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DE L'EFFET LAC AUX BÛCHES DE BOIS : LA DISTRIBUTION DES BRYOPHYTES DANS LES FORÊTS DU LAC SUPÉRIEUR

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FROM LAKE EFFECT TO LOGS : THE DISTRIBUTION OF BRYOPHYTES IN LAKE SUPERIOR'S FORESTS

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FORWARD

This dissertation is presented in the form of an article with multiple authors. I, Deanna Holt-Schmitt, am the main person responsible for the data collection, analyzing, and writing of this article. My research supervisor, Nicole Fenton, contributed to the design of the study and assisted in interpretation of the results. She also was critical in the editing and revision of the contents of this article. Field work planning and completion was carried out jointly with Rémi Boisvert, who also assisted with some of the statistical analysis.

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RÉSUMÉ

Les bryophytes sont une composante fondamentale de l'écosystème forestier boréal, contribuant à la productivité primaire et à la succession forestière. Afin de maintenir des communautés de bryophytes diversifiées, l'hétérogénéité des habitats à l'échelle du substrat, du peuplement et du paysage est essentielle. Le climat humide du lac Supérieur offre un excellent habitat à une plus grande diversité d'espèces de bryophytes, avec un paysage accidenté qui crée des microclimats et des vieilles forêts avec une abondance de substrats disponibles pour la colonisation des bryophytes. Cependant, l'augmentation des activités anthropiques telles que la foresterie, l'exploitation minière et l'extraction d'agrégats menacent les conditions environnementales propices aux bryophytes. Afin de protéger les bryophytes, cette étude vise à identifier les facteurs environnementaux ayant la plus grande influence sur leur richesse diversité. Notre objectif principal est de déterminer la relation entre l'humidité ambiante généré par le lac Supérieur, en fonction de la distance au lac, et la diversité et la richesse des bryophytes. Notre objectif secondaire est d'évaluer l'effet de l'échelle spatiale sur les patrons de la richesse et de la diversité en utilisant des facteurs environnementaux au niveau du paysage, du peuplement et du substrat.

Pour atteindre nos objectifs, huit transects de dix parcelles chacun ont été disposés perpendiculairement aux rives nord et est du lac Supérieur. Les dix parcelles ont été disposées le long du gradient avec des distances de 0, 1, 2,5, 5, 10, 20, 35, 55, 75, 100 km du bord du lac. Des sondes d'humidité et de température ont été placés sur trois parcelles par transect et ont enregistré de septembre 2021 à septembre 2022. Au niveau du peuplement, les parcelles ont été sélectionnées en fonction de l'âge de la forêt, de sa composition et de sa proximité à partir de variables confondantes telles que les routes, les voies ferrées et les sources d'eau. Les variables forestières recueillies comprenaient l'âge relatif, la composition du peuplement forestier, la surface terrière, le couvert forestier et le sol. Dans chaque parcelle, des bryophytes ont été échantillonnées sur cinq réplicas de quatre substrats : le boismort au sol, les roches, les bouleaux et les épinettes vivantes. La longueur, la superficie et le dhp ont été collectés sur les substrats associés, et les roches ont été soumises à un test d'acide. Les échantillons de bryophytes ont été séchés sur le terrain et identifiés en laboratoire. L'analyse de la richesse, de la diversité et de la composition a été réalisée à l'aide de régressions linéaires, de modèles mixtes et d'ordinations à l'aide du logiciel R.

Cette étude a permis d'identifier 145 espèces de bryophytes, dont 22 espèces répertoriées comme étant en voie de disparition en Ontario. Nous avons identifié une relation négative entre la richesse et la diversité des bryophytes avec la distance du lac Supérieur, et donc l'humidité de l'effet lac, atteignant ainsi notre premier objectif. La richesse et la diversité des espèces de bryophytes étaient les plus hautes dans les cinq premiers kilomètres du bord du lac. Ces valeurs ont diminué sur les distances moyennes de 10 à 35 km et ont légèrement augmenté sur les distances les plus éloignées de 55 à 100 km, reproduisant le modèle d'humidité de l'effet de lac que nous avons observé. Généralement, les mousses avaient une richesse moyenne plus élevée que les hépatiques, et le bois mort avait le plus d'occurrences des espèces. L'inclusion de variables environnementales au niveau du peuplement et du paysage a modéré la relation entre la richesse en bryophytes et la distance. La richesse et la diversité des bryophytes étaient associées de manière significative aux facteurs liés au peuplement et au paysage à l'échelle du site, qui à leur tour étaient associés à l'orientation géographique des transects sur la rive nord ou est du lac Supérieur. L'inclusion supplémentaire de variables au niveau du substrat a conduit à une augmentation du nombre de modèles significatifs avec une diversité gamma divisée par groupe taxonomique et type de substrat. Ces résultats répondent à notre deuxième objectif d'évaluer l'effet d'échelle sur les patrons de diversité, nous conduisant à croire que la richesse et la diversité des bryophytes sont influencées par une hiérarchie de variables environnementales, le niveau de substrat présentant la plus grande influence, suivi du niveau du peuplement et du paysage. Cette évaluation d'identification de la hiérarchie d'influence des variables environnementales permet de prioriser les stratégies de protection et de gestion forestière. Cela contribuera à conserver toutes les bryophytes et la biodiversité de l’écosystème dans son ensemble.

ABSTRACT

Bryophytes are a fundamental component of the boreal forest ecosystem, contributing to primary productivity and forest succession. In order to maintain diverse bryophyte communities, habitat heterogeneity at the substrate, stand, and landscape scale is essential. The humid climate of Lake Superior provides this excellent habitat for a high diversity of bryophyte species, with a rugged landscape that creates high humidity microclimates and older forests with an abundance of substrates available for bryophyte colonization. However, increasing anthropogenic activities such as forestry, mining, and aggregate extraction threaten environmental conditions suitable for bryophytes. In order to protect bryophytes, this study aims to identify the environmental factors with the largest influence on richness and diversity. Our primary objective is to determine the relationship between Lake Superior's humidity, using distance from the lake, on bryophyte diversity and richness. Our secondary objective is to evaluate the effect of scale on richness and diversity using environmental factors at the landscape, stand, and substrate level.

To achieve our objectives, eight transects containing ten sites each were arranged perpendicular to the northern and eastern shores of Lake Superior. The ten sites were arranged in a gradient with distances of 0, 1, 2.5, 5, 10, 20, 35, 55, 75, 100km from the lake shore. Data loggers were placed on three sites per transect and recorded temperature and humidity from September 2021 to 2022. At the stand level, sites were selected based on forest age, composition, and distance from potentially confounding factors such as roads, railways, and water sources. Forest variables collected included relative age, over- and understory composition of woody, herbaceous, and non-vascular plants, basal area, canopy cover, and soil type. Within each site, bryophytes were sampled from five replicates of four substrates: logs, rocks, and live birch and spruce trees. The length and dbh of logs and surface area of rocks were collected from the substrates, as well as rocks being subjected to an acid test. Bryophyte samples were dried in the field and identified in the laboratory. Analysis on richness, diversity, and composition was conducted using linear regressions, mixed models, and ordinations using R software.

This study resulted in the identification of 145 bryophyte species, including 22 species listed as endangered in Ontario. We identified a negative relationship between bryophyte richness and diversity with distance from Lake Superior, and lake-effect humidity, achieving our first objective. Both richness and diversity in bryophyte species had the highest occurrences within the first five kilometers from the shore. These values were lower in the middle distances of 10-35km and increased slightly in the inland distances of 55-100km, replicating the pattern in lake-effect humidity we observed. Consistently, mosses had higher mean richness than liverworts, and log substrates had highest number of species occurrences as compared to other sampled substrate types. The inclusion of stand and landscape level environmental variables decreased the relationship between bryophyte richness and distance. Bryophyte richness and diversity was significantly associated with stand and landscape level factors at the site scale, which in turn were associated with the geographic orientation of the transects on the north or east shore of Lake Superior. The further inclusion of substrate level variables led to an increase in significant models with gamma diversity divided by taxonomic group and substrate type. These results achieve our second objective of evaluating the effect of spatial scale on bryophyte diversity patterns, leading us to believe that bryophyte richness and diversity is influenced by a hierarchy of environmental variables with the substrate level exhibiting the greatest influence, followed by the stand, and landscape level. This evaluation of identifying the hierarchy of influence of environmental variables allows for the prioritization of protection

strategies and forest management. This will aid in conserving all bryophytes and the biodiversity of the ecosystem as a whole.

CHAPTER I

GENERAL INTRODUCTION

1.1 The bryophyte component

Bryophytes are an important component of the boreal forest ecosystem. Despite their small stature, the high abundance of bryophytes means they are substantial primary producers of biomass, and production can exceed the values of herbaceous species in stands at intermediate stages of succession (Kumar et al., 2018; Müller et al., 2019). Bryophytes impact carbon and nutrient cycles by contributing up to 13% of gross primary productivity and storing up to 50% of gross CO_2 uptake in forests (Botting & Fredeen, 2006; Greiser et al., 2021; Müller et al., 2019).

The unique physiology of bryophytes allows them to colonize many substrates unsuitable for higher plants; essential for ecosystem succession in the boreal forest (Green et al., 2011; Müller et al., 2019). Along with lichens, bryophytes are among the first plants to colonize exposed bedrock, making them essential for primary soil formation (Hudson et al., 2021). Ground bryophyte communities act as a diffusive barrier over soil by conserving water and regulating temperature extremes (Moore et al., 2019). Despite their limited stature, bryophyte communities are a key component of carbon cycles, primary production, and succession in the boreal forest ecosystem (Greiser et al., 2021; Hudson et al., 2021; Müller et al., 2019).

Many bryophytes favour moist environments as poikilohydric species, and their water content is often at equilibrium with their environment (Green et al., 2011; Merinero et al., 2020). Their sensitivity to desiccation varies by species and seasonally (Green et al., 2011). One water conservation strategy is their small stature (Proctor et al., 2007). Their limited size increases their surface area to volume ratio and allows for more interaction between individual cells and the atmosphere; this allows for water to be absorbed directly into the cell that requires it (Proctor et al., 2007). Other structures allow them to separate water storage from gas exchange such as concave leaves that are hydrophilic to keep water close to the stem, and using papillae and mammillae to move water between structures on leaf surfaces (Green et al., 2011). Mosses also grow in cushions and turfs to enhance water storage at the community level (Green et al., 2011). The capacity to control water content within and between individuals allows for bryophyte growth and persistence despite variable moisture availability (Bartels et al., 2018).

In bryophytes of boreal and temperate ecosystems, yearly growth is timed around the wetter portions of the growing season, i.e. the spring and fall (Hudson et al., 2021). Their metabolic activities rely on microclimate conditions of increased water availability, often in the form of humidity, fog, or dew (Botting & Fredeen, 2006; Green et al., 2011). In landscapes where atmospheric moisture is frequently higher, bryophytes growing withing closed forests are able to maintain metabolic productivity consistently, even during an infrequent dry period (Hudson et al., 2021; Ratcliffe, 1968). Moisture in the form of precipitation is also beneficial to bryophyte growth and metabolism; however, the distribution and frequency of the precipitation is more important than the amount as bryophytes have limited abilities to store water, unlike higher plants (Ratcliffe, 1968).

Due to their high sensitivity to anthropogenic activities, bryophytes are often used as indicator species (Newmaster et al., 2003). Anthropogenic disturbances can greatly reduce the abundance and diversity of bryophyte species in the boreal forest with activities such as timber harvesting, mineral exploration, and agriculture (Newmaster et al., 2003; Wester et al., 2018). Disruptions in forest ecosystems can affect the humidity, light levels, temperature, and availability of substrates for colonization (Newmaster et al., 2003). Forest management practices such as clear-cutting and draining drastically reduce bryophyte species presence, and limit the capacity of forests to buffer temperatures, creating super-heated areas where moisture is pulled from adjacent stands (Greiser et al., 2021; Newmaster et al., 2003). Re-establishment of these communities, once humidity conditions are re-established, depends on substrate availability and source populations. Lack of available substrates for colonization or low species diversity in adjacent forests will greatly increase the time for bryophyte recolonization (Boudreault et al., 2018; Newmaster et al., 2003). Areas that have seen increased severity or frequency of disturbances through anthropogenic activities can lose bryophyte diversity over time, as these sensitive species are unable to recolonize.

1.2 Lake Superior's climate

Lake Superior imposes a large climatic effect on the surrounding boreal forests (Scott & Huff, 1996). Its size and alignment with prevailing winds spread moderating temperatures and increased atmospheric moisture approximately 80km inland from its shores (Scott & Huff, 1996). It's estimated that 48% of the moisture evaporated remains in the atmosphere downwind of the lake as increased cloud cover, water vapor, fog, and precipitation (Scott & Huff, 1996; Wester et al., 2018). These cooler and wetter sites along Superior's shore support arctic-alpine plant species, extending their distribution beyond their typical favoured environments (Wester et al., 2018). Many bryophyte species are able to colonize these shores and maintain a high photosynthetic rate due to water availability (Greiser et al., 2021; Lee & La Roi, 1979a). Areas of high atmospheric humidity support bryophyte species richness and diversity; for example, many European bryophytes show a bias to the Atlantic costal region (Mills & Macdonald, 2004; Ratcliffe, 1968).

The topography of Lake Superior's shoreline creates a number of differing microclimates within the forest stands that work to increase bryophyte biodiversity (Ratcliffe, 1968; Wester et al., 2018). The north-east shore consists of rugged and exposed bedrock formed into ridges and kettles, creating a landscape of cooler than normal and warmer than normal climate pockets (Wester et al., 2018). This mosaic of microclimates works to increase resource gradients and habitat variety at local stand levels and directly affects species diversity (Tukiainen et al., 2017; Wester et al., 2018). Increased diversity of geological features has been strongly associated with increased richness of bryophytes, especially threatened species (Tukiainen et al., 2017). For bryophytes on the Atlantic coast of the British Isles, the rugged terrain magnifies local humidity, while ice action increases habitat availability through fragmentation of the shoreline (Ratcliffe, 1968). Similar situations occur on the Pacific coast of British Columbia where pockets of diverse old growth are associated with high humidity habitats such as depressions, canyons, and spray zones (Newmaster et al., 2003). The increased geodiversity of Lake Superior's shore has numerous microclimates which maximize the stand level habitat heterogeneity (Tukiainen et al., 2017; Wester et al., 2018). This is observed less frequently as the topography becomes less variable inland (Wester et al., 2018).

1.3 Local habitat heterogeneity

While climactic gradients may determine species distributions (Lawler et al., 2015), the geophysical and stand level processes affecting the heterogeneity of the understory have a greater influence on bryophyte species diversity at local scales (Tukiainen et al., 2017). Many studies have shown that increased habitat heterogeneity leads to an increase in bryophyte species (Fenton & Bergeron, 2008; Mills & Macdonald, 2004; Newmaster et al., 2003). High degrees of habitat heterogeneity is generally associated with stand age and continuity, small-scale disturbances, and the availability of a variety of substrate types (Boudreault et al., 2018; Fenton & Bergeron, 2008; Kumar et al., 2018; Newmaster et al., 2003).

The closed environment of a forest stand provides favourable environmental conditions such as higher humidity, lower wind, and lower light intensity, which are preferred for bryophyte colonization (Newmaster et al., 2003). Allowing a forest ecosystem to age allows for the creation of a diversity of substrate habitats and for colonization by bryophytes with different functional traits (Boudreault et al., 2018). The increase in variety and availability of substrates then allows for colonization by rare and endemic species, and those with reduced tolerance to competition, those that require specific growing conditions, and late successional species (Austrheim et al., 2005; Boudreault et al., 2018; Newmaster et al., 2003). Consequently, old growth stands contain a greater species richness and biomass of bryophytes than younger stands (Kumar et al., 2018; Newmaster et al., 2003).

The development of habitat heterogeneity in old growth forests often occurs from the accumulation of unpredictable small-scale disturbances (Boudreault et al., 2018;

Fenton & Bergeron, 2008). These random occurrences create a variety of substrates available for colonization and allow for unique assemblages of smaller, less competitive species (Boudreault et al., 2018; Fenton & Bergeron, 2008). A small disturbance, such as windthrow bringing down a canopy tree, can create multiple different microclimates and substrates for a greater diversity of bryophyte species (Jonsson & Esseen, 1990). The exposure from the canopy gap will allow for species more tolerant to higher light intensities, while the exposure of soil and rocks below the roots allows for species with high nutrient requirements (Boudreault et al., 2018). The availability of coarse woody material (CWM) at varying stages of decay also works to amplify the variety of substrates and therefore the diversity of bryophyte assemblages (Boudreault et al., 2018; Crites & Dale, 1998; Newmaster et al., 2003). The constant process of succession through small-scale disturbances in old growth forests provides permanent availability of a large variety of substrates for bryophyte colonization, promoting diversity (Jonsson & Esseen, 1990; Lee & La Roi, 1979b; Müller et al., 2019).

1.4 Bryophyte conservation

While species distribution maps provide a general idea of climactic requirements, omission of microclimate conditions can give a false description of a population’s range (Merinero et al., 2020; Ratcliffe, 1968). Multiple studies have shown the inclusion of topography, stand continuity, and habitat heterogeneity at local scales work to increase bryophyte diversity (Boudreault et al., 2018; Fenton & Bergeron, 2008; Tukiainen et al., 2017). The growing requirements and vulnerability of bryophyte species varies throughout its climactic scope (Merinero et al., 2020; Ratcliffe, 1968). Lake Superior’s climactic influence provides favourable conditions for a variety of bryophyte species, and the inclusion of microclimate variation can further demonstrate the present species diversity of bryophytes.

Old growth stands are particularly sensitive to management practices that occur in the boreal forest (Boudreault et al., 2018; Wester et al., 2018). Unfavourable conditions caused by anthropogenic disturbances can cause drastic reductions in bryophyte abundance and diversity (Newmaster et al., 2003). The inclusion of landscape, site and substrate level scales in this study, when identifying bryophyte species distribution on Lake Superior’s north-east shore will help to determine more accurate population ranges (Boudreault et al., 2018; Merinero et al., 2020). This will allow for the identification of rare and endemic species for better conservation strategies and protected spaces (Tukiainen et al., 2017). Determining critical habitats will also prioritize conservation strategies for the increased protection of all bryophyte species (Boudreault et al., 2018; Tukiainen et al., 2017).

1.5 Hypothesis and objectives

The overall objective of this study is to observe how the lake-effect humidity and landscape heterogeneity influence the distribution of bryophyte species in surrounding forests. We hypothesize that the increased landscape heterogeneity and humid climate of Lake Superior work to create variability in habitats along its shores (Scott & Huff, 1996; Wester et al., 2018). Moving inland, the topography decreases, humidity levels are lower, and anthropogenic disturbances increase, which negatively affect bryophyte presence and abundance (Müller et al., 2019; Newmaster et al., 2003; Wester et al., 2018). The first specific objective of this study is to determine the simple relationship between richness and composition with distance using eight transects along the north-east of Lake Superior's shoreline. Thus, our first specific hypothesis is that we will observe a gradient of decreasing bryophyte richness and diversity with increased distance from Lake Superior. Secondly, geophysical and stand-level processes affecting the heterogeneity of the understory have a large influence on bryophyte diversity and composition on a local scale, while climatic gradients, topography, and stand continuity will influence species composition at the landscape scale (Boudreault et al., 2018; Fenton & Bergeron, 2008; Tukiainen et al., 2017). Therefore, our second specific objective is to evaluate the effect of spatial scale on the diversity of bryophyte species at both the site and substrate scale by analysing the impact of environmental variables at the climatic, stand, and substrate level. Our second hypothesis is: richness and diversity will be largely influenced by substrate level variables, while stand and landscape variables will have a lesser influence on the presence of species at both the site and substrate scale. As bryophyte species differ between taxonomic groups and colonizing substrate preferences, our third hypothesis is: we expect the relationships between environmental variables at the climatic, stand, and substrate level, and species diversity and composition, to differ between mosses and liverworts, and among preferred substrate types.

