UNIVERSITÉ DU QUÉBEC EN ABITIBI-TÉMISCAMINGUE

COMMUNAUTÉS DE BRYOPHYTES ET PLANTES VASCULAIRES DES HABITATS RARES DE L'ABITIBI-TÉMISCAMINGUE EN RELATION AVEC LES VARIABLES CLIMATIQUES OU GÉOCHIMIQUES

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AVANT-PROPOS

La thèse est présentée sous la forme de trois chapitres successifs, chacun représentant un article, couplés avec une introduction et une conclusion générales. Le premier chapitre a été publié à la revue « Biodiversity and Conservation », le troisième chapitre a été soumis à la revue « Community Ecology ». Le second chapitre sera soumis à la suite de l'évaluation de la thèse. Les auteurs sont toujours les mêmes et annoncés dans le même ordre, à savoir « Nils Ambec, Yves Bergeron & Nicole J. Fenton » car je suis le principal responsable de l'étude, de la collecte des données, de leur analyse et de la rédaction de l'article. Ma directrice (Nicole J. Fenton) et mon codirecteur (Yves Bergeron) de recherche ont contribué à la conception de l'étude. Ils ont aussi révisé de manière critique et constructive le contenu des articles.

Tous les articles traitent des communautés de plantes vasculaires et des bryophytes en Abitibi avec quelques placettes en Baie de James. Le chapitre 1 et 3 sont exclusivement issus de données que j'ai collectées dans le cadre de ma thèse, données climatiques du chapitre 1 et données géochimiques du chapitre 3 comprises. Le chapitre 2, en revanche, inclut mes données d'inventaires forestiers à celles d'autres étudiants (Xiangbo Yin, Marion Barbé, Marion Noualhaguet) et de points d'observation écologiques du gouvernement du Québec.

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AIC	Akaike Information Criterion
ANOVA	Analysis of variance
B	Abandoned beaver pond
DR	Dry rock habitat
F	Old-growth forest located on hills
L	Limestone outcrop
M	Mine tailing
NMDS	Non-metric multidimensional scaling
PCoA	Principal Coordinates Analysis
PERMANOVA	Permutational multivariate analysis of variance
U	Ultramafic outcrop
VIF	Variance Inflation Factor
WR	Wet rocks habitat

LISTE DES SYMBOLES ET DES UNITÉS

cm	centimeters
km	kilometers
m	meters
°C	celsius degrees

RÉSUMÉ

L'être humain a altéré ou remplacé 75% des systèmes terrestres planétaires, avec un rythme croissant de façon exponentielle depuis le début de la mondialisation. Ces modifications, couplées aux changements climatiques globaux, obligent tous les organismes à des adaptations extrêmement rapides à l'échelle de leur évolution, qu'elles soient physiologiques ou écologiques. Les plantes, à travers leur mode de vie fixe, sont particulièrement vulnérables aux menaces que représente les activités anthropiques et les changements globaux car elles sont forcées de s'adapter ou de s'éteindre. Ce n'est qu'à travers la dispersion de leurs propagules que les plantes peuvent migrer, lorsqu'un habitat propice est accessible pour leur établissement. Le système boréal ne fait d'ailleurs pas exception aux menaces anthropiques car, malgré une faible densité de population, c'est par exemple 23% du domaine du domaine boréal canadien qui a déjà été altéré par les activités humaines. Les changements climatiques sont de surcroît accélérés dans les régions les plus froides, comme le montrent les récents pics de chaleurs aux pôles ou les canicules récurrentes des régions boréales.

Le domaine boréal a longtemps été perçu comme une zone du globe hébergeant une biodiversité de façon homogène à l'échelle régionale. Cependant, des études de plus en plus nombreuses tendent à prouver le contraire. Des habitats rares à l'échelle régionale ont par exemple été décrits dans le domaine boréal. Ces habitats peuvent résulter de la structure forestière, d'une géologie particulière ou bien encore de l'histoire de la zone en question. Dans un contexte d'anthropisation grandissante, ces habitats sont d'autant plus menacés qu'ils ne se retrouvent pas en grande quantité sur le territoire : cela signifiant que leur disparition peut signifier une extinction locale des espèces en étant dépendante pour se développer.

C'est dans ce contexte que prend place la présente thèse, dans la région de l'Abitibi, à l'ouest du Québec, au Canada. Parmi les quelques collines de cette région très plate, les plus hautes étaient dans une situation anciennement émergée, soit des îles, durant la présence du lac proglaciaire Ojibway de 10 200 BP (Before Present = avant aujourd'hui) à 8 200 BP. Ces collines ont été colonisées à partir de la marge sud du lac, 1 000 ans avant le reste du territoire, alors submergé. Les dépôts glaciolacustres accumulés sur deux millénaires ont recouvert le socle de roche mère de la région lors de la décharge du lac proglaciaire Ojibway, créant ce que l'on appelle aujourd'hui la ceinture d'argile. Cette dernière s'étale entre l'Ontario et le Québec et recouvre un large socle de roches mafiques vieilles de 2,5 milliards d'années : la ceinture verte de l'Abitibi. L'argile superposée aux roches mafiques de façon extensive suggèrerait une apparente homogénéité du sol de la région d'étude.

Cette région, très plate, est couverte à 85% de forêts altérées par les activités humaines, faisant en sorte que les vieilles forêts sont devenues un habitat de plus en plus rare, bien qu'une partie d'entre elles se retrouvent sur les rares massifs de la région. Cependant, bien que la foresterie couvre de plus grandes surfaces de ce territoire, ce sont les mines qui constituent le premier secteur économique de la région, en particulier les mines d'or. De façon générale, les sites miniers abandonnés ont de fortes concentrations de métaux lourds dans leurs sols, bien que les éléments concentrés dans ces résidus d'exploitation minière varient selon le minerai extrait et la technique employée pour l'extraire. Cette concentration non-naturelle de métaux lourds mais aussi d'autres éléments chimiques en fait des habitats ouverts et stressants pour la croissance des plantes. Dans un contexte dominé par les forêts et les milieux humides, ces milieux décapés et ouverts représentent un habitat rare à l'échelle régionale. Les uniques milieux naturels pouvant s'en rapprocher sont les affleurements ultramafiques et les affleurements calcaires qui présentent également des sols créant des conditions de croissance stressantes pour les plantes sur le long terme. Les secteurs exposés en amont des barrages de castor abandonnés, bien que n'offrant pas de sols stressants pour la croissance des plantes, représentent également un milieu naturellement ouvert durant un cours laps de temps avant d'être colonisés. Cette ouverture du milieu peut également être comparée aux affleurements rocheux secs et humides que l'on retrouve sur les rares collines de la région, bien qu'ils ne créent pas de stress géochimique à la croissance des plantes.

Ces habitats rares que constituent les collines, leurs vieilles forêts et affleurements rocheux secs et humide, les vieilles forêts de plaine et les milieux naturellement ouverts à cause du stress géochimique qu'ils créent pour la croissance des plantes sont peu étudiés à l'échelle régionale en comparaison des forêts et tourbières de la plaine.

Les principales problématiques abordées dans cette thèse étaient de savoir si ces habitats hébergent des plantes rares et une richesse spécifique originale mais également de savoir s'ils hébergent des communautés différentes entre eux, et pour quelles raisons. L'étude poussée des communautés végétales de plantes vasculaires et de bryophytes de ces habitats permettra de découvrir leur biodiversité mais également de caractériser les assemblages spécifiques qu'on y retrouve. La prise en compte de la température et de l'humidité relative pour les collines, et de la géochimie pour les substrats stressants permettra une appréciation plus fine expliquant les variations d'assemblages spécifiques que l'on pourrait observer lorsqu'on les compare entre eux.

Côté climat, cette thèse a permis de découvrir que celui retrouvé en haut des collines de la région est significativement plus chaud de 2°C que celui retrouvé en plaine bien que les forêts des collines anciennement submergées aient une température significativement plus importante que les collines anciennement émergées. Cependant, le nombre de jours de gel durant la saison végétative ne diffère pas entre les deux types de collines ni entre les collines et la plaine. De plus, les forêts des collines les plus hautes de la région concentrent une humidité relative plus importante que les collines anciennement submergées. Ces différences climatiques ne semblent pas influencer la richesse spécifique mais ont un impact significatif sur les formes de croissance des végétaux étudiés, pouvant éventuellement influencer à long terme les communautés végétales des collines anciennement émergées.

Nous avons aussi découvert que les collines anciennement émergées hébergent deux fois plus d'espèces de bryophytes qui leur sont exclusives que les collines anciennement submergées mais qu'il s'agit de l'inverse pour les espèces de plantes vasculaires exclusives. On retrouve ce même contraste entre les vieilles forêts de plaine ou de colline et les catégories de jeunes forêts de plaine. Cependant, les vieilles forêts des collines ont un nombre d'espèces indicatrices de bryophytes et de plantes vasculaires bien plus élevé que les vieilles forêts de plaine, notamment avec 6 espèces d'arbre, ce qui implique des différences structurales forestières majeures. Nous suggérons qu'en plus d'avoir une température plus élevée qu'en plaine, les zones abritées de forêt de colline en général puissent éviter de façon chronique les feux de forêt, impliquant des structures de vieille forêt différentes de celles retrouvées en plaine. De surcroît, les plus hautes collines sont plus accidentées encore et permettraient sûrement, comme le suggère l'humidité relative de leurs forêts, une protection locale accrue contre les feux extensifs, et l'entretient de forêt ancienne plus humides et ombragées encore que celles des collines les moins hautes. Ce point explicite clairement que ces différences ne semblent pas provenir d'une colonisation opérée un millénaire avant le reste du territoire.

Les résultats obtenus sur les anciens sites miniers, en revanche, montrent que leur géochimie variable se rapproche parfois de celle de sites naturels, spécialement les affleurements calcaires. Comme la géochimie semble fortement conditionner les variations des communautés végétales qu'on y trouve, cela conduit à des cortèges de sites miniers qui peuvent ressembler à des cortèges naturels. Les espèces de bryophytes ont une meilleure valeur indicatrice en ce sens, car elles montrent toujours des tendances plus marquées que chez les vasculaires lorsque l'on compare les habitats ou anciennes situations de collines. La quasi-totalité des espèces retrouvées sont généralistes et/ou rudérales dans la région.

Ces résultats permettent de mettre en lumière un climat, une richesse spécifique et des communautés uniques aux collines de l'Abitibi. La grande variabilité des communautés végétales généralistes des sites miniers, en revanche, devrait donner des pistes lorsqu'arrive le temps de les restaurer. Ces derniers n'offrent pas un apport spécifique original significatif à l'échelle de la région. Cette étape est importante dans un contexte d'exploration minière et d'exploitation forestière vouées à augmenter, car connaître les subtilités des habitats potentiels d'un territoire pour une espèce avant qu'ils disparaissent est vital pour cette espèce, et la complexité du paysage.

Mots clés : communautés végétales, bryophytes, plantes, climat, collines, géochimie, sites miniers, contrastes

ABSTRACT

Humans have altered or replaced 75% of the world's terrestrial systems, at an exponentially increasing rate since the beginning of globalisation. These changes, coupled with global climate change, are forcing all organisms to make extremely rapid adaptations on an evolutionary scale, whether physiological or ecological. Plants, through their fixed way of life, are particularly vulnerable to the threats posed by anthropogenic activities and global change as they are forced to adapt or become extinct. It is only through the dispersal of their propagules that plants can migrate when a suitable habitat is available for their establishment. The boreal system is no exception to these anthropogenic threats, as 23% of the Canadian boreal domain has already been altered by human activities, despite low population density. Climate change is also accelerating in the coldest regions, as evidenced by recent heat spikes at the poles or recurrent heat waves in the boreal regions.

The boreal domain has long been perceived as an area of the globe hosting a homogeneously distributed biodiversity at a regional scale. However, a growing number of studies tend to prove the contrary. For example, regionally rare habitats have been described in the boreal domain. These habitats can be the result of forest structure, a particular geology, or the history of the area in question. In a context of increasing anthropisation, these habitats are even more threatened as they are not found in large quantities on the territory: this means that their disappearance may mean a local extinction of the species that depend on them for their development.

It is in this context that the present thesis takes place, in the Abitibi region of western Quebec, Canada. Among the few hills in this very flat region, the highest ones were in a formerly emergent state, i.e. islands, during the presence of the proglacial Lake Ojibway from 10,200 BP (Before Present) to 8,200 BP. These hills were colonised by plants from the southern margin of the lake, 1,000 years before the rest of the territory was submerged. Glaciolacustrine deposits accumulated over two millennia and have covered the bedrock in the region when proglacial Lake Ojibway discharged, creating what is now known as the Clay Belt. This belt stretches between Ontario and Quebec and covers a broad base of 2.5-billion-year-old mafic rocks: the Abitibi Greenbelt. The clay superimposed on the mafic rocks in an extensive manner would suggest an apparent homogeneity of the soil in the study area.

This very flat region is 85% covered by forests many of which are altered by human activities, making old-growth forests an increasingly rare habitat, albeit some of them can be found on the region's few massifs. However, although forestry activities occur on large areas of this territory, mining is the main economic sector in the region, particularly gold mining. In general, abandoned mine sites have high concentrations of

heavy metals in their soils, although the elements concentrated in these mining residues vary according to the ore extracted and the technique used to extract it. This unnatural concentration of heavy metals and other chemical elements makes them open habitats that are stressful for plant growth. In a context dominated by forests and wetlands, these open, bare environments represent a rare habitat on a regional scale. The only natural environments that come close are ultramafic outcrops and limestone outcrops, which also have soils that create stressful growing conditions for plants over the long term. Exposed areas upstream of abandoned beaver dams, although not offering stressful soils for plant growth, also represent a naturally open environment for a short period of time before being colonised. This openness can also be compared to the dry and wet rocky outcrops found on the few hills in the region, although they do not create geochemical stress to plant growth.

These rare hill habitats, their dry and wet old-growth forests and rock outcrops, lowland old-growth forests and naturally open environments because of the geochemical stress they create for plant growth are poorly studied on a regional scale compared to lowland forests and peatlands.

The main questions addressed in this thesis were to know if these habitats host rare plants and an original specific richness but also to know if they host different communities between them, and for what reasons. The detailed study of the vascular plant and bryophyte communities of these habitats will allow us to discover their biodiversity but also to characterise the specific assemblages found there. Considering the temperature and relative humidity of the hills, and the geochemistry for the stressful substrates, will allow a finer appreciation explaining the variations of specific assemblages that could be observed when comparing them.

In terms of climate, this thesis has found that the climate found on the hilltops of the region is significantly warmer by 2°C than that found on the plains, although the forests on the formerly submerged hills have a significantly higher temperature than the formerly emerged hills. However, the number of frost days during the growing season does not differ between the two hill types or between the hills and the plain. Furthermore, the forests on the highest hills in the region have a higher relative humidity than the formerly submerged hills. These climatic differences do not seem to influence species richness but have a significant impact on the lifeforms of the plants studied, which may then influence the plant communities of the formerly submerged hills in the long term.

We also found that formerly emerged hills have twice as many bryophyte species exclusive to them as formerly submerged hills, but the reverse is true for exclusive vascular plant species. The same contrast is found between old-growth plain or hill forests and the young plain forest categories. However, old-growth hill forests have a much higher number of bryophyte and vascular plant indicator species than old-growth

plain forests, notably with 6 tree species, implying major forest structural differences. We suggest that in addition to having a higher temperature than the plains, sheltered areas of hill forest in general may chronically avoid forest fires, implying different old-growth forest structures than those found on the plains. Moreover, the higher hills are even more rugged and would surely allow, as the high relative humidity of their forests suggests, greater local protection against extensive fires, and the maintenance of even wetter and shadier old-growth forest than those on the lower hills. This point makes it clear that these differences do not appear to be the result of colonisation a millennium ago.

Results from former mine sites, on the other hand, show that their variable geochemistry sometimes resembles that of natural sites, especially limestone outcrops. As the geochemistry seems to strongly condition the variations of the plant communities found there, this leads to mine site assemblages that can resemble natural assemblages. Bryophytes play a better role as indicator species in this sense, as they always show stronger trends than vascular plants when comparing habitats or former hill states. Almost all the species found are generalists and/or ruderals in the region.

These results highlight the climate, species richness and communities unique to the Abitibi Hills. The great variability of the generalist plant communities of the mine sites, on the other hand, should provide clues when the time comes to restore them. The latter do not offer a significant original specific contribution at the scale of the region. This step is important in a context of increasing mining exploration and forestry exploitation, as knowing the subtleties of potential habitats for a species before they disappear is vital for the species, and the complexity of the landscape.

Keywords : plant communities, bryophytes, plants, climate, hills, geochemistry, mine tailings, contrasts

INTRODUCTION GENERALE

1.1 Contexte

Environ 75% des écosystèmes terrestres ont été altérés ou remplacés par les activités humaines depuis le début de la révolution industrielle (Ellis *et al*, 2012). L'impact humain est aujourd'hui assez conséquent pour être enregistré dans les sédiments à l'échelle mondiale, certains scientifiques évoquent notre potentielle entrée dans l'ère de l'anthropocène (Subramanian, 2019; Certini & Scalenghe, 2015). En sus, nos activités accentuent les changements climatiques et ce signal est également déjà détectable au cours des deux derniers siècles (Hawkins *et al*, 2020). Ce constat entraîne des conséquences pour la biodiversité, les réseaux trophiques ou encore la structure des écosystèmes. Face à la perturbation anthropique mondiale, la plupart des organismes se retrouvent face à un défi majeur : migrer, s'adapter ou s'extirper. Malheureusement certaines espèces n'en ont pas eu le temps car si l'on ne s'accorde pas encore sur ses réelles raisons, l'occurrence de la sixième extinction de masse de la biodiversité mondiale fait l'objet d'un consensus scientifique (Ceballos & Ehrlich, 2018).

Les impacts de nos activités sont d'autant plus visibles lorsque l'on se rapproche des pôles (Gillett *et al*, 2008). Ainsi, les systèmes arctiques, antarctiques et boréaux sont les plus menacés à court terme avec une augmentation des températures moyennes de 0.5°C par décennie (Gauthier *et al*, 2015a). Cela n'est pas anecdotique car le domaine boréal, second biome terrestre en superficie, couvre environ 17 millions de kilomètres carrés, soit un tiers des forêts du globe (Gauthier *et al*, 2015a; Kuosmanen *et al*, 2016; Kayes & Mallik, 2020). La pression de sélection exercée sur les organismes est donc exacerbée dans la zone boréale. De plus, bien que faiblement peuplée (Brandt *et al*, 2013; Hanberry, 2022), la forêt boréale représente une réserve de bois, dont la récolte a été rendue possible par la mécanisation de l'industrie forestière (Martin, 2019). Cette faible densité de peuplement humain a aussi favorisé des industries minières loin des métropoles, comme par exemple au Canada (Government of Canada, 2022).

C'est dans ce contexte de changements accentués en milieu boréal et de crise de la biodiversité qu'il est nécessaire de mieux appréhender les facteurs expliquant la répartition et la diversité des espèces du système boréal. En effet, l'érosion de la biodiversité est une problématique de plus en plus préoccupante à l'échelle planétaire, et perturbe la dynamique des écosystèmes (Tollefson, 2019; Pachauri *et al*, 2015).

La présente étude prend place en Abitibi, à l'ouest du Québec, au Canada. Cette région très plate comporte toutefois quelques massifs rocheux (Girard-Côté, 2007). Parmi ces quelques collines, les plus hautes étaient dans une situation anciennement émergée, soit des îles, durant la présence du lac proglaciaire Ojibway de 10 200 BP (Before Present = avant aujourd'hui) à 8 200 BP (Godbout *et al*, 2017). Ces collines ont été colonisées par des végétaux à partir de la marge sud du lac, 1 000 ans avant le reste du territoire, alors submergé (Vogel *et al*, 2023). Les dépôts glaciolacustres accumulés sur deux millénaires ont recouvert la roche mère lors de la décharge du lac proglaciaire Ojibway, créant ce que l'on appelle aujourd'hui la ceinture d'argile (Veillette, 1994; Vincent & Hardy, 1977). Cette dernière s'étale entre l'Ontario et le Québec et recouvre un large socle de roches mafiques vieilles de 2,5 milliards d'années : la ceinture verte de l'Abitibi (Monecke *et al*, 2017). L'argile superposée aux roches mafiques de façon extensive suggèrerait une apparente homogénéité du sol de la région d'étude.

Cette région est couverte à 85% de forêts altérées par les activités humaines en grande partie (MRNFP, 2004; Lafond & Ladouceur, 1968), faisant en sorte que les vieilles forêts sont devenues un habitat de plus en plus rare, bien qu'une partie d'entre elles se retrouvent sur les rares massifs de la région (Girard-Côté, 2007). Cependant, bien que la foresterie opère sur des grandes superficies de ce territoire, ce sont les mines qui constituent le premier secteur économique de la région, en particulier les mines d'or

(Rabeau *et al*, 2010; CREAT, 2020). De façon générale, les sites miniers abandonnés ont de fortes concentrations de métaux lourds dans leurs sols, bien que les éléments concentrés dans ces résidus d'exploitation minière varient selon le minerai extrait et la technique employée pour l'extraire. Cette concentration non-naturelle de métaux lourds mais aussi d'autres éléments chimiques en fait des habitats ouverts et stressants pour la croissance des plantes (Munford *et al*, 2020; Gagnon *et al*, 2021a). Dans un contexte dominé par les forêts et les milieux humides, ces milieux décapés et ouverts représentent un habitat rare à l'échelle régionale. Les uniques milieux naturels pouvant s'en rapprocher sont les affleurements ultramafiques et les affleurements calcaires qui présentent également des sols créant des conditions de croissance stressantes pour les plantes sur le long terme (van der Ent *et al*, 2015; Tropek *et al*, 2010). Les secteurs exposés en amont des barrages de castor abandonnés, bien que n'offrant pas de sols stressants pour la croissance des plantes, représentent également un milieu naturellement ouvert durant un cours laps de temps avant d'être colonisés. Cette ouverture du milieu peut également être comparée aux affleurements rocheux secs et humides que l'on retrouve sur les rares collines de la région, bien qu'ils ne créent pas de stress géochimique à la croissance des plantes.

Ces habitats rares que constituent les collines, leurs vieilles forêts et affleurements rocheux secs et humide, les vieilles forêts de plaine et les milieux naturellement ouverts à cause du stress géochimique qu'ils créent pour la croissance des plantes sont peu étudiés à l'échelle régionale en comparaison des forêts et tourbières de la plaine.

1.2 Biodiversité des milieux naturels et d'origine anthropique

1.2.1 Les milieux naturels

Une théorie de conservation de la biodiversité émerge à la fin des années 1980, elle met en opposition les termes filtres fins et filtres bruts, où le terme filtre désigne le maillage pris en compte. Les filtres fins ou bruts définissent à quelle échelle appréhender les problématiques de conservation : à l'échelle spécifique à travers les filtres fins ou à l'échelle de l'habitat pour les filtres bruts (Noss, 1987). Cela conduit à questionner les efforts de conservation de la biodiversité, habituellement axés sur les espèces clef, ou filtres fins, qui pourraient plutôt s'appuyer sur la conservation d'habitats, ou filtres bruts (Hunter *et al*, 1988). Cette théorie se rapproche également de la notion « d'espèce parapluie », avec l'exemple bien connu des pandas géants pour lesquels on a protégé des zones (MacKinnon & De Wulf, 1994) qui ont bénéficié à plus d'une centaine d'espèces menacées, partageant le même habitat (Li & Pimm, 2016). La théorie des filtres bruts est aujourd'hui devenue une approche plébiscitée même si la conservation de la biodiversité et de l'environnement requiert des approches à différentes échelles (Tingley *et al*, 2014; Lemelin & Darveau, 2006). Ces filtres, lorsqu'ils concernent des milieux naturels, prennent en compte des systèmes peu représentés à l'échelle du territoire que l'on peut qualifier de « naturellement rares ». Ce sont soit des systèmes de couvrant des surfaces réduites (jusqu'à quelques centaines d'hectares) mais que l'on retrouve globalement sur le territoire étudié (prés salés, affleurements rocheux…) soit des systèmes de plus grande taille mais géographiquement restreints (plateau volcanique, estuaire). Le dernier élément retenu pour définir cet écosystème naturellement rare est qu'il doit recouvrir moins de 0,5% de la région étudiée (Williams *et al*, 2007).

La conservation de la nature à travers les filtres bruts a conduit à la constitution d'une liste rouge des écosystèmes produite par l'Union Internationale pour la Conservation de la Nature (UICN). Cette dernière répertorie tous les types de milieux rares, dont la plupart ont obtenu ce statut suite à l'action humaine (Rodríguez *et al*, 2011). La problématique et la connaissance des écosystèmes naturellement rares, également appelés îles écologiques (Cartwright, 2019), « n'est [cependant] toujours pas traitée de façon adéquate par les systèmes de classification du paysage » de façon générale (Williams *et al*, 2007). Il est en effet difficile de trouver de la littérature à ce sujet dans le domaine boréal, où l'on parlera plutôt de la structure forestière comme vecteur d'hétérogénéité d'habitat sur le territoire (Hekkala *et al*, 2023) ou de points chauds de biodiversité (Hörnberg *et al*, 1998; Saarimaa *et al*, 2019). Les points chauds de biodiversité évoquent de fait des habitats rares ou tout du moins peu commun dans le système boréal et rejoignent les tendances générales d'espèces spécialistes de milieux particuliers (Williams *et al*, 2009) allant des sols ultramafiques (van der Ent *et al*, 2015; Favero-Longo *et al*, 2018) aux sources chaudes (Rozanov *et al*, 2017) en passant par les affleurements ferreux (Erskine *et al*, 2012; Jacobi *et al*, 2011).

Le contexte régional de l'Abitibi étant dominé par des groupements forestier en majeure partie altérés par les pratiques de foresterie (Gaudreau, 1979; Lafond & Ladouceur, 1968), ce sont les vieilles forêts, de plaine ou de collines, qui dénotent en premier sur le territoire. Viennent ensuite les habitats naturellement ouverts et avec une végétation rare soit les affleurements rocheux secs ou humides des rares collines de la région ou bien les affleurements rocheux occasionnant un stress de croissance pour les plantes à travers de fortes concentrations de certains éléments chimiques comme le calcaire et les roches ultramafiques. Enfin, bien que ça ne soit que passager, les terres exposées en amont des barrages de castor abandonnés révèlent un sol nu prêt à la colonisation et cela reste rare à l'échelle du paysage boréal. La connaissance de leur biodiversité et des raisons qui l'expliquent permettront de les valoriser scientifiquement.

1.2.2 Les milieux d'origine anthropique

Les habitats perturbés, principalement par le secteur primaire, l'urbanisation ou la récréation (Walker, 2012), sont associés à une diminution de la biodiversité mondiale (Tollefson, 2019). Ils conduisent cependant parfois à la création de milieux favorables à certains groupes taxonomiques, notamment par l'ouverture de l'habitat qui favorisera par exemple la présence de rapaces ou d'orchidées (Chester & Robson, 2013; Greenwood, 1978; Adamowski, 2006; Burda, 1999). Les exploitations minières, à travers une très forte altération de l'habitat, sont un de ces exemples ambivalents (Prach *et al*, 2011; Ali, 2009, 2003). Les mines et leurs résidus couvrent environ 0.039% de la partie terrestre du globe, et on les retrouve dans toutes les régions du monde (Maus *et al*, 2020). En Abitibi il s'agit d'un des principaux secteurs d'emplois, avec plus de 170 mines actives et désaffectées et 22% du territoire couvert par des titres d'exploitation miniers (CREAT, 2020). Dans le contexte forestier régional les anciens sites miniers abandonnés représentent des îlots complètement isolés car ouverts et peu végétalisés avec une géochimie différente du fait de leurs résidus d'exploitation minière (Dekoninck *et al*, 2010).

On retrouve généralement des études traitant de l'apport en biodiversité faunique rare des sites miniers (anciens ou actifs) (Deikumah *et al*, 2014; Jaffé *et al*, 2016; Boschen *et al*, 2016). L'apport total en biodiversité végétale des anciens sites miniers est en revanche très peu développé dans la communauté scientifique (Batty, 2005) si ce n'est pour des espèces excessivement rares inféodées à ces milieux (Callaghan & Bowyer, 2011; Boisson *et al*, 2017). La végétation n'y est, le plus souvent, traitée qu'à des fins de phytoremédiation (Wang *et al*, 2017), par exemple à travers les différentes capacités de bio-accumulation des bryophytes, lichens et plantes vasculaires (Balabanova *et al*, 2014). La description des cortèges végétaux des anciens sites miniers de l'Abitibi est l'occasion d'enrichir les connaissances de la flore régionale ainsi que de mieux comprendre la colonisation naturelle de ces milieux et ce qui les distinguent entre eux.

1.3 La colonisation post-glaciaire du Québec par les végétaux

La dernière période glaciaire, le Wisconsinien, s'est achevée il y a environ 10 200 ans avant aujourd'hui (Godbout *et al*, 2017). Durant cette période, la calotte glaciaire laurentidienne couvrait à son maximum la quasi-totalité de l'Est canadien excepté une petite partie du Golfe du Saint-Laurent et de la côte du Labrador (Rogerson, 1981; Grant, 1977; Belland, 1987). Cette configuration a conduit à trois catégories de refuges pour les bryophytes et trachéophytes. Les nunataks, mot issu du groenlandais, qui sont des sommets de montagnes cernés de glace que l'on peut toujours observer sur les calottes glaciaires arctiques. Viennent ensuite les montagnes côtières libres de glace puis, les terres côtières à la marge de la calotte glaciaire (Parks Canada, 1994; Murray, 1987; Funder, 1979; Holland, 1981; Argus & Davis, 1962; Ritchie, 1992, 1987; Mooney & Billings, 1961; Soltis *et al*, 1992). Avec ces refuges, ainsi que les zones libres de glace périphériques, le Québec (et l'est du Canada ainsi que le nord-est des États-Unis de manière générale) a connu 5 types de colonisateurs végétaux (Belland, 1987). On retrouve tout d'abord les colonisateurs du sud, issus des populations ayant évité la calotte glaciaire à de plus basses latitudes. Il y a ensuite les colonisateurs du nord stricts (principalement arctiques) puis ceux du nord et/ou de l'ouest, ils sont détectés à l'aide d'espèces que l'on retrouve de façon disjointe entre le Québec, le Labrador et les Maritimes. On retrouve finalement les colonisateurs issus de refuges glaciaires, sur des zones n'ayant pas été couvertes par la calotte glaciaire. En leur sein se déclinent deux sous catégories : les premiers sont issus des refuges glaciaires et/ou sont venus de l'ouest, on les retrouve de façon isolée autour du Golfe du Saint-Laurent, ou à l'est du territoire considéré. Les seconds sont soit issus des refuges glaciaires et/ou d'une introduction humaine, on les retrouve principalement en Terre-Neuve mais aussi autour du Golfe du Saint-Laurent.

Ces colonisateurs ont façonné la distribution des communautés végétales retrouvées aujourd'hui au Québec avec des répartitions pouvant être disjointes ou continues (Ritchie, 1987; Belland, 1987). En Abitibi, la retraite glaciaire qui a eu lieu il y a environ 10200 ans a conduit à la création du paléolac Ojibway qui recouvrait l'Abitibi et le Témiscamingue (Godbout *et al*, 2017). La partie terrestre pouvant être colonisée par des végétaux dans la région est constituée uniquement d'îles jusqu'à la vidange du lac, il y a 8200 ans (Barber *et al*, 1999). Les plaines ont ensuite été colonisées (Richard, 1980), soit 2000 ans entre la colonisation des plaines et celle, supposée, des collines de l'Abitibi. Nous souhaiterions savoir si cette colonisation supposément antérieure est encore détectable à travers les associations végétales de ces paléoîles aujourd'hui ou non, et d'en expliquer la raison.

1.4 Les effets du climat sur les végétaux

Les plantes étant des organismes sessiles (Walker & Sharpe, 2010), elles ne peuvent pas se déplacer pour éviter une météorologie qui ne leur convient pas. Leur survie face à des changements climatiques dépend donc d'une réponse efficace au stress thermique ou hydrique (Nievola *et al*, 2017; Tibbitts, 1979). Cela explique la résistance exacerbée de nombreuses plantes aux conditions environnementales. Ce mode de vie conditionne également leur aire de répartition ou tout du moins l'habitat et le contexte où elles vont se développer (Viña, 2002).

La température est le principal paramètre influençant la distribution latitudinale et altitudinale des organismes sur Terre (Viña, 2002). D'ailleurs, excepté pour les arbres du domaine boréal ou alpin et les xérophytes adaptés aux climats extrêmement chauds, il est communément admis que les plantes ne se développent pas en dehors de la fourchette allant de -10 à 60°C (Taiz *et al*, 2015). En-dessous de ces températures, le gel des cellules est à prévoir alors que la dénaturation des protéines s'opèrera au-dessus de ces températures (Taiz *et al*, 2015). La zone d'étude a enregistré 53 jours de gel dans les plaines durant la saison végétative (mai à octobre) d'août 2020 à août 2021, ces gels durant la croissance des plantes ont également un impact direct sur leur développement (Pearce, 2001). D'autre part, l'humidité, bien qu'ayant un effet sur le développement des plantes à travers l'évapotranspiration, la thermorégulation ou tout simplement la croissance (Tibbitts, 1979), est un paramètre moins pris en compte par les stations météorologiques.

Bien que cette étude porte sur des éléments topographiques de moins de 500 m d'altitude, la température et l'humidité relative seront systématiquement pris en compte lors de l'étude des communautés végétales des collines abitibiennes. En effet, bien que les études traitant de ce sujet semblent rares, il est reconnu que les petits éléments topographiques puissent avoir des températures moyennes plus élevés que celles rencontrées dans les vallées, et des événements de gels moins abondants (Zelazny, 2007; MacHattie & McCormack, 1961). On estime en revanche qu'il n'y a pas de relation entre l'humidité atmosphérique et les gradients altitudinaux (Lee & La Roi, 1979; Körner, 2007). Cependant, de basses températures entraînent une humidité plus importante (Valsson & Bharat, 2011) et, si des différences de température venaient à être rencontrées entre les collines les plus hautes et les plus basses, il conviendrait de vérifier qu'il n'y a pas de différence d'humidité relative entre ces deux types de collines.

1.5 La physico-chimie du sol et les végétaux

Les plantes se développent sur un substrat, que ce soit sur de l'eau, de la roche, un autre organisme vivant ou, plus communément, sur une couche de matière organique. La physico-chimie dudit substrat revêt ainsi une grande importance pour le développement de la plante car, si ce n'est pour les espèces parasites ou hétérotrophes, elle en tirera ses apports en eau, nutriment et associations symbiotiques (Verdonck *et al*, 1982). En effet, la granulométrie, le drainage, la présence de symbiotes racinaires potentiels, d'espèces végétales compagnes ou encore la teneur en certains éléments chimiques vont conditionner la possibilité pour une graine ou une spore de se développer à l'endroit où elle se dépose dans le paysage (Hosseini *et al*, 2021; Aloisio *et al*, 2019).

L'un des meilleurs exemple de cette dépendance au substrat est la dualité basiphile contre acidophile, auquel on peut ajouter les espèces mésophiles qui se développent dans des intervalles de pH plus importants (Ewald, 2003). Chez certaines espèces de bryophytes par exemple (*Palustriella falcata*, *Drepanocladus turgescens*…), longtemps décrites comme calciphiles, le pH semble de fait plus important que les concentrations en calcium de leur milieu de croissance (Ambec *et al*, Subm.). En revanche, les végétaux peuvent tout de même être sensibles à la teneur de certains éléments chimiques dans leur substrat, comme le fer, le cuivre ou le cobalt, conduisant parfois à de l'endémisme très localisé (Boisson *et al*, 2017; Jacobi *et al*, 2011).

Bien que les fonctions biologiques des végétaux ne soient visiblement pas impactées par des éléments qui seraient fatals au règne animal tels que le cadmium ou l'arsenic (DalCorso *et al*, 2008; Verbruggen *et al*, 2009), il apparaît que la géochimie naturelle, ou de sites miniers, puisse fortement conditionner les espèces végétales s'y développant (Tropek *et al*, 2010; Erskine *et al*, 2012; Johnson & Steingraeber, 2003; Rola *et al*, 2015). Pour cette raison, il est primordial d'analyser la géochimie des sites miniers, calcaires, ultramafiques et les étangs de castor abandonnés.

1.6 Objectifs

Les principales problématiques de cette thèse sont de savoir si les affleurements rocheux humides et secs ainsi que les vieilles forêts de colline, mais aussi les différentes classes d'âge de peuplements forestiers de plaine ou bien les sites miniers abandonnés, les affleurements ultramafiques et calcaire et, finalement, les secteurs exposés en amont des barrages de castor abandonnés, hébergent des plantes rares et une richesse spécifique originale mais également de savoir s'ils hébergent des communautés différentes entre eux, et pour quelles raisons. L'étude poussée des communautés végétales de plantes vasculaires et de bryophytes de ces habitats permettra de découvrir leur biodiversité mais également de caractériser les assemblages spécifiques qu'on y retrouve. La prise en compte de la température et de l'humidité relative pour les collines, et de la géochimie pour les substrats stressants permettra une appréciation plus fine expliquant les variations d'assemblages spécifiques que l'on pourrait observer lorsqu'on les compare entre eux.

Plus particulièrement, la comparaison se fera entre paléo-îles (les plus hautes) et collines anciennement submergées (les plus basses) pour le chapitre 1, entre différentes classes d'âge de forêts et les forêts des dix collines étudiées pour le chapitre 2 et entre des sites miniers abandonnés et des habitats naturellement ouverts (étangs de castor abandonnés) et stressants (affleurements calcaires et ultramafiques) pour les plantes dans le chapitre 3. La totalité des sites du chapitre 1 se situent en Abitibi (Figure 2.1) une petite partie des sites se situe de surcroît en Eeyou-Istchee Baie de James pour le chapitre 2 (Figure 3.1) ou au nord du Témiscamingue pour le chapitre 3 (Figure 4.1).

CHAPITRE 2: PLANT COMMUNITY AND CLIMATE DIFFER BETWEEN FORMER ISLANDS AND SUBMERGED HILLS BY PROGLACIAL LAKE OJIBWAY IN EASTERN BOREAL CANADA

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2.1 Abstract

Rare habitats result from the geochemistry, history, or topography of the environment. They shelter regionally rare species (i.e., those with only a few mentions) and are threatened by global changes and human activities. On the clay plains of western Québec, the scattered highest hills emerged from the proglacial lake Ojibway (10 200-8 200 BP) as islands and were potentially colonised 2 000 years before their present surroundings. This study aims to determine if the effect of this earlier colonisation is still visible today in comparison with nearby formerly submerged hills. To do so, vascular plants and bryophytes were sampled for all habitats (i.e., old-growth forest, wet rock, and dry rock) at matched pairs of formerly emerged and submerged hills with known disturbance histories. Hourly temperature and relative humidity were recorded the top and bottom of each hill for one year. We found that former islands housed richer bryophyte communities than formerly submerged hills while the opposite was true for vascular plants. Old-growth forest was the richest habitat. Although hilltop temperatures are higher than those of the plains, the former islands that made up the higher hills were colder and wetter than the smaller, formerly submerged hills. This did not affect the diversity of bryophytes, but it did have an impact on the diversity of most vascular plant life forms. We believe that the rugged higher hills create more microclimatic heterogeneity and are fire and climate refugia. Disturbances explains a higher vascular plant diversity on lower hills. We conclude that no former island effect exists as such, but rather a complex climate and fire refugia resulting of a more rugged topography in former islands that allowed old-growth dependent species to accumulate through millennia in the right habitat structure. These results give new perspectives to discriminate apparently common habitats.

2.2 Résumé

Les habitats rares résultent de la géochimie, de l'histoire ou de la topographie de l'environnement. Ils abritent des espèces rares à l'échelle régionale (c'est-à-dire dont il n'existe que quelques mentions) et sont menacés par les changements globaux et les activités humaines. Dans les plaines argileuses de l'ouest du Québec, les plus hautes collines dispersées ont émergé du lac proglaciaire Ojibway (10 200-8 200 BP) sous forme d'îles et ont été potentiellement colonisées 2 000 ans avant leur environnement actuel. Cette étude vise à déterminer si l'effet de cette colonisation antérieure est encore visible aujourd'hui par rapport aux collines voisines anciennement submergées. Pour ce faire, des plantes vasculaires et des bryophytes ont été prélevées dans tous les habitats (forêt ancienne, roches humides et roches sèches) sur des paires appariées de collines anciennement émergées et submergées dont l'histoire des perturbations est connue. La température horaire et l'humidité relative ont été enregistrées au sommet et au pied de chaque colline pendant un an. Nous avons constaté que les anciennes îles abritaient des communautés de bryophytes plus riches que les collines anciennement submergées, tandis que l'inverse était vrai pour les plantes vasculaires. La forêt ancienne était l'habitat le plus riche. Bien que les températures au sommet des collines soient plus élevées que celles des plaines, les anciennes îles qui composaient les collines les plus élevées étaient plus froides et plus humides que les petites collines anciennement submergées. Cela n'a pas affecté la diversité des bryophytes, mais a eu un impact sur la diversité de la plupart des formes de vie des plantes vasculaires. Nous pensons que les collines plus élevées et accidentées créent une plus grande hétérogénéité microclimatique et constituent des refuges pour les incendies et le climat. Les perturbations expliquent la plus grande diversité de plantes vasculaires sur les collines inférieures. Nous concluons qu'il n'existe pas d'effet d'ancienne île en tant que tel, mais plutôt un climat complexe et des refuges contre le feu résultant d'une topographie plus accidentée dans les anciennes îles qui ont permis aux espèces

dépendantes des forêts anciennes de s'accumuler au cours des millénaires dans la structure d'habitat appropriée. Ces résultats ouvrent de nouvelles perspectives pour distinguer des habitats apparemment communs.

