A REVIEW OF ANTHROPOGENIC THREATS AND THE DECLINE OF AT-RISK LICHEN POPULATIONS IN CANADA

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ABSTRACT

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Lichens are among the most common species in Canada, but their population has declined in recent years. This review focuses on the key factors associated with the decline in lichen species in Canada. The study investigated the anthropogenic threats linked to the deterioration of at-risk lichen species. The study mainly focused on the effect of human factors since they have been established to have a significant role in the decline of lichen species in Canada. Existing studies from Lakehead University Library Database and Google Scholar were used as data sources. The study found that loss of habitat through deforestation and fire is associated with a decline in the lichen population. Also, overexploitation through large-scale logging and wood harvesting, agricultural activities, including clearing forests for land use or farming activities, and urbanization and air pollution from industrial activities are associated with a decline in the number of lichen species in Canada. Lichen conservation measures should be enacted and supported in Canada to reduce human activities and improve the growth and survival of lichens.

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INTRODUCTION

Lichens have significant ecological importance and are necessary for the survival of the surrounding ecosystems (Cameron and Toms 2016; Power *et al.* 2018). They provide food and shelter for wildlife, which helps to maintain the ecosystems that support them. Lichens absorb nutrients and contaminants from the atmosphere; hence their health is a good indication of the contaminants in the environment. These microorganisms are formed due to a symbiotic relationship between a fungus and algae, cyanobacteria, or both. The fungus protects the algae in lichens, ensuring their survival and providing extra ways for converting carbon dioxide to oxygen, which is required for life in humans and animals, among other species (Cameron & Toms 2016).

With over 2500 registered species, Canada has the world's greatest lichen diversity, the majority of which occur in the arctic-alpine and boreal forest ecosystems (Cameron & Toms 2016). However, several lichen species in Canada have decreased dramatically during the last few decades. For example, the Boreal felt lichen (*Erioderma pedicellatum* (Hue) P.M.Jorg.) species in Nova Scotia is estimated to have declined by more than 90% between the 1980s and 2000s. Similarly, there are reported cases of a decline in *Calicium viride* Pers., *Evernia prunastri* (L.) Ach., *Chrysothrix candelaris* (L.) J. R. Laundon., and *Ramalina* Ach. species in Canada due to urbanization that has reduced biodiversity (Lättman *et al*. 2014). It is well known that air pollution that occurs due to increased urbanization in Canada has resulted in substantial changes in quantity and composition of air causing a greater damage to lichen species, mainly the urban lichen flora (Lisowska 2011). Also, there has been a reduction in the number of lichens in Canada like Cryptic Paw Lichen scientifically known as *Nephroma occultum* Wetmore. presented in the COSEWIC assessment reports 2019 (Government of Canada 2019a). This species needs specific habitat requirements for their growth, including humid old coastal and cedar hemlock forests that have kept moist from groundwater. The species also grows only through vegetative propagules, however with increasing habitat loss, the number of *Nephroma occultum* has declined. The main causes of habitat loss are forest harvesting and climate changes that have altered the patterns of warmer drier summers and winter precipitation needed for lichen growth and survival. Also, there is a reported decline in the population of Vole Ears Lichen (*Erioderma mollissimum* (G. Sampaio) Du Rietz.) in Canada. Based on the COSEWIC Assessment and Status Report, it is well established that *Erioderma mollissimum* has drastically declined due to climate change, destruction of habitats from wood harvesting and forest clearance, and air pollution (Government of Canada 2021). Other lichen species that have been found to decline in Canada include Black-foam Lichen or *Anzia colpodes* (Ach.) Stizenb. Wood harvesting and logging are the main threats and limiting factors that have led to a decline in the number of *Anzia colpodes* (Government of Canada 2015).

Additionally, a 49% species population decline is projected by 2040 in Nova Scotia (Cameron and Toms 2016). The declining lichen populations are, thus, expected to continue without appropriate interventions. However, the success of lichen preservation interventions will be determined by their ability to target the specific factors causing the population decline. Therefore, it is critical to examine the factors threatening the lichen populations in Canada.

The goal of this thesis is to review anthropogenic threats associated with the decline of at-risk lichen populations in Canada. In Canada, lichen populations serve an important role in the survival of wildlife, mainly because they form the primary diet for the caribou, among other herbivores, during winter seasons (Power *et al*. 2018). In this thesis, I will examine the effect of human factors, such as fires and air pollution, on lichen populations in Canada. Human factors will be investigated because previous studies have established existing associations between human activities and declining lichen populations (Government of Canada 2019a, Venter *et al*. 2006; Woo-Durand *et al*. 2020). A review and synthesis of the literature is presented to identify and define current research gaps related to factors threatening at-risk lichen populations in Canada. The literature collected primarily relates to common lichen monitoring practices and the need for this monitoring in Canada, which are explored in-depth in this study. An evaluation of the effective lichen conservation tools is provided.

LITERATURE REVIEW

Lichens are formed due to a symbiotic relationship between algae and fungi (Cameron and Toms 2016; Power *et al*. 2018). The algae or cyanobacteria living within the fungi filaments produce carbohydrates for the lichens via photosynthesis. The fungus anchors and protects the algae and absorbs and retains water and nutrients from the environment, making lichens self-sustaining (Miller 2000). As a result, lichens grow on almost any surface and do not require nutritional or moisture support from the surface.

Lichens are among the oldest living organisms that exist in varying environmental and climatic conditions ranging from sea level to mountain tops and desert to the arctic (Miller 2000). Despite their lengthy lifespans and self-sufficiency, lichens grow at a slower rate, and some species are unable to reproduce. As a result, some lichen species have gone extinct, while others are in danger of becoming extinct. Table 1 below shows various Lichen species in the Species at risk public registry 2021, providing their conservation status and range.

Table 1. Lichens species at risk in Canada from SARA public registry

COSEWIC common name	Scientific name	COSEWIC status	Range
Ghost Antler Lichen	*Pseudevernia cladonia* (Tuck.) Hale & W.L. Culb.	Not at Risk	Quebec, New Brunswick, Nova Scotia
Blue Felt Lichen	*Degelia plumbea* (Lightf.) P.M. Jorg. & P. James.	Special Concern	Newfoundland and Labrador, New

