

The Effect of Silvicultural and Environmental Conditions on the Lichen Biota of
Residual Trees in Managed Forests in Ontario, Canada

By

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ABSTRACT

THE EFFECT OF SILVICULTURAL AND ENVIRONMENTAL CONDITIONS ON THE LICHEN BIOTA OF RESIDUAL TREES IN ONTARIO, CANADA

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In Ontario, standing trees are reserved to “lifeboat” organisms in harvested forests. I examined epiphytic lichen on residual trees in two natural and managed mixedwood forests. Effects of management intensity, tree species, diameter at breast height (DBH), elevation, and distance to landscape features were investigated on lichen species richness, abundance and community composition on residual trees at three levels of silvicultural intensity. I found that silvicultural intensity had no effect on community composition at both locations, but had some effect on richness or abundance. Tree type (high/low bark pH), DBH, and distance to roads and remnant forest were the most important variables affecting lichen communities, explaining 51% of variance in communities in the first two axes of ordination in Timmins and 43% in Petawawa. Forestry practices in these experimental plots appear to provide the range of habitat variables required to support lichen communities similar to that of an unmanaged forest.

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CHAPTER ONE

Introduction

1.1 Background

Of the approximately 400 million hectares of forest in Canada (NRC 2014), over half (258 604 300 hectares) are managed for forestry (CNFI 2013). Prior to the last few decades, conventional forestry was focused on the harvest and production of wood biomass for timber or pulp (i.e., sustained yield). These practices gave little consideration to aesthetic values or the health and preservation of local floral and faunal communities (Lindenmayer et al. 2012). As a result, negative effects have been wide ranging, and include effects on benthic invertebrate populations (Newbold et al. 1980), the storage of soil organic carbon (Pennock and Kessel, 1997), scenic value (Nibe 1989) and understory community composition (Haeussler et al. 2002). Recognition of the issues caused by conventional forestry practices started a revolution in forest management (Gustafsson et al. 2012). Objectives shifted from harvest for sustained yield to sustainable forest management as a whole.

Approximately 25 years ago, beginning in North America's Pacific Northwest, "retention forestry" or "green tree retention" was introduced as a method of sustainable forest management (Gustafsson et al. 2012). The aim was to balance forest production and its impact on forest ecosystems. This new practice saw the retention of trees within cut blocks, here referred to as residual trees, with the intention of creating continuity in both structure and function as the forest regrows (Gustafsson et al. 2012; Boch et al. 2013). In the past, trees have been retained under traditional "seed tree" silviculture. Their purpose was simple; to provide a seed source for the next generation of trees within the cut block. Trees were selected to be windfirm and produce the largest number of seeds (MNR 2000). Residual trees, however, left uncut on the landscape, were also to "lifeboat" species of the previous forest so they may help populate the next

generation of flora and fauna (Franklin et al. 1997; Rosenvald and Löhmus 2008; Schei et al. 2013). They can act as biological refugia, a seed source for regenerating trees, increase habitat connectivity, maintain microhabitats, and increase stand structural complexity (Guevara et al. 1986; Elmqvist 2001; Manning et al. 2006; Manning et al. 2009). In the years following its introduction, scientists and managers acknowledged the biological benefits of retention forestry (Gustasson et al. 2012).

Retention forestry has been studied in forests all over the world. In ash (*Eucalyptus regnans*; species' authorities and scientific names are in appendix four) dominated forests of Australia, small mammal populations were shown to be conserved by the uncut tree islands left after harvest (Lindenmayer et al. 2010). Retention of rainfall and of nutrients such as carbon, nitrogen, potassium and phosphorus was greater in the soil below the remnant scattered trees of Australian grassy woodlands (Ludwig et al. 1999; Prober et al. 2002). In a Finish mixedwood boreal forest, retained trees preserved the richness of rare and red-listed beetles (Hyvarinen et al. 2006). In a Swedish boreal forest, retention trees provided habitat for ectomycorrhizal fungi species that did not survive in the cleared forest (Dahlberg et al. 2001). A meta-analysis of bird responses to partial harvesting across North America found that retention of 50% of tree stems could prevent a decreased abundance of all 54 species studied (Vanderwel et al. 2007). In Canada, large scale research projects such as Variable Retention Adaptive Management (VRAM) and Ecosystem Management Emulating Natural Disturbance (EMEND) have investigated the effects of retention trees on regenerating forests. VRAM monitored structural components of the forest such as the number of snags and volume of dead wood, and biological components such as shrub, herbaceous and moss cover (Huggard 2004). EMEND is comprised of smaller projects with study organisms ranging from spiders (Pinzon et al. 2012) and moths (Morneau 2002) to over (Solarik 2010) and understory plants (Fenniak 2001). One organism important to forest biodiversity (Newmaster and Bell 2002; Boch et al. 2013) appears to have not been assessed: lichen.

Lichen have several functional roles in forest ecosystems. They are a critical food source for caribou (Rominger et al. 1996), an occasional food source for deer (Gray and Servello 1995), and they provide habitat for invertebrates (Patterson et al. 1995) and nesting material for birds (Singer et al. 1991) and mammals (Hayward and Rosentreter 1994). They also contribute to the decomposition of dead woody material (Stokland et al. 2012) and the cycling of nutrients (Knops et al. 1991). Lichen do this through the interception and depletion of nitrogen in canopy through fall (Woods et al. 2012), nitrogen fixation, nutrient leaching and decomposition in litterfall (Nash 2008). In addition, lichen are also good bioindicators. Some lichen species are sensitive to environmental conditions such as air pollution (Beckett 1995; Nimis et al. 2002), herbicide exposure (McMullin et al. 2011), temperature, humidity (Coxson and Coyle 2003) and substrate pH (van Herk 2001). Air quality and ecosystem integrity can be monitored well with lichens because of their unique physiology (Beckett 1995; Ellis et al. 2009).

Lichen are composite organisms comprised of a mycobiont (fungus) and photobiont (algae, cyanobacteria or both; Nash 2008). A cross section of a lichen (foliose growth form) is illustrated in Figure 1.1. The cortices lack a protective waxy cuticle, which allows for the absorption of nutrients from the atmosphere and precipitation (Büdel and Scheidegger 2008). The success of the mycobiont-photobiont relationship comes from shared resources. The mycobiont provides protection for the photobiont and prevents desiccation (Beckett et al. 2008). The photobiont produces mobile carbohydrates that are used by the mycobiont (Richardson et al. 1967). In the presence of enough moisture (i.e. precipitation or humidity) to wet the lichen surface, the upper surface of the mycobiont becomes translucent allowing light to reach the photobiont within (Medlin 1996). The permeability of the mycobiont layer allows this to happen almost immediately (Hale 1973). Lichen growth is therefore based on the amount of time an individual receives light while wet (Hale 1973). Lichens lack roots to take up nutrients, but they have rhizines, which appear similar to the roots of vascular

plants, but they are only holdfasts to its substrate (Büdel and Scheidegger 2008). Other necessary nutrients are absorbed through the thallus surface (Nash 2008).

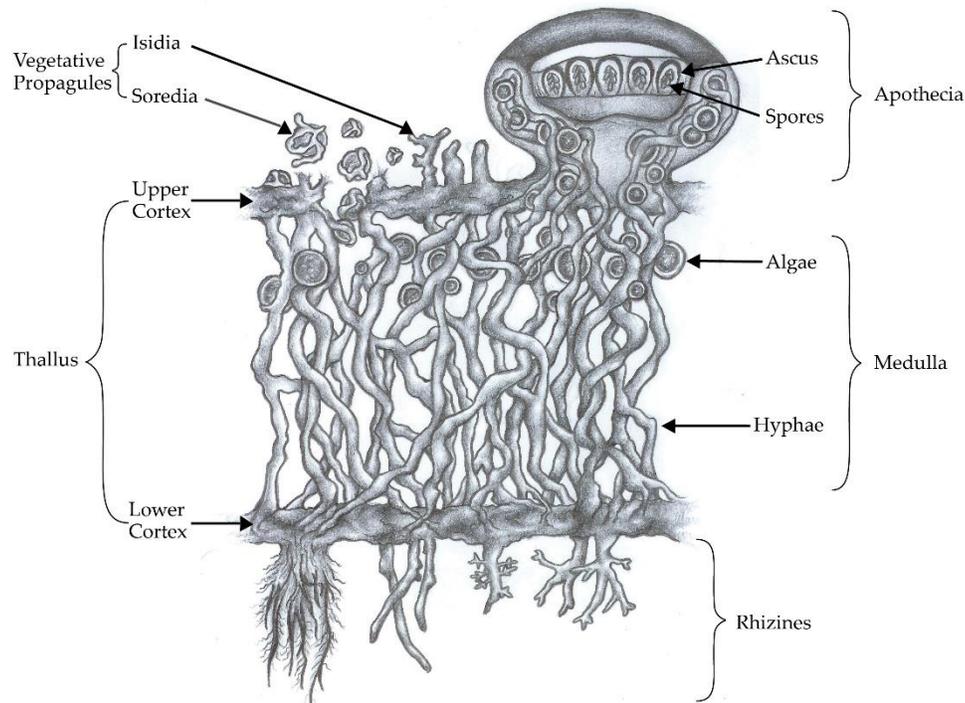


Figure 1.1: Lichen cross section. Taken from McMullin and Newmaster (2010). Illustration by Nicole Daoust.

There are three broad lichen growth forms: fruticose, foliose, and crustose (Büdel and Scheidegger 2008). Fruticose species can either be erect (e.g., *Cladonia* spp.) or pendant (e.g., *Bryoria* spp.). This form is mostly defined by its lack of a lower surface, but there are a few rare exceptions. The mycobiont layer completely surrounds the central photobiont (Büdel and Scheidegger 2008). Foliose species, as their name suggests, take a leaf-like form (e.g., *Parmelia* spp.) and are either prostrate or ascending from their substrate. They are also defined by their distinct upper and lower fungal cortex and they live upon, rather than within, their substrate (Büdel and Scheidegger 2008). The third form, crustose, is defined by a thallus without a lower cortex. Instead, fungal hyphae grow into the substrate and these species cannot be removed without removing their substrate as well (e.g., *Buellia* spp.; Büdel and Scheidegger 2008). The

form, and particularly exchange surface area of a lichen, play an important role in its use by humans as bioindicator (Nash 2008).

Lichens occur on a wide variety of substrates. Those that live on rock are described as saxicolous, those on soil are terricolous, those on deadwood are lignicolous and those on the bark of trees are corticolous (Boch et al. 2008). Many species can live on a variety of substrate types, others are more specific to particular types of trees, rock or soil (Brodo 1973). My study will focus on epiphytic species (those living on trees) with some lignicolous and terricolous species.

Some species of epiphytic lichen are used as indicators of forest continuity. What defines continuity will vary between forest types, but generally this term is used to describe the state of a forest in the absence of disturbance (Rose 1976 in Selva 2013). Characteristics of these species' biology make them suitable indicators; first of which is rate of growth.

Hale (1973) states that lichen have a "legendarily" slow growth rate. Foliose species average 1-2.5 mm a year, fruticose are faster with 2-6.0 (30) mm a year, and crustose are the slowest with less than a millimetre a year (Hale 1973). This growth rate will change with moisture, light, temperature and nutrients available (Hale 1973). This slow rate of growth requires a substrate that's stable in the same time frame as the lifespan of a lichen. Old trees are. Therefore, typically colonized by many more lichen species than younger trees (Esseen et al. 1992; Uliczka and Angelstam 1999; Sillett et al. 2000).

The dispersal limitations of some lichen species also help to make them good indicators of forest continuity. Lichen can reproduce vegetative and sexually. Vegetative propagules include soredia, isidia and thallus fragments; listed here in order of increasing tissue mass of each propagule (Pyatt 1973). All three of these propagules include tissues from both the mycobiont and photobiont and are passively dispersed by the wind, insects, animals or rain (Pyatt 1973). Sexual propagules are spores containing only fungal tissue. Spores are generally smaller than vegetative propagules and can be actively expelled from the thallus

to initiate dispersal when the conditions are right (Pyatt 1973). Lichen with larger propagule size are generally more limited in their dispersal, making it difficult to colonize beyond established habitat (Sillet et al. 2000). This is why inoculum sources close to harvested areas is important to lichen diversity in secondary forests (Halpern and Spies 1995).

The permeability of lichen thalli also contribute to their usefulness as forest continuity indicators. The thallus surface provides little protection from the drying conditions of high temperature or wind exposure (Hale 1973). These are the microclimatic conditions typical of disturbed forest habitat (Chen et al. 1993), but wind exposure is also increased at higher elevations (Berryman and McCune 2006). Disturbances can be natural (e.g., fire) or artificial (e.g., harvested forest). As stated previously, the thallus must be wet for a lichen to grow, and under such conditions there may be insufficient moisture for adequate photosynthesis. This is why forest edge (Esseen and Renhorn 1998; Rheault et al. 2003) and elevation (Berryman and McCune 2006) effects and proximity to sources of higher humidity are important to epiphytic lichen.

Lichen form can also influence a species' performance as an indicator of forest continuity. The lichen thallus alone is not effective in retaining water. The relationship with its substrate, however, improves the lichen's ability to attain adequate moisture for photosynthesis (Brodo 1973). Water vapour can become trapped between a foliose thallus and its substrate and crustose species are in intimate contact with their substrate and can access its stored moisture. In the case of epiphytic lichens, it is generally the wood or bark of a tree, which can retain moisture much longer than a lichen thallus (Blum 1973). Fruticose species, however, cannot rely on the associated substrate for moisture retention. Consequently, branched fruticose lichen forms have adapted to this by capturing humid air between their branches to slow moisture loss (Blum 1973). The differences in surface area can also affect the area of absorption for hazardous material such as herbicides. McMullin et al. (2012) found that branched species are more sensitive to herbicides and hypothesized that it is due to greater

surface area and slower moisture loss. The sensitivity of lichen physiology, as presented above, provided evidence that forest disturbance can have an effect on lichen.

Lichen, as a bioindicator, have been used in a number of studies to assess the continuity of harvested forests (Hazell and Gustafsson 1999; Lõhumus et al. 2006; Hedenås and Hedstrom 2007; Jairus et al 2009; Perhans et al. 2009; Lõhumus and Lõhumus 2010; Boch et al. 2013; Lundström et al. 2013; Schei et al. 2013). Most of such studies come from Sweden, Finland and Estonia where there is great concern for the lichen of managed forests. For many years the forestry practices here were “amongst the most mechanized and efficient in the world” (Esseen et al. 1997) which led to the homogeneity of forest habitats and the eventual loss of lichen species (Ingelög 1987 in Esseen et al. 1997; Burglund and Jonsson 2005). None of these studies have reported fewer species or less abundant lichen on residual trees compared to conventional forestry systems. In most cases, residual trees provided critical habitat for lichen following silviculture. Research on residual trees and lichens appears to be limited in Canada (Coxson and Stevenson 2005; Edman et al. 2008), and there has been no known studies done in Ontario’s mixedwood forests.

The majority of Ontario’s mixedwood forest is managed by the Ontario Ministry of Natural Resources and Forestry (OMNRF) in consult with forestry companies and communities (CCFM 2012). As a part of its mandate to conserve forest biodiversity, OMNRF uses a “coarse and fine filter approach” (Hunter 1990) to ecosystem based forest management (OMNR 2010). These “filters” are sets of management criteria intended to provide adequate habitat to general and specific elements of forest biodiversity. Currently, the Stand and Site Guide (2010) outlines how retention forestry can be utilized in Ontario forests. A diversity of ecosystem conditions are provided for using the coarse filter. In practice, this is the retention of elements of structural diversity (i.e., residual trees) and landscape features that would survive a natural forest disturbance. This strategy takes advantage of the current ecosystem’s resilience to a certain type and

frequency of disturbance. If this retention can be emulated in the management of forests, then the structure and function of an ecosystem may persist, which will benefit the regenerating forest (Suffling and Perera 2004). The fine filter includes specific habitat requirements of species of concern. For example, harvesting is prohibited within 75 m of an active osprey nest and downed woody material and potential wildlife trees (i.e. old cavity trees) will be retained within 300 m (OMNR 2010). However, recent legislation could cause problems for silviculture in Ontario.

Ontario's Living Legacy Land Use Strategy (OMNR 1999) was implemented in 1999 and amended in 2008. The primary objectives include completing the Ontario Parks system and determining land use according to Ontario's needs for tourism and recreation. Although the strategy benefits resource-based tourism (e.g., provincial parks and conservation areas), it will require better land use efficiency in the province as the proposed ~2.4 million hectares of protected area will limit land available to forestry companies by 12% (Bell et al. 2008). In light of this, silvicultural methods have been developed with increasing management intensity. The goal of these methods is a shorter rotation length; i.e., yielding more high value trees in a shorter amount of time. Components of these management strategies include: planting only the best genetic material, physical and chemical soil preparation, herbicide spray, intraspecific thinning and site amelioration (e.g., fertilization, irrigation or drainage; Bell et al. 2008).

The responses of terrestrial lichen to silvicultural practices with increased intensity were examined by Newmaster et al. (2002) in Ontario's boreal mixedwood. They show that lichen are sensitive to silvicultural treatments with significantly lower species richness in areas harvested and sprayed with herbicide than in areas harvested without herbicide use or in unharvested forests. The response of epiphytic lichen on residual trees to different intensities of harvesting has not yet been examined in Ontario.

The aim of my study is to better understand how well residual trees serve as habitat for lichen under increasing silvicultural intensity. I wish to do this for two

main reasons. 1, to understand the contribution of residual trees to community diversity. 2, to accumulate information useful to forest managers in the adaptive management of Ontario mixedwoods. In order to best manage Ontario mixedwood forests, we need to know how well residual trees are behaving as lichen habitat and what variables optimize lichen diversity.

1.2 Research questions and predictions

Two research questions will be investigated in my study; both of which aim to understand how well residual trees in Ontario's managed mixedwood forests serve as habitat for lichen.

The first research question addresses the conditions under different management intensities: Does management intensity influence the lichen community on residual trees? Lower per tree lichen species richness and abundance is expected as management intensity increases because fewer lichen species can survive in an increasingly disturbed habitat. Greater intensity is expected to yield a change in the dominant lichen form growing on exposed residual trees because of the greater surface area for herbicide adsorption in some forms. The abundance of crustose lichen is expected to be greatest under higher management intensity and lowest in unmanaged forest; the opposite will be found for fruticose lichen. My last prediction is that lichen community composition will be different on managed and unmanaged trees because of the physiological differences of some species and their different habitat requirements.

My second research question addresses the natural habitat characteristics of residual trees: Does tree species, tree diameter at breast height (DBH), elevation or spatial relationship with stand features affect the lichen of residual trees? If tree species affects the lichen of residual trees, then per tree lichen species richness and community composition will change with the species of its residual tree. If tree DBH affects the lichen of residual trees, then per tree lichen species richness will increase with tree DBH and lichen community composition will vary

with DBH because a greater number of lichens are often found on older and larger trees than on younger ones (Jüriado et al. 2009; Nascimbene et al. 2012). If spatial relationship to stand features affects the lichen of residual trees, then 1) per tree lichen species richness will increase with distance from the nearest road and hydrowire due to the drying these features can cause to lichen thalli (Chen et al. 1993; Rheault et al. 2003); 2) per tree lichen species richness will decrease with distance from the nearest river and wetland because of the decreasing atmospheric moisture available to lichen thalli farther from these features (Danehy and Kirpes 2000; Stewart and Mallik 2006); 3) per tree lichen species richness will decrease with distance from the nearest unmanaged forest because of the greater propagule dispersal distance; and 4) lichen community composition will vary with distance according to species biological characteristics.

CHAPTER TWO

Methods

2.1 Study Sites

2.1.1 History

My project was a part of a larger program lead by researchers at the Ontario Forest Research Institute (OFRI), of the OMNRF to define different management intensities and investigate their efficacy in obtaining certain forestry goals. (Bell et al. 2008). Data collected by these researchers includes: forest biodiversity, crop trees, economics, genetics, pathology and soils. In 2001, the NEBIE plot network was established to further explore these elements of forest management in the province. NEBIE (Natural, Extensive, Basic, Intensive and Elite) is an acronym

for the levels of management intensity applied. The network is made up of eight locations across central and northern Ontario (Figure 2.1; OMNR 2011).



Figure 2.1: Locations of NEBIE plot installations across Ontario.

At each NEBIE location, a set of five treatment plots comprises a block with four blocks per location following a randomized complete block design. Each intensity is applied to its own 100X200 m plot. The following described intensities are those that pertain to my study:

Natural: Natural forests are those that have not been managed by humans.

These act as the control, only ever having been disturbed by natural events such as fire, weather, pests or pathogens. These are not necessarily pristine forests.

Basic: Trees are harvested leaving residual trees and the site is made suitable for the next generation using mechanical (e.g. scarification) or chemical (e.g. herbicide application) site preparation. The next generation of crop tree seedlings are planted using material of similar genetic quality to that already existing at the

site. No more than one herbicide spray is applied to control interspecific competition at the beginning of the rotation, and the prevention of damage from fire and insects is managed at the landscape scale. The goal is to shorten the rotation length by 80%, ending in the standard harvest of the site according to the Crown Forest Sustainability Act (1994).

Intensive: Trees are harvested, leaving only residual trees of high quality that will benefit the next generation (benefits are determined on a site by site basis). The site is further prepared mechanically (e.g., scarification) or chemically (e.g., herbicide or fertilizer application) before planting seedlings of high genetic quality and only preferred species at high density on the site. As the site matures, it is revisited as management continues. Inter- and intra- specific competition is managed as required with weeding (by herbicide application or manual means), thinning and pruning. Regeneration is protected from threats such as insects, disease, fire and mammalian herbivory by means of prevention and suppression. The goal is to shorten the rotation length by 60%, ending in the careful harvest of 90% of stems with a diameter at breast height greater than 10 cm.

These intensities were chosen to represent a low, medium and high management intensity. Basic and Intensive are the more commonly used intensities in Ontario and were therefore selected over Extensive and Elite respectively. Bell et al. (2008) discuss these treatments and intensities in further detail.

Tree removal at the NEBIE sites was governed by the Forest Management Guide for Natural Disturbance Pattern Emulation (NDPE; OMNR 2001). This strategy uses a particular ecosystem's specialized resilience to the natural disturbance of a particular area. If this natural disturbance is emulated in the management of forests, then the structure of an ecosystem can persist, and therefore so can its function, strengthening the regenerating forest (Suffling and Perera 2004).

The NDPE guide outlines how structural diversity should be retained for the benefit of regenerating forests:

(1) Twenty-five standing trees with DBH >10 cm and heights >3 m must be left uncut for every hectare of harvested area, six of which must be living large diameter cavity trees (often large trembling aspen or hard maple), commonly referred to as residual trees.

(2) The person harvesting selects the remaining nineteen trees based on two orders of preference. (a) Relative fire tolerance of selected tree species. Specifically, fire-tolerant trees are likely to be those left standing following a fire disturbance, species are selected according to their relative tolerance to fire. Tree species in descending order of fire tolerance are: red (*Pinus resinosa*) and white pine (*P. strobus*), poplar (*Populus* spp.), sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*) or oak (*Quercus* spp.), lowland Scots pine (*Pinus sylvestris*), paper birch (*Betula papyrifera*), upland jack pine (*P. banksiana*) or Scots pine, and balsam fir (*Abies balsamea*) (species authorities are in appendix four). (b) Vitality. Few living and more dead and damaged trees are likely to remain following a fire disturbance. Residual tree condition in order of preference is: snags, dying trees, and living trees. Their location within the plot and aggregation is left to the discretion of the harvester, but it is suggested that spacing is optimized for machinery manoeuvrability and worker safety. An example of the spacing of residual trees can be seen in Figure 2.2 and Figure 2.32.3, for the Timmins and Petawawa sites respectively. These light detection and ranging (LiDAR) images come from the Canadian Institute of Forestry. The silvicultural system implemented in Petawawa was different from Timmins. The Petawawa location was harvested using a white pine shelterwood system. The uncut tall white pines in Petawawa can be seen in this image (within harvested plots outlined in red). Shelterwood systems involve the retention of mature trees in the overstory to shelter the regenerating understory. Once this regeneration becomes established, the shelter trees are often harvested (Canadian Forest Service 1995).