CHAPTER II

THE INFLUENCE OF CLIMATIC GRADIENTS AND MULTI-SCALE ENVIRONMENTAL FACTORS ON BRYOPHYTE RICHNESS AND DIVERSITY

2.1 Abstract

Bryophyte diversity is associated with environmental variables at multiple scales including climactic gradients in humidity, stand age and composition, and the abundance of substrates. The inclusion of habitat heterogeneity across a landscape at both fine and coarse-grained scales creates a more accurate map of species distributions as microclimate conditions can buffer larger climatic gradients. This led our study to focus on two objectives 1) determine the relationship between bryophyte richness and diversity with distance based on lake-effect humidity, and 2) evaluate the effect of spatial scale on bryophyte richness and abundance using environmental variables at the landscape, stand, and substrate level. These objectives were achieved by surveying bryophyte species on multiple substrates (logs, rocks, and live trees) in the mixed-wood forests on the north-east shore of Lake Superior. Proximity to the lake had a positive correlation with an increase in richness and diversity of bryophyte species. The relationship with distance decreased with the inclusion of environmental variables at the site and substrate level. Bryophyte association with environmental factors at the site and substrate level were divided by the geographic orientation of the transects with sites in the east zone associated with higher than average stand dbh, canopy cover, and a higher percentage of deciduous trees, whereas sites in the north were associated with a higher frequency of low humidity events. The effect of scale demonstrated that evaluating bryophyte richness and diversity at the substrate level led to the greatest number of significant models and the greatest number of significant associations with environmental variables. The division of bryophyte richness and diversity by

taxonomic type and substrate grouping displayed how a species' niche is associated with specific characteristics in their preferred substrate's growth form and nutrient availability, further demonstrating the substrate-specific nature of bryophytes.

2.2 Introduction

The poikilohydric nature of bryophytes links their metabolic and reproductive efficiency to the availability of water in their surrounding environment (Green et al., 2011; Merinero et al., 2020). This had led to bryophytes developing specific structures, such as papillae and mammillae, and growth forms, such as cushions and turfs, to control water availability within a plant, among plants within a colony, and among species within a community (Bartels et al., 2018; Green et al., 2011; Proctor et al., 2007). Growth and reproductive cycles are also timed around the wetter portions of the year to increase productivity (Hudson et al., 2021). However, for bryophytes living in closed forest microclimates with consistently high humidity, metabolic activity can persist even through dry periods (Hudson et al., 2021; Ratcliffe, 1968). Water availability in the form of atmospheric moisture, fog, dew, or frequent, but short periods of precipitation are all beneficial to promoting bryophyte growth and reproduction year-round (Botting & Fredeen, 2006; Green et al., 2011; Ratcliffe, 1968).

Lake Superior imposes a large climactic influence over the study region. Its influence, termed the "lake-effect", is most obvious in the increased amounts of precipitation and moderating temperatures (Scott & Huff, 1996). Up to 100% more precipitation is delivered downwind of Lake Superior, with increases in precipitation observed from northwest to southeast (Scott & Huff, 1996). The lake provides increased atmospheric humidity to the surrounding landscape through increased water vapour, fog, and precipitation, which makes the ideal climate for bryophyte colonization (Scott & Huff, 1996; Wester et al., 2018). This atmospheric moisture is estimated to reach at least 80km inland, so the surrounding forests are cooler and wetter (Scott & Huff, 1996; Wester et al., 2018). These forests containing a higher water availability allow bryophytes to maintain a higher photosynthetic rate, as well as support higher species richness and diversity (Greiser et al., 2021; Lee & La Roi, 1979a; Mills & Macdonald, 2004).

Despite the small stature of bryophytes, landscape level climatic gradients and topography can affect species richness and diversity. Lake Superior's humidity combined with the rugged topography create pockets of warmer, cooler, and wetter microclimates that create a mosaic across the landscape (Ratcliffe, 1968; Tukiainen et al., 2017; Wester et al., 2018). These moist and geologically diverse landscapes are strongly associated with higher bryophyte diversity in locations such as the Atlantic coast of the British Isles and the Pacific coast of British Columbia (Newmaster et al., 2003; Ratcliffe, 1968). While landscape climatic gradients and topography can determine the larger pool of bryophyte species where colonization is possible, environmental factors at a local stand and substrate scale determine species richness and diversity.

Habitat heterogeneity is the key concept in bryophyte diversity as a larger number of unique habitats allow for a greater number of species assemblages (Fenton & Bergeron, 2008; Mills & Macdonald, 2004; Newmaster et al., 2003). Simply put, the more individual substrates for bryophytes to colonise, the greater number of bryophytes. Heterogeneity at the stand level is often associated with age, composition, small-scale disturbances, and the availability of a variety of substrate types, such as trees, rocks, and CWM (Boudreault et al., 2018; Fenton & Bergeron, 2008; Kumar et al., 2018). As a mixed-wood forest ages through succession, so too do the bryophyte colonies within it; defining unique assemblages of species across the variety of habitat types (Boudreault et al., 2018). Species that are rare or endemic, have limited reproductive dispersal abilities, or require specific growing conditions have better chances of establishing and growing with time and a heterogeneous habitat (Austrheim et al., 2005; Boudreault et al., 2018; Newmaster et al., 2003). As time also leads to forest succession and small-scale disturbances, the number and variety of substrates of various qualities increases as well. The variety of CWM at various decay classes, different sized rocks and boulders, a variety of tree species at differing ages, all increase the habitat heterogeneity by increasing the availability of substrates. Therefore, a greater richness and diversity of bryophytes can be achieved with greater habitat heterogeneity at the stand and substrate scale; protecting these heterogenous habitats in turn protects a greater number of individual species.

While the shores of Lake Superior have a high potential for rich and diverse bryophyte populations, they are under threat from the many anthropogenic activities that also occur in this region. Forestry, mining, and aggregate exploration are common activities in this region than can greatly reduce the richness and diversity of bryophytes through reducing humidity and substrate availability and increasing light levels and temperature (Newmaster et al., 2003; Wester et al., 2018). In order to reduce the risk to bryophytes and target areas for protection, this study's objective is to 1) determine the simple relationship between richness and diversity with distance from Lake Superior, and 2) evaluate the effect of spatial scale on bryophyte species by analysing environmental variables at the landscape, stand, and substrate level. Our first hypothesis is that we will observe a gradient of decreasing bryophyte richness and diversity with increased distance. In terms of the effect of spatial scale, our second hypothesis is richness and diversity will be largely influenced by substrate level variables, while stand and landscape variables will have a lesser influence on the presence of species at both the site and substrate scale. And finally, due to the substrate-specific nature of bryophytes, our third hypothesis is environmental variables at multiple spatial scales will not affect richness and diversity similarly between taxonomic groups mosses, liverworts, and the substrate types they colonize.

2.3 Methodology

2.3.1 Study area

Our study is conducted on the north-east shore of Lake Superior, Ontario, Canada. The area resides in the Ontario Shield ecozone and includes the Lake Abitibi, Lake Nipigon, Lake Temagami, and Georgian Bay ecoregions (Wester et al., 2018). The underlying Precambrian shield consists of a bedrock of mostly granite that has been molded by glacial and aeolian processes (Wester et al., 2018). The topography consists of steep scarps and mesas along the northern shoreline, and rolling hills farther inland (Wester et al., 2018). The drainage is highly variable across the landscape and soil characteristics vary from the Clay Belt in the Abitibi ecoregion, to alternating depths of acidic coarse-textured morainal material, to exposed bedrock in the southern Georgian Bay ecoregion (Wester et al., 2018).

The stands across this landscape largely consist of mixed coniferous forests (Wester et al., 2018). These stands largely contain boreal species including spruce, fir, pine, larch, birch, aspen, and poplar (Wester et al., 2018). Southern parts of this research area also include a mix of temperate and boreal vegetation, including tree species such as maple, cedar, ash, and mountain ash (Wester et al., 2018). The moderating climate of Lake Superior further creates pockets of warmer climate allowing for more temperate forest species to flourish (Wester et al., 2018). Pockets of colder climates along the shoreline also support arctic-alpine species (Wester et al., 2018).

2.3.2 Sampling methods

To determine if a gradient in bryophyte diversity would be observed in relation to a lake effect, eight transects were plotted along the shore of Lake Superior. The transects were grouped into three orientations, north-south, northeast-southwest, and west-east to ensure transects were perpendicular to the shoreline. Each transect spanned 100km inland with ten site points at distances of 0, 1, 2.5, 5, 10, 20, 35, 55, 75, 100km from shore. To ensure forests were similar across all transects, we focused on mixed-wood stands and sites at least 80 years of age since anthropogenic or natural disturbances. The sites were also placed at least one kilometer from a road or rail tracks to reduce impacts of pollution. In addition, a one-kilometer buffer between sites and any type of water body, excluding Lake Superior, was also including to reduce confounding influence of humidity and temperature (Hillman & Nielsen, 2023).

Sites measuring 24m in diameter were pre-determined based on reported forest compositions and multiple environmental variables were sampled to determine the relative age and similarities of forests between both sites and transects. In the event a chosen site was inaccessible or contained unsuitable forest characteristics, it was moved to the next closest location, or the site was removed from the study. Of the 80 sites selected for this study, 54 were sampled. To determine relative light availability, percent canopy cover was measured using a convex spherical densiometer where four measurements were taken in the center of each plot and values averaged. Three of the largest tree species within the site were cored at breast height to provide a minimum estimate of stand age. The basal area of the site was determined by a 10 BAF prism. All trees included in the basal area count were measured for their diameter at breast height (dbh; 1.3m above the ground) to indicate the density of trees within the stand and provide an additional measure of basal area. All herbaceous plant species and saplings growing within the site were recorded as presence/absence data. A shallow soil profile (approximately 30 cm deep) was dug in the center of the site to observe the characteristics. Thickness of organic layer, colour, soil texture, and presence of rocks (including their size) was used to describe the soil profile (Soil Classification Working Group, 1998). Both the presence of herbaceous plants and soil description give us some indication of the reason for species presence and the productivity of the selected site.

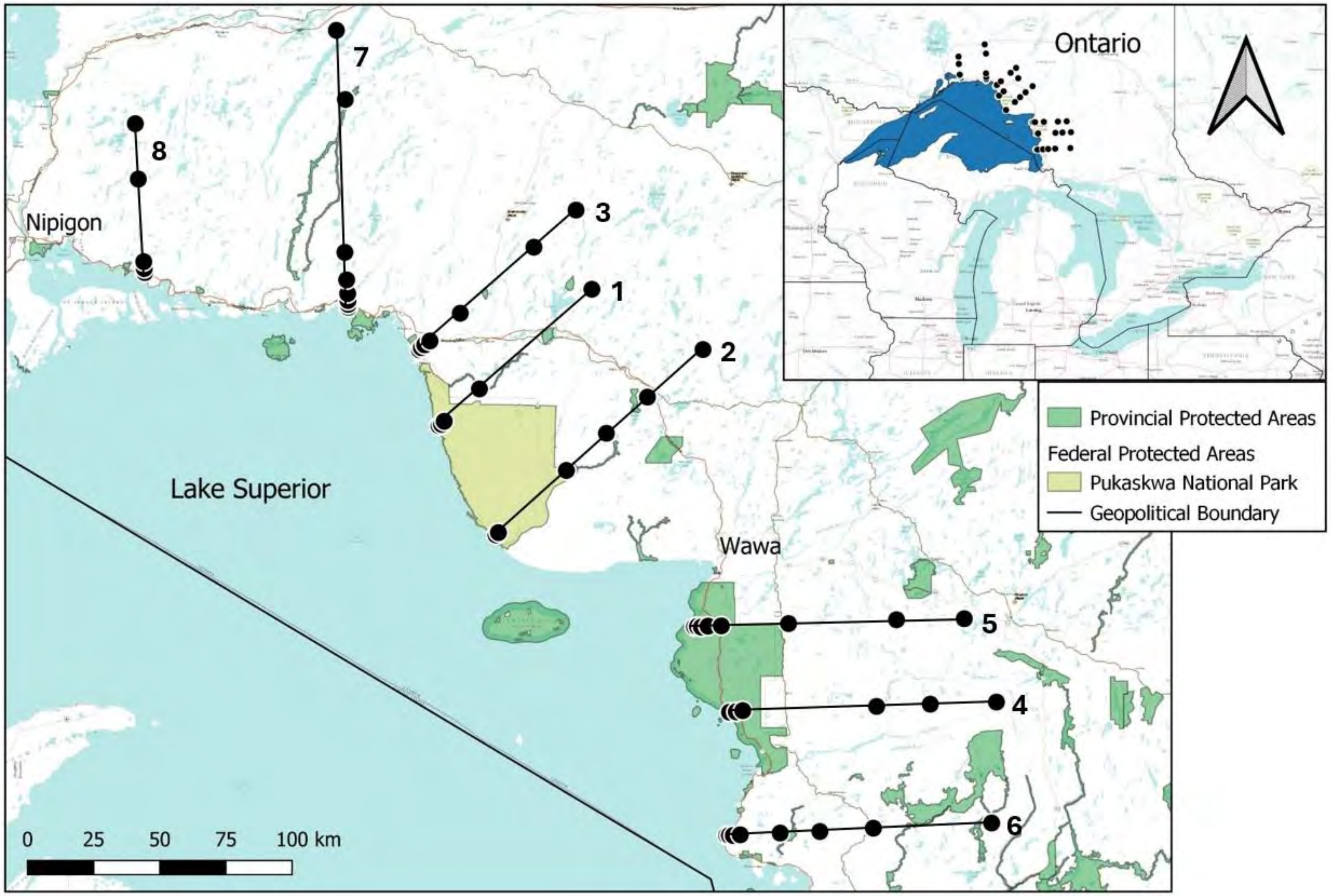


Figure 2.1 Map of study area including sites (indicated by black circles) on the north-east shore of Lake Superior, Ontario, Canada. Sites were arranged into eight transects containing ten sites each. Provincially protected areas are indicated by green polygons while federally protected areas, Pukaskwa National Park, is indicated by yellow polygons.

Using temperature and humidity data, the distance and intensity of Lake Superior's climactic effect can be identified. Thus, the extent of the impact of climate on the bryophyte species present can be evaluated. This data was collected by Honest Observer By Onset (HOBO) data loggers that recorded the temperature and humidity level of the site every hour for one year (September 2021 to September 2022). Three data loggers were placed on each transect. The transect was divided into three groups, shore (sites 0, 1, 2.5, and 5km), middle (sites 10, 20, and 35km), and inland (sites 55, 75, and 100km) sites and the HOBOs were placed on one site from each grouping (1F, 1I, 2H, 2J, 3A, 3D, 3H, 4A, 4D, 4I, 5B, 5E, 5I, 6G, 6J, 7B, 7E, 7I, 8B, 8D, and 8G; data from weather stations provided by Environment Canada and Pukaskwa National Park were used as shore sites for transects 1 and 2; the HOBO on site 6C was not recovered). The HOBO device was placed on a tree in the center of the chosen site, approximately 30 cm above the ground.

To ensure bryophyte richness and diversity were associated with landscape and spatial scale, not substrate availability, the following protocol was used. Four substrates were selected for sampling, including logs, rocks, and both live birch and spruce trees. Five replicate samples of each of the four substrates were selected within each site. Substrates were selected based on their distance from the center of the site. Log substrates were selected based on decay class, ideally between decay class three and four to obtain peak species richness, using the chart found in Maser et al. (1979); (Mills & Macdonald, 2004). When sample logs varied in decay class along their length, only the area in decay class three to four was sampled. Sampled logs were measured for their length, diameter at midpoint, and length of area sampled. The original species of the log was included if known; if unknown, a sample of wood was collected. Identifying the tree species of logs is a significant predictor in bryophyte species richness (Mills & Macdonald, 2004). Selected rock substrates had to be greater than one meter squared and were measured for length, width, and height to calculate an approximate surface area. Selected rocks were tested for whether they were acid or calcareous using a solution of Hydrochloric Acid, as rock type will affect the community assemblage of bryophytes (Spitale & Nascimbene, 2012). Live birch and spruce species were selected to be sampled due to their abundance in all four ecoregions, Lake Abitibi, Lake Nipigon, Lake Temagami, and Georgian Bay, included in the study area. Selected birch and spruce trees had a dbh greater than seven centimeters and were dived into two areas for sampling. Samples collected from the base of the tree included bryophytes collected from exposed roots and the trunk of the tree up to one meter from the ground, as different bryophyte species are found at different heights on trees and litter can affect bryophyte composition at the tree base (Mills & Macdonald, 2005). Samples labeled as trunk species were collected from the trunk and branches one meter above the ground. All trees selected for sampling were measured for dbh.

Collected bryophytes were placed in paper bags and left open to dry to avoid mold. The samples were then transported to University of Quebec in Abitibi-Témiscamingue. Identification of the bryophyte species occurred in a lab setting using both dissecting and light microscopes. The following guides were used to identify and name the species collected for this study: Flore des bryophytes du Québec-Labrador volume 1-3 by Jean Faubert, Moss Flora of the Maritime Provinces by Robert Ireland, and The Liverwort Flora of the British Isles by Jean Paton (Faubert, 2014; Ireland & Hanes, 1982; Paton, 1999).

2.3.3 Statistical analysis

All statistical analysis in this study was completed in R 4.2.2 (R Core Team, 2022). Significance was set at $p \leq 0.05$ for all statistical analyses. The first objective of determining the relationship between bryophyte richness and composition with distance from Lake Superior was completed in multiple parts. First, to determine if there were changes in climatic conditions with distance, ANOVAs were used to test the differences between daily minimum relative humidity and daily maximum temperatures collected from the HOBO data loggers between the three group distances (shore group: sites 0, 1, 2.5, and 5km,; middle group: sites 10, 20, and 35km; and inland group: sites 55, 75, and 100km). Then, the relationship between distance and bryophyte richness and community composition was evaluated with three different techniques. Graphs depicting the gamma diversity and cumulative diversity with increasing distance were visually analysed to depict the relationship between bryophyte richness and distance based on lake-effect humidity. Secondly, to evaluate the relationship between bryophyte composition and distance, a Venn diagram was produced by hand. Finally, to evaluate the direct relationship with bryophyte richness and distance, three linear models at the landscape scale, were conducted between the total bryophytes, mosses, and liverworts with distance from the lake. All linear model assumptions were met, and validation plots were satisfactory.

To meet the second objective of evaluating the effect of spatial scale on bryophyte richness and composition, four statistical analyses were conducted. First, to evaluate the combined effect of distance, landscape, and stand variables on site-scale bryophyte richness, we completed site scale linear regressions including these variables for both taxonomic groups mosses and liverworts. Environmental variables at the landscape and stand scale were incorporated as fixed effects including, latitude, longitude, altitude, forest canopy cover, forest minimum age, average stand dbh, percentage of deciduous trees (the proportion of deciduous trees above 7cm at dbh within the basal area of the site), frequency of low humidity periods (10th percentile of humidity values determined at the site level), and average length of low humidity periods; no random effects were included. Gaussian family models were used. Secondly, we used generalized linear mixed models (GLMMs) to analyze alpha richness at the substrate scale with the inclusion of environmental variables also measured at the substrate scale. All environmental variables measured at the site and substrate scale were evaluated with a correlation matrix using R package *Hmisc*, results can be found in Appendix G (R Core

Team, 2022). DHARMa nonparametric dispersion tests were conducted for each model to test for over/underdispersion. Resulting residuals are standardized to generate values between 0 and 1. Each taxonomic group, (mosses and liverworts), and substrate type were analysed separately, except in the case of spruce bryophytes where mosses and liverworts were combined due to low number of liverwort species found on spruce substrates (see Appendix I). Environmental variables at the site scale included latitude, longitude, altitude, canopy cover, stand age, average stand dbh, percentage of deciduous trees as fixed-effects, and site was included as a random-effect variable. Substrate scale variables were included as fixed-effect variables for their specific substrate type including for logs, log decay class and log diameter; for rocks, rock type and rock surface area; for birch, birch species and birch dbh; and for spruce, spruce species and spruce dbh. Poisson family models were used in all GLMMs. When overdispersion was identified in the model for liverworts found on logs, it was corrected with a negative binomial distribution (nbinom2).

