and natural forest conditions in the other zones, forest diversity and resilience may actually be increased through triad and intensive plantations (Carmean 2007, Himes *et al.* 2022). As well, concerns of forest health and resilience in the conservation reserves may be reduced by using ecologically friendly silviculture techniques to mitigate the risks of forest fires, pests, and diseases (Himes *et al.* 2022). The landscape approach of triad uses diverse management techniques, which can help prevent serious failure in management systems and loss of biodiversity (Aplet and McKinley 2017). By monitoring each of the zones, eventually managers will be able to evaluate the effectiveness of various management strategies and determine the most suitable practices for local conditions (Himes *et al.* 2022).

Forest zonation also has the potential to reduce conflict between stakeholders as each zone has a specific order of uses, meaning all stakeholder uses are defined, accounted for, and have designated areas (Zhang 2005). The increased benefits derived from the forest when zoning is applied may improve public perception of intensive silviculture (Carmean 2007), for example potentially through increased job opportunities to perform treatments, increased habitat protection, and increased revenue. The ecosystem management zone serves to provide access for recreational and other non-timber uses, while still supporting the forest industry and wildlife habitat (Messier *et al.* 2009). A study involving environmentalists, foresters, and non-timber users to determine the public acceptability of triad zoning in Quebec found that although there were various public concerns over triad, all three groups preferred a variation of triad (varying proportions of the zones) over the current management regime and many agreed the current method was not able to provide the demand for timber and non-timber uses in the area (Messier *et al.* 2009). Other studies in Quebec have found similar results, with various stakeholders preferring triad to current practices (Beringer 2007). Despite challenges associated with Ontario's tenure and policy, it is ideal that forests have a single ownership (the Crown/public) to avoid the challenges of implementing triad when multiple private landowners need to cooperate (Himes *et al.* 2022).

2.3.2 CHALLENGES

There is general public concern about monocultures, herbicides, and other intensive silviculture treatments whose impacts on ecosystems are difficult to entirely account for or predict (Himes *et al.* 2022, Côté *et al.* 2010). Even when a high forest cover is maintained, monospecific plantations have been associated with the loss of forest complexity, diversity, structure, and aesthetics (Himes *et al.* 2022). As well, repetitive intensive plantations on a site can cause long-term reductions in site productivity and therefore must be managed sustainably with consistent monitoring to prevent this (Himes *et al.* 2022). Another social concern of the triad approach is that conservation areas can interfere with Indigenous peoples' access to the land for traditional purposes (Fletcher *et al.* 2021). While human activities in the conservation zone should be limited to not interfere with conservation goals, human use can be facilitated in the ecosystem management zone (the largest zone) (Messier *et al.* 2009).

Carmean (2007) outlines the importance of further research and knowledge to manage intensive plantations in northern Ontario, including an accurate way to identify productive sites, an understanding of intensive plantation impact on stand and landscape diversity, site-specific silviculture prescriptions for intensive management, and growth and yield information for intensive plantations of various species. This research is required because of the high initial investment of intensive silviculture, making it important to confidently predict increases in wood quantity and quality to justify these costs. Intensive silviculture requires accurate growth and yield information by site and species, as individual sites can produce varying yields depending on the species, therefore necessary to identify appropriate sites for intensive plantations and to manage for the appropriate species. Additionally, high rates of return from intensive silviculture are required, otherwise, there is no incentive for investment in practices that will yield the highest rates of return (Himes *et al.* 2022).

One of the major challenges in transitioning to triad management is a lack of funds (Seymour and Hunter 1992, Carmean 2007). When Seymour and Hunter introduced triad, they noted that although the benefits of intensive high-yield silviculture have been proven, they require substantial initial investments that do not pay off for a long time (1992). Investments include identifying values to delineate zones and increased silviculture costs (Carmean 2007). Seymour and Hunter (1992) also emphasized the importance of maintaining the level of current timber production during the transition. This can be problematic when allocating the land for designated uses. For example, they pondered how timber production could be maintained when dedicating large areas of land to conservation zones and it takes decades to increase productivity in the timber management zone? Allocating lands to conservation zones and increasing management activities elsewhere is costly, and how it will be paid for must be determined. In Ontario, this responsibility would need to be determined between the government and industry. Due to these challenges, they recommended complex transition strategies be developed to successfully implement the triad method.

Carmean (2007) depicted another challenge, that though ideally high production zones should be located near mills and existing roads, the actual amount and location of productive sites will vary and be distributed across each forest unit. Therefore, he proposed the solution of identifying specific productive sites that can then be used to delineate larger areas on the landscape where intensive management should be concentrated. This requires a local understanding of glacial geomorphology and soils, paired with ground truthing. Even still, productive sites are likely to be small, distributed areas across the landscape. To intensively manage these sites would require small intensive plantations, distributed across the landscape amidst less productive management and conservation areas. Though good-quality sites are ideal for intensive plantation locations, not all good-quality sites can be used for the high production zone leaving the poor-quality sites for conservation. However, small, isolated productive sites that are a far distance from mills or are inaccessible are not suitable for intensive plantations and therefore can be included in the other two zones.

It has been found that in the short-term, current practices will have higher harvest volumes and yield than if transitioning to triad zoning. However, in the long-term proper implementation of triad management can result in significantly higher harvest volumes per year than current practices (Côté *et al.* 2010, Binkley 1997). In most of Côté *et al.'s* modelled triad approaches in a study area of Quebec, the effects of the management techniques were not apparent until a minimum of 100 years after the transition began (2010). This exemplifies the need for long-term planning when implementing the triad approach because despite producing more ecological and economical benefits than current practices, it will take time for these to be significant.