			Brunswick, Nova Scotia
Boreal Felt Lichen	*Erioderma pedicellatum*	Special Concern	Newfoundland and Labrador
Flooded Jellyskin	*Leptogium rivulare* (Ach.) Mont.	Special Concern	Manitoba, Ontario, Quebec
Frosted Glass-whiskers	*Sclerophora peronella* (Ach.) Tibell.	Special Concern	Nova Scotia
Golden-eye Lichen	*Teloschistes chrysophthalmus* (L.) Th. Fr.	Special Concern	Manitoba, Ontario
Mountain Crab-eye	*Acroscyphus sphaerophoroides* Lev.	Special Concern	British Columbia
Oldgrowth Specklebelly Lichen	*Pseudocyphellaria rainierensis* Vain.	Special Concern	British Columbia
Peacock Vinyl Lichen	*Leptogium polycarpum* P.M. Jorg. & Goward.	Special Concern	British Columbia
Western Waterfan	*Peltigera gowardii* Lendemer & H.E.O'Brien.	Special Concern	British Columbia
Black-foam Lichen	*Anzia colpodes*	Threatened	Ontario, Quebec, New Brunswick, Nova Scotia
Crumpled Tarpaper Lichen	*Collema coniophilum* Goward.	Threatened	British Columbia
Cryptic Paw Lichen	*Nephroma occultum*	Threatened	British Columbia
Eastern Waterfan	*Peltigera hydrothyria* Miądl. & Lutzoni.	Threatened	Quebec, New Brunswick, Nova Scotia
Seaside Bone Lichen	*Hypogymnia heterophylla* L.H. Pike.	Threatened	British Columbia
Seaside Centipede Lichen	*Heterodermia sitchensis* Goward & W.J. Noble.	Threatened	British Columbia
Smoker’s Lung Lichen	*Lobaria retigera* (Bory) Trevisan.	Threatened	British Columbia
White-rimmed Shingle Lichen	*Fuscopannaria leucosticta* (Tuck.) P.M. Jorg.	Threatened	Ontario, Quebec, New Brunswick, Nova Scotia

Wrinkled Shingle Lichen	*Pannaria lurida* (Mont.) Nyl.	Threatened	Prince Edward Island, Newfoundland and Labrador, New Brunswick, Nova Scotia
Batwing Vinyl Lichen	*Leptogium platynum* (Tuck.) Herre.	Endangered	British Columbia
Boreal Felt Lichen	*Erioderma pedicellatum*	Endangered	New Brunswick, Nova Scotia
Pale-bellied Frost Lichen	*Physconia subpallida* Essl.	Endangered	Ontario, Quebec
Vole Ears Lichen	*Erioderma mollissimum* (G. Sampaio) Du Rietz.	Endangered	Newfoundland and Labrador, New Brunswick, Nova Scotia

(Source: Species at risk public registry 2021)

IMPORTANCE OF LICHENS

The importance of lichens can be grouped into those related to ecology and human use. Lichens occur in a wide range of habitats, including those considered extreme, and grow on almost all surfaces, including rocks, moss, and trees (Copper 1953; Miller 2000). An early study by Copper (1953) established that lichens play an essential role in soil formation and plant succession. Lichen's growth on rocks and soil initiates and sustains the surface breakdown with continued growth and successions. Pioneer lichens can occur on smooth rock surfaces and, with continued growth and evolution, can pry into rock crevices initiating breakdown. Additionally, dead lichens and their cells fall off to mix with soil-forming humus, promoting the life of other plants. Lichens and their successors, mosses, have pioneered the existence of plants in succession to rocks and different primal habitats, initiating the creation of soil and humus.

Lichens can live in severe environments such as deserts and arctic winters because of their capacity to absorb and store moisture, nutrients, and UV (Miller 2000). Lichens can survive in extremely dry climates and reproduce in bare rock and sand where plants and other dense flora cannot. Some lichen species are used as food for wildlife and other organisms, whose survival in these harsh habitats is facilitated by the existing lichen populations. Lichens may thrive and reproduce in a variety of habitats, including deep forests. The lichen population in these forests serves as the primary diet for caribou and other wildlife in winter, facilitating their survival.

The ability of lichens to survive in harsh habitats also facilitates their growth following disasters such as wildfires (Cameron and Toms 2016). The appearance of lichen species such as *Cladonia stellaris* (Opiz) Pouzar & Vezda. and *Stereocaulon paschale* (L.) Hoffm. in Canadian forests is regarded as the final phase in forest regeneration following a fire (Kershaw 1977). These two lichen species are very reliant on soil pH (<=6) and face little competition from higher plants that predominate in the boreal zone. Forest recovery following a fire incident is complex and is impeded by factors such as limited moisture and temperature fluctuations due to missing canopy cover. Fortunately, lichens can grow and reproduce in harsh environments, providing a favourable habitat for developing spruce seedlings. The *C. stellaris* and *S. paschale* colonize a site and, with successive moss formation, build ground coverings that encourage moisture elevation in soils and humus, aiding the growth and development of tree seedlings.

Lichens are sensitive to environmental contaminants such as nitrogen, despite their capacity to thrive under difficult climatic circumstances (Cameron and Toms 2016;

Wannaz et al. 2012). Lichens absorb water and nutrients from the atmospheric disposition, which are affected by nitrogen deposition. Lichens also absorb air pollutants such as metals in the atmosphere. Therefore, lichen communities can be used to monitor levels of environmental pollution. Sett and Kundu (2016) recognized lichens as useful bio-indicators of air quality due to their capacity to detect air pollution at low levels. The authors discovered that epiphytic lichens could detect metal disposition on the surfaces where they grow and are eco-friendly in flora and fauna communities. Lichens respond differently to various types and quantities of pollution, so the presence and absence of different lichen species can be used to infer pollution levels from atmospheric elements. However, not all lichen species are sensitive to air pollution, and the level of sensitivity varies among species.

MONITORING OF LICHEN POPULATION IN CANADA

Need For Monitoring

The Canadian boreal and arctic forests contain many of the lichen species in the region, which support the forest ecosystem and are used as a food source for the local people (Cameron and Toms 2016). However, populations of some lichen species in the region have declined dramatically over time and are at risk of extinction in the absence of proper monitoring and conservation efforts. The Boreal felt lichen (*Erioderma pedicellatum*) is an example of a critically endangered lichen species, and its population in Nova Scotia is estimated to have declined by more than 90% between the 1980s and 2000s, and populations are projected to decline by an additional 49 % by 2040.

Monitoring lichen populations in Canada is critical for assessing the present state of conservation and the need for future initiatives. Venter *et al*. (2006) acknowledged the need for monitoring lichen populations in Canada, noting the rapid environmental changes and their ability to affect lichen communities. Figure 1 shows an image of Boreal felt lichen (*E. pedicellatum*).

Figure 1. Boreal felt lichen (Erioderma pedicellatum).

Source: Species at risk public registry, SARA 2021.

Monitoring Approaches

Different lichen species respond differently to environmental conditions (Kennedy *et al*. 2020; Theau *et al*. 2005). Monitoring lichen species helps in the identification of populations that are endangered or threatened and, therefore, requires conservation initiatives. Various approaches have been applied to monitoring lichen populations, and different strategies may be used depending on site accessibility and other considerations. For example, Nordberg and Allard (2014) used satellite data to study techniques for monitoring lichen populations in the mountain regions of Sweden. The study showed that lichen cover is helpful as a monitoring indicator due to its ecological importance and ability to map based on spectral characteristics. The study made use of hyperspectral imaging scanner data and analyzed the various spectral properties of plant communities in mountain ranges. The authors compared the plant cover and detected lichen groups using colour-infrared (CIR) aerial photos of the field at a resolution of 1:60000. The findings concluded that satellite imaging might be used to reliably monitor lichen populations in locations with forest cover, such as mountain ranges with different vegetation.