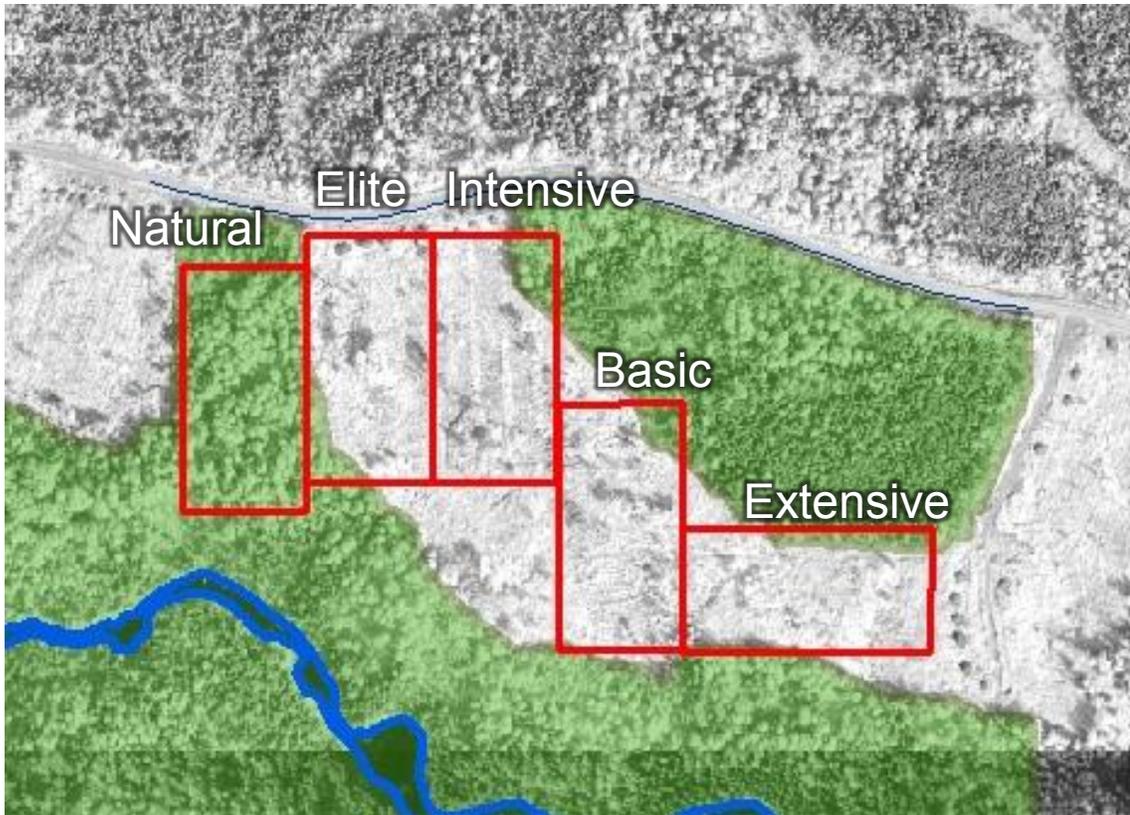


Figure 2.2: Timmins block one showing the density of residual trees in each plot. The dark blue line is a road segment, blue outlines the river, and green is the undisturbed forest. Image from 2005, three years after harvest.

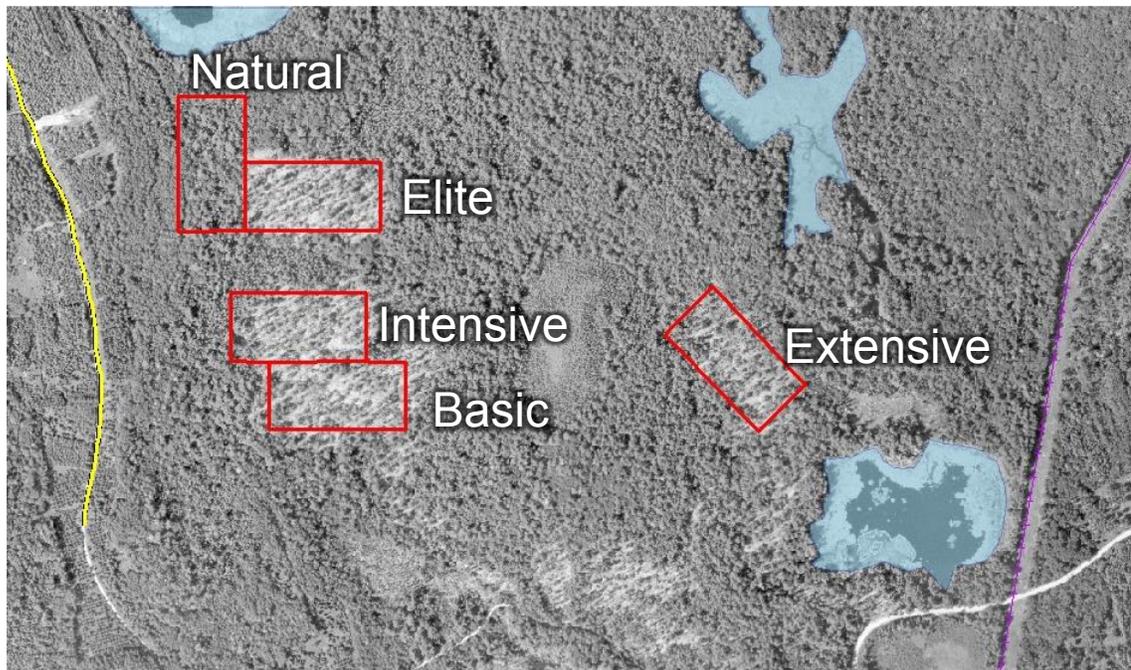


Figure 2.3: Petawawa block one showing the density of trees in each plot. Yellow line is the road, purple is the hydrowire and blue is the wetlands. Image from 2006, shortly after harvest.

Two of the eight NEBIE installation locations were chosen for this study. The first in Timmins and the second in Petawawa. These mixedwood sites were chosen as they are the forest types in greatest need of science-based policy development (Bell, personal communication), as most has been focused on boreal conifer systems in the past. They also represent mixedwood forests from the north and south of Ontario's planning area.

2.1.2 Timmins

The Timmins site is located at 48°21'N, 81°18'W (OMNRF unpublished data) just south of the town itself in the Lake Abitibi ecoregion (Crins et al. 2009). It receives an average of 558.3 mm of rain and 311 cm of snow annually, with an average January temperature of -16.8°C and July temperature of 17.5°C (Environment Canada 2014a). The forest cover is a mixedwood dominated by balsam fir, trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*), with a lesser presence of black spruce (*Picea mariana*) and paper birch

(OMNRF unpublished data). The pre-harvest stands were 85-90 years old. The plot layout is shown in Figure 2.42.4.

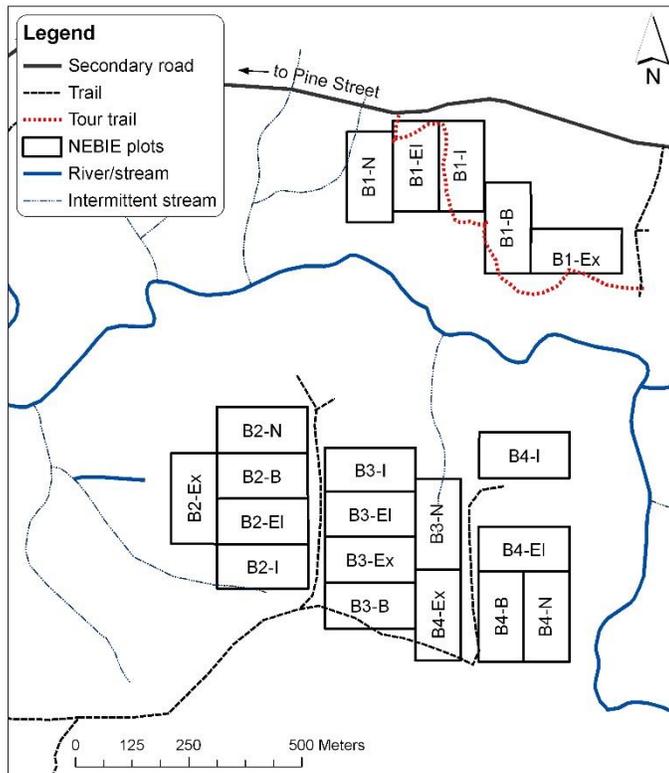


Figure 2.4: Timmins NEBIE plot layout. (OMNRF unpublished data).

Harvest at the Timmins location was completed in the fall of 2002, in 2003 Basic plots were trenched once and Intensive twice in a checkerboard pattern, and both intensities were planted with nursery trees (white spruce) in 2004. Herbicide treatments began in 2005 on the Basic plots with a backpack application of glyphosate to reduce resource competition for crop trees. The precision of a backpack sprayer allows the forester to target the understory vegetation competing with crop trees for resources while avoiding shrubs that could be browsed by moose (e.g. dogwood (*Cornus* spp.) or mountain ash (*Sorbus* spp.); OMNR 2010). Intensive plots were also sprayed, but it was applied in 27 m strips evenly distributed across the width of the plot, leaving approximately 4.5 m strips unsprayed. The resulting vegetation pattern can be seen in Figure 2.52.5. This procedure was repeated in Intensive plots in 2007. The sites were visited once

more in 2008 to plant more trees, white spruce to Basic block two and all Intensive plots (OMNRF unpublished data).



Figure 2.5: Picture taken in the summer of 2013 showing the effects of herbicide application in 27 m strips. The trees seen to the left and right of the image are regrowth since the time of harvest.

2.1.3 Petawawa

The Petawawa site is located at 45°58'N, 77°26'W (OMNRF unpublished) within the Petawawa Research Forest in the Georgian Bay ecoregion (Crins et al 2009). It receives an average of 682.2 mm of rain and 182 cm of snow annually, with an average January temperature of -11.8°C and July temperature of 20.3°C (Environment Canada 2014b). The forest cover is mixedwood dominated by white pine with a lesser presence of balsam fir black spruce, poplar species (*Populus* spp.), red maple (*Acer rubrum*), red pine, paper birch and white spruce. The pre-harvest stands were 79-112 years old (OMNRF unpublished data). The plot layout is illustrated in Figure 2.6.

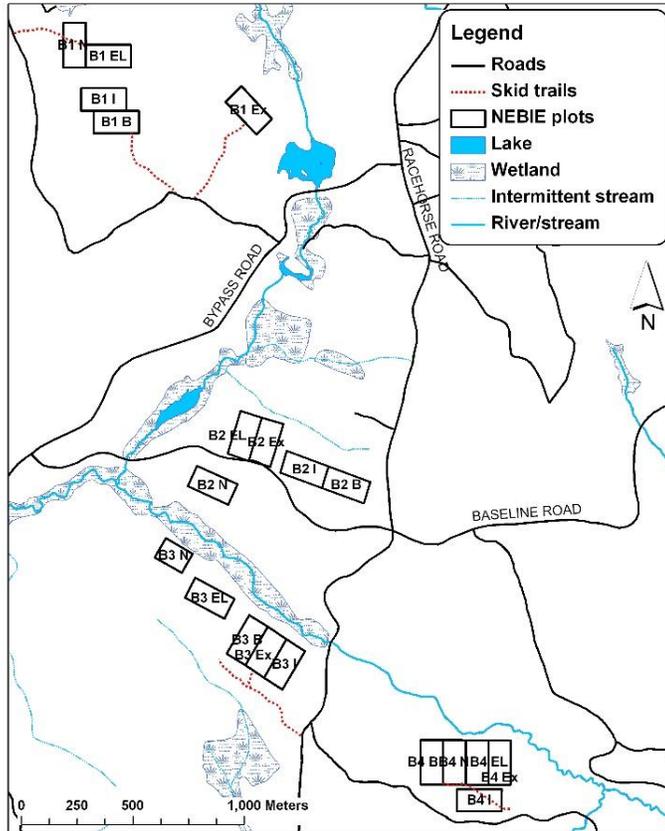


Figure 2.6: Petawawa NEBIE plot layout. (OMNRF unpublished data).

Harvest of the Petawawa location began in the fall of 2005 and ended in the winter of 2006. Foresters returned to the Basic and Intensive plots in 2007 for the ground application of “Vantage Plus Max” herbicide and collection of blowdown from a windstorm in the previous year. Vantage Plus Max is a glyphosate (dimethylamine salt, 480g/L) based herbicide used to clear herbaceous understory vegetation (Dow AgroSciences nd(a)). It was applied by a skidder with a back mounted sprayer that is approximately three meters above the ground. In 2008, white spruce seedlings were planted in block two. Block four Basic received a ground application of a 1% “Vision” herbicide solution from backpack sprayers. Vision is a glyphosate (isopropylamine salt, 356g/L) based herbicide created to control woody species competing with crop trees (Monsanto nd; Newmaster et al. 1999). The site was visited once more in 2010 when a 2% solution of “Release” was applied to Intensive plots using a backpack sprayer (OMNRF unpublished). Release is a triclopyr (butoxyethyl ester, 755g/L) based

herbicide used to control woody and herbaceous plants in managed forests (Dow AgroSciences nd(b); Newmaster et al. 1999).

2.2 Data collection

2.2.1 Tree and lichen survey

Residual trees were examined in the Natural, Intensive and Basic intensities of each of the four blocks in both sites. Ten trees from each two hectare plot were selected using a random number generator to determine the number of paces (1-50) to the tree to be surveyed. The same was done to determine direction (cardinal or intermediate). Forty experimental units (trees) were assessed per intensity at each location. Once a tree was selected, a Garmin GPSMAP 62st was set up at its base for no less than ten minutes to record the tree's coordinates and elevation. Ten minutes provided time for the waypoint averaging function to repeatedly measure the tree's coordinates (accurate on this device to 3 m) and produce the best estimate of the tree's location. Datasheets (Appendix one) were used to record the tree's species and diameter at breast height along with any unique tree features (e.g., no reachable branches or moss coverage at the base; when in the field, I noticed these attributes changed tree-to-tree and note was made in the case they were important to the discussion of results). DBH was measured using a diameter tape. Tree species were later categorized into trees of higher and lower bark pH as bark pH is an important variable for the colonization of many lichen species (Coppins 1984; van Herk 2001; Nash 2008). Micro- and macrolichen on each tree assessed were surveyed on the trunk from its base where it meets the soil to 2 m up the bole. All branches within this area were assessed and five branches above 2 m were cut off and assessed. The five cut branches were selected based on the limitations of the trimmer: no higher than 3.6 m and no thicker than 7 cm. Lichens were only surveyed in this zone on the tree, canopy lichen existed above the 3.6 m mark, but were not surveyed. Lichen species and abundance class were recorded. Lichen species were later

categorized by form (fruticose, foliose and crustose). For each specimen that could not be confidently identified in the field, multiple voucher samples were collected for laboratory identification. Specimens were dried in labeled paper bags for at least three days. Abundance was classified using a size chart (Appendix one) printed on overhead sheets which included five classes: class one = $<4 \text{ cm}^2$, class two = $4 \text{ cm}^2 < x < 36 \text{ cm}^2$, class three = $36 \text{ cm}^2 < x < 100 \text{ cm}^2$, class 4 = $100 \text{ cm}^2 < x < 200 \text{ cm}^2$, class 5 = $>200 \text{ cm}^2$. Specimen location on the tree was also recorded as follows: bottom = $<0.5 \text{ m}$ from where the trunk meets the ground, middle = $0.5 \text{ m} < x < 2 \text{ m}$ on trunk, top = above 2 m (i.e., the five cut branches). See Appendix one for example datasheet.

2.2.2 Lichen identification

Voucher specimens were identified, and form types classified, at the Biodiversity Institute of Ontario Herbarium using stereo and compound microscopes to observe morphological and chemical characteristics. Chemical compounds were determined using spot tests with para-phenylenediamine in ethyl alcohol, sodium hypochlorite, and 10 % potassium hydroxide (Brodo et al. 2001). Specimens that could not be reliably identified by morphology or spot tests were confirmed using thin-layer chromatography following Culberson and Kristinsson (1970) and Orange et al. (2001). Voucher specimens are stored at the Biodiversity Institute of Ontario Herbarium (OAC) at the University of Guelph, Ontario.

2.2.3 Proximity measurement for landscape features

Using aerial images, provided by the OMNRF and Tembec (a Canadian forest products company), natural and manmade features at each location were digitized. LiDAR data and digital images of Timmins in 2006 and enhanced forest resource inventory (eFRI) digital images of Petawawa in 2006 were used to do this at the resolution of the image ($\sim 1:800$).

In Timmins, these features were named “forest”, “road”, and “river”. Disturbance to the forest beyond Timmins plot boundaries during harvest was visible in the 2006 images (Figure 2.2). The forest beyond this disturbed area was designated

as the “forest” feature. No such disturbance was visible in the Petawawa images, so the “forest” feature was not digitized. The “road” feature was digitized from the edges of local roads larger than skid trails. None of these roads were paved and were generally used seasonally by hunters, recreational riders and harvesters. The “river” feature was digitized from the banks of rivers at the Timmins location. Petawawa’s features were named “road”, “hydrowire” and “wetland”. The “road” feature was similar to Timmins in that it is single lane dirt and gravel road, but is used by the research forest workers and not hunters. The “hydrowire” feature was defined by the edge of the area cleared of trees under the lines. The “wetland” feature was defined by the treeless edge of the wet area surrounding the river.

Plot edge shapefiles were overlain on areal images to outline the plots. These were provided by the OMNRF and are accurate to 15 m. The Near tool in ArcMAP 10.1 was used to determine the distance from each surveyed residual tree to the nearest point on natural and manmade features in the stand.

2.3 Data Analysis

2.3.1 Univariate

R version 3.1.0 and R studio were used to organise the data and determine the species richness per tree. The calculation of descriptive statistics and analysis of variance were completed in IBM SPSS statistics version 21. An alpha of 0.05 was used in all tests. One-sample Kolmogorov-Smirnov tests were used to identify normality in the distribution of all continuous variables. These variables are lichen species richness per tree, the number of species in each abundance class (1-5), the number of species of each form (fruticose, foliose and crustose), tree DBH and the nearest distance from each tree to stand features. The null hypothesis of the variables following a normal distribution was not met, for all but Timmins tree DBH ($p = 0.086$), distance from Timmins trees to the nearest river ($p = 0.812$), lichen species richness on trees in Petawawa ($p = 0.053$), distance from Petawawa trees to the nearest road ($p = 0.572$); therefore nonparametric

tests were employed. Kruskal-Wallis tests were used to identify significant differences in richness, number of species in each abundance class, and number of species for each form per tree, when exposed to a different intensity and when found on different tree species. If a significant difference was found, the causal groups were identified through pairwise comparisons following Dunn's procedure (1964) based on rank sums, created just for this purpose. For the continuous independent variables, tree DBH and distance to habitat features, Spearman's rank coefficient was used to determine if there is a monotonic relationship between these and the dependant variables. A rejection of the null hypothesis means that there is evidence of a relationship between the independent and dependant variables where an increase in the independent variable results in either an increase or decrease in the dependant variable (e.g. linear or quadratic).

2.3.2 Multivariate

CANOCO 4.5 was used to complete a multivariate analysis of the data. This analysis was used to identify variation in lichen community composition on residual trees and the environmental variables that could explain this variation in each location. Two matrices were constructed for each location. The species matrix contained all species identified at the location in columns and all trees in rows with the abundance class of the lichen species found on that tree in the intersect. There were 117 columns for Timmins and 130 for Petawawa and 120 rows for both locations. The environmental variable matrix contained the same number of rows with a residual tree for each and the corresponding environmental variables in columns. For Timmins these variables were; block, intensity, tree bark type (a column for high and low bark pH), elevation (to the nearest meter), DBH (to the nearest half centimeter), UTM easting and northing, and distance to road, forest and river. For Petawawa these variables were; block, intensity, tree bark type, elevation, DBH, UTM easting and northing, and distance to road, hydrowire and wetland.

Analysis began with a principal component analysis (PCA; Pearson 1901; ter Braak 1998) to determine the length of the ordination axis and whether a linear or curvilinear model should be used. The assumptions of PCA were violated for both locations as the length of the primary axis was greater than three and a half standard deviations (SD) in Timmins and greater than four and a half SD in Petawawa. It was therefore suitable to use a canonical correspondence analysis (CCA; ter Braak 1986) to study the variation in lichen community composition of residual trees. The direct ordination finds patterns in community variation that can be best explained by the environmental variables, producing an ordination where trees are points in space defined by their axis scores and a bi-plot with an arrow for each environmental variable.

CHAPTER THREE

Results

3.1 Lichen species richness

Eight hundred and thirty-nine lichen specimens were collected in Timmins, resulting in 117 identified species. Fifty-two of these species were not found at the Petawawa location. Eight hundred and seventy-seven lichen specimens were collected in Petawawa, resulting in 130 identified species. Seventy-one of these were not found in Timmins. Sampling effort is illustrated in the species accumulation curves with gradually decreasing slopes (Figure 3.1 and Figure 3.2).

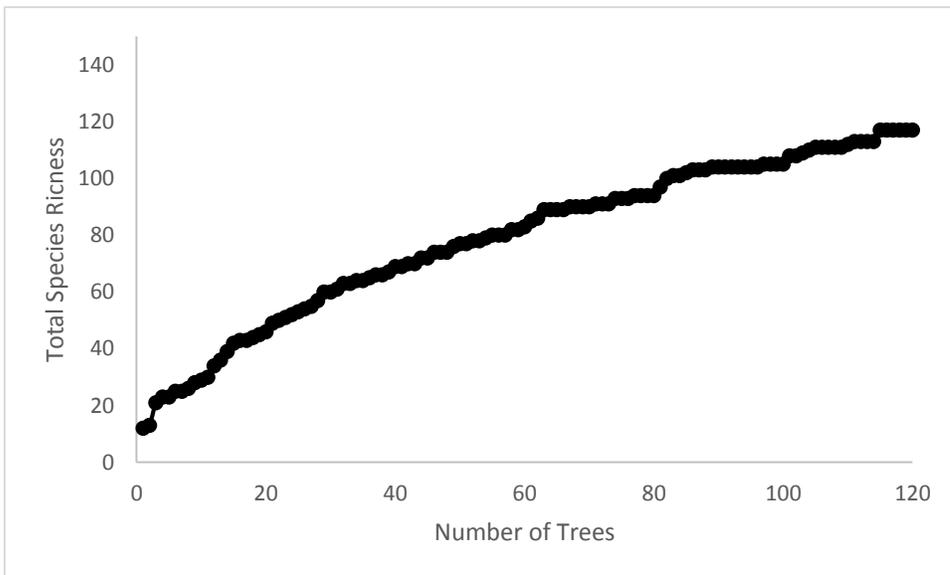


Figure 3.1: Species accumulation curve for all 120 residual trees from Timmins, Ontario.