Binley (1997) explained that for the triad approach to be effective, clear management rules for each zone must be defined in agreement with society's values, and there must be effective institutional arrangements so that there are appropriate incentives for those responsible for management. He also stated that the conservation zones should be managed to sustain ecological values through thorough monitoring of ecosystem processes and specified species population levels. Along with a unique set of rules and standards for the wood production zone should be developed by provincial governments to allow for increased productivity. For example, rules regarding minimum rotation ages, visual aesthetics, and adjacency of clear-cuts should be minimal to achieve major increases in yield only within this zone.

In Canada, forest management on public land is primarily regulated by provincial governments and to implement triad successfully it is clear that many of these regulations would need to change (Messier *et al.* 2009). Binkley (1997) suggested that a set of institutional arrangements and forest tenure agreements that better serve society would need to be created. As well, forest management regulations must be reformed to permit and encourage intensive management of commercial products in the wood production zone, intensive management of environmental services in the conservation zone, and a combination in the ecosystem management zone. Binkley (1997) outlined that this could involve strengthening government parks programs to coordinate management activity and capital investment required to ensure the conservation zone provides anticipated environmental values. In the wood production zone, stronger property rights for industry or outright privatization could be employed to provide incentives for investments to achieve higher productivity. Binkley claimed that stronger property rights would increase the amount of available capital for investments while also allowing more flexibility to changing conditions (climate change, changing societal values, etc.). The current management responsibility regime in Ontario has created a system where stands are harvested at commercial maturity, with minimum regeneration efforts made to meet the minimum requirements at the lowest cost possible. This system does not support intensive management, and it must be determined who is responsible for investments to produce fully stocked stands to implement a zoning management regime.

It is also necessary to consider that conservation areas are still susceptible to wildfire and other natural disturbances, which would make them overall unusable caribou habitats for 40 years or more as in harvested areas (Armstrong *et al.* 2012). Yet Messier *et al.* recommend that to maintain biodiversity in the conservation zone, natural disturbances should be able to occur (2009). This poses a challenge for selecting conservation areas, as a single forest fire could potentially impact the entire zone. They proposed spreading out the conservation areas as a potential to solution to this, however, when zoning for caribou the conservation zones should be aggregated as much as possible to provide their continuous habitat needs. However, it was also suggested that continuous zoning beyond the boundaries of FMUs could be planned. The demand to dedicate areas for caribou conservation exemplifies the need to consider this, as this could apply broad landscape-level management to balance the trade-offs between caribou habitat conservation and natural disturbance risk.

Much research on the triad approach is still needed as it is largely theoretical. While there have been many studies and trials in different locations on triad zone management, unfortunately, many were abandoned before true evaluation of effectiveness could be determined, representing a need for long-term research and results (Côté *et al.* 2010, Messier *et al.* 2009). Continuous monitoring of the impacts of triad in research areas is crucial to understanding its applicability, effectiveness, and applying adaptive management for desired effects (Messier *et al.* 2009). As well, the implementation of the triad method will require a cultural change among forestry professionals who are accustomed to current practices (Messier *et al.* 2009).

2.3.3 ZONING & IMPLEMENTATION

Triad requires a thorough consideration of all landscape values and issues to plan the zones (Himes *et al.* 2022). As well, triad requires flexibility over time to adapt to changing conditions and social values, along with support from stakeholders (Himes *et al.* 2022). It is important to understand the long-term economic and environmental impacts of this method as the effects on productivity and the landscape can vary depending on how the system is implemented (Côté *et al.* 2010). For example, as with any management regime, it is important to determine how well triad achieves a forest composition and configuration that resembles the natural disturbance regime of the region. The success of the triad method to emulate natural landscape patterns while meeting other objectives, such as maintaining an economically viable forest industry, depends on how much area is dedicated to each zone (Côté *et al.* 2010). The optimal proportion of each zone will vary for each forest or region, but typically an equal split between the three is not recommended (Seymour and Hunter 1999). Each forest will have a different ideal proportion of each zone that would need to be modelled for on a case-by-case basis. The percentages of each zone should be decided using the best available science and consultation with stakeholders, with room for flexibility over time (Himes *et al.* 2022). Due to public concerns about intensive silviculture, the amount of area within the wood production zone that is dedicated to high-yield plantations should not exceed 4%, as any more would not likely be socially acceptable (Côté *et al.* 2010).

There are different methods of separating the forest area into zones. Seymour and Hunter (1992) describe the method of determining the wood production zones first by selecting areas of low ecological significance, ideally close to mills and roads, with the potential for high productivity. Followed by identifying areas of ecological significance and value, with input from the public, to set aside as reserves for the conservation zone. However, Seymour and Hunter (1992) and Himes *et al.* (2022) have also suggested that it is more favourable to give conservation zone selection priority, ensuring important ecological values are protected and located in a way that maintains gene flow and species movement. Conservation areas should be determined with consideration of important ecosystem types and habitat requirements of key species, while when possible being a greater size than the largest natural disturbances that occur in the area. Then, the wood production area can be determined based on meeting wood demand and making up for lower yields in the other two zones. Despite which zone selection method is applied, areas should be designated to zones they are best suited for with public and Indigenous consultation. The remaining land after the wood production and conservation zones have been determined can comprise the ecosystem management zone, which is typically the largest zone (Seymour and Hunter 1992, Himes *et al.* 2022). The wood production zone can also be further subdivided, for example, there can be designated areas for plantations, intensive management, and extensive management (Côté *et al.* 2010). A similar method can be applied to the ecosystem management zone if the conservation zone needs to be distributed, by managing certain areas of the ecosystem management zone with a greater emphasis on environmental values to connect conservation areas (Himes *et al.* 2022). As well, in the ecosystem management zone, different harvesting systems can be used to emulate differing desired conditions (Côté *et al.* 2010).