In Canada, remote sensing and mapping of the spatial distribution and forest cover have been effectively used to monitor lichen species that are important food sources for wildlife in different environments (Kennedy *et al*. 2020; Theau *et al*. 2005). Theau *et al*. (2005) used Landsat TM data to study lichen cover while monitoring caribou herds in northern Quebec, Canada. The results showed that spectral analysis and enhanced classification were successful for defining lichen land cover and abundance. The study recommended using satellite imagery with further investigations, including its application over a wider region.

Kennedy *et al*. (2020) used topography and climatic data, and satellite imagery to explore the effectiveness of employing machine learning approaches to analyze lichen cover and changes in Canada and Alaska. The study improved on prior work by Theau *et al*. (2005) by focusing on terricolous microlichens, an essential food source for caribou. Instead of tracking caribou herds, Kennedy *et al*. (2020) explored a larger region and concentrated on lichen cover. Additionally, the study used aerial imagery and focused on machine analysis, indicating the usefulness of satellite imaging for mapping. The authors concluded that deep neural networks are an accurate approach for predicting lichen cover in forests.

FACTORS THAT THREATHEN THE LICHEN POPUATION IN CANADA

Climate change and anthropogenic activities have led to loss and changes in biodiversity distribution, among other environmental implications (Venter *et al*. 2006; Woo-Durand *et al*. 2020). Venter *et al*. (2006) investigated the dangers to lichen species in Canada, focusing on those listed by the Committee on the Status of Endangered Wildlife in Canada as endangered, threatened, or extinct (COSEWIC). The findings of the study categorized the factors in order of impact as habitat loss, overexploitation, species interactions, natural causes, and pollution. Human activities were responsible for nearly half of the causes of habitat loss and pollution, including agriculture (46%) and urbanization (44%). Other causes of habitat loss were attributed to wildfires.

A later study by Woo-Durand *et al*. (2020) found similar results, with habitat loss being attributed to declines in 82% of endangered lichen species. Climate change was reported as an additional threat affecting 13% of at-risk lichen species. The authors emphasized that anthropogenic threats to lichen species were increasing rapidly because of introduced species, over-exploitation, pollution, and habitat loss. The authors concluded a need for continuous threat monitoring, especially given the recent increase in risk to the lichen population associated with climate change.

CONSERVATION OPTIONS

Densely populated regions are the most affected in terms of lichen species endangerment (McMullin and Lendemer 2013; McMullan *et al*. 2013). In southern Ontario, the effect of urbanization, agriculture, and industrialization in the densely populated area on the ecosystem is highly significant (McMullin and Lendemer 2013). McMullin and Lendemer studied the lichen diversity and conservation efforts in 24 vegetation communities within southern Ontario. Their study identified new species for the first time in the country and region, demonstrating the influence of new species introductions on lichen diversity. The study also indicated that second-growth forests recorded more significant lichen populations, indicating reforestation as a conservation effort for lichen biodiversity. Furthermore, the forest regions with the greatest lichen diversity exhibited variances in canopy closure, tree species, and vegetation variation. According to the study, considering lichen conservation as a forest or vegetation conservation was more likely to yield better results.

A study examining the effectiveness of lichen conservation measures in Canada by McMullin *et al*. (2013) focused on the boreal forest region. The boreal forest is recognized for its abundance of lichens, which play a crucial role in the survival of the endangered caribou in North America. McMullin *et al*. (2013) examined the effects of silvicultural activities on lichen diversity in the boreal forest and how to include ecological integrity into the operations. The authors noted the possibility of a conflict between the region's prevalent forest management techniques and lichen protection. Herbicide use, for example, was found to have a detrimental impact on lichen diversity in the short term. However, herbicide-treated forest had lower lichen biomass but higher beta and gamma diversity than untreated forests. The authors concluded that while boreal forest silvicultural methods influenced lichen biomass, it was not as severe as the consequences of wildfires. The authors recommended reducing chemical treatments in areas with high lichen biomass or where they are endangered.

Effective lichen conservation efforts are limited by the lack of research on the subject. Several researchers recommend further studies on integrating existing forest and vegetative conservation efforts with lichen diversity alongside accurate mapping to identify endangered species and regions (Allen *et al*. 2019; McMullan *et al*. 2013). Allen *et al*. (2019) advocated utilizing big data to document risks to lichen populations and biodiversity declines as the foundation for creating conservation strategies. The study looked at lichen diversity in the United States and Canada and found improvement in utilizing big data to conserve and monitor endangered species. Additionally, the updated COSEWIC recommendations emphasize the role of data in mapping the endangered species, fluctuations and trends, and the threatening factors in developing effective conservation frameworks (Government of Canada 2019a).

MATERIALS AND METHODS

I reviewed the literature pertaining to factors affecting lichens populations in Canada over the last 20 years. The majority of the material examined for this thesis came from Canada, as the paper's primary focus is on the Lichen community in Canada. A thorough study of the literature on the importance of lichens was examined. The primary source for the published reports and peer-reviewed articles used was from the Lakehead University Library Database. In addition, I searched Google Scholar and manually scanned reference lists from primary articles to collect relevant information for the study. Lichen, Pioneer species, COSEWIC reports, endangered species, climate change, satellite imaging, CIR, Lichen habitat, biodiversity, and indicators, were among the key terms and words employed in the searches for the relevant articles. For the study, status reports and recovery strategies authored by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for vulnerable and endangered lichen species were also critically assessed.

RESULTS AND DISCUSSION

Several main threats of human disturbances to lichen populations were identified from the literature search. These threats include habitat loss, overexploitation, agriculture, urbanization, and air pollution. A summary table (See Table 2) was created to show main studies of Canadian species and the human factors that threaten the growth and survival of lichen species.

Table 2. Lichen Species, Human Factors Threatening Their Survival and Corresponding Studies

COSEWIC Common Name	Scientific Name	Human Factors Threatening Lichen Survival and Growth	Studies
Flexuous Golden Stubble Lichen	*Chaenotheca servitii* Nadv.	Logging in Nova Scotia	COSEWIC (2003)
Frosted Glass-whiskers	*Sclerophora peronella*	Habitat loss and degradation, and acid rain and other atmospheric pollutants	Government of Canada (2016a)
Red Oak Stubble Lichen	*Phaeocalicium minutissimum* (G. Merr.) Selva.	Logging	COSEWIC (2003)
Ghost Antler Lichen	*Pseudevernia cladonia*	Forest removal, logging, Cutting of mature, coastal and montane spruce-fir forests, housing development,	Government of Canada. (2011a)

		climate change, wind farm development	
Blue Felt Lichen	*Degelia plumbea*	Loss of forest continuity through logging, microclimate changes, Land development for housing and cottages, policy changes in the forest industry that has caused increased biomass, air pollution due to industrial developments, acid rain	Richardson (2010), Coffey and Fahrig (2012), Horstkotte *et al*. (2011).
Boreal Felt Lichen	*Erioderma pedicellatum*	Logging, air pollution, forest pesticides, forest fires, climatic changes such as global warming and moose herbivory	Scheidegger (2002), Cameron and Neily (2008), Cameron & Toms (2016), Coffey and Fahrig (2012), Horstkotte *et al*. (2011).
Flooded Jellyskin	*Leptogium rivulare*	Climate change, droughts, logging, wood harvesting, agricultural and forestry effluents, mining, quarrying, air pollutants from urbanization	McCune *et al*. (2019), Government of Canada (2015a), Coffey and Fahrig (2012), Lättman *et al*. (2014) Lisowska (2011),