2.3 Introduction

The perennial presence of a species at a given area in a landscape stems from its colonisation capacity. The first step in establishing a presence is dispersal from a source population (Eriksson, 1993; Pärtel *et al*, 1996; Lõhmus *et al*, 2014). The dispersal ability of a species is governed by its morphology and dispersal strategy (anemochory, zoochory, etc.) and the connectivity of the habitat on which it depends between the source population and the environment to be colonised (Lõhmus *et al*, 2014). After dispersal, the colonisation process ultimately depends on the establishment and continued survival of the species in the system. Both dispersal and colonisation depend on a favourable habitat and environmental conditions for establishment, as well as the presence of favourable stochastic events like dispersal-friendly storm events and the absence of deleterious events such as fires, summer frosts, etc. (Ellis *et al*, 2012; Lõhmus *et al*, 2014).

With extensive areas covered in ice, ice ages greatly affected the colonisation capacity of organisms at time scales of 100,000 years (Shackleton, 2000; Ramírez-Barahona & Eguiarte, 2013; Wang *et al*, 2020). Indeed, as ice sheets expanded, they limited access to soil for plants, microorganisms and the rest of the food chain. Furthermore, the colder conditions in adjacent regions also made survival and reproduction more difficult for species (Bennett, 1997; Hewitt, 2003; Allen *et al*, 2020). During this period, most organisms could only persist in residual ice-free areas, called glacial refugia. The repeated ice advances even concentrated species in glacial refugia over millennia, resulting in some of the richest biodiversity hotspots on earth (McGlone *et al*, 2001; Harrison & Noss, 2017; Montoya *et al*, 2018; Chung *et al*, 2018). By creating such constraints, past glaciations have contributed to the current distribution of many organisms (Davies *et al*, 2011; Normand *et al*, 2011), after hundreds of thousands of years of temperature and moisture changes (Bennett, 1997; Hewitt, 2003; Allen *et al*, 2020). After each Late Glacial Maximum (LGM), these refugia represented the starting point of recolonisation of the landmass following glacial retreat. In some cases, however, the recolonisation process has encountered a major obstacle, when melting ice created huge and persistent bodies of water, once again covering usable soil for most organisms (Wang *et al*, 2015; Sutherland *et al*, 2019; Pitman *et al*, 2020).

In North America, the maximum glacial extent of the Laurentide ice sheet occurred around 20,000 years BP, during the global LGM (Hughes *et al*, 2013). The ice cap started retreating several millennia later, and the proglacial lake Ojibway (Figure 2.1) south of James Bay formed around 10,200 BP (Coleman, 1909; Godbout *et al*, 2017). Although no paper has estimated the surface area of Lake Ojibway during its different phases, the surface of the Clay Belt it lefts after its emptying is of 180000 km², more than twice the size of lake Superior (Kent, 1966). Within the lake, a few elevated hills were, as a former state, islands at the time (Coleman, 1909; Veillette, 1994). After lake Ojibway drained around 8,200 BP, it left a huge basin of clay deposits, the Clay Belt (Richard, 1980) and the former islands became today's highest hills, ranging from 380 m to 500 m (Barber *et al*, 1999).

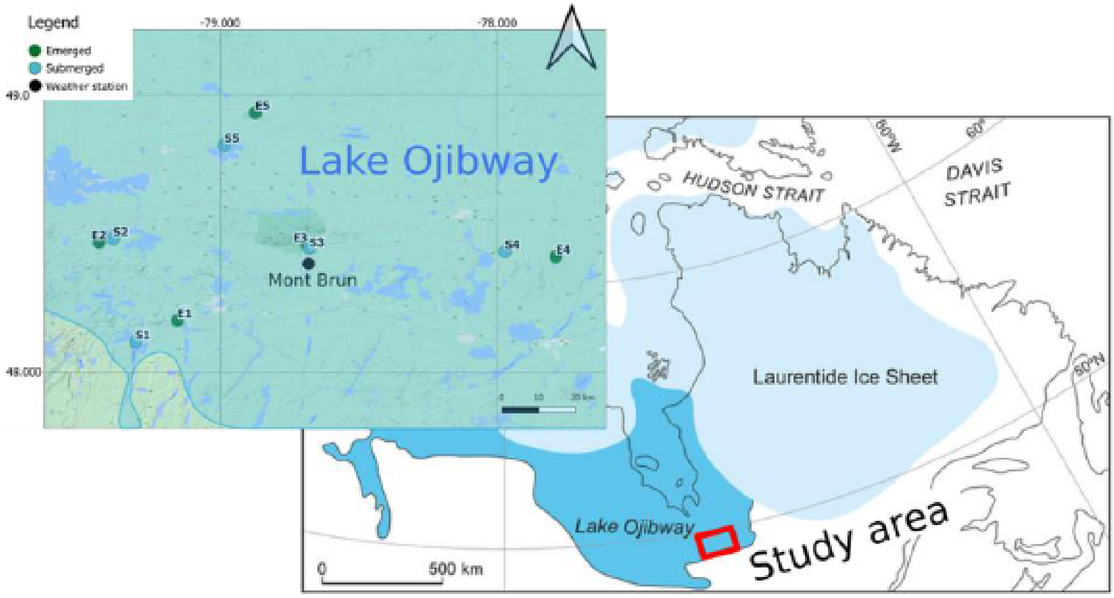

Figure 2.1: Map of the proglacial lake Ojibway created around 10200 BP (based on Harrison et al, 2019), and the study area. The study area map itself shows the formerly emerged (E) and submerged (S) hills with the former position of the lakeshores when the glacial retreat started and how they were paired. The location of the Mont Brun weather station is also shown.

Rising above the clay plain, often with exposed bedrock, hills in general represent unique habitats in the region (Godbout *et al*, 2017). However, the substrates found on the hills differs between formerly emerged and submerged hills. Till-based substrates are found on formerly emerged hills while clay or sand are found on formerly submerged hills, which are hills less than 380 m high. The Abitibian clay belt is dominated by human-altered forests resulting from extensive forest harvesting and agricultural clearing (Lafond & Ladouceur, 1968; Gaudreau, 1979; Martineau & Gervais, 2014). In addition the elevation of these hills creates natural firebreaks in contrast with the surrounding plains (Rogeau *et al*, 2018) making them relatively inaccessible, which resulted in a higher proportion of old-growth forests (Larocque et al. 2003; Rogeau et al. 2018; Jodłowski and Kalinowski 2018).

Once revealed after the ice sheet retreat, these islands of barren land surrounded by water were isolated from the mainland and could only be colonised by vascular plants and bryophytes via dispersal from the lakeshore since they are sessile organisms (van der Pijl, 1982). Proglacial lake Ojibway persisted for around 2000 years; therefore these islands could have been colonised 2000 years before the clay plains. Not much is known about the early and current plant communities on these former islands, especially the bryophytes. However current knowledge indicates that they do support a number of regionally rare vascular plant species (Martineau & Gervais, 2014). Climatic data indicates that the hills are warmer than the plains, which should partly explain the presence of these rare vascular plants. This study aims to determine if the vegetation of former islands differs from the vegetation on nearby, lower elevation hills that were submerged during the full extent of Lake Ojibway, despite their geographic proximity and relatively small differences in elevation. If this is the case, we aim to determine if it is due to the early colonisation of former islands or rather because of differences in microclimate or soil between the two types of hills.

To answer this question, we surveyed vascular plant and bryophyte communities during the summer of 2020 in three kinds of habitats which are dry rocks, wet oozing cliffs and old-growth forests on formerly submerged and emerged Abitibian hills. We also collected a year long record of temperature and relative humidity (summer 2020 to summer 2021) on each hill. We hypothesize that (1) temperature and relative humidity and (2) species composition and species richness will be different between emerged and submerged hills because of both climate and the former island effect. Finally, we hypothesize that 3) contrasts between former states (emerge or submerged) or habitats will be higher for bryophyte than vascular plant communities since bryophytes are more affected by microhabitats and microclimatic conditions than vascular plants (Cole *et al*, 2008; Toro Manríquez *et al*, 2020).

2.4 Materials and methods

2.4.1 Study area

The study was conducted in the south-eastern part of the Clay Belt area, eastern Canada (Figure 2.1). The Clay Belt is characterized by clay deposits left by proglacial Lake Ojibway during the Wisconsinan glaciation (Vincent & Hardy, 1977). About 85% of the region is currently forested (MRNFP, 2004) and forests are mostly dominated by black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*) and jack pine (*Pinus banksiana*). Natural fires are the most frequent natural disturbance and the fire cycle for the 1920-2002 period was over 300 years (Couillard *et al*, 2022). The mean temperature in winter was -11.64°C (November to March) and in summer was 10.09°C summer (April to October) with an annual mean of 1°C, measured at the permanent Mont Brun weather station in the centre of the study area (near sites E3 and S3, Figure 1) during the 1981-2010 period. Annually, there is 707,7 mm of rain and 281,2 cm of snow (Environment Canada, 2021).

2.4.2 Site selection and sampling

2.4.2.1 Site selection

Five replicates of formerly emerged/submerged pairs of hills (located approximately 10 km apart from each other) were selected (Figure 2.1). Emerged (E) or submerged (S) refers to the former state of each selected hill during the full extension of Lake

Ojibway. The elevation required for a hill to be classified as "emerged" was determined locally using the maximum levels of proglacial lake Ojibway as indicated on government maps (Veillette, 1994). The altitude of sampled habitats ranged from 375 to 465 m for E hills and 280 to 350 m for S hills. The altitude of the surrounding plains ranged from 250 to 300 m. All hills were primarily composed of mafic rocks, over which till, and at lower elevations, clay, are overlain (NRCan, 2021). To be selected, every hill had to contain three types of habitats. The first are stands of old-growth forest (F) that were at least 100 years old and dominated by *Abies balsamea* or *Picea* spp. and old-growth indicator species like *Thuja occidentalis* (Bergeron & Fenton, 2012). These stands were selected using a fire history map of the area (Bergeron *et al*, 2004). The second habitat was dry rocks (DR), corresponding to extensive (>1000 m²) exposed rocky outcrops located on the highest south facing part of the hills. DR were located using satellite imagery. Finally, wet rocks (WR) were north-facing vertical oozing cliffs of at least 30 m², usually surrounded by the selected old-growth forest stand. WR were located using topographical maps and searching for north facing steep slopes as well as using our personal knowledge of the region.

2.4.2.2 Environmental variable sampling

On each hill, temperature, and relative humidity at 10 to 20 cm above the ground were recorded with data loggers (HOBO U23 Pro v2) at the highest and lowest forested points found on the south facing slope of each hill. The altitude of each datalogger was noted. Only one downhill datalogger was placed for each pair of emerged and submerged hills when they were within 4 km of each other. Data were recorded hourly for one year from August 2020 to August 2021. Among the 15 dataloggers used, 13 worked year-round and were used in analysis. Temperatures reference in plains come from Mont Brun weather station, located at 304.8 m high.

2.4.2.3 Vegetation sampling

The sampling was done in one month, July of 2020, which allowed us to detect plants with the same accuracy. At approximatively the same altitude for each hill, we established 1 plot in each of DR, WR and F habitats. DR and WR habitats were sampled with ten randomly placed 50 x 50 cm quadrats (Orange, 2008) spaced at least 1 m apart (total quadrat area was 2.5 m^2). F habitats were sampled with three randomly placed 5 x 10 m quadrats (total quadrat area was 150 m^2) following the protocol of Barbé et al. (2017) and each quadrat was located at least 50 m from each other within the forest stand. Despite a total of 150 m² in forest and only 2.5 m² in WR and DR, the sampling effort was the same. Rocky areas were less extensive but more rugged with complex structures to colonise for plants. We believe that our sampling effort gave us the same communities precision in the three sampled habitats.

Bryophytes were systematically collected from all substrates in each quadrat for identification in the laboratory. We identified every different vascular plant species we saw in the field, and unknown vascular plants were collected for subsequent laboratory identification. A final 20-minute survey was performed outside of the quadrats but within the habitat during which any previously unidentified species (vascular or bryophyte) was collected to be as exhaustive as possible. Species nomenclature and known distribution follows Bryoquel (Société québécoise de bryologie, 2021) for bryophytes and Canadensys for vascular plants (Canadensys, 2021). New bryophyte species for the region were determined using Bryoquel. The identification of these species was checked by specialists from the Société Québécoise de Bryologie.

2.4.3 Data processing

2.4.3.1 Microclimatic variables

From hourly values, we choose to keep the mean temperature, the number of frost days and the relative humidity for each logger during the growing season only (April to October) as this is when understory plants are confronted by the weather in boreal ecosystems with snow cover from November to March. In addition, frosts during the vegetative season have a significant impact on plant development(Pearce, 2001) and we also calculated their occurrence. We defined a frost day as a day when at least one hourly temperature was below 0 °C during a 24-hour period.

2.4.3.2 Species richness

Gamma diversity was calculated for both vascular and bryophyte species as the total number of species present. To facilitate interpretation of the results, bryophyte species were classified by life form: acrocarpous mosses, pleurocarpous mosses, sphagna and liverworts (leafy and thallose liverworts were grouped). Vascular plant species were also classified into four life forms based on their strata in the forest and their ecology (Walker & Sharpe, 2010; Berg *et al*, 2020): herbaceous, pteridophytes, shrubs, and trees. With the aim to try to better discriminate both states and habitats', we also chose to look at their exclusive species richness by determining which species were found in only a single habitat or state (i.e. either E or S state; or F, DR or WR habitats). Each species found only in one single habitat, or one single state, was considered exclusive to that habitat or state.

2.4.4 Statistical analysis

Statistical analyses were based on presence-absence data. All replicate quadrats for each state x habitat combination were pooled for each hill, eliminating the need for mixed models (N = 5 hills x 2 states x 3 habitats = 30). Specific richness and composition analyses were performed either at state level (N = 5 hills x 1 state x 3 merged habitats = 15), either at habitat level (N = 5 hills x 2 states x 1 habitat = 10) except for the gamma richness for the whole dataset, which was analysed for a state or a habitat. The data as well as figures were processed using R version 4.0.3 (R Core Team, 2020).

2.4.4.1 Microclimatic variables

To determine if temperature and relative humidity of hourly measures, as well as the number of frost days varied significantly between states at the top and at the foot of hills, we first used a two factor ANOVA followed by Tukey HSD post-hoc tests. Finally we built interaction plots using package ggplot2 version 3.4.0 (Wickham, 2016).

2.4.4.2 Richness

Total species richness, exclusive species richness, and the richness of specific life forms for bryophytes and vascular plants were compared between states, habitats and their interaction using two factors' ANOVAs followed by Tukey HSD post-hoc tests. Finally we built boxplots using package ggplot2 version 3.4.0 (Wickham, 2016).

Diversity within class Sphagna was not analysed beyond this point as the maximum richness over all plots was 4 species.

To determine if the bryophytes and vascular plant life form richness was significantly influenced by the number of frost days, relative humidity and habitat, we built a Generalised Linear Model (GLM). Temperatures were not added to the model because they were significantly correlated with the number of frost days (Pearson's correlation coefficient: $r = -0.71$; p-value = 0.007). As only 13 out of 15 dataloggers worked all year long, we made a regression to generalise climatic data for all hills as follow. The regression of the number of frost days during the vegetative season (April to October) as a function of altitude for each state (**E**: coefficient = 0.13 and $R^2 = 0.21$; S: coefficient = -0.13 and $R^2 = 0.18$) was used to associate a predicted value for numbers of frost days during the vegetative season (April to October) for the altitude of each habitat x state combination. The regression of the relative humidity during the vegetative season (April to October) as a function of altitude for each state (**E**: coefficient = -0.038 and $R^2 = 0.94$; S: coefficient = 0.08 and $R^2 = 0.15$) was used to associate a predicted value for relative humidity for the altitude of each habitat x state combination. The fitted poisson GLM models were structured as follows: **Life form at the plot level ~ Number of frost days (corrected predictions for the plot elevation) + Relative Humidity days (corrected predictions for the plot elevation) + Habitat**, where humidity and number of frost days are continuous data and habitat is categorical. Interaction terms were excluded due to high Variance Inflation Factors (VIF >5) as evaluated by function vif of package rms version 6.4-1 (Harrell, 2015).

2.4.4.3 Specific and life form composition in bryophytes and vascular plants

We evaluated variation in vascular plant and bryophyte assemblages between states and habitats by a PCoA ordination with the function betadisper of package vegan version 2.6-4 using the Bray-Curtis distance as appropriate for presence/absence data (Oksanen *et al*, 2017). All species were included in the ordination. Ellipses represent a 95% confidence interval for the community of plants found at each state and habitat combination.

To determine if the assemblages of bryophytes and vascular plant species varied significantly among habitat types, states, and their interaction we performed a Permutational multivariate analysis of variance (PERMANOVA). PERMANOVAs were performed with the function adonis2 in the vegan package version 2.6-4 (Oksanen *et al*, 2017), specifying 999 permutations and Bray-Curtis distances.

2.5 Results

2.5.1 Temperature, relative humidity, and number of frost days during the vegetative season

Hill state, logger position and their interaction significantly affected mean temperature (ANOVA: $F = 23.7$; p-value < 0.001) and relative humidity (ANOVA: $F= 350.0$; p-value < 0.001). With a minimum mean value of 12°C at hill foot and around 0.5°C more at hilltops, hills were warmer than plains since there was only a mean temperature of 10.2 °C at Mont Brun weather (Figure 2.2). Temperatures were lower at emerged hills at upper and lower positions than submerged hills. Relative humidity was not available at Mont Brun weather station. However, emerged hills showed a significantly higher relative humidity than submerged ones at upper and lower positions, the relative humidity was also significantly higher at the lower position than at the higher ones for emerged hills. The relative humidity it did not significantly differ between upper and lower positions on submerged hills. Mean frost day counts were higher at emerged sites than at submerged sites, but the effects of hill type, logger position and their interaction were not significant (ANOVA: F = 0.83 on 3 and 9 DF; p-value = 0.51; Figure 2.3). The number of vegetative frost days was 53 at Mont Brun, like at the base of the lowest submerged hills.

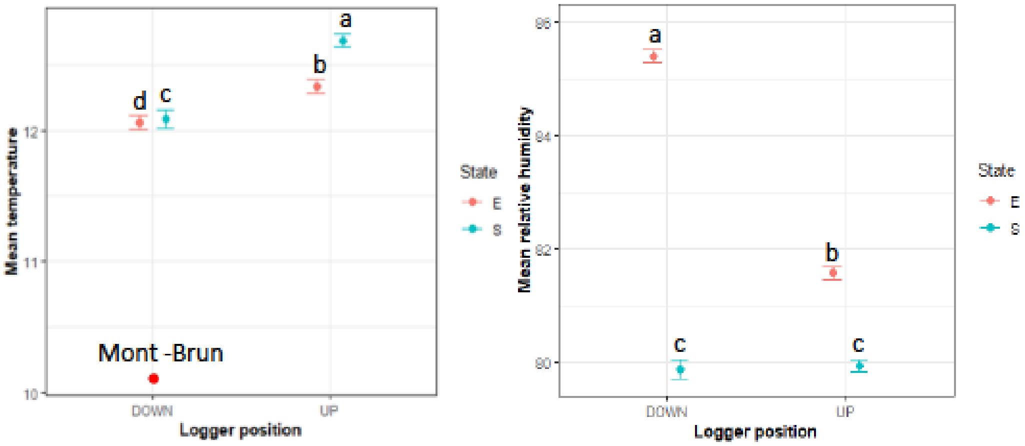

Figure 2.2: Plots comparing the mean temperature (LEFT) and relative humidity (RIGHT) values between UP and DOWN loggers of each hill state during the vegetative season. The red dot on the mean temperature plot represents the mean temperature at the Mont Brun weather station, located on the clay plains. Letters above each point and its standard error indicate statistical groups of replicates determined by Tukey HSD. No relative humidity value for Mont Brun weather station is indicated as it was not available.

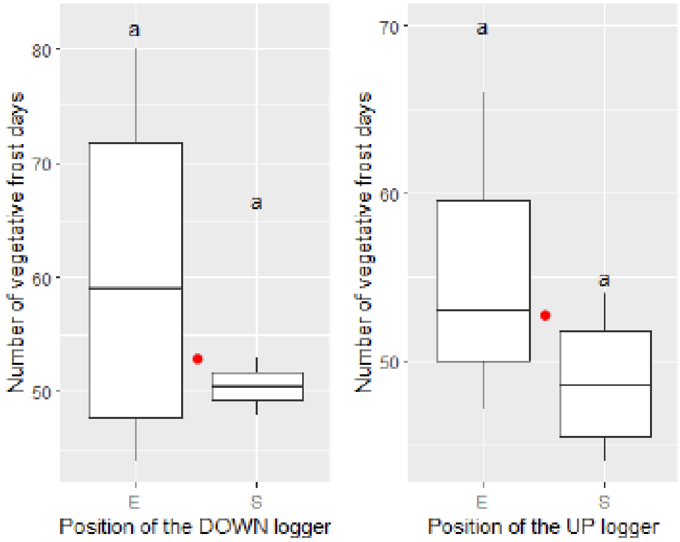

Figure 2.3: Boxplots comparing the mean number of frost days during the vegetative season between UP and DOWN loggers of each state. The red dot represents the number of frost days for the same period at Mont Brun's weather. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

2.5.2 Species richness and composition

2.5.2.1 Bryophytes

Total gamma diversity was of 166 bryophyte species across all hill states and habitat types (APPENDICE A). More species were found overall on emerged hills (151 species) than on submerged hills (130 species). Species richness was particularly low in DR compared to other habitats: a total of 61 species were found in DR, 106 in WR, and 126 in F.

Plot mean bryophyte species richness (Figure 2.4.A; 2.4.B) differed significantly among habitat classes, but state and the interaction of state and habitat did not significantly affect richness (ANOVA: F = 17.6 on 5 and 24 DF; p-value < 0.001). F had the highest specific richness followed by WR and then DR (Figure 2.4.A; 2.4.B).

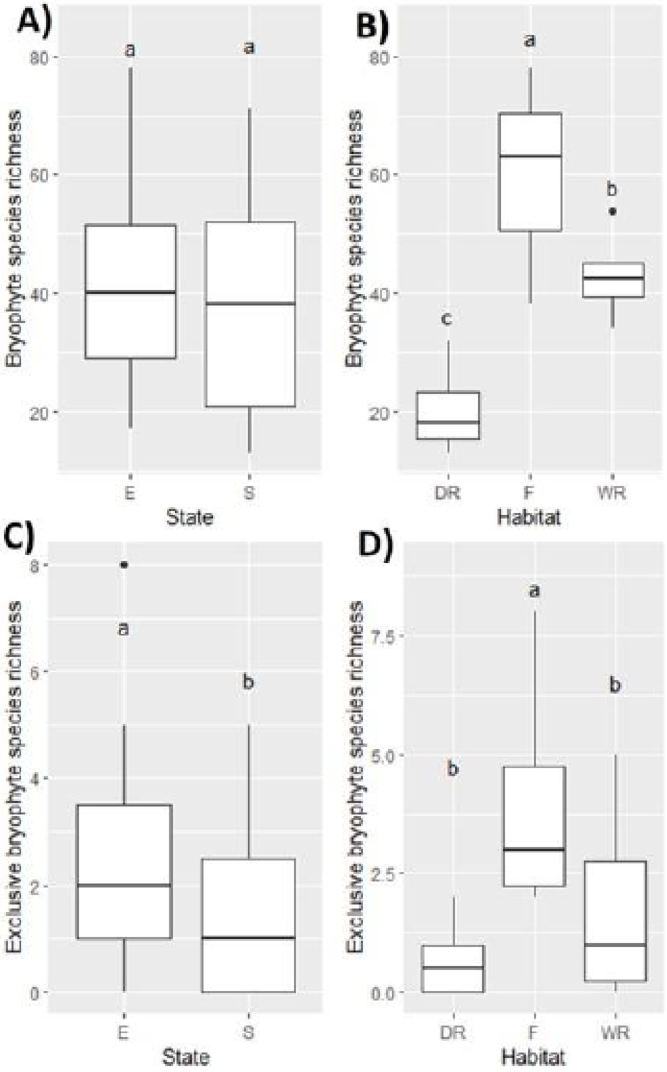

Figure 2.4: Boxplot showing the mean bryophytes species richness for (A) each state and (B) habitat and the mean exclusive bryophytes species richness for each state (C) and habitat (C). Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

To go further, liverworts was the life-form with the highest total richness (57 species), followed by pleurocarpous mosses (54 species), acrocarpous mosses (50 species) and only 5 sphagna species. Liverworts and acrocarpous mosses were the life forms with the highest mean richness in each state, while liverworts and pleurocarpous mosses were the life forms with the highest mean richness in each habitat (Figure 2.5.A; 2.5.B). Mean liverwort richness differed significantly among habitats (ANOVA: F = 10.01 on 5 and 24 DF; p-value < 0.001), while state and the interaction between state and habitat had no significant effect. The same pattern was observed for acrocarpous (ANOVA: F = 6.36 on 5 and 24 DF; p-value < 0.001) and pleurocarpous mosses (ANOVA: F = 18.83 on 5 and 24 DF; p-value < 0.001) mosses.

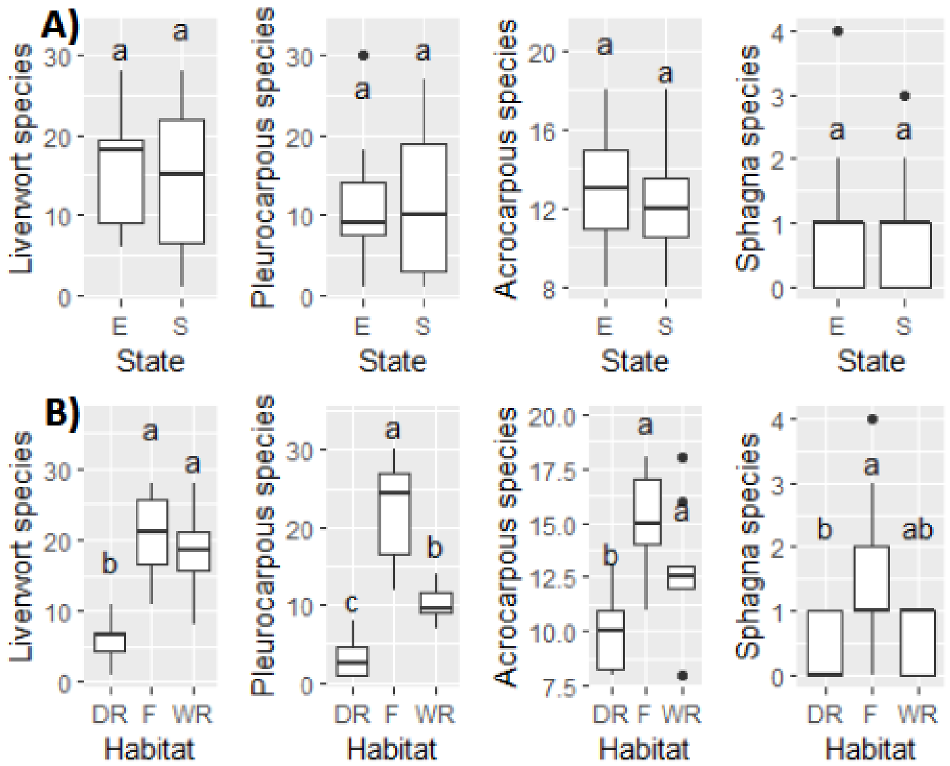

Figure 2.5: Boxplot representing the mean number of each life form of bryophytes in (A) each state and in (B) each habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

Mean plot level exclusive species richness (Figure 2.4.C; 2.4.D) varied significantly with state and habitat but not their interactions (ANOVA: F= 7.31 on 5 and 24 DF, p-value < 0.001). F had the highest exclusive specific richness followed by WR and DR while emerged hills had the highest exclusive species richness (Figure 2.4.C; 2.4.D).

Some bryophyte species were exclusively found in a particular state (51 species) or habitat (80 species) (Table 2.1). There was more than twice as many exclusive species on E hills (37 species) than on S hills (15 species). The number of exclusive species was the highest in F (46 species), intermediate in WR (23 species) and lowest in DR (11 species). E hills housed many exclusive liverwort species (three *Calypogeia* species, two *Lophozia* species, etc.) while S hills housed three liverwort species, but three *Brachythecium* species among many pleurocarpous mosses. Most exclusive species were only found in one or two different plots but *Barbilophozia hatcheri* was found in three E plots in different habitats and *Plagiomnium cuspidatum* was found in three different S and F plots (Table 2.1). New regional mentions essentially concerned liverwort species. Twelve new species for the region were found on E hills, like the north-eastern America endemic *Frullania selwyniana* or the more Atlantic-related *Trichocolea tomentella*, while two new species were found on S hills, *Diplophyllum apiculatum* and *Lejeunea cavifolia* (Table 2.1).

Table 2.1 : Bryophyte species found exclusively in a state (formerly emerged or submerged) with their counts per state in combination with an exclusive habitat when, as appropriate. If the species is state exclusive but not habitat exclusive, a NA is associated to its "Exclusive habitat" column. Species names in bold indicate a new mention for the Abitibi region.

Emerged only species	Habitat exclusive	Submerged only species	Habitat exclusive
Barbilophosia hatcheri (A. Evans) Loeske	*NA*	*Brachythecium erythrorrhizon* Schimp.	F
Barbilophosia sudetica (Nees ex Huebener) L. Söderstr., De Roo & Hedd.	*NA*	*Brachythecium laetum* (Brid.) Schimp.	F
Bryum laevifilum Syed	WR	*Brachythecium rutabulum* (Hedw.) Schimp.	F
Bryum pseudotriquetrum (Hedw.) G. Gaertn., B. Mey. & Scherb.	F	*Bryoerythrophyllum recurvirostrum* (Hedw.) P.C. Chen	F
Calypogeia muelleriana (Schiffn.) Müll. Frib.	F	*Dicranella heteromalla* (Hedw.) Schimp.	DR
Calypogeia neogaea **(R.M. Schust.) Bakalin**	**WR**	***Diplophyllum apiculatum*** **(A. Evans) Steph.**	**WR**
Calypogeia sphagnicola **(Arnell & J. Perss.) Warnst. & Loeske**	**F**	*Drepanocladus aduncus* (Hedw.) Warnst.	DR
Chiloscyphus pallescens (Ehrh.) Dumort. var. *pallescens*	F	*Drummondia prorepens* (Hedw.) E. Britton	F
Cinclidium subrotundum **Lindb.**	**F**	*Homalia trichomanoides* (Hedw.) Schimp.	F
Dicranum ontariense W.L. Peterson	F	*Hygroamblystegium varium* (Hedw.) Mönk. var. *varium*	F
Dicranum undulatum Schrad. ex Brid.	*NA*	***Lejeunea cavifolia*** **(Ehrh.) Lindb.**	**WR**
Diphyscium foliosum **(Hedw.) D. Mohr**	**WR**	*Nyholmiella obtusifolia* (Schrad. ex Brid.) Holmen & E. Warncke	F
Fissidens osmundoides Hedw.	*NA*	*Orthotrichum* Hedw.	F
Frullania selwyniana **Pearson**	**F**	*Pellia neesiana* (Gottsche) Limpr.	WR
Grimmia longirostris Hook.	DR	*Plagiomnium cuspidatum* (Hedw.) T.J. Kop.	F
Homomallium adnatum (Hedw.) Broth.	DR		
Hypnum fauriei **Cardot**	**F**		
Leucobryum glaucum (Hedw.) Ångström	DR		
Lophozia debiliformis **R.M. Schuster & Damsh.**	**WR**		
Odontoschisma francisci **(Hook.) L. Söderstr. & Váña**	**DR**		
Pellia epiphylla (L.) Corda	F		
Philonotis fontana (Hedw.) Brid. var. *fontana*	WR		
Plagiomnium ellipticum (Brid.) T.J. Kop.	F		
Pseudobryum cinclidioides (Huebener) T.J. Kop.	F		
Pseudotaxiphyllum distichaceum **(Mitt.) Z. Iwats.**	**WR**		
Pterigynandrum filiforme Hedw.	WR		
Racomitrium affine **(Schleich. ex F. Weber & D. Mohr) Lindb.**	**WR**		
Racomitrium sudeticum (Funck) Bruch & Schimp.	WR		
Rhytidiadelphus subpinnatus (Lindb.) T.J. Kop.	F		
Rhytidiadelphus triquetrus (Hedw.) Warnst.	F		
Scapania mucronata **H. Buch**	**WR**		
Schistochilopsis incisa (Schrad.) Konstant. var. *incisa*	WR		
Sphagnum centrale C.E.O. Jensen	F		
Sphagnum fallax H. Klinggr.	WR		
Thuidium delicatulum (Hedw.) Schimp.	F		
Trichocolea tomentella **(Ehrh.) Dumort.**	**F**		

Habitat was the only significant parameter influencing life form group richness (Table 2.2). Lifeforms richness were significantly influenced by F habitats. Liverwort and pleurocarpous richness were significantly influenced by WR habitats but liverwort richness only was influenced by DR habitats. When looking at the specific composition, habitat was the only parameter significantly influencing bryophyte species composition (PERMANOVA: $R^2 = 0.39$; p-value = 0.001) while state and the interaction between state and habitat had no effect. The PCoA shows that habitats shelter distinct communities, except for some F and WR replicates, but that when they are paired with states, the communities globally overlap at a 95% confidence interval (Figure 2.6).

Table 2.2: Summary of the results of the GLMs for each bryophyte life form group richness in function of habitat, the number of frost days during the vegetative season and relative humidity.

	Liverworts		Pleurocarpous		Acrocarpous	
	SE	p-value	SE	p-value	SE	p-value
Habitat						
F	0.15	<0.001	0.19	<0.001	0.13	0.001
WR	0.15	<0.001	0.2	<0.001		NS
DR	2.55	<0.01		NS		NS
Vegetative frost days		NS		NS		NS
Relative humidity		NS		NS		NS

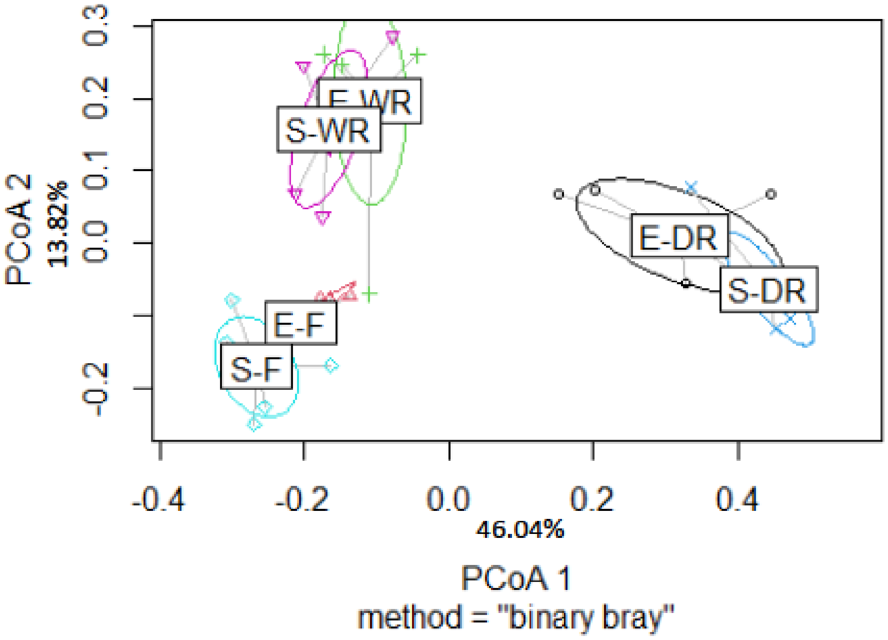

Figure 2.6: Two PCoA axes habitat mapping using binary-bray method and distance between bryophytes assemblages representing 59.86% of their variability. Ellipses represent the mean 95% confidence interval.

2.5.2.2 Vascular plants

The study allowed to detect a total gamma diversity of 89 different vascular plant species (APPENDICE B). Fewer species were found overall on emerged hills (66 species) than on submerged hills (79 species) with a lot of common species like *Picea mariana* or *Rubus pubescens*. The highest species richness was found in F (63 species) but was similar in DR and WR with 50 and 47 species respectively.

Plot mean vascular species richness (Figure 2.7.A; 2.7.B) differed significantly among habitat classes, but state and the interaction of state and habitat had no significant effect on richness (ANOVA: F = 4.89 on 5 and 24 DF; p-value = 0.02). F had a higher species richness than WR and DR.

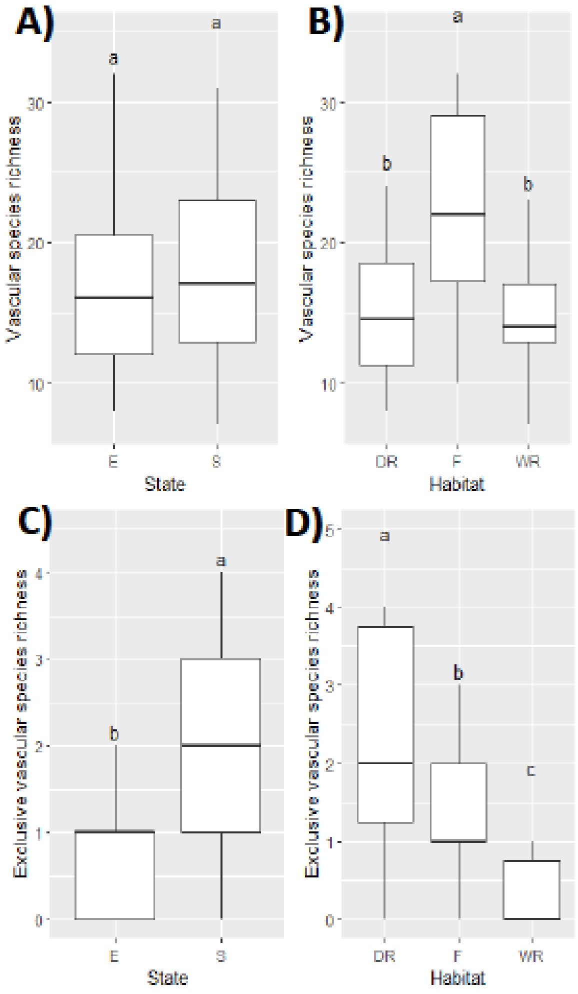

Figure 2.7: Boxplot showing the mean vascular species richness for (A) each state and (B) each habitat and the mean exclusive vascular species richness for (C) each state and (D) each habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

To go further, life form richness was highest for herbaceous species (41 species), followed by shrubs (23 species), pteridophytes (13 species) and trees (12 species).

Shrubs and herbaceous species were the life forms with the highest mean richness in each state (Figure 2.8.A) and habitat (Figure 2.8.B). At the hill level, herbaceous (ANOVA: F = 10.01 on 5 and 24 DF; p-value < 0.001) and shrubs (ANOVA: F = 3.29 on 5 and 24 DF; p-value = 0.02) mean richness differed significantly among habitats, while state and the interaction between state and habitat had no significant effect. Nothing was significant for pteridophytes (ANOVA: F = 1.33 on 5 and 24 DF; p-value = 0.29) and trees (ANOVA: F = 2.1 on 5 and 24 DF; p-value = 0.1).

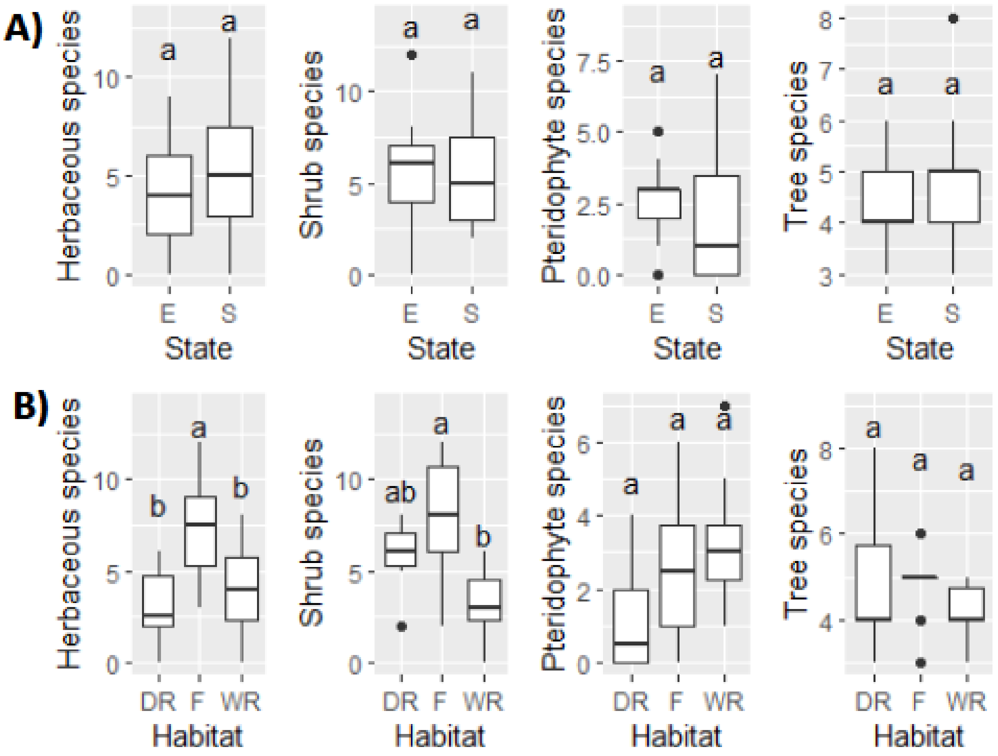

Figure 2.8: Boxplot representing the mean number of each life form of vascular plant in (A) each state and (B) each habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

Some vascular plant species were exclusive to a particular state (39 species) or habitat (44 species) (Figure 2.7.C; 2.7.D; Table 3). There was twice as many exclusive species in S (26 species) than in E (13 species), and no new species were found for the region (Table 2.3). Most exclusive species consisted of understory vegetation, but S hills also housed three exclusive tree species (*Pinus strobus*, *Populus tremuloides* and *Larix laricina*). The number of exclusive species was higher in DR (20 species) and in F (18 species) than in WR (6 species). At the hill level, the mean exclusive species richness was significantly influenced by habitat, state, and their interaction (ANOVA: F= 12.7 on 5 and 24 DF, p-value < 0.001). The only pertinent interaction was between DR habitat in E and S (Tukey HSD post-hoc test: difference = 2.2; p-adjusted < 0.001). Most exclusive species were only found in one plot except for *Claytosmunda claytoniana* in E hills and *Eurybia macrophylla*, *Pyrola asarifolia* and *Streptopus lanceolatus* in S hills, which were found at two different plots and different habitats.