To analyse the effect of spatial scale on bryophyte composition we used principal component analysis (PCoA) using species absence data, at different spatial scales. In the first PCoA, coloured dots representing each site (n = 48) showed distance from the lake. Significant species were calculated to have a maximum correlation ($p \leq 0.05$) with distance using the envfit function and included 9 species significant to either one or two group distances (Figure 4). The second PCoA contained all sites (n = 54) and included all landscape and stand level environmental variables measured at the site level. The final analysis included the presence and absence of species per each substrate (i.e., all species on five replicates of the four substrates per site). All landscape, stand, and substrate level environmental variables, measured at both the stand and substrate level, were used in this GLMM analysis. Taxonomic group, mosses and liverworts, and substrate type were analysed separately, except in the case of rock and spruce bryophytes, where mosses and liverworts were combined due to low liverwort species presence. Substrate level PCoAs were based on dissimilarity matrices using Jaccard distance and environmental variable effects on species composition was verified using a permutation test of 999 iterations (Appendix J).

2.4 Results

2.4.1 Climate conditions

Daily low relative humidity values are significantly different between distance groups from Lake Superior (shore 0-5, middle 10-35, and inland 55-100km). The results from our analysis indicate that we can reject the null hypothesis and accept that there is a difference in daily relative humidity values between the three distance groups (p-value < 0.001) (Appendix B). The Tukey post hoc test indicated that distance two group is significantly different from group one (adj p = 0.001) and group three (adj p = 0.001) (Appendix B). Distance groups one and three are not significantly different from each other. Most locations also experience a spring drop in humidity between March and May. This pattern was most evident in the middle distances, where the relative humidity dropped significantly lower than shore and inland locations (Figure 2.2). Despite distance group two having significantly different relative humidity than groups one and three, the relative humidity remained consistently high year-round, with an average of 87.6% across all distances (Table 2.1).

Analysis of the daily maximum temperature resulted in no significant difference between the three distance groups (p = 0.893) between the recorded time span of September 19th 2021 to September 10th 2022 (Appendix B). The Tukey post hoc test indicated that distance group two differed from distance groups one by 0.175°C (p = 0.885) and three by -0.129°C (p = 0.935) (Appendix B). Group distance one and three are not significantly different (p = 0.989).

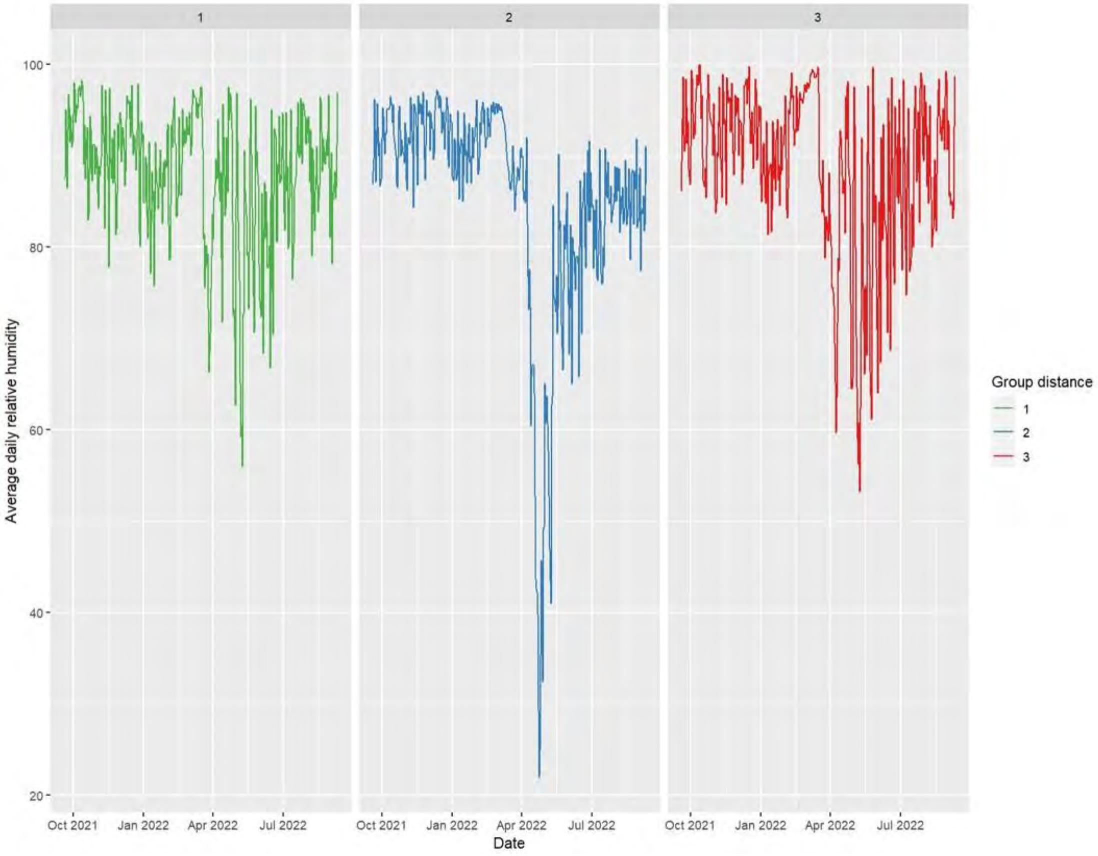


Figure 2.2 Average daily relative humidity from September 19th, 2021 to September 10th, 2022 of the three group distances (1 = 0-5, 2 = 10-35, and 3 = 55-100km) from the lake.

Table 2.1 Mean daily minimum relative humidity and maximum temperature, obtained from data loggers, with standard deviation for each group distance.

Group distance	**Mean daily minimum relative humidity**	**Standard deviation**	**Mean daily maximum temperature** (°C)	**Standard deviation**
0-5km	76.539	16.845	6.704	11.728
10-35km	74.012	26.036	6.879	12.515
55-100km	77.339	21.610	6.750	12.833

2.4.2 Species richness

The north-east shore of Lake Superior has a very diverse bryophyte community with 145 species recorded during this study. This included 100 mosses, of which 45 were acrocarpous and 55 were pleurocarpous, one Sphagnum, and 44 liverwort species. Despite this diversity, eight bryophytes made up 50% of all occurrences: *Dicranum montanum* Hedw., *Hypnum pallescens* (Hedw.) P. Beauv., *Plagiothecium laetum* Schmip., *Pleurozium schreberi* (Brid.) Mitt., *Sanionia uncinata* (Hedw.) Loeske., *Lophocolea heterophylla* (Schrad.) Dumort., *Jamesoniella autumnalis* (DC.) Stephani, and *Ptilidium pulcherrimum* (Weber) Vain. In contrast, 40% of total bryophyte species had five or less occurrences throughout the study area. Moss species found on logs had the highest mean number of species, significantly different from all taxonomic and substrate groups except for rock moss (Appendix C). Rocks had the highest number of species occurrences within a single site (24 species), however there was a large variance in species richness among all sites sampled. Across all substrate groups, moss consistently had significantly higher mean species richness than liverworts (Figure 2.3).

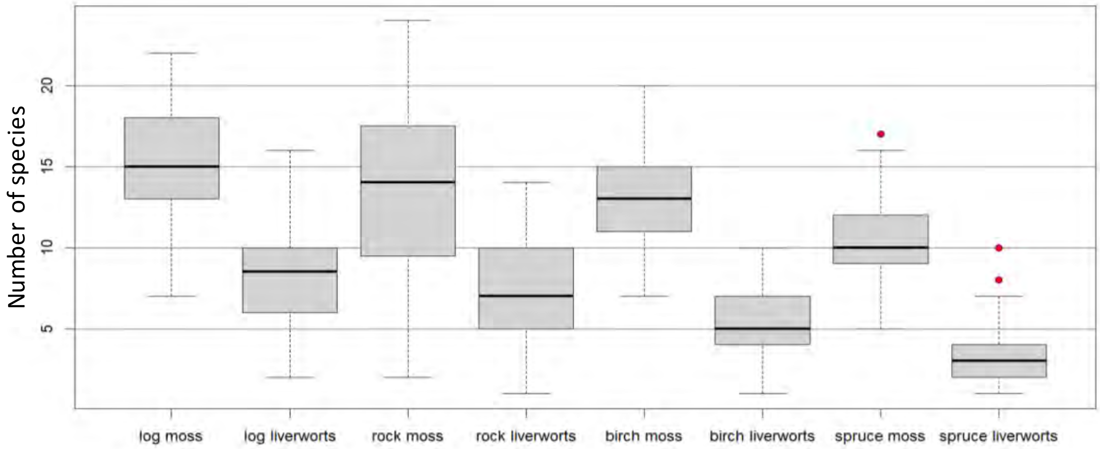


Figure 2.3 Mean number of species per taxonomic group and substrate type. Box plot representing the median, maximum, and minimum number of species per substrate. Red points represent outliers.

Bryophyte species richness decreased with distance from the lake. Total richness was highest within the first five kilometers from the shore, dipped in the intermediate distances (10-35km), and increased marginally at the furthest distances inland (55-100km) (Figure 2.4a). In fact, 95.2% of the total species diversity within this study was found within the first 5km from Lake Superior (Figure 2.4b). The three inland distances of 55, 75, and 100km held 65.5% of the total species, while the middle distances of 10, 20, and 35km only represented 57.9% of the total species diversity.

The same pattern is illustrated in species composition in Figure 2.5 where a Venn diagram shows the 0-5km group contained 40 species unique to the shore distance, while only 5 species were unique to the inland distances of 55-100km, and the 10-35km group had no species specifically associated with the middle distances. Additionally, 16 species were shared between the 0-5km and 55-100km groups, while two and ten species were shared between the 10-35km and the 55-100km or 0-5km groups, respectively. 72 species are shared between all groups.

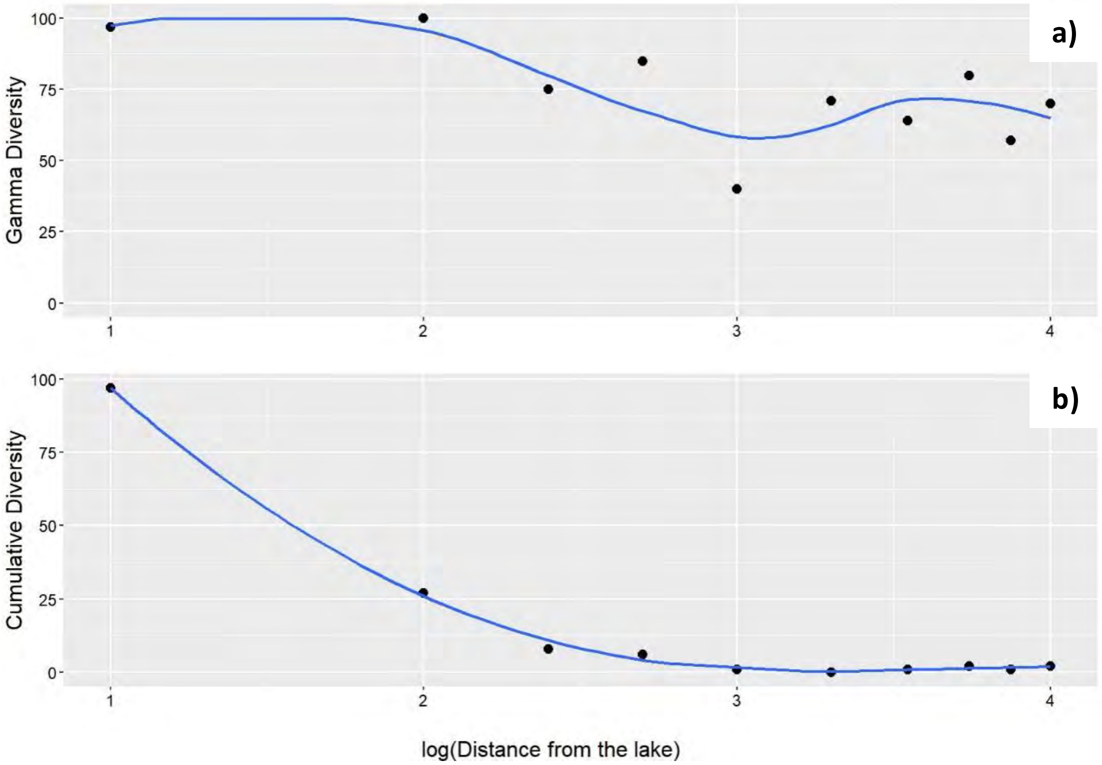


Figure 2.4 Gamma richness (total number of species per distance (a) and cumulative species diversity (b) plotted against site distance from the lake, where distances were log transformed (log(distance)+2). Blue line represents a spline calculated using a nonparametric regression.

Figure 2.5 Venn diagram of the 145 bryophyte species found in this study divided into three groups of distances 0-5km (shown in blue), 10-35km (shown in red), and 55-100km (shown in green). The numbers within the circles indicate the number of species at that distance.

At the site level, we observed an overall decrease in the number of species with an increasing distance from the lake. A linear model of the relationship between the number of species per site and the site distance resulted in a highly significant, but weak relationship (F-stat = 1.450, $R^2 = 0.027$, p = 0.001). To investigate differences in taxonomy between bryophytes, the model was divided into taxonomic groups, true mosses and liverworts. A significant negative relationship was found between the number of moss species per site and distance from the lake, improving the R squared value, which however remained low ($R^2 = 0.045$, p = 0.001) (Figure 2.6a). The number of liverwort species and distance from the lake also resulted in a significant negative relationship, however the R squared was not improved compared to the total species model ($R^2 = 0.026$, p = 0.001) (Figure 2.6b). The low R-squared values from all three linear models show that very little (<5%) of the variance found in the number of bryophyte species at the site level can be explained by distance from the lake or decreases in relative humidity. The number of bryophyte species at each site and at each distance varies a great deal between the eight transects, and in addition all eight transects have dramatically different slopes. Despite this, these results address our first objective in determining the relationship between bryophyte richness and composition with distance from Lake Superior to be an overall negative correlation.

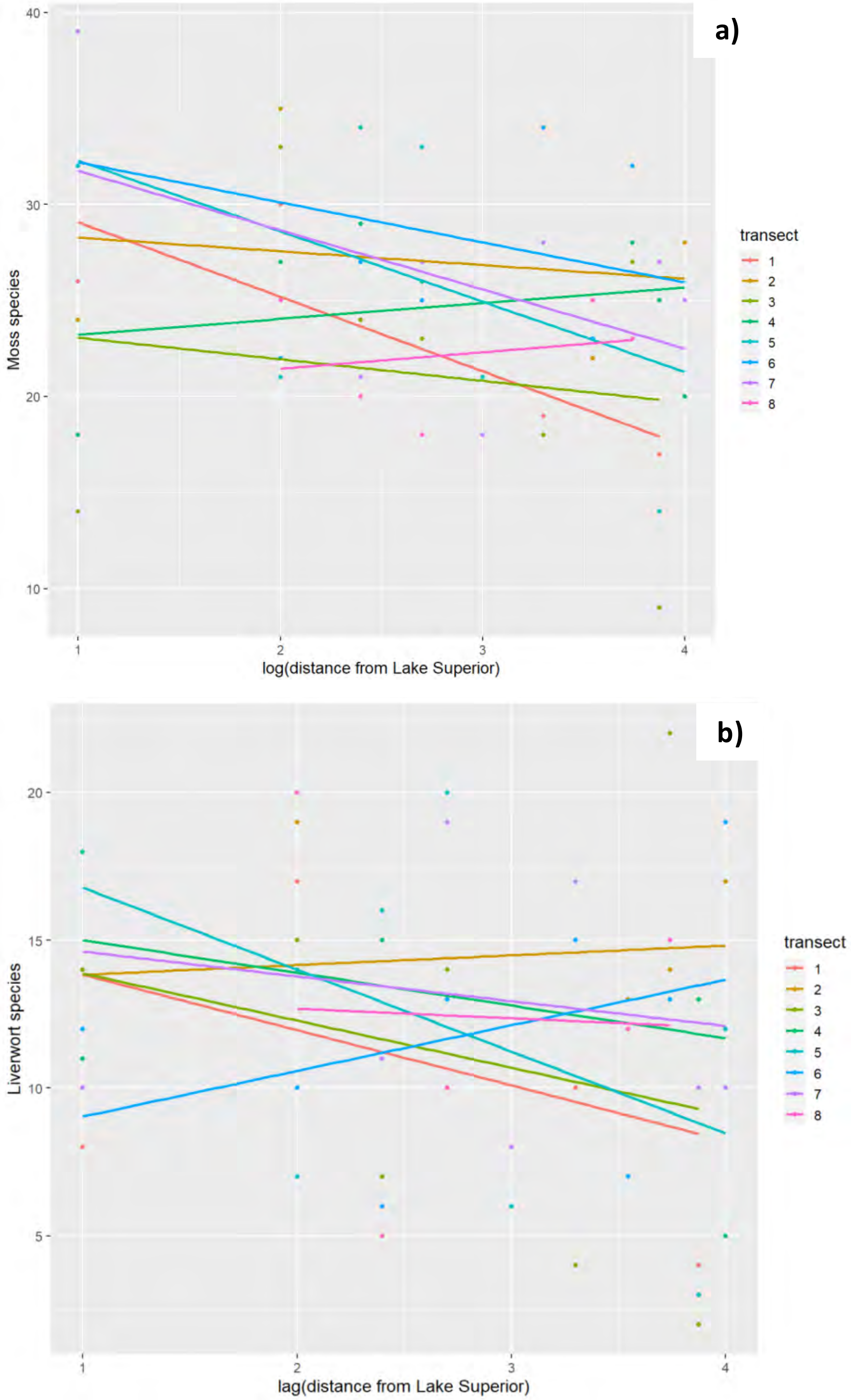


Figure 2.6 Alpha diversity (number of species per site for moss (a) and liverworts (b) plotted against distance from the lake for the 54 sites sampled, where distances were log transformed (log(distance)+2). Coloured lines represent the trend for each of the eight transects using a linear model.

2.4.3 Spatial scale and bryophyte diversity

The inclusion of landscape and stand level variables in models to explain variations in alpha richness at the site scale resulted in no significant relationship with distance from the lake when bryophytes were divided by taxonomic group: mosses (F-stat = 2.429, p -value = 0.125) and liverworts (F-stat = 1.416, p-value = 0.239). To address our second objective of evaluating the effect of spatial scale on bryophyte richness and diversity, data was further divided by splitting each taxonomic group by substrate type (Appendix I). Alpha richness of spruce moss calculated as the total number of moss species on all spruce trees within a site was the only model to result in a significant relationship with distance from the lake (F-stat = 4.79, p = 0.013) (Table 2.1). Significant explanatory variables for this model included latitude (p = 0.025), altitude (p = 0.015), and stand age (p = 0.001), with latitude having a much larger estimate than both altitude and stand age. Two other alpha richness models at the site scale, log liverworts and rock moss, resulted in no significant relationship with distance, but did include significant explanatory variables. The log liverwort richness model indicated that altitude (p = 0.025) and stand age (p = 0.030) as significant variables. Additionally, the rock moss model and distance resulted in a significant intercept (p = 0.049). All other taxonomic and substrate group models were not significant.

Table 2.2 Significant results ($p \leq 0.05$) of the site-scale linear regression models with species richness as the response variable, distance from Lake Superior as well as latitude, longitude, altitude, canopy cover, stand age, average stand dbh, percentage of deciduous trees, frequency of low humidity periods, and average length of low humidity periods as explanatory variables.