			Lewis and Brinker (2017a)
Golden-eye Lichen	*Teloschistes chrysophthalmus*	Severe weather, recreational activities, invasive species, air pollution, livestock grazing, fire, climate change	Lewis and Brinker (2017b), Government of Canada. (2016b), Coffey and Fahrig (2012),
Mountain Crab-eye	*Acroscyphus sphaerophoroides*	Urbanization (Development pressures for roads, pipeline, hydroelectricity, mining and forestry) and climate change	Government of Canada (2016d)
Oldgrowth Specklebelly Lichen	*Pseudocyphellaria rainierensis*	Logging causing global climate change, wildfire, industrial-scale forestry	Government of Canada (2010)
Peacock Vinyl Lichen	*Leptogium polycarpum*	air pollution from urbanization, nitrogenous aerosols, habitat loss from forestry	Government of Canada (2011b), Coffey and Fahrig (2012)
Western Waterfan	*Peltigera gowardii*	Habitat loss or degradation, urbanization (Road or trail construction),	Government of Canada. (2013), Richardson *et al*. (2013a)
Black-foam Lichen	*Anzia colpodes*	Wood harvesting and logging	Government of Canada (2015a)
Crumpled Tarpaper Lichen	*Collema coniophilum*	Deforestation, logging, fire	Government of Canada. (2010)

Cryptic Paw Lichen	*Nephroma occultum*	Habitat loss through forest harvesting, and climate changes	Cameron *et al*. (2013b), Government of Canada (2019a).
Eastern Waterfan	*Peltigera hydrothyria*	Vegetation, deforestations along riverbanks, mineral exploration, air pollution	Cameron and Richardson (2006), Cameron and Toms (2016), Richardson *et al*. (2013b)
Seaside Bone Lichen	*Hypogymnia heterophylla*	Loss of habitat and deforestation leading to climate change	Government of Canada (2008), Cameron *et al*. (2013b), Cameron *et al*. (2013a)
Seaside Centipede Lichen	*Heterodermia sitchensis*	Logging	Government of Canada (2014)
Smoker's Lung Lichen	*Lobaria retigera*	Urbanization (expansion of transportation, construction of roads), logging, wood harvesting,	Government of Canada (2018)
White-rimmed Shingle Lichen	*Fuscopannaria leucosticta*	logging and wood harvesting	Government of Canada. (2019b)
Wrinkled Shingle Lichen	*Pannaria lurida*	logging and wood harvesting, urbanization (residential and commercial	Government of Canada (2016c)

		developments, transportation)	
Batwing Vinyl Lichen	*Leptogium platynum*	Loss of habitat and air pollution	Government of Canada. (2016e), Coffey and Fahrig (2012),
Pale-bellied Frost Lichen	*Physconia subpallida*	Air pollution, land clearing and forest fragmentation	Government of Canada (2009), Coffey and Fahrig (2012)
Vole Ears Lichen	*Erioderma mollissimum*	Climate change, destruction of habitats from wood harvesting and forest clearance, and air pollution	Government of Canada (2021), Coffey and Fahrig (2012)

From the reviewed studies, one report demonstrated a significant decrease in the lichen population in Canada (Cameron and Toms 2016), as presented in Figure 2.

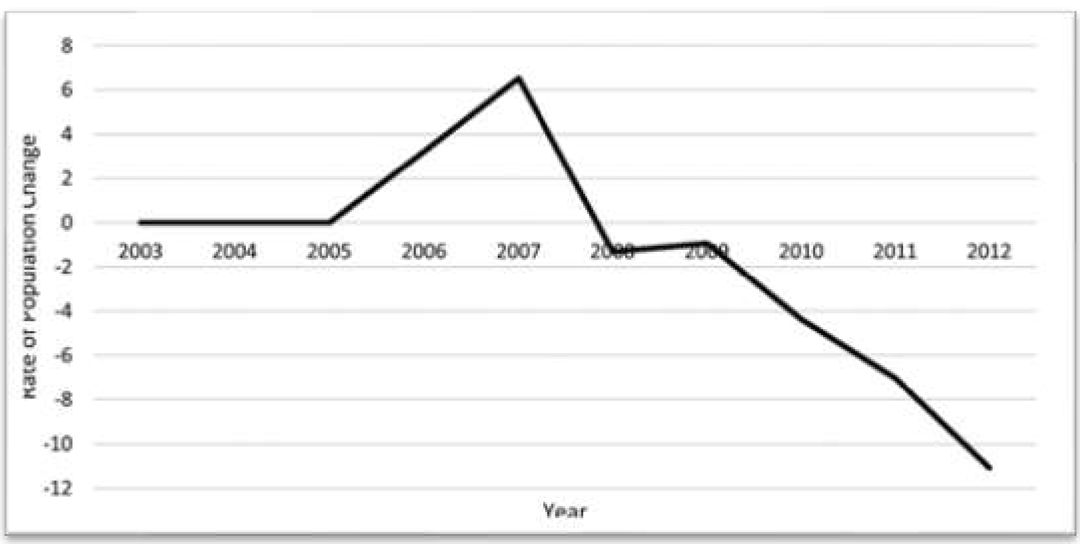

Figure 2. Decline in lichen population in Canada between 2003 and 2012.

(Source: Cameron and Toms 2016)

LOSS OF HABITAT

The issue of loss of habitat describes the impacts of human activities, including deforestation and climate change, that have led to a decline in the population of lichens in Canada (Cameron *et al*. 2013a; Government of Canada 2016a; Payette and Delwaide 2018). It was found that the clearing of forested lands has significantly contributed to a decline in lichen population because most lichens depend on trees and other natural resources for survival. For example, Payette and Delwaide (2018) showed that deforestation in the southern part of lichen woodlands in Atlantic Canada has resulted in successive depletion of trees following the recurrent fire that progressively reduced the regenerative potentials of lichens mainly the black spruce population. The recurrent fire in the region is exacerbated (made worse) by poor surfaces of moist seedbeds, which are essential for the growth of lichens. Similar findings were discovered in studies that revealed that deforestation is the primary concern driving a drop in the lichen population in Canada, particularly for *Erioderma pedicellatum,* which is mostly found in old-growth forests (Cameron *et al*. 2013a; Richardson 2010; Richardson *et al*. 2013b).

Further, Cameron *et al*. (2013a) demonstrated that deforestation is the primary human activity that negatively affects the growth of *Erioderma pedicellatum* due to the lack of formal protection of habitat in Canada, despite the introduction of Nature Conservancy of Canada land. It was also found that fire activity has contributed to deforestation in Canada, which causes a decline in the population of lichens like arctic-alpine species (Scheidegger 2002; Government of Canada 2016b; Lewis and Brinker 2017b). Savard and Payette (2013) examined the potential causal factors to lichen population decline and their effects on the diversity of lichen species, including arctic-alpine species across the boreal forest zone in eastern Canada. The study found that in the tundra summits in the boreal forest in the eastern part of Canada, fire activity affects the vegetation composition and diversity of arctic-alpine species, which has resulted in population decline (Richardson *et al*. 2013b). The study also established that deforestation events due to fire have resulted in low diversity or a decline in lichen species in the eastern part of Canada.