Various ecological features should be represented in the conservation areas while focusing on the most important objectives because a smaller number of values allows for greater areas of these values to be protected to sustain landscape-scale processes (Côté *et al.* 2010, Binkley 1997). It is beneficial to surround the conservation zones with buffers of ecosystem management zones and establish corridors connecting conservation areas (Côté *et al.* 2010).

Côté *et al.* (2010) described the use of a spatially explicit landscape model to assess the impacts of various proportions of the three zones on the forest's condition in comparison to a natural disturbance scenario. This can then be used to compare the forest's condition under current management practices. The amount of old-growth forest and landscape configuration can be used to determine triad impacts on the environment as they are traditionally negatively affected by management activities and are important for conserving ecological features. It can also be used to compare harvest volumes to analyze trade-offs between environmental and economic benefits.

Côté *et al.* (2010) modelled this in an area of Quebec's boreal transition forest to determine the most optimal zoning strategy and benefits. They found that four different variations of triad management produced a landscape that more closely resembled that of a modelled natural disturbance only forest than current, coarse filter management practices. Generally, the forest more closely resembled natural conditions with more old-growth characteristics when ecosystem management and conservation zones were increased. However, the natural disturbance only model still produced greater areas with old-growth attributes than any of the triad or current management strategies. In addition, the resemblance to a natural landscape structure is dependent on the size of the clearcuts, as larger clearcuts create larger, even-aged stands to benefit species with large home ranges (i.e., woodland caribou, pine marten) (Potvin *et al.* 1999).

To address the various challenges Canada's forest sector has been facing, the triad system was suggested as a possible solution in Quebec (Messier *et al.* 2009). Now, triad is the management paradigm in Quebec and Nova Scotia, and has been proposed for one of the globe's largest research forests, the Elliott State Research Forest in

Oregon, USA (Himes *et al.* 2022). Messier *et al.* (2009) found that all the potential zoning options in a trial area of Quebec with varying proportions of each zone had higher economic efficiency while reducing environmental impacts than the current management practices in place. The zoning plan implemented in the trial area was 11% conservation, 69% ecosystem management, and 20% wood production. However, a zonation option with higher proportions of wood production (40%) and conservation (20%) zones was calculated to have the highest yield and lowest costs while providing a greater conservation area than the implemented option. This suggests that if the public is willing to dedicate larger areas to wood production, greater areas can be dedicated to conservation while increasing economic efficiency. Although, depending on the ecosystem management and conservation zones' ability to provide ecological and recreational values along with social pressures will determine what zoning options are desirable. When selecting areas for each zone in Nova Scotia, it was determined that only 16% of Crown forests (246,000 ha) would be suitable for the wood production zone, while much less would realistically be allocated (Himes *et al.* 2022). In contrast, the conservation areas comprised 33% (514,000 ha) of their Crown forest while 51% (783,000 ha) was designated for the ecosystem management zone (Himes *et al.* 2022).

2.3.4 ONTARIO CARIBOU ZONING EXAMPLES

A plan using a zonation method was developed for the Abitibi-River Forest by the Ontario Regional Working Group (ORWG) of the Canadian Boreal Forest Agreement (CBFA) (2012) in northeastern Ontario to conserve Kesagami Range woodland caribou habitat while sustaining a sufficient timber supply to mills in the region. This proposed zoning plan aimed to balance conservation with the needs of the forest industry and community wellbeing. By dedicating an area to wood supply, the expansion of disturbance in the caribou range would be limited, while providing an estimated wood supply increase of 20% within the first thirty years. There were three zones proposed, one is located where there is existing disturbance from human activities, with no caribou inhabitancy, generally higher wood values, and is a closer distance to existing mills. This zone was recommended to be managed without the use of a DCHS, similar to areas outside the continuous caribou distribution, with some caribou recovery efforts and other ecological objectives. The other two zones conserve caribou habitat as there has been minimal human disturbance and there are caribou present in the area. Of the two zones with an emphasis on caribou conservation, one's dedicated to providing intact caribou habitat with no forest harvesting. The other is a caribou recovery zone where normal forest operations will be supplemented with caribou recovery objectives, through the continued use of the DCHS approach. This proposed zonation strategy resembles that of triad, with modifications for local needs. Figure 5 maps the CBFA's recommended spatial zonation of the Abitibi-River Forest.