Model variables	F-statistic	Estimates±error	t value	p-value
Spruce moss	4.790	-	-	0.013
Latitude	-	5.400 ± 2.013	2.682	0.025
Altitude	-	-0.016 ± 0.005	-2.994	0.015
Stand age	-	-0.083 ± 0.015	-5.487	<0.001
Log liverworts	1.721	-	-	0.213
Altitude	-	-0.031 ± 0.011	-2.683	0.025
Stand age	-	-0.085 ± 0.033	-2.563	0.030
Rock moss	1.193	-	-	0.343
Intercept	-	-170.1 ± 82.16	2.072	0.049

To evaluate the effect of spatial scale on bryophyte richness, the following models were created using landscape, stand, and substrate environmental variables and alpha richness of each bryophyte group calculated as the number of species per substrate (i.e., all species on five replicates of the four substrates per site). This resulted in significant values for all models (Appendix I). DHARMa nonparametric dispersion tests resulted in three models being slightly underdispersed including rock moss (c-hat = 0.64), birch moss (c-hat = 0.75), and birch liverworts (c-hat = 0.61). For both log and rock models, the liverworts had more significant relationships with environmental variables than the mosses, including substrate-scale variables such as log decay class ($p = 0.001$) for the log liverwort model and both rock type ($p = 0.001$) and rock surface area ($p = 0.001$) for the rock liverwort model (Table 2.2). For the model of liverworts on log substrates, canopy cover was also a significant variable ($p = 0.021$) with a very strong estimate compared to other significant variables. Both log moss and rock moss models resulted in a significant effect only with deciduous ratio, the proportion of deciduous to coniferous trees. In contrast, the birch models resulted in the mosses having a greater number of significant relationships with the both the site-scale and substrate scale variables. However, both birch moss and liverworts had a significant relationship with the dbh of the sampled birch tree ($p = 0.001$ and $p = 0.008$, respectively) (Table 2.2). For the spruce bryophyte model, only stand age was found to be a significant variable ($p = 0.010$).

Table 2.3 Significant results ($p \leq 0.05$) of the substrate-scale generalized linear mixed models with species richness as the response variable, distance from Lake Superior as well as latitude, longitude, altitude, canopy cover, stand age, average stand dbh, percentage of deciduous trees, as explanatory variables, and site as a random fixed effect variable. Substrate-scale explanatory variables for logs included log decay class and log diameter, for rocks included rock type and rock surface area, for birch included birch species *Betula papyrifera* and birch dbh, and for spruce included spruce species *Picea glauca*, spruce species *Picea mariana*, and spruce dbh.

Model variables	**Estimates±error**	**z value**	**p-value**
Log moss			
Deciduous ratio	0.428 ± 0.203	2.107	0.035
Log liverworts			
Altitude	-0.002 ± 0.001	-2.130	0.033
Canopy cover	2.572 ± 1.117	2.302	0.021
Log decay class	0.295 ± 0.089	3.299	0.001
Rock moss			
Deciduous ratio	-0.710 ± 0.360	-1.974	0.048
Rock liverworts			
Altitude	0.001 ± 0.001	2.072	0.038
Rock type	-0.619 ± 0.128	-4.820	0.000
Rock surface area	0.033 ± 0.009	3.520	0.000
Birch moss			
Average dbh	-0.016 ± 0.007	-2.269	0.023
Birch species	-0.235 ± 0.103	-2.276	0.023
Birch dbh	0.011 ± 0.003	3.553	0.000
Birch liverworts			
Birch dbh	0.012 ± 0.004	2.664	0.008
Spruce bryophytes			
Stand age	-0.003 ± 0.001	-2.574	0.010

2.4.4 Spatial scale and bryophyte composition

PCoAs were used to investigate community composition of all bryophytes at the site scale. A clear distinction in distance from the lake associated with axis two (7.61%) was identified (Figure 2.7a). While a majority of sites at the furthest distances (55-100km) are clustered together with similar characteristics, a few of these sites show similarities to those in the shore and middle distances (0-5 and 10-35km). Nine species were identified as statistically significant ($p < 0.05$) with specific distances from Lake Superior. Species *Hylocomium splendens* (Hedw.) Schimp. and *Jungermannia leiantha* Grolle were both indicators of close proximity to the lake (0-5km) (Figure 6a). While the species *Geocalyx graveolens* (Schrad.) Nees was significant for both shore and middle distances from the lake (0-5km and 10-35km) (Figure 2.7a). A majority species significantly related with distance were indicators of both shore and inland sites (0-5 and 55-100km) including, *Orthotrichum speciosum* Nees, *Brachythecium campestre* (Müll. Hal.) Schimp., *Brachythecium erythrorrhizon* Schimp., *Herzogiella striatella* (Brid.) Z. Iwats., *Riccardia latifrons* (Lindb.) Lindb. The final species, *Pylaisia selwynii* Kindb., was indictive of both middle and inland distances (35-100km) (Figure 2.7a).

Site scale composition across all sites, most noticeably displayed a division depending on geographic orientation. Sites with a north-south orientation, considered the north zone were association with longitude. These sites in the northern most range of our study area tended to have a higher frequency of low humidity events (Figure 2.7b). Sites with an east-west orientation, or the east zone, were associated with latitude. These sites tended to have a higher average dbh, a higher percentage of deciduous trees, and increased canopy cover (Figure 2.7b). Sites occurring in the middle of the study area were associated with both older stands and longer durations of low humidity events, likely associated with location of provincial and national parks within the study area (Figure 2.7b).

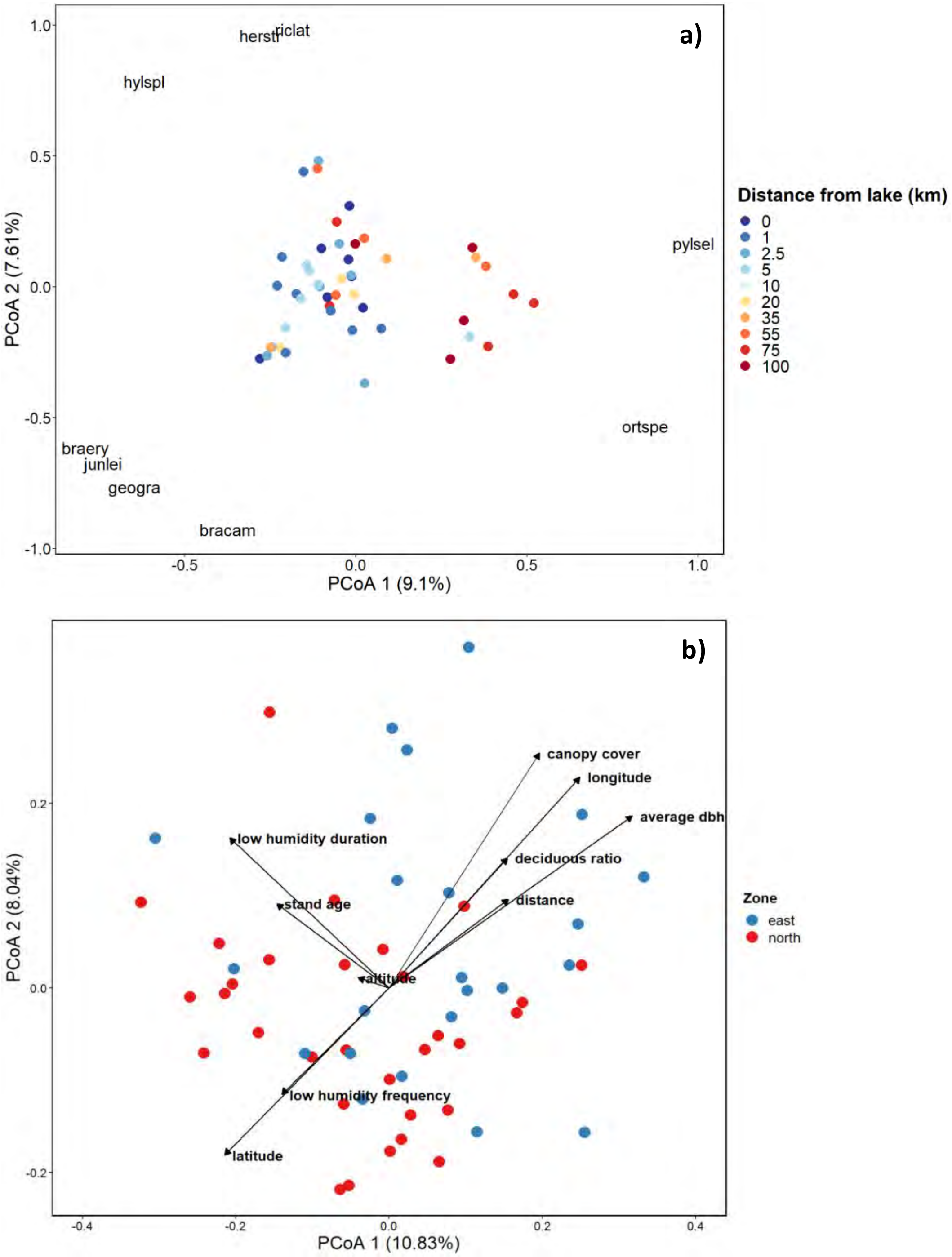


Figure 2.7 Site scale principal coordinates analyses (PCoA) ordinations for a) selected sites (n = 48), and b) all sites (n = 54). Sites are represented by different colours indicating a) distance from the lake, or b) geographic zone (east, north). Species (n = 9) significantly associated with distance from the lake are included in a), while b) includes all environmental variables tested with permutation analysis. Eigenvalue of each axis is shown in parentheses.

Accepting hypothesis two where bryophyte richness is largely influenced by substrate level variables with our substrate scale GLMM's, led to the performing our PCoA's at the substrate-scale to examine the dissimilarity of the bryophyte community at a finer scale. Our results show that there was no common driver of composition at the landscape, stand, or substrate scale across all taxonomic groups or substrate types (Appendix J). Rather, our models show that environmental variables affected each grouping differently. In the log moss PCoA, axis 1 and two explained 7.95% and 6.92% of the variation in composition respectively (Figure 2.8a). The permutation test showed the log moss model had the largest number of significant variables including distance (R^2 = 0.022, p = 0.014), latitude (R^2 = 0.063, p = 0.001), longitude (R^2 = 0.019, p = 0.018), canopy cover (R^2 = 0.085, p = 0.001), stand age (R^2 = 0.033, p = 0.003), average dbh (R^2 = 0.053, p = 0.001), and log diameter (R^2 = 0.024, p = 0.008) (Table 2.3). The log liverwort PCoA explained less variation than log moss, with an axis 1 of 6.46% and axis 2 of 3.53% (Figure 2.8b). The log liverworts also had less explanatory environmental variables including distance (R^2 = 0.020, p = 0.020), altitude (R^2 = 0.016, p = 0.036), stand age (R^2 = 0.022, p = 0.019), and average dbh (R^2 = 0.016, p = 0.039) (Table 2.3).

The combined rock bryophytes PCoA resulted in an axis 1 explaining 8.79% and axis 2 explaining 6.47% of the variance in composition (Figure 2.8c). Associated variables included average dbh (R^2 = 0.032, p = 0.031) as well as both substrate level characteristics rock surface area and rock type (Table 2.3). The birch moss PCoA explains 7.83% and 6.55% of the variation in composition while the birch liverworts only explained 4.9% and 3.68% for axis 1 and 2 respectively (Figure 2.9a and b). However, birch liverworts had more significant variables including distance (R^2 = 0.046, p = 0.001), latitude (R^2 = 0.015, p = 0.028), canopy cover (R^2 = 0.033, p = 0.002), deciduous ratio (R^2 = 0.017, p = 0.016), and birch dbh (R^2 = 0.046, p = 0.001) (Table 2.3). While significant variables for birch moss only included distance (R^2 = 0.039, p = 0.001) and canopy cover (R^2 = 0.033, p = 0.002) (Table 2.3). Finally, the total spruce bryophytes PCoA, axis 1 and 2 accounted for 7.79% and 6.74% of the variance in composition (Figure 2.9c). Significant variables included only canopy cover ($R^2 = 0.021$, $p = 0.005$) and stand age ($R^2 = 0.020$, $p = 0.010$) (Table 2.3). The dissimilarity in relationships between the environmental variable and species diversity for mosses and liverworts, as well as by colonizing substrate led us to accept our third hypothesis where the mosses, liverworts, and their substrate preferences affect relationships with environmental variables at the landscape, stand, and substrate level differently.

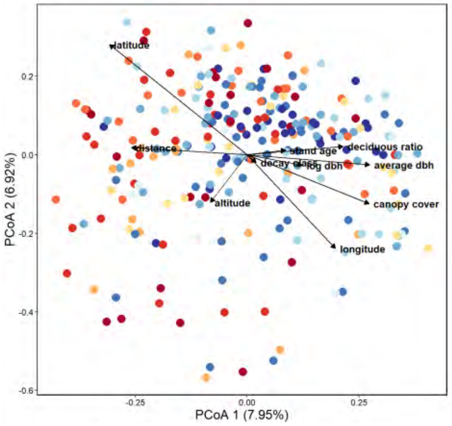
Table 2.4 Significant results ($p \leq 0.05$) of the permutation tests of 999 iterations on the environmental variables for each PCoA model. Distance from Lake Superior, latitude, longitude, altitude, canopy cover, stand age, average dbh, and deciduous ratio were recorded at the site scale. Log decay class, log diameter, rock type, rock surface area, birch species, birch dbh, spruce species, and spruce dbh were recorded at the substrate scale.

Model variables	**R^2**	**p-value**
Log moss		
Distance	0.022	0.014
Latitude	0.063	0.001
Longitude	0.019	0.018
Canopy cover	0.085	0.001
Stand age	0.033	0.003
Average dbh	0.053	0.001
Log diameter	0.024	0.008
Log liverworts		
Distance	0.020	0.020
Altitude	0.016	0.036
Stand age	0.022	0.019
Average dbh	0.016	0.039
Rock bryophytes		
Average dbh	0.032	0.031

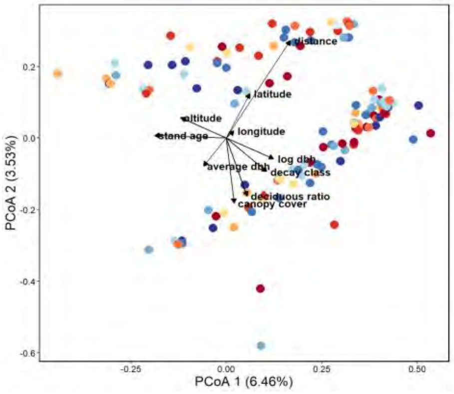
Table 2.4 suite

Rock type	0.050	0.011
Rock surface area	0.079	0.003
Birch moss		
Distance	0.039	0.001
Canopy cover	0.033	0.002
Birch liverworts		
Distance	0.046	0.001
Latitude	0.015	0.028
Canopy cover	0.033	0.002
Deciduous ratio	0.017	0.016
Birch dbh	0.046	0.001
Spruce bryophytes		
Canopy cover	0.021	0.005
Stand age	0.020	0.010

a) Log moss



b) Log liverworts



c) Rock bryophytes

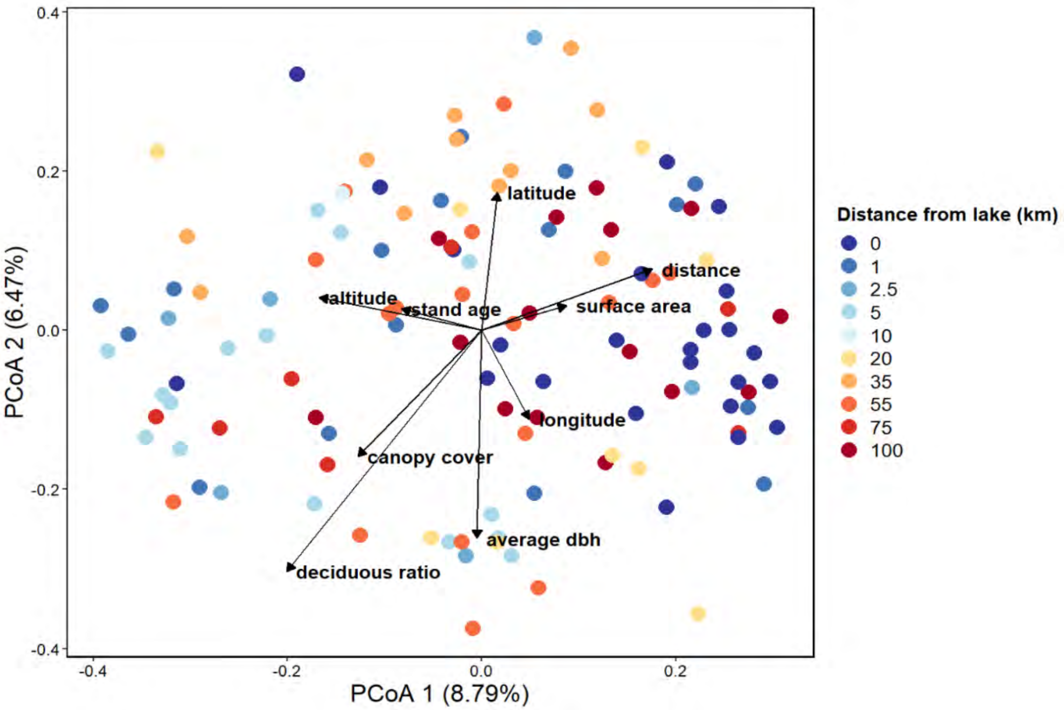
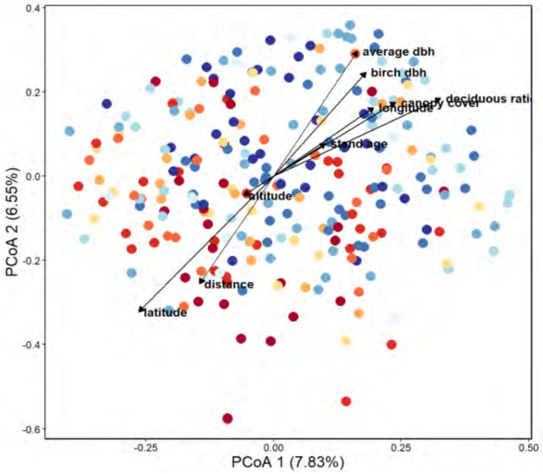
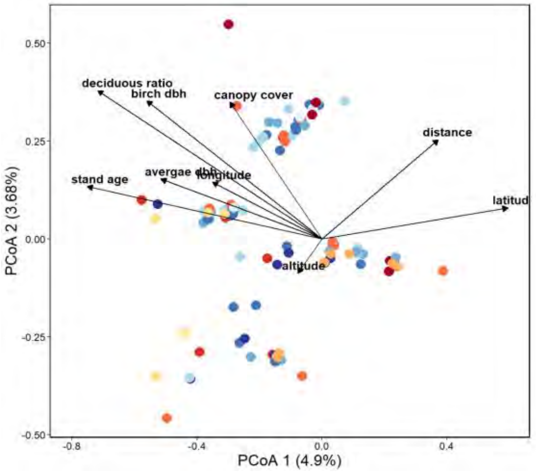


Figure 2.8 Substrate-scale principal component analysis (PCoA) ordinations for a) log moss, b) log liverworts, and c) rock bryophytes. Individual substrates are represented by dots with colour indicating the distance from Lake Superior. All environmental variables tested with permutation analysis are included (log diameter labeled as log dbh). Eigenvalue of each axis is shown in parentheses.

a) Birch moss



b) Birch liverworts



c) Spruce bryophytes

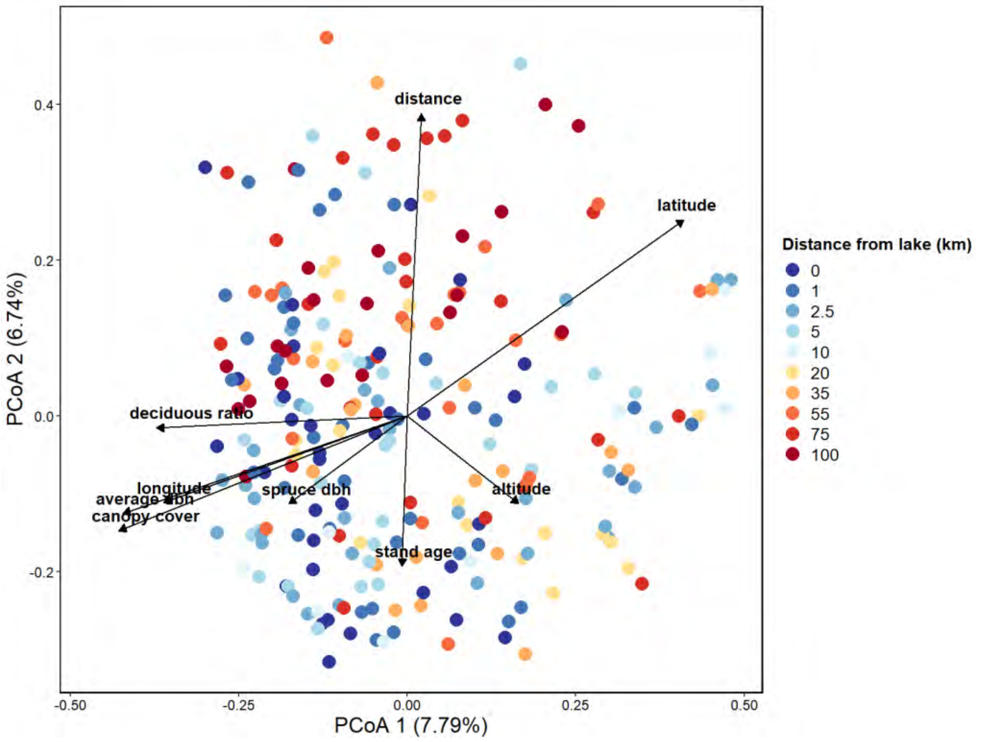


Figure 2.9 Substrate-scale principal component analysis (PCoA) ordinations for a) birch moss, b) birch liverworts, and c) spruce bryophytes. Individual substrates are represented by dots with colour indicating the distance from Lake Superior. Significant environmental variables tested with permutation analysis are included. Eigenvalue of each axis is shown in parentheses.