Similarly, one of the reviewed studies illustrated that loss of habitat due to deforestation and changing weather conditions like the occurrence of powerful windstorms facilitated a decline in the population of lichens in Canada (Lauriault 2020; Lewis and Brinker 2017b). The research established that deforestation has led to stochastic events that have contributed to habitat loss, causing a decline in lichen species, including the boreal felt lichen. Also, stochastic events like spruce budworm outbreaks were found to strain the survival of the boreal lichen population in Canada (Solomon *et al*. 2003).

Cameron *et al*. (2013b) found that habitat loss through industrial forestry activities negatively impacted the endangered of *Erioderma pedicellatum,* especially in Nova Scotia, leading to a reduction or a decline in the population associated with harvesting of balsam fir, *Abies balsamea* (L.) Mill., which is the main host for boreal felt lichen. Additionally, forest harvesting within the landscape of *Erioderma pedicellatum* increases the risk of mortality of this lichen species by negatively impacting the microclimate of their habitat.

OVEREXPLOITATION AND HABITAT ALTERATION

Overexploitation refers to the impacts of human actions such as overharvesting of natural resources critical to the development and survival of lichens in Canada (Allen *et al*. 2019; Basu 2011; Cameron *et al*. 2013b). The reviewed studies illustrated that overexploitation through logging, and wood harvesting is the main threat to the survival of boreal felt lichen in Canada. According to the Nova Scotia Department of Lands and Forestry (2020), large-scale cutting of forest trees through logging and wood harvesting has created forest fragmentation, contributing to a decline in the population of different species of lichens in Canada. Similarly, the Nova Scotia Department of Lands and Forestry reported that overcutting in the forests and overuse of trees had increased the exposure of lichens to the drying effects of sun, temperature, and wind, therefore significantly reducing the survival of lichens. Further, Allen *et al*. (2019) demonstrated that overexploitation through human activities, such as black-market trading and extensive harvesting, has facilitated a decline in the population of endangered lichen species in Canada, as presented in Figure 3.

Figure 3. A comparison of bark-dwelling lichen communities. There is a decline in lichen population in Oak tree bark (left).

Source: Allens *et al*. (2019)

Basu (2011) showed that these human activities result in habitat fragmentation due to extensive logging practices that have made several lichen species like *Erioderma pedicellatum* restricted to isolated populations in Nova Scotia and Newfoundland, Canada, thereby reducing their survival. Further, Cameron *et al*. (2013b) demonstrated that overexploitation through large-scale forest harvesting affects the humidity needed by lichens to grow. This over-cutting of trees increases evaporation and wind within the adjacent forests, therefore negatively affecting the humidity.

Consequently, these forests may lose moisture that is needed for the growth of lichens, hence reducing their survival, which is associated with a decline in their population (Cameron *et al*. 2013b). In addition to forestry, there is also excessive use of land, resulting in a reduced population of lichens in Canada. One article retrieved from the databases demonstrated that in Canada, specifically in Nova Scotia, a decline in the population of lichens is attributed to excessive forestry and overuse of lands (Nova Scotia Department of Lands and Forestry 2020). It was found that the population of lichens, mostly the endangered species of *Erioderma pedicellatum*, is very small and is only restricted to specific areas because of increased human activities or overexploitation such as large-scale harvesting. Also, overexploitation in terms of large-scale logging facilitates the onset of acid rain. Research by Cameron and Neily (2008) that investigated the habitats of cyanolichens in Canada, mainly in Nova Scotia, found that the population of *Erioderma pedicellatum* continues to decline due to excessive cutting of trees or large-scale logging that serves as the main habitats of these types of lichens. The research indicated that the increasing forest harvesting and development in the coastal region of Nova Scotia place *Erioderma pedicellatum* at higher risk of poor development due to the loss of their habitat.

Cameron and Richardson (2006) conducted research to investigate the occurrence and abundance of epiphytic cyanolichens in Nova Scotia, Canada. The study demonstrated that despite the presence of cyanolichens, the number continues to decline in Nova Scotia due to overexploitation that has led to drying events that affect the growth and survival of lichens. Additionally, the research showed that increased human activities in Nova Scotia have resulted in habitat destruction and increased acid rain that affect the growth and survival of cyanolichens, mainly the boreal felt lichen or *Erioderma pedicellatum*.

AGRICULTURE

The theme of agriculture describes the effects of human activities, mainly agricultural practices, on the population of lichens in Canada (Allens *et al*. 2019; Chagnon and Boudreau 2019; McCune *et al*. 2019). In this present research, it was found that high-intensity agricultural land use has resulted in a decline in the lichen population in Canada since most lands are preserved for farming activities. McCune *et al*. (2019) demonstrated that intensive agricultural land use and associated effluents contributed to the decline of lichens in Canada. It was found that clearing forests for farming and the use of pesticides negatively affect the growth and survival of lichens. Land development for agricultural activities also creates landscape alterations and disturbances for the lichen population, therefore reducing their survival. Nova Scotia Department of Lands and Forestry (2020) reported that the development of land for agriculture creates landscape alterations, which threatens lichen species, mainly boreal felt lichen since their habitat is destroyed. This affects the growth and survival of this species in Nova Scotia, Canada.

Increasing agricultural practices and shrub vegetation have played a major part in the decline of the lichen population. Reviewed studies established that even though lichen species were widely distributed in Canada, the lichen population in various areas of agriculture has been declining due to the negative impacts of agricultural practice (Allens *et al*. 2019; Government of Canada 2015). Further, Chagnon and Boudreau (2019) illustrated that in Canada, particularly in the Nunavik (Québec), shrub vegetation has detrimental effects on lichens due to competition for light. Also, Chagnon and

Boudreau explained that competition for light between lichens and shrub vegetation is the main driving force of lichen decline in Canada. This is attributed to the fact that lichens are poor competitors; therefore, they are affected by the shade caused by the shrub heights and litter accumulation that leads to lichens' slow growth rate. Besides, shrub vegetation causes greater availability of soil nutrients by enhancing the amount of organic matter and warming soils, which can negatively impact the growth of some lichens that mostly grow, perform better, and survive in nutrient-poor habitats where there is less competition. The review indicated that extensive agricultural practices have resulted in soil pollution, affecting the growth and survival of some species of lichens in Canada.

URBANIZATION AND AIR POLLUTION

The subject of urbanization and air pollution examines the impacts of human activities such as urban housing development and infrastructure (Coffey and Fahrig 2012; Government of Canada 2011b; Government of Canada 2013; Lättman. 2014; Government of Canada 2016c; Lisowska 2011; Richardson *et al*. 2013a). My review found that urbanization has resulted in a reduction in lichen biodiversity due to land development for housing (Lättman *et al*. 2014). It was also found that urbanization has contributed to fragmentation and loss of habitat for lichen species. Moreover, urban areas play a significant role in pollution through industrial activities. This leads to the release of harmful substances, including sulphur dioxide and nitrogen oxide, that result in significant damage to many species of lichen.