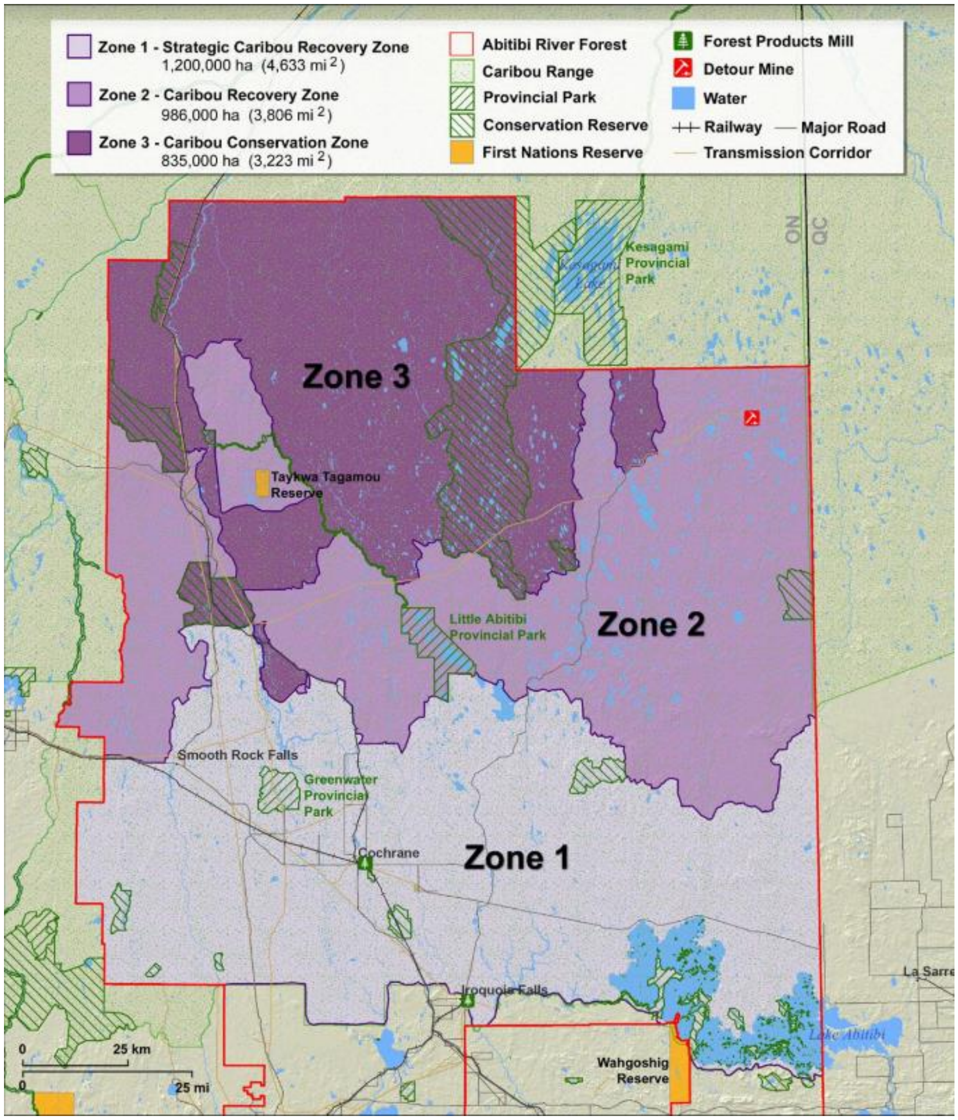

Figure 5. Map of the CBFA's recommended spatial zonation of the Abitibi-River Forest (ORWG of the CBFA 2012).

The ORWG of the CBFA (2012) considered input from Indigenous communities in the area during the preparation of these recommendations. By dedicating areas that do not permit forestry operations, multiple community values were also satisfied including protecting historic trails, remote tourism opportunities, and preservation of heritage sites. Different scenarios were modelled to determine the most appropriate plan, with the removal of the DCHS in zone 1 resulting in the greatest supply of wood volume. Whereas when zone 1 maintained the use of the DCHS or had additional mature conifer management requirements for caribou habitat, the wood supply was even lower than expected from current management strategies. The scenario that provided the greatest wood supply when modelled also has less disturbance after 100 years than expected from the current LTMD for the forest. Removal of the DCHS was then recommended in zone 1 to balance timber supply and caribou habitat needs. Additionally, this zoning plan coincides with the recommendations laid out in Ontario's CCP and the conditions of the Endangered Species Act. Figure 6 maps a comparison of the modelled human disturbances between the current LTMD and the recommended zoning approach for the Abitibi-River Forest.