2.5 Discussion

2.5.1 Effect of distance

Our results show a negative correlation between bryophyte richness and diversity with distance, and therefore a positive relationship with lake-effect humidity, achieving our first objective of identifying the relationship between bryophyte species and distance from Lake Superior. Analysis of humidity show the highest levels within the first five km from the lake, with a drop between 10-35 km, and increases again in the 55-100km distance. This exact pattern can be seen in the gamma diversity with the greatest number of species found within the first five km and a decrease in richness between 10-35km. When comparing diversity to lake-effect humidity, our Venn diagram of species shows the largest number of unique species occur at the 0-5 km distance with 40 species. The inland distances of 55-100 km contained five species unique to that distance, while the middle distances had no unique species. This relationship with humidity, and therefore distance from Lake Superior has been identified in previous studies where high humidity and moisture has been a strong indicator of increased species richness and composition (Austrheim et al., 2005; Mills & Macdonald, 2004; Ratcliffe, 1968). Indeed, many studies have shown greater bryophyte richness closest to more humid environments such as the costal cliffs and forests of the western UK and British Columbia, similar conditions to the shores of Lake Superior (Newmaster et al., 2003; Ratcliffe, 1968).

The decreasing gradient in bryophyte richness and diversity with distance from the lake was clear and supports the acceptance of our first hypothesis. Our results show that distance based on lake-effect humidity is a driver of bryophyte richness, but the focus of our study on the microclimate level increases the habitat heterogeneity and better explains the mosaic of bryophyte communities. Our results show that species richness per distance varied greatly between each of the eight transects. Both Scott and Huff

(1996) and Hillman and Nielsen (2023) suggested that the reach of Superiors' lake-effect can fluctuate depending on topographical influences such as gradients in elevation. A clear example of the influence in topography can be seen in the comparison of moss richness between two sites separated by 45km, 4A and 5A. While both sites were sampled at the lakeshore, richness varied from 18 moss species at 4A to 32 moss species at 5A. The difference between these sites is the topography. Site 4A occurred in a low lying area surrounded by sandy beaches, while site 5A was located in Old Woman Bay with a rugged shoreline surrounded by steep cliffs. This increased geodiversity of site 5A helps to capture the lake-effect humidity and create wetter site conditions and substrates, therefore providing a more heterogenous habitat for bryophytes (Newmaster et al., 2003). Tukiainen et al. (2017) found variables in geodiversity to improve predictive models for bryophyte richness and while some of our results align with these claims, further investigation is needed.

2.5.2 Effect of scale

Our second objective was to evaluate the effect of spatial scale on the richness and diversity of bryophytes. The inclusion of environmental variables at the landscape and stand scales led to significant associations with bryophyte diversity and composition. The relationship with distance from the lake, however, decreased in strength with the addition of landscape and stand level factors for all taxonomic and colonizing substrate groups, leading us to believe that stand variables have a greater influence than lake-effect humidity at the site level. Only one site level model, the spruce moss, resulted in a significant relationship with distance as well as latitude, altitude, and stand age. Overall, higher diversity was associated with landscape and stand factors, which were divided by geographic orientation. In fact, the north-south or east-west orientation of the transects determined stand level-factors, such as canopy cover and average dbh, that proved to have more of an influence over bryophyte diversity.

While significant results were obtained at the site-level analysis, they were limited. Previous research has shown environmental variables at coarser scales, such as the landscape and stand level, have not explained bryophyte species richness sufficiently, and the substrate specific nature of bryophytes may be the reason (Kuglerová et al., 2016; Mills & Macdonald, 2004). These lead to examining bryophyte diversity and composition interactions at the substrate level.

The inclusion of fine-scale variables in the substrate level analysis improved the number of significant relationships between bryophyte composition and environmental variables. This led to all taxonomic and substrate grouping types to result in significant models, and the acceptance of our second hypothesis of bryophyte richness and diversity to be largely influenced by substrate level variables. These results are consistent with previous research conducted by Mills and Macdonald (2005), where it was found that bryophyte composition is related to a hierarchy of factors at multiple scales including the finer scale such as the substrate level to the coarse scale such as landscape level influence. This was mirrored in our results as no specific environmental variables were associated with all models, rather the hierarchy of influence depended on both the taxonomic group and colonizing substrate. The relationship with distance from the lake was retained with half of the substrate-level models, while other models were associated with stand and substrate level factors only. Although our initial site scale relationship between richness and distance from the lake was found to be significant yet weak, we found the inclusion of environmental factors at the substrate scale was more effective at explaining variation in bryophyte species richness and diversity.

2.5.3 Effect of stand

Forest composition is an important factor on the influence of bryophyte diversity and composition. While the entirety of the study area was selected for its mixed-wood composition, to provide a more heterogeneous understory environment for a greater bryophyte diversity, the geographic orientation of the transects into an east and north zone separated forest composition characteristics (Kumar et al., 2018). The east zone was associated with a higher ratio of deciduous trees and higher canopy cover, which in turn was associated with both log and rock moss, as well as log liverworts, respectively. This combination of favourable environmental conditions including mixed-wood, high canopy cover, and high deciduous ratio, may have contributed to both log and rock bryophytes to have the highest species diversity out of all taxonomic and substrate type groupings. Both birch moss and liverworts were correlated with increased canopy cover and deciduous ratio. However, this relationship is likely skewed due to the substrate specific nature of bryophytes already being partial to the characteristics of birch trees.

Contrary to previous research, this study found low associations between stand age and increased bryophyte diversity. Multiple researchers have found older and late successional stands have the highest bryophyte biomass, diversity, and occurrences of species with infrequent or restricted reproduction (Boudreault et al., 2018; Fenton & Bergeron, 2008; Kumar et al., 2018). The lack of relationship with stand age in this study may be due to our measured stand age range being 166 years, whereas previous research was conducted on stands 200-350+ years old (Fenton & Bergeron, 2008; Kumar et al., 2018). However, spruce bryophytes were consistently associated with stand age across all models. While bryophyte diversity on spruce trees was generally low, this association between stand age and increased bryophyte diversity on spruce trees may be a consequence of older stand containing larger trees and therefore a larger surface area for increased species richness. This explanation however doesn't explain the lack of association between increased bryophyte diversity on birch trees and stand age. Therefore, further investigation into this relationship is needed.

2.5.4 Effect of substrate

Bryophyte diversity and community composition was largely affected at the substrate level; and as a majority of bryophytes exhibit substrate specificity, these results were to be expected (Kuglerová et al., 2016; Mills & Macdonald, 2004). In alignment with our third hypothesis, the relationship between environmental variables and bryophyte species differed by taxonomic group, mosses and liverworts, as well as the colonizing substrate. We found that the substrates log and rocks to have a higher diversity than both birch and spruce trees. While CWM, including logs, tend to have a high overall bryophyte diversity, this study maximized those findings by targeting samples of intermediate decay classes for higher community composition (Mills & Macdonald, 2004). The high variance in rock bryophyte diversity may be related to rock type and composition on a scale that was not sampled in this study. Spitale and Nascimbene (2012) found that patterns of bryophyte diversity on rocks are dependent on both rock type, its composition of minerals, and spatial structure, but diversity can be affected by reproductive dispersal abilities especially when there are fewer occurrences of rocks in the ecosystem. Rock substrate occurrences in the targeted stand types of this study were infrequent; however, when rocks were abundant, bryophyte species diversity was high. This feast or famine situation of rock substrate availability may have caused the large variance in species presence across the study landscape.

Finally, the difference in species richness between birch and spruce trees, with birch having a higher overall species diversity has been found in previous research by Mills and Macdonald (2004) where hardwoods averaged both higher bryophyte cover and richness than softwoods. However, the overall diversity found on both these tree bases is low compared to previous studies where it was found that richness was high due to the colonization of both epiphytic and forest floor bryophytes (Mills & Macdonald, 2004).

2.6 Conclusion

Our study has shown an increased distance from Lake Superior has a negative correlation with both the richness and diversity of bryophyte species. Gamma diversity of bryophytes reflected the pattern of lake-effect humidity being highest at the shore, dropping to a low in the middle distances, and increasing in the inland distances. Bryophyte species diversity also displayed a similar pattern where the shore distances had eight times (40 species) the number of unique species than that of the inland distances (5 species), while in the middle there where no species unique to its distance from the lake. Models displaying the direct relationship with species richness and distance from the lake also indicated a clear decrease in the number of species with increased distance from Lake Superior.

Our exploration into the effect of spatial scale on bryophyte richness and diversity showed the inclusion of stand level variables had a greater effect than distance from the lake. In fact, only one model, spruce moss (F-stat = 4.79, p = 0.013), resulted in a significant relationship with distances and the stand level variables latitude (p = 0.025), altitude (p = 0.015), and stand age (p = 0.001) (Table 2.1). Diversity was influenced by landscape and stand level factors related to the geographic orientation of the transects. Species diversity in the east zone was related to an increased average stand dbh, canopy cover, and a higher percentage of deciduous trees, where diversity in the north zone was related to a higher frequency of low humidity events.

This study found environmental variables correlating with bryophyte richness and diversity in a hierarchy of influence, with the substrate level exhibiting the greatest influence. All substrate level models produced significant results and improved the number of significant correlations with environmental variables. In alignment with our third hypothesis, each grouping of mosses, liverworts, and their colonizing substrate resulted in specific correlations with their own unique set of environmental variables. This further demonstrates the substrate-specific nature of bryophytes with their specific niche determining their substrate preferences.

Bryophyte richness and diversity in mixed-wood boreal forests cannot be targeted by improving the quality of a few environmental variables, but rather a hierarchy of factors contribute to the greatest diversity. Our study has shown that bryophytes need an abundance and variety of colonizing substrates, variation in stand features, as well as a source of humidity, like Lake Superior. The inclusion of these microclimate conditions in mapping species distributions or protecting area from anthropogenic activities will aid in conservation and preservation. Overall, ensuring a heterogenous habitat to maximise bryophyte diversity will contribute to overall forest health and biodiversity.

CHAPTER III

GENERAL DISCUSSION

Our study has shown that distance from Lake Superior has an overall positive effect on bryophyte species diversity and richness. Increasing distance from the lake reduces the total and cumulative richness, displaying a pattern similar to the decrease in lake-effect humidity. The addition of stand- and substrate-level environmental variables decreased this direct association with distance. Rather, bryophyte richness and diversity were associated with stand level factors that related to geographic orientation, with communities in the east and north zone displaying different tendencies. The inclusion of substrate level environmental variables led to the explanation power of bryophyte richness and diversity. This study further confirmed the substrate specificity of bryophytes, with each taxonomic group type displaying significant associations with their respective substrate. With these results, we believe that bryophyte species diversity is influenced by a hierarchy of environmental factors, with the substrate level being of greatest importance, while stand- and landscape-level factors influence which species are capable of colonizing within the habitat. Lake Superior's imposing humidity on its north-east forests have proven to be an excellent heterogeneous habitat for a diverse community of bryophytes yet focus on the local scale of individual stands and the substrates within will be needed to maintain high bryophyte diversity.

Our analysis of lake-effect humidity leads to unanswered questions on how far the moisture travels inland and the effect on bryophytes beyond the 100km mark. While our data loggers measured very moist forest occurring year-round, we identified a distinct drop in humidity at the 10-35km distances and increase at the 55-100km distances. While Scott & Huff (1996) previous identified the lake-effect distance as 80km and possibly more, we are left wondering if this value is an overstatement and the humidity only reached up to 10km, due to the significantly lower humidity values found in the middle distances. Perhaps the humid forests we measured in the 55-100km distances of our study exist regardless of the lake-effect. Unfortunately, no research was found indicating the normal humidity levels year-round in these mixed-wood boreal forests, so no comparison can be made. Further research into the humidity and bryophyte richness at distances beyond our 100km transects would provide interesting results.

Understanding the drivers of bryophyte diversity and community assemblages help to prioritize habitat conservation efforts to ensure the highest biodiversity. We have added to previous research concluding that diverse bryophyte communities require heterogeneity in their habitats at multiple scales including a variety of quality substrates, old stands with mixed tree species composition, variety in topography, and humid environments (where possible). As the landscape surrounding Lake Superior is faced with greater threats of anthropogenic expansion and activities that degrade the conditions required by many bryophyte species, we can use this research to protect bryophyte habitats. For example, logging can be improved leaving woody debris behind as suitable substrates for bryophyte colonization (Crites & Dale, 1998), or sensitive habitats and/or species can be protected by ensuring generous buffer zones from mining operations (Yin et al., 2022). Ensuring that consideration for bryophyte protection is included in overall habitat conservation will ensure the ecosystem productivity and biodiversity of theses forests can continue.

APPENDIX A

Land cover, temperature, precipitation, and substrate types for the four ecoregions within study area; recorded between 1982-96 (Wester et al., 2018).

Ecoregion	**Land cover**	**Mean annual temperature (C°)**	**Mean annual precipitation (mm)**	**Mean summer precipitation (mm)**	**Major substrate types**
Lake Abitibi	Mixed forest (29.5%) Coniferous forest (28.1%) Deciduous forest (7.2%) Water (6.7%)	-0.5 – 2.5	652 – 1029	220 – 291	Mesisiols (24%) Humo-ferric Podzols (23%) Gleysols (18%) Gray Luvisols (15%) Rocky areas within forest cover (13%) Brunisols (4%)
Lake Nipigon	Mixed forest (23.5%) Coniferous forest (23.0%) Water (17.1%) Deciduous forest (9.0%)	-1.7 – 2.1	654 – 879	231 – 298	Humo-ferric Podzols (37%) Dystric Brunisols (26%) Acidic bedrock (25%) Mesisols (8%)
Lake Temagami	Mixed forest (33.2%) Coniferous forest (19.9%) Deciduous forest (17.1%) Water (10.9%)	0.8 – 4.3	725 – 1148	217 – 291	Thinly covered acidic bedrock (61%) Humo-ferric Podzols (27%) Mesisols (7%) Gleysols (4%) Dystric Brunisols (1%)
Georgian Bay	Mixed forest (32.0%) Deciduous forest (22.2%) Coniferous forest (12.1%) Water (11.0%)	2.8 – 6.2	771 – 1134	204 – 304	Humo-ferric Podzols (59%) Acidic bedrock (26%) Mesisols (6%) Melanic Brunisols (4%)

APPENDIX B

Results of the ANOVA for daily maximum temperature and daily low relative humidity for each group distance (1 = 0-5km, 2 = 10-35km, and 3 = 55-100km). Significant effects ($p \leq 0.05$) are shown in bold.

	Sum of squares	**F value**	**p-value**
Temperature (C°)	34.00	0.113	0.893
Relative humidity (%)	**12566**	**14.04**	**0.000**

Results of the Tukey multiple comparison of means post hoc test on the differences in daily maximum temperature and daily low relative humidity between the three group distances (1 = 0-5km, 2 = 10-35km, and 3 = 55-100km). Significant effects ($p \leq 0.05$) are shown in bold.

	Group distance	**Group distance**	**Difference**	**p adjusted**
Temperature (C°)	Group distance 1	Group distance 2	0.175	0.885
	Group distance 1	Group distance 3	0.045	0.989
	Group distance 2	Group distance 3	-0.129	0.935
Relative humidity (%)	**Group distance 1**	**Group distance 2**	**-2.526**	**0.000**
	Group distance 1	Group distance 3	0.800	0.325
	Group distance 2	**Group distance 3**	**1.831**	**0.000**

APPENDIX C

Results of the ANOVA for number of species per taxonomic group and substrate type. Significant effects ($p \leq 0.05$) are shown in bold.

	df	**Sum of Squares**	**Mean Square**	**F value**	**p-value**
Taxonomic group and substrate	7	6250	892.9	87.03	0.000

Results of the Tukey multiple comparison of means post hoc test on the number of species per taxonomic group and substrate type. Significant effects ($p \leq 0.05$) are shown in bold.

Species substrate 1	**Species substrate 2**	**Difference**	**p adjusted**
Birch moss	**Birch liverworts**	**7.704**	**0.000**
Log liverworts	**Birch liverworts**	**2.778**	**0.000**
Log moss	**Birch liverworts**	**9.926**	**0.000**
Rock liverworts	Birch liverworts	1.768	0.200
Rock moss	**Birch liverworts**	**7.889**	**0.000**
Spruce liverworts	**Birch liverworts**	**-2.019**	**0.025**
Spruce moss	**Birch liverworts**	**4.963**	**0.000**
Log liverworts	**Birch moss**	**-4.926**	**0.000**
Log moss	**Birch moss**	**2.222**	**0.008**
Rock liverworts	**Birch moss**	**-5.936**	**0.000**
Rock moss	Birch moss	0.185	1.000
Spruce liverworts	**Birch moss**	**-9.722**	**0.000**
Spruce moss	**Birch moss**	**-2.741**	**0.000**
Log moss	**Log liverworts**	**7.148**	**0.000**
Rock liverworts	Log liverworts	-1.010	0.844
Rock moss	**Log liverworts**	**5.111**	**0.000**
Spruce liverworts	**Log liverworts**	**-4.796**	**0.000**
Spruce moss	**Log liverworts**	**2.185**	**0.010**
Rock liverworts	**Log moss**	**-8.158**	**0.000**
Rock moss	**Log moss**	**-2.037**	**0.080**
Spruce liverworts	**Log moss**	**-11.94**	**0.000**
Spruce moss	**Log moss**	**-4.963**	**0.000**
Rock moss	**Rock liverworts**	**6.121**	**0.000**

Spruce liverworts	**Rock liverworts**	**-3.786**	**0.000**
Spruce moss	**Rock liverworts**	**3.195**	**0.000**
Spruce liverworts	**Rock moss**	**-9.907**	**0.000**
Spruce moss	**Rock moss**	**-2.926**	**0.001**
Spruce moss	**Spruce liverworts**	**6.981**	**0.000**

APPENDIX D

Environmental variables at the individual site level. Latitude, longitude, and altitude values were collected from the Garmin GPSMAP 64s device. Canopy cover was calculated using four estimates of cover using a densiometer from the center point of the site.