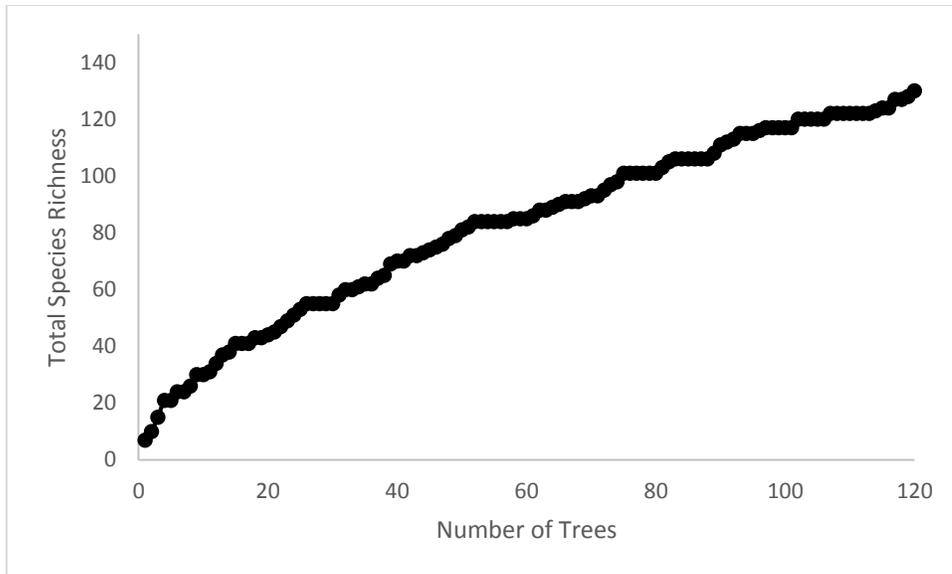


Figure 3.2: Species accumulation curve for all 120 residual trees surveyed in Petawawa, Ontario.

Species of all lichen form types were found in each location. Twenty-seven fruticose, 25 foliose and 65 crustose species were found in Timmins. In Petawawa, there were 30 fruticose, 37 foliose and 63 crustose species. The number of species found per tree ranged from one to nineteen in Timmins and one to fifteen in Petawawa. Over half of species found in both locations were present on fewer than ten of the 120 trees. Only two species in Timmins were found on at least half of all trees; *Parmelia sulcata* (60 trees) and *Lepraria* spp. (61 trees). One lichen species in Petawawa was found on more than half of trees; *Lecanora thysanophora* (67 trees). See Table 3.13.1 for the number of lichen species and average lichen species richness per tree found in each intensity in each location.

Table 3.1: Number of total lichen species found and the average lichen species richness with standard deviation in brackets per tree in each intensity in each location.

Location	Intensity	Number of species	Average richness/tree
Timmins	Natural	70	8.5 (4.8)
	Basic	55	5.8 (4.6)
	Intensive	64	6.5 (4.5)
Petawawa	Natural	65	7.4 (3.6)
	Basic	71	7.3 (3.5)
	Intensive	73	7.3 (3.5)

No species of provincial or national concern were found in either location, but a species relatively new to the province (*Cladonia norvegica*; Schram et al. 2013; McMullin and Lewis 2014) was collected from the base of four trees in Petawawa.

3.2 Tree species richness

Ten tree species were surveyed in Timmins; six in the higher bark pH category: ash (*Fraxinus* spp.), balsam poplar, big-toothed aspen, paper birch, poplar, and trembling aspen, and four in the lower bark pH category: balsam fir, black spruce, red pine, , and white spruce. Their DBH ranged from 10 to 72 cm with an average of 29.5 cm and their elevation ranged from 303 to 308 meters above sea level. Fifteen tree species were surveyed in Petawawa; ten in the higher bark pH category: balsam poplar, black ash, maple, mountain maple, paper birch, poplar, red maple, red oak, sugar maple and trembling aspen, and five in the lower bark pH category: balsam fir, black spruce, red pine, white pine and white spruce. Their DBH ranged from 11 cm to 81.5 cm with an average of 31.5 cm and their elevation ranged from 49 to 69 meters above sea level. See tables in appendix two for more detailed tree data from Timmins and Petawawa.

3.3 Variable distribution

In the data collected from Timmins, the distribution of tree DBH, the number of species per tree in all abundance classes (1-5), the number of species per tree of each form type (fruticose, foliose and crustose), and the distance between each tree and hydrowires and wetland areas were not normal ($\alpha=0.05$). Only lichen species richness per tree and distance from each tree to the road were normally distributed. In Petawawa, the distribution of lichen species richness per tree, the number of species per tree in all abundance classes (1-5), the number of species per tree of each form type (fruticose, foliose and crustose), and the distance between each tree and the road and forest were not normal ($\alpha=0.05$). Only tree DBH and the distance to the river were normally distributed.

The overall shape of the distributions of the continuous variables at both sites was the same; generally positively skewed with a negative kurtosis.

3.4 Kruskal-Wallis test results

3.4.1 Lichen richness between intensities

In Timmins, there was a significant difference in the median lichen species richness per tree among silvicultural intensities ($p=0.36$; Figure 3.3.3). Trees exposed to the Basic intensity had significantly lower lichen species richness compared to those in the Natural intensity ($p=0.37$). The same was not found in Petawawa. The lichen species richness per tree was the same in all silvicultural intensities ($p=0.999$) in Petawawa (Figure 3.4.3.4).

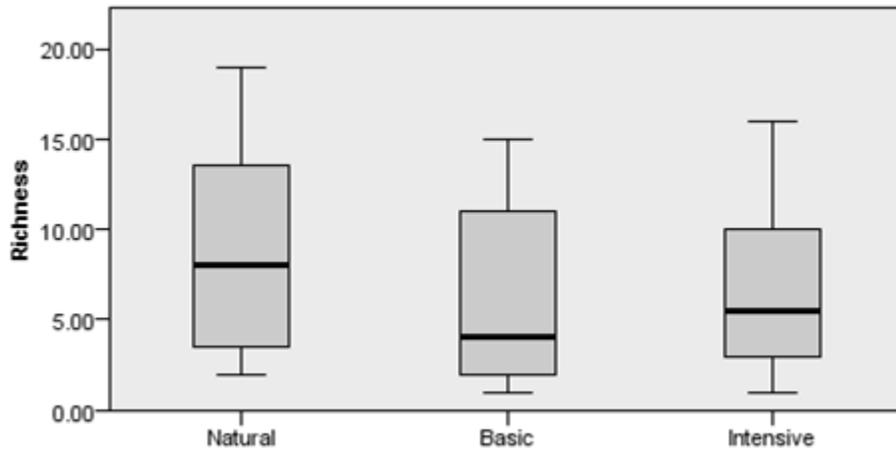


Figure 3: Box plot of lichen species richness per tree by silvicultural intensity in Timmins.

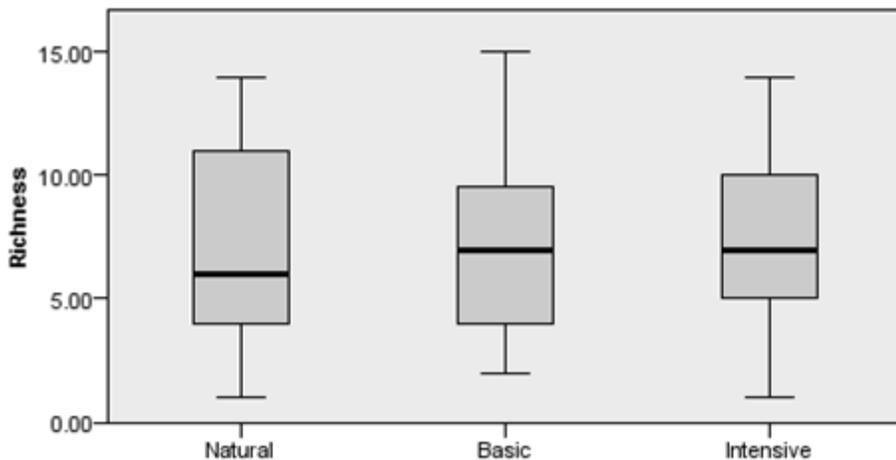


Figure 3.4: Box plot of lichen species richness per tree by silvicultural intensity in Petawawa.

3.4.2 Lichen abundance class between intensities

The Natural intensity in Timmins had significantly more species in abundance class 2 per tree than those in the Basic intensity ($p=0.026$). The number of species in all other abundance classes was unchanged by intensity. In Petawawa, the number of species in all abundance classes was also unchanged by intensity.

3.4.3 Lichen form between intensities

The number of fruticose and foliose species per tree did not change with intensity in Timmins. Trees within the Natural intensity had significantly more crustose species per tree than those in either the basic ($p < 0.0001$) or intensive ($p = 0.005$) intensities.

In Petawawa, the number of foliose and crustose species per tree did not change with intensity. There were significantly more fruticose species present per tree in Basic when compared to Natural intensities ($p = 0.033$).

3.4.4 Lichen richness between tree species

Lichen species richness per tree was not the same for all tree species in Timmins ($p < 0.0001$), though it was constant for red pine, ash and big-tooth aspen. Balsam fir had a significantly higher richness than other poplar species ($p = 0.001$), trembling aspen trees ($p = 0.001$) and paper birch ($p = 0.005$). White spruce had a significantly higher richness than poplar species ($p = 0.001$), trembling aspen ($p = 0.001$), and paper birch ($p = 0.005$). Black spruce had a significantly higher richness than trembling aspen ($p = 0.002$), other poplar species ($p = 0.002$), and paper birch ($p = 0.005$).

In Petawawa, lichen species richness per tree was not the same for all tree species ($p < 0.0001$), though it was constant for amur maple, balsam poplar and other poplar species. Balsam fir had significantly higher richness per tree than red maple ($p < 0.0001$) and sugar maple ($p < 0.0001$). White pine had significantly higher richness per tree than red maple ($p = 0.005$) and sugar maple ($p = 0.001$).

3.4.5 Lichen abundance class between tree species

In Timmins, significant differences in the number of species in an abundance class across tree species was found in abundance class one ($p < 0.0001$), two ($p < 0.000$), three ($p < 0.0001$) and four ($p = 0.012$). The number of species in abundance class one per tree was significantly greater on balsam fir than trembling aspen ($p = 0.001$), other poplar species ($p = 0.001$), and paper birch

($p=0.013$). The same was true of black spruce compared to trembling aspen ($p=0.004$), other poplar species ($p=0.002$), and paper birch ($p=0.041$). White pine have a greater number of species in abundance class one per tree than trembling aspen ($p=0.008$) and other poplar species ($p=0.008$). White pine also have a significantly greater number of species in abundance class two per tree than trembling aspen ($p=0.005$) and paper birch ($p=0.005$). Both balsam fir and black spruce have a greater number of species in abundance class three per tree than other poplar species ($p=0.009$; $p=0.032$). None of the pairwise comparisons for abundance class four and tree species were significant.

In Petawawa, significant differences in the number of species in an abundance class across tree species was found in abundance class one ($p=0.001$), two ($p<0.000$), and three ($p=0.012$). Balsam fir had significantly more species in abundance class one than either red or sugar maple ($p=0.032$, $p<0.0001$ respectively). Balsam fir and white pine have significantly more individuals in abundance class 2 than maple trees ($p=0.043$, $p=0.033$ respectively). None of the pairwise comparisons from abundance class three were significantly different.

3.4.6 Lichen form and tree species

In Timmins, there were differences across tree species in the number of species of fruticose ($p<0.0001$), foliose ($p<0.0001$), and crustose ($p<0.0001$) lichen per tree. Balsam fir had a greater number of fruticose species per tree than *Populus* sp. ($p<0.0001$). White pine also had a greater number of fruticose species per tree than *Populus* sp. ($p<0.0001$), but also more than balsam poplar ($p=0.017$) and trembling aspen ($p=0.004$). Black spruce had more fruticose species than trembling aspen ($p=0.033$) and *Populus* sp. ($p<0.0001$). Lastly, paper birch also had more than *Populus* sp. ($p=0.031$). Balsam fir had a greater number of foliose species per tree than *Populus* sp. ($p<0.0001$), trembling aspen ($p=0.011$), and paper birch ($p=0.006$). The same was true of white and black pine when compared to *Populus* sp. ($p<0.0001$; $p<0.0001$), trembling aspen ($p=0.015$; $p=0.017$), and paper birch ($p=0.008$; $p=0.008$). Balsam fir had a greater number of crustose species per tree than trembling aspen ($p=0.023$) and paper birch

($p=0.001$). *Populus* sp. also had more crustose species than paper birch ($p=0.006$).

Similarly in Petawawa, there were significant differences across tree species in the number of species of fruticose ($p<0.0001$), foliose ($p<0.0001$), and crustose ($p<0.0001$) lichen per tree. White pine had a significantly greater number of fruticose lichen than both red and sugar maple trees ($p=0.001$ and $p<0.0001$ respectively). White pine had a significantly greater number of foliose lichens per tree than both red and sugar maple ($K=45.09$, $p=0.020$ and $K=37.91$, $p=0.016$ respectively). Balsam fir also had significantly more foliose lichens per tree than red maple ($K=44.93$, $p=0.048$). Balsam fir had a significantly greater number of crustose lichens per tree than both red and white pine ($K=-81.47$, $p<0.001$ and $K=-52.56$, $p<0.001$ respectively).

3.5 Spearman's correlation results

The continuous explanatory variables were correlated with lichen richness, abundance and form to yield some significant relationships. In Timmins, there was a significant negative relationship between tree DBH and the number of lichen in abundance class one ($\rho=-0.247$, $p=0.007$) and number of foliose lichen per tree ($\rho=-0.233$, $p=0.01$). There was a significant negative relationship between the distance to the road and the number of lichen in abundance class four per tree ($\rho=-0.180$, $p=0.049$). There was a significant negative relationship between the distance from the tree to the forest edge and lichen richness ($\rho=-0.223$, $p=0.015$), the number of lichen in abundance class two ($\rho=-0.208$, $p=0.023$), and the number of crustose species ($\rho=-0.348$, $p<0.0001$). All other correlations, including all with distance to river, were insignificant.

In Petawawa, there was a significant positive relationship between DBH and the number of lichen per tree in the third abundance class ($\rho=0.194$, $p=0.034$), the number of lichen per tree in the fifth abundance class ($\rho=0.34$, $p<0.0001$) and the number of fruticose species per tree ($\rho=0.489$, $p<0.0001$). There was a significant negative relationship between tree DBH and the number of crustose

species per tree ($\rho=-0.388$, $p<0.0001$). All other correlations, including all distance measures, were not significant.

3.6 Canonical correspondence analyses

The relationships between lichen species, residual trees and environmental variables were interpretable in the canonical correspondence analysis (CCA) for both locations. See Table 3.23.2 for the sampling statistics and Figure 3.5 for the ordination for Timmins and Table 3.3 and Figure 3.6 for Petawawa. The tree's block was used as a covariate in the analysis, and the intensity variable was not found to explain any of the variation in lichen community composition in either location ($p<0.001$ for both), so it was removed from the analysis. Four outliers had to be removed from each location's ordination. Residual tree numbers 128, 135, 166 and 230 were removed from the Timmins analysis, and 21, 64, 72 and 90 were removed from the Petawawa analysis. The presence of

Table 3.2: Sampling statistics for variables used in canonical correspondence analysis (CCA) of 116 trees, 117 lichen species, and 9 environmental variables in Timmins, Ontario. t -values >1.725 are significant at $p<0.05$ and indicate important canonical coefficients (ter Braak, 1998). These have been underlined in the below table.

Variable	Inter set correlations		Canonical coefficient		t -value	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Low bark pH	-0.8538	-0.0027	<u>-0.9349</u>	<u>0.1789</u>	<u>-14.7902</u>	<u>3.8431</u>
High bark pH	0.8538	0.0027	<u>0.8212</u>	0.1581	<u>2.9038</u>	0.7254
Elevation (m)	-0.1567	-0.2248	-0.0728	-0.0658	-1.0251	-1.2589
DBH (cm)	0.4712	0.3626	<u>0.1860</u>	<u>0.2855</u>	<u>2.8759</u>	<u>5.9924</u>
North	0.0167	-0.0691	-0.8944	<u>-4.5107</u>	-0.4164	<u>-2.8514</u>
East	-0.0192	0.0245	-0.1256	0.0793	-0.8593	0.7372
Distance to forest	0.0207	0.5943	<u>-0.1608</u>	<u>0.4101</u>	<u>-2.2584</u>	<u>7.8190</u>
Distance to road	-0.0139	0.0589	-1.0245	<u>-4.5257</u>	-0.4785	<u>-2.8703</u>
Distance to river	0.0416	0.1734	0.0913	0.1420	0.7663	1.6182

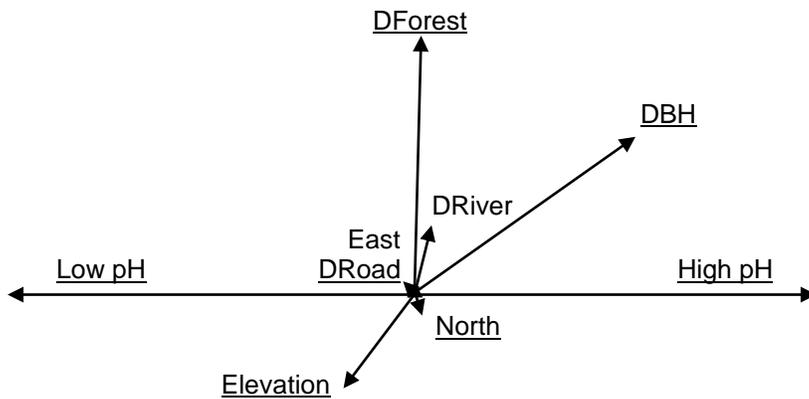
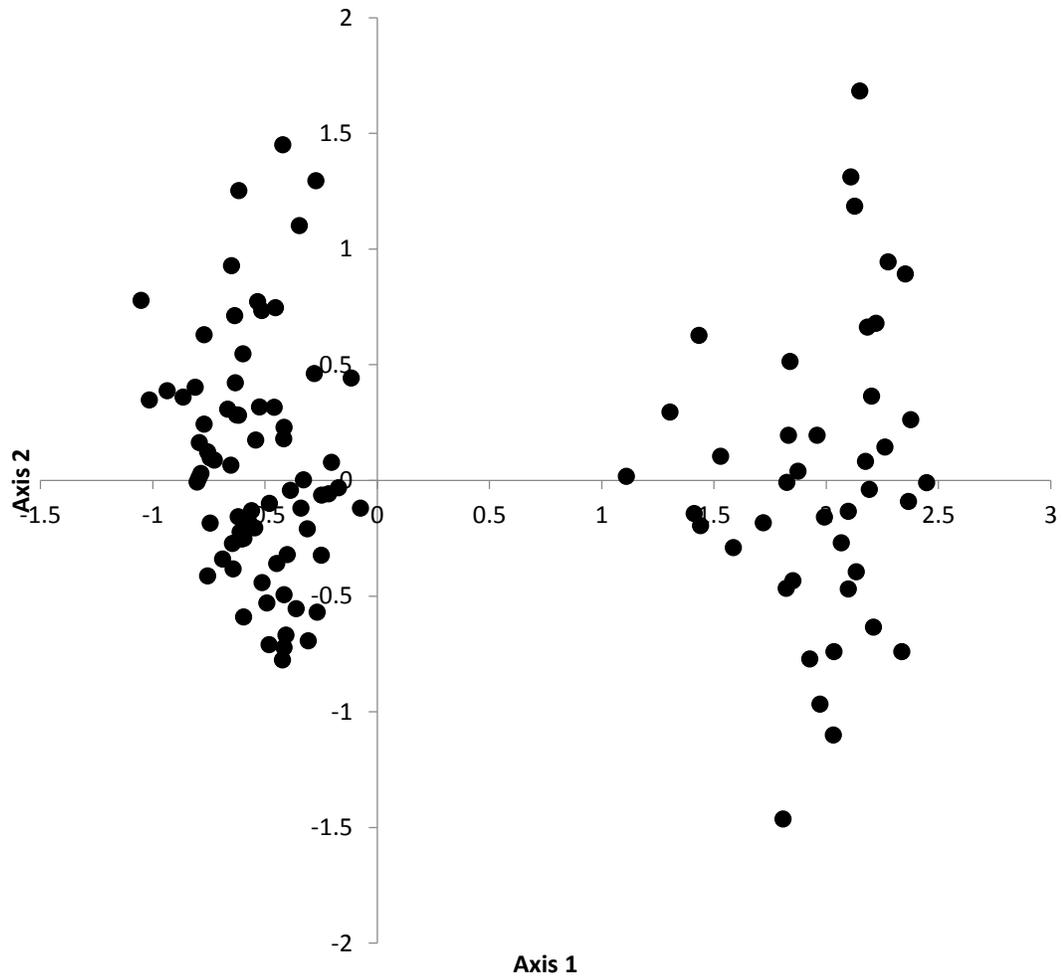


Figure 4: CCA ordination of 117 lichen species and 116 residual trees from Timmins constrained by nine environmental variables in the below bi-plot diagram. Each point represents a tree. Points closer together have similar lichen species composition than those farther apart. Variable names underlined in bi-plot are significantly correlated.

Table 3.3: Sampling statistics for variables used in canonical correspondence analysis (CCA) of 116 trees, 130 lichen species, and 9 environmental variables in Petawawa, Ontario. t-values > 1.725 are significant at p < 0.05 and indicate important canonical coefficients (ter Braak, 1998). These have been underlined in the below table.