Habitat and relative humidity significantly influenced the life form group richness (Table 2.4). Herbaceous and pteridophytes richness were significantly influenced by F habitat. Shrubs and pteridophytes richness were significantly influenced by WR.

Habitat was the only parameter that significantly influenced vascular species composition (PERMANOVA: $R^2 = 0.24$; p-value = 0.001). Indeed, DR communities are distinguished from F and WR ones, although the distance between their state's assemblages is almost inexistent for all different habitats (Figure 2.9).

Table 2.3: Vascular plant species exclusively found in a state (formerly emerged or submerged) in combination with a habitat when it is the case. If the species is state exclusive but not habitat exclusive, a NA is associated to its "Habitat exclusive" column.

Emerged only species	Habitat exclusive	Submerged only species	Habitat exclusive
Carex deflexa Hornemann	WR	*Aralia hispida* Ventenat	DR
Carex leptalea Wahlenberg	F	*Capnoides sempervirens* (Linnaeus) Borkhausen	DR
Carex stipata Muhlenberg ex Willdenow	F	*Carex foenea* Willdenow	DR
Claytosmunda claytoniana (Linnaeus) Metzgar & Rouhan	*NA*	*Carex intumescens* Rudge	F
Deschampia flexuosa	DR	*Carex tenera* Dewey	DR
Diervilla lonicera Miller	DR	*Drosera rotundifolia* Linnaeus	DR
Goodyera repens (Linnaeus) R. Brown	F	*Eupatorium perfoliatum* Linnaeus	F
Galium triflorum Michaux	F	*Eurybia macrophylla* (Linnaeus) Cassini	*NA*
Kalmia polifolia Wangenheim	DR	*Gaultheria procumbens* Linnaeus	F
Ribes glandulosum Grauer	DR	*Goodyera tesselata* Loddiges	F
Thalictrum pubescens Pursh	F	*Gymnocarpium disjunctum* (Ruprecht) Ching	WR
Viburnum lentago Linnaeus	DR	*Juncus bufonius* Linnaeus	DR
		Larix laricina (Du Roi) K. Koch	DR
		Lonicera villosa (Michaux) Roemer & Schultes	F
		Lycopodium clavatum Linnaeus	DR
		Mitella nuda Linnaeus	F
		Petasites frigidus var. *palmatus* (Aiton) Cronquist	F
		Pinus strobus Linnaeus	DR
		Populus tremuloides Michaux	F
		Pteridium aquilinum (Linnaeus) Kuhn	WR
		Pyrola asarifolia Michaux	*NA*
		Salix bebbiana Sargent	DR
		Scirpus atrocinctus Fernald	DR
		Scirpus atrovirens Willdenow	DR
		Streptopus lanceolatus (Aiton) Reveal var. *lanceolatus*	*NA*

Table 2.4: Summary of the results of the GLMs for each vascular plant life form group richness in function of habitat, the number of frost days during the vegetative season and relative humidity.

	Herbaceous		Shrubs		Pteridophytes		Trees	
	SE	p-value	SE	p-value	SE	p-value	SE	p-value
Habitat								
F	0.22	<0.001		NS	0.35	0.03		NS
WR		NS	0.22	0.006	0.34	0.003		NS
DR		NS		NS		NS		NS
Vegetative Frost days		NS		NS		NS		NS
Relative humidity	0.06	0.02	0.06	0.03	0.08	<0.05		NS

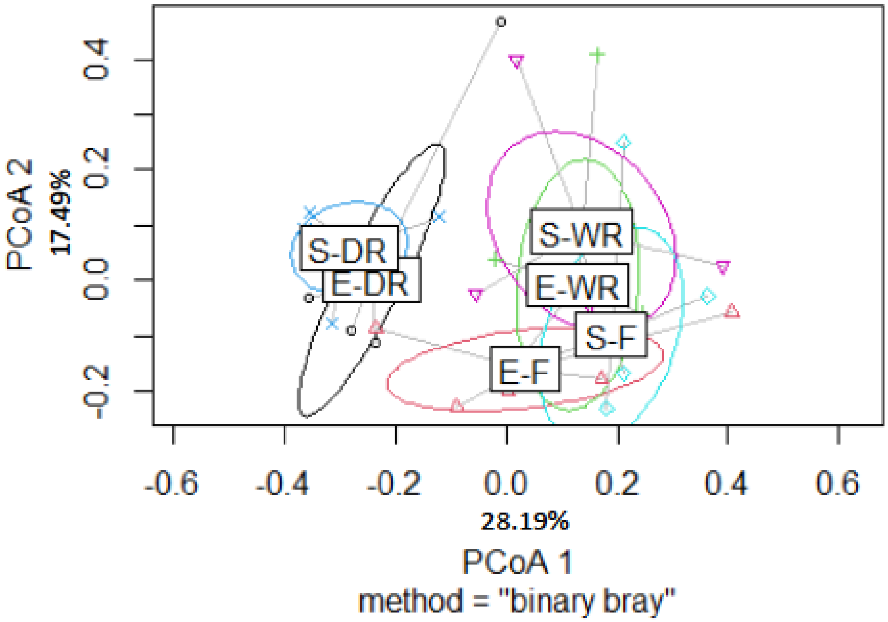

Figure 2.9: Two PCoA axes habitat mapping using binary-bray method and distance between vascular plant assemblages representing 45.68% of their variability. Ellipses represent the composition variability of each category at a mean 95% confidence interval.

2.6 Discussion

We validated our first hypothesis as there was significantly lower temperatures and higher relative humidity on E hills than S hills. Our second hypothesis was only partially validated since bryophyte and vascular species richness and community composition did not differ between former states but bryophyte exclusive species richness was higher on E hills than S hills while it was the opposite for vascular plants. Finally, we validated our third hypothesis because we found that bryophyte species composition was more contrasted between DR and the other habitats while communities of vascular plants were more overlapping between habitats.

2.6.1 Temperatures and relative humidity contrasts

Generally, the seasonal pattern in mean maximum temperature along an altitudinal gradient is not observed when the difference in elevation between the lowland and highland station is less than 300 m (Harding, 1978), and is almost undetectable at heights below 400 m (Meteorological Office, 1975). However, despite fitting these topographic criteria, we found a significant different between these former states. Temperatures were significantly warmer on top of S hills than on top of E ones. Colder E hills also shown a non-significant higher number of frost days. Therefore, the influence of temperature on hillside plant communities cannot be refuted as it has been found in other studies (MacHattie & McCormack, 1961), although no clear relationship was found in this study. The higher Abitibi hills are known to support southern species not often found in the surrounding plains, such as red maple (*Acer rubrum*) (Tremblay *et al*, 2002). This species was thought to be the remnants of larger populations observed during the warmer mid-Holocene period (Tremblay *et al*, 2002) empirically associated with milder temperatures on these hilltops (Dugas, 1975) compared to the plain, which was 2°C colder (mean temperature for the same period) at Mont Brun than at the base of the hills. The number of frost days during the vegetative season, on the contrary, was similar between Mont Brun and the base of studied hills. However, such species appear to have been most probably promoted on their northern range by a change in fire cycles, removing coniferous species, and microclimatic conditions (Mondou Laperrière, 2022).

In our study, the relative humidity gradient does not follow the same pattern: relative humidity was higher at E hilltops than S hilltops. Relative humidity also decreases significantly with altitude, with more humid conditions at the base of emerged hills than submerged hills, but humidity is not typically believed to be related to altitudinal gradients (Lee & La Roi, 1979; Körner, 2007). It is therefore likely that the higher relative humidity of former islands is related to the fact that lower temperatures lead to higher relative humidity (Valsson & Bharat, 2011). Relative humidity may then influence the richness and composition of hillside plants (Greiser *et al*, 2021), as has been found with most vascular plant life forms but not with those of bryophytes in this study.

2.6.2 State

The presence of unreworked deep till deposits on former islands (Godbout *et al*, 2017) in comparison to clay and sand on formerly submerged hills may explain differences in vegetation because of the richer substrate it creates (von Engeln, 1914) but analyses showed that, except for F bryophytes, state had no effect on the total plant species richness and composition. Therefore, since vascular plants globally interact with the soil for water and nutrient absorption, unlike many bryophyte species (saxicolous, saproxylic) that are dependent on wet and dry deposition of water and nutrients, we suggest that the substrate type may not impact the communities and that differences in composition, primarily in exclusive species, are the result of some other factor. Twice as many exclusive bryophyte species than exclusive vascular plant species on E hills than on S hills suggests a distinct exclusive bryophyte flora can be found on the former islands.

No pristine post-glacial vegetation communities can be found of course as, for example, the DR on one of the studied former islands was a closed black spruce (*Picea mariana*) forest 3,775 BP for about 2,300 years (Larocque *et al*, 2003). The vegetation was then modified by regional climate and fires (Larocque *et al*, 2003) but slopes, ridges and crests of these more rugged former islands create small refugia from fires (Rogeau *et al*, 2018; U.S. Forest Service, 2020). Natural firebreaks created by such topographic variations are able to preserve ecosystems from fire disturbances during centuries (Rogeau *et al*, 2018; U.S. Forest Service, 2020). Even small fire refugia can preserve forest structure and species (Coop *et al*, 2019; Downing *et al*, 2020), at least in some patches (Barbé *et al*, 2017; Kolden *et al*, 2017), that are then able to recolonise burned areas. Fire refugia promote old-growth forests systems which in turn promote old-growth dependant species who will find wetter conditions, and substrate diversity, on former islands (Kövendi-Jakó *et al*, 2016; Rehm *et al*, 2019; Toro Manríquez *et al*, 2020), which old growth tree species help to maintain because of the denser shade they create (Spies & Franklin, 1991; Wirth *et al*, 2009). Since bryophytes are more dependent on humidity than vascular plants (Vittoz *et al*, 2010), more humid former islands will shelter more bryophyte species, including a high diversity of liverworts. On the other hand, S exclusive vascular plant species were often wet-linked species such as *Carex foenea*, *C. intumescens*, *C. tenera*, *Drosera rotundifolia*, *Juncus buffosus*, *Larix laricina*, *Scirpus atrovirens* and *S. atrocinctus*. These wet-linked S exclusive vascular plant species are all, except *Carex intumescens*, found in DR habitats. This type of habitat corresponds to constant water-filled rockpools, probably because lower

S hills are smoother than E hills and offer more flat bedrock susceptible to retain water. In contrast E exclusive vascular species were more variable in their habitat affinities with only three *Carex* species (*C. deflexa*, *C. leptalea*, *C. stipata*), graminoids, shrubs, an orchid (*Goodyera repens*) and a fern (*Claytosmunda claytoniana*).

2.6.3 Habitats

Contrasts between habitat and state are less important for the richness or assemblages composition of vascular plants than for bryophytes. Microhabitats, including some vascular plants, are very important for bryophytes (Cole *et al*, 2008). Decaying logs and rocks shelter more microhabitats and bryophytes species than other habitats in boreal systems (Cole *et al*, 2008). Rocks are also known to shelter more species in cavities and fissures than on exposed parts (Hespanhol *et al*, 2011). If bryophytes are more dependent on humidity than vascular plants (Vittoz *et al*, 2010) and their richness is based on small habitat dependent species (Fenton & Bergeron, 2008), it could explain why shadier and wetter WR and F habitats support a greater richness of bryophyte species than open DR habitats.

Forests and the habitats within them, such as WR, have a high potential species richness, but this richness ceases to accumulate over long periods of time, such as a millennium (Hastings, 1980; Hixon *et al*, 2002; Clark & McLachlan, 2003). Old-growth forests experience secondary disturbance, such as tree fall (Martin, 2019), but not a reset of their old-growth communities (Shorohova *et al*, 2011). These punctual disturbances create opportunities for an opportunistic part of the assemblage that will colonise liberated space and then disappear as they are replaced by more competitive species. This means that vascular plant assemblages may be more fluctuating in less ancient and 'fire-sheltered' areas, such as S hills, where secondary disturbances are more common. We believe that this element is more important in vascular plant composition than the fact that it is warmer on S hills than on E hills, and therefore more conducive to vascular plant diversity since the number of frost days during the vegetative season were not associated with any life form's richness.

Differences between E and S hills exist in terms of climate and exclusive species. Our current study indicates that these differences do not result from a former island effect, but rather from multiple factors resulting in heterogeneous fire refuges that are generally colder, more humid and, above all, more stable for the plant communities over the millennia. We suggest that topography creates heterogeneity that also creates natural firebreaks and allows more species to establish in the resulting old-growth systems (Rogeau *et al*, 2018; U.S. Forest Service, 2020). Consequently, bryophyte assemblages may have remained stable on E hills, in restricted areas with the right habitat structures. This diversity of micro-habitats leads to a greater resilience for habitat-specific species. The long-distance dispersal abilities of bryophyte species (Barbé *et al*, 2016; Sundberg, 2013) support this fact, otherwise we would not find so many rare and E exclusive bryophyte species but rather the same species in the same habitats whatever the former state of the hill. Poorer vascular plant assemblages fluctuate less in these E old-growth forest systems. We did not find regionally rare species on the studied hills although they are known to occur on some hills in the region. We could therefore conclude that regionally rare bryophyte species are more abundant on E hills than regionally rare vascular plant species. In a context of global changes and increasing anthropogenic activities, contrasting habitats that are not as obvious as limestone outcrops or ultramafic areas need to be better understood. Otherwise, the regional diversity could be altered inadvertently, which might still be the case on these hills.

2.7 Aknowledgments

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CHAPITRE 3: OLD-GROWTH FORESTS ON HILLS AND PLAINS SUPPORT UNIQUE BRYOPHYTE AND VASCULAR PLANT COMMUNITIES IN EASTERN BOREAL CANADA

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3.1 Abstract

Covering 17 million square kilometres, the boreal realm has long been described as homogeneous. However, in recent years it has been shown that this is not true as boreal forests differ in structure as they age and in response to the disturbances they experience. In a human altered landscape, the scarce old-growth stands offer habitat for old-growth specialist species. These rare habitats contribute to landscape heterogeneity, and so to biodiversity. On the Abitibi plains, in western Québec, Canada, the landscape is dominated by human altered forests developing on clay soils overlying a predominantly mafic bedrock. Within this human modified landscape, rare habitats consist of non-harvested and non-burned old-growth forests located either on the plain or on difficult to access hills. With this study, we wanted to determine if vascular plant and bryophyte communities in old-growth forests on hills and on plains differ from each other and from younger stands, while controlling for the effects of surface deposit type, and stand type. To do so, we used extensive datasets of ecological observation points. Light and moisture preferences for indicator and most frequent species were also used to characterise the habitat represented by forest age categories. We hypothesised that (1) old-growth forests communities will differ from younger forest communities as old forests have a wetter and shadier atmosphere and house late successional species but also that (2) old-growth forests on hills and plains differ from each other because of the differences in the climates of their habitats and the lower intensity of disturbance they have experienced. We validated hypothesis (1) and (2) because the communities found in >100 years plains and old-growth hills forest categories were distinct from younger plains forests but also from each other. However, even if the stand age and a contrasting climate between the hills and the plains seem to the best explanation for these differences, we found an effect of surface deposit, stand type, and moisture and light preferences on the communities. Old-growth categories were also the only categories distinguished by their indicator species. Our results help to better discriminate and enhance biodiversity contrasts in the boreal realm. Therefore, our results could help to improve habitat conservation strategies in the region through a finer appreciation of forest habitat types in an apparently homogeneous context.

3.2 Résumé

Couvrant 17 millions de kilomètres carrés, le domaine boréal a longtemps été décrit comme homogène. Toutefois, ces dernières années, il a été démontré que ce n'était pas le cas, car la structure des forêts boréales change au fur et à mesure qu'elles vieillissent et en réponse aux perturbations qu'elles subissent. Dans un paysage anthropisé, les rares peuplements anciens offrent un habitat aux espèces spécialistes des vieilles forêts. Ces habitats rares contribuent à l'hétérogénéité du paysage et donc à la biodiversité. Dans les plaines de l'Abitibi, dans l'ouest du Québec, au Canada, le paysage est dominé par des forêts modifiées par les activités humaines qui se développent sur des sols argileux recouvrant un substrat rocheux principalement mafique. Dans ce paysage altéré, les vieilles forêts constituent des habitats rares, non exploités et non brûlés, situés soit dans la plaine, soit sur des collines difficiles d'accès. Cette étude visait à déterminer si les communautés de plantes vasculaires et de bryophytes des vieilles forêts situées sur les collines et dans les plaines diffèrent les unes des autres et des peuplements plus jeunes, tout en contrôlant les effets du type de dépôt de surface et du type de peuplement. Pour ce faire, nous avons utilisé de vastes ensembles de données de points d'observation écologiques. Les préférences en matière de lumière et d'humidité des espèces indicatrices et les plus fréquentes ont également été utilisées pour caractériser l'habitat représenté par les catégories d'âge des forêts. Nous avons émis l'hypothèse que (1) les communautés des vieilles forêts seront différentes de celles des forêts plus jeunes, car les vieilles forêts ont une atmosphère plus humide et plus ombragée et abritent des espèces de succession tardive, mais aussi que (2) les vieilles forêts des collines et des

plaines sont différentes les unes des autres en raison des différences de climat de leurs habitats et de la moindre intensité des perturbations qu'elles ont subies. Nous avons validé les hypothèses (1) et (2) parce que les communautés trouvées dans les catégories de vieille forêt de plaine >100 ans et des vieilles forêts de colline étaient distinctes des forêts de plaine plus jeunes, mais aussi les unes des autres. Cependant, même si l'âge du peuplement et un climat contrasté entre les collines et les plaines semblent expliquer en grande partie ces différences, nous avons constaté un effet du dépôt de surface, du type de peuplement et des préférences en matière d'humidité et de lumière sur les communautés. Les deux catégories de vieilles forêts étaient également les seules qui se distinguaient par leurs espèces indicatrices. Nos résultats permettent de mieux distinguer et d'améliorer les contrastes de biodiversité dans le domaine boréal. Par conséquent, nos résultats pourraient contribuer à améliorer les stratégies de conservation des habitats dans la région grâce à une appréciation plus fine des types d'habitats forestiers dans un contexte apparemment homogène.

3.3 Introduction

Covering about 17 million square kilometres, boreal forests account for the second largest land biome after desert and xeric shrub lands, and around a third of the earth's forested areas (Gauthier *et al*, 2015b; Kuosmanen *et al*, 2016; Kayes & Mallik, 2020). Previously defined as relatively homogeneous and simple ecosystems, an increasing number of studies suggest otherwise (Ylläsjärvi & Kuuluvainen, 2009; Gauthier *et al*, 2015b; Boudreault *et al*, 2018; Glasier *et al*, 2019). Indeed, as knowledge progresses, studies have found that boreal forests are naturally heterogeneous (Kuosmanen *et al*, 2016; Molina *et al*, 2018) and that this heterogeneity increases habitat diversity and biodiversity potential. However, the spatial distribution of biodiversity in boreal systems is still under surveyed as it is an extremely wide area and most of the territory is remote, often inaccessible via roads (Brandt *et al*, 2013). Most of the economy in the boreal realm is focused on the primary sector such as logging, mining and agriculture (Bogdanski, 2008) creating a mosaic of stands of various ages and a global rejuvenation of the forests leading to a greater abundance of broadleaf trees (e.g. poplars) than before industrialisation (Danneyrolles *et al*, 2018). Such alterations can lead to an increase in local biodiversity through an increase in the variety of habitats available, but regional biodiversity becomes more homogeneous because the disturbances are also homogeneous (Danneyrolles *et al*, 2018, 2021). Alterations to habitats can also change the composition or species richness of the communities they house and therefore the representativeness of certain functional traits of these plants, which can lead to a change in the functioning of the system (Wei *et al*, 2021).

Part of the Clay Belt, the Abitibian plains are on clay soils found in western Québec and are dominated by human altered forests (Lafond & Ladouceur, 1968; Valeria *et al*, 2008; Danneyrolles *et al*, 2018). The clay layer was deposited by proglacial Lake Ojibway, which was established after the Last Glacial Maximum (Coleman, 1909; Vincent & Hardy, 1977; Veillette, 1994). The Abitibi region is also part of the Abitibi Greenstone Belt with bedrock underlying the clay that is mostly mafic and ultramafic (Monecke *et al*, 2017). Although the Abitibi landscape is dominated by clay soils and may appear homogeneous, other types of soil deposits exist such as sand, rock or till. Such variations in surface deposits may influence the vegetation at the stand level (Légaré *et al*, 2001). A second element that brings variation to the region are the scattered topographic elements represented by rocky hills of 550 m and less stand out from the relatively flat and homogeneous plain (280-310 m). These hills, outcrops of the Canadian Shield, are known to house rare plant species at the regional scale and have a different climate than the one found in plains (Martineau and Gervais 2014; Ambec et al. under review). In addition, they seem to be climate and fire refugia in certain rugged places (Larocque et al. 2003; Ambec et al. under review). However, no studies have compared the communities of these rare old-growth hills forests to other regional forest types.

Rare habitats result from the geochemistry, history, or topography of the environment with regards to the regional landscape (Holdaway *et al*, 2012; Cartwright, 2019). They can be defined as either small scattered systems (up to a few hundred hectares like salt meadows, limestone and other rocky outcrops, etc.), or larger systems that are geographically restricted (volcanic plateau, estuary). In both cases, the system covers a small amount of the studied territory (Williams *et al*, 2007; Cartwright, 2019). These rare habitats, because of their uniqueness, always contribute to landscape heterogeneity, which is important, since landscape heterogeneity is a vector of biodiversity as it increases the range of habitats and environmental conditions found on the territory (Heikkinen & Neuvonen, 1997; Pollock *et al*, 1998; Gould, 2000; Kark, 2007). However, some areas on Earth have more heterogeneous landscapes than others. For example, geologically rich areas like coastal zones (Zamrsky *et al*, 2020) or highly disturbed areas such as volcanic fields (Del Moral & Grishin, 1999; Walker, 2012) create a denser mosaic of habitat heterogeneity than systems encountering a high climate stability and surficial deposit homogeneity (Newnham, 1992; Larocque *et al*, 2003).

The main objective of this study is to determine whether old-growth forests on both hills and plains house a different floristic diversity than the forests in the rest of the region, and to determine why they differ, via the study of bryophytes and vascular plants. To do so, we used our pre-existing research and governmental databases for bryophytes and vascular plants in forests ranging from 30 to over 100 years old in plains, and old-growth forests on hills. We hypothesised that (1) old-growth forest hill communities will differ from plains old-growth forest communities because of the difference in climate, soils and the small areas where the perturbations can occur on hills, but that (2) old-growth plains communities will also differ from younger plains forest age categories, as old forests have different microclimate and light conditions associated with late successional species. Our study aims to better discriminate and enhance biodiversity contrasts in the boreal realm.

3.4 Material and methods

3.4.1 Study area

The study was conducted in the Abitibi region and in the southern part of the Eeyou Istchee James Bay Territory, eastern Canada (Figure 3.1). Forests are mostly dominated by black spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburgh), balsam fir (*Abies balsamea* (Linnaeus) Miller), trembling aspen (*Populus tremuloides* Michaux), white birch (*Betula papyrifera* Marshall) and jack pine (*Pinus banksiana* Lambert). Natural fires are the most frequent natural disturbance and the fire-cycle for the 1920-2002 period was over 300 years (Bergeron *et al*, 2003). The mean temperature in winter was -11.88°C (November to March) and in summer was 9.89°C (April to October) with an annual mean of 0.8°C, measured at the closest weather station to the centre of the study area (Lac-Berry WGS 84: 48.720131, -78.228632) during the 1981-2010 period. Annually, there is 670.4 mm of rain and 212.5 cm of snow (Environment Canada, 2021).

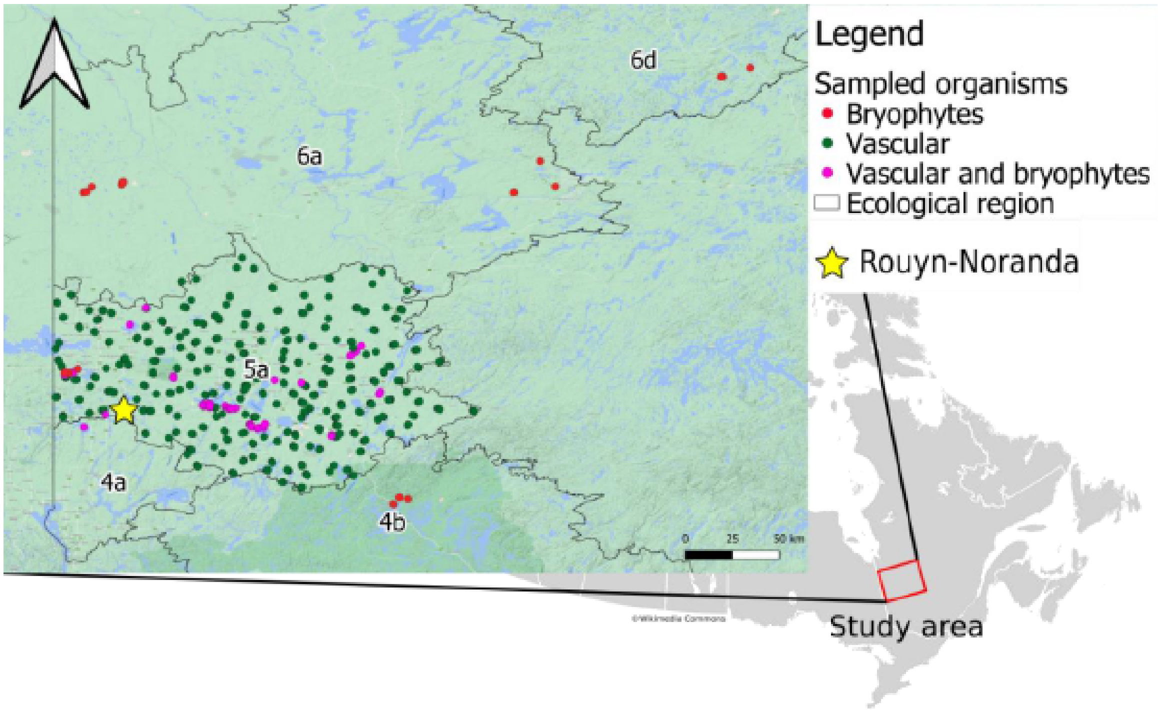

Figure 3.1: Map of the location of the study area. The study area map itself shows the distribution of sampled sites and their contents: either vascular plants, bryophytes or both.

3.4.2 Datasets: origin of the data

Forest stands older than 30 years old were selected for this study as they are more likely than younger stands to have a forest-like structure with trees taller than 15 m. All forest stands over 30 years in age, the age of the stand, surface deposit and the stand type data were extracted from Québec's fifth ecoforestry inventory. Due to the lack of bryophyte plots, 11 outlier plots in Eeyou Istchee James Bay where also selected for the study and the information about their stand's age was extracted from the fourth ecoforestry inventory.

Data for vascular plants and bryophytes came from our lab (Barbé *et al*, 2017; Yin *et al*, 2022; Noualhaguet *et al*, 2023) or from the government databases and were sampled following two different methods depending on data origin. 723 sites with only vascular plant data came from governmental ecological observation points for the Abitibi region, sampled with a single 400 m^2 plot in each site (Saucier *et al*, 1994). In addition, 88 sites with bryophytes, and sometimes vascular plant data, came from our lab and followed another sampling protocol. In each studied forest stand we randomly placed three 5 x 10 m plots (50 m^2) following the protocol of Barbé et al. (2017). Each plot was located at least 50 m from each other within the forest stand.

Bryophytes were systematically collected from all substrates in each plot for further identification in the laboratory. The substrates were classified as: bases of broadleaved and coniferous trees, rocks, coarse woody debris, and snags. All vascular plants present in each plot were determined to species level during fieldwork or during a subsequent laboratory identification. Species nomenclature follows Bryoquel (Société québécoise de bryologie, 2021) for bryophytes and Canadensys for vascular plants (Canadensys, 2021).

3.4.3 Data processing

3.4.3.1 Stand age, surface deposits and stand type

We cross-referenced the information from the ecoforestry maps (Berger *et al*, 2015) and our databases to obtain forest age, surface deposit and stand type in a single table using QGIS 3.24.1 (QGIS Association, 2022). Forests were classified into four age categories: 30-50, 50-70, 70-90 and more than 100 years old (>100). >100 years forest age category refers to the old-growth forests found on the plains. “Hill” stands were old-growth forest plots sampled on the top of 10 Abitibian hills. Stands with imprecise information on forest age were removed from the dataset to keep the most accurate data possible. Such requirements resulted in the removal of 484 governmental sites out of the 1265 found in Abitibi, as well as around 70 sites out of the 188 from our lab’s data (Appendice C; Appendice D).

We suspected the surface deposits to be an important co-variable influencing vegetation composition as the type of surface deposit has been found to have a significant effect on the composition of plant communities (Légaré *et al*, 2001). The surface deposit type represents the layer of loose material that overlies bedrock or outcrops at the surface. Consequently, surface deposit influences the vegetation that overlies it (Belleau *et al*, 2011) by modifying drainage and permeability (Gleeson *et al*, 2011) or nutrient availability (Kübler *et al*, 2021). Surface deposit types were grouped under the term “Till” for the various till categories or under “Rock” for rock and moraines. We used six categories of surface deposits: dune, juxtaglacial, glaciolacustrine, till, rock, or organic. Dune surface deposits consist of sand which shows a high drainage capacity. The juxtaglacial deposits sometimes exceed 40 m in thickness in sub horizontal stratification with various grain sizes ranging from sand to decimetre blocks, while glaciolacustrine deposits are general fine textured and layered because of their deposition at the bottom of the lake, and till deposits have a variety of textures and are not sorted. These variations in sorting of material create differences in permeability and drainage. Finally, the surficial deposit “rocks” are generally exposed bedrock (Canadian Shield) without topsoil, and organic deposits consist of more than 40 cm of organic matter, which contains available nutrients essential for plant growth (Appendice E). However, given the low number of rock and juxtaglacial replicates in the bryophyte datasets, we have chosen to sub-group them under the term 'till' in the bryophyte dataset, as these surface deposits have a high drainage capacity.

We also suspected that stand type, the tree composition of the stand, may have an effect on plant communities since, for example, it can change the carbon storage in the soil and the litter composition (Hart & Chen, 2006; Cavard *et al*, 2010). Stand type was the synthesis of the dominance in broadleaved or coniferous trees at the stand scale, determined using codes describing the most abundant tree species in the stand in the ecoforestry maps. The stand type was described as "broadleaf" if it contained only broadleaved trees as dominant species and as "coniferous" if it contained only coniferous trees as dominant species. A dominant species is a species which account for the highest percentage of cover in the studied stand. The stand type was described as a mixed but with broadleaved trees dominant over coniferous ("BroadConif") if the most abundant tree species was a broadleaved one but not the second or the third. The opposite was also true: when the most abundant tree species was a coniferous but the second or the third ("ConifBroad") (Appendice E). However, due to the low number of non-conifer replicates in the bryophyte datasets, we chose to sub-group them under the term 'other' in the bryophyte dataset, as we were not able to process them properly.

3.4.3.2 Species richness and composition

Total species richness was calculated for both vascular and bryophyte species as the total number of species present in a site, by pooling the three 5 x 10 m plots when the data came from our lab. This structure of data eliminates the need for mixed models. With the aim to try to better discriminate both forest age categories, we also chose to look at exclusive species richness by determining which species were found in only a single forest age category (i.e. 30-50, 50-70, 70-90, >100 or hill). Each species found only in one single category was then declared exclusive to it.

We also chose to compare mosses, liverworts and sphagna abundance among the whole dataset in each forest age category since liverworts may be more abundant in old-growth forests (Fenton & Bergeron, 2008). The same comparison was made between herbaceous, shrubs and trees for vascular plants to determine if there is a difference in lifeforms abundance between forest age categories. The category "herbaceous" included pteridophytes and clubmosses as a non-lignified lifeform for any analysis based on lifeforms.

Since the data came from different sources, identifications to the species level of *Salix* and *Carex* were not always disponible. Because there are numerous *Carex* species in a wide range of ecological conditions, *Carex* were removed from the analyses. We kept *Salix* genus for all *Salix* species since it is found in young stands and forest gaps in the studied habitats.

3.4.3.3 Ecological preferences

We wanted to know which parameters out of forest age, surface deposits of stand type may significantly influence the value of each ecological preferences even if the species were selected per forest age categories (Tobner *et al*, 2016). We selected light, moisture, or pH indicator values as they are important environmental variables for plants. Next, we selected a combination of the 15 most indicative and abundant bryophytes and herbaceous plants by forest age category following statistical analyses that we will detail in the next section. We took as many indicative species as possible for each category but also included the most abundant species to reach 15 species. Herbaceous species, as opposed to shrubs and trees, were selected because, similarly to bryophytes, they develop close to the ground and may respond faster to perturbations than trees and shrubs.

Values of Ellenberg's indices of light, moisture, and pH in our selected bryophyte species came from BRYOATT (Hill, 2007). To stay consistent with the bryophyte's functional traits, we choose to look at light and moisture requirements for the selected herbaceous vascular plants in the TOPIC database (Aubin *et al*, 2017) but pH requirements were not available in the literature. Moisture requirements ranged from humid to xeric-mesic in 6 categories, so we decided to start from a value of 6 for humid and decreasingly down to 1 for xeric-mesic category. Light requirements ranged from shade intolerant to shade tolerant in 3 categories, so we decided to start from a value of 3 for shade intolerant (more light) and decreasingly down to 1 for shade tolerant category.

3.4.4 Statistical analysis

Statistical analyses were based on presence-absence data. Richness and composition analyses were performed either at the gamma diversity scale for the whole study area, or at the scale of one forest age category (N = 5). The data as well as figures were processed using R version 4.0.3 (R Core Team, 2020).

3.4.4.1 Richness

Mean total and mean exclusive species richness were compared between forest age categories, surface deposits, type of stands and their interaction using three factor Analyses of variance (ANOVA) with "forest_age*surface_deposit*stand_type". Finally we built boxplots with the functions ggplot and geom_boxplot in the ggplot2 package (Wickham, 2016). If an interaction between two parameters was detected by the ANOVA, we made a faceted boxplot based on one of these parameters using the function facet_wrap in our ggplot. We illustrated the boxplots showing values in every forest age, surface deposit, or stand type categories to see a potential interaction between parameters.

3.4.4.2 Composition

To check if the richness of each lifeform varied significantly among either the forest age categories, surface deposit types, stand type or a combination of them, we performed three factor ANOVAs with "forest_age*surface_deposit*stand_type" followed by Tukey HSD post-hoc tests. Finally we built boxplots with the functions ggplot and geom_boxplot in the ggplot2 package (Wickham, 2016). If an interaction between two parameters was detected by the ANOVA, we made a faceted boxplot based on one of these parameters using the function facet_wrap in our ggplot. If a triple interaction occurred, we made the same with the three possible two-way interactions. We illustrated the boxplots showing values in every forest age, surface deposit, or stand type categories to see a potential interaction between parameters.

To determine indicator species for both bryophytes and vascular plants datasets per each forest age category, we performed a matrix analysis seeking for them with the function multipatt in the indicspecies package (De Cáceres *et al*, 2011). We then only kept the selected species, with a p-value < 0.05, and created a heatmap showing their statistical values with the function heatmaply in the heatmaply package (Galili *et al*, 2018).

To check if the number of bryophyte and vascular plant indicator species per forest age category varied significantly among either the forest age categories, surface deposit types, stand type or a combination of them, we performed a three factors ANOVAs with “forest_age*surface_deposit*stand_type”.

To determine if the assemblages of bryophytes and vascular plant species varied significantly among either the forest age categories, surface deposit types, stand type or a combination of them, we performed a Permutational multivariate analysis of variance (PERMANOVA). PERMANOVAs were performed with the function adonis2 in the vegan package (Oksanen *et al*, 2017), with our species matrix in function of “forest_age*surface_deposit*stand_type”. PERMANOVAs were based on the Bray-Curtis distance specifying that we are working on binary data (permutations = 999). As all quadrats in each forest age category were pooled, no random variables were included.

To represent the variability of the plant assemblages in the 760 studied sites, we performed a Non-Metric Multidimensional Scaling (NMDS). The NMDS were built with the function metaMDS in the vegan package (Oksanen *et al*, 2017) using the Bray-Curtis distance. We then proceeded to add the ellipses of their 95% confidence interval on the NMDS based on our previous PERMANOVAs to represent the significant effect of forest age category, surface deposit or stand type on bryophytes or vascular plants.

3.4.4.3 Ecological preferences

The database containing only forest age category indicator species for the totality of the bryophyte or vascular plant plots allowed a light, moisture, or pH value to be assigned to the presence of a species. Thus, we were able to calculate an average of each functional trait by excluding zero values to have an average value of each functional trait for each plot studied. Each functional trait value was then compared between forest age categories, surface deposits, type of stand and their interaction using three factors ANOVAs with "forest_age*surface_deposit*stand_type" followed by Tukey HSD post-hoc tests. Finally we built boxplots with the functions ggplot and geom_boxplot in the ggplot2 package (Wickham, 2016). If an interaction between two parameters was detected by the ANOVA, we made a faceted boxplot based on one of these parameters using the function facet_wrap in our ggplot. If a triple interaction occurred, we made the same with the three possible two-way interactions. We illustrated the boxplots showing values in every forest age, surface deposit, or stand type categories to see a potential interaction between parameters.

3.5 Results

3.5.1 Bryophyte species richness and composition

In this study we worked on a total gamma diversity of 211 bryophyte species across all forest age categories. Species richness was particularly low in 50-70 years forests compared to other habitats with a total of 37 species compared to more than 110 for every other age category. Indeed, 117 species were found in 30-50 years forest, 123 in 70-90 years forest, 125 in hills old-growth forests and 149 in >100 years forests. Similarly, mean species richness (Figure 3.2) differed significantly among forest age categories and in interaction with surface deposit type (Table 3.1). Hill and >100 old-growth forests had the highest mean richness in association on glaciolacustrine or till deposits. On till, the highest richness was found in hill and plains old-growth forests, then in all other forest age categories. On the other hand, moss richness was significantly influenced by the interactions between surface deposits and forest age.

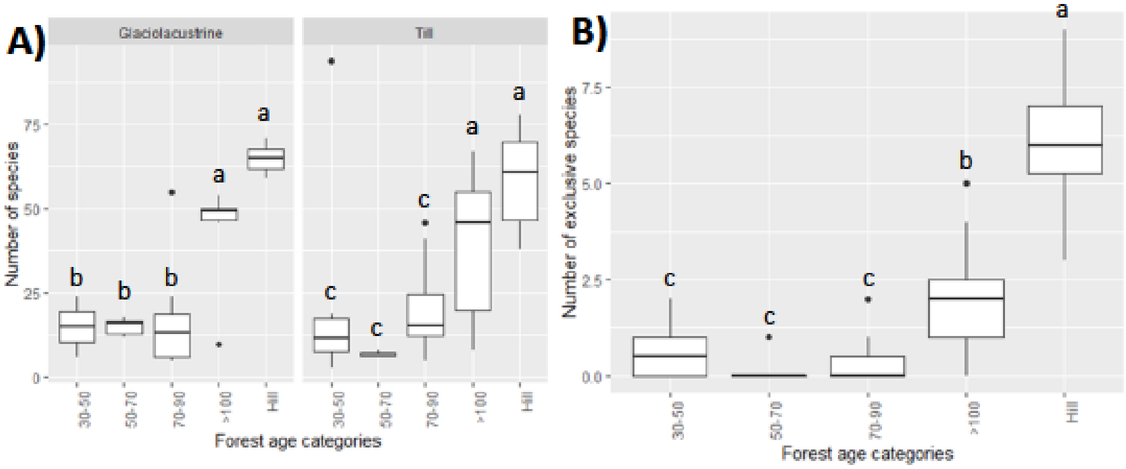

Figure 3.2: Boxplots showing (A) the mean bryophytes species richness for each forest age category on the two dominant surface deposit types; (B) the mean exclusive bryophytes species richness per age category. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

Table 3.1: ANOVA results for the bryophytes total richness

Parameters and interactions	F-value	p-value
N = 89		
Forest age	19.91	<0.001
Surface deposits	0.34	NS
Stand type	2.66	NS
Forest age*surface deposits	3.45	<0.008
Forest age*type of stand	1.23	NS
Surface deposits*type of stand	1.53	NS
Forest age*surface deposits*type of stand	2.23	NS

Indeed, moss richness was the highest in >100 and hill old-growth forest on glaciolacustrine deposits but only in hill old-growth forests on till (Figure 3.3; Table 3.2). Tukey tests did not reveal any other pairwise differences. Liverwort richness differed significantly among forest age categories. Indeed, the liverwort richness was the highest in hill old-growth forests, then >100 old-growth forests then the other younger categories (Figure 3.3; Table 3.3). Sphagna richness differed significantly among forest age, surface deposits and type of stand categories and the interaction between forest age and type of stand. Despite a significant effect of the stand type, we found no significant differences between sphagna richness in the four stand types in post-hoc tests. On another hand, sphagna richness was the highest in >100 years old forests, and on organic surface deposits (Figure 3.3; Table 3.4).