Site	**Distance (km)**	**Latitude**	**Longitude**	**Altitude (m)**	**Canopy Cover (%)**	**Stand Age**	**Average DBH (cm)**	**Decidious Ratio (%)**	**Frequency of Low Humidity Period**	**Average Length of Low Humidity Period (hours)**
1A	0	48.4020	48.4020	186.9	0.89	NA	20.06	0.13	NA	NA
1B	1	48.4072	48.4072	274.6	0.74	NA	18.25	0.50	NA	NA
1C	2.5	48.4151	48.4151	242.2	0.83	NA	23.42	0.33	NA	NA
1F	20	48.4953	48.4953	406.1	0.83	NA	20.41	0.65	0.1517	6.1509
1I	75	48.8482	48.8482	347.9	0.66	166	24.68	0.41	0.3624	6.6357
2A	0	48.0373	48.0373	457.3	0.95	112	25.42	0.42	NA	NA
2B	1	48.0412	48.0412	489.3	0.93	113	12.05	0.00	NA	NA
2G	35	48.2733	48.2733	442.9	0.67	91	25.25	0.25	NA	NA
2H	55	48.3921	48.3921	444.8	0.53	67	22.94	0.06	0.3904	6.1583
2I	75	48.4808	48.4808	187.6	0.62	117	26.33	0.44	NA	NA
2J	100	48.6542	48.6542	266.7	0.73	144	24.54	0.33	0.3287	7.3190

Site	Distance (km)	Latitude	Longitude	Altitude (m)	Canopy Cover (%)	Stand Age	Average DBH (cm)	Decidious Ratio (%)	Frequency of Low Humidity Period	Average Length of Low Humidity Period (hours)
3A	0	48.6509	48.6509	206.5	0.61	88	22.36	0.29	0.4466	5.3836
3B	1	48.6570	48.6570	194.7	0.69	86	21.55	0.53	NA	NA
3C	2.5	48.6611	48.6611	251.7	0.66	92	18.24	0.38	NA	NA
3D	5	48.6902	48.6902	321.3	0.64	110	18.15	0.21	0.2528	6.3933
3F	20	48.7870	48.7870	337.4	0.60	109	21.28	0.44	NA	NA
3H	55	48.9958	48.9958	320.4	0.63	118	16.54	0.38	0.2949	6.9615
3I	75	49.1213	49.1213	177.9	0.66	65	23.48	0.22	NA	NA
4A	0	47.4486	47.4486	210.1	0.59	139	18.54	0.25	0.4691	5.1257
4B	1	47.4488	47.4488	289.9	0.76	146	26.20	0.40	NA	NA
4C	2.5	47.4501	47.4501	277.0	0.86	94	33.00	0.92	NA	NA
4D	5	47.4592	47.4592	422.7	0.73	81	23.59	0.55	0.3652	6.2093
4H	55	47.4928	47.4928	434.3	0.76	132	29.09	0.31	NA	NA
4I	75	47.4052	47.4052	493.4	0.72	89	27.13	0.31	0.1994	5.2319
4J	100	47.4646	47.4646	211.8	0.80	62	21.40	0.67	NA	NA
5A	0	47.7932	47.7932	249.9	0.56	105	24.10	0.13	NA	NA
5B	1	47.7953	47.7953	332.5	0.73	87	17.74	0.12	0.4101	5.8630
5C	2.5	47.7755	47.7755	403.9	0.67	123	15.86	0.83	NA	NA

Site	Distance (km)	Latitude	Longitude	Altitude (m)	Canopy Cover (%)	Stand Age	Average DBH (cm)	Decidious Ratio (%)	Frequency of Low Humidity Period	Average Length of Low Humidity Period (hours)
5D	5	47.7469	47.7469	359.7	0.77	109	32.19	0.61	NA	NA
5E	10	47.7442	47.7442	385.8	0.72	136	25.15	0.29	0.2921	5.5743
5G	35	47.7661	47.7661	452.1	0.83	135	13.50	0.25	NA	NA
5I	75	47.7599	47.7599	491.1	0.72	101	17.71	0.14	0.3315	7.6186
5J	100	47.7309	47.7309	190.9	0.79	40	15.71	0.25	NA	NA
6A	0	47.0516	47.0516	207.6	0.61	128	20.30	0.27	NA	NA
6B	1	47.0376	47.0376	209.5	0.71	114	22.59	0.76	NA	NA
6C	2.5	47.0387	47.0387	265.6	0.85	106	34.56	0.67	NA	NA
6D	5	47.0419	47.0419	279.0	0.82	86	27.65	0.50	NA	NA
6F	20	47.0760	47.0760	450.2	0.79	131	27.11	0.45	NA	NA
6G	35	47.0758	47.0758	338.0	0.78	54	27.71	0.33	0.3062	6.9815
6H	55	47.0676	47.0676	448.4	0.80	75	29.25	0.88	NA	NA
6J	100	47.0891	47.0891	440.6	0.64	25	16.59	0.09	0.2612	6.5385
7A	0	48.7903	48.7903	201.8	0.57	62	19.48	0.33	NA	NA
7B	1	48.8000	48.8000	308.0	0.76	119	23.74	0.42	0.3933	6.4214
7C	2.5	48.8108	48.8108	382.1	0.56	84	20.59	0.27	NA	NA
7D	5	48.8354	48.8354	328.8	0.70	115	27.70	0.40	NA	NA

Site	Distance (km)	Latitude	Longitude	Altitude (m)	Canopy Cover (%)	Stand Age	Average DBH (cm)	Decidious Ratio (%)	Frequency of Low Humidity Period	Average Length of Low Humidity Period (hours)
7E	10	48.8799	48.8799	347.1	0.62	119	16.72	0.30	0.1826	7.9063
7F	20	48.9718	48.9718	325.0	0.72	137	17.29	0.47	NA	NA
7I	75	49.4589	49.4589	371.4	0.63	83	18.21	0.58	0.2865	7.9000
7J	100	49.6970	49.6970	355.0	0.63	63	21.85	0.24	NA	NA
8B	1	48.9052	48.9052	215.1	0.70	68	28.50	0.25	0.4017	6.2867
8C	2.5	48.9165	48.9165	344.6	0.50	94	22.77	0.00	NA	NA
8D	5	48.9405	48.9405	273.7	0.57	50	21.98	0.33	0.3652	6.3876
8G	35	49.2082	49.2082	438.0	0.62	98	22.10	0.40	0.3989	6.2867
8H	55	49.3778	49.3778	440.1	0.76	84	20.00	0.47	NA	NA

APPENDIX E

Names, authorities, and codes of the bryophyte species found (Faubert, 2014; Ireland & Hanes, 1982; Paton, 1999).

Species	Code
Acrocarpous Moss	
Andreaea rupestris A. Roth	andrup
Aulacomnium androgynum (Hedw.) Schwägr.	auland
Aulacomnium palustre (Hedw.) Schwägr.	aulpal
Bryum capillare Hedw.	brycap
Ceratodon purpureus (Hedw.) Brid.	cerpur
Cynodontium strumiferum (Hedw.) Lindb.	cynstr
Dicranella heteromalla (Hedw.) Schimp.	dichet
Dicranum flagellare Hedw.	dicfla
Dicranum fulvum Hook.	dicful
Dicranum fuscescens Turner	dicfus
Dicranum montanum Hedw.	dicmon
Dicranum ontariense W.L. Peterson	dicont
Dicranum polysetum Sw.	dicpol
Dicranum scoparium Hedw.	dicsco
Dicranum viride (Sull. & Lesq.) Lindb.	dicvir
Distichium capillaceum (Hedw.) Bruch & Schimp.	discap
Fissidens adianthoides Hedw.	fisadi
Fissidens dubius P. Beauv.	fisdub
Grimmia longirostris Hook.	grilon
Grimmia muehlenbeckii Schimp.	grimue
Grimmia rivularis Brid.	gririv
Mnium spinulosum Bruch & Schimp.	mnispi
Orthotrichum anomalum Hedw.	ortano
Orthotrichum elegans Schwägr. ex Hook. & Grev.	ortele
Orthotrichum obtusifolium Schrad. ex Brid.	ortobt
Orthotrichum speciosum Nees	ortspe
Orthotrichum stellatum Brid.	ortste
Paraleucobryum longifolium (Ehrh. ex Hedw.) Loeske	parlon
Plagiomnium ellipticum (Brid.) T.J. Kop.	plaell
Plagiopus oerderianus (Swartz) H.A. Crum & L.E. Anderson	plaoer
Pohlia cruda (Hedw.) Lindb.	pohcru
Pohlia elongata Hedw.	pohelo
Pohlia melanodon (Brid.) A.J. Shaw	pohmel

Species	Code
Pohlia nutans (Hedw.) Lindb.	pohnut
Polytrichum commune Hedw.	polcom
Rhizomnium punctatum (Hedw.) T.J. Kop.	rhipun
Schistidium apocarpum (Hedw.) Bruch & Schimp.	schapo
Schistidium papillosum Culm.	schpap
Schistidium rivulare (Brid.) Podp.	schriv
Tetraphis pellucida Hedw.	tetpel
Tortella humilis (Hedw.) Jenn.	torhum
Tortella tortuosa (Hedw.) Limpr.	tortor
Ulota coarctata (P. Beauv.) Hammar	ulocoa
Ulota crispa (Hedw.) Brid.	ulocri
Ulota hutchinsiae (Sm.) Hammar	Ulohut
Pleurocarpous Moss	
Amblystegium serpens (Hedw.) Schimp.	ambser
Amblystegium varium (Hedw.) Lindb.	ambvar
Anomodon attenuatus (Hedw.) Huebener	anoatt
Brachythecium albicans (Hedw.) Schimp.	braalb
Brachythecium campestre (Müll. Hal.) Schimp.	bracam
Brachythecium curtum (Lindb.) Limpr.	bracur
Brachythecium erythrorrhizon Schimp.	braery
Brachythecium laetum (Brid.) Schimp.	bralae
Brachythecium populeum (Hedw.) Schimp.	brapop
Brachythecium reflexum (Starke) Schimp.	braref
Brachythecium rutabulum (Hedw.) Schimp.	brarut
Brachythecium starkii (Brid.) Schimp.	brasta
Brachythecium velutinum (Hedw.) Schimp.	bravel
Brotherella recurvans (Michx.) M. Fleisch.	brorec
Callicladium haldanianum (Grev.) H.A. Crum	calhal
Campyliadelphus chrysophyllus (Brid.) Kanda	camchr
Campylophyllum hispidulum (Brid.) Hedenäs	camhis
Eurhynchium pulchellum (Hedw.) Jenn.	eurpul
Hedwigia ciliata (Hedw.) P. Beauv.	hedcil
Herzogiella striatella (Brid.) Z. Iwats.	herstr
Herzogiella turfacea (Lindb.) Z. Iwats.	hertur
Heterocladium dimorphum (Brid.) Schimp.	hetdim
Homalia trichomanoides (Hedw.) Schimp.	homtri
Homomallium adnatum (Hedw.) Broth.	homadn
Hylocomium splendens (Hedw.) Schimp.	hylspl
Hylocomiastrum pyrenaicum (Spruce) M. Fleisch. ex Broth.	hylpyr
Hylocomiastrum umbratum (Hedw.) M. Fleisch. ex Broth.	hylumb

Species	Code
Hypnum cupressiforme Hedw.	hypcup
Hypnum curvifolium Hedw.	hypcur
Hypnum imponens Hedw.	hypimp
Hypnum lindbergii Mitt.	hyplin
Hypnum pallescens (Hedw.) P. Beauv.	hyppal
Isopterygiopsis muelleriana (Schimp.) Z. Iwats.	isomue
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	isopul
Leskeella nervosa (Brid.) Loeske	lesner
Myurella julacea (Schwägr.) Schimp.	myujul
Myurella sibirica (Müll. Hal.) Reimers	myusib
Neckera pennata Hedw.	necpen
Oxyrrhynchium hians (Hedw.) Loeske	oxyhia
Plagiothecium denticulatum (Hedw.) Schimp.	pladet
Plagiothecium laetum Schimp.	plalae
Platydictya confervoides (Brid.) H.A. Crum	placon
Platydictya subtilis (Hedw.) H.A. Crum	plasub
Platygyrium repens (Brid.) Schimp.	plarep
Pleurozium schreberi (Willd. ex Brid.) Mitt.	plesch
Pseudotaxiphyllum distichaceum (Mitt.) Z. Iwats.	psedis
Pseudotaxiphyllum elegans (Brid.) Z. Iwats.	pseele
Pterigynandrum filiform Hedw.	ptefil
Ptilium crista-castrensis (Hedw.) De Not.	pticri
Pylaisia selwynii Kindb.	pylsel
Rhytidiadelphus triquetrus (Hedw.) Warnst.	rhytri
Sanionia uncinata (Hedw.) Loeske	sanunc
Taxiphyllum deplanatum (Bruch & Schimp. ex Sull.) M. Fleisch.	taxdip
Thuidium delicatulum (Hedw.) Schimp.	thudel
Thuidium recognitum (Hedw.) Lindb.	thurec
Sphagnum Moss	
Sphagnum capillifolium (Ehrh.) Hedw.	sphcap
Liverworts	
Anastrophyllum hellerianum (Nees ex Lindenb.) R.M. Schust.	anahel
Anastrophyllum michauxii (F. Weber) H. Buch	anamic
Anastrophyllum minutum (Schreb.) R.M. Schust.	anamin
Barbilophozia attenuata (Mart.) Loeske	baratt
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	barbar
Barbilophozia hatcheri (A. Evans) Loeske	barhat
Barbilophozia kunzeana (Huebener) Müll. Frib.	barkun
Bazzania trilobata (L.) Gray	baztri
Blepharostoma trichophyllum (L.) Dumort.	bletri

Species	**Code**
Calypogeia integristipula Steph.	calint
Cephalozia bicuspidata (L.) Dumort.	cepbic
Cephalozia lunulifolia (Dumort.) Dumort.	ceplun
Cephaloziella divaricata (Sm.) Schiffn.	cepdiv
Cephaloziella rubella (Nees) Warnst.	ceprub
Cololejeunea biddlecomiae (Austin ex Pearson) A. Evans	colbid
Frullania asagrayana Mont.	fruasa
Frullania bolanderi Austin	frubol
Frullania eboracensis Lehm.	fruebo
Frullania microphylla (Gottsche) Pearson	frumic
Frullania oakesiana Austin	fruoak
Frullania selwyniana Pearson	frusel
Geocalyx graveolens (Schrad.) Nees	geogra
Jamesoniella autumnalis (DC.) Steph.	jamaut
Jungermannia leiantha Grolle	junlei
Lejeunea cavifolia (Ehrh.) Lindb.	lejcav
Lepidozia reptans (L.) Dumort.	leprep
Lophocolea heterophylla (Schrad.) Dumort.	lophet
Lophocolea minor Nees	lopmin
Lophozia ascendens (Warnst.) R.M. Schust.	lopasc
Lophozia bicrenata (Schmidel ex Hoffm.) Dumort.	lopbic
Lophozia longidens (Lindb.) Macoun	loplon
Lophozia ventricosa (Dicks.) Dumort.	lopven
Nowellia curvifolia (Dicks.) Mitt.	nowcur
Plagiochila porelloides (Torr. ex Nees) Lindenb.	plapor
Ptilidium ciliare (L.) Hampe	pticil
Ptilidium pulcherrimum (Weber) Vain.	ptipul
Radula complanata (L.) Dumort.	radcom
Riccardia chamedryfolia (With.) Grolle	riccham
Riccardia latifrons (Lindb.) Lindb.	riclat
Scapania apiculata Spruce	scaapi
Scapania irrigua (Nees) Nees	scairr
Scapania nemorea (L.) Grolle	scanem
Tritomaria exsecta (Schmidel) Schiffn. ex Loeske	triexa
Tritomaria exsectiformis (Breidl.) Schiffn. ex Loeske	triexi

APPENDIX F

Acrocarpous moss species found on sites 1A to 5B. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	**Site**																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Acrocarpous Moss																											
Andreaea rupestris	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacomnium androgynum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacomnium palustre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Bryum capillare	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratodon purpureus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cynodontium strumiferum	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Dicranella heteromalla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dicranum flagellare	2	7	2	8	5	1	3	7	3	1	2	4	0	3	4	4	8	5	0	5	1	0	5	9	0	3	1
Dicranum fulvum	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	**Site**																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Dicranum fuscescens	3	3	0	6	0	4	0	6	3	1	4	6	1	3	13	9	9	8	2	0	2	3	8	8	0	4	2
Dicranum montanum	18	18	17	10	9	15	18	12	11	18	13	15	14	15	15	16	10	10	17	17	17	16	18	12	6	21	15
Dicranum ontariense	0	4	3	2	0	2	1	4	0	0	0	0	3	5	0	2	0	3	3	1	0	3	2	0	0	0	3
Dicranum polysetum	1	2	1	1	1	2	2	1	2	0	1	0	1	4	2	0	4	3	2	1	1	0	1	0	0	2	0
Dicranum scoparium	2	1	3	5	2	4	7	4	6	3	6	0	10	4	5	3	3	3	7	3	1	3	4	2	0	0	3
Dicranum viride	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2	0	0	5	4	2	1	1	1	3	0
Distichium capillaceum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fissidens adianthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fissidens dubius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grimmia longirostris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grimmia muehlenbeckii	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Grimmia rivularis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mnium spinulosum	3	1	2	0	0	2	2	0	1	3	7	0	1	1	0	0	2	4	0	1	2	1	6	1	6	9	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Orthotrichum anomalum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Orthotrichum elegans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthotrichum obtusifolium	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Orthotrichum speciosum	0	0	1	0	2	0	2	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Orthotrichum stellatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Paraleucobryum longifolium	7	4	0	0	0	0	8	3	3	7	4	1	5	0	1	0	2	0	6	1	1	5	4	4	0	7	0
Plagiomnium ellipticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Plagiopus oerderianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Pohlia cruda	2	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	3	1	0	0	0	0	1	1	0	1	0
Pohlia elongata	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Pohlia melanodon	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohlia nutans	0	1	0	1	0	0	1	1	1	0	0	0	2	1	0	0	1	1	0	0	0	0	1	0	0	0	0
Polytrichum commune	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0	0	0	1	0	0	0
Rhizomnium punctatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Schistidium apocarpum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schistidium papillosum	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schistidium rivulare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraphis pellucida	0	2	1	1	0	2	0	0	1	0	0	2	1	5	2	3	0	1	5	3	2	3	3	4	0	3	2
Tortella humilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tortella tortuosa	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Ulota coarctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulota crispa	1	0	0	0	0	1	3	0	0	0	0	0	1	0	3	0	0	0	0	2	1	3	0	0	0	0	2
Ulota hutchinsiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Acrocarpous moss species found on sites 5C to 8H. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Acrocarpous Moss																											
Andreaea rupestris	0	0	0	0	0	0	0	0	0	0	5	0	0	1	1	0	0	1	0	1	0	0	0	0	0	2	0
Aulacomnium androgynum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulacomnium palustre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bryum capillare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Ceratodon purpureus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cynodontium strumiferum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Dicranella heteromalla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dicranum flagellare	2	1	3	10	5	8	0	0	0	0	0	5	0	9	0	1	2	0	0	0	2	4	5	0	4	5	3
Dicranum fulvum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Dicranum fuscescens	3	0	2	5	4	9	8	1	1	0	0	0	1	2	4	0	7	10	12	2	1	5	0	10	6	3	10
Dicranum montanum	37	12	14	14	7	10	17	11	15	10	10	13	12	16	20	22	16	21	8	21	3	4	17	15	13	19	12