Variable	Inter set correlations		Canonical coefficient		t-value	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Low bark pH	-0.8316	0.0165	<u>-1.1429</u>	<u>-0.1631</u>	<u>-16.3484</u>	<u>-2.0381</u>
High bark pH	0.8316	-0.0165	1.0255	0.1138	3.7355	1.1200
Elevation (m)	0.1819	0.1215	<u>0.1688</u>	<u>0.2961</u>	<u>1.8079</u>	<u>2.7697</u>
DBH (cm)	-0.1434	0.3052	<u>-0.1566</u>	<u>0.3851</u>	<u>-2.3106</u>	<u>4.9631</u>
North	-0.1716	0.0302	0.7132	<u>-1.4493</u>	1.3139	<u>-2.3323</u>
East	0.3321	-0.3925	<u>1.0370</u>	-0.2922	<u>4.3897</u>	-1.0803
Distance to road	-0.1219	0.7073	<u>0.3312</u>	<u>0.9992</u>	<u>3.4416</u>	<u>9.0686</u>
Distance to hydrowire	-0.0692	-0.1239	<u>-0.3888</u>	0.1838	<u>-2.5033</u>	1.0338
Distance to wetland	0.0463	-0.3133	0.1455	<u>-0.3174</u>	1.1982	<u>-2.2833</u>

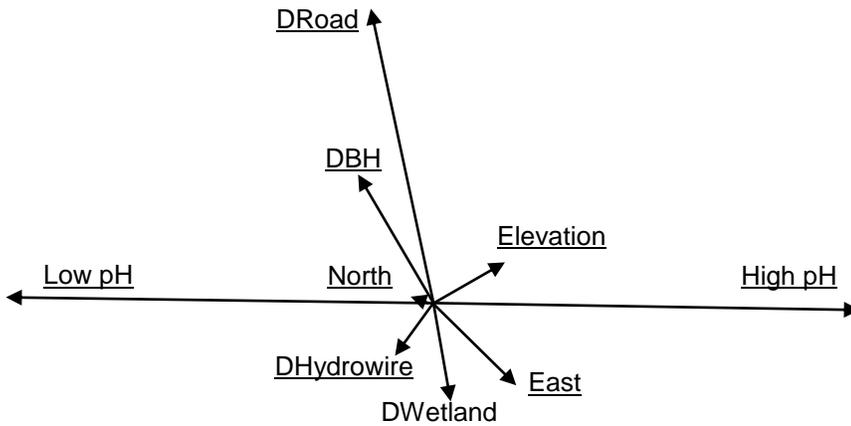
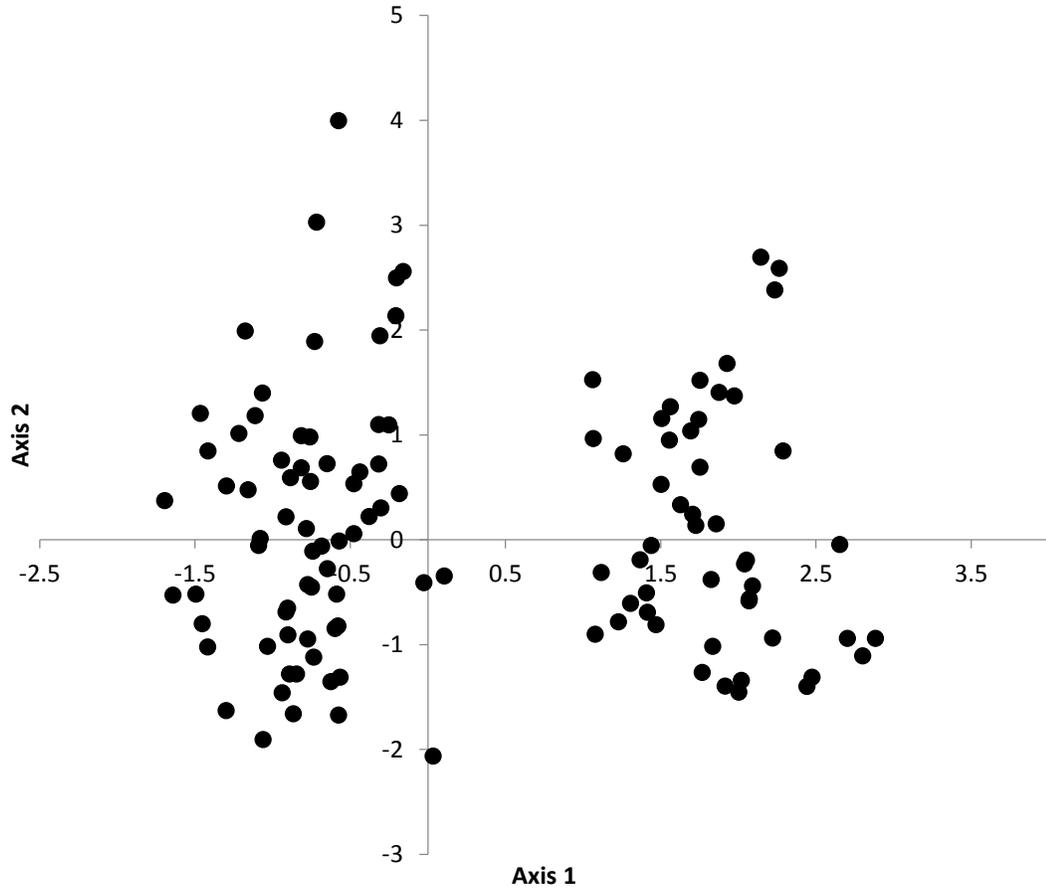


Figure 5: CCA ordination of 130 lichen species and 116 residual trees from Petawawa constrained by nine environmental variables in the below bi-plot diagram. Each point represents a tree. Points closer together have similar lichen species composition than those farther apart. Variable names underlined in bi-plot are significantly correlated.

The length of the primary and secondary axis in the Timmins ordination is 3.5 SD and 3.1 SD respectively. This indicates considerable variation in Timmins lichen community composition. The same is true in the Petawawa ordination where the primary axis covers 4.5 SD and the secondary covers 6.1 SD.

The correlation between environmental variables and ordination axis were high in both sites and accounted for 51.2% and 42.6% of the variation in the primary and secondary axis in Timmins and Petawawa respectively (Tables 3.4 and 3.5).

Table 3.4: Summary of canonical correspondence analysis (CCA) of 116 trees, 117 lichen species, and 9 environmental variables in Timmins.

Axis	1	2	3	4
Eigenvalue	0.515	0.210	0.160	0.136
Species/environment correlation	0.873	0.772	0.719	0.764
Cumulative % variance of species data explained	36.3	51.2	62.5	72.1

Table 3.5: Summary of canonical correspondence analysis (CCA) of 116 trees, 130 lichen species, and 9 environmental variables in Petawawa, Ontario.

Axis	1	2	3	4
Eigenvalue	0.388	0.222	0.178	0.166
Species/environment correlation	0.880	0.820	0.814	0.794
Cumulative % variance of species data explained	27.1	42.6	55.1	66.7

The two distinct groups along axis one seen in both Figures 3.5 and 3.6 are created by the differences in community composition between lichens of trees with higher and lower bark pH. This can be read from the bi-plot inset in each ordination. The length of the arrow indicates the relative explanatory strength an environmental variable. The arrows point to the area of the ordination space where you will find trees defined by a greater value of that environmental variable. For example, looking to the Timmins ordination and bi-plot, those points closer to the top right of the ordination space will represent trees with greater DBHs than those to the bottom left. In Timmins, 85 lichen species were found on low bark pH trees, 56 of which are not found on high bark pH trees in the same location. Of those species unique to low bark pH trees, 16 are fruticose and 16 are foliose. Fifty lichen species were found on high bark pH trees, with only 21

not found on low bark pH trees. Of these 21 species, four are foliose, all others were crustose. The mean lichen species richness per tree on low bark pH trees (8.8) is significantly greater than that on high bark pH trees (4.1; $p=5.4 \times 10^{-8}$). In Petawawa, 104 lichen species were found on low bark pH trees, 63 of which were not found on high bark pH trees in the same location. Sixty-six lichen species were found on low bark pH trees, with only 25 found on high bark pH trees. Of these 25 species, 2 are fruticose, 7 foliose, and the rest are crustose. The average species richness per tree on low bark pH trees (9.2) is significantly greater than that on high bark pH trees (5.0; $p=4.1 \times 10^{-12}$).

The lichen species composition of Timmins trees at the extremes of the tree bark type (Table 3.6 and Figure 3.7), DBH (Table 3.7 and Figure 3.8) and distance to forest (Table 3.8 and Figure 3.9) variables are listed below with their form and abundance class. These are the environmental variables most strongly correlated with lichen community composition at this location. Extremes were determined by the variable value not ordination scores to illustrate where the extreme variable values lay on the ordination space.

Table 3.6: Lichen species composition, abundance and form for Timmins trees at the extremes of the tree bark type (low vs. high bark pH) gradient.

Environmental Gradient	Tree Number	Species List	Abundance	Form
High bark pH trees	222	<i>Gyalolechia xanthostigmoidea</i>	5	crustose
		<i>Lecanora</i> spp.	2	crustose
	140	<i>Cladonia ochrochlora</i>	2	fruticose
		<i>Cladonia chlorophaea</i>	2	fruticose
		<i>Lecanora allophana f. sorediata</i>	2	crustose
	226	<i>Lecanora allophana</i>	4	crustose
		<i>Biatora</i> spp.	1	crustose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		<i>Bilimbia cf. sabuletorum</i>	2	crustose
	197	<i>Caloplaca pyracea</i>	2	crustose
		<i>Lepraria</i> spp.	1	crustose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		Species 11*	1	crustose
	168	<i>Lepraria</i> spp.	2	crustose
		<i>Cladonia</i> spp.	2	fruticose
		<i>Lecanora cirumborealis</i>	3	crustose
<i>Biatora vernalis</i>		3	crustose	
Low bark pH trees	133	<i>Hypogymnia physodes</i>	1	foliose
		<i>Buellia erubescens</i>	1	crustose
		<i>Evernia mesomorpha</i>	1	fruticose
		<i>Phycia adscendens</i>	1	foliose
		<i>Scoliciosporum chlorococcum</i>	1	crustose
	127	<i>Hypogymnia physodes</i>	1	foliose
		<i>Buellia erubescens</i>	1	crustose
	126	<i>Parmelia sulcata</i>	4	foliose
		<i>Evernia mesomorpha</i>	2	fruticose
		<i>Coenogonium luteum</i>	1	crustose
		<i>Rinodina</i> spp.	1	crustose
	218	<i>Lepraria</i> spp.	1	crustose
	191	<i>Usnea cf. scabrata</i>	4	fruticose
		<i>Hypogymnia physodes</i>	2	foliose
		<i>Parmelia sulcata</i>	3	foliose
		<i>Lecanora symmicta</i>	1	crustose
<i>Buellia erubescens</i>		2	crustose	
<i>Lepraria</i> spp.		2	crustose	
<i>Bryoria furcellatta</i>		1	fruticose	
<i>Evernia mesomorpha</i>		3	fruticose	

	<i>Lecanora allophana</i> f. <i>sorediata</i>	1	crustose
	<i>Lecania croatica</i>	1	crustose

*Crustose lichen resembling a species of *Rinodina*, but could not be confirmed.

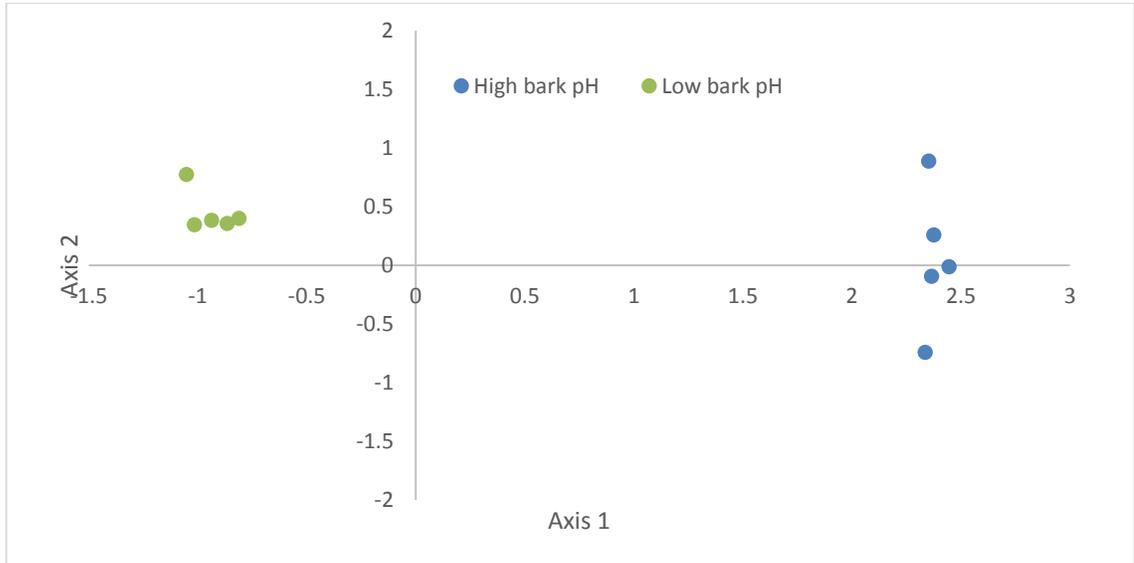


Figure 6: Location of the five points at either end of the tree bark type gradient in Timmins. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

Table 3.7: Lichen species composition, abundance and form for Timmins trees at the extremes of the tree DBH gradient.

Environmental Gradient	Tree Number	Species List	Abundance	Form
Smaller trees	137	<i>Cladonia ochrochlora</i>	3	fruticose
		<i>Parmelia sulcata</i>	3	foliose
		<i>Bryoria furcellatta</i>	1	fruticose
		<i>Lecanora symmicta</i>	1	crustose
		<i>Evernia mesomorpha</i>	4	fruticose
		<i>Usnea hirta</i>	1	fruticose
		<i>Melanelixia subaurifera</i>	2	foliose
		<i>Tuckermannopsis americana</i>	1	foliose
		<i>Hypogymnia physodes</i>	2	foliose
		<i>Lecanora pulicaris</i>	1	crustose
		<i>Hypogymnia tubulosa</i>	1	foliose
	191	<i>Usnea</i> cf. <i>scabrata</i>	4	fruticose
		<i>Hypogymnia physodes</i>	2	foliose
<i>Parmelia sulcata</i>		3	foliose	

		<i>Lecanora symmicta</i>	1	crustose
		<i>Buellia erubescens</i>	2	crustose
		<i>Lepraria</i> spp.	2	crustose
		<i>Bryoria furcellatta</i>	1	fruticose
		<i>Evernia mesomorpha</i>	3	fruticose
		<i>Lecanora allophana</i> f. <i>sorediata</i>	1	crustose
		<i>Lecania croatica</i>	1	crustose
	127	<i>Hypogymnia physodes</i>	1	foliose
		<i>Buellia erubescens</i>	1	crustose
	133	<i>Hypogymnia physodes</i>	1	foliose
		<i>Buellia erubescens</i>	1	crustose
		<i>Evernia mesomorpha</i>	1	fruticose
		<i>Physcia adscendens</i>	1	foliose
		<i>Scoliciosporum chlorococcum</i>	1	crustose
229	<i>Buellia erubescens</i>	2	crustose	
Larger trees	181	<i>Lepraria</i> spp.	1	crustose
		<i>Parmelia sulcata</i>	2	foliose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		<i>Xanthoria</i> spp.	1	foliose
		<i>Cladonia fimbriata</i>	2	fruticose
		<i>Caloplaca pyracea</i>	1	crustose
		<i>Lecanora albula</i>	1	crustose
	197	<i>Caloplaca pyracea</i>	2	crustose
		<i>Lepraria</i> spp.	1	crustose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		Species 11*	1	crustose
	187	<i>Caloplaca pyracea</i>	1	crustose
		<i>Leptogium hirsutum</i>	3	foliose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		<i>Lecanora allophana</i> f. <i>sorediata</i>	1	crustose
	212	<i>Buellia erubescens</i>	3	crustose
		<i>Lecanora allophana</i> f. <i>sorediata</i>	2	crustose
		<i>Caloplaca pyracea</i>	2	crustose
		<i>Cladonia</i> spp.	4	fruticose
	132	<i>Vulpicidia pinastris</i>	2	foliose
		<i>Cladonia ochrochlora</i>	1	fruticose
		<i>Gyalolechia xanthostigmoidea</i>	2	crustose
		<i>Melanelixia subaurifera</i>	1	foliose
		<i>Cladonia chlorophaea</i>	2	fruticose
		<i>Cladonia</i> spp.	1	fruticose

*Crustose lichen resembling a species of *Rinodina*, but could not be confirmed.

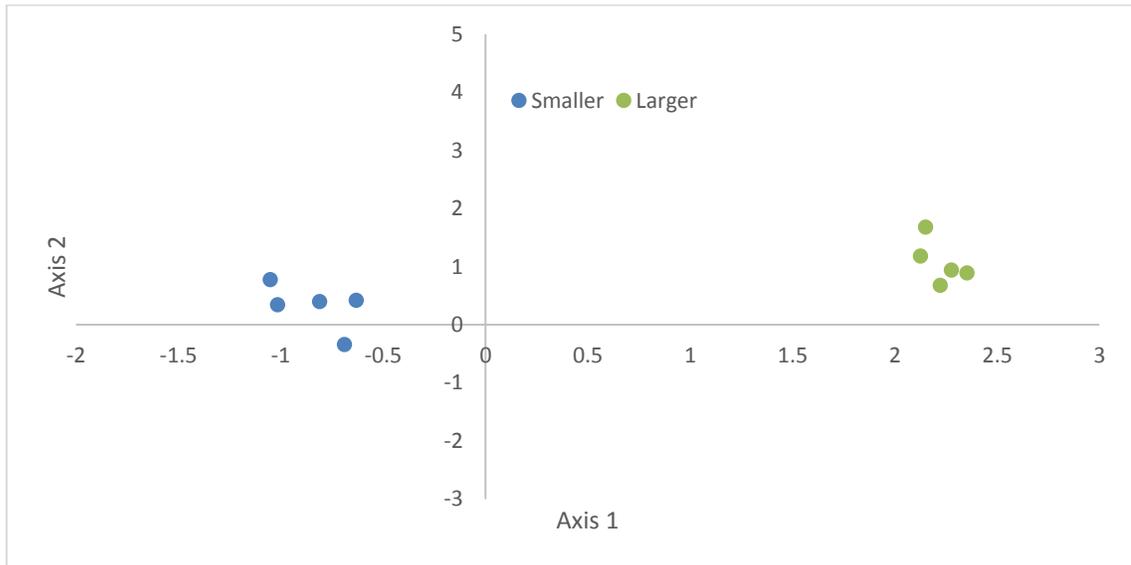


Figure 7 Five largest and smallest Timmins trees (based on DBH) are highlighted in the ordination space. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

Table 1 Lichen species composition, abundance and form for Timmins trees at the extremes of the distance to forest gradient.

Environmental Gradient	Tree Number	Species List	Abundance	Form
Closer trees	140	<i>Cladonia ochrochlora</i>	2	fruticose
		<i>Cladonia chlorophaea</i>	2	fruticose
		<i>Lecanora allophana f. sorediata</i>	2	crustose
	168	<i>Lepraria</i> spp.	2	crustose
		<i>Cladonia</i> spp.	2	fruticose
		<i>Lecanora cirumborealis</i>	3	crustose
		<i>Biatora vernalis</i>	3	crustose
	148	<i>Cladonia ochrochlora</i>	2	fruticose
		<i>Parmelia</i> spp.	2	foliose
		<i>Gyalolechia xanthostigmoidea</i>	2	crustose
		<i>Lepraria</i> spp.	2	crustose
		<i>Buellia erubescens</i>	2	crustose
		<i>Peltigera praetextata</i>	2	foliose
		<i>Biatora vernalis</i>	2	crustose
	208	<i>Biatora</i> spp.	1	crustose
<i>Lepraria</i> spp.		2	crustose	
210	<i>Lepraria</i> spp.	1	crustose	

		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		<i>Biatora</i> spp.	2	crustose
Farther trees	181	<i>Lepraria</i> spp.	1	crustose
		<i>Parmelia sulcata</i>	2	foliose
		<i>Gyalolechia xanthostigmoidea</i>	1	crustose
		<i>Xanthoria</i> spp.	1	foliose
		<i>Cladonia fimbriata</i>	2	fruticose
		<i>Caloplaca pyracea</i>	1	crustose
		<i>Caloplaca pyracea</i>	2	crustose
	193	<i>Bilimbia sabuletorum</i>	3	crustose
		<i>Gyalolechia xanthostigmoidea</i>	2	crustose
		<i>Cladonia</i> spp.	5	fruticose
	184	<i>Lepraria</i> spp.	2	crustose
		<i>Tuckermannopsis americana</i>	2	foliose
	192	<i>Bryoria furcellatta</i>	1	fruticose
		<i>Evernia mesomorpha</i>	1	fruticose
		<i>Melanohalea olivacea</i>	1	foliose
		<i>Buellia erubescens</i>	1	crustose
		<i>Parmelia sulcata</i>	2	foliose
		<i>Cladonia ochrochlora</i>	5	fruticose
		<i>Cladonia chlorophaea</i>	5	fruticose
		<i>Lepraria</i> spp.	2	crustose
		<i>Lecanora pulicaris</i>	1	crustose
		191	<i>Usnea cf. scabrata</i>	4
	<i>Hypogymnia physodes</i>		2	foliose
	<i>Parmelia sulcata</i>		3	foliose
	<i>Lecanora symmicta</i>		1	crustose
	<i>Buellia erubescens</i>		2	crustose
	<i>Lepraria</i> spp.		2	crustose
	<i>Bryoria furcellatta</i>		1	fruticose
	<i>Evernia mesomorpha</i>		3	fruticose
	<i>Lecanora allophana</i> f. <i>sorediata</i>		1	crustose
<i>Lecania croatica</i>	1		crustose	

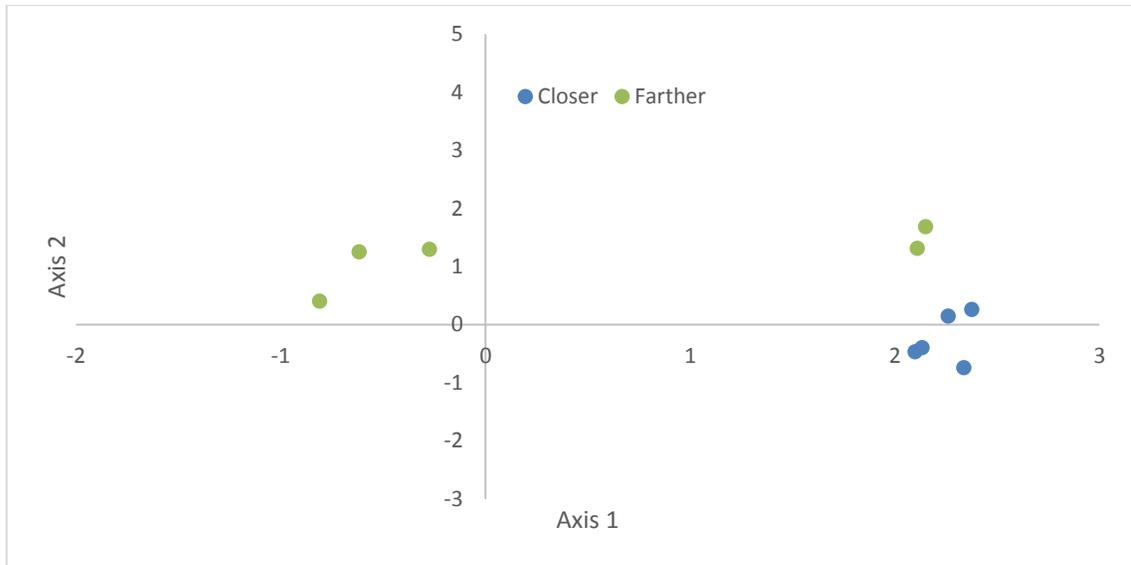


Figure 8: Five closest trees to and farthest from the forest in Timmins are highlighted in the ordination space. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

The lichen species composition of Petawawa residual trees at the extremes of tree bark type, (Table 3.9 and Figure 3.10), DBH (Table 3.10 and Figure 3.11) and distance to road (Table 3.11 and Figure 3.12) variables are listed below with their form and abundance class. These are the environmental variables most strongly correlated with lichen community composition at this location.