Lisowska (2011) found that industrial activities have substantially changed the quantity and composition of air pollutants which are critical drivers for the decline of lichen flora in urban areas. This study found that urbanization is associated with air pollution from vehicles that affect the growth and survival of macrolichens in Canada. This was found in one of the articles by Coffey and Fahrig (2012), which illustrated that across urban Ottawa, atmospheric pollution or vehicle pollution and urban microclimate negatively impact the growth of macrolichens. The research also demonstrated that industrial pollution, either through industrial agriculture or natural activities, plays a crucial role in the growth and survival of lichen species in Ottawa. It was shown that in Ottawa city, automobiles and other vehicles emit a huge amount of air pollution that affects lichens' distribution and survival by hindering their growth. The fumigation from such vehicles releases nitric acid that causes air pollution, damaging lichens' fungal and algal cells. By releasing such contaminants, the growth of lichens is affected, leading to their decline, especially in urban areas in Ottawa and surrounding areas.

Similarly, sulphur dioxide and nitrogen oxides are among the identified urban pollutants affecting the growth and survival of lichen species in Canada. In the Ontario region of Canada, urban pollutants, including sulphur dioxide and nitrogen oxides, have a significant impact on the lichen population (Warren *et al*., 2019). The research revealed that in the Erie-Ontario Plain and Ontario Lowlands of Canada, sulphur dioxide and nitrogen oxides in the urban ecozone are in the highest amounts. They are caused by coal-fired power plants, which affect the growth of lichens.

DEFORESTATION AND GROWTH OF LICHEN POPULATIONS

Based on the deforestation and growth of the lichen population, reviewed studies indicated that a decline in the population of lichens in Canada is attributed to deforestation and since lichens are highly dependent on trees and related natural resources to survive, cutting down of trees, especially in the southern part of woodlands in Atlantic Canada contributes significantly to a decline of the lichen population due to habitat loss (Cameron, 2013a; Woo-Durand 2020). Similar information by Venter *et al*. (2006), demonstrated that human activities, including clearing of forests for land use, had a significant contribution to a decline in the population of lichens because such activities negatively impact the growth and survival of lichen species in Canada. Woo-Durand *et al*. (2020) showed that human activities like deforestation lead to habitat loss, influencing the growth and survival of endangered lichen species.

WOOD HARVESTING AND LOOGING

Reviewed studies showed the role of overexploitation through wood harvesting and logging as among the human factors that lead to a decline in lichen population in Canada (Cichowski *et al*. 2022; Horstkotte *et al.* 2011; Stone *et al*. 2008). Large-scale cutting of trees in terms of increased wood harvesting and logging contributed significantly to the loss of lichen populations (Horstkotte *et al*. 2011; Nova Scotia Department of Lands and Forestry 2020). Further, through wood harvesting, logging, and forest fragmentation in Canada has led to a decline in various species of lichens (Cameron *et al*. 2013b; Cameron and Neily 2008). Also, overcutting trees in the forest and overuse of trees increasingly exposed different varieties of lichens to sun and wind, negatively affecting growth and survival. These human activities, such as extensive harvesting, reflect overexploitation of trees, which has caused a decline in the population of endangered lichen species in Canada (Allen *et al*. 2019). It is evident that extensive logging practices, large-scale forest harvesting, and over-cutting of trees lead to climate change that is unfavorable for lichens to grow and survive, thereby declining the number of species. These findings supported the work of Woo-Durand (2020), which showed anthropogenic threats of climate change in reducing the growth and survival of lichen species in Canada. In the study, Woo-Durand (2020) showed that overexploitation is one of the critical factors that cause climate change, leading to a decline of lichens. Additionally, Woo-Durand (2020) found that overexploitation affects approximately 13% of lichens, especially the at-risk species of lichens, due to loss of habitat. Also, Cameron and Toms (2016) concluded that overuse of trees that cause rapid environmental changes is associated with poor policy implementation of forest preservation that create unfavorable conditions for endangered lichen species.

LAND PREPARATION AND LAND ALTERATION

Reviewed studies illustrated that extensive land preparation for farming causes landscape alterations that negatively impact the growth of lichen species in Canada (Cichowski *et al*. 2022; Richardson 2010; Rickbeil *et al*. 2017). The literature reviewed showed that farming, land preparation, and intensive use of the land had caused a decline in the population of lichens in Canada (Cichowski *et al*. 2022). Agricultural practices, including overuse of lands, clearing of forests for farming practices, and developing lands for other agricultural practices, are associated with landscape alterations and disturb lichens, reducing the number of lichen species. Moreover, the existing body of literature showed increased agricultural or farming practices as the main cause of the reduced number of lichens (Venter *et al*. 2006). The literature demonstrated that a decline in the population of lichens across Canada is common in areas with increasing agricultural practices that negatively affect the growth and survival of lichens.

Also, it is evident that shrub vegetation is one of the key agricultural practices that cause landscape alterations that threaten the growth and survival of lichens species (Chagnon and Boudreau 2019). It is well-established that an increase in such farming or agricultural practices fosters nutrient competition for light between the shrub vegetation and light. Consequently, the shrub heights and accumulation of litter prevent lichens from getting sunlight, which is the driving force of their growth. The study showed that such competition increases the availability of nutrients due to the vast amounts of organic matter and warm soil that prevent some lichens, especially those that grow in habitats with poor nutrients and less competition. Similarly, McMullin and Lendemer's (2013) work revealed that agriculture in densely populated areas in Southern Ontario, Canada, is the main contributing factor for the decline of lichen species.

INDUSTRIALIZATION AND LICHEN GROWTH

Some studies illustrated that industrialization is among the human factors associated with a decline in lichen communities in Canada (LeBlanc and Sloover 2011; Matthes *et al*. 2000). It is well documented that industrialization through land development for housing has resulted in the reduction of lichen biodiversity (LeBlanc and Sloover 2011). Further, habitat fragmentation and loss of habitat have increased through such urbanization practices, leading to poor growth and survival of lichens (Coffey and Fahrig (2012; Lisowska 2011; McMullin and Lendemer 2013). The study revealed urban areas as the main source of pollution due to increasing industrial activities that affect the survival of lichens. Heavy metal pollution and sulphuring acid from industrial activities in urban areas also contributed to a decline in the lichen population in Canada. Some of the reviewed studies showed that acidic compounds, including sulphuric acid and heavy metals, are among the contributing factors to the decline of lichen species (Gibson *et al*. 2013; Poplawski *et al*. 2011). It was found that fuel combustion for space heating from heavy metals that are used in snow clearing results in higher concentrations of acidic compounds and heavy metals, especially in cold winters, which affect the growth and survival of lichen species in Canada (Gibson *et al*. 2013).

Other reviewed studies established that harmful substances from industrial activities are released into the environment, leading to air pollution that greatly affects lichen species (Coxson and Coyle 2003; Pescott *et al*. 2015). Similarly, industrialization and air pollution from vehicles, urban microclimate, and fumigation contributes to a decline in lichen population because of the atmospheric elements in such pollution that damage the algal and fungal cells of lichens, therefore negatively impacting their growth (Coffey and Fahrig 2012; Sett and Kundu 2016). Sett and Kundu (2016) demonstrated industrialization causes increased pollution levels from the atmospheric elements that affect the survival of lichens since some of these species are sensitive to the elements; hence cannot survive or grow.