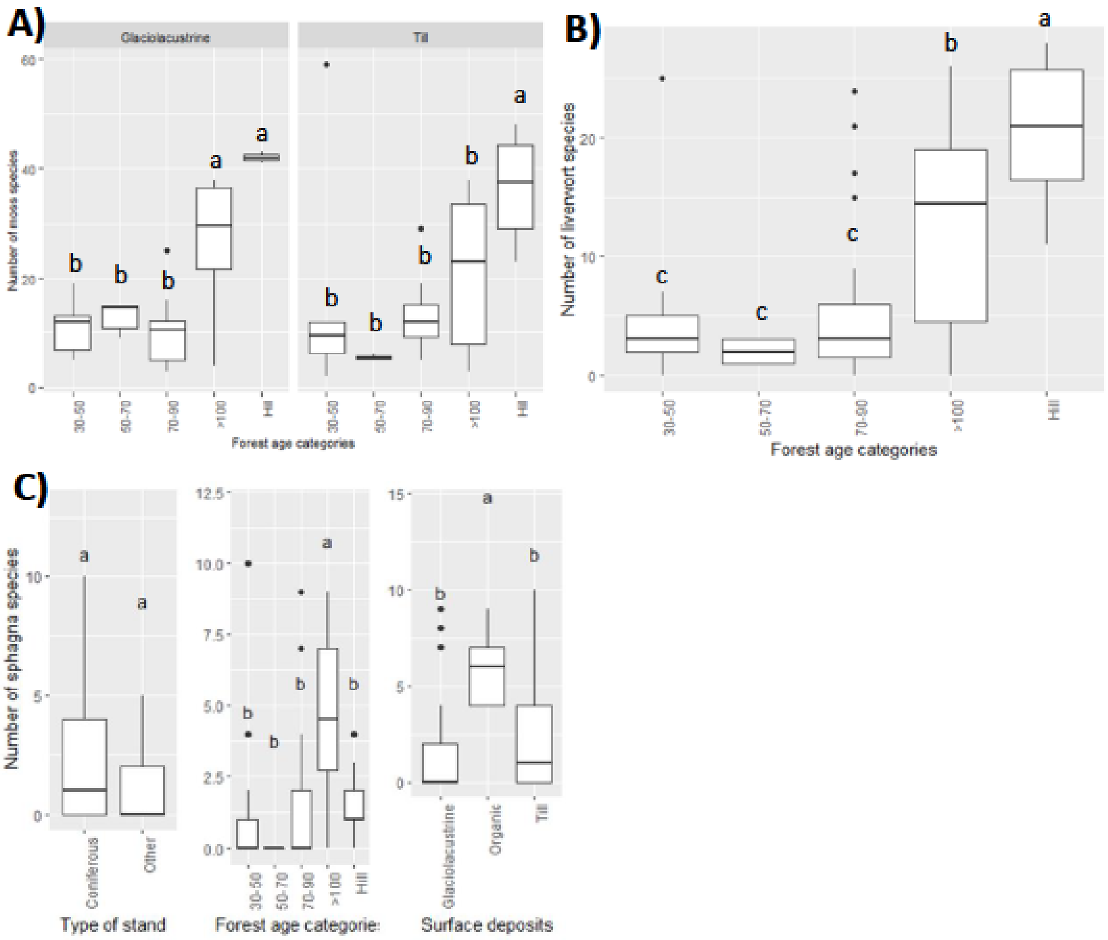

Figure 3.3: Boxplots showing (A) the average moss species richness for each forest age category on the shared surface deposits; (B) the average liverwort species richness for each forest age category on the shared surface deposit types; (C) the average sphagna species richness for each stand type then for each forest age category and then each surface deposit types. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD

Table 3.2: ANOVA results for moss species richness

Parameters and interactions	F-value	p-value
N = 89		
Forest age	16.77	<0.001
Surface deposits	0.22	NS
Stand type	0.41	NS
Forest age*surface deposits	4.86	<0.001
Forest age*type of stand	2.47	NS
Surface deposits*type of stand	0.69	NS
Forest age*surface deposits*type of stand	1.93	NS

Table 3.3: ANOVA results for liverwort species richness

Parameters and interactions	F-value	p-value
N = 89		
Forest age	17.76	<0.001
Surface deposits	0.56	NS
Stand type	1.57	NS
Forest age*surface deposits	1.89	NS
Forest age*type of stand	0.21	NS
Surface deposits*type of stand	0.02	NS
Forest age*surface deposits*type of stand	0.04	NS

Table 3.4: ANOVA results for sphagna species richness

Parameters and interactions	F-value	p-value
N = 89		
Forest age	14.42	<0.001
Surface deposits	4.77	<0.02
Stand type	13.23	<0.001
Forest age*surface deposits	1.27	NS
Forest age*type of stand	3.4	<0.03
Surface deposits*type of stand	0.35	NS
Forest age*surface deposits*type of stand	1.58	NS

Of the 211 studied bryophytes species, 63 were found exclusively in one forest age category. There were approximately twice as many exclusive species in hill old-growth forests (22 species) and >100 forests (21 species) than in 30-50 years forest (11 species) and 70-90 (8 species) years forests, while 50-70 years forests only sheltered one exclusive species which was *Tortella humilis* (Hedw.) Jenn. at only one site. The mean number of exclusive species per replicate differed significantly among forest age categories (ANOVA: F = 72.61; p-value < 0.001) (Figure 3.2; Appendice F). The frequency of occurrence of each exclusive species for a forest age category varied considerably. Individual exclusive species occurred more frequently in old-growth forests while 30-50, 50-70 and 70-90 years forests sheltered only one replicate of each of their exclusive species.

The heatmap representing the indicator bryophyte species illustrates similar results as both old-growth forests and >100 years forests had a lot of indicator species while almost no indicator species were found for the other forest age (Figure 3.4). There were 23 liverworts species among the 55 hills old-growth indicator species with *Sphenolobus minutus* and *Marsupella emarginata* (Ehrh.) Dumort. Var. *emarginata* in the five highest indicator species, along with *Brachythecium plumosum*, *Pylaisia selwynii* Kindb. And *Brachythecium acuminatum* (Hedw.) Austin. The 23 >100 years forests indicator species have much lower statistical values than hills ones, the highest being

indicator species have much lower statistical values than hills ones, the highest being

0.737 for *Sphagnum russowii* Warnst., which is below the ten first statistical values of hills old-growth indicator species. However, it is still much more than the only 50-70 years forests indicator species, *Sciuro-hypnum oedipodium* (Mitten) Ignatov & Huttunen (statistical value: 0.403) and the lack of indicator species for the other categories. The ANOVA found that such indicator species were significantly influenced by stand type (ANOVA: F = 11.08; p-value = 0.001) in addition with the forest age category (ANOVA: F = 3.58; p-value = 0.01) (Appendice G).

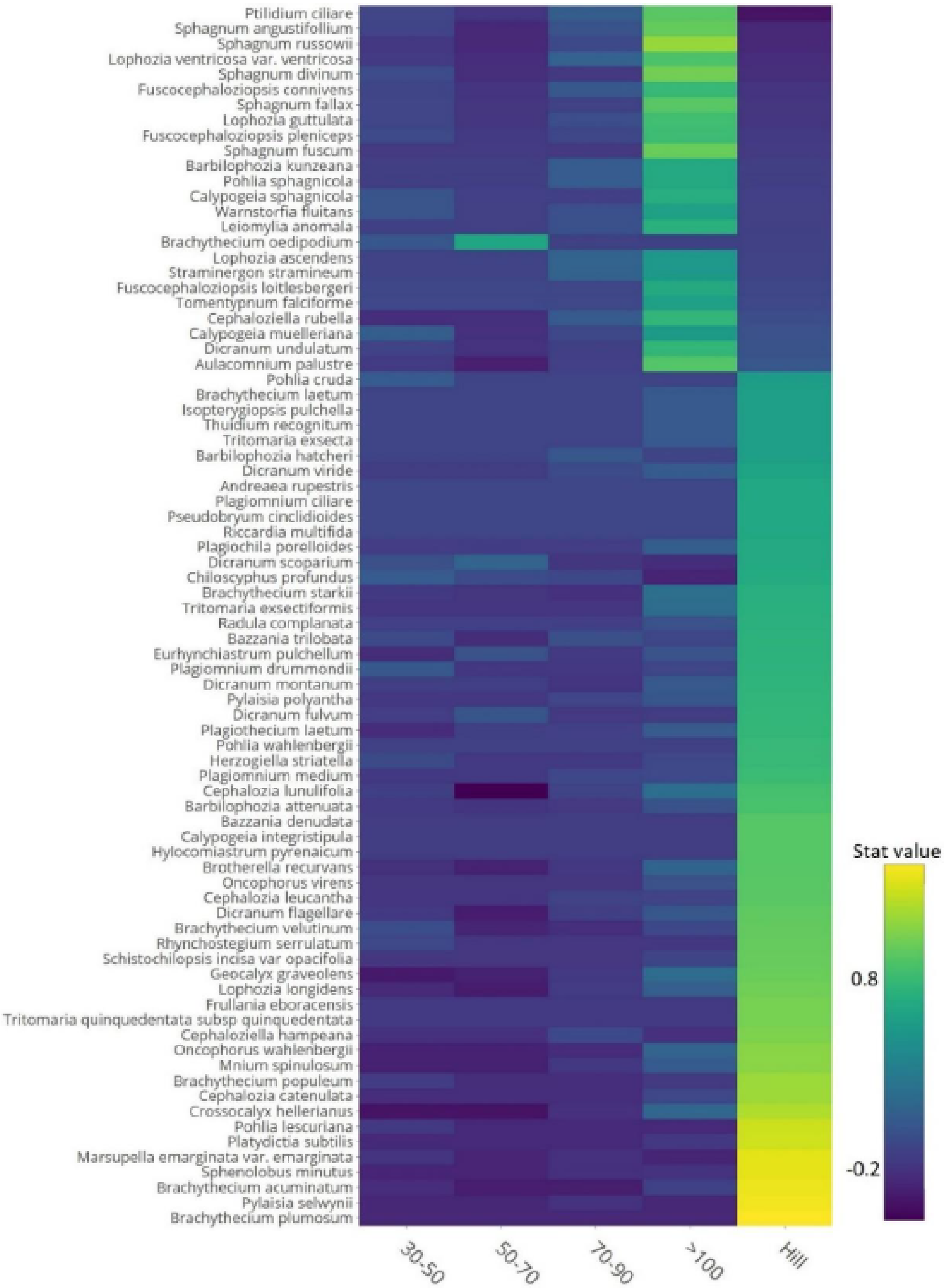

Figure 3.4: Heatmap representing the significative bryophyte indicator species and the forest age categories they are associated with. Colour legend indicates the statistical value associated between the forest age category and the species.

Different bryophyte communities are found within forest age categories (PERMANOVA: $R^2 = 0.27$; p-value = 0.001) and the interaction between forest age categories and stand types (PERMANOVA: $R^2 = 0.04$; p-value < 0.03). According to the NMDS analysis, bryophyte communities found in the 30-50, 50-70 and 70-90 years forest categories were globally distinct from the other categories, even if 30-50 and 70-90 years forests are a bit more scattered than 50-70 years forests (Figure 3.5). Hill old-growth forests are the most distinct and clustered together communities, even if they overlap with some >100 years forests, which are also globally distinct along the NMDS2 axis (Figure 3.5). For stand type, it appears that conifers and other stand types do not have distinct communities as they are all mixed together (Figure 3.5).

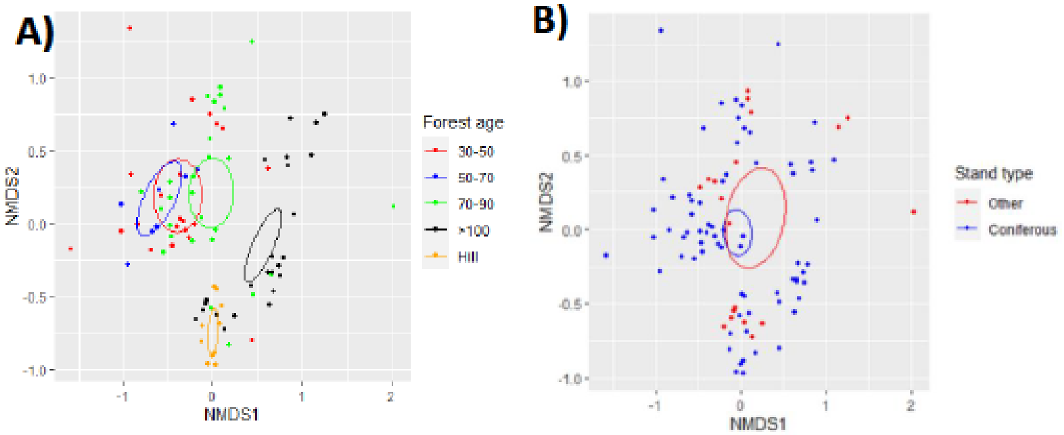

Figure 3.5: Two-dimensional NMDS with a stress value of 0.14 using the Bray-Curtis distance between replicate sites of bryophyte assemblages according to (A) forest age categories and (B) stand type categories. The ellipses represent the standard error for either forest age or stand type category.

3.5.2 Vascular plant species richness and composition

The total gamma diversity for vascular plants reached 190 species across all forest age categories. Species richness was particularly low in hills old-growth forests compared to other habitats with a total of only 58 species compared to more than 90 for every other age category. Indeed, 92 species were found in >100, 120 in 70-90, 155 in 50-70 and 167 in 30-50 years forests. Similarly, mean species richness (Figure 3.6) differed significantly among forest age categories (ANOVA: $F = 3.748$; p-value = 0.005) and stand types (ANOVA: $F = 3.06$; p-value = 0.03) but not between surface deposits or any interaction between these parameters (Appendice H). >100 and coniferous forests had the lowest mean richness followed by hills old-growth forests, 70-90 years forest age category and broadleaf and conifbroad then all the other categories. Also, the mean number of tree (Appendice I) and shrub (Appendice J) species differed significantly among forest age categories (ANOVA: $F > 5$; p-value < 0.005) whereas stand type was the only parameter significantly influencing the herbaceous (Appendice K) mean richness (ANOVA: $F = 3$; p-value = 0.03) (Figure 3.7). In addition, the mean number of tree species differed significantly among surface deposit categories (ANOVA: $F = 3$; p-value = 0.03) although Tukey HSD tests did not confirm it. The mean number of shrub and tree species was the highest in 30-50 and 50-70 forest age categories (ANOVA: $F > 5.09$; p-value < 0.001) with hills old-growth forests having the same mean number of tree species. The 70-90 years forest age category had the second highest number of shrub and trees species. >100 forest age category always had the lower richness for trees, together with hills old-growth forest for shrubs richness (Figure 3.7).

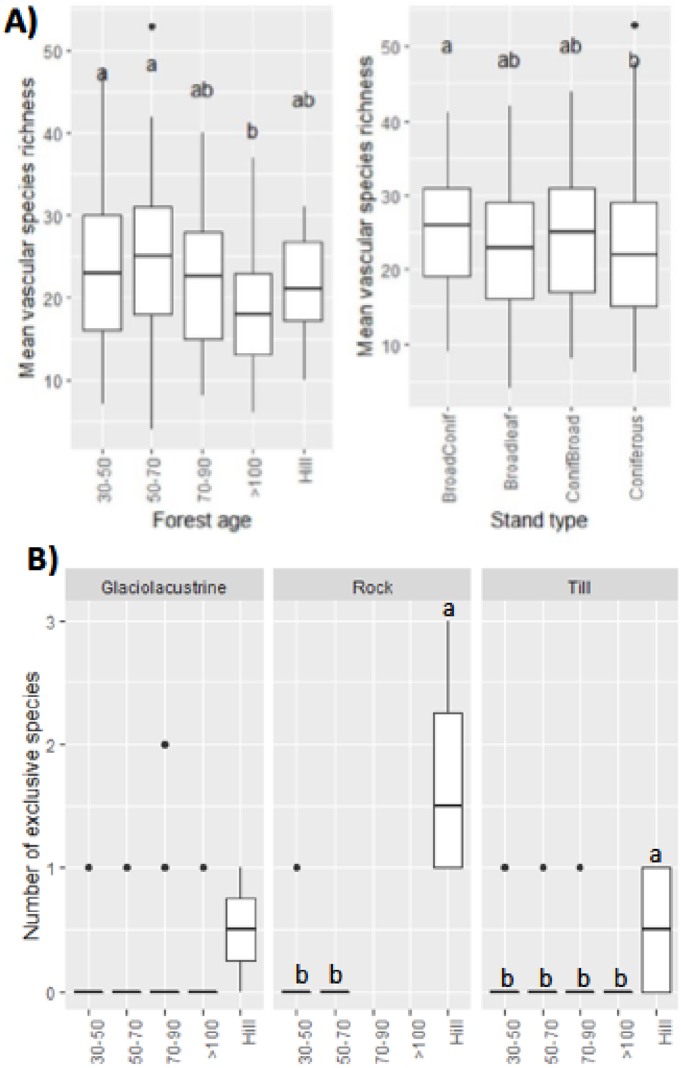

Figure 3.6: Boxplots showing (A) the mean vascular plant species richness for each forest age category and stand type; (B) the mean exclusive vascular plant richness for each forest age category and the shared surface deposit types. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD. No letters meaning there are no differences.

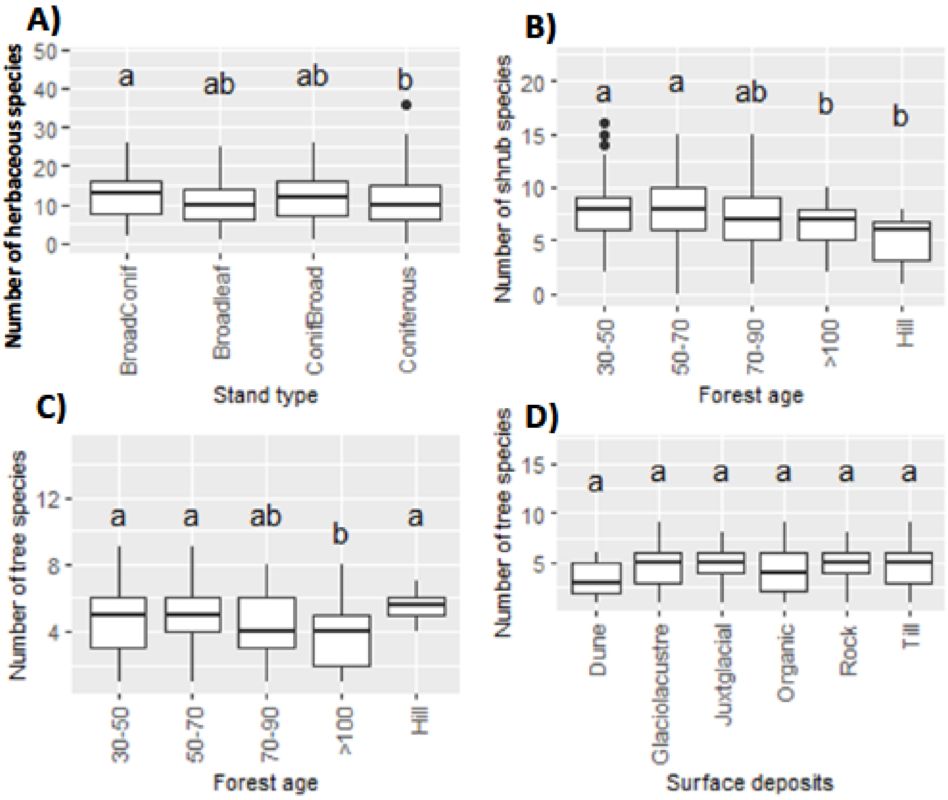

Figure 3.7: Boxplots showing (A) the mean herbaceous richness for stand type; (B) the mean shrub richness for each forest age category; (C) the mean tree richness for each forest age category; (D) the mean tree richness for each surface deposit. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

Of the 190 studied species, 43 were exclusive to a forest age category. There was almost a total of twice as many exclusive species in 30-50 forests (22 species) than 50-70 ones (12 species), followed by almost a third of the last value in hill old-growth forests (5 species) and 70-90 ones (4 species). Finally, there was only one mention of *Aralia hispida* Ventenat in >100 forests. The mean number of exclusive species per replicate differed significantly among forest age categories (ANOVA: F = 25.46; p-value < 0.001) and their interaction with surface deposits (ANOVA: F = 4.25; p-value < 0.001) (Appendice L). Indeed, hill old-growth forests had the highest number of exclusive vascular plant species on glaciolacustrine and till deposits followed by >100 years old-growth forests on till deposits only (Figure 3.6). On the other hand, the frequency of occurrence of each exclusive species for a forest age category varied considerably. Individual exclusive species occurred more frequently in 30-50 forests, followed by 50-70 and 70-90 forests while, as said before, >100 forests sheltered only one replicate of one exclusive species: *Aralia hispida*.

The heatmap representing the indicator species separates hill and >100 old-growth forests with many indicator species while other forest age communities do not include such indicator species (Figure 3.8). There were 17 hills old-growth indicator species with *Thuja occidentalis* Linnaeus, *Gymnocarpium dryopteris*, *Dendrolycopodium dendroideum*, *Taxus canadensis* Marshall and *Phegopteris connectilis* (Michaux) Watt in the five highest indicator species. Again, the five >100 forests indicator species have much lower statistical values than hills ones, the highest being 0.321 for *Maianthemum trifolium* (Linnaeus) Sloboda which is below the eight first statistical values of hills old-growth indicator species. However, it is still much more than the only 70-90 forests indicator species, *Neottia cordata* (statistical value: 0.142) and the lack of indicator species for the other categories. The ANOVA found that this indicator species abundance was in fact significantly influenced by stand type and surface deposit but not the forest age category (Table 3.5).

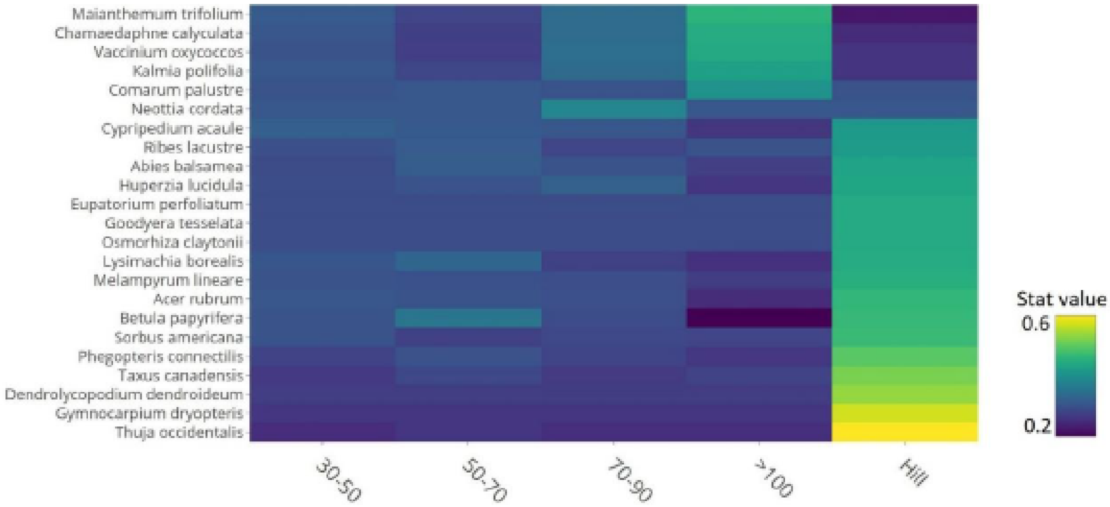

Figure 3.8: Heatmap representing the significative vascular plant indicator species and the forest age categories they are associated with. Colour legend indicates the statistical value associated between the forest age category and the species.

Table 3.5: ANOVA results for vascular plant indicator species richness

Parameters and interactions	F-value	p-value
N = 740		
Forest age	1.56	NS
Surface deposits	2.76	0.02
Stand type	2.89	0.04
Forest age*surface deposits	0.88	NS
Forest age*type of stand	1.14	NS
Surface deposits*type of stand	1.1	NS
Forest age*surface deposits*type of stand	0.75	NS

Different vascular plant communities are found within forest age categories (PERMANOVA: $R^2 = 0.02$; p-value = 0.001), stand types (PERMANOVA: $R^2 = 0.01$; p-value = 0.005) and surface deposits (PERMANOVA: $R^2 = 0.01$; p-value = 0.002). In another hand, the interaction between forest age categories, stand types or surface deposits did not significantly affect the distance between vascular plant communities. However, the NMDS analyses show that such differences are impossible to spot among the produced cloud of points for each variable (Figure 3.9).

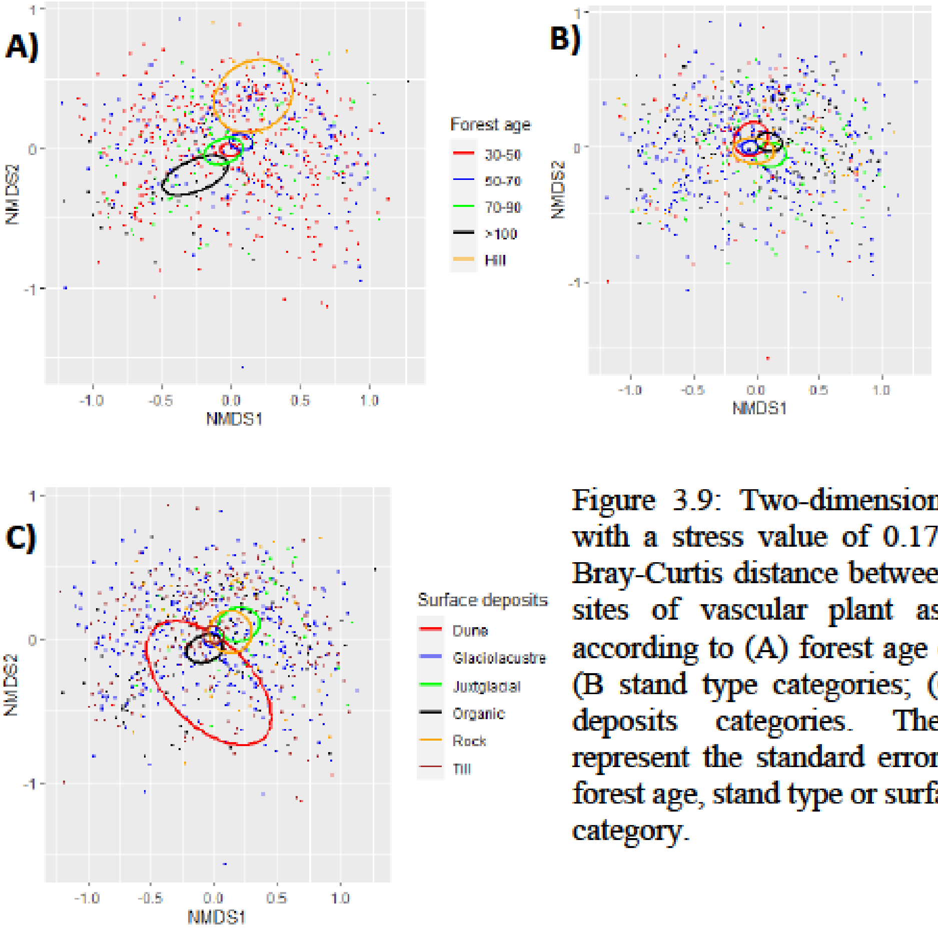

Figure 3.9: Two-dimensional NMDS with a stress value of 0.17 using the Bray-Curtis distance between replicate sites of vascular plant assemblages according to (A) forest age categories; (B stand type categories; (C) surface deposits categories. The ellipses represent the standard error for either forest age, stand type or surface deposit category.

Table 3.6: ANOVA results for the light values in bryophyte indicator species.

Parameters and interactions	F-value	p-value
N = 89		
Forest age	47.85	<0.001
Stand type	2.99	NS
Surface deposits	2.12	NS
Forest age*type of stand	2.8	<0.05
Forest age*surface deposits	0.49	NS
Surface deposits*type of stand	0.43	NS
Forest age*surface deposits*type of stand	0.14	NS

3.5.3 Ecological preferences

3.5.3.1 Bryophytes

The mean Ellenberg light index values were significantly influenced by the interaction between forest age and stand type (Table 3.6). Mean Ellenberg light index values were the highest in the >100 forest age category and the lowest in the hill old-growth forests in coniferous stands while no significant differences were observed in other type of stands (Figure 3.10).

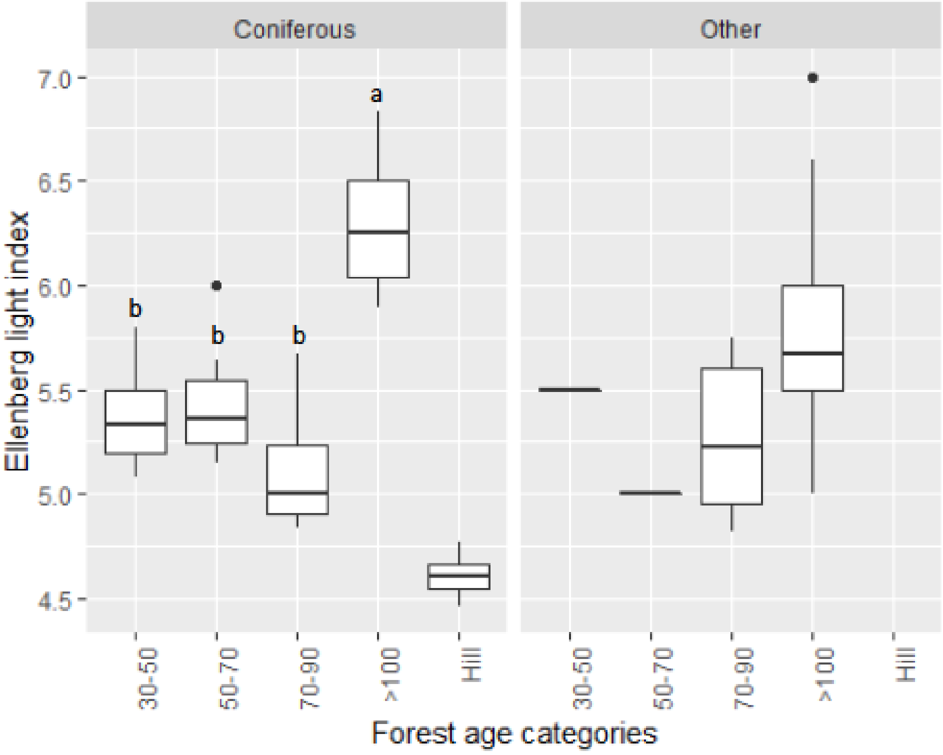

Figure 3.10: Boxplot showing the mean light Ellenberg index values in bryophyte indicator species for each forest age category in each stand type category. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD, no letters meaning no significant differences.

The mean Ellenberg moisture index values were significantly influenced by the forest age (Table 3.7). Mean Ellenberg moisture index values were always the highest in >100 and hill old-growth forests (Figure 3.11). The mean Ellenberg mean pH values were significantly different between forest age categories (ANOVA: F = 3.71; p-value < 0.009) (Appendice N) with a higher pH value in 30-50, 70-90 and >100 forest age categories (Figure 3.12).

Table 3.7: ANOVA results for the moisture values in bryophyte indicator species.

Parameters and interactions	F-value	p-value
N = 89		
Forest age	21.57	<0.001
Stand type	0.01	NS
Surface deposits	0.92	NS
Forest age*type of stand	1.89	NS
Forest age*surface deposits	0.25	NS
Surface deposits*type of stand	1.72	NS
Forest age*surface deposits*type of stand	1.36	NS

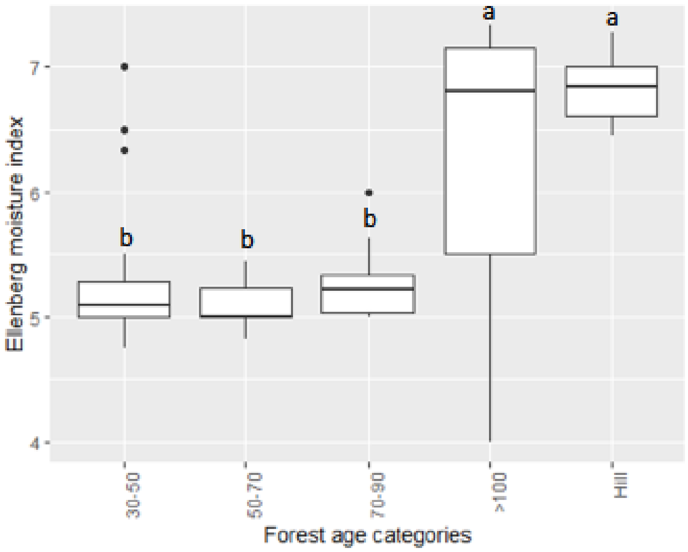

Figure 3.11: Boxplot showing the mean moisture Ellenberg index values in bryophyte indicator species for each forest age category. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

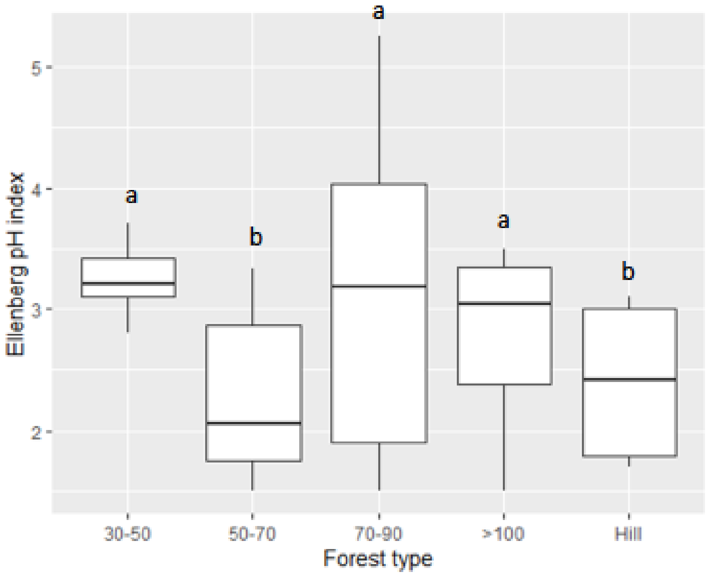

Figure 3.12: Boxplot showing the mean pH Ellenberg index values in bryophyte indicator species for each forest age category. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

3.5.3.2 Vascular plants

Mean light index values were significantly different between forest age categories (ANOVA: F = 11.71; p-value <0.001) and in the interaction between forest age and surface deposit categories (ANOVA: F = 1.87; p-value = 0.03) (Appendice O). When we look at the surface deposits where sites represented all forest age categories, we can see that >100 forest age category on organic and tills showed the highest light index values (Figure 3.13).

Mean moisture index values were significantly different between forest age categories (ANOVA: F = 9.41; p-value <0.001) and in the interaction between stand type and surface deposit categories (ANOVA: F = 2.27; p-value <0.005) (Appendice P). We can see that the highest moisture index was found in >100 years forest age category (Figure 3.14). When we look at the shared surface deposits in interaction with stand types we can see that coniferous and broadleaf forests had the lowest moisture index on rock and that coniferous dominated mixed forests (ConifBroad) show the highest moisture value on organic deposits.

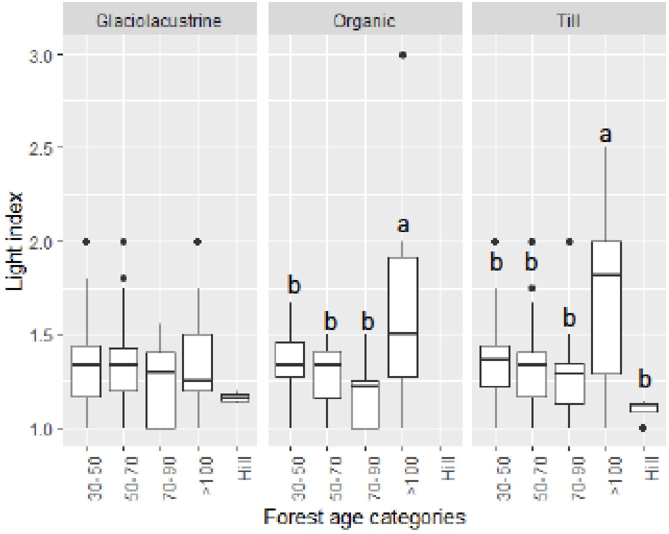

Figure 3.13: Boxplot showing the mean light index values in vascular plant indicator species for each forest age category and the shared surface deposit types. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD. No letters meaning there are no differences.

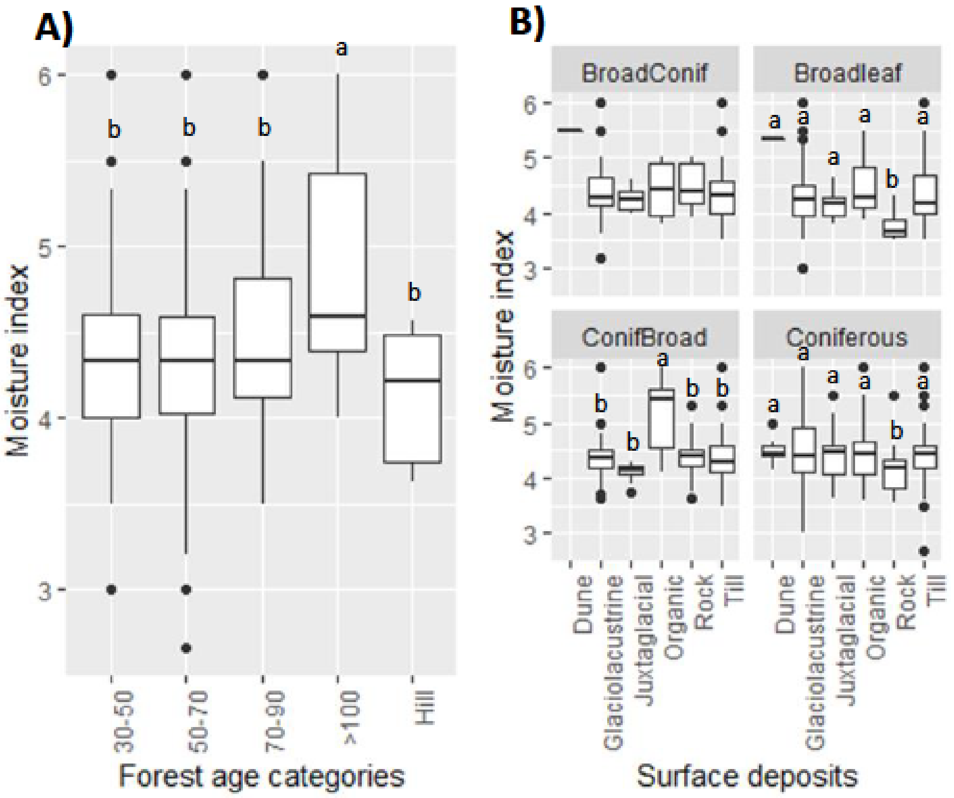

Figure 3.14: Boxplots showing the mean moisture index values in vascular plant indicator species for (A) each forest age category; (B) each surface deposits per stand types. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD. No letters meaning there are no differences.

3.6 Discussion

We wanted to know if old-growth forest bryophyte and vascular plant communities plants will differ from younger forests on the plains (30-50, 50-70 and 70-90 years) but also if hill and plains old-growth forest communities (>100 years) will differ. Although forest age category explained most of the variation in specific richness, composition and indicator species characteristics, stand type and surface deposit type had a minor impact on these plant communities, often in interaction with forest age.

Overall old growth forests had the highest total species richness of bryophytes and the lowest species richness of vascular plants. Plains and hill old growth forests also had many indicator species of bryophytes and vascular plants and housed a distinct plant community composition that distinguished them from each other but also from the more homogeneous categories of younger forests. We believe that working on the relative abundance of vascular plant species rather than presence-absence would have allowed us to detect more subtle differences, particularly in vascular plant communities. However, we found significant patterns using our presence-absence dataset.

3.6.1 Old-growth forests *versus* younger forests communities

Our first hypothesis dealt with the differences between old-growth forests in general and younger forests. Our two old-growth categories, hill and >100 years plain forests, showed a consistent higher total and exclusive bryophyte specific richness as well as higher moss and liverwort species richness regardless of the surface deposit or stand type. In contrast, old-growth forests only showed a lower total vascular plant specific richness and a lower herbaceous and shrub species richness than younger categories regardless of surface deposit or stand type. However, we only found indicator species within old-growth forests, both for bryophytes and vascular plants. The differences detected between old-growth forest communities and microclimatic values will be discussed later.

3.6.1.1 Specific richness

The higher specific richness of bryophytes in old-growth forests that we found is consistent with the literature (Cooper-Ellis, 1998; Fenton & Bergeron, 2008). In both old-growth categories, the heterogeneity created by snags and woody debris accumulated through time would indeed promote bryophyte species richness (Cole *et al*, 2008; Boudreault *et al*, 2018; Müller *et al*, 2019), especially via small habitat-dependent species (Fenton & Bergeron, 2008). Bryophytes are dependent on moisture (Vittoz *et al*, 2010) and the old forests we studied have higher moisture values than the young forests (based on Ellenberg moisture index values), which means that they represent a moist atmosphere favourable to bryophytes in contrast to the younger forest categories. Vascular plant richness, on the other hand, seemed to be promoted by younger stands.

Forests have a high potential species richness, but this richness ceases to accumulate over time (Hastings 1980; Hixon et al. 2002; Clark and McLachlan 2003, Ambec et al., Subm.), probably through interspecific stabilisation mechanisms (Clark *et al*, 2003; Clark & McLachlan, 2003; Kneitel & Chase, 2004). Indeed, vascular plants not dependent on old-growth habitats will migrate to less competitive neighbouring locations (Horn & MacArthur, 1972; Hastings, 1980; Tilman, 1994; Hixon *et al*, 2002) to find easier access to resources (Pacala & Rees, 1998; Bolker & Pacala, 1999). Their ability to find resources will determine their persistence in the system. The main feature in old-growth forests is that they experience secondary perturbations, such as tree fall (Martin, 2019), but not a reset of their old-growth communities (Shorohova *et al*, 2011). Under the theory of intermediate disturbance hypothesis (Bongers *et al*, 2009), a higher vascular plant specific richness will then be found in moderately disturbed habitats while only an opportunistic part of the assemblage will colonise an old-growth forest following a secondary disturbance and then disappear as the forest recovers, because these species behave in a pioneering manner. This means that vascular plant assemblages will be more diverse in younger forests, contributing to an increase in the average species richness of these young forests (Ambec *et al*, 2023). This is partly supported by the fact that the forests with the highest vascular plant richness are the deciduous-dominated mixed forests, whereas coniferous forests have the lowest. This pattern correlates with successional patterns as post-disturbance mixed forests in the boreal domain tend to be replaced by coniferous-dominated forests over time (Taylor & Chen, 2011).