Table 2 Lichen species composition, abundance and form for Petawawa trees at the extremes of the tree bark type (low vs. high bark pH) gradient

Environmental Gradient	Tree Number	Species List	Abundance	Form
High bark pH trees	47	<i>Lecanora thysanophora</i>	4	crustose
		<i>Buellia erubescens</i>	2	crustose
		<i>Lepraria</i> spp.	2	crustose
		<i>Physciella chloantha</i>	3	foliose
	46	Species #10*	2	crustose
		<i>Lepraria</i> spp.	3	crustose
	45	<i>Buellia erubescens</i>	1	crustose
		<i>Lecanora thysanophora</i>	3	crustose
		<i>Cladonia ochrochlora</i>	2	fruticose
		<i>Fuscidea pusilla</i>	1	crustose
		<i>Lecanora allophana</i> f. <i>sorediata</i>	1	crustose
	49	<i>Lecanora hybocarpa</i>	1	crustose

		<i>Lepraria</i> spp.	5	crustose	
		<i>Parmelia</i> spp.	1	foliose	
		<i>Buellia erubescens</i>	2	crustose	
		<i>Lecanora thysanophora</i>	3	crustose	
		<i>Cladonia ochrochlora</i>	4	fruticose	
		<i>Melanelixia subaurifera</i>	1	foliose	
	44		<i>Cladonia chlorophaea</i>	1	fruticose
			<i>Cladonia coniocraea</i>	3	fruticose
			<i>Buellia erubescens</i>	3	crustose
			<i>Lecanora thysanophora</i>	2	crustose
			<i>Ropalospora viridis</i>	2	crustose
	80		<i>Parmelia sulcata</i>	4	foliose
			<i>Cladonia ochrochlora</i>	5	fruticose
			<i>Imshaugia aleurites</i>	1	foliose
			<i>Bryoria furcellatta</i>	3	fruticose
			<i>Cladonia chlorophaea</i>	2	fruticose
			<i>Usnocetraria oakesiana</i>	3	foliose
			<i>Variolaria pustulata</i>	3	crustose
			<i>Evernia mesomorpha</i>	2	fruticose
			<i>Hypogymnia physodes</i>	3	foliose
		<i>Usnea hirta</i>	2	fruticose	
		<i>Cladonia</i> spp.	2	fruticose	
		<i>Cladonia deformis</i>	1	fruticose	
103			<i>Melanelixia subaurifera</i>	3	foliose
		<i>Lepraria</i> spp.	3	crustose	
		<i>Parmelia</i> spp.	1	foliose	
		<i>Usnea</i> spp.	1	fruticose	
		<i>Tuckermannopsis americana</i>	1	foliose	
		<i>Cladonia ochrochlora</i>	4	fruticose	
		<i>Cladonia chlorophaea</i>	2	fruticose	
		<i>Evernia mesomorpha</i>	1	fruticose	
66		<i>Cladonia chlorophaea</i>	5	fruticose	
		<i>Cladonia norvegica</i>	3	fruticose	
		<i>Parmelia squarrosa</i>	1	foliose	
		<i>Ochrolechia arborea</i>	1	crustose	
		<i>Buellia disciformis</i>	2	crustose	
		<i>Physconia detersa</i>	1	foliose	
		<i>Cladonia fimbriata</i>	1	fruticose	
61		<i>Bryoria furcellatta</i>	1	fruticose	
		<i>Usnea hirta</i>	2	fruticose	
		<i>Hypogymnia physodes</i>	3	foliose	

Low bark pH trees

106	<i>Parmelia sulcata</i>	5	foliose
	<i>Evernia mesomorpha</i>	1	fruticose
	<i>Cladonia coniocraea</i>	3	fruticose
	<i>Cladonia grayi</i>	2	fruticose
	<i>Loxospora elatina</i>	2	crustose
	<i>Parmelia saxatilis</i>	5	foliose
	<i>Cladonia coniocraea</i>	3	fruticose
	<i>Cladonia grayi</i>	1	fruticose
	<i>Cladonia fimbriata</i>	1	fruticose
	<i>Hypogymnia</i> spp.	1	foliose
	<i>Lepraria</i> spp.	1	crustose
	<i>Usnea</i> spp.	1	fruticose
	<i>Tuckermannopsis americana</i>	1	foliose

*unknown crustose lichen with the following reactions: K- KC- C- P+Y
UV+Y/white.

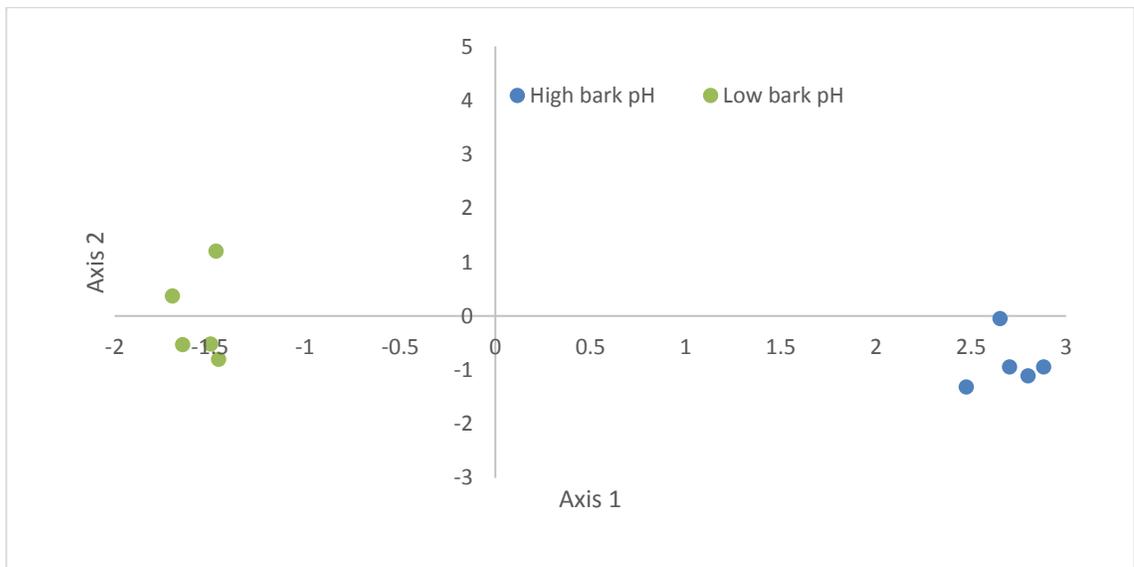


Figure 9 Location of the five points at either end of the tree bark type gradient in Petawawa. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

Table 3 Lichen species composition, abundance and form for Petawawa trees at the extremes of the tree DBH gradient.

Environmental Gradient	Tree Number	Species List	Abundance	Form
Smaller trees	9	<i>Lecanora symmicta</i>	1	crustose
		<i>Melanelixia subaurifera</i>	2	foliose
		<i>Usnea hirta</i>	1	fruticose

		<i>Lepraria</i> spp.	2	crustose		
		<i>Cladonia ochrochlora</i>	1	fruticose		
		<i>Buellia erubescens</i>	1	crustose		
		<i>Lecanora pulicaris</i>	4	crustose		
		<i>Lecania croatica</i>	2	crustose		
		<i>Cladonia fimbriata</i>	1	fruticose		
		<i>Parmelia</i> spp.	1	foliose		
	31		<i>Tuckermannopsis orbata</i>	2	foliose	
			<i>Parmelia sulcata</i>	3	foliose	
			<i>Hypogymnia physodes</i>	1	foliose	
			<i>Melanelixia subaurifera</i>	1	foliose	
			<i>Lepraria</i> sp.	1	crustose	
			<i>Flavoparmelia caperata</i>	1	foliose	
			<i>Lecanora symmicta</i>	1	crustose	
			<i>Evernia mesomorpha</i>	1	fruticose	
			<i>Ochrolechia arborea</i>	1	crustose	
			<i>Buellia erubescens</i>	2	crustose	
			<i>Lepraria</i> cf. <i>finkii</i>	2	crustose	
			Species #7*	2	crustose	
			<i>Usnea</i> spp.	1	fruticose	
		68		<i>Rinodina</i> spp.	1	crustose
				Twins**	1	crustose
			<i>Usnea</i> spp.	1	fruticose	
			<i>Biatora pycnidiata</i>	1	crustose	
			<i>Melanelixia subaurifera</i>	1	foliose	
			<i>Lecanora thysanophora</i>	2	crustose	
			<i>Parmelia</i> spp.	1	foliose	
	100		Twins**	2	crustose	
			<i>Parmelia sulcata</i>	1	foliose	
			<i>Tuckermannopsis orbata</i>	1	foliose	
			<i>Lecanora thysanophora</i>	3	crustose	
			<i>Evernia mesomorpha</i>	1	fruticose	
			<i>Buellia erubescens</i>	1	crustose	
			<i>Rinodina</i> spp.	1	crustose	
			<i>Usnea</i> spp.	1	fruticose	
			<i>Melanelixia subaurifera</i>	1	foliose	
			<i>Lecanora symmicta</i>	1	crustose	
			<i>Lecanora pulicaris</i>	1	crustose	
			<i>Buellia erubescens</i>	2	crustose	
		<i>Hypogymnia physodes</i>	1	foliose		
		<i>Ochrolechia arborea</i>	1	crustose		

		<i>Fuscidea arboricola</i>	3	crustose
	110	<i>Melanelixia subaurifera</i>	2	foliose
		<i>Parmelia sulcata</i>	1	foliose
		<i>Lepraria</i> spp.	3	crustose
		<i>Usnea</i> spp.	1	fruticose
		<i>Lecanora symmicta</i>	1	crustose
		<i>Lecanora thysanophora</i>	1	crustose
		<i>Cladonia fimbriata</i>	2	fruticose
		<i>Cladonia ochrochlora</i>	3	fruticose
		<i>Evernia mesomorpha</i>	1	fruticose
		<i>Tuckermannopsis americana</i>	1	foliose
Larger trees	1	<i>Usnea hirta</i>	2	fruticose
		<i>Bryoria</i> spp.	1	fruticose
		<i>Parmelia sulcata</i>	2	foliose
		<i>Lepraria</i> spp.	1	crustose
		<i>Cladonia coniocraea</i>	4	fruticose
		<i>Cladonia macillenta</i> subsp. <i>macillenta</i>	4	fruticose
		<i>Loxospora elatina</i>	2	crustose
	4	<i>Parmelia</i> spp.	2	foliose
		<i>Imshaugia aleurites</i>	2	foliose
		<i>Hypogymnia physodes</i>	2	foliose
		<i>Cladonia coniocraea</i>	3	fruticose
		<i>Cladonia ochrochlora</i>	1	fruticose
		<i>Cladonia macillenta</i> subsp. <i>macillenta</i>	1	fruticose
		<i>Bryoria furcellatta</i>	3	fruticose
		<i>Usnea hirta</i>	2	fruticose
		<i>Tuckermannopsis americana</i>	1	foliose
		<i>Lecanora thysanophora</i>	3	crustose
		61	<i>Bryoria furcellatta</i>	1
	<i>Usnea hirta</i>		2	fruticose
	<i>Hypogymnia physodes</i>		3	foliose
	<i>Parmelia sulcata</i>		5	foliose
	<i>Evernia mesomorpha</i>		1	fruticose
	<i>Cladonia coniocraea</i>		3	fruticose
	<i>Cladonia grayi</i>		2	fruticose
	<i>Loxospora elatina</i>		2	crustose
	<i>Parmelia saxatilis</i>		5	foliose
	71	<i>Evernia mesomorpha</i>	1	fruticose
<i>Parmelia sulcata</i>		1	foliose	
Species #8***		2	crustose	

		<i>Lepraria</i> sp.	2	crustose	
		<i>Hypogymnia physodes</i>	2	foliose	
		<i>Cladonia grayi</i>	1	fruticose	
		<i>Cladonia ochrochlora</i>	3	fruticose	
		<i>Usnocetraria oakesiana</i>	1	foliose	
		<i>Lepraria</i> spp.	2	crustose	
	93		<i>Parmelia sulcata</i>	4	foliose
			<i>Bryoria furcellatta</i>	4	fruticose
			<i>Evernia mesomorpha</i>	3	fruticose
			<i>Hypogymnia physodes</i>	4	foliose
			<i>Cladonia coniocraea</i>	5	fruticose
			<i>Lepraria</i> spp.	1	crustose
			<i>Usnea hirta</i>	3	fruticose
			<i>Loxospora elatina</i>	2	crustose
			<i>Cladonia merochlorophaea</i>	3	fruticose
			<i>Cladonia digitata</i>	2	fruticose
			<i>Calicium parvum</i>	1	crustose
			<i>Cladonia macilenta</i> var. <i>bacillaris</i>	1	fruticose
			<i>Tuckermannopsis orbata</i>	1	foliose

*unknown crustose species, corticate with white prothallus, yellow apothecia <2 cm in diameter, spores 7.5x4 um and 2-4 celled, thallus and apothecia: K+Y, KC+Y, C-.

**classification given to species that were either *Fuscidea pusilla* or *Ropalospora viridis*, but could not be confidently identified as one of the other.

***unknown crustose lichen with all chemical reactions negative, but for P+R on thallus.

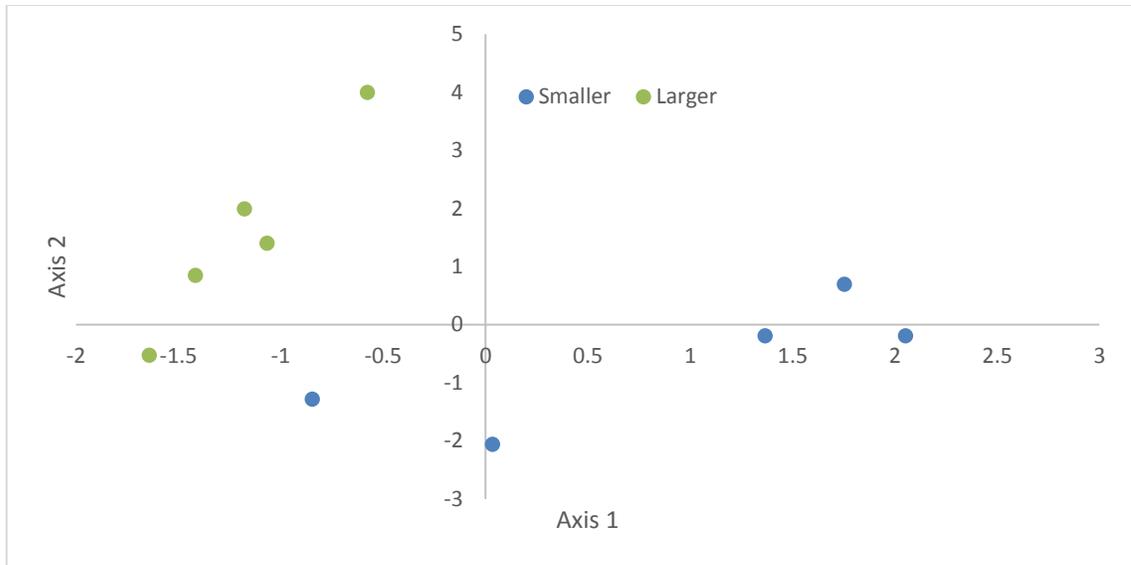


Figure 10 Five largest and smallest Petawawa trees (based on DBH) are highlighted in the ordination space. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

Table 4: Lichen species composition, abundance and form for Petawawa trees at the extremes of the distance to road gradient.

Environmental Gradient	Tree Number	Species List	Abundance	Form
Closer trees	42	<i>Lepraria finkii</i>	5	crustose
		<i>Lecanora thysanophora</i>	5	crustose
		<i>Myelochroa galbina</i>	3	foliose
		<i>Phlyctis</i> spp.	2	crustose
		<i>Cladonia chlorophaea</i>	2	fruticose
		<i>Cladonia coniocraea</i>	1	fruticose
	41	<i>Parmelia sulcata</i>	2	foliose
		<i>Usnea</i> spp.	1	fruticose
		<i>Fuscidea arboricola</i>	4	crustose
		<i>Tuckermannopsis americana</i>	1	foliose
		<i>Evernia mesomorpha</i>	1	fruticose
		<i>Cladonia coniocraea</i>	4	fruticose
		<i>Cladonia grayi</i>	3	fruticose
	<i>Hypogymnia</i> spp.	1	foliose	
	43	<i>Lecanora thysanophora</i>	4	crustose
		<i>Lepraria</i> spp.	4	crustose
		<i>Buellia erubescens</i>	2	crustose
		<i>Cladonia</i> spp.	1	fruticose
<i>Parmelia sulcata</i>		1	foliose	

	60	<i>Lepraria finkii</i>	5	crustose
		<i>Lecanora thysanophora</i>	4	crustose
		<i>Parmelia sulcata</i>	1	foliose
	58	<i>Phaeophyscia kairamoi</i>	1	foliose
		<i>Physconia detersa</i>	1	foliose
		<i>Lecanora</i> spp.	3	crustose
		<i>Lecanora thysanophora</i>	4	crustose
		<i>Cladonia coniocraea</i>	3	fruticose
		<i>Lepraria finkii</i>	1	crustose
	81	<i>Lepraria</i> spp.	4	crustose
<i>Cladonia norvegica</i>		3	fruticose	
<i>Micarea</i> sp.		2	crustose	
<i>Usnocetraria oakesiana</i>		2	foliose	
<i>Phaeophyscia pusilloides</i>		1	foliose	
<i>Calicium viride</i>		1	crustose	
83		<i>Lecanora</i> spp.	1	crustose
	<i>Lepraria</i> cf. <i>neglecta</i>	3	crustose	
	<i>Melanelixia subaurifera</i>	1	foliose	
	<i>Lecanora thysanophora</i>	2	crustose	
	<i>Stenocybe major</i>	1	crustose	
	<i>Lecanora pulcaris</i>	2	crustose	
	<i>Cladonia coniocraea</i>	2	fruticose	
	Twins*	1	crustose	
82	<i>Usnocetraria oakesiana</i>	3	foliose	
	<i>Cladonia coniocraea</i>	3	fruticose	
	<i>Cladonia norvegica</i>	1	fruticose	
	<i>Micarea</i> sp.	4	crustose	
	<i>Cladonia grayi</i>	2	fruticose	
	<i>Calicium trabinellum</i>	1	crustose	
84	<i>Lepraria</i> spp.	2	crustose	
	<i>Lecanora thysanophora</i>	3	crustose	
	<i>Parmelia sulcata</i>	3	foliose	
	<i>Tuckermannopsis americana</i>	2	foliose	
	<i>Evernia mesomorpha</i>	1	fruticose	
	<i>Hypogymnia physodes</i>	1	foliose	
	<i>Loxospora elatina</i>	1	crustose	
89	<i>Peltigera praetextata</i>	2	foliose	
	<i>Cladonia coniocraea</i>	2	fruticose	
	<i>Lepraria</i> spp.	1	crustose	
	<i>Lecanora thysanophora</i>	5	crustose	
	<i>Cladonia</i> cf. <i>ochrochlora</i>	1	fruticose	
Farther trees				

*the name given to specimens that could not be confidently identified as *Fuscidea pusilla* or *Ropalospora viridis*. These are very morphologically and ecologically similar species (Lendemer 2011).

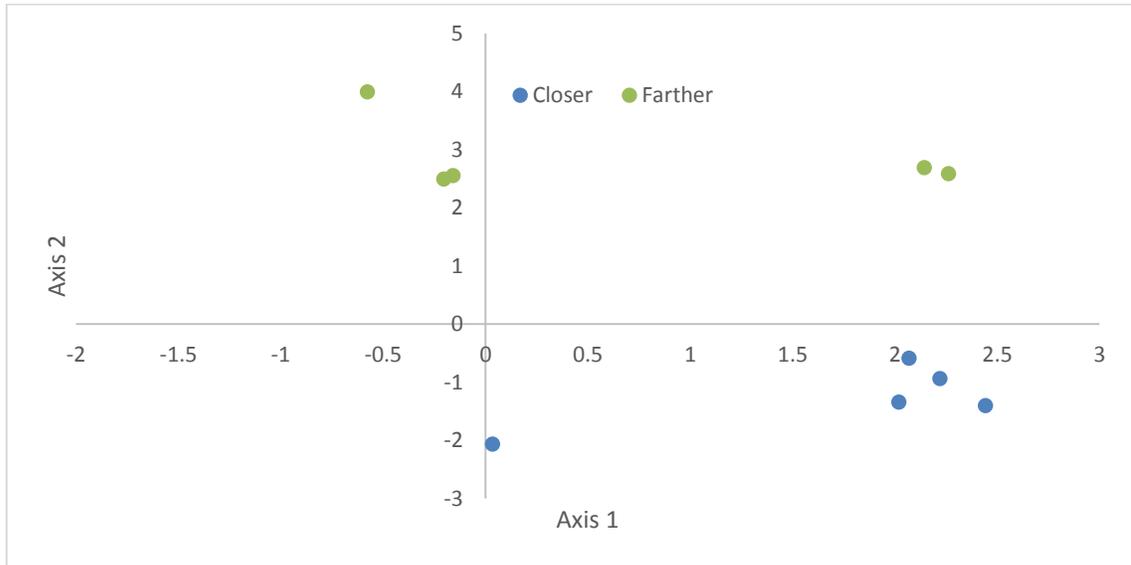


Figure 11 Five closest trees to and farthest from the road in Petawawa are highlighted in the ordination space. Points were chosen using highest and lowest values for the environmental variable, ties decided by the axis score.

CHAPTER FOUR

Discussion

My objectives were to determine if silvicultural intensity effects the lichen on residual trees and to investigate environmental variables that could explain their lichen species richness, abundance, form and community composition using data from two NEBIE locations in Ontario. The results aim to inform forest managers on the effects of their practice on epiphytic lichen. I found no silvicultural intensity effect on lichen species richness, abundance or community composition at either location except the Basic intensity in Timmins. Basic had significantly lower species richness and fewer species in abundance class two per tree compared to Natural. Of the environmental variables proposed (tree species, tree bark type, tree DBH, elevation and distance to landscape features) many were able to explain some of the variation in the measures of lichen on residual trees. Lichen communities are best described by the combination of multiple habitat variables. In the following discussion, each habitat variable will be treated individually to identify their unique influence, if it exist, before concluding with the cumulative importance of the explanatory variables examined.

4.1 Intensity

I predicted silvicultural intensity would have a negative impact on the lichen of residual trees. I proposed that the lichen species richness per tree would decrease with increasing silvicultural intensity because fewer species would be able to survive the habitat transition from a closed canopy forest to the exposure of a standing residual tree or herbicide spray. The only significant difference in richness between intensities was found in Timmins. Natural plots had significantly more lichen species per tree than Basic. This could be explained by habitat availability on sections of residual trees in these intensities. There were 40% more specimens found in the middle (from 0.5 to 2 m from the ground) and 30% more found in the top (above 2 m) of the surveyed sections of Natural

compared to Basic trees. Natural trees had more branches on these sections of their trunks than Basic trees, providing more potential lichen habitat (Figure 4.1). Many of the branches of trees, specifically conifers, in the Basic intensity would have been lost during the harvest process, broken off by passing skidders. The availability of branches on residual trees is important to the abundance of lichen in managed forests (Esseen et al. 1996). Most of the species in this mid-top section of the tree were crustose lichen of smaller abundance classes. This could also explain finding significantly more crustose species and more lichen of abundance class two per tree in Natural versus Basic intensities. The number of specimens found from the ground to 0.5 m up the trunk were similar between intensities. These were generally *Cladonia* species, which are common on the mossy bases of trees where moisture is higher (Brodo et al. 2001).