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Dicranum ontariense	5	0	0	0	0	0	3	1	0	0	0	0	0	0	0	9	1	2	3	1	0	0	2	2	2	1	0
Dicranum polysetum	2	1	0	6	9	0	2	1	1	0	0	0	1	0	0	0	3	0	1	3	2	2	1	1	4	4	2
Dicranum scoparium	13	3	2	8	5	4	5	3	1	0	2	1	6	3	3	3	5	3	1	6	1	2	7	5	7	8	3
Dicranum viride	1	6	2	0	0	0	0	0	1	4	9	1	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Distichium capillaceum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Fissidens adianthoides	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fissidens dubius	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grimmia longirostris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Grimmia muehlenbeckii	0	0	0	1	0	0	0	0	0	0	3	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	0
Grimmia rivularis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mnium spinulosum	0	0	1	1	0	2	1	0	0	2	0	0	7	3	2	1	0	0	0	2	2	2	0	1	0	0	1
Orthotrichum anomalum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Orthotrichum elegans	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Orthotrichum obtusifolium	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Orthotrichum speciosum	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	1	0	0	0	0	0
Orthotrichum stellatum	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraleucobryum longifolium	3	9	2	3	0	4	2	0	0	1	9	0	8	4	1	6	0	5	1	8	0	0	1	0	0	2	1
Plagiomnium ellipticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagiopus oerderianus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohlia cruda	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0	1	0	0	0	0	0	0	0	1	0
Pohlia elongata	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohlia melanodon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohlia nutans	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	1	2	3	0	3	1	0	1	2	0	4	2
Polytrichum commune	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhizomnium punctatum	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schistidium apocarpum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schistidium papillosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	5C	5D	5E	5G	5I	5J	6A	6B	6C	6D	6F	6G	6H	6J	7A	7B	7C	7D	7E	7F	7I	7J	8B	8C	8D	8G	8H
Schistidium rivulare	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetraphis pellucida	2	3	1	4	2	4	2	0	0	0	1	0	0	2	0	14	2	6	2	3	2	1	2	0	0	1	0
Tortella humilis	0	3	0	0	0	0	0	0	1	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tortella tortuosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ulota coarctata	0	0	0	0	0	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Ulota crispa	6	5	0	0	0	0	0	2	0	4	3	2	3	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Ulota hutchinsiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Pleurocarpous moss species found on sites 1A to 5B. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	**Site**																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Pleurocarpous Moss																											
Amblystegium serpens	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	4	0
Amblystegium varium	0	1	0	0	0	0	0	0	0	3	2	0	2	0	1	0	0	0	0	0	0	5	2	0	5	0	0
Anomodon attenuatus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium albicans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium campestre	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	2	0
Brachythecium curtum	4	3	7	5	0	0	0	3	2	0	7	0	1	1	0	1	2	3	1	2	2	0	5	0	0	0	4
Brachythecium erythrorrhizon	0	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Brachythecium laetum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium populeum	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Brachythecium reflexum	4	0	4	4	0	3	6	5	1	6	1	0	0	1	1	1	3	0	0	0	3	5	10	8	3	0	1
Brachythecium rutabulum	0	0	2	7	1	5	3	1	0	1	2	2	0	0	0	1	1	0	0	0	1	1	1	0	4	0	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Brachythecium starkii	0	0	2	0	1	3	0	0	0	0	0	0	3	1	0	0	0	0	0	2	0	3	2	0	0	0	2
Brachythecium velutinum	0	0	0	0	4	2	2	1	3	5	3	0	0	0	0	1	2	1	0	0	1	0	1	0	4	0	0
Brotherella recurvans	0	2	3	0	0	1	0	1	0	0	0	0	1	1	3	0	2	0	18	4	6	16	0	6	0	0	3
Callicladium haldanianum	2	1	6	5	1	5	1	5	0	4	2	0	2	2	3	1	2	1	2	5	10	14	6	8	5	0	3
Campyliadelphus chrysophyllus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Campylophyllum hispidulum	0	0	0	0	0	0	0	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Eurhynchium pulchellum	0	0	0	0	0	0	5	0	0	1	2	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0
Hedwigia ciliata	4	0	0	0	0	0	2	1	0	2	2	0	1	0	0	0	0	0	0	1	0	0	0	2	0	4	0
Herzogiella striatella	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	1
Herzogiella turfacea	1	1	9	3	0	4	4	2	1	4	5	3	0	5	4	2	3	7	2	1	0	1	4	1	5	1	3
Heterocladium dimorphum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homalia trichomanoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homomallium adnatum	3	1	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Species	**Site**																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Hylocomium splendens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Hylocomiastrum pyrenaicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hylocomiastrum umbratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hypnum cupressiforme	0	0	1	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hypnum curvifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypnum imponens	2	2	1	0	3	0	1	0	4	3	0	0	2	0	2	0	1	1	0	2	3	7	1	0	1	1	0
Hypnum lindbergii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Hypnum pallescens	14	12	9	9	5	16	14	12	5	15	12	12	18	5	12	4	4	6	5	12	12	9	17	10	6	15	6
Isopterygiopsis muelleriana	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Isopterygiopsis pulchella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Leskeella nervosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myurella julacea	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myurella sibirica	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Neckera pennata	0	0	2	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2	0
Oxyrrhynchium hians	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagiothecium denticulatum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Plagiothecium laetum	13	6	9	9	6	7	8	11	5	2	4	11	8	10	10	14	2	6	10	6	8	9	15	13	5	10	9
Platydictya confervoides	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Platydictya subtilis	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Platygyrium repens	9	0	2	0	1	3	8	0	2	6	2	5	3	3	4	0	0	0	8	7	13	10	0	1	6	17	3
Pleurozium schreberi	5	9	6	6	11	3	4	7	7	6	8	7	5	15	6	11	11	8	5	1	2	5	6	4	0	3	8
Pseudotaxiphyllum distichaceum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	2	0	0	0
Pseudotaxiphyllum elegans	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pterigynandrum filiform	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	0
Ptilium crista-castrensis	2	1	2	5	3	2	0	0	2	1	4	0	1	4	6	4	4	3	1	2	2	1	2	0	0	0	8
Pylaisia selwynii	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Rhytidiadelphus triquetrus	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Sanionia uncinata	11	6	10	11	6	6	16	8	10	16	15	11	18	11	7	3	11	12	6	6	6	7	14	4	6	14	4
Taxiphyllum deplanatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thuidium delicatulum	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Thuidium recognitum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Pleurocarpous moss species found on sites 5C to 8H. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Pleurocarpous Moss																											
Amblystegium serpens	1	0	0	0	0	0	4	0	2	1	0	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0
Amblystegium varium	3	7	0	2	0	2	0	0	3	6	11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anomodon attenuatus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium albicans	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium campestre	0	0	0	0	0	0	1	4	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Brachythecium curtum	7	0	0	2	0	3	0	0	3	0	1	0	2	4	7	5	0	0	3	2	1	2	2	2	9	1	7
Brachythecium erythrorrhizon	1	1	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium laetum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachythecium populeum	0	1	0	0	0	0	2	0	1	0	2	0	0	0	1	0	0	1	0	2	0	0	0	0	0	0	0
Brachythecium reflexum	10	4	0	3	1	11	0	3	6	2	5	3	10	1	3	1	1	4	2	5	1	0	1	1	3	0	7
Brachythecium rutabulum	3	2	0	0	0	1	0	0	2	1	1	0	0	0	3	1	3	7	1	2	1	2	0	0	1	0	0

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Brachythecium starkii	2	3	1	0	0	3	2	3	1	1	0	1	3	0	0	1	0	1	0	0	1	0	1	1	0	0	3
Brachythecium velutinum	2	3	1	2	1	1	5	0	5	0	1	1	4	0	0	0	1	0	0	1	6	3	0	0	0	1	3
Brotherella recurvans	9	4	3	3	0	2	1	7	1	5	1	1	4	0	1	3	1	9	1	1	0	0	2	2	0	2	2
Callicladium haldanianum	13	7	2	4	1	8	7	10	13	9	6	9	3	1	5	1	1	2	2	4	3	0	11	1	1	0	1
Campyliadelphus chrysophyllus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Campylophyllum hispidulum	0	2	0	0	0	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
Eurhynchium pulchellum	0	0	2	0	0	1	4	0	0	2	0	0	1	0	3	0	0	0	0	0	2	3	0	0	1	0	0
Hedwigia ciliata	0	0	0	1	0	0	1	0	0	1	3	0	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Herzogiella striatella	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Herzogiella turfacea	6	1	0	0	3	8	5	1	0	0	0	2	0	0	1	5	2	3	0	4	3	3	1	4	7	3	5
Heterocladium dimorphum	0	1	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homalia trichomanoides	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homomallium adnatum	1	0	1	0	0	0	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0		0

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Hylocomium splendens	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Hylocomiastrum pyrenaicum	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hylocomiastrum umbratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypnum cupressiforme	1	0	0	0	0	1	1	0	0	0	1	3	1	1	0	0	0	0	0	4	0	0	0	0	0	0	0
Hypnum curvifolium	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Hypnum imponens	4	7	3	1	0	3	0	7	7	3	5	8	4	4	5	0	4	0	0	4	2	1	2	0	0	1	0
Hypnum lindbergii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypnum pallescens	19	11	12	8	2	12	8	16	14	12	12	1	14	4	14	6	6	16	6	7	5	3	14	4	8	7	8
Isopterygiopsis muelleriana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Isopterygiopsis pulchella	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Leskeella nervosa	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myurella julacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myurella sibirica	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Neckera pennata	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
Oxyrrhynchium hians	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagiothecium denticulatum	0	1	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Plagiothecium laetum	24	9	6	15	8	14	4	2	13	8	6	5	6	8	11	19	8	12	12	9	1	3	10	8	10	6	9
Platydictya confervoides	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Platydictya subtilis	0	1	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Platygyrium repens	15	12	10	2	0	0	2	7	14	8	10	10	7	0	5	4	0	2	0	2	2	0	4	0	0	1	1
Pleurozium schreberi	15	2	0	14	11	5	2	2	2	1	0	2	2	10	5	11	13	3	11	8	3	12	6	11	10	10	8
Pseudotaxiphyllum distichaceum	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudotaxiphyllum elegans	0	1	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
Pterigynandrum filiform	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptilium crista-castrensis	11	0	0	1	0	2	0	0	2	0	0	1	0	2	2	4	6	1	6	1	1	2	2	7	5	2	6
Pylaisia selwynii	0	0	5	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Rhytidiadelphus triquetrus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	1	0	0	1	0
Sanionia uncinata	12	9	5	8	2	14	13	8	4	4	2	6	4	4	17	11	7	10	6	14	11	13	10	4	9	4	11
Taxiphyllum deplanatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Thuidium delicatulum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	0	0	0
Thuidium recognitum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0

Sphagnum moss and liverwort species found on sites 1A to 5B. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Sphagnum Moss																											
Sphagnum capillifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liverworts																											
Anastrophyllum hellerianum	0	0	3	2	1	2	3	0	1	3	4	1	3	0	2	0	4	3	1	2	1	2	3	3	0	1	0
Anastrophyllum michauxii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Anastrophyllum minutum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0
Barbilophozia attenuata	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	5	0	0	0	0	4	0	6	0	0	0
Barbilophozia barbata	4	2	0	0	0	0	5	1	2	3	3	1	1	0	0	0	2	2	3	2	0	0	2	0	0	2	1
Barbilophozia hatcheri	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barbilophozia kunzeana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bazzania trilobata	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	0	1	0	0	0
Blepharostoma trichophyllum	0	2	1	1	0	3	0	3	2	3	6	3	2	0	3	0	5	3	2	2	0	8	5	4	0	4	1
Calypogeia integristipula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Cephalozia bicuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0
Cephalozia lunulifolia	0	0	0	1	0	2	0	0	0	0	0	0	0	0	1	0	3	1	0	0	5	5	0	2	0	0	0
Cephaloziella divaricata	0	1	0	0	0	0	1	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephaloziella rubella	0	3	3	0	0	0	1	0	0	0	0	0	3	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Cololejeunea biddlecomiae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Frullania asagrayana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Frullania bolanderi	0	1	10	0	0	0	8	0	0	0	0	2	2	0	3	0	0	1	1	1	5	5	0	0	0	4	0
Frullania eboracensis	3	1	6	2	0	0	4	0	0	0	0	1	0	0	1	0	0	2	1	3	0	1	0	0	0	0	0
Frullania microphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frullania oakesiana	2	0	1	2	0	0	3	0	0	0	1	1	0	0	1	0	0	6	1	0	0	0	5	3	7	1	0
Frullania selwyniana	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Geocalyx graveolens	0	0	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0
Jamesoniella autumnalis	0	3	9	9	6	5	5	3	2	10	12	1	6	1	6	3	9	8	3	6	8	12	17	12	2	4	4

Species	Site																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Jungermannia leiantha	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Lejeunea cavifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lepidozia reptans	2	1	0	0	0	4	0	3	2	0	1	2	0	1	1	1	4	0	3	0	0	2	1	2	0	2	0
Lophocolea heterophylla	11	6	11	6	2	4	9	4	2	5	9	5	7	3	10	4	3	5	5	0	4	12	8	9	9	7	10
Lophocolea minor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophozia ascendens	0	2	4	0	0	1	2	1	0	4	4	1	2	0	1	0	3	1	0	0	0	2	1	0	0	0	0
Lophozia bicrenata	0	0	0	0	0	0	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	4	1	0	1	0
Lophozia longidens	3	1	1	0	0	0	4	0	3	0	2	2	7	0	1	0	2	1	0	1	0	0	3	0	0	4	0
Lophozia ventricosa	0	1	0	0	0	0	1	0	4	1	2	0	4	0	0	0	4	0	0	0	1	1	0	1	0	1	0
Nowellia curvifolia	0	2	3	2	0	3	0	1	0	2	3	1	2	1	2	0	3	2	1	1	2	3	1	2	0	3	2
Plagiochila porelloides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Ptilidium ciliare	0	3	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	8	1
Ptilidium pulcherrimum	18	19	19	19	17	18	20	18	18	19	20	16	18	20	19	19	19	16	19	16	16	18	18	14	11	10	20

Species	**Site**																										
	1A	**1B**	**1C**	**1F**	**1I**	**2A**	**2B**	**2G**	**2H**	**2I**	**2J**	**3A**	**3B**	**3C**	**3D**	**3F**	**3H**	**3I**	**4A**	**4B**	**4C**	**4D**	**4H**	**4I**	**4J**	**5A**	**5B**
Radula complanata	0	0	3	0	0	0	3	0	1	1	2	1	2	0	2	0	1	5	0	1	2	0	0	0	2	0	0
Riccardia chamedryfolia	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Riccardia latifrons	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0
Scapania apiculata	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Scapania irrigua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scapania nemorea	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	1	5	0	0	0	4	0
Tritomaria exsecta	0	0	1	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	2	2	0	1	0	0	0
Tritomaria exsectiformis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5	0

Sphagnum moss and liverwort species found on sites 5C to 8H. Values represent the number of occurrences total for each site and may include multiple occurrences on multiple substrates.

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Sphagnum Moss																											
Sphagnum capillifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Liverworts																											
Anastrophyllum hellerianum	2	0	1	1	2	2	3	1	0	0	0	1	0	1	0	1	1	1	0	1	0	3	2	0	5	1	3
Anastrophyllum michauxii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Anastrophyllum minutum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1
Barbilophozia attenuata	0	3	3	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	2
Barbilophozia barbata	1	2	0	0	0	1	1	0	0	1	4	0	7	2	0	2	0	0	0	1	1	1	1	0	0	0	1
Barbilophozia hatcheri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Barbilophozia kunzeana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bazzania trilobata	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Blepharostoma trichophyllum	4	4	0	4	0	4	6	0	1	3	1	0	4	7	3	8	2	5	1	5	1	2	1	0	2	1	4
Calypogeia integristipula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Species	**Site**																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Cephalozia bicuspidata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephalozia lunulifolia	0	1	0	1	1	5	0	0	0	2	0	0	0	1	0	1	2	2	0	0	1	0	1	0	0	0	1
Cephaloziella divaricata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	2	0	0	1	0
Cephaloziella rubella	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	2	2	0	0	0	0	0	0	1	0	0
Cololejeunea biddlecomiae	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Frullania asagrayana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frullania bolanderi	5	6	0	0	0	0	0	1	4	5	6	3	4	0	0	0	0	0	0	1	0	0	1	2	0	0	0
Frullania eboracensis	1	1	0	0	0	0	0	5	0	0	2	5	1	1	1	0	0	0	0	4	6	0	0	0	0	0	0
Frullania microphylla	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Frullania oakesiana	2	2	0	0	0	1	0	0	0	0	0	0	1	4	1	0	0	0	0	1	0	1	2	0	0	1	2
Frullania selwyniana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geocalyx graveolens	0	0	0	1	0	0	0	0	2	0	3	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0
Jamesoniella autumnalis	17	10	5	6	2	7	6	9	6	5	6	4	11	11	1	8	3	1	5	9	5	4	5	0	6	0	5

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Jungermannia leiantha	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	1	0	0
Lejeunea cavifolia	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidozia reptans	2	2	0	2	0	3	3	2	0	0	0	0	1	3	0	7	0	7	4	1	0	0	2	0	0	2	1
Lophocolea heterophylla	23	10	9	6	0	13	11	11	14	8	12	6	12	3	3	11	7	9	10	11	4	5	8	1	8	4	5
Lophocolea minor	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophozia ascendens	0	1	2	0	0	0	4	0	0	1	1	0	0	0	0	2	0	2	3	1	0	0	2	0	4	0	6
Lophozia bicrenata	0	0	0	3	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0
Lophozia longidens	0	2	0	0	0	2	0	0	0	0	0	0	2	5	1	4	0	5	0	2	0	1	0	2	0	5	1
Lophozia ventricosa	1	2	0	0	0	0	0	0	0	0	0	0	1	0	0	7	1	4	1	2	0	0	3	3	0	4	1
Nowellia curvifolia	4	0	1	0	0	2	3	3	0	1	0	4	0	3	1	1	2	1	0	0	1	2	3	0	5	0	3
Plagiochila porelloides	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptilidium ciliare	1	0	0	1	0	0	0	0	0	0	0	0	0	1	2	1	1	1	0	0	0	1	1	0	0	5	0
Ptilidium pulcherrimum	47	16	18	19	14	14	9	19	17	13	8	15	12	22	21	20	22	22	20	22	10	18	18	17	21	21	16

Species	Site																										
	5C	**5D**	**5E**	**5G**	**5I**	**5J**	**6A**	**6B**	**6C**	**6D**	**6F**	**6G**	**6H**	**6J**	**7A**	**7B**	**7C**	**7D**	**7E**	**7F**	**7I**	**7J**	**8B**	**8C**	**8D**	**8G**	**8H**
Radula complanata	3	6	0	0	0	1	3	1	0	4	5	0	0	5	0	0	0	0	0	0	5	0	0	0	0	1	0
Riccardia chamedryfolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1
Riccardia latifrons	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Scapania apiculata	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scapania irrigua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Scapania nemorea	2	1	0	0	0	0	0	0	0	0	4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tritomaria exsecta	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Tritomaria exsectiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0	0

APPENDIX G

Results of the correlation matrix, using p values, on site and substrate scale environmental variables. Abbreviations for environmental variables include distance = distance from Lake Superior, lat = latitude, long = longitude, alt = altitude, % cvr = percent canopy cover, min age = stand minimum age, % dec = deciduous ratio, freq = frequency of low humidity periods, avg length = average length of low humidity periods, log decay = log decay class, log dbh = log diameter, rock type = whether the rock as a boulder or rock wall, birch spp = birch species, birch dbh = birch diameter at breast height, spruce spp = spruce species, and spruce dbh = spruce diameter at breast height.

	dist	**lat**	**long**	**alt**	**% cvr**	**min age**	**% dec**	**freq**	**avg length**	**log decay**	**log dbh**	**rock type**	**rock SA**	**birch spp**	**birch dbh**	**spruce spp**	**spruce dbh**
dist	**1.00**	0.09	0.36	0.18	-0.07	-0.27	-0.08	-0.30	0.42	0.05	0.07	0.32	0.25	-0.12	-0.34	-0.13	0.02
lat	0.09	**1.00**	-0.84	-0.09	-0.41	-0.05	-0.22	0.05	0.37	0.11	-0.14	-0.20	-0.13	-0.33	-0.18	0.38	0.02
long	0.36	-0.84	**1.00**	0.11	0.32	0.03	0.15	-0.19	-0.13	-0.10	0.17	0.33	0.23	0.24	0.05	-0.37	-0.01
alt	0.18	-0.09	0.11	**1.00**	0.15	0.09	-0.07	-0.48	0.15	0.02	0.06	0.05	0.12	0.25	-0.04	0.13	-0.09
% cvr	-0.07	-0.41	0.32	0.15	**1.00**	0.13	0.32	-0.33	0.01	0.08	0.29	0.00	-0.11	0.22	0.22	-0.58	0.14
min age	-0.27	-0.05	0.03	0.09	0.13	**1.00**	0.11	0.05	0.01	0.13	0.17	-0.06	0.07	0.02	0.31	-0.03	-0.03
% dec	-0.08	-0.22	0.15	-0.07	0.32	0.11	**1.00**	-0.26	0.16	0.05	0.15	0.01	-0.08	0.31	0.33	-0.38	0.13
freq	-0.30	0.05	-0.19	-0.48	-0.33	0.05	-0.26	**1.00**	-0.34	-0.11	0.04	-0.14	0.00	0.05	0.16	0.20	0.00
avg length	0.42	0.37	-0.13	0.15	0.01	0.01	0.16	-0.34	**1.00**	0.28	0.11	0.14	-0.11	-0.04	-0.19	-0.31	0.16
log decay	0.05	0.11	-0.10	0.02	0.08	0.13	0.05	-0.11	0.28	**1.00**	0.17	0.07	-0.03	-0.03	-0.08	-0.20	-0.10
log dbh	0.07	-0.14	0.17	0.06	0.29	0.17	0.15	0.04	0.11	0.17	**1.00**	0.14	0.10	0.23	0.16	-0.31	0.11
rock type	0.32	-0.20	0.33	0.05	0.00	-0.06	0.01	-0.14	0.14	0.07	0.14	**1.00**	0.39	-0.14	-0.16	-0.02	0.07

rock SA	0.25	-0.13	0.23	0.12	-0.11	0.07	-0.08	0.00	-0.11	-0.03	0.10	0.39	**1.00**	0.00	-0.20	0.04	0.05
birch spp	-0.12	-0.33	0.24	0.25	0.22	0.02	0.31	0.05	-0.04	-0.03	0.23	-0.14	0.00	**1.00**	0.15	-0.27	0.26
birch dbh	-0.34	-0.18	0.05	-0.04	0.22	0.31	0.33	0.16	-0.19	-0.08	0.16	-0.16	-0.20	0.15	**1.00**	-0.15	0.09
spruce spp	-0.13	0.38	-0.37	0.13	-0.58	-0.03	-0.38	0.20	-0.31	-0.20	-0.31	-0.02	0.04	-0.27	-0.15	**1.00**	-0.25
spruce dbh	0.02	0.02	-0.01	-0.09	0.14	-0.03	0.13	0.00	0.16	-0.10	0.11	0.07	0.05	0.26	0.09	-0.25	**1.00**

APPENDIX H

Results of the site-scale linear regression models with species richness as the response variable, distance from Lake Superior as well as latitude, longitude, altitude, canopy cover, stand age, average stand dbh, deciduous ratio, frequency of low humidity periods, and average length of low humidity periods as explanatory variables. Significant effects (p ≤ 0.05) are shown in bold.