3.6.1.2 Composition of plant communities

The composition of the plant communities reacted differently depending on the resolution at which they were considered, as the specific composition and the life form composition gave different results. In addition, the composition of bryophyte communities as a whole differed more between the categories of our explanatory variables than vascular plants. R^2 are extremely low in the processed PERMANOVAs ($R^2 < 0.05$), except for the forest age category on bryophyte communities' distance ($R^2 = 0.29$). This is consistent with the NMDS results (Figure 3.5; Figure 3.9) where no visually clear pattern appears in vascular plant communities for either forest age, surface deposit or stand type. Differences in vascular plant communities between forest age categories were easier to see when looking at their lifeform richness as shrub richness is the lowest in both old-growth forests and tree richness is the lowest in >100 years plain forests. Consequently, our results seem consistent with the literature as vascular plant communities in boreal forests are more influenced by the age of the stand since the last disturbance than surface deposits or stand types (Kumar *et al*, 2018). Indeed, these generalist species are mostly influenced by the age structure of their habitat rather than other characteristics of their habitat such as light or moisture availability (Kuuluvainen & Gauthier, 2018).

3.6.1.3 Indicator species

The vascular plant and bryophyte communities and their species richness clearly distinguished our two categories of old-growth forest from the three younger forests. One way to understand the difference between these two old-growth forest categories is to look at their indicator species.

For bryophytes, these species were also significantly affected by stand type and surface deposits, whereas vascular plants were not affected by forest age classes but rather by surface deposits and stand type. For vascular plants, the explanation could be that similar plant communities were found in the younger stands (30-50, 50-70 and 70-90), which could explain the lack of indicator species for each of these forest age categories. We therefore selected the 15 most abundant species in each of the younger forest age categories, which are extremely common and found in all these forest age categories. This selection resulted in no bryophyte species indicative of young forests and five vascular plant species indicative of all the younger forest categories combined: *Diervilla lonicera* Miller, *Eurybia macrophylla* (Linnaeus) Cassini, *Ribes glandulosum* Grauer, *Chamaenerion angustifolium* (Linnaeus) Scopoli *subsp. angustifolium* and *Corylus cornuta* Marshall. This may be because boreal vascular plant species are often considered generalists (Kuuluvainen & Gauthier, 2018). Thus, these generalist and abundant species in younger forests categories do not reflect a single forest age category but rather species mostly related to open understory habitats (Martineau & Gervais, 2014). These generalist species may then homogenise our analyses of indicator species and functional traits because they simply group the three younger forest categories together. It also shows that these young forests are similar in composition. The absence of bryophyte indicator species shared between younger stands is probably due to the low bryophyte richness in these forest age categories, much lower than in >100 years forests and hill old-growth categories. which could be linked to a lower humidity, and less diverse and abundant microhabitats. On the other hand, we believe that the two categories of old-growth forest have distinct indicator and exclusive species, which makes them distinct from each other.

3.6.2 Old-growth hill forests *versus* old-growth plain forests

Our second hypothesis dealt with the difference between hill and >100 years plains old-growth forests. Even if old-growth forests communities differentiate well from the three younger forest age categories, we found fundamental differences between these two old-growth categories, whether in terms of species richness, composition or functional traits of the species inhabiting them.

3.6.2.1 Specific richness

The exclusive species richness was always significantly higher in hill old-growth forests than in any other categories except for vascular plants on glaciolacustrine deposits where exclusive species richness is just apparently higher in hill old-growth forests in general. Total bryophyte species richness was significantly higher in hill old-growth forests than in plains ones. Also, we found the lowest vascular plant species richness in >100 years plain forests and coniferous stands. Ellenberg index values for bryophyte and vascular plant indicator species in both old-growth forest types indicate that they have a comparable moisture index but indicate that hills forests have a lower light index values than >100 years plain forests. Bryophyte specific richness should benefit from a combination of higher moisture and temperature in hills old-growth forests (Greiser *et al*, 2021), where greater shade conditions would limit evaporation and overheating of the substrate (De Frenne *et al*, 2013) as well as the diversity of non-shade tolerant vascular plant species (Messier *et al*, 2009).

3.6.2.2 Composition of plant communities and indicator species

The differences between bryophyte and vascular plant communities seem to be much better explained by the forest age categories than by the other parameters studied, as indicated on the NMDSs (Figure 3.5; Figure 3.9). Indeed, bryophyte communities are quite distinguishable between our two old-growth forest categories and the younger categories whereas it was difficult to detect a pattern for vascular plant communities on the NMDS. Looking into indicator species may help when it comes to differentiate old-growth communities, even in vascular plants.

Stands ranging from 30 to 90 years old consist mostly of even-aged forests, resulting from clearcuts or fires. It may explain the absence of indicator species representing one of these forest age categories, even more because a part of these forests' species are also found in old-growth forests (Bergeron & Fenton, 2012; Savilaakso *et al*, 2021). In contrast, the high indicator values of bryophyte and vascular plant indicator species in old-growth forest categories allow us to better understand the reasons of such different composition.

Hill old-growth communities have six trees as indicator species (*Thuja occidentalis, Taxus canadensis, Betula papyrifera* Marshall, *Abies balsamea* (Linnaeus) Miller, *Sorbus americana* Marshall and *Acer rubrum* Linnaeus), which is surprising in a forested landscape usually defined with low tree diversity (Kayes & Mallik, 2020). With the absence of indicator tree species in plains forests, this result highlights the structural contrast between hills and all other categories of forests because it even affects the tree strata level. Our hills old-growth forests housed many white cedar (*Thuja occidentalis)* and our surprisingly high tree indicator species resemble what has been found in white cedar forests in Manitoba's hills (Grotte, 2007).

Shadier, slopier and rocky conditions occur in hill old-growth communities with *Thuja occidentalis*, *Taxus canadensis*, *Betula papyrifera* and *Abies balsamea* being indicator species, as it has been found in Manitoba for white-cedar and balsam-fir mixed stands (Grotte, 2007). In >100 years forests communities, ericaceous indicator species like *Chamaedaphne calyculata* (Linnaeus) Moench, *Kalmia polifolia* Wangenheim or *Vaccinum oxycoccos* Linnaeus and sphagna indicator species like *Sphagnum angustifolium* (Warnst.) C.E.O. Jensen, *S. divinum* Flatberg & Hassel, *S. fallax* H. Klinggr. or *S. fuscum* (Schimp.) H. Klinggr. indicate lighter, damper and more acidic conditions, as the Ellenberg index for light, moisture in both bryophyte and vascular plant indicator species suggest. In addition, hill old-growth forests seemed also moister than the other forest age categories when looking at functional traits in both bryophyte and vascular plant indicator species. Mature forests are indeed known to retain their understory humidity (De Frenne *et al*, 2013). The high relative humidity found in hill old-growth systems (Ambec *et al*, 2023) may then also be present in >100 forests as suggests the high proportion of liverworts and Ericaceae in these systems (Ratcliffe, 1968). Even if these differences lead to the same contrasts between a high bryophyte richness and a low vascular plant one, the habitat these two categories of forest represented is different and house different species.

The main explanation may be climate and topography. These two old-growth categories may have in common a mechanism of fire refugia. The topography is indeed known to create recuring fire refugia areas which surely explain the persistence of hills old-growth systems (Rogeau *et al*, 2018). On the other hand, damper forests on the plains with a lot of bog related species like sphagna and Ericaceae may be protected from fires as it has been found for peatlands (Stralberg *et al*, 2020; Kuntzemann, 2021). Both old-growth forest categories become unevenly-aged with a higher structural heterogeneity than young even-aged forests with the passage of time and the accumulation of secondary perturbations (Bergeron & Fenton, 2012; Martin & Valeria, 2022). Since >100 years lowland forests and hills old-growth forests seemed different, both in their indicator species and whole plant communities, we believe that the topography and contrasting microclimatic conditions may have a long-term impact on vegetation, and especially rare plant species, in the studied boreal area (Tukiainen *et al*, 2017; Ambec *et al*, 2023).

3.7 Conclusion

We found differences in specific richness, composition and indicator species between old-growth forests and younger forests but also between hill and >100 years plains old-growth forests. The reason why old-growth forests exist naturally is that they are in places that are less prone to fire or natural random fire exclusions (Cyr *et al*, 2005), allowing them to age and create complex structures of habitat. However, the difference between old-growth forests on the hills and those on the plains is that they seem to provide a fire and logging refugia for different reasons: rugged topography for hills and damp soil for plains. In the past, before industrial logging modified the forest age structure of the landscape, other types of old growth forests may have been distinguished. However, the residual old growth forests examined in this study were primarily humid when on the plains. Other sites existed but they may have been lost in the overall portrait. This is already a basis for discrimination. Our results indeed suggest that forest age is the main parameter influencing the variation among plant communities among the studied parameters. Bryophytes seemed to better categorise forest age categories than vascular plants, but we found a surprisingly high indicator tree species richness in hill old-growth forests. Our work on functional traits strongly supports a microclimatic change in old-growth forests. Indeed, vascular plants and bryophytes indicated higher moisture index values as well as a higher light index value in >100 years old-growth forests. Then, old-growth forest communities are different than younger ones because of their structure and microclimatic parameters but plains and hills old-growth forests differ because of the topography, microclimate and the reason they can age in the landscape. However, old-growth plains forests, as well as hills ones, need to be included in territorial management as they represent a non-negligible part of the regional biodiversity alone. Beyond plants, such systems' input in the landscape biodiversity are without doubt of common interest (Spies & Franklin, 1991).

3.8 Acknowledgments

We want to thank funders of the NSERC-UQAT chair on northern biodiversity in a mining context. We want to thank "*Corrige moi*" for students' reviews, Megan Wong as our field assistant, Julie Arsenault for her help in field work organisation and herbarium management and the Société Québécoise de Bryologie for rare bryophytes species check-up. We want to thank our lab students and former students Marion Barbé, Marion Noualhaguet and Xiangbo Yin for sharing their datasets.

CHAPITRE 4: VEGETATION CONTRASTS BETWEEN MINE TAILINGS AND NATURALLY STRESSFUL SOILS IN BOREAL CANADA

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4.1 Abstract

Seventy-five percent of the earth's ecosystems have been altered because of anthropogenic activities since industrialisation. While these disturbances negatively affect biodiversity, they can promote certain species, usually in open habitats. Highly polluted mine tailings, like other habitats with particular geochemistry, create stressful growth conditions for plants. These sites create a rare habitat at the regional scale and promote a small number of species. We want to determine if mine tailings house a specific flora or if their flora resembles naturally open habitats with stressful growth conditions soils for plants. The Abitibi region, eastern Canada, concentrates a cluster of mines with tailing sites along a rich geological fault. We compared plant communities (vascular plants and bryophytes) on mine tailings with those on ultramafic and limestone outcrops. Controls consisted of abandoned beaver ponds as these are naturally open habitats without stressful growth conditions soils for plants. We hypothesize that species communities on mine tailing sites (1) are not homogeneous among replicates and (2) are different from other stressful habitats. We believe that such differences will appear because (3) of the diverse geochemistry of mines driving plant species assemblages. Our results validate hypotheses (1) and (3) since mine tailing communities were not always similar, mostly because of their differing geochemistry. We rejected hypothesis (2) as mine tailings communities did resemble some natural sites, mostly limestone outcrop communities. These results help to better understand the variability of the plant communities of these habitats. Moreover, our results suggest that the renaturalisation of mine tailings will not result in the loss of a unique flora.

4.2 Résumé

Soixante-quinze pourcents des écosystèmes de la planète ont été altérés par les activités anthropiques depuis l'industrialisation. Si ces perturbations ont un impact négatif sur la biodiversité, elles peuvent favoriser certaines espèces, généralement dans des habitats ouverts. Les résidus miniers hautement pollués, comme d'autres habitats présentant une géochimie particulière, créent des conditions stressantes pour la croissance des plantes. Ces sites constituent un habitat rare à l'échelle régionale et favorisent un petit nombre d'espèces. Nous voulons déterminer si les résidus miniers abritent une flore spécifique ou si leur flore ressemble à celle des habitats naturellement ouverts avec des sols stressants pour la croissance des plantes. La région de l'Abitibi, dans l'est du Canada, concentre un ensemble de mines avec des sites de résidus miniers le long d'une riche faille géologique. Nous avons comparé les communautés végétales (plantes vasculaires et bryophytes) sur les résidus miniers avec celles retrouvées sur les affleurements ultramafiques et calcaires. Les sites témoins consistaient en des étangs de castors abandonnés, car il s'agit d'habitats naturellement ouverts sans sol stressant pour la croissance des plantes. Nous supposons que les communautés d'espèces sur les sites de résidus miniers (1) ne sont pas homogènes entre les réplicas et (2) sont différentes des autres habitats stressants. Nous pensons que de telles différences apparaîtront en raison (3) de la géochimie diverse des mines qui détermine les assemblages d'espèces végétales. Nos résultats valident les hypothèses (1) et (3) puisque les communautés de résidus miniers n'étaient pas toujours similaires, principalement en raison de leur géochimie différente. Nous avons rejeté l'hypothèse (2) car les communautés de résidus miniers ressemblaient à certains sites naturels, principalement des communautés d'affleurements calcaires. Ces résultats aident à mieux comprendre la variabilité des communautés végétales de ces habitats. De plus, nos résultats suggèrent que la restauration des sites à résidus miniers n'entraînera pas la perte d'une flore unique.

4.3 Introduction

Since the beginning of industrialisation, 75% of the earth's ecosystems have been altered or have been replaced because of anthropogenic activities (Ellis *et al*, 2012). Most of these changes are caused by the primary sector, urbanisation and recreation (Walker, 2012), and have contributed to a drastic decrease in the world's biodiversity (Tollefson, 2019). However, these perturbations can create favourable habitats for some species, including rare species (Greenwood, 1978; Burda, 1998; Adamowski, 2006; Chester & Robson, 2013).

Anthropogenic activities can create favourable habitats for ruderal species (Takala *et al*, 2014; Root-Bernstein & Svenning, 2018), when they do not destroy or degrade all of the ecosystems of a given type within a region (Root-Bernstein & Svenning, 2018; Metera *et al*, 2010). In this case, heterogeneity is considered as a vector for increasing biodiversity through the creation of new types of habitats (Heikkinen & Neuvonen, 1997; Pollock *et al*, 1998; Gould, 2000).

Mining sites are both known to host rare species and to be extremely damaging to biodiversity (Prach *et al*, 2011). They represent approximately 0.039% of the earth's surface and are found on all inhabited continents (Maus *et al*, 2020). They can shelter rare species at the regional scale (Jacobi *et al*, 2011; Boschen *et al*, 2016; Sonter *et al*, 2018), mainly because of the habitat alteration and the content of certain chemical elements in the soil (Ali, 2003, 2009). Species colonisation primarily occurs after the cessation of activities and disturbances onsite have stopped. The habitat created on an abandoned mining site includes infrastructures such as roads, mine settling ponds and mine tailings, constituted of mining wastes (Wang *et al*, 2017).

When established on mine tailings, plants, which are sessile, must deal with high concentrations of metals or heavy metals (Rola *et al*, 2015; Santos *et al*, 2017). The geochemistry of mine tailings is highly variable and depends on the type of mineral and the extraction method (Ali, 2009; Jain *et al*, 2015; Sonter *et al*, 2018). Indeed, contaminating elements can be the extracted ore, or elements used in the extraction, such as arsenic, cyanide, lead, cadmium and mercury (Ali, 2009; Jain *et al*, 2015; Sonter *et al*, 2018). The anthropogenically induced concentration increase of elements in the soil can result in a stress for plant development, like copper or mercury (Santos *et al*, 2017). The same is true for stressful habitats of natural origin such as ultramafic outcrops or high-metal content areas (Jacobi *et al*, 2011; van der Ent *et al*, 2015). In the vast boreal domain, the network of abandoned mine sites created by the spatial restriction of valuable mineral deposits creates a network of specific habitats in a generally forested context.

Canada's mineral production was valued at $43.8 billion in 2020, and gold was its top-ranked commodity (Government of Canada, 2022). In Abitibi, western Quebec, the Cadillac fault found within the Abitibi greenstone belt is home to Canada's largest gold deposit (Robert, 1989) and have generated numerous mine tailings sites (Rabeau *et al*, 2010). However, the dominant surface deposits in Abitibi are constituted of clay and glaciolacustrine remains (Dugas, 1975; Martineau & Gervais, 2014) and the landscape of the region is dominated by extensive human-altered boreal forests developing on clay and glaciolacustrine remains (Lafond & Ladouceur, 1968; Gaudreau, 1979; Martineau & Gervais, 2014). Scattered mine tailings contribute to the heterogeneity of the regionally forested landscape (Dekoninck *et al*, 2010) although they are not the only open habitats with stressful soils in Abitibi. The Abitibi greenstone belt also contains small ultramafic cores (Monecke *et al*, 2017) and limestone outcrops can be found in nearby Témiscamingue (Grant & Owsiacki, 1987). The lack of forest on these rocky habitats may either be because the soil is stressful for plant development or because it is the degraded result of post-fire vegetation maintained by the late Holocene disturbance regime of high fire frequency (Asselin *et al*, 2006).

To our knowledge, no study has compared the vegetation on tailings with that of natural open habitats with comparable geochemical properties for plant growth. On the other hand, with the knowledge of rare plant species linked to mine tailings (Callaghan & Bowyer, 2011) there is also the ethical aspect of choosing between conserving extremely polluted environments that favour such species and the desire to restore these sites so that nature can regain its rights.

The main objective of this study is to determine if mine tailings plant communities differ from their natural stressful soil analogs in terms of bryophytes and vascular plants and if they house rare plant species. Plant communities on ultramafic cores and limestone outcrops will be compared to plant communities on mine tailings. Abandoned beaver ponds were used as a control as they constitute an open habitat without a stressful soil. We hypothesize that species communities on mine tailing sites are (1) not homogeneous and (2) are different from other stressful habitats, mostly because (3) of the variable geochemistry of mine sites driving plant species assemblages. Determining whether the communities found in anthropogenic habitats differ from those found in natural ones is of interest as the renaturation of all mine tailing sites is currently planned. A better knowledge and understanding of the mechanisms explaining the presence of plant species in such habitats could help in decision making, as well as in establishing restoration objectives.

4.4 Material and methods

4.4.1 Study area

The study was conducted in the Abitibi greenstone belt, eastern Canada, with the addition of limestone sites in Témiscamingue (Figure 4.1). The Abitibi greenstone belt was formed by volcanic activities 2.6 billion years ago and is dominated by a mafic bedrock (Monecke *et al*, 2017). Two distinct and original geological features stand out in this context. On the one hand, scattered ultramafic cores, often containing asbestos (Tiphane, 1973), are found across the landscape and on the other hand, there are many abandoned mine tailings along the Cadillac fault, a world-class gold deposit with more than 170 active and closed mines (Robert, 1989; Ispolatov *et al*, 2008; CREAT, 2020). In order to include an additional natural stressful soil, limestone outcrops and quarries in nearby Témiscamingue were included in the study (Grant & Owsiacki, 1987)

The mean temperature during winter was -11.64°C (November to March 1981-2010) and during summer was 10.09°C summer (April to October 1981-2010) with an annual mean of 1°C, measured at the weather station in the centre of the study area. Annually, there is 707.7 mm of rain and 281.2 cm of snow (Environment Canada, 2021). The Abitibi and the Témiscamingue regions are respectively the hinges between the boreal and temperate forest domains (MFFP, 2003). The forest is classified as the balsam fir (*Abies balsamea* (Linnaeus) Miller) and white birch (*Betula papyrifera* Marshall) vegetation zone in the north and the balsam fir and yellow birch (*Betula alleghaniensis* Britton) zone in the south (MFFP, 2003). Other tree species include black spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburgh), trembling aspen (*Populus tremuloides* Michaux), and jack pine (*Pinus banksiana* Lambert). In addition to the vegetation, Abitibi houses around 35% percent of the whole provincial beaver population (*Castor canadensis* Khul), with a density almost twice as high as the rest of the province. As ecological engineers (Rosell *et al*, 2005), they locally open the environment and create pioneer habitat for the vegetation (Levine & Meyer, 2019), as do mining sites, and limestone or ultramafic outcrops.

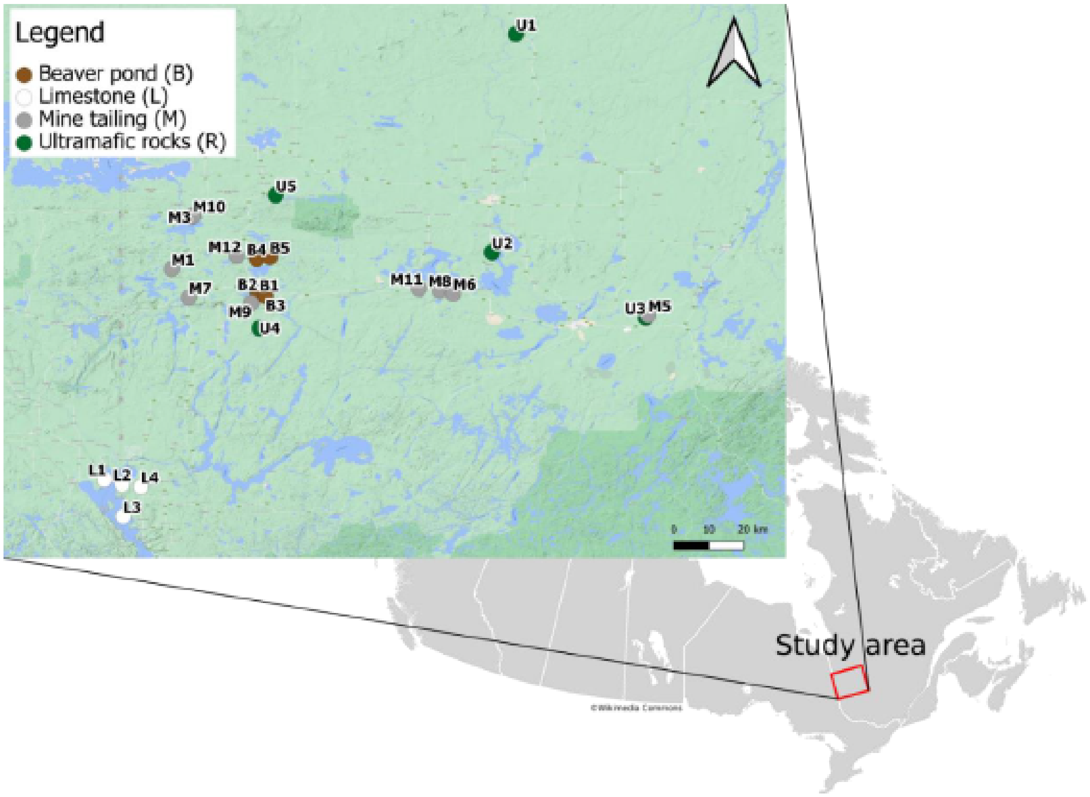

Figure 4.1: Map showing the study area, in Abitibi for all sites except limestone (L) ones in the Témiscamingue area, Canada. The map of the study area displays the repartition of the four kinds of studied habitats and their codes, abandoned beaver ponds (B), limestone outcrops and abandoned quarries (L), abandoned mine tailings (M) and ultramafic rocky outcrops (U).

4.4.2 Site selection and sampling

4.4.2.1 Site selection

Four types of regionally rare open habitats were selected. Abandoned mine tailings (M) were compared to ultramafic outcrops (U), limestone outcrops and quarries (L) and abandoned beaver ponds (B). As the only non-natural and geochemically variable substrate consisted of disused mines, the number of replicates was higher (11). As stressful soil comparisons, we sampled five replicates of U and four replicates of L, as they were difficult to find and access. Finally, five abandoned beaver ponds (B) were sampled as a control (Figure 4.1). The total number of studied sites was then 11 M + 5 U + 4 L + 5 B = 25. Due to the great variability in the age since abandonment and their relatively small number, the age of the mine sites could not be considered in this study.

The eleven non-restaured mine tailing sites (M) were chosen using a provincial map indicating non-restored, safe and government-owned abandoned mines (MERN, 2020). Ultramafic sites were selected using the SIGEOM online maps (NRCan, 2021) and confirmed in the field; they contained asbestos among other ultramafic-linked chemicals. Limestone sites, which are extremely rare in the area, were selected using both SIGEOM and bibliography (Grant & Owsiacki, 1987; NRCan, 2021). Finally, abandoned beaver ponds were selected using personal knowledge of the area and satellite imagery.

4.4.2.2 Geochemistry sampling

A mineral sample of at least 500 g, composed of either sand, clay, or rock, was collected in the middle of each of the 24 studied sites.

4.4.2.3 Vegetation sampling

All habitats were sampled following the same protocol, differing only in the number of 1 m x 50 m quadrats used (adapted from Barbé et al. 2017). Three quadrats spaced at equal distances from each other were disposed from one border to the other if the site area was < 15 ha. Five quadrats spaced at equal distances from each other were if the site area was >15 ha.

Bryophytes were systematically collected from all substrates in each quadrat for identification in the laboratory. The substrates were classified as: sand, clay, humus, rock, coarse woody debris, peat and base of snag or living three. All vascular plants present in each quadrat were determined to species level during fieldwork, and unknown vascular plants were collected for subsequent laboratory identification. A final 20-minute survey was performed outside of the of quadrats but within the habitat during which any previously unidentified species (vascular or bryophyte) were collected to minimise observer oversight. Species nomenclature follows Bryoquel (Société québécoise de bryologie, 2021) for bryophytes and Canadensys for vascular plants (Canadensys, 2021). New mentions of species for the region were checked by specialists from the Société Québécoise de Bryologie.

4.4.3 Data processing

4.4.3.1 Geochemistry

The analyses were performed by H2Lab, following North American norms. M sands and B clay were analysed after total dehydration using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Wilschefski & Baxter, 2019). Analysed elements were Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn and Zr. L and U rock samples were analysed with a X-ray fluorescence spectrometry (XRF) (Potts & Webb, 1992) after a whole rock fusion and a Loss on ignition (LOI) at 1000C for XRF. Analysed elements were Al2O3, BaO, CaO, Cr2O3, Fe2O3, K2O, MgO, MnO, Na2O, P2O5, SO3, SiO2, SrO and TiO2.

The soil tests differed depending on whether the substrate to be tested was solid (rock) or loose (sand and clay), resulting in different oxides and chemical elements lists as well as the lack of pH values in rock samples. To analyse all sites together we were forced to remove pH values although they are important for plant development. We also choose to keep the chemical elements in common and to convert oxides into pure periodic element (for example Fe2O3 to Fe) thanks to their conversion tables and chemical reaction equations. This selection led us to keep aluminium (Al), calcium (Ca), chromium (Cr), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn) and sodium (Na) but forced us to remove some heavy metals such as arsenic (As) or cadmium (Cd).

4.4.3.2 Species richness

Species richness was calculated using several filters to better describe diversity patterns. Total species richness was calculated for both vascular and bryophyte species as the total number of species present. With the aim to try to better discriminate among habitats, we also chose to look at exclusive species richness by determining which species were found in only a single habitat type (i.e. either M, U, L or B habitats). Each species found only in one single habitat type was then declared exclusive to it.

4.4.4 Statistical analyses

Statistical analyses were based on presence-absence data. All replicate quadrats for each site were pooled, eliminating the need for mixed models. Richness and composition analyses were performed at the habitat type level (N = 11 M + 5 U + 4 L + 5 B = 25 sites) except for the gamma diversity for the whole study. The data as well as figures were processed using R version 4.0.3 (R Core Team, 2020).

4.4.4.1 Richness

Total species richness and exclusive species richness for bryophytes and vascular plants were compared between the four habitats using two factor ANOVAs followed by Tukey HSD post-hoc tests. Finally we built boxplots with the functions ggplot and geom_boxplot in the ggplot2 package (Wickham, 2016).

To determine the completeness of our sampling effort we produced species accumulation curves using the function specaccum in the vegan package (Oksanen *et al*, 2017). The values of the asymptote of each curve were selected as the last value of the lagged difference (diff()) of each habitat specaccum richness value divided by the lagged difference (diff()) of the same habitat specaccum sites value.

To compensate for the apparent under-sampling of habitats L and B, we produced rarefaction curves to assess the asymptote of the specific richness curve of each habitat using the function rarecurve in the vegan package (Oksanen *et al*, 2017).

4.4.4.2 Composition

To represent the distance among plant assemblages in each habitat we performed a Principal coordinates Analysis (PCoA) ordination. PCoA was performed with the function betadisper from the vegan package using the Bray-Curtis distance specifying that we are working on binary data (Oksanen *et al*, 2017). All species were included in the ordination. Standard-error ellipses represent the region that contains 95% of all samples that can be drawn from the underlying Gaussian distribution.

To determine if the distances in composition between bryophytes and vascular plant communities was linked to the geographic distance between sites, we performed a Mantel test using the mantel function based on Spearman method. The function was run between the geographical standard distance matrix extracted from QGis and the Bray-Curtis dissimilarity matrix created thanks to the vegdist function in the vegan package (Oksanen *et al*, 2017). The test was run for all habitats and M replicates only.

To determine if the bryophytes and vascular plant communities, as well as the replicates of the different habitat types varied significantly among them in terms of geochemistry, we built a Principal coordinates Analysis (PCoA) ordination for bryophytes and vascular communities using decostand and vegdist in Scores for axis 1 and axis 2 were then used to produce the PCoA plot with the functions ggplot and geom_point in the ggplot2 package (Wickham, 2016). Labels were displayed thanks to the function geom_text_repel in the ggrepel package (Slowikowski *et al*, 2021).

4.5 Results

4.5.1 Species richness and composition

4.5.1.1 Bryophytes

We found a total gamma diversity of 133 different bryophyte species among the four habitat types (M, U, L, B). The species richness was the highest in M (67 species), followed by L (55 species), B (51 species) then U (42 species). In contrast, mean species richness (Figure 4.2) did not differ significantly among habitat types (ANOVA: F = 0.4838; p-value = 0.70). However, the species accumulation curves show that U and M habitats are closer to an asymptote than L and B (Figure 4.3). This suggests that the sampling effort was sufficient in U and M habitats but may be ameliorated in L and B. Showing a similar pattern, our rarefaction analysis (Figure 4.4) would predict that B sites total diversity would be the highest, followed by L then M sites with a similar value, then U sites.

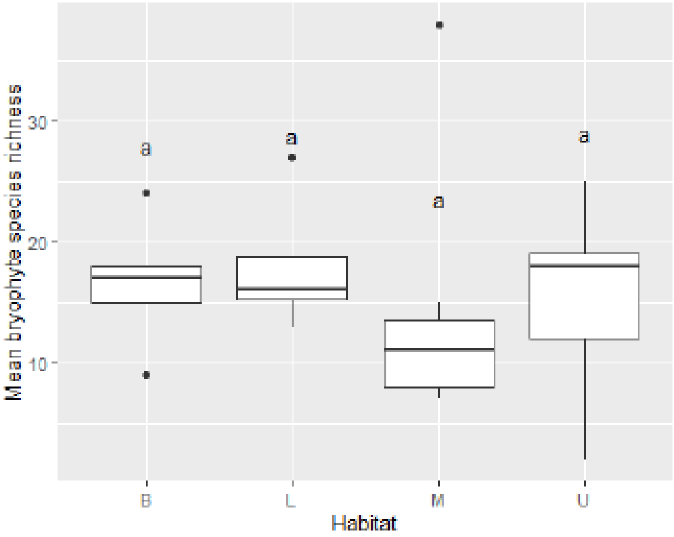

Figure 4.2: Boxplot showing the mean bryophytes species richness for each replicate of habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

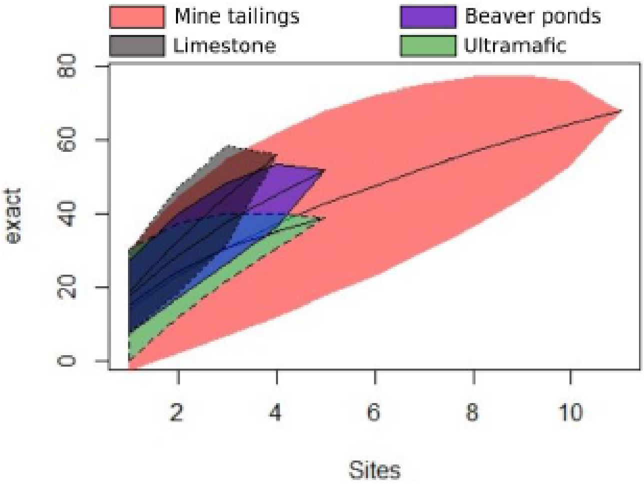

Figure 4.3: Bryophyte species accumulation curves for each habitat.

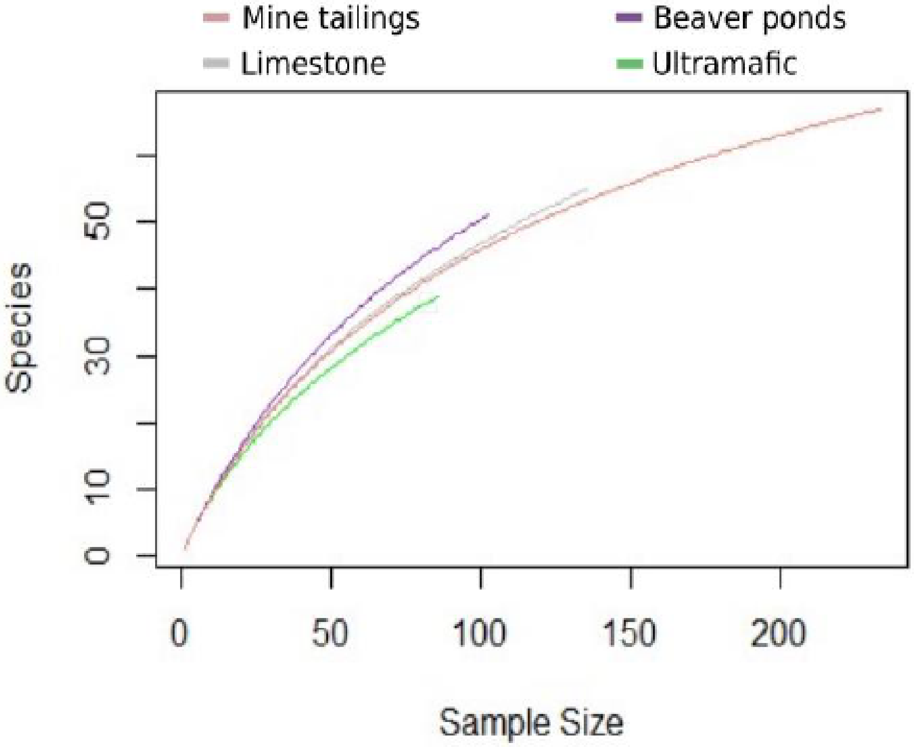

Figure 4.4: Bryophyte species rarefaction curves for each habitat.

Of the 133 bryophyte species, 80 were exclusively found in a particular habitat type and most shared species were common, like *Pohlia lescuriana* or *Dicranum polysetum*. The number of exclusive species declined from B and M habitats (25 species each), to L habitats (17 species) and finally U habitats (9 species). Two new species for the region were found in M habitats, *Reboulia hemisphaerica* and *Odontoschisma franciscii*, the later shared with U habitats. Two new regional mentions were also found in L habitats with *Calypogeia sphagnicola* and *Fissidens taxifolius*. One new species for the region was discovered in B, *Physcomitrium immersum* (Table 4.1). The mean exclusive species richness differed significantly between habitat types (ANOVA: F = 3.312; p-value = 0.04) with B sheltering the highest exclusive species richness, followed by L, then M and U habitat types (Figure 4.5).

Table 4.1: Bryophyte species exclusively found in one habitat. Species names in bold indicate a new mention for the Abitibi region.

Mine tailings (M)	
Brachythecium erythrorrhizon Schimp.	*Hypnum lindbergii* Mitt.
Breidleria pratensis (Koch ex Spruce) Loeske	*Leptobryum pyriforme* (Hedw.) Wilson
Brotherella recurvans (Michx.) M. Fleisch.	*Lophozia sudetica* (Nees ex Huebener) Grolle
Bryum blindii Bruch & Schimp.	*Odontoschisma fluitans* (Nees) L. Söderstr. & Váňa
Bryum pallescens Schleich. ex Schwägr	*Oncophorus virens* (Hedw.) Brid.
Cephalozia pleniceps (Austin) Lindb.	*Plagiothecium cavifolium* (Brid.) Z. Iwats.
Dichodontium pellucidum (Hedw.) Schimp.	*Plagiothecium laetum* Schimp.
Dicranella crispa (Hedw.) Schimp.	*Pohlia melanodon* (Brid.) A.J. Shaw
Dicranella subulata (Hedw.) Schimp.	***Reboulia hemisphaerica*** (L.) Raddi
Didymodon tophaceus (Brid.) Lisa	*Scapania irrigua* (Nees) Nees
Herzogiella turfacea (Lindb.) Z. Iwats.	*Scapania undulata* (L.) Dumort
Hygroamblystegium varium (Hedw.) Mönk var *varium*	*Sphagnum rubellum* Wilson
	Tomenthypnum nitens (Hedw.) Loeske
Abandoned beaver ponds (B)	
Atrichum crispum (James) Sull.	*Leptodictyum riparium* (Hedw.) Warnst
Brachythecium laetum (Brid.) Schimp.	*Lophocolea minor* Nees
Brachythecium plumosum (Hedw.) Schimp	*Mnium hornum* Hedw.
Brachythecium reflexum (Starke) Schimp. Qc	***Physcomitrium immersum*** Sull.

Table 4.1: continued

Brachythecium rivulare Schimp.	*Platydictya jungermannioides* (Brid.) H.A. Crum
Brachythecium starkii (Brid.) Schimp.	*Platydictya subtilis* (Hedw.) H.A. Crum
Bryoerythrophyllum recurvirostrum (Hedw.) P.C. Chen	*Pohlia cruda* (Hedw.) Lindb.
Bryum argenteum Hedw	*Pseudobryum cinclidioides* (Huebener) T.J. Kop.
Callicladium haldanianum (Grev.) H.A. Crum	*Pseudocampylium radicale* (P. Beauv.) Vanderp. & Hedenäs
Ceratodon purpureus (Hedw.) Brid.	*Pylaisia intricata* (Hedw.) Schimp.
Chiloscyphus pallescens (Ehrh. ex Hoffm.) Dumort	*Rhizomnium appalachianum* T.J. Kop.
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	*Rhizomnium punctatum* (Hedw.) T.J. Kop.
	Rhynchostegium aquaticum A. Jaeger
Limestone (L)	
***Calypogeia sphagnicola* (Arnell & J. Perss.) Warnst. & Loeske**	*Leiomylia anomala* (Hook.) J.J. Engel & Braggins
Campylophyllum hispidulum (Brid.) Hedenäs	*Leucobryum glaucum* (Hedw.) Ångström
Dicranum fulvum Hook.	*Plagiomnium cuspidatum* (Hedw.) T.J. Kop
Dicranum leioneuron Kindb.	*Pseudoleskeella nervosa* (Brid.) Nyholm
Dicranum viride (Sull. & Lesq.) Lindb	*Ptilidium pulcherrimum* (Weber) Hampe
Fissidens taxifolius Hedw.	*Rhytidiadelphus triquetrus* (Hedw.) Warnst.
Hypnum cupressiforme Hedw. var *cupressiforme*	*Sphagnum fuscum* (Schimp.) H. Klinggr.
Hypnum recurvatum (Lindb. & Arnell) Kindb.	*Syntrichia ruralis* (Hedw.) F. Weber & D. Mohr
Ultramafic (U)	
Andreaea rupestris Hedw.	*Dicranum undulatum* Schrad. ex Brid.
Brachythecium rutabulum (Hedw.) Schimp.	*Lophozia ventricosa* (Dicks.) Dumort. var *ventricosa*
Calypogeia neesiana (C. Massal. & Carestia) Müll. Frib.	*Racomitrium microcarpum* (Hedw.) Brid.
Cephalozia leucantha Spruce	*Sphenolobus minutus* (Schreb. ex D. Crantz) Berggr.
Dicranum flagellare Hedw	

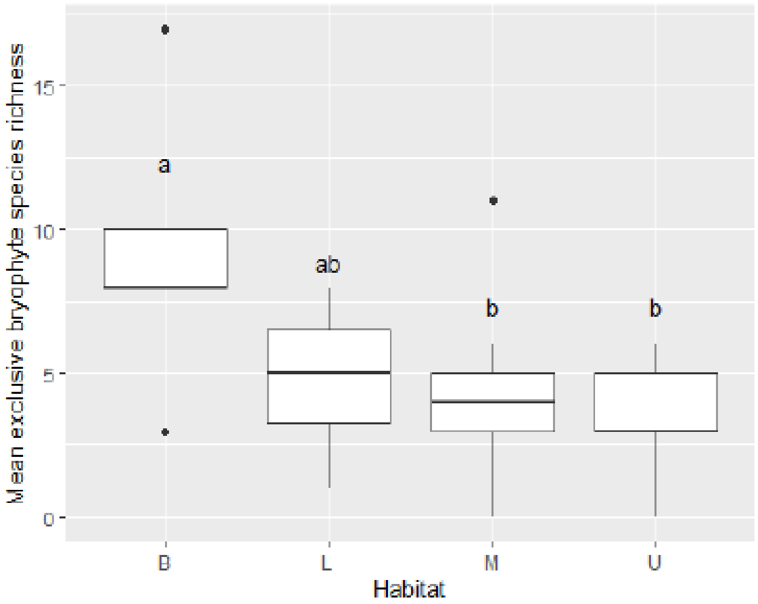

Figure 4.6: Boxplot showing the mean exclusive bryophytes species richness for each replicate of habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

The PCoA analysis shows that most M replicates are grouped altogether but some of the sites are mixed with L or U habitats. Even if some sites are overlapping in the standard-error ellipse of another habitat, most of the replicates of one habitat are quite isolated from the other habitats based on their species composition (Figure 4.6). Resemblance between communities does not seem related with the proximity of the studied sites (Mantel statistic r = 0.09; p-value = 0.12) and the same is true for M sites taken apart (Mantel statistic r = 0.06, p-value = 0.37).