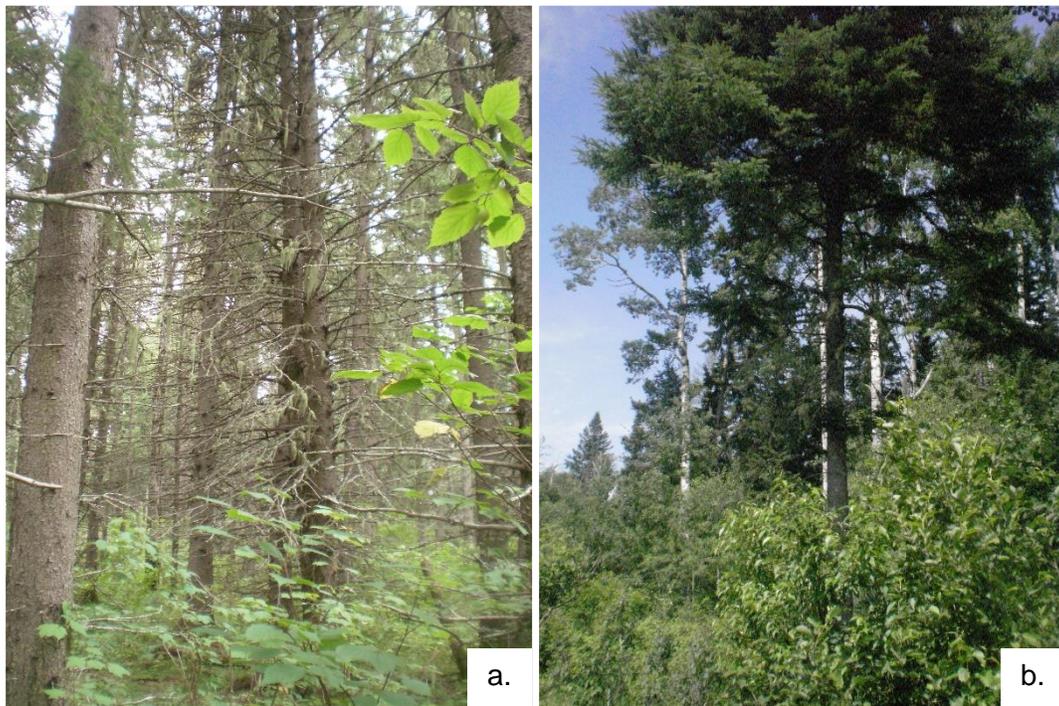


Figure 12 Example images (Timmins in 2013) of coniferous branches in the Natural (a.) and Basic (b.) intensities. Notice that the first branch in b. begin approximately 3 m from the base of the trunk compared to a. where the branches begin close to the base of the trunk.

In Petawawa, there were no significant differences in lichen species richness or abundance class per tree between intensities. There were, however, significantly

more fruticose lichen per tree in Basic than in Natural intensities. There was approximately twice the incidence of both pendant and *Cladonia* spp. fruticose species in Basic compared to Natural. The difference in pendant species could be explained by the increased exposure to light without the drying impact of strong winds. This result is similar to what Waterhouse et al.'s (2007) study showed where *Bryoria* spp. biomass in trees of partially (30%) cut stands was greater than in uncut stands. Pendant lichen such as *Alectoria sarmentosa* (Esseen and Renhorn 1998) and *Bryoria* spp. (Esseen 1985) are fragile and tend to fragment in the wind. If the winds of managed Petawawa plots were too strong, I would have observed greater fragmentation (Esseen and Renhorn 1998) and, therefore, smaller abundance classes of pendant fruticose species in Basic versus Natural intensities. *Cladonia* spp., on the other hand, live at the bases of trees, and are likely not as sensitive to wind damage because the thallus is not as fine and they are more protected at the base of the tree. The greater incidence of fruticose species in Basic over Natural intensities could also be due to the lack of competition with bryophytes on the bases of Basic trees. While surveying, the presence and abundance of moss coverage on residual trees was recorded. Only two Basic trees surveyed had moss at least 1 m up the trunk, while 14 of the 40 Natural trees had moss at least 1 m up the trunk. This isn't surprising as bryophytes are known to be particularly sensitive to silvicultural treatment (Lõhumus et al. 2006). Lichens are known to compete with bryophytes for habitat (Juriado et al. 2009), which could be the reason there is a difference in *Cladonia* spp. frequency seen between Basic and Natural residual trees on the shared space at their base.

The few significant differences in lichen richness, abundance and form between intensities, discussed above, did not result in residual trees with different lichen community composition. Intensity was eliminated from the CCA as it did not explain any of the variation in lichen communities. Although several studies have found silvicultural treatment to affect lichen communities (Esseen et al. 1996; Newmaster et al. 1999; Newmaster and Bell 2002; Hedenås and Ericson 2003; Hilmo et al 2005; Newmaster et al. 2007; Waterhouse et al. 2007; Johansson

2008; Hilmo et al. 2005), there are also some to agree with my result, showing little to no silvicultural damage (Coxson and Stevenson 2005; Löhmus et al 2006; Root et al. 2007; Jairus et al 2009; Löhmus and Löhmus 2010).

Coxson and Stevenson (2005) examined the effects of silviculture on lichens and in British Columbia and found results similar to my own. They studied an old-growth cedar-hemlock (*Thuja plicata* and *Tsuga heterophylla*) forest that was harvested retaining 0, 30, 70 and 100% (uncut) of forest area. Biomass of four lichen groups (*Bryoria*, cyanolichens, foliose and *Alectoria*) was estimated on the branches and litter of trees. In their sites overall, they found no treatment effect at any level of retention for the *Bryoria*, cyanolichens or foliose groups. Treatment (both 30 and 70%) significantly decreased the biomass of the *Alectoria* group at the centre and edge of cuts. They concluded that lichen retention on residual trees was adequate, meeting the goal of maintaining structural diversity to support functional diversity.

The first group of lichens contains species belonging to the genera *Bryoria* or *Nodobryoria*. No species from the latter were found in my sites. Timmins *Bryoria* spp. abundance between managed and Natural trees agrees with Coxson and Stevenson's (2005) results; there was no management effect. This wasn't true of abundance in Petawawa. Here, *Bryoria* spp. were found more frequently (three times the records) in Basic compared to Natural intensities. Again, this is likely due to the greater exposure to sunlight in managed plots without the fragmenting effects of wind.

The second group of lichens studied by Coxson and Stevenson (2005), cyanolichens, are defined by their use of cyanobacteria (usually *Nostoc*) to photosynthesize instead of an algae, as in most lichens (Brodo et al. 2001). Cyanolichens are used as indicators of forest health and continuity (Kuusinen 1995; Sillett and McCune 1998; Hedenås and Ericson 2000; Thormann 2006; Aragon et al. 2010) because of their particular sensitivity to local humidity (Lange et al. 1988) and disturbance (Richardson and Cameron 2004). They require liquid water to photosynthesize (as opposed to green algae-containing lichen

which can make use of water vapour) and don't have a great water holding capacity (Lange et al. 1989). This means that their growth or colonization is hindered in dry open habitats. I did not find many cyanolichens on either managed or Natural trees of either location, in fact there was just one recorded in Timmins on a Natural tree, so comparison is difficult. However, the simple presence of the cyanolichens (*Peltigera evansiana*, *Peltigera praetextata*, *Peltigera canina* and *Peltigera elisabethae*) at the bases of managed and Natural Petawawa trees is a good indication that habitat continuity has been maintained through silvicultural intensity. Although cyanolichens were not found frequently (on two Intensive and three Natural trees), they were abundant when present with an abundance class of five for species in each intensity.

The third group studied by Coxson and Stevenson (2005) was foliose lichen that do not contain cyanobacteria. In both Timmins and Petawawa, increased silvicultural intensity did not result in a difference in foliose lichen abundance per tree. Their study also found no difference in foliose lichen abundance over all sites, but they did find local differences (e.g., a trend in abundance with distance to cut edge or with percent retention) in the foliose group at some sites, that I did not. These relationships were positive in some sites and negative in others, clearly illustrating site specific results.

The fourth group, *Alectoria*, contains species of *Alectoria* and *Usnea*. No *Alectoria* species were found in either of my locations, but *Usnea* spp. were well represented in both. In this group my results differ most from those of Coxson and Stevenson (2005). In Timmins there was no difference in the abundance of *Usnea* spp. per tree, but they were found more frequently on Natural over Basic or Intensive trees. The difference in frequency in *Usnea* spp. and not *Bryoria* spp. is likely due to a difference in humidity preference between the two pendant fruticose lichen. To be successful, *Usnea* spp. requires a moist stable habitat, while *Bryoria* spp. prefer better ventilated, less humid habitats (Benson and Coxson 2002). It is possible that a decrease in humidity at the branch level (*Usnea* spp. were only found on branches 2 m above the ground) occurred as a

result of silvicultural treatment, making these branches of residual trees less suitable for *Usnea* spp. Here the observation of more trees with *Usnea* spp. in managed (most in Basic) over Natural intensities, with no increase in average abundance class per tree, agrees with the pattern of *Bryoria* spp. found on Petawawa trees. This indicates that any change in humidity that may have occurred following harvest was not enough to affect the number of trees *Usnea* spp. can inhabit. I believe this increase in prevalence on managed trees can be explained by greater access to sunlight in these intensities due to the removal of surrounding trees. Although studies on *Usnea* spp. have reported a negative effect (Coxson and Stevenson 2005) and no effect (Stone et al. 2008) of silvicultural treatment, this is the first I am aware of to report an increase in frequency with intensity.

Lõhmus et al. (2006) studied the epiphytic bryophytes and lichens of trees in green-tree retention (GTR) cuts and the adjacent forest. GTR requires large living trees to be left unharvested (Runnel et al. 2013). In Lõhmus et al.'s (2006) study in Estonia, there is at least 5 m³ left per hectare and they are generally left as solitary trees. Lichen cover and vitality was measured on living birch (*Betula* spp.), aspen (*Populus tremula*), ash (*Fraxinus excelsior*) and Scots pine (*Pinus sylvestris*) two years after harvest. They found that only 2% more lichen thalli were damaged on the GTR trees than in the adjacent forest, there was no significant difference in lichen cover and no significant loss of species. Particular attention was paid to sorediate and granulose crustose lichen as they are sensitive to desiccation in exposed habitats (Tønsberg 1992). Lõhmus et al. (2006) found that vitality or cover of species they surveyed fitting this description was not negatively affected by GTR management. The same is true of the lichen of Petawawa residual trees. Here I found that these lichen (e.g., *Loxospora elantina*, *Ropalospora viridis*, *Fucidia pusilla* or *Lecania croatica*) were just as prevalent in the Basic and Intensive intensities as in Natural. The same was not true of Timmins sorediate and granulose crusts. As discussed above, there were significantly more crustose species overall on trees in the Natural intensity than in Basic or Intensive, likely due to increased habitat availability. I believe this is

the same reason more of these crusts were found in Natural than either Basic or Intensive. With the exception of this group of Timmins crustose species, my results agree with Löhmus et al. (2006) in that lichen of residual trees are robust in the face of silvicultural treatment.

My results were supported again when these GTR stands were revisited at five years after harvest by Löhmus and Löhmus (2010), this time looking at lichen community composition in addition to species richness of residual trees. They also found that lichen species richness and community composition was the same on the residual and forest trees. Most of their tree-to-tree lichen community differences were explained by host tree species, more than any other measured environmental variable. This agrees with my results and will be covered in the following section.

One additional group of lichens to discuss when looking at the continuity of a forest through silvicultural is the calicioid lichens, which include 'stubble' lichens (Selva 1994). Calicioid lichens are defined by their mazaedium, a powdery mass within the apothecia which contains their spores and the tall stocks these apothecia grow atop. This differs from most lichens whose spores are contained within their apothecia or perithecia and whose stocks, if present, are shorter and thinner (Selva 2013; see Figure 4.2 for an example image). Suits of stubble lichens have been used as indicators of old-growth forests (Holien 1996; Selva 1994). This is a result of the vast majority of these lichens' preference for old trees with rough sturdy bark that doesn't easily flake away, and humid locations where they will not be subjected to direct precipitation or sunlight (Holien 1996; Selva 2013). All of the stubble species found, with the exception of *Calicium trabinellum*, are considered indicators of old-growth forest in New England and New Brunswick (Selva 1994). Calicioids in Natural (*Chaenotheca laevigata*, *C. chrysocephala*, *Chaenothecopsis nana*, *C. marcineae*, and *Calicium parvum*) and Basic (*Calicium trabinellum*) and Intensive (*Chaenotheca ferruginea* and *C. chrysocephala*) intensities in Timmins and Natural (*Calicium viride* and *C. trabinellum*) and Basic (*Chaenothecopsis cf. nana* and *Calicium parvum*)

intensities in Petawawa is a good indication that the measures taken to ensure structural and functional continuity in managed forests were successful.



Figure 13 *Calicium virde* on a cedar taken by Chris Bjork in BC, Canada. Example of calicioid lichen

In conclusion, although subsets of species had differences in abundance or prevalence between managed and Natural trees, the overall lichen species composition at both Timmins and Petawawa was not driven by silvicultural intensity. Other environmental variables such as tree bark type and DBH were more important to composition.

4.2 Tree species and type

Univariate analyses were used to explore the relationship between tree species, lichen richness, abundance and form. Lichen species richness was generally greater on low bark pH residual trees (Timmins: balsam fir, white and black spruce; Petawawa: balsam fir and white pine), they had more species in the smaller abundance classes (Timmins: 1, 2 and 3; Petawawa: 1 and 2), and more fruticose, foliose and crustose species per tree than high bark pH trees in both locations. Based on this pattern, tree species were categorized by bark type for the CCA and resulted in the strongest explanatory variable influencing lichen community composition on residual trees.

Lichen species richness and composition's relationship with specific substrate species has been well documented (Schmitt and Slack 1990; Uliczka and

Angelstam 1999; Mezaka et al. 2008, 2012; Bartels and Chen 2010; McMullin et al. 2010; Berg et al. 2013). The necessity of a diverse tree population to host a diverse lichen population (Juriado et al. 2009), particularly through silvicultural treatment has also been shown by a number of authors (Lõhmus et al. 2006; Odor et al. 2013; Runnel et al. 2013). The driver behind this relationship between lichen and their substrate has been found to depend more on the substrate properties rather than simply the substrate species (Ranius et al. 2008; Juriado et al. 2009). Attributes such as bark crevice depth, pH, stability and water holding capacity can change over the surface of a single tree or between trees of the same species (Gustafsson and Eriksson 1995), though these attributes may be more similar within rather than between trees species (Barkman 1958; Odor et al. 2013). Conifers are generally associated with lower bark pH and greater crevice depth, and deciduous trees with higher pH and smoother bark (Snell and Keller 2003; Mezaka and Znotina 2006). In my survey, I found a few (28) species with at least 80% of their observations from lower bark pH trees (e.g., *Bryoria furcellata*, *Tuckermanopsis americana*, *T. orbata*, *Loxospora elantina*, *Usnea filipendula* and *U. subfloridana*), but fewer (11) with 80% of their observations coming from high bark pH trees (e.g., *Caloplaca pyracea*, *Bilimbia sabulorum*, *Gyalolechia xanthostigmoidea* and *Lecanora cirumborealis*). Most lichen species were found on both high and low bark pH trees, though there were some species found on trees of only one type (found at least three times exclusively on low pH: *Cladonia merochlorophaea*, *C. norvegica*, *Lepraria neglecta*, *Melanelixia* sp.; found at least three times exclusively on high pH: *Caloplaca pyracea*, *Bilimbia sabulorum*, *Gyalolechia xanthostigmoidea*). In my study, higher lichen species richness was found on trees with lower bark pH (mostly conifers) than on high pH (deciduous) in both sites. Two previous studies found the opposite, deciduous trees had greater lichen species richness than conifers (Nascimbene et al. 2012; Mezaka et al. 2012). My sites had a greater number of conifers, which may be the reason for contrasting results; there may have been fewer propagules in the area from lichen species that only colonize deciduous trees.

Retention of trees with higher and lower bark pH following harvest is necessary to support the lichen species found more often on one or the other. Therefore, tree bark type is an important variable to consider when retaining trees for lichen diversity.

4.3 Tree DBH

Tree diameter at breast height (DBH) was included as a possible explanatory variable for two reasons. First, a larger DBH will usually have a greater surface area for lichen to colonize (Lie et al. 2009). Second, DBH is often used as a proxy for the age of a tree (Schmitt and Slack 1990; Mezaka et al. 2012). Older trees have not only been present in the stand longer, giving them more opportunity to be colonized by lichen, but they also provide stable habitat conditions favoured by many lichen species (Goward and Campbell 2005; Waterhouse et al. 2007). Lichen are often poor colonizers and slow growers (Hale 1973; Sillett et al. 2000) requiring undisturbed habitat for long periods of time to successfully survive in a stand. Large trees are not old and old trees are not always large (Lie et al. 2009; Cecile et al. 2013), but DBH is typically positively correlated with tree age (Ellis and Coppins 2006; Pokharel 2008). A relationship between DBH and lichen species has been reported in multiple studies (Root et al. 2007; Mezaka et al. 2008; Odor et al. 2013). Therefore, I investigated the relationship between DBH and lichen community at Timmins and Petawawa locations.

Residual tree DBH wasn't correlated with lichen species richness at either location, but it was related to the abundance and form of lichen on each tree. In Timmins, an increase in DBH was significantly correlated with fewer species in abundance class one per tree. Fewer smaller lichen on larger trees is likely the result of the length of time those trees have been present in the stand. Lichen have had time to colonize and grow on these trees, while those of smaller trees haven't had the same chance. In Petawawa, an increase in DBH was significantly correlated with more species per tree in abundance classes three and five, more fruticose species and fewer crustose species. There appears to

be more lichen in larger abundance classes on larger trees for the same reason there are fewer in smaller classes - the time larger trees have spent in the stand. Larger trees have been present in the stand long enough to allow lichen to grow out of the smaller abundance classes and accumulate on the tree. The results of Root et al. (2007) support my results, more fruticose lichen occur on larger trees due to the habitat stability they provide over a long period of time.

These differences in lichen form on surveyed trees lead to changes in lichen community composition with DBH. This is interpreted from the CCA as DBH was identified as a significant and highly correlated environmental variable in both locations. In Timmins, the communities of smaller trees tended to have greater similarity than those of larger trees, which were often made up of common crustose species, but with equal representation of fruticose and foliose species. These results are illustrated by the tight cluster of blue points in Figure 4.3. In Petawawa, DBH was not as strong an explanatory variable as in Timmins, which is illustrated by the shorter associated arrow in the bi-plot and point overlap in Figure 4.4 between categories. There was a greater spread of plot points along the DBH gradient, not showing the clustering around smaller trees as seen in Timmins. In both locations, members of all form types, common and uncommon species and groups such as old growth indicators (square points on plot) and stubble lichen (triangles on plot) are found across the gradient of DBH indicating that no one size contains more species richness than another. Residual trees with a range of diameters, therefore, is required to hold the full range of lichen diversity at each location, making it an important variable to consider when retaining trees for lichen diversity.

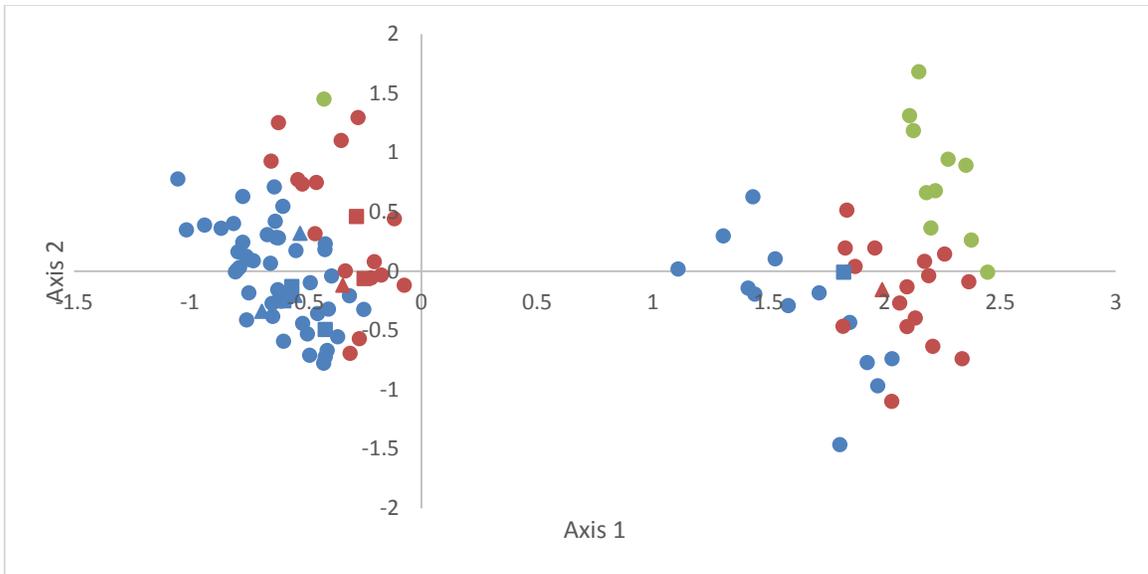


Figure 14 Timmins plot ordination showing spread of tree DBH. Blue = small (11-34.5 cm). Red = medium (35-58.5 cm). Green = large (59-81.5 cm). Trees with old growth indicators (Selva 1994) as squares, trees with stubble lichen as triangles and trees with both as diamonds. The tight cluster of blue dots indicates similar lichen species composition on smaller trees.

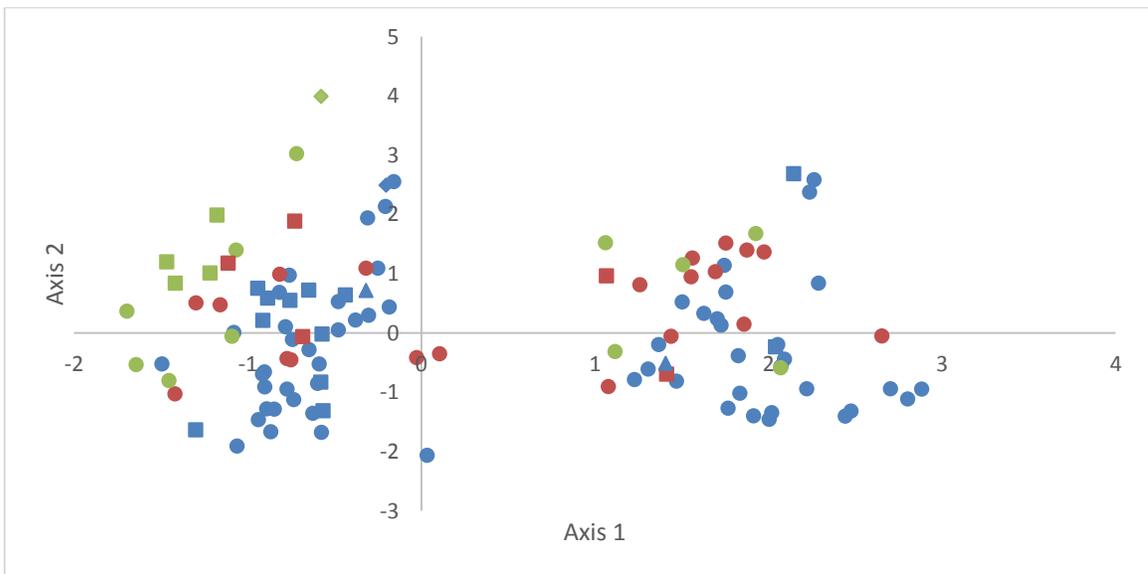


Figure 15 Petawawa plot ordination showing the spread of tree DBH. Blue = small (11-34.5 cm). Red = medium (35-58.5 cm). Green = large (59-81.5 cm). Trees with old growth indicators (Selva 1994) as squares, trees with stubble lichen as triangles and trees with both as diamonds. Notice the overlap of points from different categories.