CONCLUSION

Lichen species are known to have ecological importance and are involved in the provision of food and shelter to wildlife. Lichen species are common in Canada, which is considered to be the leading country globally with the highest population of different types of lichens. Despite the existence of lichens in Canada, their population has drastically decreased, which is attributed to anthropogenic threats like habitat loss, overexploitation, agriculture, urbanization, and air pollution, overexploitation of land through logging and wood harvesting, and land preparation for agricultural activities. The use of pesticides for farming or agriculture practices, harmful substances and industrial activities or urbanization cause air pollution, resulting in a decline in the number of lichen species in Canada. Thus, lichen conservation measures should be enacted across Canada to minimize human activities. Also, industries should consider lichen conservation measures to reduce the emission of substances that affect the ecosystem and the growth and survival of lichen species. Also, monitoring lichens through mapping, topography and climatic data, and satellite imagery should be considered the key measure to assess the affected areas and take the necessary precautions to ensure the growth and survival of lichen species in the affected areas improved.

LITERATURE CITED

Allen, J. L., McMullin, R. T., Tripp, E. A., & Lendemer, J. C. 2019. Lichen conservation in North America: a review of current practices and research in Canada and the United States. *Biodiversity and Conservation*, *28*(12), 3103-3138.

Basu, S. K. 2011. Book Review: Species on the edge of survival. International Union for Conservation of Nature (IUCN) Red List. *Blue Jay*, *69*(4), 186-188.

Cameron, R. P., & Neily, T. 2008. Heuristic model for identifying the habitats of Erioderma pedicellatum and other rare cyanolichens in Nova Scotia, Canada. *The Bryologist*, *111*(4), 650-658.

Cameron, R. P., & Richardson, D. H. 2006. Occurrence and abundance of epiphytic cyanolichens in protected areas of Nova Scotia, Canada. *Opuscula Philolichenum*, *3*(5), 5-14.

Cameron, R. P., & Toms, B. 2016. Population decline of endangered lichen *Erioderma pedicellatum* in Nova Scotia, Canada. *Botany*, *94*(7), 565-571.

Cameron, R., Goudie, I., & Richardson, D. 2013a. Habitat loss exceeds habitat regeneration for an IUCN flagship lichen epiphyte: Erioderma pedicellatum. Canadian Journal of Forest Research, 43(11), 1075-1080.

Cameron, R. P., Neily, T., & Clapp, H. 2013b. Forest harvesting impacts on mortality of an endangered lichen at the landscape and stand scales. *Canadian Journal of Forest Research*, *43*(5), 507-511.

Chagnon, C., & Boudreau, S. 2019. Shrub canopy induces a decline in lichen abundance and diversity in Nunavik (Québec, Canada). *Arctic, Antarctic, and Alpine Research*, *51*(1), 521-532.

Cichowski, D., Sutherland, G. D., McNay, R. S., & Sulyma, R. 2022. Direct and indirect effects of habitat disturbances on caribou terrestrial forage lichens in Montane Forests of British Columbia. *Forests*, *13*(2), 1-27.

Coffey, H. M., & Fahrig, L. 2012. Relative effects of vehicle pollution, moisture and colonization sources on urban lichens. *Journal of Applied Ecology*, *49*(6), 1467-1474.

Cooper, R. 1953. The role of lichens in soil formation and plant succession. *Ecology*, *34*(4), 805-807.

COSEWIC. 2003. COSEWIC Annual Report 2003.

Coxson, D.S & Coyle, M. 2003. Niche partitioning and photosynthetic response of alectorioid lichens from subalpine spruce-fir forest in north-central British Columbia, Canada: the role of canopy microclimate gradients. *Lichenologist 35*, 157–175.

Gibson, M. D., Heal, M. R., Li, Z., Kuchta, J., King, G. H., Hayes, A., & Lambert, S. 2013. The spatial and seasonal variation of nitrogen dioxide and sulfur dioxide in Cape Breton Highlands National Park, Canada, and the association with lichen abundance. *Atmospheric Environment*, *64*, 303-311.

Government of Canada. 2008. Seaside bone (*Hypogymnia heterophylla*) COSEWIC assessment and status report: chapter 8.

Government of Canada. 2009. Pale-bellied Frost Lichen (*Physconia subpallida):* COSEWIC assessment and status report 2009.

Government of Canada. 2010. Crumpled tarpaper lichen (*Collema coniophilum):* COSEWIC assessment and status report 2010.

Government of Canada. 2011a. Ghost antler lichen (*Pseudevernia cladonia):* COSEWIC assessment and status report 2011.

Government of Canada. 2011b. Peacock vinyl lichen (*Leptogium polycarpum):* COSEWIC assessment and status report 2011.

Government of Canada. 2013. COSEWIC Assessment and Status Report on the Western Waterfan, *Peltigera gowardii* in Canada – 2013.

Government of Canada. 2014. Seaside centipede lichen (*Heterodermia sitchensis)* COSEWIC assessment and status report: chapter 13.

Government of Canada. 2015. COSEWIC assessment and status report on the black-foam lichen *Anzia colpodes* in Canada – 2015.

Government of Canada. 2016a. Frosted glass-whiskers (*Sclerophora peronella*) COSEWIC assessment and status report.

Government of Canada. 2016b. Golden-eye lichen (*Teloschistes chrysophthalmus):* COSEWIC assessment and status report 2016.

Government of Canada. 2016c. Batwing vinyl (*Leptogium platynum):* COSEWIC assessment and status report 2011.

Government of Canada. 2016d. COSEWIC assessment and status report on the mountain crab-eye, *Acroscyphus sphaerophoroides,* in Canada.

Government of Canada. 2016e. COSEWIC Assessment and status report on the Wrinkled Shingle Lichen, *Pannaria lurida* in Canada – 2016.

Government of Canada. 2018. Smoker's Lung Lichen (*Lobaria retigera*): COSEWIC assessment and status report 2018.

Government of Canada. 2019a. COSEWIC Assessment and Status Report on the Cryptic Paw Lichen (*Nephroma occultum*) in Canada 2019.

Government of Canada. 2019b. White-rimmed Shingle Lichen (*Fuscopannaria leucosticta):* COSEWIC assessment and status report 2019.

Government of Canada. 2021. Vole Ears Lichen (*Erioderma mollissimum*): COSEWIC assessment and status report 2021.

Horstkotte, T., Moen, J., Lämås, T., & Helle, T. 2011. The legacy of logging—estimating arboreal lichen occurrence in a boreal multiple-use landscape on a two-century scale. *PloS One*, *6*(12), e28779.

Kennedy, B., Pouliot, D., Manseau, M., Fraser, R., Duffe, J., Pasher, J., Olthof, I. 2020. Assessment of Landsat-based terricolous macrolichen cover retrieval and change analysis over caribou ranges in northern Canada and Alaska. *Remote Sensing of Environment*, *240*, 111694.