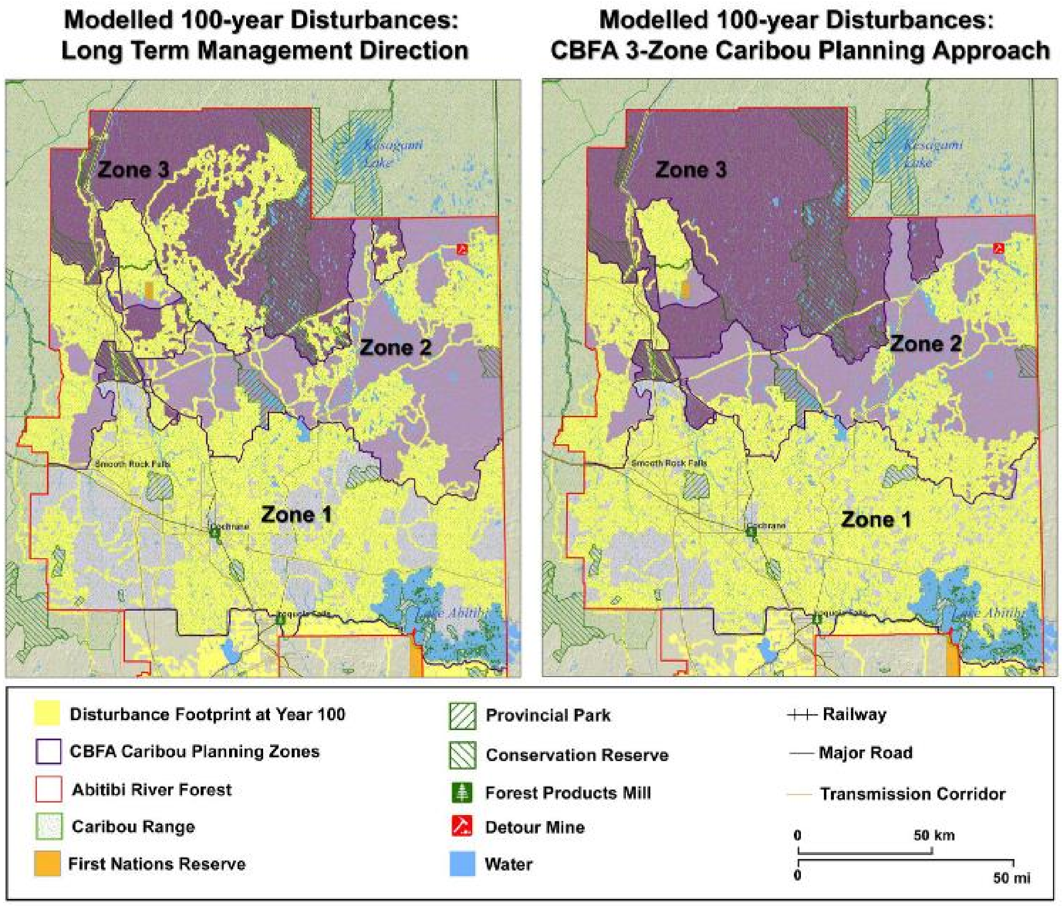

Figure 6. Map comparing the modelled human disturbances between the current LTMD and the recommended zoning approach for the Abitibi-River Forest (ORWG of the CBFA 2012).

Another example is a study in the Wabadowgang Noopming Forest, formerly the Armstrong-Whitesand Forest, in northwestern Ontario that designed a model to assess the trade-offs between caribou habitat protection and harvesting costs. Though harvest is relatively recent in much of the continuous caribou distribution zone, increases in harvest operations have the potential to increase forest fragmentation and decrease caribou populations (Yemshanov *et al.* 2021). Such as the case in the Wabadowgang Noopming Forest, where a proposed wood pellet and cogeneration plant in Armstrong, Ontario would increase harvest levels (Yemshanov *et al.* 2021). To mitigate these effects on caribou, the protection of sensitive caribou habitat is being considered (Neegan Burnside Ltd. 2014). This poses competition for forest area between harvesting and caribou habitat (Yemshanov *et al.* 2021).

Yemshanov *et al.* (2021) found that the DCHS did not cause a significant increase in timber supply costs when a portion of the forest typically in the southern more disturbed areas was exempt from the DCHS. However, when the entire forest was subject to the DCHS the timber supply cost increase is more significant. Meanwhile, maximizing the amount of protected caribou habitat while implementing a DCHS across the entire forest resulted in an average of \$3.3 m^{-2} increase in delivered wood costs. This was a noticeable increase, considering it only provided an additional 5.0%-9.5% increase in protected caribou habitat. This increase in delivered wood costs occurs when implementing long-term habitat protection because it requires much more spatial reallocation of harvest sites to protect enough suitable caribou habitat.

Yemshanov *et al.* (2021) also found that the most cost-effective areas to dedicate for long-term habitat protection were prime caribou habitat areas near the borders of the FMU, where mature forests exist undisturbed by harvesting. This habitat protection could be achieved by allocating most harvest to the south-central area (not subject to the DCHS) of the forest, already disturbed and lacking prime caribou habitat, with a concentrated road network and the use of intensive management. The remainder of the forest would be subject to the DCHS and the balance between protected areas and the DCHS method could reduce the negative impacts of harvest activities on caribou populations while preventing greater increases in delivered wood costs as found when only prioritizing habitat protection. This closely resembles a triad method, striking a balance between reasonable wood costs and caribou habitat protection.

3.0 LITERATURE REVIEW METHODOLOGY

To select sources for the literature review the Lakehead University Omni online library database was most prominently used. In addition to electronic databases, a manual search through the literature cited of relevant articles was conducted to identify additional sources. As well, internet searches were used to source governments or professional organizations. Some of the keywords and descriptors used to search these resources include triad forestry, forest zoning, ecological forestry, intensive management, sustainable forest management, woodland caribou habitat, caribou management, and multiple-use forestry.

Sources were evaluated for selection based on various criteria. These included the reputability of the author/s, whether the article had been cited by other authors, how thorough the literature cited appeared, the variety of sources in the literature cited, and the relevancy to the objectives of the literature review. All articles sourced had to be peer-reviewed to ensure credibility. Articles published recently were ideal in describing the long-term effects and possible applications of the triad method, however, these were limited. Research from previous decades first introducing the method were relevant and valuable in describing the core concepts. When examining these sources, the methods were reviewed to determine if proper research procedures were conducted. When reviewing articles that were primarily literature reviews, biased sources were avoided and sources with a variety of relevant, recent sources were favoured.

The limitations of the methodology used in this critical review of literature include potential bias in source selection and data extraction. Despite the use of standardized inclusion and exclusion criteria, some relevant sources may have been missed due to limitations in time and resources. In addition, the subjective nature of information extraction and analysis may have resulted in biases during the interpretation of findings.