4.4 Elevation

Tree elevation was included as a possible explanatory variable in the analysis because it has been found to influence other forest lichen communities (Peck and McCune 1997; Shanti and McCune 2006), and could identify upland and lowland habitats. Upland habitats are generally dryer with coarse well drained soil and a more open canopy of pine and spruce. Lowlands are wetter with poorly drained soil and a tighter canopy of black spruce and larch (Taylor et al. 2009). My results indicated that elevation was not a strong explanatory variable of lichen community composition on residual trees. Elevation did not explain a significant amount of variation in community composition in Timmins. It was a statistically significant variable in Petawawa, but relative to the other variables, it explained little of the variation. The poor explanatory power may be due to the elevational differences between trees in each location. The greatest difference in elevation in Timmins was 35 m and 19 m in Petawawa. This range was likely not enough to cause the change in lowland to upland habitat required to change the lichen populations of trees. With such minimal changes in elevation, this does not appear to be an important variable to consider when retaining trees for lichen diversity.

4.5 Distance to landscape features

4.5.1 Distance to roads

Distance to roads was considered a possible explanatory variable because roads are a known source of disturbance to lichen habitat (Ahmadjian and Hale 1973; Glenn et al. 1995; Klos et al. 2009; Nascimbene et al. 2014). The disturbance is twofold. First, the exhaust from cars and dust from the dirt road add contaminants and particulates to the air, lowering its quality. Lichen do not have control of air exchange in the same way vascular plants do with leaf stomata and a waxy cuticle (Brodo et al. 2001). There is therefore little barrier to contaminants entering their tissues, making some species sensitive to this pollution (Nash 2008). Secondly, the deforested area creates an edge in the natural forest,

exposing surrounding lichen to more direct sunlight and stronger winds. These can fragment, dry and scorch surrounding lichen (Esseen and Renhorn 1998).

The results from Timmins show that distance to a road was not correlated with lichen richness, abundance or form and explained relatively little of the variation in community composition. This weak relationship may be related to the low volume of traffic frequenting the roads near the Timmins location. The dirt road is most often used by logging vehicles, hunters and recreational trail riders (personal observation). All of these uses are seasonal and don't lead to the volume of traffic likely to cause a concentration of airborne particulates large enough to damage lichen populations of residual trees (Glenn et al. 1995).

In Petawawa there was no correlation between distance to a road and lichen species richness, abundance or form. The results of the CCA however, found a strong relationship between the distance to a road and lichen community composition, it is second only to tree type. Looking at the ten trees closest to (60-91 m) and farthest from (380-448 m) the road to illustrate the communities at these extremes, almost the same number of species are found (34 and 33 respectively), but different suits of lichen are present. There are 19 species unique to the closer trees, 15 found at both distances, and 18 unique to the farther trees. Species known to favour the exposed habitat of roadsides such as *Ochrolechia arboria* (Nash et al. 2001), were found only on those trees closer to the roads, while others, such as the calicioid lichens, *Calicium trabinellum* and *C. viride*, were found only on trees farther away. It is not surprising to find these calicioid lichens farther from a source of disturbance such as the road, because they favour continuity (the absence of disturbance) and are often used as indicators of mature forest and ecological continuity (Selva 2013). On trees closer to the road, more sorediate species were found than sexually reproducing species. Soredia, contains algal and fungal tissues, both components necessary for a new lichen to grow. Soredia can be passively dispersed by a number of vehicles/vectors including animals, insects, splash from rain droplets and wind (Pyatt 1973). Soredia are small (~25-100 μm in diameter; Hudson 1992)

hydrophobic balls making wind an ideal vehicle for their dispersal (Pyatt 1973). Ascospores, however, contain only fungal tissues. In order to create a new lichen, this spore must come in contact with a photobiont in a suitable habitat. They are generally much smaller (~5-200 μm long) than soredia and can in turn be dispersed much farther by the wind (Pyatt 1973). Unlike soredia, they can also be actively expelled into the air to be caught in a passing breeze (Pyatt 1973). Moisture and temperature are critical to the creation and release of spores; dry thalli that are too hot or too cold will have poor spore production (Ingold 1960 and Versegny 1965 in Ahmadjian and Hale 1973), which may help to explain why there is a greater number of soredia producing lichen found closer to the roads. The cleared area of the road could create a point of access for wind born soredia to reach and colonize forest trees, while those farther from the road may have to rely more on local dispersers to do the same. Forest edges can create warmer, dryer microclimates (Chen et al. 1993; Boudreault et al. 2008), and ascospore production can be inhibited in these conditions, which could help to explain why more ascospore-producing lichen are found on trees farther from the road in Petawawa. Distance to roads appears to be an important variable to consider when retaining trees for lichen diversity in Petawawa.

4.5.2 Distance to forest

Distance to forest was included as a possible explanatory variable as intact forests can serve as a significant inoculum source for the recolonization of residual trees (Dettki et al. 2000; Waterhouse et al. 2007). A lichen's presence on its substrate is a result of successful colonization and growth (Boudreault et al. 2008). Colonization can be limited by two variables: dispersal distance or habitat quality (Buckley 2011). The importance of these variables varies between different lichen species (e.g., habitat quality is more important to *Lobaria pulmonaria* (Werth et al. 2006) and dispersal limitation is more important to *L. oregano* (Sillett et al. 2000)). In my study, however, habitat quality of residual trees does not seem to be the major limiting factor for most dispersers as there was little difference in lichen species richness between Natural (i.e., forest) and

managed trees. Therefore, distance to the intact forest was used to explain the variation in lichen community composition on Timmins residual trees. My results show that with decreasing distance to the relatively undisturbed forest, lichen richness, the number of individuals in abundance class two, and number of crustose lichen per tree increased. These results are supported by a study from Buckley (2011) on the lichen of mountain beech trees and their proximity to a source population of an intact remnant forest. After she accounted for tree size and distance within 1 km of the forest, there was still a strong negative relationship between lichen richness and proximity to the forest. Dettki et al. (2000) also reported significantly more fruticose and foliose lichen on branches of Scots pine when closer to adjacent old-growth forests. They did not survey for crustose species. My results differ here from Dettki et al. (2000) because there was no significant difference in fruticose or foliose species between Natural (i.e., forest) and Basic or Intensive trees. There was, however, significantly more crustose species on Natural trees. This could be why a relationship between proximity to these trees and crustose lichen was found. The majority of species found on these trees were crustose, which could also explain the higher lichen species richness associated with trees closer to the forest. In Timmins, distance to residual forest does appear to be an important variable to consider when retaining trees for lichen diversity.

4.5.3 Distance to river and wetland

Distance to a river in Timmins and to a wetland in Petawawa were considered possible explanatory variables because moisture and relative humidity can be higher nearer to such water bodies, even in managed forests (Danehy and Kirpes 2000; Stewart and Mallik 2006), and as moisture availability is a critical component of lichen habitat (Waterhouse et al. 2007). My results show no correlation between the distance to these features and lichen richness, abundance or form in either location. Distance to a river did not explain a significant portion of variation in lichen community composition in Timmins, and in Petawawa, distance to a wetland explained relatively little as well. This may be

because of how far away the surveyed trees were from these features. In Timmins, trees were an average of 293 m away from the river's edge (min: 58 m; max: 620 m). In Petawawa, trees were an average of 351 m away from the edge of the wetland (min: 29 m; max: 1343 m). This was perhaps too far for the benefit of a water body to reach the surveyed trees. At this distance, proximity to the river and wetland does not appear to be a factor of concern when retaining residual trees for lichen diversity in Timmins and Petawawa.

4.5.5 Distance to hydrowire

Distance to the treeless area under hydrowires in Petawawa was included as a possible explanatory variable because the opening in the forest has the potential to affect the neighbouring forest habitat. Forest edges can result in harsh environments for interior forest species (Chen et al. 1993; Rheault et al. 2003). My results did not support those findings as lichen richness, abundance and form per tree were not correlated with distance to the hydrowire, nor did it explain much of the variation in lichen community composition. The epiphytic lichen on Petawawa trees appears not to be affected by proximity to this feature. Without direct measures of the light, wind and humidity conditions between the edge and surveyed trees, it is not certain that there are no changes in these microclimatic variables, or that there are changes, but they are too weak to greatly impact the lichen communities of nearer trees. I can report that the spatial relationship with hydrowires appears to not be a factor of concern when retaining residual trees for lichen diversity in Petawawa.

CHAPTER FIVE

Conclusion

Dominant industrial forest management reduces heterogeneity by managing for timber rather than for a productive ecosystem. Changes in silvicultural guidelines, including the goal of natural disturbance emulation, have led to an ecosystem based approach to forest management. These changes, including the retention of structural diversity in the form of residual trees following harvest, appears to have succeeded in providing a range of habitat variables in these two hectare NEBIE locations required to support a lichen community similar to that of an unmanaged forest.

I attempted to identify the single most influential variable controlling the lichen on residual trees, but what have I found is that lichen richness, abundance and community composition at these sites is best described by multiple environmental variables. These variables combined better explain lichen community structure than silvicultural intensity at approximately ten years post-harvest. At values along each continuum, a combination of tree type, DBH, distance to roads, and distance to inoculum source (i.e., intact forest) combine to influence the epiphytic lichen community. This conclusion is supported by other studies looking at multiple habitat variables and lichen. Juriado et al. (2009) found all values of tree DBH, stand age, bark pH, bryophyte cover and light availability to contribute to the lichen composition of floodplain forests in Estonia. McMullin et al. (2010) found at the stand scale the structural variables; stand age, stem density, snag stem density and deciduous stem density and abundance, at values across each spectra, were all critical to the support of the lichen communities in Nova Scotia's southwestern coniferous forests. Odor et al. (2013) found all values of tree DBH, tree species and relative light availability to explain the lichen composition of Hungarian secondary mixed forests. The pattern emerging; lichen diversity is positively correlated with heterogeneity in forest ecosystems.

The results of my project can inform forest managers in Ontario on the effects current practices have on epiphytic lichen in these patches of managed mixedwood forests and how they could be optimized. Care should be taken, however, in the up-scaling of these results. They come from two hectare plots, a substantially smaller harvested area than the average Ontario operations (average of 40 hectares in these forest types; MNR 2011), and this should be taken into consideration in application of these results. The significantly greater species richness per tree found on Natural over Basic intensities in Timmins suggest that the availability of smaller lower branches on residual trees may be important to richness, and therefore damage and loss of these branches during harvest should be minimized. Although low bark pH residual trees had a higher per tree richness than high bark pH trees, the retention of both following harvest is necessary to support a more diverse lichen community. A range of DBH appears to be necessary to support a richer and more diverse lichen community, not just trees with a greater DBH which are favoured for retention. The location of residual trees with respect to different landscape features could be optimized to maximize lichen diversity and community complexity. Trees closer to and farther from roads hold different suits of lichen species. The retention of both can provide for a more diverse lichen community. Distance from residual trees to the nearest relatively undisturbed forest is important to some species with limited dispersal. Proximity to these forests should be considered when retaining trees following harvest. With an average distance of approximately 300 m from the nearest river or wetland, trees relatively close to these features need not be favoured for retention for a more diverse lichen community. The same is true of trees relatively far from the cleared area under hydrowires. There appears to be no benefit to lichen diversity in retaining these trees over those closer to hydrowires. After just less than ten years following harvest, there is no effect of silvicultural intensity on lichen community composition on residual trees in these two hectare cut blocks. Overall, the management guidelines in place to conserve biodiversity appear to be successful with respect to epiphytic lichen of residual trees at this time since harvest in Timmins and Petawawa NEBIE sites.

This study has also generated additional research questions for future research. I linked dispersal limitations to the patterns in lichen richness, form and community composition seen with distance to forest in Timmins. This raises questions about the influence of wind direction on this relationship. Will the communities found on up-wind and down-wind trees differ significantly? Perhaps old silvicultural systems such as strip harvesting, traditionally implemented to take advantage of the wind direction for the purposes of tree seed dispersal (MNR 2013), could benefit the dispersal of lichen propagules to residual trees as well. This proximity to the relatively undisturbed forest may also provide some protection from the elements for lichen of residual trees in the initial years following harvest, making it a better habitat for colonization. This raises the question of the benefit of aggregated over individual residual trees as habitat for lichen (Moen and Jonsson 2003; Perhans et al. 2009; Schei et al. 2013), which has yet to be addressed in Ontario's managed mixedwood forests.

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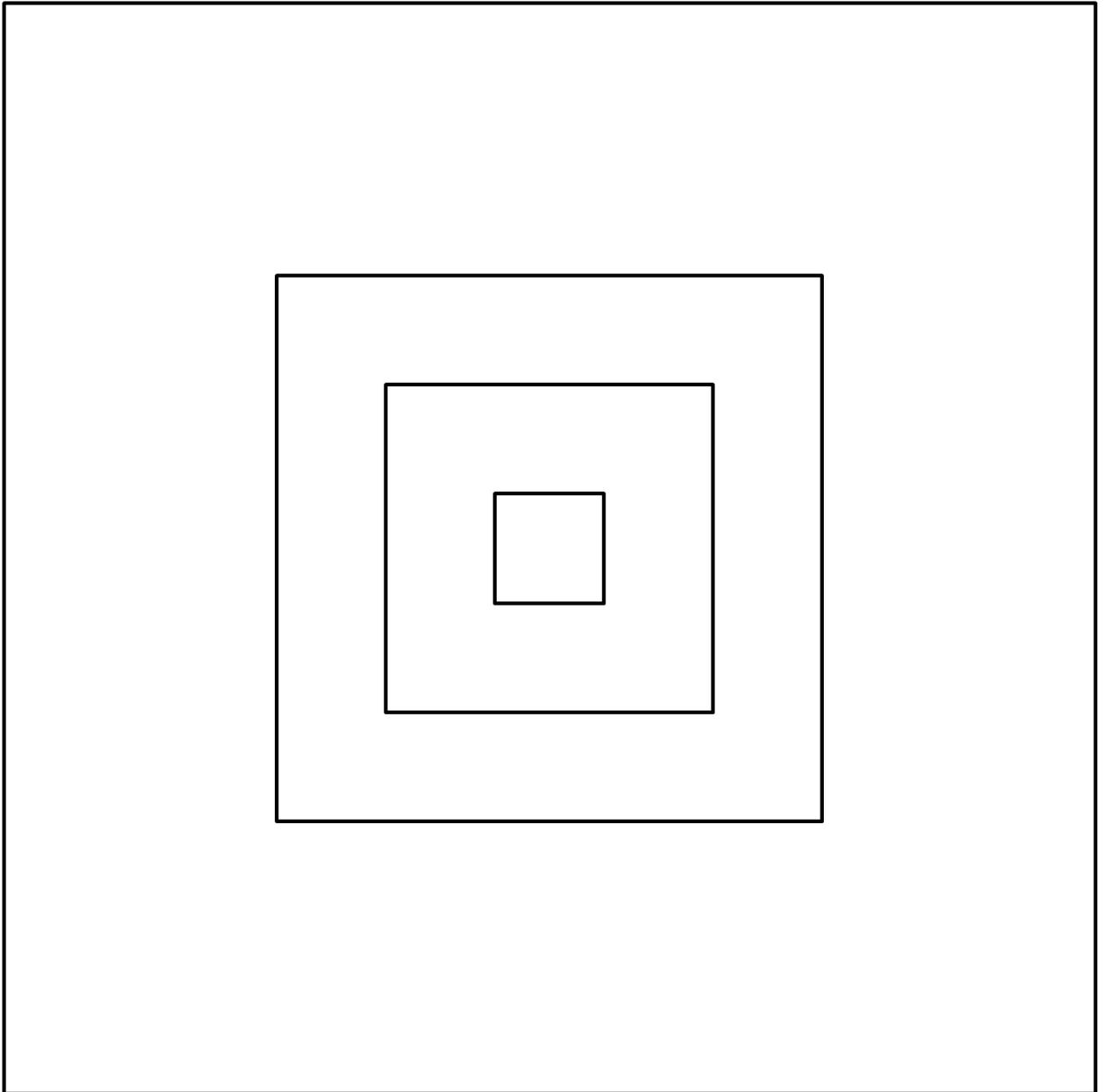
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APPENDICIES

Appendix one: example datasheets

Timmins Block 1 Natural					Date:	
Tree #	DBH (cm)	Tree Species	Coordinates		Comments...	
			N	W		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Example of datasheet used for the collection of tree information in the field.



Abundance class size chart. class one: $<4 \text{ cm}^2$, class two: $4 \text{ cm}^2 < x < 36 \text{ cm}^2$, class three: $36 \text{ cm}^2 < x < 100 \text{ cm}^2$, class 4: $100 \text{ cm}^2 < x < 200 \text{ cm}^2$, class 5: $>200 \text{ cm}^2$ (scaled to fit page).

Appendix two: tree data

Timmins residual tree description. DBH measured to the nearest half centimeter. Lichen species richness per tree. Tree elevation rounded to the nearest meter. Distance from tree to nearest point on landscape feature to nearest meter.

Block	Treatment	Tree Number	Tree Species	DBH (cm)	Richness	Elevation (m)	Distance (m) to		
							Forest	Road	River
1	Basic	121	<i>Betula papyrifera</i>	25	12	313	2	188	297
		122	<i>Populus tremuloides</i>	24	1	313	9	201	287
		123	<i>Picea glauca</i>	27	11	314	3	195	285
		124	<i>Populus tremuloides</i>	21	3	323	8	200	280
		125	<i>Populus tremuloides</i>	16	1	319	32	230	251
		126	<i>Picea glauca</i>	14.5	4	314	45	239	247
		127	<i>Abies balsamea</i>	11	2	313	53	244	248
		128	<i>Populus tremuloides</i>	16.5	1	316	58	263	220
		129	<i>Populus balsamifera</i>	24.5	2	320	77	268	224
		130	<i>Populus balsamifera</i>	15.5	2	323	82	265	217
	Intensive	131	<i>Populus spp.</i>	19.5	2	313	60	110	273
		132	<i>Populus spp.</i>	60	6	311	69	112	264
		133	<i>Abies balsamea</i>	12	5	309	97	157	229
		134	<i>Picea glauca</i>	52	8	311	78	194	206
		135	<i>Populus grandidentata</i>	13	2	309	87	183	214
		136	<i>Populus balsamifera</i>	25.5	2	309	98	173	230
		137	<i>Picea mariana</i>	10	11	313	3	83	329
		138	<i>Picea mariana</i>	17.5	8	315	2	98	328
		139	<i>Picea mariana</i>	20.5	8	320	0	93	331
		140	<i>Populus tremuloides</i>	52.5	3	303	0	78	336
	Natural	141	<i>Picea mariana</i>	20.5	11	338	0	45	257
		142	<i>Abies balsamea</i>	21	7	321	0	68	232
		143	<i>Populus tremuloides</i>	40.5	3	325	0	62	237
		144	<i>Betula papyrifera</i>	25.5	2	317	0	81	219
		145	<i>Abies balsamea</i>	21	14	323	0	113	186
		146	<i>Populus spp.</i>	47	5	338	0	141	159
		147	<i>Abies balsamea</i>	21	14	321	0	150	152
		148	<i>Populus spp.</i>	50	7	313	0	144	160
		149	<i>Picea mariana</i>	16.5	16	315	0	162	140
		150	<i>Populus spp.</i>	37	4	311	0	161	139
2	Basic	151	<i>Betula papyrifera</i>	31	14	306	38	828	376
		152	<i>Picea glauca</i>	46	9	313	64	856	402

		153	<i>Picea glauca</i>	20	8	317	83	875	420	
		154	<i>Abies balsamea</i>	23.5	12	314	93	893	421	
		155	<i>Picea glauca</i>	19	11	311	93	896	415	
		156	<i>Betula papyrifera</i>	39	2	312	81	883	405	
		157	<i>Betula papyrifera</i>	25	3	312	79	875	413	
		158	<i>Betula papyrifera</i>	17	2	313	82	854	432	
		159	<i>Picea glauca</i>	19	13	307	77	848	429	
		160	<i>Betula papyrifera</i>	32.5	4	311	85	842	424	
	Intensive	161	<i>Picea glauca</i>	29	13	320	90	1030	602	
		162	<i>Populus spp.</i>	36	4	312	66	1055	620	
		163	<i>Picea glauca</i>	37	12	314	27	1055	598	
		164	<i>Picea glauca</i>	19	11	318	25	1042	580	
	2	Intensive	165	<i>Picea glauca</i>	41	11	328	35	1025	551
			166	<i>Populus spp.</i>	41	2	318	7	1053	567
			167	<i>Picea glauca</i>	27	4	317	14	1046	554
			168	<i>Populus spp.</i>	42	4	306	0	1064	564
169			<i>Populus spp.</i>	44	4	315	16	1046	544	
170			<i>Populus spp.</i>	54	2	313	64	999	542	
Natural		171	<i>Betula papyrifera</i>	15	3	313	0	743	338	
		172	<i>Picea glauca</i>	43	13	314	0	726	316	
		173	<i>Populus spp.</i>	30	3	321	0	743	322	
		174	<i>Picea mariana</i>	24	8	318	0	736	313	
		175	<i>Abies balsamea</i>	21	16	313	0	704	284	
		176	<i>Picea mariana</i>	29	4	325	0	692	254	
		177	<i>Populus spp.</i>	16.5	3	312	0	685	239	
		178	<i>Picea mariana</i>	38	12	323	0	703	260	
		179	<i>Picea glauca</i>	36	15	324	0	735	279	
		180	<i>Populus spp.</i>	40	8	328	0	763	301	
3		Basic	181	<i>Populus spp.</i>	72	7	315	124	1123	383
			182	<i>Betula papyrifera</i>	32	12	314	98	1098	378
	183		<i>Abies balsamea</i>	24.5	14	318	90	1092	372	
	184		<i>Betula papyrifera</i>	32	2	306	120	1110	423	
	185		<i>Fraxinus spp.</i>	13	11	314	77	1081	359	
	186		<i>Betula papyrifera</i>	33	3	314	76	1071	393	
	187		<i>Populus spp.</i>	64	4	317	70	1061	401	
	188		<i>Populus spp.</i>	32	5	315	68	1052	411	
	189		<i>Populus spp.</i>	30	4	320	55	1033	418	
	190		<i>Populus spp.</i>	32	4	317	54	1038	409	
	Intensive	191	<i>Picea glauca</i>	10.5	10	313	103	813	371	
		192	<i>Betula papyrifera</i>	48	10	315	106	815	372	
		193	<i>Populus spp.</i>	59	3	316	122	807	351	

		194	<i>Populus spp.</i>	37	14	319	96	803	338	
		195	<i>Betula papyrifera</i>	45	4	321	91	827	359	
		196	<i>Picea mariana</i>	20	10	318	67	796	323	
		197	<i>Populus spp.</i>	64.5	4	319	69	797	325	
		198	<i>Populus spp.</i>	53	1	317	72	786	315	
		199	<i>Populus spp.</i>	45	3	319	35	791	309	
		200	<i>Picea mariana</i>	17.5	16	312	10	793	305	
		201	<i>Populus balsamifera</i>	19	9	303	0	855	342	
		202	<i>Abies balsamea</i>	15.5	11	319	0	850	329	
		203	<i>Picea glauca</i>	38	10	326	0	865	339	
	204	<i>Picea mariana</i>	29	4	321	0	874	349		
	205	<i>Picea mariana</i>	17	14	331	0	886	349		
	206	<i>Picea mariana</i>	39	8	328	0	896	351		
	207	<i>Abies balsamea</i>	27	14	328	0	900	346		
	208	<i>Populus spp.</i>	45	2	327	0	885	329		
	209	<i>Populus spp.</i>	23.5	6	315	0	917	357		
	210	<i>Populus spp.</i>	39	3	322	0	918	358		
	4	Basic	211	<i>Picea mariana</i>	17.5	11	330	29	1115	157
			212	<i>Populus spp.</i>	63	4	325	54	1103	183
			213	<i>Betula papyrifera</i>	22	1	332	60	1089	193
214			<i>Abies balsamea</i>	15	5	324	54	1074	190	
215			<i>Picea mariana</i>	15.5	5	317	54	1074	191	
216			<i>Betula papyrifera</i>	29	1	323	72	1003	229	
217			<i>Betula papyrifera</i>	37	3	320	71	1013	224	
218			<i>Betula papyrifera</i>	17	1	324	88	1032	234	
219			<i>Betula papyrifera</i>	26	5	327	53	1023	200	
220			<i>Abies balsamea</i>	18.5	15	328	52	1021	201	
221		<i>Picea mariana</i>	25.5	10	317	42	723	168		
222		<i>Populus spp.</i>	55	2	315	16	713	150		
223		<i>Picea mariana</i>	19	9	318	10	707	144		
224		<i>Picea glauca</i>	27	12	316	4	696	134		
225		<i>Picea mariana</i>	33	10	316	9	696	137		
226		<i>Populus spp.</i>	41	4	309	3	676	134		
227		<i>Picea mariana</i>	17.5	9	309	33	705	165		
228		<i>Populus spp.</i>	35	6	318	3	688	133		
229		<i>Abies balsamea</i>	12	1	312	61	731	195		
230		<i>Populus spp.</i>	10.5	1	311	78	763	206		
231	<i>Abies balsamea</i>	14.5	19	330	0	999	132			
232	<i>Betula papyrifera</i>	44.5	8	320	0	1004	104			
233	<i>Abies balsamea</i>	16	15	324	0	1023	91			
234	<i>Populus tremuloides</i>	30	3	329	0	1053	76			

	235	<i>Picea mariana</i>	24.5	13	331	0	1051	77
	236	<i>Betula papyrifera</i>	16	4	325	0	1056	66
	237	<i>Betula papyrifera</i>	12.5	2	330	0	1072	58
	238	<i>Populus</i> spp.	31.5	2	333	0	1087	70
	239	<i>Pinus resinosa</i>	23.5	15	335	0	1038	102
	240	<i>Abies balsamea</i>	27	11	337	0	1092	82

Petawawa residual tree description. DBH measured to the nearest half centimeter. Lichen species richness per tree. Tree elevation rounded to the nearest meter. Distance from tree to nearest point on landscape feature to nearest meter.