Kershaw, K. A. 1977. Studies on lichen-dominated systems. XX. An examination of some aspects of the northern boreal lichen woodlands in Canada. *Canadian Journal of Botany*, *55*(4), 393-410.

Lättman, H., Bergman, K. O., Rapp, M., Tälle, M., Westerberg, L., & Milberg, P. 2014. Decline in lichen biodiversity on oak trunks due to urbanization. *Nordic Journal of Botany*, *32*(4), 518-528.

Lauriault, P. 2020. *An effective detection strategy and determining critical habitat characteristics for Boreal Felt Lichen (Erioderma pedicellatum) in Newfoundland, Canada* (Doctoral dissertation, Memorial University of Newfoundland).

LeBlanc, S. F., & Sloover, J. D. 2011. Relation between industrialization and the distribution and growth of epiphytic lichens and mosses in Montreal. *Canadian Journal Of Botany, 48*(8), 1485-1496.

Lewis, C., and Brinker, S. 2017a. COSEWIC Assessment and Status Report on the Flooded Jellyskin, Leptogium rivulare in Canada.

Lewis, C., and Brinker, S. 2017b. COSEWIC Assessment and Status Report on the Golden-eye Lichen, *Teloschistes chrysophthalmus*, Prairie / Boreal population, Great Lakes population in Canada.

Lisowska, M. 2011. Lichen decolonization in an urban-industrial area of southern Poland as a result of air quality improvement. *Environmental Monitoring & Assessment 179*, 177-190.

Matthes, U., Ryan, B. D., & Larson, D. W. 2000. Community structure of epilithic lichens on the cliffs of the Niagara Escarpment, Ontario, Canada. *Plant ecology*, *148*(2), 233-244.

McCune, J. L., Colla, S. R., Coristine, L. E., Davy, C. M., Flockhart, D. T., Schuster, R., & Orihel, D. M. 2019. Are we accurately estimating the potential role of pollution in the decline of species at risk in Canada? *Facets*, *4*(1), 598-614.

McMullin, R. T., & Lendemer, J. C. 2013. Lichen biodiversity and conservation status in the Copeland Forest Resources Management Area: a lichen-rich second-growth forest in southern Ontario. *The Canadian Field-Naturalist*, *127*(3), 240-254.

Mcmullin, R. T., Thompson, I. D., & Newmaster, S. G. 2013. Lichen conservation in heavily managed boreal forests. *Conservation Biology*, *27*(5), 1020-1030.

Miller, D. 2000. Lichens, wildfire, and caribou on the taiga ecosystem of northcentral Canada. *Rangifer*, 195-207.

Nordberg, M. L., & Allard, A. 2002. A remote sensing methodology for monitoring lichen cover. *Canadian Journal of Remote Sensing*, *28*(2), 262-274.

Nova Scotia Department of Lands and Forestry. 2020. Recovery Plan for Boreal Felt

Lichen (*Erioderma pedicellatum*) in Nova Scotia [Final]. Nova Scotia Endangered Species Act Recovery Plan Series.

Payette, S., & Delwaide, A. 2018. Tamm review: The North American lichen woodland. *Forest Ecology and Management*, 417, 167–183.

Pescott, O. L., Simkin, J. M., August, T. A., Randle, Z., Dore, A. J., & Botham, M. S. (2015). Air pollution and its effects on lichens, bryophytes, and lichen-feeding Lepidoptera: review and evidence from biological records. *Biological Journal of the Linnean Society*, *115*(3), 611-635.

Poplawski, K., Setton, E., McEwen, B., Hrebenyk, D., Graham, M., & Keller, P. (2011). Impact of cruise ship emissions in Victoria, BC, Canada. *Atmospheric Environment, 45*(4), 824-833.

Power, T. D., Cameron, R. P., Neily, T., & Toms, B. 2018. Forest structure and site conditions of Boreal felt lichen (*Erioderma pedicellatum*) habitat in Cape Breton, Nova Scotia, Canada. *Botany*, *96*(7), 449-459.

Richardson, D. 2010. COSEWIC Assessment and Status Report on the Blue Felt Lichen, *Degelia plumbea.*

Richardson, D. Anderson, F., and Cameron, R. 2013a. COSEWIC assessment and status report on the Western Waterfan, *Peltigera gowardii* in Canada.

Richardson, D. Anderson, F., and Cameron, R. 2013b. COSEWIC assessment and status report on the Eastern Waterfan, Peltigera hydrothyria in Canada.

Rickbeil, G. J., Hermosilla, T., Coops, N. C., White, J. C., & Wulder, M. A. 2017. Estimating changes in lichen mat volume through time and related effects on barren-ground caribou (*Rangifer tarandus groenlandicus*) movement. *PLoS One*, *12*(3), e0172669.

Savard, J., & Payette, S. 2013. Origin and plant species diversity of high-altitude tundra summits across the boreal forest zone in eastern Canada. *Écoscience, 20*(3), 283-295.

Scheidegger. C. 2002. COSEWIC assessment and status report on the Boreal Felt Lichen, *Erioderma pedicellatum.*

Sett, R., & Kundu, M. 2016. Epiphytic lichens: their usefulness as bio-indicators of air pollution. *Donnish Journal of Research in Environmental Studies*, *3*(3), 17-24.

Solomon, D. S., Zhang, L., Brann, T. B., & Larrick, D. S. 2003. Mortality patterns following spruce budworm infestation in unprotected spruce-fir forests in Maine. *Northern Journal of Applied Forestry*, *20*(4), 148-153.

Species at risk public registry. 2021. Species at Risk Act (SARA). Lichens status report. Government of Canada.

Stone, I., Ouellet, J. P., Sirois, L., Arseneau, M. J., & St-Laurent, M. H. 2008. Impacts of silvicultural treatments on arboreal lichen biomass in balsam fir stands on Québec's Gaspé Peninsula: Implications for a relict caribou herd. *Forest Ecology And Management, 255*(7), 2733-2742.

Theau, J., Peddle, D. R., & Duguay, C. R. 2005. Mapping lichen in a caribou habitat of Northern Quebec, Canada, using an enhancement classification method and spectral mixture analysis. *Remote sensing of environment*, *94*(2), 232-243.

Venter, O., Brodeur, N. N., Nemiroff, L., Belland, B., Dolinsek, I. J., & Grant, J. W. 2006. Threats to endangered species in Canada. *Bioscience*, *56*(11), 903-910.

Wannaz, E. D., Carreras, H. A., Rodriguez, J. H., & Pignata, M. L. 2012. Use of biomonitors for the identification of heavy metals emission sources. *Ecological Indicators*, *20*, 163-169.

Warren, R. J., Casterline, S., Goodman, M., Kocher, M., Zaluski, R., & Battaglia, J. H. 2019. Long-term lichen trends in a rust belt region. *Journal of Urban Ecology*, *5*(1), 1-7.

Woo-Durand, C., Matte, J. M., Cuddihy, G., McGourdji, C. L., Venter, O., & Grant, J. W. 2020. Increasing importance of climate change and other threats to at-risk species in Canada. *Environmental Reviews*, *28*(4), 449-456.