4.0 DISCUSSION & FUTURE DIRECTION

Managing forests with consideration of woodland caribou currently poses difficult trade-offs (OMECP 2020) and current SFM in Ontario disproportionately values wood supply over other environmental and social objectives, despite aiming to value them equally (Robson and Davis 2014). Triad zoning has been described as better able to meet social, economic, and environmental values (Seymour and Hunter 1992), and hence its ability to conserve caribou while meeting other objectives should be explored. It is clear that current extensive management practices requiring widespread road networks and harvest disturbance pose risks to species sensitive to even less intensive management, such as caribou (OMECP 2020, Himes *et al.* 2022). While triad reduces forest fragmentation (Beese *et al.* 2003), having the potential to benefit caribou persistence. As well, the demand for the protection of caribou habitat has been increasing, and current parks and protected areas are not sufficient in size to conserve caribou habitat (Armstrong *et al.* 2012). The public has also expressed a significant amount of concern that the CCP does not provide direction for how much habitat will be protected, with many placing a high value on prescribing important caribou habitat areas for conservation to be protected from human development and disturbance (Armstrong *et al.* 2012). Further, limited timber supplies in the coming years may deem it necessary for governments to provide new policies and incentives for intensive silviculture (Park and Wilson 2007). These exemplify the need to explore alternative management options, and triad presents a potential opportunity to provide immediate demands for habitat protection while improving long-term wood supply. For these reasons, research areas of triad and efforts to monitor caribou in northern Ontario should both be increased. However, because it requires a long time to attain results of caribou reinhabiting renewed harvest areas, the DCHS approach should be continued to determine its effectiveness (OMECP 2020). The considerations and associated recommendations or mitigations to implement triad in northern Ontario for caribou conservation while meeting other objectives are described below in the environmental, economic, and social considerations sections. Please note that these sections are interconnected, with considerable overlap between them.

4.1 ENVIRONMENTAL CONSIDERATIONS

Conservation zones within a triad system should focus on protecting important objectives and key species (Côté *et al.* 2010, Binkley 1997), providing an ideal opportunity to protect critical caribou habitat in theory. To spatially model triad zoning in northern Ontario for woodland caribou conservation, suggestions to include the amount of old-growth forest and landscape configuration (Côté *et al.* 2010) could be modified to include specific caribou habitat and landscape pattern requirements to determine triad's effectiveness at meeting caribou objectives. It is difficult to practice this as caribou conservation requires landscape management, with entire ranges being considered important (Armstrong *et al.* 2012). Although, the benefits that triad could bring to caribou management could complement the current DCHS approach.

In FMUs at the southern extent of the continuous distribution of caribou to prevent further range recession, conservation zones could be selected in current high-use caribou areas. As forestry is relatively recent in the FMUs within the continuous caribou distribution zone (OMECP 2020), similar to the Wabadowgang Noopming Forest, the conservation zones when applicable could be located at the borders of the FMU, where harvesting and road building have not yet occurred (Yemshanov *et al.* 2021). Large clearcuts better resemble natural forest conditions by creating large, even-aged stands (Potvin *et al.* 1999) so the DCHS approach should be applied in the ecosystem management zone to emulate natural disturbances and aim to provide desired caribou and other species habitats across a larger portion of the landscape. These conservation zones could be planned in conjunction with adjacent FMU's, as the DCHS are (Armstrong *et al.* 2012), for regional landscape management with corridors connecting adjacent conservation zones either through the zones themselves or with strategically planned DCHS blocks.

The use of deferral areas to ensure there is always useable caribou habitat (Armstrong *et al.* 2012) could be continued in the ecosystem management zone. These areas could act as insurance, providing caribou habitat in the instance that a natural disturbance impacted the entire conservation zone. Deferral areas for caribou habitat in the ecosystem management zone could also work to maintain flexibility over time by ensuring spatial adaptability to changing conditions, which is necessary when planning triad zoning (Himes *et al.* 2022). As well, having the conservation zone could essentially 'buy time' until results of caribou reinhabiting harvest areas are available, while still researching an alternative method. This could work similarly to the DCHS deferral approach, if caribou are found to successfully reinhabit renewed harvest blocks the conservation area could eventually be harvested, rotating suitable areas in the ecosystem management zone to designated areas for caribou habitat conservation.

Conservation zone susceptibility to natural disturbance which would cause them to be unusable caribou habitat for 40 years or more (Armstrong *et al.* 2012) could also be mitigated by this combined approach. Despite suggestions that conservation zones should be larger than local natural disturbances (Himes *et al.* 2022), that would not be possible for large forest fires in northern Ontario. If areas with high forest fire risk are not able to dedicate areas for conservation zones due to uncertainty, regions with longer fire return intervals could be considered for triad zoning instead, for example in northeastern Ontario (Ter-Mikaelian *et al.* 2009). In areas of higher fire risk and shorter return intervals, such as northwestern Ontario (Ter-Mikaelian *et al.* 2009), low disturbance management interventions could be considered in the conservation zone to mitigate these risks (Himes *et al.* 2022). The method of spreading out the conservation zone in small, distributed areas to reduce the risk of loss to natural disturbances (Messier *et al.* 2009) would not effectively provide continuous tracts of caribou habitat. However, as suggested by Côté *et al.* smaller, distributed conservation zones should be connected with corridors (2010). Another potential mitigation measure for distributed conservation zones to reduce the risk of loss from natural disturbance to provide caribou habitat could be solved with the combined triad and DCHS approach, as DCHS blocks could be planned to maintain corridors between conservation zones.