Block	Treatment	Tree Number	Tree Species	DBH (cm)	Richness	Elevation (m)	Distance (m) to		
							Road	Hydro	Wetland
1	Basic	1	<i>Pinus strobus</i>	69.5	7	62	390	1007	570
		2	<i>Pinus resinosa</i>	43.5	3	62	378	1019	561
		3	<i>Pinus strobus</i>	57.5	8	65	351	1048	534
		4	<i>Pinus strobus</i>	81.5	10	67	333	1067	523
		5	<i>Acer saccharum</i>	22	2	60	348	1056	505
		6	<i>Populus</i> sp.	37.5	6	63	318	1083	514
		7	<i>Acer</i> sp.	21.5	2	64	325	1076	512
		8	<i>Pinus strobus</i>	35	10	65	310	1088	527
		9	<i>Abies balsamea</i>	11	10	62	299	1097	536
		10	<i>Quercus rubra</i>	21	4	62	278	1119	528
	Intensive	11	<i>Pinus strobus</i>	47	5	62	264	1150	442
		12	<i>Abies balsamea</i>	13	12	66	280	1145	415
		13	<i>Abies balsamea</i>	19.5	10	64	291	1139	398
		14	<i>Pinus strobus</i>	66	5	64	302	1124	417
		15	<i>Pinus strobus</i>	44	14	65	326	1102	419
		16	<i>Acer saccharum</i>	21.5	4	65	328	1100	419
		17	<i>Pinus strobus</i>	66	2	65	339	1077	457
		18	<i>Abies balsamea</i>	24.5	8	66	323	1092	455
		19	<i>Acer spicatum</i>	18	3	65	338	1077	462
		20	<i>Abies balsamea</i>	57.5	5	65	350	1070	453
	Natural	21	<i>Fraxinus nigra</i>	14.5	2	64	193	1326	1326
		22	<i>Picea glauca</i>	17	8	69	182	1334	1334
		23	<i>Picea glauca</i>	25	9	64	167	1343	1343
		24	<i>Acer saccharum</i>	14	4	68	189	1323	1323
		25	<i>Acer saccharum</i>	31.5	6	65	189	1316	1316
		26	<i>Pinus strobus</i>	38	11	66	228	1286	1286
		27	<i>Pinus strobus</i>	49	12	68	236	1287	1287
		28	<i>Acer saccharum</i>	12.5	5	66	246	1289	1289
		29	<i>Abies balsamea</i>	12.5	11	68	258	1278	1278
		30	<i>Populus tremuloides</i>	26	6	66	222	1313	1313

2	Basic	31	<i>Abies balsamea</i>	12	13	63	222	267	494
		32	<i>Acer saccharum</i>	23	6	64	213	256	502
		33	<i>Pinus strobus</i>	62	5	63	207	240	520
		34	<i>Acer rubrum</i>	19.5	4	62	202	232	527
		35	<i>Acer saccharum</i>	20.5	4	63	194	295	492
		36	<i>Abies balsamea</i>	13.5	12	63	165	323	483
		37	<i>Abies balsamea</i>	15	14	64	149	337	481
		38	<i>Acer rubrum</i>	50.5	3	65	157	337	451
		39	<i>Picea glauca</i>	44.5	11	64	148	348	440
		40	<i>Acer rubrum</i>	52.5	5	62	152	344	442
	Intensive	41	<i>Pinus strobus</i>	32	8	62	63	33	423
		42	<i>Quercus rubra</i>	43	6	63	59	49	418
		43	<i>Acer saccharum</i>	17	5	64	69	53	427
		44	<i>Acer rubrum</i>	16	5	60	99	70	457
		45	<i>Acer saccharum</i>	23.5	5	60	127	99	485
		46	<i>Acer saccharum</i>	15.5	2	60	126	112	482
		47	<i>Acer saccharum</i>	15	4	60	131	119	486
		48	<i>Abies balsamea</i>	15.5	7	65	135	130	489
		49	<i>Acer spicatum</i>	13	7	60	152	145	504
		50	<i>Abies balsamea</i>	16	14	61	153	151	505
	Natural	51	<i>Picea mariana</i>	18.5	12	62	101	343	153
		52	<i>Pinus strobus</i>	22	11	62	115	330	142
		53	<i>Acer saccharum</i>	13	4	63	127	313	129
		54	<i>Pinus strobus</i>	61.5	12	64	122	289	131
		55	<i>Abies balsamea</i>	20.5	14	63	106	297	148
		56	<i>Betula papyrifera</i>	19	1	62	92	281	161
		57	<i>Acer saccharum</i>	20	4	63	86	281	167
		58	<i>Populus tremuloides</i>	25.5	6	58	83	253	175
		59	<i>Acer saccharum</i>	13	4	62	87	253	171
		60	<i>Acer sp.</i>	23	3	60	82	257	175
3	Basic	61	<i>Pinus strobus</i>	68	9	62	309	91	82
		62	<i>Abies balsamea</i>	13	9	59	293	99	63
		63	<i>Pinus strobus</i>	49	9	61	336	69	103
		64	<i>Pinus resinosa</i>	41	3	63	310	85	75
		65	<i>Pinus resinosa</i>	64	8	63	321	93	104
		66	<i>Pinus resinosa</i>	29.5	7	61	320	96	104
		67	<i>Acer rubrum</i>	15.5	6	64	330	100	133
		68	<i>Picea mariana</i>	11.5	7	59	348	84	157

4	Intensive	69	<i>Pinus strobus</i>	56.5	6	60	358	72	156
		70	<i>Pinus strobus</i>	63.5	11	60	369	62	166
		71	<i>Pinus strobus</i>	72	9	63	254	213	227
		72	<i>Acer rubrum</i>	20.5	3	62	218	235	179
		73	<i>Populus sp.</i>	20.5	6	62	203	253	172
		74	<i>Acer rubrum</i>	24	8	60	218	233	173
		75	<i>Pinus strobus</i>	63	12	61	205	244	163
		76	<i>Fraxinus nigra</i>	15.5	1	63	213	228	151
		77	<i>Abies balsamea</i>	16.5	12	61	202	237	139
		78	<i>Acer sp.</i>	17	5	61	190	245	122
		79	<i>Acer sp.</i>	20	5	61	200	234	123
		80	<i>Pinus strobus</i>	70	12	61	158	280	110
	Natural	81	<i>Pinus strobus</i>	61.5	6	57	448	321	73
		82	<i>Pinus strobus</i>	37.5	6	57	423	323	48
		83	<i>Abies balsamea</i>	18	8	58	429	320	51
		84	<i>Acer saccharum</i>	16	7	54	419	309	31
		85	<i>Abies balsamea</i>	13.5	3	55	395	336	29
		86	<i>Acer rubrum</i>	16.5	2	49	380	368	47
		87	<i>Pinus resinosa</i>	59	5	56	392	362	50
		88	<i>Abies balsamea</i>	18	7	61	414	377	84
89		<i>Acer saccharum</i>	21.5	6	57	417	360	72	
90		<i>Populus tremuloides</i>	40.5	7	63	451	344	95	
Basic	91	<i>Populus tremuloides</i>	30.5	5	60	132	1027	191	
	92	<i>Acer saccharum</i>	24	8	59	148	1028	173	
	93	<i>Pinus strobus</i>	69	13	60	144	997	179	
	94	<i>Acer rubrum</i>	23	3	62	168	1020	153	
	95	<i>Picea glauca</i>	14	4	63	176	1014	146	
	96	<i>Pinus strobus</i>	59	9	60	198	1025	124	
	97	<i>Pinus strobus</i>	44	7	57	210	1027	113	
	98	<i>Acer rubrum</i>	16	4	62	185	1020	137	
	99	<i>Populus balsamifera</i>	47	8	58	179	1029	142	
	100	<i>Abies balsamea</i>	11	15	62	179	1017	143	
Intensive	101	<i>Quercus rubra</i>	26.5	11	58	107	1328	280	
	102	<i>Pinus strobus</i>	59	13	60	87	1318	294	
	103	<i>Betula papyrifera</i>	21	8	62	91	1293	281	
	104	<i>Acer rubrum</i>	21	5	60	107	1286	264	
	105	<i>Pinus resinosa</i>	44.5	8	63	106	1292	266	
	106	<i>Pinus resinosa</i>	45	7	60	92	1279	276	

		107	<i>Acer saccharum</i>	27	7	61	108	1265	257
		108	<i>Pinus strobus</i>	50	13	61	97	1239	263
		109	<i>Pinus resinosa</i>	19	4	63	110	1273	257
		110	<i>Picea mariana</i>	11.5	10	60	122	1259	243
	Natural	111	<i>Abies balsamea</i>	13.5	11	58	254	1106	78
		112	<i>Acer rubrum</i>	17	3	58	270	1137	68
		113	<i>Populus balsamifera</i>	44.5	6	56	250	1123	84
		114	<i>Abies balsamea</i>	13	14	61	253	1123	81
		115	<i>Pinus strobus</i>	41.5	14	59	253	1107	80
		116	<i>Acer saccharum</i>	21	2	57	268	1157	76
		117	<i>Pinus strobus</i>	45.5	14	58	269	1172	81
		118	<i>Populus tremuloides</i>	41.5	6	60	252	1162	95
		119	<i>Abies balsamea</i>	21.5	12	61	242	1151	101
		120	<i>Populus tremuloides</i>	26.5	10	60	195	1156	151

Appendix three: site photos of intensities

Timmins Natural



Timmins Basic



Timmins Intensive



Petawawa Natural



Petawawa Basic



Petawawa Intensive



Appendix four: species and authorities

Vascular species scientific and common names with authorities.

Scientific names	Common name	Authorities
<i>Abies balsamea</i>	Balsam fir	(L.) Mill.
<i>Acer rubrum</i>	Red maple	L.
<i>Acer saccharum</i>	Sugar maple	Marsh.
<i>Acer</i> sp.	Maple	--
<i>Acer spicatum</i>	Mountain maple	Lam.
<i>Betula papyrifera</i>	Paper birch	Marsh.
<i>Cornus</i> spp.	Dogwood	--
<i>Eucalyptus regnans</i>	Mountain ash	F.Muell.
<i>Fraxinus excelsior</i>	European ash	L.
<i>Fraxinus nigra</i>	Black ash	Marsh.
<i>Picea glauca</i>	White spruce	(Moench) Voss
<i>Picea mariana</i>	Black spruce	(Mill.) B. S. P.
<i>Pinus resinosa</i>	Red pine	Ait.
<i>Pinus strobus</i>	White pine	L.
<i>Pinus sylvestris</i>	Scots pine	L.
<i>Populus balsamifera</i>	Balsam poplar	L.
<i>Populus</i> sp.	Poplar	--
<i>Populus tremula</i>	European aspen	L.
<i>Populus tremuloides</i>	Trembling aspen	Michx.
<i>Quercus rubra</i>	Red oak	L.
<i>Sorbus</i> spp.	Mountain ash	--
<i>Thuja plicata</i>	Western red cedar	Donn ex D. Don
<i>Tsuga heterophylla</i>	Western hemlock	(Raf.) Sarg.

Lichen species scientific names and authorities.

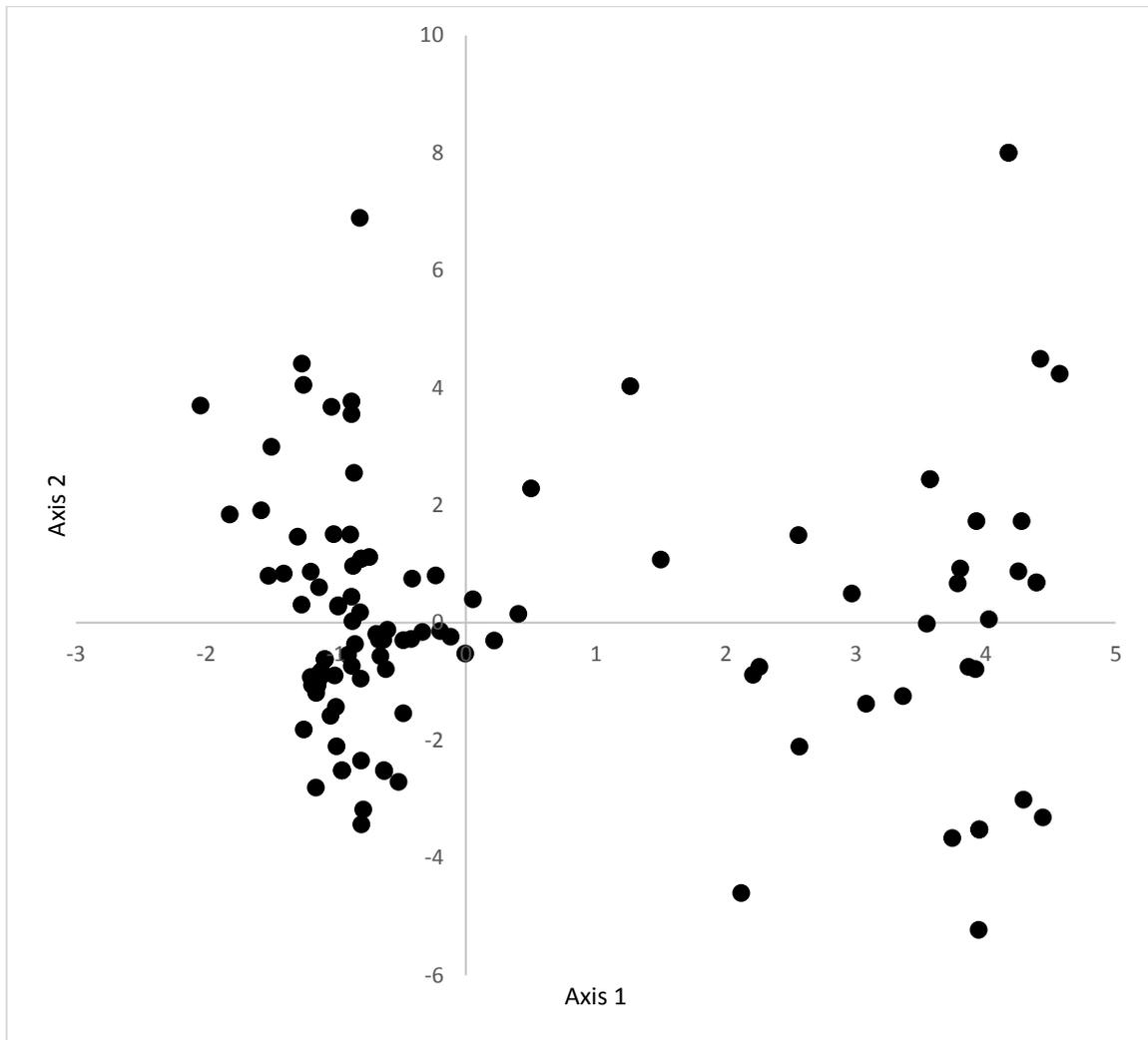
Scientific names	Authorities
<i>Alectoria sarmentosa</i>	(Ach.) Ach.
<i>Biatora pycnidata</i>	Printzen & Tønsberg
<i>Biatora</i> spp.	--
<i>Biatora vernalis</i>	(L.) Fr.
<i>Bilimbia sabuletorum</i>	(Schreber) Arnold
<i>Bryoria furcellata</i>	(Fr.) Brodo & D. Hawksw.
<i>Bryoria</i> spp.	--
<i>Buellia disciformis</i>	(Fr.) Mudd
<i>Buellia erubescens</i>	Arnold

<i>Calicium parvum</i>	Tibell
<i>Calicium trabinellum</i>	(Ach.) Ach
<i>Calicium viride</i>	Pers.
<i>Caloplaca pyracea</i>	(Ach.) Th. Fr.
<i>Chaenotheca chrysocephala</i>	(Ach.) Th. Fr.
<i>Chaenotheca ferruginea</i>	(Turner ex Sm.) Mig.
<i>Chaenotheca laevigata</i>	Nádv.
<i>Chaenothecopsis marcineae</i>	Selva (Selva)
<i>Chaenothecopsis nana</i>	Tibell
<i>Cladonia chlorophaea</i>	(Flörke ex Sommerf.) Spreng.
<i>Cladonia coniocraea</i>	(Flörke) Spreng.
<i>Cladonia deformis</i>	(L.) Hoffm.
<i>Cladonia digitata</i>	(L.) Hoffm.
<i>Cladonia fimbriata</i>	(L.) Fr.
<i>Cladonia grayi</i>	G. Merr. ex Sandst.
<i>Cladonia macilenta</i> var. <i>bacillaris</i>	(Genth) Schaer.
<i>Cladonia macilenta</i> var. <i>macilenta</i>	Hoffm.
<i>Cladonia merochlorophaea</i>	Asahina
<i>Cladonia norvegica</i>	Tønsberg & Holien
<i>Cladonia ochrochlora</i>	Flörke
<i>Cladonia</i> spp.	--
<i>Coenogonium luteum</i>	(Dicks.) Kalb & Lücking
<i>Evernia mesomorpha</i>	Nyl.
<i>Flavoparmelia caperata</i>	(L.) Hale
<i>Fuscidea arboricola</i>	Coppins & Tønsberg
<i>Fuscidea pusilla</i>	Tønsberg
<i>Gyalolechia xanthostigmoidea</i>	(Räs.) Søchting, Frödén & Arup
<i>Hypogymnia physodes</i>	(L.) Nyl.
<i>Hypogymnia</i> spp.	--
<i>Hypogymnia tubulosa</i>	(Schaer.)
<i>Imshaugia aleurites</i>	(Ach.) S.F. Mey.
<i>Lecania croatica</i>	(Zahlbr.) Kotlov
<i>Lecanora albula</i>	(Nyl.) Hue
<i>Lecanora allophana</i>	Nyl.
<i>Lecanora allophana</i> f. <i>sorediata</i>	Nyl.
<i>Lecanora cirumborealis</i>	Brodo & Vitik.
<i>Lecanora hybocarpa</i>	(Tuck.) Brodo
<i>Lecanora pulcaris</i>	(Pers.) Ach.
<i>Lecanora</i> spp.	--
<i>Lecanora symmicta</i>	(Ach.) Ach.
<i>Lecanora thysanophora</i>	Harris
<i>Lepraria</i> cf. <i>neglecta</i>	(Nyl.) Erichsen
<i>Lepraria finkii</i>	(B. de Lesd.) R. C. Harris

<i>Lepraria</i> sp.	--
<i>Leptogium hirsutum</i>	Sierk
<i>Loxospora elatina</i>	(Ach.) A. Massal.
<i>Melanelixia subaurifera</i>	(Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch
<i>Melanohalea olivacea</i>	(L.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch
<i>Micarea</i> sp.	--
<i>Myelochroa galbina</i>	(Ach.) Elix & Hale
<i>Ochrolechia arborea</i>	(Kreyer) Almb.
<i>Parmelia saxatilis</i>	(L.) Ach.
<i>Parmelia</i> spp.	--
<i>Parmelia squarrosa</i>	Hale
<i>Parmelia sulcata</i>	Taylor
<i>Peltigera canina</i>	(L.) Willd.
<i>Peltigera elisabethae</i>	Gyeln.
<i>Peltigera evansiana</i>	Gyeln.
<i>Peltigera praetextata</i>	(Flörke ex Sommerf.) Zopf
<i>Phaeophyscia kairamoi</i>	(Vain.) Moberg
<i>Phaeophyscia pusilloides</i>	(Zahlbr.) Essl.
<i>Phlyctis</i> spp.	--
<i>Physcia adscendens</i>	(Fr.) H. Olivier
<i>Physciella chloantha</i>	(Ach.) Essl.
<i>Physconia detersa</i>	(Nyl.) Poelt
<i>Rinodina</i> spp.	--
<i>Ropalospora viridis</i>	(Tønsberg) Tønsbergs
<i>Scoliciosporum chlorococcum</i>	(Stenh.) Vězda
<i>Stenocybe major</i>	(Nyl.) Körb.
<i>Tuckermannopsis americana</i>	(Spreng.) Hale
<i>Tuckermannopsis orbata</i>	(Nyl.) M. J. Lai
<i>Usnea</i> cf. <i>scabrata</i>	Nyl.
<i>Usnea filipendula</i>	Stirt.
<i>Usnea hirta</i>	(L.) F. H. Wigg.
<i>Usnea subfloridana</i>	Stirt.
<i>Usnea</i> spp.	--
<i>Usnocetraria oakesiana</i>	(Tuck.) M.J. Lai & C.J. Wei
<i>Variolaria pustulata</i>	(Brodo & W. L. Culb.) Lendemer, Hodkinson & R. C. Harris
<i>Vulpicidia pinastri</i>	(Scop.) J.-E. Mattsson & M.J. Lai
<i>Xanthoria</i> spp.	--

Appendix five: species ordinations

CCA ordination of 117 lichen species and 116 residual trees from Timmins constrained by nine environmental variables in the bi-plot diagram found in figure 3.5. Each point represents a lichen species. Points closer together are more commonly found on the same trees than those farther apart.



CCA ordination of 130 lichen species and 116 residual trees from Petawawa constrained by nine environmental variables in the bi-plot diagram found in figure 3.6. Each point represents a lichen species. Points closer together are more commonly found on the same trees than those farther apart.