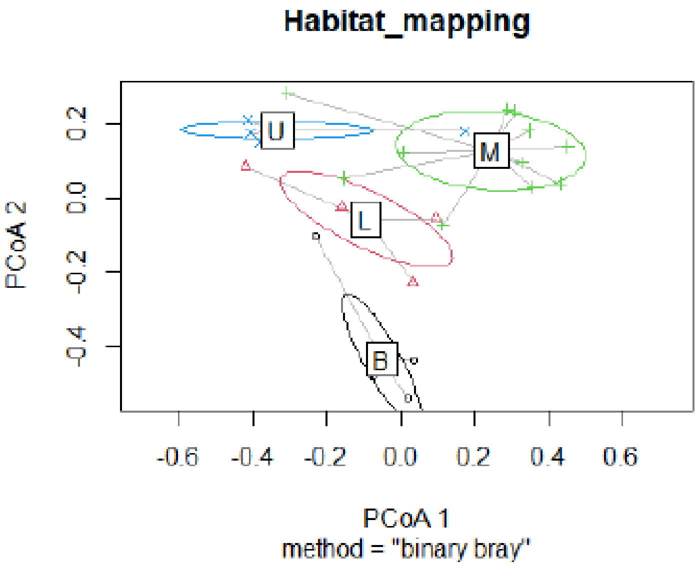

Figure 4.7: Two PCoA axes habitat x state mapping based on Bray-Curtis distance between bryophyte assemblages representing 42.6% of their variability. Ellipses represent the standard-error.

4.5.1.2 Vascular plants

We found 236 vascular plant species among the four habitat types (M, U, L, B). The species richness was the highest in M (135 species), followed by L (121 species), B (100 species) then U (64 species). The mean species richness varied significantly between habitats (ANOVA: F = 5.31; p-value = 0.007) and was higher in L sites, followed by B and M sites and, finally U sites (Figure 4.7). However, the species accumulation curves show that B, U and M habitats are closer to an asymptote than L (Figure 4.8). It means that the sampling effort was sufficient in B, U and M habitats but may be ameliorated in L. Showing a similar pattern, our rarefaction analysis (Figure

4.9) would predict that L sites total diversity would be the highest, followed by M then B sites with a similar value, then U sites.

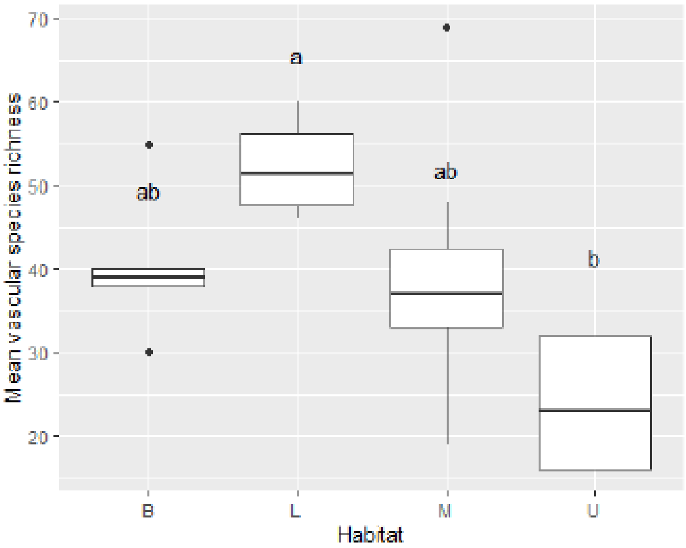

Figure 4.7: Boxplot showing the mean vascular plants species richness for each replicate of habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

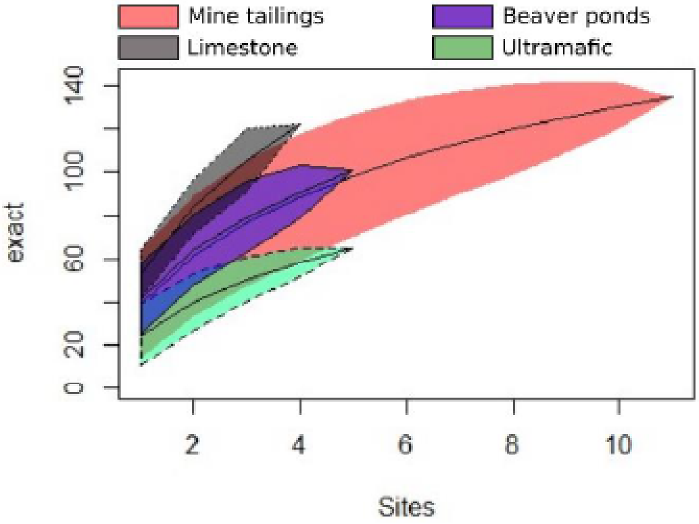

Figure 4.8: Vascular plant species accumulation curves for each habitat and their 95% confident interval.

Of the 273 vascular plant species, 128 were exclusively found in a particular habitat, and shared species were common, like *Betula papyrifera*, *Chamaenerion angustifolium* subsp *angustifolium*; however, a few were infrequent like *Antennaria howellii* subsp *canadensis*. The number of exclusive species was higher in L (45 species), then M (40 species), B (33 species) and U habitats (9 species). There were no new mentions for the region. The mean exclusive species richness differed significantly between habitats (ANOVA: F = 11.7; p-value < 0.001) with B and L habitats sheltering a higher exclusive species richness than M and U habitats (Figure 4.10).

A PCoA based analysis showed more overlapping and closer standard-error ellipses between habitats than for bryophytes (Figure 4.11). M vascular plant communities are similar to those of the L sites, and to a lesser extent to those of the U sites but B sites remain apart. It appears that the resemblance between communities is not related with the proximity of the studied sites (Mantel statistic r = -0.02839; p-value = 0.5978) and the same is true for M sites taken apart (Mantel statistic r = 0.1242, p-value = 0.3022).

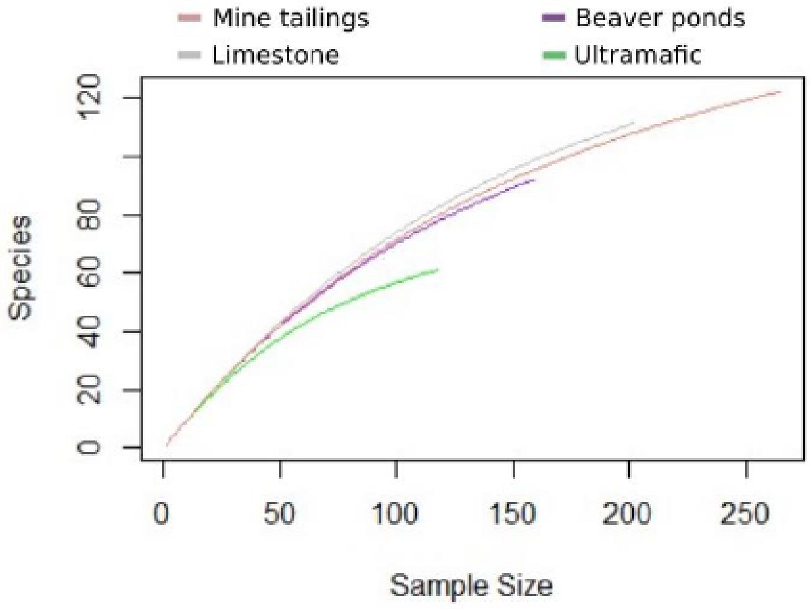

Figure 4.9: Vascular plant species rarefaction curves for each habitat.

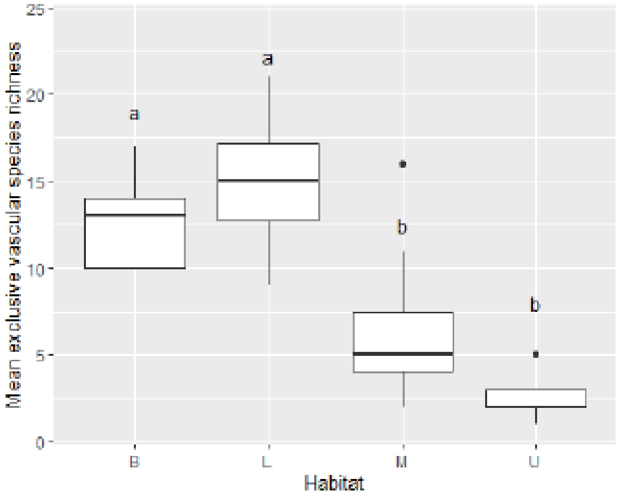

Figure 4.10: Boxplot showing the mean exclusive vascular plants species richness for each replicate of habitat. Letters above each boxplot indicate statistical groups of replicates determined by Tukey HSD.

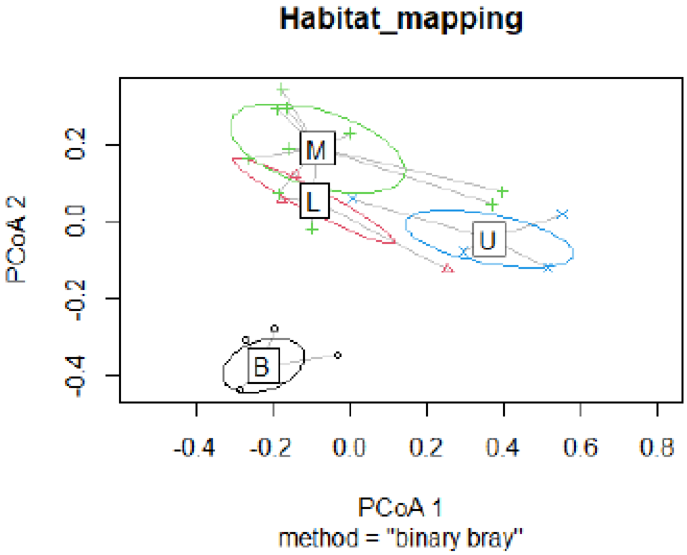

Figure 4.11: Two PCoA axes habitat x state mapping based on Bray-Curtis distance between vascular assemblages representing 45.5% of their variability. Ellipses represent the standard-error.

4.5.2 Geochemistry and specific composition

4.5.2.1 Bryophytes

The PCoA analysis clearly shows that both site and bryophyte species variability were centred along the first axis (Figure 4.12) with aluminium (Al), sodium (Na) and calcium (Ca) on the left and manganese (Mn) and chromium (Cr) on the right. Site position based on geochemistry almost perfectly discriminated between L and B sites while M and U sites were more mixed along the first axis. Species were not linked to any kind of element-related communities (i.e. calciphilous, ultramafic) with common *Ptilidium pulcherrinum* or *Leucobryum glaucum* on the left. Only *Bryum blindii*, at far right, is associated with mine tailings in Quebec.

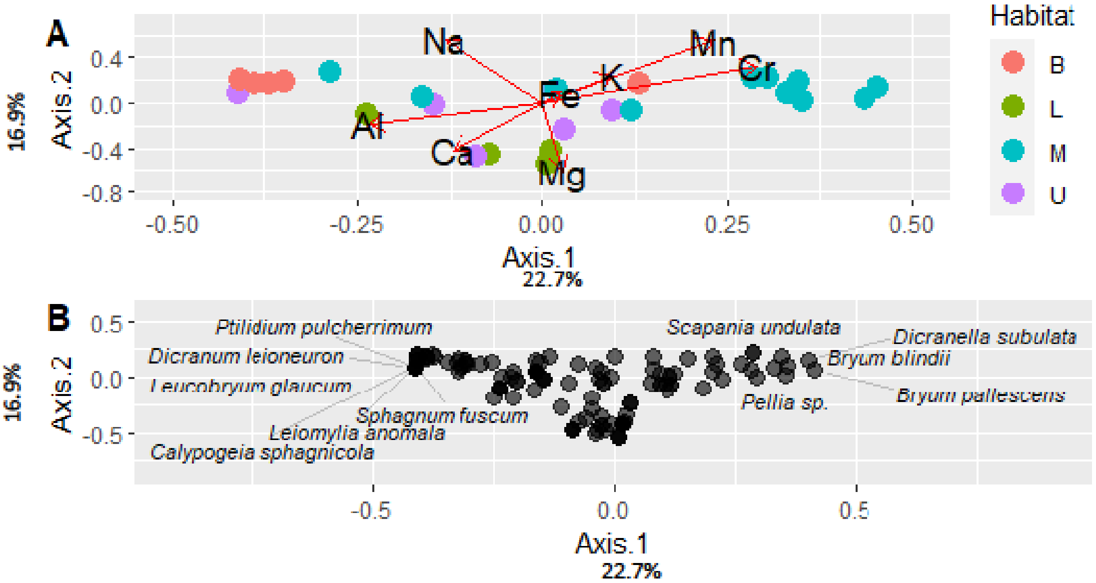

Figure 4.12: PCoAs whose axes are based on the geochemistry and bryophyte assemblages' distances of all studied sites representing 39.6% of the variability of the distances between (A) studied sites and (B) the species one by one.

4.5.2.2 Vascular plants

As with the bryophytes, the PCoA analysis clearly shows that both site and vascular plant species variability were centred along the first axis (Figure 4.13) with magnesium (Mg) and calcium (Ca) on the left and manganese (Mn), sodium (Na) and potassium (K) on the right. However, vascular plants species were less centred on the first axis than bryophytes species. Site position based on geochemistry almost perfectly discriminates between L and B sites, but again, M and U sites are more mixed along the first axis. Species were not linked to any kind of element-related communities (i.e. calciphilous, ultramafic…) with common *Heracleum maximum*, *Alopecurus aequalis*, *Dendrolycopodium dendroideum*, *Geocaulon lividum* or *Viburnum edule* on both ends of the first axis.

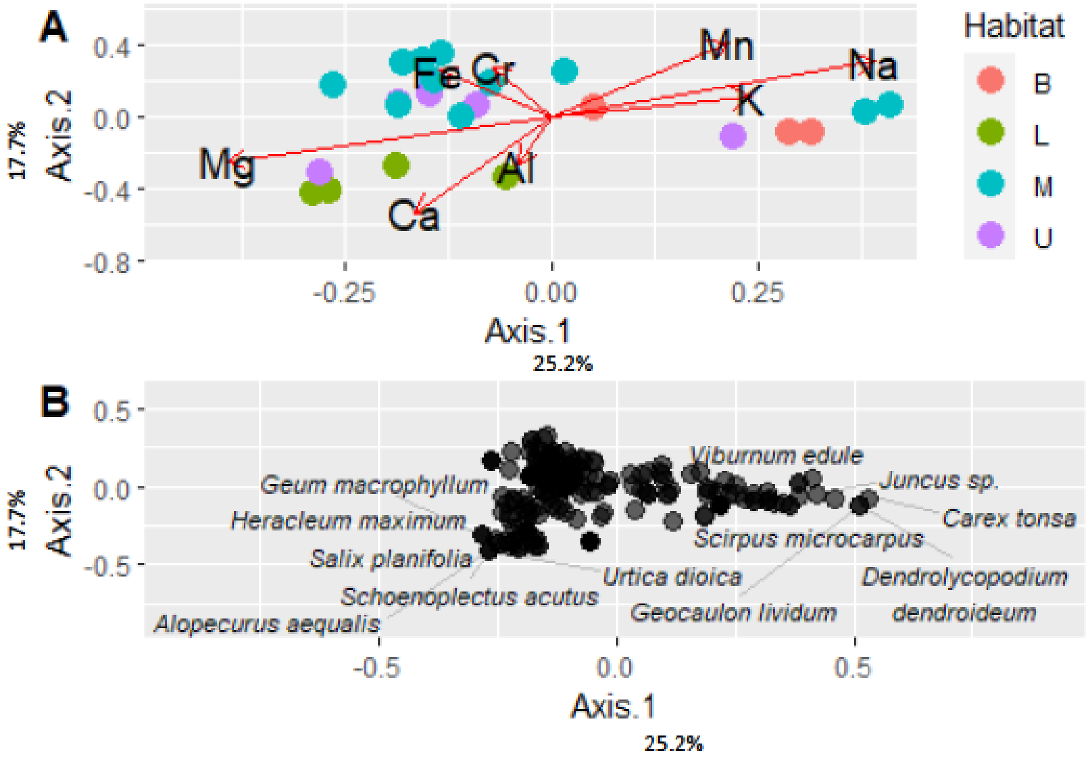

Figure 4.13: PCoAs whose axes are based on the geochemistry and vascular plant assemblages' distances of all studied sites representing 43.2% of the variability of the distances between (A) studied sites and (B) the species one by one.

4.6 Discussion

Mine tailings plant communities do not bring a novel species richness at the regional scale, except for two bryophyte species. Although the species accumulation curves for L habitat are still steep, other habitats seemed sufficiently sampled to represent their plant diversity. There was no difference in bryophyte richness between habitats while vascular plant species richness varied significantly between three groups: L > B & M > U. On the contrary, the number of habitat exclusive species varied significantly between three groups for bryophytes (B > L > M & U) and two for vascular plants (B

& L > M & U). PCoAs better discriminated bryophytes than vascular plants between habitats, with M sites being the most heterogeneous. The geographic proximity between sites did not explain the resemblance of their plant communities.

4.6.1 Specific richness and community composition

We found a high total specific richness on a small variety of open habitats (133 bryophyte and 236 vascular plant species) and only the mean vascular plant species richness was significantly different between habitats. The reason may reside in the diversity of vascular plant strata, ranging from trees to grasses, that allowed the overlap of more species on a same surface (Morsdorf *et al*, 2010). This is not the case for mats and crusts of bryophytes on open habitats (Bates, 1998). With a mean bryophyte richness ranging from 12 to 18 species in our four habitats we are in the same range as boulders or mine tailings bryophyte studies (Kimmerer & Driscoll, 2000; Ren *et al*, 2021).

Most of the species we found were regionally common and often non-native. Indeed, the vast diversity of cattails, horsetails, sedges, willows, rushes, goldenrods, haircap mosses was also found in other open habitats such as wetlands, rocky outcrops, trails, mine tailings or wastelands (Marie-Victorin *et al*, 2002; Martineau & Gervais, 2014). Other mine tailings studies in Ontario and Québec also suggest the specific richness dominance of grasses and shrubs over trees (Munford *et al*, 2020; Gagnon *et al*, 2021b, 2021a). The only exception in our study were *Reboulia hemisphaerica* and *Bryum blindii*, commonly found and abundant on mine tailings only, which is not described in the literature. Mantel tests results suggest that the plant communities we studied were not subject to the effect of their habitat isolation, as suggested by previous studies on boulders (Kimmerer & Driscoll, 2000). Moreover, the isolation between uncommon habitat patches in a forested system have already been described as non-significant on these patches' diversity in plants and pollinators (Pinto *et al*, 2020). This is again in agreement with our results. We then believe that dispersal between these patches of habitat is efficient.

Despite having a steeper accumulation curve asymptote for L habitat in both bryophytes and vascular plants, our analyses determined that L communities differed from other habitats. B and L communities always sheltered more exclusive species than M and U. The reason may be because B, with a regionally common substrate, and L, known for a rich and specific flora (Cottle, 2004; Tropek *et al*, 2010) are less toxic for plants in general than mine tailings and ultramafic areas (Proctor, 1970; Pędziwiatr *et al*, 2018; Mourinha *et al*, 2022). Also, L site vegetation may differ because they are in a slightly more southern and warmer climate than the other sites, while B site vegetation may differ because it develops in a damper context. The less contrasted habitat seems to be U, with the smallest proportion of exclusive species, a low specific richness, and a wide overlap of plant communities with other stressful soils habitats. However, the numerous M replicates were the most heterogeneously distributed among other habitats, likely indicating a great amplitude of geochemical composition within studied mine tailings.

4.6.2 The importance of geochemistry

The objective of this study was to determine if mine tailings plant communities were different from natural stressful soils such as limestone and ultramafic outcrops. Our control, B sites, worked well since its communities are distinct from M, U and L communities. On another hand, we saw that there is a high variability of plant communities and geochemistry within M sites. This high variability leads to a similarity with L and U communities and geochemistry. The principal reason for the variability among M replicates is that the studied mining sites were targeting either gold, silver, copper, zinc or molybdenite-bismuth, and sometimes a combination of those elements at different times during the 20th century. Techniques varied to extract each or a combination of these elements and evolved to be more efficient (Coulson, 2012). The accumulation in the soil of chemicals used by humans, such as mercury or cyanide, to extract high densities of valuable minerals, also leads to a high geochemical diversity of mining waste (Ali, 2003). In our PCoA analyses, calcium was always on the left with L, most U sites, and some M sites. However, the L sites contained four times (19.3-32.1%) the amount of calcium found in the most calcium-rich sites of M and U (3.6-7.4 %). These geochemical contrasts between each habitat reflect the differences between their communities, with half of the species encountered during the study being habitat specific.

For bryophytes, the PCoA's first axis highlighted the importance of aluminium, sodium, calcium, manganese, and chromium. For vascular plants, the PCoA's first axis highlighted the importance of magnesium, calcium, manganese, potassium, and sodium. Potassium, sodium, calcium, iron, magnesium and manganese are essential elements for plants at the right concentration (Kirkby & Pilbeam, 1984; White & Karley, 2010; Maathuis, 2014; Hauer-Jákli & Tränkner, 2019; Schmidt *et al*, 2020; Alejandro *et al*, 2020). However, above a certain point, these elements become harmful for plants as aluminium and chromium can be (Singh *et al*, 2016; Muhammad *et al*, 2019; Sharma *et al*, 2020).

For bryophytes, the only mine specific species was *Bryum blindii* (Gagnon, 1987; Sheng *et al*, 2021), which could simply grow on basic/limestone substrates as described in North America (Ryan, 1996; FNA, 2014). Mine tailings house more weedy and tolerant bryophyte species such as *Pohlia nutans* (Shaw, 1990a; Bates & Farmer, 1992). Moreover, metal-rich specialised ecotypes appears in some bryophyte species, allowing mining site populations or urban populations of such tolerant species to better develop in mine tailings than rural ones (Shaw, 1990b, 1994). To survive in such environments, bryophytes usually tend to bioaccumulate heavy metals into their tissues usually leading to an alteration of their cell structure or reproductive capacities (Stanković *et al*, 2018). Except for some *Polytrichum*, *Dicranum* and *Pohlia* species (Shaw, 1990a; Stanković *et al*, 2018), the bryophyte communities we found in mine tailings have not been previously described in the literature. We suggest that the bryophyte communities found during this study represent tolerant, but not specialised, species to the harsh conditions created by stressful soils. It appears to be the same for vascular plants, for which the toxicity of heavy metals begin when metal concentrations are too high, leading to physiological and morphological alterations (Angulo-Bejarano *et al*, 2021). We found common and stress tolerant species as suggested by other studies on tailings who found various horsetails, *Typha latifolia*, scattered trees like *Larix laricina*, *Picea mariana, Populus tremuloides, P. balsamifera* and many native and non-native grasses and herbaceous, some typically found in disturbed habitats such as *Chamerion angustifolium* (Young *et al*, 2013; Martineau & Gervais, 2014; Omari *et al*, 2020). The low diversity of tree species paired with a high diversity of grasses and herbaceous plants reflects a pioneer type community on tailings, which may be maintained by unfavourable stressful soils in M, U and L sites (Conesa *et al*, 2006; Wang *et al*, 2017; Nikolić, 2020). In the end, geochemistry may not explain M diversity alone, but it certainly drives an important part of the specific assemblages.

We were in obligation to remove heavy metals like cadmium (Cd) and arsenic (As) from the analyses since they were only analysed for M and B sites due to the different types of samples. These elements are harmful for animals and they tend to bioaccumulate in the trophic chain but they are currently not known to be involved in any plant biological function (DalCorso *et al*, 2008; Verbruggen *et al*, 2009; Singh *et al*, 2016). It was then believed that these elements may be removed from the current study of plant communities. As an informative indication arsenic value ranged from

2.1 to more than 10000 ppm in M sites and from 4.1 to 52.8 ppm in B sites. Cadmium values in M sites were all lower than 0.4 ppm while they were ranging from 0.34 to 22.7 ppm in B sites.

4.7 Conclusion

Mine tailings (M), as well as other anthropogenic habitats, are known to shelter a specific diversity of species (Batty, 2005; Erskine *et al*, 2012; Rola *et al*, 2015). However in our study we found that the community was almost identical to that found in naturally uncommon habitats (U, L) with an unusual geochemistry (Jacobi *et al*, 2011; Holdaway *et al*, 2012; Boschen *et al*, 2016). Our results show that M sites are heterogeneous in geochemistry and plant assemblages, therefore can be sub-grouped. However, mine tailings plant diversity is almost exclusively constituted of common and widespread species. Mine tailings biodiversity is also so variable that we cannot ascertain mine tailings inputs for the regional biodiversity, except for *Reboulia hemisphaerica* and *Bryum blindii*. We therefore recommend renaturalising mine tailings, as this will not result in the loss of unique flora.

4.8 Acknowledgments

We want to thank funders of the NSERC-UQAT Industrial Chair on northern biodiversity in a mining context. We want to thank "*Corrige moi*" for students' reviews, Sébastien Bouchard as our field assistant, Julie Arsenault for her help in field work organisation and herbarium management and the Société Québécoise de Bryologie for rare bryophytes species check-up.

CONCLUSION GENERALE

Cette thèse a tout d'abord permis de combler une lacune des connaissances floristiques, surtout pour les bryophytes, d'habitats peu connus de l'Abitibi. En effet, ce sont au total presque une trentaine de nouvelles mentions d'espèces de bryophytes pour la région qui ont été faites sur les collines et les sites miniers abandonnés de la région. Ces connaissances s'ajoutent aux inventaires accumulés dans les forêts et tourbières de la région au cours des dernières années, permettant une vision d'ensemble un peu plus claire de la bryoflore régionale. Il reste cependant de nombreuses choses à découvrir en Abitibi.

Les communautés de ces habitats rares à l'échelle régionale ont également été un peu mieux cernées. Les forêts anciennes des collines abritent en effet de nombreuses espèces indicatrices en comparaison des forêts de plaine, même parmi les plus vieilles. Les forêts des plus hautes collines de la région étant d'autant plus riches en bryophytes et pauvres en plantes vasculaires que les collines les plus basses. En revanche, les cortèges de plantes retrouvés sur les sites miniers ne se démarquent pas réellement d'autres sites ouverts comportant un substrat stressant pour les plantes. Ces habitats stressants semblent accueillir des espèces tolérantes, avec de larges préférences écologiques, et une diversité importante que nos inventaires n'ont vraisemblablement pas réussi à couvrir.

Les raisons de ces différences varient selon les milieux étudiés. Il semblerait que des contrastes significatifs de températures et d'humidités durant la saison végétative existent entre collines de hauteur différentes, ce qui ne semble pas être décrit dans la littérature à notre connaissance, mais surtout avec la plaine environnante, ce qui est déjà décrit bien que les études à ce sujet manquent, dans la littérature. Les températures plus clémentes des collines, bien que les plus hautes soient significativement plus froides et plus humides que les plus basses, pourraient expliquer les différences de cortège que l'on retrouve entre collines mais aussi avec les forêts de plaine. A cela s'ajoutent des effets confondants : un climat plus stable, un substrat rocheux affleurant, un refuge contre les feux de forêts ou, plus récemment, les coupes forestières, grâce à des versants, crêtes et falaises. A contrario, la grande variabilité géochimique des sites miniers semble les conduire à ressembler à des sites calcaires ou ultramafiques, ce qui se reflète dans leurs communautés végétales. De surcroît, les courbes d'accumulation d'espèces de tous les habitats ouverts échantillonnés pointent du doigt une énorme diversité spécifique potentielle de ces habitats. Les espèces exclusives de ces habitats ouverts pourraient donc très bien ne pas l'être, et si ce n'est *Bryum blindii* et *Reboulia hemisphaerica*, il semblerait qu'il n'y ait pas d'espèces vraiment inféodées aux sites miniers désaffectés d'Abitibi.

Les vieilles forêts et affleurements rocheux des plus hautes collines de la région sont des habitats à part, très peu représentés sur le territoire, même si les vieilles forêts retrouvées sur les collines de façon générale diffèrent des veilles forêts de plaine. On peut espérer que ces hautes collines constituent un îlot climatique pour les espèces qu'on y retrouve et qui sont confrontées à des changements climatiques exacerbés en milieu boréal. La topographie accidentée de ces habitats rares semble suffisante pour les protéger d'une combustion complète par les feux de forêts ou de l'exploitation minière et forestière. La création de réserves naturelles ou de parcs, comme c'est déjà le cas pour les collines du parc national d'Aiguebelle, la réserve de biodiversité du lac Chicobi ou le tout récent parc des collines Kékéko, permettront éventuellement une meilleure veille de l'état de santé de ces communautés végétales. D'autre part, les sites miniers abandonnés, bien qu'apparemment sous-échantillonnés, ne semblent pas apporter une biodiversité singulière à la région. Pour cette raison, et le fait que leurs résidus soient extrêmement nocifs pour la majorité des animaux, leur restauration devrait être priorisée. En revanche, la spécificité géochimique de ces sites miniers pourrait permettre d'axer les travaux de restauration, car tous les sites et leurs polluants ne sont pas les mêmes.

De façon plus générale, cette thèse a permis de complexifier notre appréhension des vieilles forêts du domaine boréal mais également de comparer des résidus miniers à d'autres types d'habitats stressants pour les plantes bien que naturels. Ce dernier point ne semble pas disponible dans la littérature car les cortèges végétaux ne sont pas étudiés dans leur intégrité. Cet aspect de la thèse est donc particulièrement novateur car il amène à étudier des habitats qui ont été sous-échantillonnés dans la région mais également étudiés un à un par la littérature existante. Bien que nous n'ayons trouvé qu'un très faible nombre d'espèces rares et que les sites miniers abandonnés n'aient pas de valeur pour la biodiversité en apparence, nous pensons qu'il serait judicieux d'étudier la physiologie et la génétique des plantes qui y prospèrent en plus de leur abondance relative. En effet, nous n'avons étudié que le sol et essayer de le mettre en relation avec la composition ou la richesse spécifique qui s'y développe alors que nous ne savons pas à quel point ces habitats stressants peuvent façonner la réponse physiologique des plantes à leur environnement ainsi que leur patrimoine génétique, qui pourrait différer d'une population à l'autre si l'on en croit quelques rares études. Peut-être que les cortèges de plantes des milieux stressants sont similaires et constitués d'espèces communes ou rudérales mais nous ne savons pas si le fonctionnement de ces cortèges diffère, si la reproduction des individus qui le composent ou leur façon d'assimiler les nutriments est comparable.

Pour les vieilles forêts et les collines étudiées en milieu boréal, notre approche climatique sur de petits éléments topographiques semble assez isolée au sein de la littérature scientifique mais a permis d'avancer sur un certain nombre de points. L'humidité relative des vieilles forêts de colline s'accorde à ce que l'on peut retrouver en plaine alors que la température y est plus importante et la lumière moins abondante si l'on se fie au cortège d'espèces indicatrices qui y poussent. Il serait judicieux d'étendre cette approche à d'autres régions du domaine boréal, souvent marqué par un faible relief.

Enfin, nos résultats permettent d'arriver à des résultats interprétables et novateurs à l'échelle que nous avons choisie. Le niveau de finesse de notre étude pourra toujours être amélioré, bien entendu, et nous pensons que la première étape serait de travailler avec des notions d'abondance spécifique pour aller au-delà de la présence absence. Les notions de compétition, de génétique des populations ou de reproduction auraient également pu être utiles. En effet les plantes réagissent à leur environnement à travers des mécanismes de compétition, de reproduction et donc de sélection. Cependant, nos études des préférences écologiques d'espèces indicatrices nous ont par exemple donné un appui supplémentaire à notre réflexion au sujet des besoins écologiques des communautés végétales retrouvées dans les forêts de la région. Ces moyens indirects permettent également de mieux caractériser les cortèges d'espèces d'un milieu

APPENDICE A: LIST OF THE BRYOPHYTE SPECIES FOUND DURING THE SURVEY AND THEIR NUMBER OF OCCURRENCES IN EACH STATE (N = 5 (HILLS) X 3 (HABITATS) = 15) OR HABITAT (N = 2 (STATES) X 5 (HILLS) = 10). SPECIES NAMES IN BOLD INDICATE A NEW MENTION FOR THE ABITIBI REGION.

Species	**E**	**S**	**DR**	**F**	**WR**
Anastrophyllum michauxii (F. Weber) H. Buch	1	4	2	1	2
Andreaea rupestris Hedw.	10	7	9	2	6
Aulacomnium palustre (Hedw.) Schwägr.	2	3	0	2	3
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	6	6	3	5	4
Barbilophozia hatcheri (A. Evans) Loeske	3	0	0	2	1
Barbilophozia sudetica (Nees ex Huebener) L. Söderstr., De Roo & Hedd.	2	0	1	0	1
Bartramia pomiformis Hedw.	3	4	0	0	7
Bazzania denudata (Lindenb. & Gottsche) Trevis.	1	4	0	4	1
Bazzania trilobata (L.) Gray	4	4	0	5	3

Species	**E**	**S**	**DR**	**F**	**WR**
Blepharostoma trichophyllum (L.) Dumort. subsp. trichophyllum	9	10	0	9	10
Brachythecium acuminatum (Hedw.) Austin	8	7	2	10	3
Brachythecium acutum (Mitt.) Sull.	1	2	0	2	1
Brachythecium campestre (Müll. Hal.) Schimp.	2	3	0	5	0
Brachythecium curtum (Lindb.) Limpr.	6	7	0	9	4
Brachythecium erythrorrhizon Schimp.	0	2	0	2	0
Brachythecium laetum (Brid.) Schimp.	0	2	0	2	0
Brachythecium plumosum (Hedw.) Schimp.	6	4	0	9	1
Brachythecium populeum (Hedw.) Schimp.	3	4	0	7	0
Brachythecium reflexum (Starke) Schimp.	8	6	2	10	2
Brachythecium rutabulum (Hedw.) Schimp.	0	2	0	2	0
Brachythecium starkei (Brid.) Schimp.	3	4	0	7	0

Species	**E**	**S**	**DR**	**F**	**WR**
Brachythecium velutinum (Hedw.) Schimp.	2	5	0	7	0
Brotherella recurvans (Michx.) M. Fleisch.	5	4	0	7	2
Bryoerythrophyllum recurvirostrum (Hedw.) P.C. Chen	0	1	0	1	0
Bryum laevifilum Syed	1	0	0	0	1
Bryum pseudotriquetrum (Hedw.) G. Gaertn., B. Mey. & Scherb.	1	0	0	1	0
Callicladium haldanianum (Grev.) H.A. Crum	8	8	1	9	6
Calypogeia integristipula Steph.	6	3	2	4	3
Calypogeia muelleriana (Schiffn.) Müll. Frib.	1	0	0	1	0
Calypogeia neesiana (C. Massal. & Carestia) Müll. Frib.	4	5	1	3	5
Calypogeia neogaea (R.M. Schust.) Bakalin	1	0	0	0	1
Calypogeia sphagnicola (Arnell & J. Perss.) Warnst. & Loeske	1	0	0	1	0

Species	**E**	**S**	**DR**	**F**	**WR**
Campylophyllum hispidulum (Brid.) Hedenäs	2	1	0	3	0
Cephalozia bicuspidata (L.) Dumort.	3	1	0	0	4
Cephaloziella hampeana (Nees) Schiffn. ex Loeske	9	4	9	1	2
Cephaloziella rubella (Nees) Warnst. var. rubella	7	5	4	6	3
Chiloscyphus pallescens (Ehrh.) Dumort. var. pallescens	2	0	0	2	0
Cinclidium subrotundum Lindb.	1	0	0	1	0
Crossocalyx hellerianus (Nees ex Lindenb.) Meyl.	6	8	0	10	4
Dicranella heteromalla (Hedw.) Schimp.	0	1	1	0	0
Dicranella subulata (Hedw.) Schimp.	2	1	0	0	3
Dicranum acutifolium (Lindb. & Arnell) C.E.O. Jensen	4	1	5	0	0
Dicranum flagellare Hedw.	12	13	5	10	10
Dicranum fulvum Hook.	9	6	2	5	8
Dicranum fuscescens Turner	8	9	7	7	3

Species	**E**	**S**	**DR**	**F**	**WR**
Dicranum montanum Hedw.	14	12	6	10	10
Dicranum ontariense W.L. Peterson	1	0	0	1	0
Dicranum polysetum Sw.	11	12	9	9	5
Dicranum scoparium Hedw.	10	11	3	10	8
Dicranum undulatum Schrad. ex Brid.	2	0	0	1	1
Dicranum viride (Sull. & Lesq.) Lindb.	1	2	0	3	0
Didymodon fallax (Hedw.) R.H. Zander	3	1	1	0	3
Diphyscium foliosum (Hedw.) D. Mohr	1	0	0	0	1
Diplophyllum apiculatum (A. Evans) Steph.	0	2	0	0	2
Drepanocladus aduncus (Hedw.) Warnst.	0	1	1	0	0
Drummondia prorepens (Hedw.) E. Britton	0	1	0	1	0
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	2	6	0	5	3
Fissidens osmundoides Hedw.	2	0	0	1	1
Frullania eboracensis Lehm.	2	3	0	5	0

Species	**E**	**S**	**DR**	**F**	**WR**
Frullania oakesiana Austin	1	3	0	4	0
Frullania selwyniana Pearson	1	0	0	1	0
Fuscocephaloziopsis catenulata (Huebener) Váňa & L. Söderstr. subsp. *catenulata*	5	6	0	7	4
Fuscocephaloziopsis leucantha (Spruce) Váňa & L. Söderstr.	7	5	1	5	6
Fuscocephaloziopsis lunulifolia (Dumort.) Váňa & L. Söderstr.	8	9	0	9	8
Geocalyx graveolens (Schrad.) Nees	6	7	0	10	3
Grimmia longirostris Hook.	1	0	1	0	0
Gymnocolea inflata (Huds.) Dumort. subsp. *inflata*	3	1	1	0	3
Hedwigia ciliata (Hedw.) P. Beauv.	2	1	1	0	2
Herzogiella striatella (Brid.) Z. Iwats.	2	3	0	4	1
Herzogiella turfacea (Lindb.) Z. Iwats.	6	8	0	8	6
Homalia trichomanoides (Hedw.) Schimp.	0	1	0	1	0
Homomallium adnatum (Hedw.) Broth.	1	0	1	0	0

Species	**E**	**S**	**DR**	**F**	**WR**
Hygroamblystegium varium (Hedw.) Mönk. var. varium	0	1	0	1	0
Hylocomiastrum pyrenaicum (Spruce) M. Fleisch. ex Broth.	2	2	0	4	0
Hylocomiastrum umbratum (Hedw.) M. Fleisch. ex Broth.	1	1	0	2	0
Hylocomium splendens (Hedw.) Schimp.	4	4	1	5	2
Hypnum cupressiforme Hedw. var. cupressiforme	3	5	0	3	5
Hypnum fauriei Cardot	1	0	0	1	0
Hypnum imponens Hedw.	2	2	0	1	3
Hypnum lindbergii Mitt.	1	1	0	1	1
Hypnum pallescens (Hedw.) P. Beauv.	12	10	3	10	9
Isopterygiopsis muelleriana (Schimp.) Z. Iwats.	6	4	1	2	1
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	2	2	2	1	7
Lejeunea cavifolia (Ehrh.) Lindb.	0	1	0	0	1
Lepidozia reptans (L.) Dumort.	11	10	2	9	10

Species	**E**	**S**	**DR**	**F**	**WR**
Leucobryum glaucum (Hedw.) Ångström	1	0	1	0	0
Lophocolea heterophylla (Schrad.) Dumort.	10	7	0	10	7
Lophozia debiliformis R.M. Schuster & Damsh.	1	0	0	0	1
Lophozia silvicola H. Buch	8	6	1	6	7
Lophozia ventricosa (Dicks.) Dumort. var. ventricosa	14	9	5	9	9
Lophoziopsis longidens (Lindb.) Konstant. & Vilnet	5	7	1	8	3
Marsupella emarginata (Ehrh.) Dumort. var. emarginata	2	1	2	0	1
Mnium spinulosum Bruch & Schimp.	4	9	0	8	5
Neoorthocaulis attenuatus (Mart.) L. Söderstr., De Roo & Hedd.	12	8	4	8	8
Nowellia curvifolia (Dicks.) Mitt.	1	7	0	6	2
Nyholmiella obtusifolia (Schrad. ex Brid.) Holmen & E. Warncke	0	2	0	2	0

Species	**E**	**S**	**DR**	**F**	**WR**
Odontoschisma francisci (Hook.) L. Söderstr. & Váňa	2	0	2	0	0
Oncophorus virens (Hedw.) Brid.	4	3	0	5	2
Oncophorus wahlenbergii Brid.	4	5	0	8	1
Orthotrichum spp.	0	2	0	2	0
Pellia epiphylla (L.) Corda	1	0	0	1	0
Pellia neesiana (Gottsche) Limpr.	0	1	0	0	1
Philonotis fontana (Hedw.) Brid. var. fontana	1	0	0	0	1
Plagiochila porelloides (Torr. ex Nees) Lindenb. var. porelloides	1	4	0	3	2
Plagiomnium ciliare (Müll. Hal.) T.J. Kop.	1	1	0	2	0
Plagiomnium cuspidatum (Hedw.) T.J. Kop.	0	3	0	3	0
Plagiomnium drummondii (Bruch & Schimp.) T.J. Kop.	1	3	0	4	0
Plagiomnium ellipticum (Brid.) T.J. Kop.	2	0	0	2	0

Species	**E**	**S**	**DR**	**F**	**WR**
Plagiomnium medium (Bruch & Schimp.) T.J. Kop.	1	3	0	4	0
Plagiothecium cavifolium (Brid.) Z. Iwats.	7	4	0	4	7
Plagiothecium laetum Schimp.	11	10	1	10	10
Plagiothecium latebricola Schimp.	4	2	0	5	1
Pleurozium schreberi (Willd. ex Brid.) Mitt.	15	15	10	10	10
Pohlia cruda (Hedw.) Lindb.	4	5	0	2	7
Pohlia lescuriana (Sull.) Ochi	13	11	9	8	7
Pohlia nutans (Hedw.) Lindb.	12	11	5	10	8
Pohlia wahlenbergii (F. Weber & D. Mohr) A.L. Andrews	1	2	0	3	0
Polytrichastrum alpinum (Hedw.) G.L. Sm.	4	3	0	0	7
Polytrichum commune Hedw. var. commune	6	6	5	6	1
Polytrichum juniperinum Hedw.	3	1	3	1	0
Polytrichum longisetum Sw. ex Brid.	1	1	0	0	2

Species	**E**	**S**	**DR**	**F**	**WR**
Polytrichum piliferum Hedw.	4	5	9	0	0
Polytrichum strictum Menzies ex Brid.	1	2	3	0	0
Pseudobryum cinclidioides (Huebener) T.J. Kop.	2	0	0	2	0
Pseudotaxiphyllum distichaceum (Mitt.) Z. Iwats.	1	0	0	0	1
Pterigynandrum filiforme Hedw.	1	0	0	0	1
Ptilidium ciliare (L.) Hampe	8	7	9	0	6
Ptilidium pulcherrimum (Weber) Vain.	14	14	8	10	10
Ptilium crista-castrensis (Hedw.) De Not.	7	7	0	10	4
Pylaisia condensata (Mitt.) A. Jaeger	7	4	1	9	1
Pylaisia intricata (Hedw.) Schimp.	2	1	1	2	0
Pylaisia polyantha (Hedw.) Schimp.	4	3	2	4	1
Racomitrium affine (Schleich. ex F. Weber & D. Mohr) Lindb.	2	0	1	3	0
Racomitrium microcarpum (Hedw.) Brid.	4	5	0	0	2
Racomitrium sudeticum (Funck) Bruch & Schimp.	2	0	9	0	0

Species	**E**	**S**	**DR**	**F**	**WR**
Radula complanata (L.) Dumort.	2	2	0	0	2
Rhizomnium punctatum (Hedw.) T.J. Kop.	2	4	0	2	0
Rhynchostegium serrulatum (Hedw.) A. Jaeger	1	4	0	5	1
Rhytidiadelphus subpinnatus (Lindb.) T.J. Kop.	1	0	0	5	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	2	0	0	1	0
Riccardia multifida (L.) Gray subsp. multifida	1	1	0	2	0
Sanionia uncinata (Hedw.) Loeske	12	10	4	10	8
Scapania irrigua (Nees) Nees subsp. irrigua	3	2	0	2	3
Scapania mucronata H. Buch	1	0	0	0	1
Scapania nemorea (L.) Grolle	4	3	0	0	7
Scapania umbrosa (Schrad.) Dumort.	3	1	0	0	4
Scapania undulata (L.) Dumort.	1	2	0	0	3
Schistidium dupretii (Thér.) W.A. Weber	1	1	2	0	0

Species	**E**	**S**	**DR**	**F**	**WR**
Schistochilopsis incisa (Schrad.) Konstant. var. incisa	1	0	0	0	1
Schistochilopsis incisa (Schrad.) Konstant. var. *opacifolia* (Culm. ex Meyl.) Bakalin	6	3	0	5	4
Serpoleskea subtilis (Hedw.) Loeske	3	5	0	8	0
Sphagnum capillifolium (Ehrh.) Hedw.	7	8	4	7	4
Sphagnum centrale C.E.O. Jensen	1	0	0	1	0
Sphagnum fallax H. Klinggr.	2	0	0	0	2
Sphagnum girgensohnii Russow	2	2	0	4	0
Sphagnum squarrosum Crome	1	2	0	3	0
Sphenolobus minutus (Schreb. ex D. Crantz) Berggr.	8	7	1	9	5
Syzygiella autumnalis (DC.) K. Feldberg, Váňa, Hentschel & Heinrichs	11	10	1	10	10
Tetraphis pellucida Hedw.	11	10	1	10	10
Thuidium delicatulum (Hedw.) Schimp.	1	0	0	1	0
Thuidium recognitum (Hedw.) Lindb.	1	1	0	2	0

Species	**E**	**S**	**DR**	**F**	**WR**
Tortella tortuosa (Hedw.) Limpr.	3	1	2	0	2
Trichocolea tomentella (Ehrh.) Dumort.	1	0	0	1	0
Tritomaria exsecta (Schmidel) Schiffn. ex Loeske	2	4	1	2	3
Tritomaria exsectiformis (Breidl.) Schiffn. ex Loeske	4	4	0	4	4
Tritomaria quinquedentata (Huds.) H. Buch subsp. quinquedentata	4	3	0	5	2

APPENDICE B: LIST OF THE VASCULAR PLANT SPECIES FOUND DURING THE SURVEY AND THEIR NUMBER OF OCCURRENCES IN EACH STATE (N = 5 (HILLS) X 3 (HABITATS) = 15) OR HABITAT (N = 2 (STATES) X 5 (HILLS) = 10).