4.2 ECONOMIC CONSIDERATIONS

In areas where caribou habitat protection is a priority, dedicating zones to protect their habitat is not feasible with current management practices as these areas must be offset with higher production areas to maintain wood supply. Additionally, with rising conservation area targets (GC 2022b), increasing the ability to produce higher yields from a smaller area is prudent regardless of caribou management. As described in the zoning recommendations for the Abitibi-River Forest, to set aside areas for caribou habitat conservation there must be an area with fewer harvest restrictions, not subject to the DCHS (ORWG of the CBFA 2012). This was also evident when exploring options to conserve caribou habitat in the Wabadowgang Noopming Forest. When dedicating areas for caribou conservation while maintaining current practices on the entire forest, unfeasible increases in delivered wood costs were predicted with only minimal habitat protection (Yemshanov *et al.* 2021). However, when an area used intensive management and was exempt from the DCHS, it prevented increases in delivered wood costs while enabling caribou habitat protection areas (Yemshanov *et al.* 2021). When modelling, this method proves successful because despite increased disturbances in the zone without a DCHS (zone 1: wood production), there is less disturbance in the part of the forest inhabited by caribou (zone 2: ecosystem management and zone 3: conservation) (ORWG of the CBFA 2012). This supports the use of triad with a wood production zone when there is a demand to protect caribou habitat and/or increase yields because when implemented correctly it manages to increase both caribou habitat protection and wood supply.

However, the Abitibi-River Forest is over 3,000,000 ha (ORWG of the CBFA 2012) which is much bigger than most other FMUs in Ontario and allows greater flexibility to maintain wood flow in the short term when zoning areas for conservation. As well as not having a reliance on intensive silviculture due to the ability to dedicate a large area to wood production (zone 1). A major consideration and challenge of implementing triad in most forests are maintaining wood supply in the short term while dedicating large areas for conservation as the increased yield from intensive silviculture takes time (Seymour and Hunter 1992, Côté *et al.* 2010). The expected decline in Ontario’s wood supply in the near future further complicates this (OMNR 2019). Although, the true essence of SFM is not prioritizing short-term economic value over long-term environmental, economic, and social sustainability.

As well, a potential mitigation measure that should be researched is zoning options across multiple FMUs to implement larger zones across the landscape. The

DCHS are currently planned across FMUs (Armstrong *et al.* 2012), and this could be continued in the ecosystem management zones. When considering the size of the Abitibi-River Forest, zoning across larger areas involving more than one FMU could be a method to reduce the wood flow challenges of triad zoning on smaller landbases. This would reduce the size of the zones in each individual FMU, while still enabling conservation zones to protect a large, connected area. As well as wood production zones maintaining wood supply, without significant areas of intensive silviculture in each FMU. Nova Scotia was also able to implement triad zoning with a smaller landbase than the Abitibi-River Forest (Himes *et al.* 2022). Sophisticated and complex landscape planning and stakeholder cooperation would be required to determine areas where this could be applied, along with modelling, research, and monitoring to confirm the effectiveness of this method.

4.3 SOCIAL CONSIDERATIONS

While the various zoning recommendations should allow flexibility to changing conditions from climate change or natural disturbance, they should also allow flexibility to changing social values (Binkley 1997). Currently, much of the public is concerned about caribou conservation, but because social concerns can change frequently it may be bold to design a management regime based on their conservation as we cannot know what will be valued in the future. However, if caribou are still at risk, they deserve management regardless of public concern. The same goes for other lesser-valued species at risk, of which the impacts of this management regime would need to be researched, mitigated, and potentially altered for their benefit. Again, a zoning approach allows a great deal of modification for local values by altering zone proportions, locations, and management activities. As well, despite the conservation zones primarily providing caribou habitat, the ecosystem management zone is recommended to be much larger and emulate natural disturbance to provide habitat for most species. The suggestion described above where eventually the conservation zone is harvested, and a portion of the ecosystem management zone becomes dedicated to conservation also allows for flexibility with changing social values. When the time comes to dedicate a new, regenerated area if caribou are no longer threatened or of value, areas can be selected based on current values. While these recommendations do aim to provide caribou habitat, they are based upon meeting other objectives more efficiently while doing so, similar to the current SFM and DCHS approach.

While intensive silviculture may be considered necessary to maintain wood supply in Ontario (Park and Wilson 2007), the various associated negative environmental impacts (Himes *et al.* 2022) display the need for balance to mitigate social concerns, as achieved with triad zoning. In addition to ecosystem management and conservation zones prioritizing ecological benefits, moderate intensive silviculture could be applied to mitigate concerns about intensive plantations. For example, only planting genetically improved monocultures of native species that naturally occur in pure, even-aged stands. Or using mixed species plantations that mimic natural succession conditions, with higher biodiversity, resilience, and better-conserving soil nutrients (Messier *et al.* 2009). While ensuring that as typical, the wood production zone occupies a relatively small portion of the landscape. Highly productive sites are also typically distributed across the landscape and locating wood production zones across the landscape is not only economically inefficient (Carmean 2007) but would fragment caribou habitat. Therefore, by aggregating the wood production zones it will likely occupy areas suitable for more moderately intensive silviculture. The successful increase in yield from moderate increases in management in the Revelstoke area supports this (Sahajanathan 1994), however, research for northern Ontario would be required. Another option would be to follow recommendations of having different zones within the wood production zone for highly and moderately intensive silviculture (Côté *et al.* 2010). With intensive plantation areas occupying under 4% of the wood production zone (Côté *et al.* 2010) and only practicing highly intensive silviculture in that designated area as smaller proportions of intensive plantations have lower environmental impacts (Himes *et al.* 2022). Research to determine fast-growing species in northern Ontario climates would also be needed.