Variables	**F-statistic**	**Estimates±error**	**t value**	**p-value**
Total moss	2.429	-	-	0.125
Intercept	-	-84.02 ± 148.7	-0.565	0.586
Distance	-	0.041 ± 0.079	0.520	0.615
Latitude	-	2.978 ± 6.949	0.429	0.678
Longitude	-	0.413 ± 4.425	0.093	0.928
Altitude	-	0.001 ± 0.018	0.084	0.935
Canopy cover	-	18.73 ± 28.39	0.660	0.526
Stand age	-	-0.050 ± 0.052	-0.954	0.365
Average dbh	-	0.013 ± 0.475	0.028	0.978
Deciduous ratio	-	6.902 ± 10.88	0.634	0.542
Frequency of low humidity period	-	-8.158 ± 19.94	-0.409	0.692
Average length of low humidity period	-	-1.764 ± 2.504	-0.705	0.499
Total liverworts	1.416	-	-	0.239
Intercept	-	-90.54 ± 194.6	-0.465	0.653
Distance	-	-0.034 ± 0.104	0.326	0.752
Latitude	-	5.279 ± 9.093	0.581	0.576
Longitude	-	1.419 ± 5.791	0.245	0.812
Altitude	-	-0.022 ± 0.024	-0.939	0.372
Canopy cover	-	25.82 ± 37.16	0.695	0.505
Stand age	-	-0.091 ± 0.069	-1.326	0.218
Average dbh	-	-0.323 ± 0.622	-0.520	0.616
Deciduous ratio	-	9.319 ± 14.24	0.654	0.529
Frequency of low humidity period	-	-7.682 ± 26.10	-0.294	0.775
Average length of low humidity period	-	-3.919 ± 3.277	-1.196	0.262
Log moss	1.012	-	-	0.497
Intercept	-	-33.47 ± 108.5	-0.308	0.765
Distance	-	-0.048 ± 0.058	-0.841	0.422
Latitude	-	2.582 ± 5.069	0.509	0.623
Longitude	-	1.097 ± 3.228	0.340	0.742

Altitude	-	-0.004 ± 0.001	-0.324	0.753
Canopy cover	-	14.69 ± 20.71	0.709	0.496
Stand age	-	-0.038 ± 0.038	-0.987	0.249
Average dbh	-	0.183 ± 0.347	0.530	0.609
Deciduous ratio	-	10.29 ± 7.943	1.296	0.227
Frequency of low humidity period	-	3.267 ± 14.55	0.225	0.827
Average length of low humidity period	-	0.892 ± 1.826	0.489	0.637
Log liverworts	1.721	-	-	0.213
Intercept	-	-20.65 ± 93.70	-0.220	0.830
Distance	-	-0.022 ± 0.050	-0.447	0.665
Latitude	-	7.183 ± 4.377	1.642	0.135
Longitude	-	3.416 ± 2.787	1.226	0.251
Altitude	-	**-0.031 ± 0.011**	**-2.683**	**0.025**
Canopy cover	-	23.79 ± 17.89	1.330	0.216
Stand age	-	**-0.085 ± 0.033**	**-2.563**	**0.030**
Average dbh	-	0.189 ± 0.299	-0.632	0.543
Deciduous ratio	-	8.441 ± 6.859	1.231	0.249
Frequency of low humidity period	-	-8.473 ± 12.56	-0.674	0.517
Average length of low humidity period	-	-2.588 ± 1.577	-1.641	0.135
Rock moss	1.193	-	-	0.343
Intercept	-	**-170.1 ± 82.16**	**2.072**	**0.0493**
Distance	-	0.004 ± 0.052	0.092	0.927
Latitude	-	-1.967 ± 4.284	-0.459	0.650
Longitude	-	0.735 ± 2.774	0.265	0.793
Altitude	-	-0.003 ± 0.010	-0.300	0.766
Canopy cover	-	9.145 ± 11.53	0.793	0.435
Stand age	-	0.000 ± 0.0362	0.022	0.982
Average dbh	-	-0.082 ± 0.199	-0.410	0.685
Deciduous ratio	-	-8.548 ± 5.382	-1.588	0.125
Rock liverworts	0.814	-	-	0.597
Intercept	-	26.50 ± 56.21	0.471	0.642
Distance	-	-0.003 ± 0.036	-0.084	0.934
Latitude	-	3.709 ± 2.931	1.265	0.218
Longitude	-	2.357 ± 1.898	1.242	0.226
Altitude	-	0.008 ± 0.007	1.158	0.258
Canopy cover	-	-0.936 ± 7.891	-0.119	0.907
Stand age	-	-0.001 ± 0.024	-0.066	0.948
Average dbh	-	0.128 ± 0.136	0.938	0.358
Deciduous ratio	-	-2.439 ± 3.682	-0.663	0.514
Birch moss	0.680	-	-	0.722
Intercept	-	-35.16 ± 94.40	-0.373	0.718

Distance	-	-0.072 ± 0.050	-1.431	0.186
Latitude	-	4.116 ± 4.410	0.933	0.375
Longitude	-	1.932 ± 2.808	0.688	0.509
Altitude	-	0.015 ± 0.011	0.1357	0.208
Canopy cover	-	14.34 ± 18.02	0.796	0.446
Stand age	-	0.004 ± 0.033	0.134	0.897
Average dbh	-	-0.125 ± 0.301	-0.415	0.688
Deciduous ratio	-	-2.862 ± 6.910	-0.414	0.688
Frequency of low humidity period	-	5.624 ± 12.65	0.444	0.667
Average length of low humidity period	-	0.386 ± 1.589	0.243	0.813
Birch liverworts	0.827	-	-	0.616
Intercept	-	-11.17 ± 69.93	-0.160	0.877
Distance	-	-0.047 ± 0.037	-1.259	0.240
Latitude	-	2.014 ± 3.267	0.616	0.55
Longitude	-	0.866 ± 2.080	0.416	0.687
Altitude	-	0.007 ± 0.008	0.884	0.400
Canopy cover	-	2.821 ± 13.35	0.211	0.837
Stand age	-	-0.016 ± 0.024	-0.684	0.511
Average dbh	-	-0.121 ± 0.223	-0.542	0.601
Deciduous ratio	-	6.545 ± 5.119	1.279	0.233
Frequency of low humidity period	-	-5.324 ± 9.378	-0.568	0.584
Average length of low humidity period	-	-0.869 ± 1.177	-0.738	0.479
Spruce moss	4.790	-	-	**0.013**
Intercept	-	1.987 ± 43.10	0.046	0.964
Distance	-	-0.021 ± 0.023	-0.924	0.379
Latitude	-	**5.400 ± 2.013**	**2.682**	**0.025**
Longitude	-	2.648 ± 1.282	2.066	0.068
Altitude	-	**-0.016 ± 0.005**	**-2.994**	**0.015**
Canopy cover	-	-1.085 ± 8.228	-0.132	0.897
Stand age	-	**-0.083 ± 0.015**	**-5.487**	**0.000**
Average dbh	-	-0.019 ± 0.137	-0.141	0.891
Deciduous ratio	-	-0.647 ± 3.155	-0.205	0.841
Frequency of low humidity period	-	-6.879 ± 5.779	-1.90	0.264
Average length of low humidity period	-	-1.255 ± 0.725	-1.730	0.117
Spruce liverworts	1.291	-	-	0.355
Intercept	-	10.94 ± 34.33	0.319	0.757
Distance	-	0.024 ± 0.018	1.326	0.218
Latitude	-	-1.860 ± 1.604	-1.160	0.276
Longitude	-	-1.012 ± 1.021	-0.991	0.348

Altitude	-	-0.005 ± 0.004	-1.379	0.201
Canopy cover	-	4.535 ± 6.555	0.692	0.506
Stand age	-	-0.012 ± 0.012	-1.038	0.326
Average dbh	-	-0.111 ± 0.109	-1.017	0.336
Deciduous ratio	-	0.881 ± 2.513	0.350	0.734
Frequency of low humidity period	-	-7.354 ± 4.604	-1.597	0.145
Average length of low humidity period	-	-0.142 ± 0.578	-0.247	0.811

APPENDIX I

Results of the substrate-scale generalized linear mixed models with species richness as the response variable, distance from Lake Superior as well as latitude, longitude, altitude, canopy cover, stand age, average stand dbh, and deciduous tree ratio, as explanatory variables, and site as a random fixed effect variable. Substrate-scale explanatory variables for logs included log decay class and log diameter, for rocks included rock type and rock surface area, for birch included birch species *Betula papyrifera* and birch dbh, and for spruce included spruce species *Picea glauca*, spruce species *Picea mariana*, and spruce dbh. Significant effects ($p \leq 0.05$) are shown in bold.

Model variables	**Estimates±error**	**z value**	**p-value**
Log moss			
Intercept	-3.363 ± 2.953	-1.139	0.255
Distance	-0.001 ± 0.002	-0.626	0.532
Latitude	0.005 ± 0.147	0.035	0.972
Longitude	-0.053 ± 0.088	-0.609	0.542
Altitude	-0.001 ± 0.000	-1.574	0.116
Canopy cover	0.051 ± 0.572	0.089	0.929
Stand age	-0.001 ± 0.001	-0.828	0.408
Average dbh	0.007 ± 0.009	0.769	0.442
Deciduous ratio	**0.428 ± 0.203**	**2.107**	**0.035**
Log decay class	0.093 ± 0.050	1.833	0.067
Log diameter	0.007 ± 0.006	1.187	0.235
Log liverworts			
Intercept	-4.639 ± 5.530	-0.839	0.402
Distance	0.002 ± 0.003	0.492	0.622
Latitude	0.139 ± 0.284	0.489	0.625
Longitude	0.026 ± 0.173	0.152	0.879
Altitude	**-0.002 ± 0.001**	**-2.130**	**0.033**
Canopy cover	**2.572 ± 1.117**	**2.302**	**0.021**
Stand age	-0.004 ± 0.002	-1.735	0.083
Average dbh	-0.023 ± 0.018	-1.339	0.181
Deciduous ratio	0.205 ± 0.399	0.515	0.606
Log decay class	**0.295 ± 0.089**	**3.299**	**0.001**
Log diameter	0.006 ± 0.010	0.611	0.541
Rock moss			
Intercept	3.734 ± 4.634	0.806	0.420
Distance	-0.002 ± 0.003	-0.804	0.421
Latitude	0.086 ± 0.222	0.389	0.697
Longitude	0.075 ± 0.154	0.488	0.626
Altitude	-0.000 ± 0.000	-1.048	0.295

Canopy cover	1.134 ± 0.664	1.709	0.088
Stand age	-0.001 ± 0.001	-0.748	0.454
Average dbh	0.012 ± 0.009	1.340	0.180
Deciduous ratio	**-0.710 ± 0.360**	**-1.974**	**0.048**
Rock type	-0.044 ± 0.098	-0.452	0.651
Rock surface area	0.009 ± 0.007	1.193	0.233
Rock liverworts			
Intercept	-3.431 ± 6.193	-0.554	0.580
Distance	0.001 ± 0.004	0.315	0.753
Latitude	0.462 ± 0.312	1.484	0.138
Longitude	0.204 ± 0.212	0.965	0.335
Altitude	**0.001 ± 0.001**	**2.072**	**0.038**
Canopy cover	0.110 ± 0.945	0.117	0.907
Stand age	-0.003 ± 0.002	-1.580	0.114
Average dbh	0.018 ± 0.012	1.459	0.144
Deciduous ratio	0.311 ± 0.483	0.644	0.519
Rock type	**-0.619 ± 0.128**	**-4.820**	**0.000**
Rock surface area	**0.033 ± 0.009**	**3.520**	**0.000**
Birch moss			
Intercept	0.056 ± 2.693	0.021	0.984
Distance	-0.002 ± 0.002	-1.339	0.181
Latitude	0.101 ± 0.115	0.877	0.381
Longitude	0.037 ± 0.078	0.470	0.638
Altitude	-0.001 ± 0.000	-1.815	0.069
Canopy cover	0.674 ± 0.438	1.537	0.124
Stand age	0.000 ± 0.001	0.311	0.756
Average dbh	**-0.016 ± 0.007**	**-2.269**	**0.023**
Deciduous ratio	0.039 ± 0.171	0.230	0.818
Birch species	**-0.235 ± 0.103**	**-2.276**	**0.023**
Birch dbh	**0.011 ± 0.003**	**3.553**	**0.000**
Birch liverworts			
Intercept	-0.650 ± 4.313	-0.151	0.880
Distance	-0.003 ± 0.003	-1.320	0.187
Latitude	0.056 ± 0.186	0.300	0.764
Longitude	0.024 ± 0.125	0.193	0.847
Altitude	0.000 ± 0.001	0.444	0.657
Canopy cover	0.892 ± 0.719	1.240	0.215
Stand age	0.000 ± 0.002	0.281	0.779
Average dbh	-0.009 ± 0.011	-0.805	0.421
Deciduous ratio	0.449 ± 0.267	1.685	0.092
Birch species	0.040 ± 0.159	0.254	0.780
Birch dbh	**0.012 ± 0.004**	**2.664**	**0.008**
Spruce bryophytes			
Intercept	3.339 ± 2.599	1.285	0.199
Distance	-0.002 ± 0.002	-1.275	0.202

Latitude	0.124 ± 0.119	1.043	0.297
Longitude	0.091 ± 0.077	1.183	0.237
Altitude	0.000 ± 0.000	0.700	0.484
Canopy cover	0.501 ± 0.478	1.048	0.294
Stand age	**-0.003 ± 0.001**	**-2.574**	**0.010**
Average dbh	0.010 ± 0.007	1.379	0.168
Deciduous ratio	0.148 ± 0.178	0.827	0.408
Spruce species white	-0.048 ± 0.194	-0.246	0.806
Spruce species black	-0.075 ± 0.192	-0.391	0.696
Spruce species dbh	-0.000 ± 0.004	-0.036	0.971

APPENDIX J

Results the permutation tests of 999 iterations on the environmental variables for the total bryophytes PCoA model. Variables included distance from Lake Superior, latitude, longitude, altitude, canopy cover, stand age, average dbh, deciduous ratio, frequency of low humidity periods, and average length of low humidity periods. Significant effects ($p \leq 0.05$) are shown in bold.

Model variables	**R^2**	**p-value**
Distance	0.045	0.495
Latitude	0.014	0.789
Longitude	0.044	0.474
Altitude	0.008	0.902
Canopy cover	0.023	0.678
Stand age	0.071	0.372
Average dbh	0.015	0.792
Deciduous ratio	0.026	0.672
Frequency of low humidity events	0.011	0.860
Average length of low humidity events	0.101	0.273

Results of the permutation tests of 999 iterations on the environmental variables for each PCoA model. Distance from Lake Superior, latitude, longitude, altitude, canopy cover, stand age, average dbh, and deciduous ratio were recorded at the site scale. Log decay class, log diameter, rock type, rock surface area, birch species, birch dbh, spruce species, and spruce dbh were recorded at the substrate scale. Significant effects ($p \leq 0.05$) are shown in bold.

Model variables	**R^2**	**p-value**
Log moss		
Distance	**0.022**	**0.014**
Latitude	**0.063**	**0.001**
Longitude	**0.019**	**0.018**
Altitude	0.004	0.299
Canopy cover	**0.085**	**0.001**
Stand age	**0.033**	**0.003**
Average dbh	**0.053**	**0.001**
Deciduous ratio	0.007	0.172
Log decay class	0.009	0.109
Log diameter	**0.024**	**0.008**
Log liverworts		
Distance	**0.020**	**0.020**

Latitude	0.002	0.720
Longitude	0.000	0.989
Altitude	**0.016**	**0.036**
Canopy cover	0.013	0.074
Stand age	**0.022**	**0.019**
Average dbh	**0.016**	**0.039**
Deciduous ratio	0.003	0.539
Log decay class	0.002	0.722
Log diameter	0.014	0.057
Rock bryophytes		
Distance	0.019	0.124
Latitude	0.004	0.641
Longitude	0.001	0.830
Altitude	0.010	0.340
Canopy cover	0.008	0.367
Stand age	0.005	0.518
Average dbh	**0.032**	**0.031**
Deciduous ratio	0.014	0.211
Rock type	**0.050**	**0.011**
Rock surface area	**0.079**	**0.003**
Birch moss		
Distance	**0.039**	**0.001**
Latitude	0.003	0.505
Longitude	0.009	0.095
Altitude	0.010	0.074
Canopy cover	**0.033**	**0.002**
Stand age	0.004	0.396
Average dbh	0.005	0.272
Deciduous ratio	0.006	0.201
Birch species	0.007	0.179
Birch dbh	0.010	0.067
Birch liverworts		
Distance	**0.046**	**0.001**
Latitude	**0.015**	**0.028**
Longitude	0.001	0.843
Altitude	0.002	0.573
Canopy cover	**0.033**	**0.002**
Stand age	0.009	0.096
Average dbh	0.006	0.187
Deciduous ratio	**0.017**	**0.016**
Birch species	0.001	0.745
Birch dbh	**0.046**	**0.001**
Spruce bryophytes		
Distance	0.011	0.068
Latitude	0.008	0.148

Longitude	0.018	0.692
Altitude	0.000	0.907
Canopy cover	**0.021**	**0.005**
Stand age	**0.020**	**0.010**
Average dbh	0.007	0.142
Deciduous ratio	0.005	0.266
Spruce species	0.005	0.637
Spruce dbh	0.001	0.723

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