Species	**E**	**S**	**DR**	**F**	**WR**
Abies balsamea (Linnaeus) Miller	3	3	2	2	2
Acer rubrum Linnaeus	3	2	2	2	1
Acer spicatum Lamarck	2	2	0	2	2
Alnus alnobetula subsp. *crispa* (Aiton) Raus	3	1	1	2	1
Alnus incana (L.) Moench subsp. *rugosa* (Du Roi) R.T. Clausen	2	1	1	2	0
Amelanchier Medikus	3	2	2	2	1
Aralia hispida Ventenat	0	1	1	0	0
Aralia nudicaulis Linnaeus	2	2	0	2	2
Avenella flexuosa (Linnaeus) Drejer	1	0	1	0	0
Betula papyrifera Marshall	3	3	2	2	2
Capnoides sempervirens (Linnaeus) Borkhausen	0	1	1	0	0

Species	**E**	**S**	**DR**	**F**	**WR**
Carex deflexa Hornemann	1	0	0	0	1
Carex disperma Dewey	1	1	0	2	0
Carex foenea Willdenow	0	1	1	0	0
Carex intumescens Rudge	0	1	0	1	0
Carex leptalea Wahlenberg	1	0	0	1	0
Carex Linnaeus	2	1	1	2	0
Carex stipata Muhlenberg ex Willdenow	1	0	0	1	0
Carex tenera Dewey	0	1	1	0	0
Carex trisperma Dewey	1	1	0	2	0
Clintonia borealis (Aiton) Rafinesque	2	2	0	2	2
Coptis trifolia (Linnaeus) Salisbury	2	2	0	2	2
Cornus canadensis Linnaeus	3	3	2	2	2
Cypripedium acaule Aiton	2	1	2	1	0
Cystopteris fragilis (Linnaeus) Bernhardi	2	2	1	0	3
Danthonia spicata (Linnaeus) P. Beauvois ex Roemer & Schultes	1	1	2	0	0

Species	**E**	**S**	**DR**	**F**	**WR**
Dendrolycopodium dendroideum (Michaux) A. Haines	2	2	0	2	2
Diervilla lonicera Miller	1	0	1	0	0
Drosera rotundifolia Linnaeus	0	1	1	0	0
Dryopteris carthusiana (Villars) H.P. Fuchs	3	3	2	2	2
Equisetum sylvaticum Linnaeus	1	1	0	2	0
Eupatorium perfoliatum Linnaeus	0	1	0	1	0
Eurybia macrophylla (Linnaeus) Cassini	0	2	0	1	1
Galium triflorum Michaux	1	0	0	1	0
Gaultheria hispidula (Linnaeus) Muhlenberg ex Bigelow	1	3	1	2	1
Gaultheria procumbens Linnaeus	0	1	0	1	0
Goodyera repens (Linnaeus) R. Brown	1	0	0	1	0
Goodyera tesselata Loddiges	0	1	0	1	0
Gymnocarpium disjunctum (Ruprecht) Ching	0	1	0	0	1
Gymnocarpium dryopteris (Linnaeus) Newman	2	2	0	2	2

Species	**E**	**S**	**DR**	**F**	**WR**
Huperzia lucidula (Michaux) Trevisan	2	2	0	2	2
Ilex mucronata (Linnaeus) M. Powell, V. Savolainen & S. Andrews	2	1	2	0	1
Juncus bufonius Linnaeus	0	1	1	0	0
Kalmia angustifolia Linnaeus	3	3	2	2	2
Kalmia polifolia Wangenheim	1	0	1	0	0
Larix laricina (Du Roi) K. Koch	0	1	1	0	0
Linnaea borealis Linnaeus	2	2	0	2	2
Lonicera canadensis Bartram ex Marshall	1	2	0	2	1
Lonicera villosa (Michaux) Roemer & Schultes	0	1	0	1	0
Lycopodium clavatum Linnaeus	0	1	1	0	0
Lysimachia borealis (Rafinesque) U. Manns & Anderberg	3	2	1	2	2
Maianthemum canadense Desfontaines	3	3	2	2	2
Melampyrum lineare Desrousseaux	2	3	2	2	1
Mitella nuda Linnaeus	0	1	0	1	0

Species	**E**	**S**	**DR**	**F**	**WR**
Moneses uniflora (Linnaeus) A. Gray	1	1	0	1	1
Claytosmunda claytoniana (Linnaeus) Metzgar & Rouhan	2	0	0	1	1
Oxalis montana Rafinesque	2	2	0	2	2
Petasites frigidus var. *palmatus* (Aiton) Cronquist	0	1	0	1	0
Phegopteris connectilis (Michaux) Watt	2	2	0	2	2
Picea glauca (Moench) Voss	2	1	2	1	0
Picea mariana (Miller) Britton, Sterns & Poggenburgh	3	3	2	2	2
Pinus banksiana Lambert	3	1	2	1	1
Pinus strobus Linnaeus	0	1	1	0	0
Polypodium virginianum Linnaeus	2	1	1	0	2
Populus tremuloides Michaux	0	1	0	1	0
Prunus pensylvanica Linnaeus	2	1	2	1	0
Pteridium aquilinum (Linnaeus) Kuhn	3	3	2	2	2
Pyrola asarifolia Michaux	0	2	0	1	1

Species	**E**	**S**	**DR**	**F**	**WR**
Rhododendron groenlandicum (Oeder) Kron & Judd	1	3	1	2	1
Ribes glandulosum Grauer	1	0	1	0	0
Ribes lacustre (Persoon) Poiret	1	1	0	2	0
Ribes triste Pallas	1	1	1	1	0
Rubus pubescens Rafinesque	1	2	0	2	1
Salix bebbiana Sargent	0	1	1	0	0
Salix discolor Muhlenberg	1	1	1	1	0
Sanicula marilandica Linnaeus	0	1	1	0	0
Scirpus atrocinctus Fernald	0	1	1	0	0
Scirpus atrovirens Willdenow	0	1	1	0	0
Solidago macrophylla Banks ex Pursh	1	1	0	0	2
Sorbus americana Marshall	3	3	2	2	2
Streptopus lanceolatus (Aiton) Reveal var. *lanceolatus*	0	2	0	1	1
Taxus canadensis Marshall	1	1	0	2	0
Thalictrum pubescens Pursh	1	0	0	1	0

Species	**E**	**S**	**DR**	**F**	**WR**
Thuja occidentalis Linnaeus	2	3	1	2	2
Vaccinium angustifolium Aiton	3	3	2	2	2
Vaccinium myrtilloides Michaux	3	3	2	2	2
Viburnum cassinoides Linnaeus	3	2	2	2	1
Viburnum lentago Linnaeus	1	0	1	0	0
Viola renifolia A. Gray	1	1	0	0	2

APPENDICE C: TABLE SHOWING THE PLOT NUMBER PER CATEGORIES IN EACH PARAMETER STUDIED

		Bryophyte plots	**Vascular plant plots**
Forest age category	30-50	21	384
	50-70	8	229
	70-90	27	80
	>100	24	37
	Hill	10	10
Surface deposit category	Glaciolacustrine	45	331
	Dune	0	9
	Juxtaglacial	0	43
	Organic	8	86
	Rock	0	45
	Till	37	226
Stand type category	Broadleaf	0	91
	BroadConif	0	106
	ConifBroad	0	172
	Coniferous	71	371
	Other	19	0

APPENDICE D: TABLE SHOWING THE SPECIES COUNT PER FOREST AGE CATEGORIES

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Amblystegium serpens (Hedw.) Schimp.	5	1	5	3	0
Anastrophyllum michauxii (F. Weber) H. Buch	1	0	0	1	2
Andreaea rupestris Hedw.	0	0	0	0	2
Aneura pinguis (L.) Dumort.	1	0	0	0	0
Atrichum angustatum (Brid.) Bruch & Schimp.	0	0	1	0	0
Atrichum tenellum (Röhl.) Bruch & Schimp.	1	0	1	1	0
Aulacomnium palustre (Hedw.) Schwägr.	2	0	3	17	2
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	0	0	2	7	6
Barbilophozia hatcheri (A. Evans) Loeske	0	0	1	0	2
Bazzania denudata (Lindenb. & Gottsche) Trevis.	0	0	0	0	5
Bazzania trilobata (L.) Gray	2	0	3	2	9
Blepharostoma trichophyllum (L.) Dumort. subsp. *trichophyllum*	4	0	6	13	24
Blindia acuta (Hedwig) Bruch & Schimper	1	0	0	0	0
Brachythecium acuminatum (Hedw.) Austin	1	0	0	3	17
Brachythecium acutum (Mitt.) Sull.	0	0	0	3	2

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Brachythecium albicans (Hedw.) Schimp.	0	0	0	1	0
Brachythecium campestre (Müll. Hal.) Schimp.	15	7	16	7	9
Brachythecium curtum (Lindb.) Limpr.	1	0	3	10	15
Brachythecium erythrorrhizon Schimp.	0	1	0	0	4
Brachythecium laetum (Brid.) Schimp.	0	0	0	1	2
Brachythecium novae-angliae (Sull. & Lesq.) Jaeg.	1	0	0	0	0
Brachythecium plumosum (Hedw.) Schimp.	0	0	0	0	12
Brachythecium populeum (Hedw.) Schimp.	1	0	0	0	11
Brachythecium reflexum (Starke) Schimp.	9	7	7	5	22
Brachythecium rutabulum (Hedw.) Schimp.	1	0	1	3	3
Brachythecium starkei (Brid.) Schimp.	3	1	3	7	12
Brachythecium velutimum (Hedw.) Schimp.	3	0	1	1	13
Breidleria pratensis (Koch ex Spruce) Loeske	2	0	0	1	0
Brotherella recurvans (Michx.) M. Fleisch.	1	0	2	4	16
Bryoerythrophyllum recurvirostrum (Hedw.) P.C. Chen	1	0	0	0	1
Bryum creberrimum Taylor	1	0	0	0	0
Bryum laevifilum Syed	0	0	1	0	0

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Bryum pseudotriquetrum (Hedw.) G. Gaertn., B. Mey. & Scherb.	0	0	0	0	2
Callicladium haldanianum (Grev.) H.A. Crum	10	5	15	5	24
Calliergon cordifolium (Hedw.) Kindb.	0	0	1	0	0
Calliergon richardsonii (Mitt.) Kindb.	0	0	0	1	0
Calypogeia integristipula Steph.	0	0	0	0	9
Calypogeia muelleriana (Schiffn.) Müll. Frib.	3	0	2	7	1
Calypogeia neesiana (C. Massal. & Carestia) Müll. Frib.	3	0	2	5	4
Calypogeia sphagnicola (Arnell & J. Perss.) Warnst. & Loeske	1	0	0	6	1
Calypogeia suecica (Arnell & J. Perss.) Müll. Frib.	1	0	0	1	0
Campyliadelphus chrysophyllus (Bridel) Kanda	0	0	1	3	5
Campylium stellatum (Hedwig) C. E. O. Jensen	0	0	0	1	0
Campylophyllum halleri (Hedw.) M. Fleisch.	1	0	1	0	0
Campylophyllum hispidulum (Brid.) Hedenäs	1	2	3	6	0
Cephalozia bicuspidata (L.) Dumort.	1	0	1	2	0
Cephaloziella elachista (J.B. Jack ex Gottsche & Rabenh.) Schiffn.	0	0	0	2	0
Cephaloziella hampeana (Nees) Schiffn. ex Loeske	0	0	2	0	7

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Cephaloziella rubella (Nees) Warnst. var. rubella	0	0	4	11	1
Cephaloziella spinigera (Lindb.) Warnst.	0	0	0	1	0
Ceratodon purpureus (Hedw.) Brid.	1	0	2	2	0
Chiloscyphus pallescens (Ehrh.) Dumort. var. pallescens	0	0	0	0	3
Cinclidium subrotundum Lindb.	0	0	0	0	1
Cirriphyllum piliferum (Hedw.) Grout	1	0	0	0	0
Crossocalyx hellerianus (Nees ex Lindenb.) Meyl.	0	0	3	6	21
Dicranella heteromalla (Hedw.) Schimp.	1	0	2	2	0
Dicranum flagellare Hedw.	5	1	7	8	25
Dicranum fulvum Hook.	1	1	1	1	5
Dicranum fuscescens Turner	14	3	21	16	11
Dicranum majus Turner var. *majus*	1	0	1	3	0
Dicranum montanum Hedw.	8	3	9	10	30
Dicranum ontariense W.L. Peterson	7	1	6	7	1
Dicranum polysetum Sw.	13	4	22	19	19
Dicranum scoparium Hedw.	11	5	11	7	23
Dicranum undulatum Schrad. ex Brid.	1	0	1	10	1
Dicranum viride (Sull. & Lesq.) Lindb.	0	0	1	2	5

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Drepanocladus aduncus (Hedw.) Warnst.	0	0	0	1	0
Drummondia prorepens (Hedw.) E. Britton	0	0	0	0	1
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	0	1	1	3	15
Fissidens osmundoides Hedw.	0	0	0	0	3
Frullania eboracensis Lehm.	0	0	0	0	9
Frullania inflata Gottsche	0	0	0	1	0
Frullania oakesiana Austin	1	0	1	6	6
Frullania selwyniana Pearson	0	0	0	0	1
Fuscocephaloziopsis catenulata (Huebener) Váňa & L.Söderstr.	0	0	0	0	11
Fuscocephaloziopsis connivens (Dicks.) Vána & L. Söderstr.	1	0	3	11	0
Fuscocephaloziopsis leucantha (Spruce) Váňa & L. Söderstr.	0	0	1	1	9
Fuscocephaloziopsis loitlesbergeri (Schiffn.) Váňa & L. Söderstr.	0	0	0	5	0
Fuscocephaloziopsis lunulifolia (Dumort.) Váňa & L. Söderstr.	5	0	7	9	21
Fuscocephaloziopsis pleniceps (Austin) Váňa & L. Söderstr.	1	0	1	9	0

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Geocalyx graveolens (Schrad.) Nees	2	1	6	9	22
Gymnocolea inflata (Huds.) Dumort. subsp. *inflata*	0	0	0	1	0
Herzogiella striatella (Brid.) Z. Iwats.	1	0	0	1	5
Herzogiella turfacea (Lindb.) Z. Iwats.	2	0	4	10	20
Homalia trichomanoides (Hedw.) Schimp.	0	0	0	1	1
Hygroamblystegium varium (Hedw.) Mönk. var. *varium*	0	2	2	1	1
Hygrohypnum eugyrium (Schimper) Loeske	0	0	1	0	0
Hylocomiastrum pyrenaicum (Spruce) M. Fleisch. ex Broth.	0	0	0	0	6
Hylocomiastrum umbratum (Hedw.) M. Fleisch. ex Broth.	1	0	2	1	2
Hylocomium splendens (Hedw.) Schimp.	3	1	6	14	10
Hypnum cupressiforme Hedw. var. *cupressiforme*	6	4	1	0	3
Hypnum fauriei Cardot	1	0	0	1	3
Hypnum imponens Hedw.	2	1	4	5	3
Hypnum lindbergii Mitt.	1	0	0	0	1
Hypnum pallescens (Hedw.) P. Beauv.	13	8	16	7	25
Isopterygiopsis muelleriana (Schimp.) Z. Iwats.	0	0	1	1	1
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	0	0	0	1	3

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Kindbergia praelonga (Hedw.) Ochyra	1	0	0	0	0
Lepidozia reptans (L.) Dumort.	4	0	8	13	24
Leptobryum pyriforme (Hedwig) Wilson	0	0	0	3	0
Liochlaena lanceolata Nees	1	0	1	2	0
Lophocolea heterophylla (Schrad.) Dumort.	20	4	20	8	28
Lophozia ascendens (Warnst.) R.M. Schust.	0	0	2	3	0
Lophozia guttulata (Lindb. & Arnell) A. Evans	1	0	2	9	0
Lophozia silvicola H. Buch	0	0	1	7	8
Lophozia ventricosa (Dicks.) Dumort. var. *ventricosa*	1	0	5	12	16
Lophoziopsis longidens (Lindb.) Konstant. & Vilnet	1	0	3	4	17
Marsupella emarginata (Ehrh.) Dumort. var. *emarginata*	1	0	1	0	0
Mesoptychia rutheana (Limpr.) L. Söderstr. & Váňa	0	0	1	0	0
Mnium hornum Hedw.	1	0	0	0	0
Mnium spinulosum Bruch & Schimp.	0	0	2	4	18
Mnium stellare Hedw.	1	0	0	0	0
Mylia anomala (Hook.) Gray	0	0	1	7	0
Neoorthocaulis attenuatus (Mart.) L. Söderstr., De Roo & Hedd.	3	1	4	4	20

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Nowellia curvifolia (Dicks.) Mitt.	3	0	7	8	10
Nyholmiella obtusifolia (Schrad. ex Brid.) Holmen & E. Warncke	0	0	2	0	3
Oncophorus virens (Hedw.) Brid.	0	0	0	2	6
Oncophorus wahlenbergii Brid.	0	0	1	5	13
Orthotrichum spp.	1	0	1	1	2
Paraleucobryum longifolium (Ehrh. ex Hedw.) Loeske	0	0	1	1	0
Pellia epiphylla (L.) Corda	0	0	0	0	2
Plagiochila porelloides (Torr. ex Nees) Lindenb. var. *porelloides*	0	0	0	2	3
Plagiomnium ciliare (Müll. Hal.) T.J. Kop.	0	0	0	0	2
Plagiomnium cuspidatum (Hedw.) T.J. Kop.	2	0	1	3	3
Plagiomnium drummondii (Bruch & Schimp.) T.J. Kop.	2	0	0	1	5
Plagiomnium ellipticum (Brid.) T.J. Kop.	2	1	0	3	2
Plagiomnium medium (Bruch & Schimp.) T.J. Kop.	0	0	1	1	6
Plagiothecium cavifolium (Brid.) Z. Iwats.	1	0	3	4	5
Plagiothecium denticulatum (Hedw.) Schimp.	4	0	3	7	0
Plagiothecium laetum Schimp.	6	3	10	10	28
Plagiothecium latebricola Schimp.	6	3	13	0	5

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Platygyrium repens (Brid.) Schimp.	0	0	1	4	0
Pleurozium schreberi (Willd. ex Brid.) Mitt.	18	6	25	22	29
Pogonatum dentatum (Menzies ex Brid.) Brid.	1	0	1	0	0
Pohlia cruda (Hedw.) Lindb.	1	0	0	0	2
Pohlia elongata Hedw. var. *elongata*	0	0	0	1	0
Pohlia lescuriana (Sull.) Ochi	1	0	0	0	15
Pohlia nutans (Hedw.) Lindb.	4	0	8	17	18
Pohlia sphagnicola (Bruch & Schimp.) Broth.	0	0	2	7	0
Pohlia wahlenbergii (F. Weber & D. Mohr) A.L. Andrews	0	0	0	0	3
Polytrichastrum alpinum (Hedw.) G.L. Sm.	1	0	0	1	0
Polytrichum commune Hedw. var. *commune*	4	1	9	8	8
Polytrichum densifolium Wilson ex Mitt.	1	0	1	1	0
Polytrichum juniperinum Hedw.	2	0	2	7	2
Polytrichum longisetum Sw. ex Brid.	1	0	2	1	0
Polytrichum pallidisetum Funck	1	0	1	0	0
Polytrichum strictum Menzies ex Brid.	2	1	3	9	0
Pseudobryum cinclidioides (Huebener) T.J. Kop.	0	0	0	0	2

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Pseudocampylium radicale (P. Beauv.) Vanderp. & Hedenäs	0	0	1	0	0
Pseudotaxiphyllum elegans (Brid.) Z. Iwats.	1	0	0	0	0
Ptilidium ciliare (L.) Hampe	4	1	8	19	0
Ptilidium pulcherrimum (Weber) Vain.	20	7	25	17	30
Ptilium crista-castrensis (Hedw.) De Not.	5	3	15	21	20
Pylaisia intricata (Hedw.) Schimp.	2	1	3	5	2
Pylaisia polyantha (Hedw.) Schimp.	0	0	1	2	4
Pylaisia selwynii Kindb.	0	0	1	0	18
Racomitrium aciculare (Hedw.) Brid.	0	0	0	0	0
Radula complanata (L.) Dumort.	0	0	0	1	4
Rhizomnium pseudopunctatum (Bruch & Schimp.) T.J. Kop.	0	0	0	2	0
Rhizomnium punctatum (Hedw.) T.J. Kop.	1	0	0	6	8
Rhynchostegium serrulatum (Hedw.) A. Jaeger	1	0	0	0	6
Rhytidiadelphus subpinnatus (Lindb.) T.J. Kop.	1	0	1	0	2
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	0	0	4	4
Riccardia latifrons (Lindb.) Lindb.	1	0	3	4	0
Riccardia multifida (L.) Gray subsp. multifida	0	0	0	0	4

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Sanionia uncinata (Hedw.) Loeske	16	8	19	13	26
Sarmentypnum exannulatum (Schimp.) Hedenäs	0	0	0	1	0
Scapania apiculata Spruce	0	0	0	1	0
Scapania irrigua (Nees) Nees subsp. irrigua	1	0	0	2	2
Scapania nemorea (L.) Grolle	1	0	0	0	0
Schistochilopsis incisa (Schrad.) Konstant. var. *opacifolia* (Culm. ex Meyl.) Bakalin	0	0	0	1	5
Schistostega pennata (Hedw.) F. Weber & D. Mohr	1	0	0	0	0
Schljakovia kunzeana (Huebener) Konstant. & Vilnet	0	0	2	6	0
Sciuro-hypnum oedipodium (Mitten) Ignatov & Huttunen	1	2	0	0	0
Serpoleskea subtilis (Hedw.) Loeske	0	0	0	1	12
Sphagnum angustifolium (Warnst.) C.E.O. Jensen	2	0	4	16	0
Sphagnum capillifolium (Ehrh.) Hedw.	2	0	9	12	11
Sphagnum centrale C.E.O. Jensen	1	0	0	2	1
Sphagnum divinum Flatberg & Hassel	2	0	1	15	0
Sphagnum fallax H. Klinggr.	1	0	1	11	0
Sphagnum fuscum (Schimp.) H. Klinggr.	0	0	0	11	0
Sphagnum girgensohnii Russow	5	0	8	8	6

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Sphagnum quinquefarium (Lindb.) Warnst.	1	0	1	0	0
Sphagnum rubellum Wilson	1	0	1	3	0
Sphagnum russowii Warnst.	1	0	3	17	0
Sphagnum squarrosum Crome	2	0	2	1	6
Sphagnum subfulvum Sjörs	0	0	1	0	0
Sphagnum subtile (Russow) Warnst.	0	0	2	1	0
Sphagnum tenerum Sull. & Lesq. ex Sull.	0	0	0	1	0
Sphagnum teres (Schimp.) Ångström	0	0	1	0	0
Sphagnum warnstorfii Russow	0	0	1	2	0
Sphagnum wulfianum Girg.	1	0	2	3	0
Sphenolobus minutus (Schreb. ex D. Crantz) Berggr.	0	0	1	1	13
Splachnum ampullaceum Hedw.	0	0	0	1	0
Straminergon stramineum (Dicks. ex Brid.) Hedenäs	0	0	2	5	0
Syzygiella autumnalis (DC.) K. Feldberg, Váňa, Hentschel & Heinrichs	8	2	10	15	29
Tetraphis pellucida Hedw.	7	0	11	14	29
Tetraplodon angustatus (Hedw.) Bruch & Schimp.	0	0	0	1	0
Thuidium delicatulum (Hedw.) Schimp.	0	0	0	0	1
Thuidium recognitum (Hedw.) Lindb.	0	0	0	1	2

Bryophyte species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Tomentypnum falcifolium (Renauld ex Nichols) Tuom.	0	0	0	4	0
Tomentypnum nitens (Hedw.) Loeske	0	0	0	2	0
Tortella humilis (Hedw.) Jenn.	0	1	0	0	0
Trichocolea tomentella (Ehrh.) Dumort.	0	0	0	0	1
Tritomaria exsecta (Schmidel) Schiffn. ex Loeske	0	0	0	0	3
Tritomaria exsectiformis (Breidl.) Schiffn. ex Loeske	0	0	0	4	5
Tritomaria laxa (Lindb.) Stotler & Crand.-Stotl.	0	0	0	1	0
Tritomaria quinquedentata (Huds.) H. Buch subsp. *quinquedentata*	0	0	0	0	5
Ulota coarctata (P. Beauv.) Hammar	1	0	1	1	0
Ulota crispa (Hedw.) Brid.	0	0	2	1	0
Warnstorfia fluitans (Hedw.) Loeske	1	0	1	5	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Abies balsamea (Linnaeus) Miller	280	179	60	26	10
Acer rubrum Linnaeus	49	27	9	1	4
Acer spicatum Lamarck	81	81	23	7	5

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Achillea millefolium Linnaeus	12	4	0	0	0
Actaea pachypoda Elliott	1	0	0	0	0
Actaea rubra (Aiton) Willdenow	23	22	6	0	0
Alnus alnobetula subsp. *crispa* (Aiton) Raus	91	34	14	3	2
Alnus incana subsp. *rugosa* (Du Roi) R.T. Clausen	192	110	40	20	3
Amelanchier Medikus	195	130	38	10	6
Anaphalis margaritacea (Linnaeus) Bentham & Hooker f.	11	4	0	0	0
Andromeda polifolia var. *latifolia* Aiton	4	1	2	0	0
Antennaria Gaertner	0	0	1	0	0
Apocynum androsaemifolium Linnaeus	14	9	0	0	0
Aralia hispida Ventenat	0	0	0	1	0
Aralia nudicaulis Linnaeus	154	117	34	8	7
Aronia melanocarpa (Michaux) Elliott	0	0	1	0	0
Eurybia macrophylla (Linnaeus) Cassini	19	8	0	3	1
Athyrium filix-femina (Linnaeus) Roth ex Mertens	54	51	9	4	0
Betula alleghaniensis Britton	1	0	1	1	0
Betula glandulosa Michaux	2	0	1	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Betula papyrifera Marshall	243	171	49	15	10
Betula pumila Linnaeus	4	2	2	2	0
Botrypus virginiamus (Linnaeus) Michaux	4	1	0	0	0
Caltha palustris Linnaeus	3	2	0	3	0
Carex Linnaeus	205	117	44	23	3
Caulophyllum thalictroides (Linnaeus) Michaux	0	1	0	0	0
Chamaedaphne calyculata (Linnaeus) Moench	34	9	11	11	0
Chamaenerion angustifolium (Linnaeus) Scopoli subsp. *angustifolium*	68	35	12	0	0
Circaea alpina Linnaeus	8	11	5	0	0
Cirsium Miller	2	1	0	0	0
Claytonia caroliniana Michaux	1	0	0	0	0
Claytosmunda claytoniana (Linnaeus) Metzgar & Rouhan	20	12	11	1	0
Climacium dendroides (Hedw.) F. Weber & D. Mohr	6	1	0	0	0
Clintonia borealis (Aiton) Rafinesque	214	157	45	17	7
Comarum palustre Linnaeus	0	1	0	2	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Comptonia peregrina (Linnaeus) J.M. Coulter	10	2	0	0	0
Coptis trifolia (Linnaeus) Salisbury	204	122	46	18	7
Corallorhiza maculata (Rafinesque) Rafinesque	0	2	0	0	0
Cornus alternifolia Linnaeus f.	10	5	1	0	0
Cornus canadensis Linnaeus	266	175	57	22	8
Cornus sericea Linnaeus	34	20	2	2	0
Corylus cornuta Marshall	65	66	20	3	0
Cypripedium acaule Aiton	30	15	5	0	2
Dendrolycopodium obscurum (Linnaeus) A. Haines	104	73	23	8	0
Diervilla lonicera Miller	136	90	27	3	0
Diphasiastrum complanatum (Linnaeus) Holub	11	3	1	0	0
Diphasiastrum digitatum (Dillenius ex A. Braun) Holub	0	1	0	0	0
Dryopteris carthusiana (Villars) H.P. Fuchs	152	106	30	9	6
Dryopteris cristata (Linnaeus) A. Gray	2	0	0	0	0
Endotropis alnifolia (L'Héritier) Hauenschild	4	2	1	2	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Epigaea repens Linnaeus	27	15	1	0	0
Equisetum Linnaeus	109	52	14	8	0
Equisetum sylvaticum Linnaeus	46	26	6	6	3
Eupatorium perfoliatum Linnaeus	0	0	0	0	1
Eriophorum Linnaeus	6	2	0	0	0
Eurybia macrophylla (Linnaeus) Cassini	124	81	26	2	0
Fallopia cilinodis (Michaux) Holub	0	1	0	0	0
Fragaria Linnaeus	39	11	4	1	0
Fraxinus nigra Marshall	2	1	0	0	0
Galium labradoricum (Wiegand) Wiegand	1	1	0	0	0
Galium Linnaeus	73	57	13	3	0
Galium triflorum Michaux	10	3	0	1	1
Gaultheria hispidula (Linnaeus) Muhlenberg ex Bigelow	198	130	52	31	6
Gaultheria procumbens Linnaeus	14	4	2	1	1
Geocaulon lividum (Richardson) Fernald	8	0	2	2	0
Geum macrophyllum Willdenow	1	0	0	0	0
Geum rivale Linnaeus	3	0	0	1	0
Goodyera R. Brown	2	2	0	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Goodyera repens (Linnaeus) R. Brown	9	12	1	1	1
Goodyera tesselata Loddiges	0	0	0	0	1
Gymnocarpium dryopteris (Linnaeus) Newman	0	0	0	0	4
Gymnocarpium disjunctum (Ruprecht) Ching	67	43	14	4	0
Heracleum maximum W. Bartram	2	1	0	0	0
Hieracium Linnaeus	20	2	0	0	0
Huperzia lucidula (Michaux) Trevisan	29	21	10	1	3
Ilex mucronata (Linnaeus) M. Powell, V. Savolainen & S. Andrews	107	55	24	6	0
Ilex verticillata (Linnaeus) A. Gray	0	0	1	0	0
Impatiens capensis Meerburgh	7	8	2	0	0
Iris versicolor Linnaeus	2	2	1	2	0
Kalmia angustifolia Linnaeus	218	125	50	26	3
Kalmia polifolia Wangenheim	24	7	8	8	0
Lactuca canadensis Linnaeus	0	1	0	0	0
Larix laricina (Du Roi) K. Koch	54	19	15	8	0
Linnaea borealis Linnaeus	194	133	36	14	7
Lonicera canadensis Bartram ex Marshall	39	34	10	3	3

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Lonicera dioica Linnaeus	1	1	0	0	0
Lonicera villosa (Michaux) Roemer & Schultes	6	7	2	2	1
Dendrolycopodium dendroideum (Michaux) A. Haines	0	0	0	0	3
Lycopodium clavatum Linnaeus	46	17	5	1	0
Lycopus uniflorus Michaux	1	0	0	0	0
Lysimachia borealis (Rafinesque) U. Manns & Anderberg	222	146	41	17	9
Maianthemum canadense Desfontaines	280	170	57	18	7
Maianthemum racemosum (Linnaeus) Link	1	2	2	0	0
Maianthemum trifolium (Linnaeus) Sloboda	63	25	17	16	0
Matteuccia struthiopteris (Linnaeus) Todaro	0	1	0	0	0
Melampyrum lineare Desrousseaux	13	7	2	0	2
Mertensia paniculata (Aiton) G. Don	2	1	0	0	0
Mitella nuda Linnaeus	44	36	9	4	1
Moneses uniflora (Linnaeus) A. Gray	4	3	1	1	1
Monotropa uniflora Linnaeus	12	6	5	0	0
Myrica gale Linnaeus	2	2	1	0	0
Nabalus Cassini	5	2	0	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Neottia cordata (Linnaeus) Richard	0	0	2	0	0
Oclemena acuminata (Michaux) Greene	50	20	5	0	0
Onoclea sensibilis Linnaeus	0	2	0	0	0
Orthilia secunda (Linnaeus) House	16	8	9	2	0
Osmorhiza claytonii (Michaux) C.B. Clarke	0	0	0	0	1
Osmundastrum cinnamomeum (Linnaeus) C. Presl	1	2	1	0	0
Ostrya virginiana (Miller) K. Koch	1	1	0	0	0
Oxalis montana Rafinesque	54	44	14	6	2
Parathelypteris noveboracensis (Linnaeus) Ching	10	2	2	0	0
Petasites frigidus var. *palmatus* (Aiton) Cronquist	51	18	5	3	1
Phegopteris connectilis (Michaux) Watt	8	11	2	0	3
Picea abies (Linnaeus) H. Karsten	1	0	0	0	0
Picea glauca (Moench) Voss	90	78	18	7	1
Picea mariana (Miller) Britton, Sterns & Poggenburgh	325	193	72	33	8
Picea rubens Sargent	2	0	0	0	0
Pinus banksiana Lambert	147	80	25	7	2

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Pinus resinosa Aiton	1	0	0	0	0
Pinus strobus Linnaeus	5	5	2	0	0
Platanthera orbiculata (Pursh) Lindley	0	2	0	0	0
Platanthera Richard	0	1	0	0	0
Polypodium virginianum Linnaeus	2	3	1	0	0
Populus balsamifera Linnaeus	17	10	2	2	0
Populus grandidentata Michaux	1	0	0	0	0
Populus tremuloides Michaux	174	102	30	6	2
Potentilla norvegica Linnaeus	1	0	0	0	0
Prunus pensylvanica Linnaeus f.	148	71	14	7	1
Prunus virginiana Linnaeus	23	20	3	1	0
Pteridium aquilinum (Linnaeus) Kuhn	91	62	20	3	2
Pyrola asarifolia Michaux	4	3	1	2	1
Pyrola elliptica Nuttall	12	14	4	0	0
Pyrola Linnaeus	13	8	1	1	0
Ranunculus abortivus Linnaeus	1	0	0	0	0
Ranunculus acris Linnaeus	8	1	2	0	0
Ranunculus Linnaeus	2	1	2	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Rhododendron canadense (Linnaeus) Torrey	2	0	0	0	0
Rhododendron groenlandicum (Oeder) Kron & Judd	208	114	47	30	4
Rhus typhina Linnaeus	0	1	0	0	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	20	16	7	0	0
Ribes americanum Miller	0	1	0	0	0
Ribes cynosbati Linnaeus	4	2	0	0	0
Ribes glandulosum Grauer	133	83	24	6	0
Ribes hirtellum Michaux	1	1	0	0	0
Ribes lacustre (Persoon) Poiret	38	29	6	4	3
Ribes triste Pallas	44	47	10	2	1
Rosa acicularis Lindley	13	11	4	0	0
Rubus allegheniensis Porter	0	1	0	0	0
Rubus chamaemorus Linnaeus	7	0	0	0	0
Rubus idaeus Linnaeus	104	66	11	5	0
Rubus pubescens Rafinesque	116	82	19	10	4
Rubus repens (Linnaeus) Kuntze	1	1	0	0	0
Salix Linnaeus	275	139	40	18	1
Sambucus canadensis Linnaeus	3	0	0	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Sambucus racemosa Linnaeus	41	26	6	5	0
Sarracenia purpurea Linnaeus	1	0	0	0	0
Scutellaria lateriflora Linnaeus	1	0	0	0	0
Senecio Linnaeus	2	0	0	0	0
Solidago Linnaeus	28	9	1	0	0
Solidago macrophylla Banks ex Pursh	31	26	4	0	0
Solidago rugosa Miller	25	11	1	1	0
Sonchus Linnaeus	1	0	0	0	0
Sorbus americana Marshall	119	59	22	10	7
Sorbus decora (Sargent) C.K. Schneider	91	83	19	6	0
Spinulum annotinum (Linnaeus) A. Haines subsp. *annotinum*	99	62	16	12	0
Spiraea alba var. *latifolia* (Aiton) Dippel	5	1	2	0	0
Stellaria Linnaeus	2	2	0	0	0
Stereocaulon paschale (L.) Hoffm.	6	2	0	0	0
Streptopus amplexifolius (Linnaeus) de Candolle	16	9	6	2	0
Streptopus lanceolatus (Aiton) Reveal var. *lanceolatus*	73	71	18	1	2

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Symphyotrichum puniceum (Linnaeus) Á. Löve & D. Löve var. *puniceum*	12	11	1	2	0
Taraxacum officinale F.H. Wiggers	8	1	0	0	0
Taxus canadensis Marshall	22	22	5	3	5
Thalictrum dioicum Linnaeus	2	0	0	0	0
Thalictrum pubescens Pursh	12	9	3	2	1
Thuja occidentalis Linnaeus	8	9	2	1	6
Trifolium Linnaeus	2	0	0	0	0
Trillidium undulatum (Willdenow) Floden & E.E. Schilling	5	1	2	1	0
Trillium cernuum Linnaeus	5	4	0	0	0
Trillium erectum Linnaeus	6	5	1	0	0
Vaccinium angustifolium Aiton	248	136	52	27	7
Vaccinium myrtilloides Michaux	274	160	56	26	7
Vaccinium oxycoccos Linnaeus	22	4	9	9	0
Vaccinium vitis-idaea Linnaeus	1	1	0	0	0
Viburnum cassinoides Linnaeus	183	104	42	9	4
Viburnum edule (Michaux) Rafinesque	62	40	13	5	0
Viburnum opulus var. *americanum* Aiton	2	2	1	0	0

Vascular plant species	**30-50**	**50-70**	**70-90**	**>100**	**Hill**
Vicia cracca Linnaeus	8	2	0	0	0
Viola Linnaeus	141	89	26	10	0
Viola pubescens Aiton	1	0	0	0	0