Management methods for caribou including increased conifer dominance and reduced levels of habitat to support moose or other ungulates (Armstrong *et al.* 2012), could potentially pose a social concern in northern Ontario as many value moose and deer for aesthetic and hunting purposes. The triad approach would allow greater emphasis on managing other species if locally desired in the ecosystem management zone, while still focusing on caribou in the conservation zone. Additionally, remote and backcountry values could be preserved in the conservation zone to satisfy tourism values. Though various studies have found public support for triad over current methods (Messier *et al.* 2009, Beringer 2007), studies and consultation with the public and Indigenous communities would be needed to determine its acceptance in northern

Ontario. The social concern that conservation zones would interfere with Indigenous peoples' access to the land for traditional purposes (Fletcher *et al.* 2021), because human activities should be limited to not interfere with conservation goals (Messier *et al.* 2009) could be mitigated by facilitating the continued use of conservation zones for traditional uses, with Indigenous communities potentially stewarding or managing these areas. Woodland caribou are also culturally significant to Indigenous communities (OMECP 2020), if conservation zone goals are to protect caribou and Indigenous communities are consulted it may improve the perception of these zones. The ecosystem management zone being the largest would also provide area for human and traditional uses (Messier *et al.* 2009), especially when areas suitable for conservation zones may not have current road access anyways. However, areas closer to towns and main roads which are typically suitable locations for wood production zones are often more accessible to the public and Indigenous communities for various uses. Although, as Carmean (2007) described, high production areas will be distributed across the landscape and therefore easily accessible areas with identified values could be exempt from the wood production zone. Though these are suggested mitigation measures, it cannot be assumed that they will be satisfactory to maintain Indigenous access to the land, and speculation cannot substitute meaningful consultation to develop a zonation option that satisfies local needs.

4.4 REGIONAL CONSIDERATIONS

Each region will have various unique considerations when implementing or proposing triad management, and all those of northern Ontario would need to be identified. For example, in northern Ontario it must be determined whether there is a sufficient workforce available to support intensive silviculture practices and thorough monitoring of ecosystem services. As well, other resource users such as mining, hydro transmission lines, and more must be considered. How will zoning impact access to these resources and will there be significant social and economic consequences? If so, can they be mitigated? These considerations require complex land use planning, in addition to the various consultation and research requirements discussed above.

Ontario's current forest policy does not support triad zoning. While policy changes may be necessary to implement triad zoning successfully, these changes could have various benefits to Ontario's forest industry. To support the wood production zone, incentives for silviculture and research can be increased (Binkley 1997). This would improve wood quality and yield, to help Canada better compete in global timber markets (Carmean 2007). Research and monitoring improvements would also benefit not just woodland caribou but entire forest ecosystems. There are various aspects of policy and triad zoning that require discussion and planning; however, they are beyond the scope of this literature review.

4.5 ADAPTIVE MANAGEMENT

Adaptive management requires changes in management as new science is learned, along with experimental testing of other methods to continuously improve management (OMECP 2020). Though the DCHS addresses long-term habitat supply, it does not address demands for immediate caribou habitat protection to prevent further range recession. Future shock in forestry is described as occurring "when the rate of change in society exceeds the willingness or ability of individuals and institutions to adapt to the change" (Kimmins 2002). Carmean brings up the concern of whether the use of extensive forestry will eventually cause future shock, suggesting that the use of intensive silviculture be explored now to resolve various challenges in Ontario (2007). As part of adaptive management, research to determine whether this zoning method can provide long-term sustainability of wood supply and caribou habitat conservation in northern Ontario should be commenced. Results will take a long time and woodland caribou are threatened now, exemplifying the need to begin exploring options sooner rather than later.

It is evident that both extensive management and triad zoning have benefits and drawbacks, and while current management works well in many ways there is always room for improvement. A combined approach may work to balance trade-offs and maximize the benefits of both management systems. Though zoning would be expensive and require a long-term commitment, it would be an investment to improve the future of forests by supporting strong forest industries and providing diverse forest benefits (Carmean 2007). While there isn't enough evidence to confidently implement triad rather than current methods everywhere, the benefits observed thus far and predicted in the future justify further experimental research areas (Himes *et al.* 2022). Since Seymour and Hunter first introduced triad, demand for wood supply has only increased (Himes *et al.* 2022), along with increased requirements for conservation areas (GC 2022b), further emphasizing the need to explore alternative management solutions. This would contribute to adaptive management, continuously researching to improve management methods with changing conditions and pressures. There is no right or wrong way to conduct forestry, and when triad is applied with adaptive management it has the potential to provide many forest benefits (Himes *et al.* 2022). Though it would not be a suitable management regime everywhere, continued research could determine where it is applicable and how to modify it for local objectives (Himes *et al.* 2022).

5.0 CONCLUSION

When triad zoning is properly implemented it can more effectively balance trade-offs between environmental, economic, and social values than current practices to derive maximum benefits from the forest. Ontario is currently facing various challenges under extensive management, with insufficient response to the SFM paradigm. Triad could serve to alleviate future wood supply shortages and meet demands to protect important woodland caribou habitat, while maintaining recreational and traditional Indigenous uses of the forest. Various other challenges in Ontario's forest industry could be addressed by this method including meeting Canada's conservation targets, reducing delivered wood costs, improving wood quality and yield, reducing fragmentation, and increasing resiliency. An approach combining some aspects of current management with triad zoning including adaptive management strategies, natural disturbance emulation in the ecosystem management zone, and the use of DCHSs and deferral areas could potentially take advantage of the benefits of both management systems. This modified zoning approach may be able to reduce some of the challenges of implementing triad zoning in northern Ontario. Although more research and public and Indigenous consultation would be certainly required to confirm this theory as triad zoning and woodland caribou management is highly complex, the evidence in the literature supports its exploration in suitable locations with a demand for caribou habitat conservation to continuously improve management strategies.

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