APPENDICE E: TABLE SHOWING THE SPECIES COUNT PER SURFACE DEPOSIT CATEGORIES

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Amblystegium serpens (Hedw.) Schimp.	0	11	0	1	0	2
Anastrophyllum michauxii (F. Weber) H. Buch	0	0	0	0	0	5
Andreaea rupestris Hedw.	0	0	0	0	1	1
Aneura pinguis (L.) Dumort.	0	1	0	0	0	0
Atrichum angustatum (Brid.) Bruch & Schimp.	0	1	0	0	0	0
Atrichum tenellum (Röhl.) Bruch & Schimp.	0	0	0	1	0	3
Aulacomnium palustre (Hedw.) Schwägr.	0	10	1	5	1	7
Neoorthocaulis attenuatus (Mart.) L. Söderstr., De Roo & Hedd.	0	5	0	2	3	12
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	0	5	0	3	2	4

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Barbilophozia hatcheri (A. Evans) Loeske	0	0	0	0	1	2
Schljakovia kunzeana (Huebener) Konstant. & Vilnet	0	3	0	2	0	4
Bazzania denudata (Lindenb. & Gottsche) Trevis.	0	1	0	0	1	2
Bazzania trilobata (L.) Gray	0	5	0	1	2	4
Blepharostoma trichophyllum (L.) Dumort. subsp. *trichophyllum*	0	12	0	4	3	15
Blindia acuta (Hedwig) Bruch & Schimper	0	0	0	0	0	1
Brachythecium acuminatum (Hedw.) Austin	0	4	0	0	4	6
Brachythecium acutum (Mitt.) Sull.	0	3	0	0	2	0
Brachythecium albicans (Hedw.) Schimp.	0	0	0	0	0	1
Brachythecium campestre (Müll. Hal.) Schimp.	0	32	0	1	1	18

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Brachythecium curtum (Lindb.) Limpr.	0	8	0	2	4	11
Sciuro-hypnum oedipodium (Mitten) Ignatov & Huttunen	0	3	0	0	0	0
Brachythecium erythrorrhizon Schimp.	0	2	0	0	1	0
Brachythecium laetum (Brid.) Schimp.	0	0	0	0	1	2
Brachythecium novae-angliae (Sull. & Lesq.) Jaeg.	0	0	0	0	0	1
Brachythecium plumosum (Hedw.) Schimp.	0	2	0	0	3	4
Brachythecium populeum (Hedw.) Schimp.	0	3	0	0	1	5
Brachythecium reflexum (Starke) Schimp.	0	21	0	1	4	14
Brachythecium rutabulum (Hedw.) Schimp.	0	1	0	1	1	5
Brachythecium starkei (Brid.) Schimp.	0	9	0	3	2	9
Brachythecium velutimum (Hedw.) Schimp.	0	5	0	0	2	7

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Breidleria pratensis (Koch ex Spruce) Loeske	0	0	0	1	0	2
Brotherella recurvans (Michx.) M. Fleisch.	0	4	0	1	1	10
Bryoerythrophyllum recurvirostrum (Hedw.) P.C. Chen	0	1	0	0	1	0
Bryum creberrimum Taylor	0	0	0	0	0	1
Bryum laevifilum Syed	0	0	0	1	0	0
Bryum pseudotriquetrum (Hedw.) G. Gaertn., B. Mey. & Scherb.	0	0	0	0	0	2
Callicladium haldanianum (Grev.) H.A. Crum	0	23	0	1	3	19
Calliergon cordifolium (Hedw.) Kindb.	0	1	0	0	0	0
Calliergon richardsonii (Mitt.) Kindb.	0	0	0	0	0	1
Calypogeia integristipula Steph.	0	1	0	0	1	2
Calypogeia muelleriana (Schiffn.) Müll. Frib.	0	3	0	5	0	7

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Calypogeia neesiana (C. Massal. & Carestia) Müll. Frib.	0	5	0	1	0	8
Calypogeia sphagnicola (Arnell & J. Perss.) Warnst. & Loeske	0	1	0	3	0	4
Calypogeia suecica (Arnell & J. Perss.) Müll. Frib.	0	1	0	0	0	3
Campyliadelphus chrysophyllus (Bridel) Kanda	0	3	0	1	0	0
Campylium stellatum (Hedwig) C. E. O. Jensen	0	0	0	1	0	0
Campylophyllum halleri (Hedw.) M. Fleisch.	0	0	0	1	0	1
Campylophyllum hispidulum (Brid.) Hedenäs	0	7	0	2	1	5
Cephalozia bicuspidata (L.) Dumort.	0	1	0	1	0	2
Fuscocephaloziopsis catenulata (Huebener) Váňa & L.Söderstr.	0	2	0	0	2	5

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Fuscocephaloziopsis leucantha (Spruce) Váňa & L. Söderstr.	0	1	0	1	1	4
Fuscocephaloziopsis lunulifolia (Dumort.) Váňa & L. Söderstr.	0	12	0	3	3	14
Cephaloziella rubella (Nees) Warnst. var. rubella	0	1	0	5	1	10
Cephaloziella spinigera (Lindb.) Warnst.	0	0	0	1	0	0
Cephaloziella elachista (J.B. Jack ex Gottsche & Rabenh.) Schiffn.	0	0	0	2	0	0
Cephaloziella hampeana (Nees) Schiffn. ex Loeske	0	1	0	1	1	5
Ceratodon purpureus (Hedw.) Brid.	0	1	0	0	0	4
Chiloscyphus pallescens (Ehrh.) Dumort. var. pallescens	0	0	0	0	1	3
Chiloscyphus profundus (Nees) J.J. Engel & R.M. Schust.	0	28	0	2	4	13
Cinclidium subrotundum Lindb.	0	0	0	0	0	1

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Cirriphyllum piliferum (Hedw.) Grout	0	0	0	0	0	1
Crossocalyx hellerianus (Nees ex Lindenb.) Meyl.	0	4	0	2	4	11
Dicranella heteromalla (Hedw.) Schimp.	0	1	0	1	0	5
Dicranum flagellare Hedw.	0	11	0	2	4	15
Dicranum fulvum Hook.	0	2	0	2	2	3
Dicranum fuscescens Turner	0	32	0	6	4	21
Dicranum majus Turner var. *majus*	0	4	0	0	0	1
Dicranum montanum Hedw.	0	17	0	4	4	17
Dicranum ontariense W.L. Peterson	0	7	0	4	1	11
Dicranum polysetum Sw.	0	32	1	8	4	23
Dicranum scoparium Hedw.	0	22	0	1	4	19
Dicranum undulatum Schrad. ex Brid.	0	2	0	5	0	7

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Dicranum viride (Sull. & Lesq.) Lindb.	0	2	0	1	1	2
Drepanocladus aduncus (Hedw.) Warnst.	0	0	0	1	0	0
Drummondia prorepens (Hedw.) E. Britton	0	1	0	0	0	0
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	0	4	0	0	1	5
Fissidens osmundoides Hedw.	0	0	0	0	0	1
Frullania eboracensis Lehm.	0	1	0	0	1	3
Frullania inflata Gottsche	0	1	0	0	0	0
Frullania oakesiana Austin	0	6	0	0	1	5
Frullania selwyniana Pearson	0	0	0	0	0	1
Fuscocephaloziopsis connivens (Dicks.) Vána & L. Söderstr.	0	3	1	5	0	6
Fuscocephaloziopsis loitlesbergeri (Schiffn.) Váňa & L. Söderstr.	0	0	0	2	0	3

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Fuscocephaloziopsis pleniceps (Austin) Váňa & L. Söderstr.	0	3	0	3	0	6
Geocalyx graveolens (Schrad.) Nees	0	11	0	3	4	12
Gymnocolea inflata (Huds.) Dumort. subsp. *inflata*	0	0	0	1	0	0
Herzogiella striatella (Brid.) Z. Iwats.	0	3	0	0	1	2
Herzogiella turfacea (Lindb.) Z. Iwats.	0	7	0	3	2	13
Homalia trichomanoides (Hedw.) Schimp.	0	1	0	0	1	1
Hygroamblystegium varium (Hedw.) Mönk. var. *varium*	0	3	0	1	1	1
Hygrohypnum eugyrium (Schimper) Loeske	0	0	0	1	0	0
Hylocomiastrum pyrenaicum (Spruce) M. Fleisch. ex Broth.	0	1	0	0	0	3

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Hylocomiastrum umbratum (Hedw.) M. Fleisch. ex Broth.	0	1	0	1	0	6
Hylocomium splendens (Hedw.) Schimp.	0	11	0	6	1	13
Hypnum cupressiforme Hedw. var. *cupressiforme*	0	13	0	0	1	1
Hypnum fauriei Cardot	0	1	0	0	0	2
Hypnum imponens Hedw.	0	6	0	1	0	8
Hypnum lindbergii Mitt.	0	1	0	0	0	1
Hypnum pallescens (Hedw.) P. Beauv.	0	29	0	1	4	22
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	0	0	0	0	0	3
Isopterygiopsis muelleriana (Schimp.) Z. Iwats.	0	0	0	1	0	2
Syzygiella autumnalis (DC.) K. Feldberg, Váňa, Hentschel & Heinrichs	0	20	0	6	4	17
Liochlaena lanceolata Nees	0	0	0	2	0	4

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Kindbergia praelonga (Hedw.) Ochyra	0	0	0	0	0	3
Mylia anomala (Hook.) Gray	0	1	0	4	0	3
Lepidozia reptans (L.) Dumort.	0	12	0	5	3	16
Leptobryum pyriforme (Hedwig) Wilson	0	1	0	1	0	1
Lophocolea heterophylla (Schrad.) Dumort.	0	9	0	1	0	7
Lophozia ascendens (Warnst.) R.M. Schust.	0	2	0	1	0	4
Lophozia guttulata (Lindb. & Arnell) A. Evans	0	4	0	2	0	8
Lophoziopsis longidens (Lindb.) Konstant. & Vilnet	0	4	0	2	4	8
Lophozia silvicola H. Buch	0	2	0	3	2	8

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Lophozia ventricosa (Dicks.) Dumort. var. *ventricosa*	0	4	0	5	0	11
Marsupella emarginata (Ehrh.) Dumort. var. *emarginata*	0	1	0	1	4	5
Mesoptychia rutheana (Limpr.) L. Söderstr. & Váňa	0	0	0	1	0	0
Mnium hornum Hedw.	0	0	0	0	0	1
Mnium spinulosum Bruch & Schimp.	0	5	0	1	3	6
Mnium stellare Hedw.	0	0	0	0	0	1
Nowellia curvifolia (Dicks.) Mitt.	0	12	0	2	2	10
Nyholmiella obtusifolia (Schrad. ex Brid.) Holmen & E. Warncke	0	2	0	1	1	0
Oncophorus virens (Hedw.) Brid.	0	3	0	0	1	3
Oncophorus wahlenbergii Brid.	0	4	0	2	2	7
Orthotrichum spp.	0	3	0	0	1	1

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Paraleucobryum longifolium (Ehrh. ex Hedw.) Loeske	0	0	0	1	0	1
Pellia epiphylla (L.) Corda	0	0	0	0	0	1
Plagiochila porelloides (Torr. ex Nees) Lindenb. var. *porelloides*	0	1	0	1	0	3
Plagiomnium ciliare (Müll. Hal.) T.J. Kop.	0	1	0	0	0	1
Plagiomnium cuspidatum (Hedw.) T.J. Kop.	0	7	0	0	1	1
Plagiomnium drummondii (Bruch & Schimp.) T.J. Kop.	0	3	0	0	1	3
Plagiomnium ellipticum (Brid.) T.J. Kop.	0	6	0	0	0	2
Plagiomnium medium (Bruch & Schimp.) T.J. Kop.	0	4	0	0	1	1
Plagiothecium cavifolium (Brid.) Z. Iwats.	0	3	0	0	2	9
Plagiothecium denticulatum (Hedw.) Schimp.	0	7	0	2	0	6

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Plagiothecium laetum Schimp.	0	17	0	4	4	16
Plagiothecium latebricola Schimp.	0	16	0	0	2	9
Serpoleskea subtilis (Hedw.) Loeske	0	2	0	0	2	5
Platygyrium repens (Brid.) Schimp.	0	2	0	1	0	2
Pleurozium schreberi (Willd. ex Brid.) Mitt.	0	41	1	8	4	29
Pogonatum dentatum (Menzies ex Brid.) Brid.	0	0	0	1	0	1
Pohlia cruda (Hedw.) Lindb.	0	0	0	0	0	3
Pohlia elongata Hedw. var. *elongata*	0	0	0	0	0	1
Pohlia lescuriana (Sull.) Ochi	0	1	0	0	4	4
Pohlia mutans (Hedw.) Lindb.	0	12	1	5	4	19
Pohlia sphagnicola (Bruch & Schimp.) Broth.	0	1	0	3	0	5

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Pohlia wahlenbergii (F. Weber & D. Mohr) A.L. Andrews	0	1	0	0	1	1
Polytrichastrum alpimum (Hedw.) G.L. Sm.	0	0	0	0	0	2
Polytrichum commune Hedw. var. *commune*	0	10	0	1	4	14
Polytrichum densifolium Wilson ex Mitt.	0	0	0	1	0	4
Polytrichum juniperinum Hedw.	0	3	0	2	0	7
Polytrichum longisetum Sw. ex Brid.	0	0	0	1	0	3
Polytrichum pallidisetum Funck	0	0	0	1	0	3
Polytrichum strictum Menzies ex Brid.	0	3	1	3	0	8
Pseudobryum cinclidioides (Huebener) T.J. Kop.	0	0	0	0	1	1
Pseudotaxiphyllum elegans (Brid.) Z. Iwats.	0	0	0	0	0	2

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Pseudocampylium radicale (P. Beauv.) Vanderp. & Hedenäs	0	0	0	1	0	0
Ptilidium ciliare (L.) Hampe	0	14	0	8	0	11
Ptilidium pulcherrimum (Weber) Vain.	0	42	0	6	4	29
Ptilium crista-castrensis (Hedw.) De Not.	0	23	1	8	4	20
Pylaisia intricata (Hedw.) Schimp.	0	7	0	1	0	6
Pylaisia polyantha (Hedw.) Schimp.	0	3	0	0	1	3
Pylaisia selwynii Kindb.	0	3	0	0	3	4
Radula complanata (L.) Dumort.	0	2	0	0	1	1
Riccardia latifrons (Lindb.) Lindb.	0	4	0	1	0	5
Riccardia multifida (L.) Gray subsp. multifida	0	1	0	0	0	1
Rhizomnium punctatum (Hedw.) T.J. Kop.	0	5	0	1	1	6

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Rhizomnium pseudopunctatum (Bruch & Schimp.) T.J. Kop.	0	1	0	0	0	1
Rhynchostegium serrulatum (Hedw.) A. Jaeger	0	3	0	0	2	1
Rhytidiadelphus subpinnatus (Lindb.) T.J. Kop.	0	0	0	1	0	2
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	3	0	0	0	3
Sanionia uncinata (Hedw.) Loeske	0	35	0	5	4	24
Sarmentypnum exannulatum (Schimp.) Hedenäs	0	0	0	1	0	0
Scapania apiculata Spruce	0	1	0	0	0	1
Scapania irrigua (Nees) Nees subsp. irrigua	0	2	0	0	0	3
Scapania nemorea (L.) Grolle	0	0	0	0	0	1
Schistochilopsis incisa (Schrad.) Konstant. var.	0	2	0	0	3	1

Bryophyte species	Dune	Glaciolacustrine	Juxtaglacial	Organic	Rock	Till
opacifolia (Culm. ex Meyl.) Bakalin						
Schistostega pennata (Hedw.) F. Weber & D. Mohr	0	0	0	0	0	1
Sphagnum angustifolium (Warnst.) C.E.O. Jensen	0	7	1	6	0	8
Sphagnum capillifolium (Ehrh.) Hedw.	0	10	1	6	2	12
Sphagnum centrale C.E.O. Jensen	0	0	0	1	0	3
Sphagnum divinum Flatberg & Hassel	0	5	1	6	0	6
Sphagnum fallax H. Klinggr.	0	3	1	5	0	5
Sphagnum fuscum (Schimp.) H. Klinggr.	0	1	1	5	0	4
Sphagnum girgensohnii Russow	0	11	0	4	1	11
Sphagnum quinquefarium (Lindb.) Warnst.	0	0	0	0	0	2

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Sphagnum rubellum Wilson	0	1	0	2	0	2
Sphagnum russowii Warnst.	0	5	1	7	0	9
Sphagnum squarrosum Crome	0	3	0	1	0	4
Sphagnum subfulvum Sjörs	0	1	0	0	0	0
Sphagnum subtile (Russow) Warnst.	0	1	0	1	0	1
Sphagnum tenerum Sull. & Lesq. ex Sull.	0	0	0	0	0	1
Sphagnum teres (Schimp.) Ångström	0	0	0	1	0	0
Sphagnum warnstorfii Russow	0	0	0	1	0	2
Sphagnum wulfianum Girg.	0	5	0	1	0	0
Sphenolobus minutus (Schreb. ex D. Crantz) Berggr.	0	1	0	2	4	4
Splachnum ampullaceum Hedw.	0	0	0	1	0	0

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Straminergon stramineum (Dicks. ex Brid.) Hedenäs	0	3	0	2	0	2
Tetraphis pellucida Hedw.	0	18	0	5	4	17
Tetraplodon angustatus (Hedw.) Bruch & Schimp.	0	0	0	0	0	1
Thuidium delicatulum (Hedw.) Schimp.	0	0	0	0	0	1
Thuidium recognitum (Hedw.) Lindb.	0	1	0	0	0	2
Tomentypnum falcifolium (Renauld ex Nichols) Tuom.	0	1	0	3	0	0
Tomentypnum nitens (Hedw.) Loeske	0	0	1	0	0	1
Tortella humilis (Hedw.) Jenn.	0	1	0	0	0	0
Trichocolea tomentella (Ehrh.) Dumort.	0	0	0	0	0	1
Tritomaria exsecta (Schmidel) Schiffn. ex Loeske	0	0	0	0	0	3

Bryophyte species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Tritomaria exsectiformis (Breidl.) Schiffn. ex Loeske	0	3	0	0	1	4
Tritomaria laxa (Lindb.) Stotler & Crand.-Stotl.	0	0	0	0	0	1
Tritomaria quinquedentata (Huds.) H. Buch subsp. *quinquedentata*	0	1	0	0	1	3
Ulota coarctata (P. Beauv.) Hammar	0	1	0	1	0	1
Ulota crispa (Hedw.) Brid.	0	0	0	1	0	2
Warnstorfia fluitans (Hedw.) Loeske	0	2	0	3	0	3

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Abies balsamea (Linnaeus) Miller	4	242	39	60	34	176
Acer rubrum Linnaeus	0	28	13	9	7	33
Acer spicatum Lamarck	1	74	18	22	15	67
Achillea millefolium Linnaeus	2	3	0	4	3	4

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Actaea pachypoda Elliott	0	0	1	0	0	0
Actaea rubra (Aiton) Willdenow	1	17	5	7	3	18
Alnus alnobetula subsp. *crispa* (Aiton) Raus	2	66	6	21	7	42
Alnus incana subsp. *rugosa* (Du Roi) R.T. Clausen	5	163	21	45	24	107
Amelanchier Medikus	3	157	20	39	25	135
Anaphalis margaritacea (Linnaeus) Bentham & Hooker f.	0	8	1	1	2	3
Andromeda polifolia var. *latifolia* Aiton	0	5	0	1	1	0
Antennaria Gaertner	0	1	0	0	0	0
Apocynum androsaemifolium Linnaeus	0	11	3	2	2	5
Aralia hispida Ventenat	0	1	0	0	0	0
Aralia nudicaulis Linnaeus	2	134	28	33	21	102
Aronia melanocarpa (Michaux) Elliott	0	1	0	0	0	0

Vascular plant species	Dune	Glaciolacustrine	Juxtaglacial	Organic	Rock	Till
Eurybia macrophylla (Linnaeus) Cassini	3	15	3	1	3	6
Athyrium filix-femina (Linnaeus) Roth ex Mertens	1	48	8	10	9	42
Betula alleghaniensis Britton	0	1	0	1	0	1
Betula glandulosa Michaux	0	2	0	0	0	1
Betula papyrifera Marshall	3	212	35	49	33	156
Betula pumila Linnaeus	0	3	0	4	2	1
Botrypus virginianus (Linnaeus) Michaux	1	1	1	0	1	1
Caltha palustris Linnaeus	0	1	1	4	0	2
Carex Linnaeus	2	186	18	54	22	110
Caulophyllum thalictroides (Linnaeus) Michaux	0	1	0	0	0	0
Chamaedaphne calyculata (Linnaeus) Moench	2	23	1	21	3	15
Chamaenerion angustifolium (Linnaeus)	3	50	8	14	4	36

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Scopoli subsp. *angustifolium*						
Circaea alpina Linnaeus	0	10	2	2	0	10
Cirsium Miller	2	0	0	0	0	1
Claytonia caroliniana Michaux	0	1	0	0	0	0
Claytosmunda claytoniana (Linnaeus) Metzgar & Rouhan	0	22	1	3	2	16
Climacium dendroides (Hedw.) F. Weber & D. Mohr	0	5	0	0	1	1
Clintonia borealis (Aiton) Rafinesque	4	182	34	52	31	137
Comarum palustre Linnaeus	0	1	0	1	0	1
Comptonia peregrina (Linnaeus) J.M. Coulter	1	7	0	0	0	4
Coptis trifolia (Linnaeus) Salisbury	4	170	28	45	23	127
Corallorhiza maculata (Rafinesque) Rafinesque	0	1	0	1	0	0

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Cornus alternifolia Linnaeus f.	0	8	2	1	0	5
Cornus canadensis Linnaeus	6	228	34	60	33	167
Cornus sericea Linnaeus	1	22	2	11	1	21
Corylus cornuta Marshall	0	65	15	17	13	44
Cypripedium acaule Aiton	0	20	3	5	2	22
Dendrolycopodium obscurum (Linnaeus) A. Haines	0	87	20	26	19	56
Diervilla lonicera Miller	3	105	16	27	19	86
Diphasiastrum complanatum (Linnaeus) Holub	0	10	2	0	0	3
Diphasiastrum digitatum (Dillenius ex A. Braun) Holub	0	1	0	0	0	0
Dryopteris carthusiana (Villars) H.P. Fuchs	2	142	24	25	22	88
Dryopteris cristata (Linnaeus) A. Gray	0	1	0	0	0	1
Endotropis alnifolia (L'Héritier) Hauenschild	0	4	0	3	1	1

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Epigaea repens Linnaeus	0	23	3	2	1	14
Equisetum Linnaeus	5	82	11	16	16	53
Equisetum sylvaticum Linnaeus	3	52	5	9	1	17
Eupatorium perfoliatum Linnaeus	0	1	0	0	0	0
Eriophorum Linnaeus	0	2	0	0	1	5
Eurybia macrophylla (Linnaeus) Cassini	3	97	17	23	19	74
Fallopia cilinodis (Michaux) Holub	0	1	0	0	0	0
Fragaria Linnaeus	2	23	4	5	6	15
Fraxinus nigra Marshall	0	2	0	0	0	1
Galium labradoricum (Wiegand) Wiegand	0	1	0	0	0	1
Galium Linnaeus	2	70	12	16	7	39
Galium triflorum Michaux	0	7	0	1	1	6
Gaultheria hispidula (Linnaeus) Muhlenberg ex Bigelow	7	182	25	53	20	130
Gaultheria procumbens Linnaeus	0	9	0	1	1	11

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Geocaulon lividum (Richardson) Fernald	1	3	2	3	0	3
Geum macrophyllum Willdenow	0	0	0	0	0	1
Geum rivale Linnaeus	0	1	0	0	1	2
Goodyera R. Brown	0	1	0	1	0	2
Goodyera repens (Linnaeus) R. Brown	0	4	5	3	2	10
Goodyera tesselata Loddiges	0	0	0	0	1	0
Gymnocarpium dryopteris (Linnaeus) Newman	0	2	0	0	0	2
Gymnocarpium disjunctum (Ruprecht) Ching	0	59	9	14	11	35
Heracleum maximum W. Bartram	0	1	0	1	0	1
Hieracium Linnaeus	0	11	0	4	2	5
Huperzia lucidula (Michaux) Trevisan	0	22	9	3	4	26
Ilex mucronata (Linnaeus) M. Powell, V. Savolainen & S. Andrews	1	77	13	19	9	73

Vascular plant species	Dune	Glaciolacustrine	Juxtaglacial	Organic	Rock	Till
Ilex verticillata (Linnaeus) A. Gray	0	0	0	0	0	1
Impatiens capensis Meerburgh	2	9	0	1	0	5
Iris versicolor Linnaeus	0	3	0	2	0	2
Kalmia angustifolia Linnaeus	5	183	18	56	22	138
Kalmia polifolia Wangenheim	1	17	1	15	3	10
Lactuca canadensis Linnaeus	0	0	0	0	0	1
Larix laricina (Du Roi) K. Koch	1	45	3	15	4	28
Linnaea borealis Linnaeus	3	172	30	45	27	107
Lonicera canadensis Bartram ex Marshall	0	39	8	8	3	31
Lonicera dioica Linnaeus	0	0	0	1	0	1
Lonicera villosa (Michaux) Roemer & Schultes	0	6	0	4	3	5
Dendrolycopodium dendroideum (Michaux) A. Haines	0	1	0	0	1	1

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Lycopodium clavatum Linnaeus	1	33	6	7	3	19
Lycopus uniflorus Michaux	0	1	0	0	0	0
Lysimachia borealis (Rafinesque) U. Manns & Anderberg	3	185	30	46	34	137
Maianthemum canadense Desfontaines	5	235	38	59	32	163
Maianthemum racemosum (Linnaeus) Link	0	2	0	1	0	2
Maianthemum trifolium (Linnaeus) Sloboda	4	48	3	24	4	38
Matteuccia struthiopteris (Linnaeus) Todaro	0	0	0	0	0	1
Melampyrum lineare Desrousseaux	0	7	0	5	1	11
Mertensia paniculata (Aiton) G. Don	0	1	0	1	1	0
Mitella nuda Linnaeus	2	40	4	15	4	29
Moneses uniflora (Linnaeus) A. Gray	0	3	0	3	1	3

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Monotropa uniflora Linnaeus	0	10	1	2	3	7
Myrica gale Linnaeus	0	2	0	3	0	0
Nabalus Cassini	0	4	0	1	1	1
Neottia cordata (Linnaeus) Richard	0	2	0	0	0	0
Oclemena acuminata (Michaux) Greene	0	36	2	5	4	28
Onoclea sensibilis Linnaeus	0	1	0	0	1	0
Orthilia secunda (Linnaeus) House	0	11	2	5	3	14
Osmorhiza claytonii (Michaux) C.B. Clarke	0	0	0	0	0	1
Osmundastrum cinnamomeum (Linnaeus) C. Presl	0	2	0	0	0	2
Ostrya virginiana (Miller) K. Koch	0	1	0	0	0	1
Oxalis montana Rafinesque	1	60	6	11	8	34

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Parathelypteris noveboracensis (Linnaeus) Ching	0	8	1	1	0	4
Petasites frigidus var. *palmatus* (Aiton) Cronquist	1	31	6	9	7	24
Phegopteris connectilis (Michaux) Watt	0	11	1	2	2	8
Picea abies (Linnaeus) H. Karsten	0	1	0	0	0	0
Picea glauca (Moench) Voss	0	97	11	19	14	53
Picea mariana (Miller) Britton, Sterns & Poggenburgh	7	288	33	75	37	191
Picea rubens Sargent	0	1	0	0	0	1
Pinus banksiana Lambert	4	125	11	21	19	81
Pinus resinosa Aiton	0	0	1	0	0	0
Pinus strobus Linnaeus	1	4	0	5	1	1
Platanthera orbiculata (Pursh) Lindley	0	0	0	0	1	1
Platanthera Richard	0	0	1	0	0	0

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Polypodium virginiamum Linnaeus	1	2	0	1	1	1
Populus balsamifera Linnaeus	2	13	2	1	1	12
Populus grandidentata Michaux	0	1	0	0	0	0
Populus tremuloides Michaux	5	136	18	32	21	102
Potentilla norvegica Linnaeus	0	0	0	0	0	1
Prunus pensylvanica Linnaeus f.	2	104	19	26	15	75
Prunus virginiana Linnaeus	0	23	1	6	2	15
Pteridium aquilimum (Linnaeus) Kuhn	1	76	12	18	13	58
Pyrola asarifolia Michaux	0	3	1	3	1	3
Pyrola elliptica Nuttall	0	11	1	4	2	12
Pyrola Linnaeus	0	8	1	6	2	6
Ranunculus abortivus Linnaeus	0	0	0	1	0	0

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Ranunculus acris Linnaeus	1	6	0	0	0	4
Ranunculus Linnaeus	0	3	0	1	0	1
Rhododendron canadense (Linnaeus) Torrey	0	2	0	0	0	0
Rhododendron groenlandicum (Oeder) Kron & Judd	6	178	19	49	22	129
Rhus typhina Linnaeus	0	0	1	0	0	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	22	6	6	0	9
Ribes americanum Miller	0	1	0	0	0	0
Ribes cynosbati Linnaeus	2	2	0	0	0	2
Ribes glandulosum Grauer	2	120	15	22	18	69
Ribes hirtellum Michaux	0	2	0	0	0	0
Ribes lacustre (Persoon) Poiret	1	33	3	11	6	26
Ribes triste Pallas	1	50	5	8	10	30
Rosa acicularis Lindley	0	10	2	6	1	9
Rubus allegheniensis Porter	0	1	0	0	0	0

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Rubus chamaemorus Linnaeus	1	2	1	0	2	1
Rubus idaeus Linnaeus	4	91	13	17	14	47
Rubus pubescens Rafinesque	3	108	13	28	15	64
Rubus repens (Linnaeus) Kuntze	0	1	0	0	0	1
Salix Linnaeus	6	219	24	51	28	145
Sambucus canadensis Linnaeus	0	0	3	0	0	0
Sambucus racemosa Linnaeus	1	42	3	10	3	19
Sarracenia purpurea Linnaeus	0	1	0	0	0	0
Scutellaria lateriflora Linnaeus	0	0	0	0	0	1
Senecio Linnaeus	0	0	0	0	1	1
Solidago Linnaeus	3	15	3	2	7	8
Solidago macrophylla Banks ex Pursh	0	16	5	10	6	24
Solidago rugosa Miller	0	16	2	5	3	12
Sonchus Linnaeus	0	0	0	0	0	1

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Sorbus americana Marshall	0	93	17	21	16	70
Sorbus decora (Sargent) C.K. Schneider	2	78	13	28	10	68
Spinulum annotimum (Linnaeus) A. Haines subsp. *annotimum*	0	95	12	20	17	45
Spiraea alba var. *latifolia* (Aiton) Dippel	0	2	0	2	1	3
Stellaria Linnaeus	0	1	0	0	1	2
Stereocaulon paschale (L.) Hoffm.	0	3	0	1	3	1
Streptopus amplexifolius (Linnaeus) de Candolle	0	11	5	1	5	11
Streptopus lanceolatus (Aiton) Reveal var. *lanceolatus*	0	64	17	17	16	51
Symphyotrichum puniceum (Linnaeus) Á. Löve & D. Löve var. *puniceum*	0	12	0	4	4	6
Taraxacum officinale F.H. Wiggers	1	5	0	1	1	1

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Taxus canadensis Marshall	0	25	7	4	3	18
Thalictrum dioicum Linnaeus	0	0	0	0	0	2
Thalictrum pubescens Pursh	0	11	0	3	2	11
Thuja occidentalis Linnaeus	0	12	3	2	2	7
Trifolium Linnaeus	0	1	0	0	0	1
Trillidium undulatum (Willdenow) Floden & E.E. Schilling	0	4	0	0	1	4
Trillium cernuum Linnaeus	0	6	0	0	0	3
Trillium erectum Linnaeus	0	5	0	2	0	5
Vaccinium angustifolium Aiton	5	220	24	53	29	139
Vaccinium myrtilloides Michaux	6	223	33	66	32	163
Vaccinium oxycoccos Linnaeus	0	17	1	12	2	12
Vaccinium vitis-idaea Linnaeus	0	1	0	0	0	1

Vascular plant species	**Dune**	**Glaciolacustrine**	**Juxtaglacial**	**Organic**	**Rock**	**Till**
Viburnum cassinoides Linnaeus	1	136	21	32	19	133
Viburnum edule (Michaux) Rafinesque	0	56	10	13	10	31
Viburnum opulus var. *americanum* Aiton	0	3	0	0	0	2
Vicia cracca Linnaeus	2	3	1	1	0	3
Viola Linnaeus	5	119	19	32	16	75
Viola pubescens Aiton	0	1	0	0	0	0

APPENDICE F: TABLE SHOWING THE SPECIES COUNT PER STAND TYPE CATEGORIES

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Amblystegium serpens (Hedw.) Schimp.	1	2	0	11
Anastrophyllum michauxii (F. Weber) H. Buch	3	0	0	2
Andreaea rupestris Hedw.	0	0	0	2
Aneura pinguis (L.) Dumort.	0	0	0	1
Atrichum angustatum (Brid.) Bruch & Schimp.	0	0	1	0
Atrichum tenellum (Röhl.) Bruch & Schimp.	2	0	0	2
Aulacomnium palustre (Hedw.) Schwägr.	0	2	3	19
Neoorthocaulis attenuatus (Mart.) L. Söderstr., De Roo & Hedd.	3	0	0	19
Barbilophozia barbata (Schmidel ex Schreb.) Loeske	0	1	1	12
Barbilophozia hatcheri (A. Evans) Loeske	0	0	0	3
Schljakovia kunzeana (Huebener) Konstant. & Vilnet	1	0	0	8
Bazzania denudata (Lindenb. & Gottsche) Trevis.	0	0	0	4

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Bazzania trilobata (L.) Gray	1	1	0	10
Blepharostoma trichophyllum (L.) Dumort. subsp. *trichophyllum*	4	2	1	27
Blindia acuta (Hedwig) Bruch & Schimper	0	0	0	1
Brachythecium acuminatum (Hedw.) Austin	1	2	0	11
Brachythecium acutum (Mitt.) Sull.	0	2	1	2
Brachythecium albicans (Hedw.) Schimp.	1	0	0	0
Brachythecium campestre (Müll. Hal.) Schimp.	5	2	5	40
Brachythecium curtum (Lindb.) Limpr.	4	2	1	18
Sciuro-hypnum oedipodium (Mitten) Ignatov & Huttunen	0	0	0	3
Brachythecium erythrorrhizon Schimp.	0	0	0	3
Brachythecium laetum (Brid.) Schimp.	1	0	0	2
Brachythecium novae-angliae (Sull. & Lesq.) Jaeg.	0	0	0	1
Brachythecium plumosum (Hedw.) Schimp.	0	0	0	9
Brachythecium populeum (Hedw.) Schimp.	1	0	0	8
Brachythecium reflexum (Starke) Schimp.	4	1	2	33
Brachythecium rutabulum (Hedw.) Schimp.	3	1	0	4

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Brachythecium starkei (Brid.) Schimp.	4	2	1	16
Brachythecium velutinum (Hedw.) Schimp.	2	0	0	12
Breidleria pratensis (Koch ex Spruce) Loeske	0	0	0	3
Brotherella recurvans (Michx.) M. Fleisch.	4	1	0	11
Bryoerythrophyllum recurvirostrum (Hedw.) P.C. Chen	0	0	0	2
Bryum creberrimum Taylor	0	0	0	1
Bryum laevifilum Syed	0	0	0	1
Bryum pseudotriquetrum (Hedw.) G. Gaertn., B. Mey. & Scherb.	1	0	0	1
Callicladium haldanianum (Grev.) H.A. Crum	5	2	4	35
Calliergon cordifolium (Hedw.) Kindb.	0	0	0	1
Calliergon richardsonii (Mitt.) Kindb.	0	0	0	1
Calypogeia integristipula Steph.	0	0	0	4
Calypogeia muelleriana (Schiffn.) Müll. Frib.	2	0	0	13
Calypogeia neesiana (C. Massal. & Carestia) Müll. Frib.	1	0	0	13

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Calypogeia sphagnicola (Arnell & J. Perss.) Warnst. & Loeske	1	0	0	7
Calypogeia suecica (Arnell & J. Perss.) Müll. Frib.	1	0	0	3
Campyliadelphus chrysophyllus (Bridel) Kanda	0	2	1	1
Campylium stellatum (Hedwig) C. E. O. Jensen	0	0	0	1
Campylophyllum halleri (Hedw.) M. Fleisch.	0	0	0	2
Campylophyllum hispidulum (Brid.) Hedenäs	0	2	1	12
Cephalozia bicuspidata (L.) Dumort.	1	0	0	3
Fuscocephaloziopsis catenulata (Huebener) Váňa & L.Söderstr.	2	0	0	7
Fuscocephaloziopsis leucantha (Spruce) Váňa & L. Söderstr.	1	0	0	6
Fuscocephaloziopsis lunulifolia (Dumort.) Váňa & L. Söderstr.	4	1	2	25
Cephaloziella rubella (Nees) Warnst. var. rubella	3	0	0	14
Cephaloziella spinigera (Lindb.) Warnst.	0	0	0	1
Cephaloziella elachista (J.B. Jack ex Gottsche & Rabenh.) Schiffn.	0	0	0	2

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Cephaloziella hampeana (Nees) Schiffn. ex Loeske	0	0	0	8
Ceratodon purpureus (Hedw.) Brid.	0	0	0	5
Chiloscyphus pallescens (Ehrh.) Dumort. var. pallescens	2	0	0	2
Chiloscyphus profundus (Nees) J.J. Engel & R.M. Schust.	2	2	4	39
Cinclidium subrotundum Lindb.	0	0	0	1
Cirriphyllum piliferum (Hedw.) Grout	0	0	0	1
Crossocalyx hellerianus (Nees ex Lindenb.) Meyl.	2	0	0	19
Dicranella heteromalla (Hedw.) Schimp.	2	0	0	5
Dicranum flagellare Hedw.	4	1	2	25
Dicranum fulvum Hook.	0	0	0	9
Dicranum fuscescens Turner	5	2	9	47
Dicranum majus Turner var. *majus*	0	2	1	2
Dicranum montanum Hedw.	4	2	2	34
Dicranum ontariense W.L. Peterson	2	0	3	18
Dicranum polysetum Sw.	4	2	8	54
Dicranum scoparium Hedw.	5	2	2	37

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Dicranum undulatum Schrad. ex Brid.	1	0	0	13
Dicranum viride (Sull. & Lesq.) Lindb.	0	1	0	5
Drepanocladus aduncus (Hedw.) Warnst.	0	0	0	1
Drummondia prorepens (Hedw.) E. Britton	0	0	0	1
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen	1	1	1	7
Fissidens osmundoides Hedw.	0	0	0	1
Frullania eboracensis Lehm.	0	0	0	5
Frullania inflata Gottsche	0	1	0	0
Frullania oakesiana Austin	2	2	1	7
Frullania selwyniana Pearson	0	0	0	1
Fuscocephaloziopsis connivens (Dicks.) Vána & L. Söderstr.	2	0	0	13
Fuscocephaloziopsis loitlesbergeri (Schiffn.) Váňa & L. Söderstr.	0	0	0	5
Fuscocephaloziopsis pleniceps (Austin) Váňa & L. Söderstr.	1	0	0	11
Geocalyx graveolens (Schrad.) Nees	4	2	1	23
Gymnocolea inflata (Huds.) Dumort. subsp. *inflata*	0	0	0	1
Herzogiella striatella (Brid.) Z. Iwats.	0	0	0	6

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Herzogiella turfacea (Lindb.) Z. Iwats.	3	1	0	21
Homalia trichomanoides (Hedw.) Schimp.	1	1	0	1
Hygroamblystegium varium (Hedw.) Mönk. var. *varium*	0	0	1	5
Hygrohypnum eugyrium (Schimper) Loeske	0	0	0	1
Hylocomiastrum pyrenaicum (Spruce) M. Fleisch. ex Broth.	0	0	0	4
Hylocomiastrum umbratum (Hedw.) M. Fleisch. ex Broth.	3	0	0	5
Hylocomium splendens (Hedw.) Schimp.	3	2	2	24
Hypnum cupressiforme Hedw. var. *cupressiforme*	1	0	1	13
Hypnum fauriei Cardot	0	1	0	2
Hypnum imponens Hedw.	4	2	1	8
Hypnum lindbergii Mitt.	0	0	0	2
Hypnum pallescens (Hedw.) P. Beauv.	5	2	5	44
Isopterygiopsis pulchella (Hedw.) Z. Iwats.	0	0	0	3
Isopterygiopsis muelleriana (Schimp.) Z. Iwats.	0	0	0	3
Syzygiella autumnalis (DC.) K. Feldberg, Váňa, Hentschel & Heinrichs	4	2	3	38

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Liochlaena lanceolata Nees	2	0	0	4
Kindbergia praelonga (Hedw.) Ochyra	2	0	0	1
Mylia anomala (Hook.) Gray	0	0	0	8
Lepidozia reptans (L.) Dumort.	3	2	2	29
Leptobryum pyriforme (Hedwig) Wilson	0	0	0	3
Lophocolea heterophylla (Schrad.) Dumort.	2	0	2	13
Lophozia ascendens (Warnst.) R.M. Schust.	2	0	0	5
Lophozia guttulata (Lindb. & Arnell) A. Evans	2	1	1	10
Lophoziopsis longidens (Lindb.) Konstant. & Vilnet	2	0	0	16
Lophozia silvicola H. Buch	1	0	0	14
Lophozia ventricosa (Dicks.) Dumort. var. *ventricosa*	4	0	0	16
Marsupella emarginata (Ehrh.) Dumort. var. *emarginata*	0	0	0	11
Mesoptychia rutheana (Limpr.) L. Söderstr. & Váňa	0	0	0	1
Mnium hornum Hedw.	0	0	0	1
Mnium spinulosum Bruch & Schimp.	2	2	1	10
Mnium stellare Hedw.	0	0	0	1

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Nowellia curvifolia (Dicks.) Mitt.	4	2	1	19
Nyholmiella obtusifolia (Schrad. ex Brid.) Holmen & E. Warncke	0	0	0	4
Oncophorus virens (Hedw.) Brid.	0	1	1	5
Oncophorus wahlenbergii Brid.	1	0	0	14
Orthotrichum spp.	1	0	0	4
Paraleucobryum longifolium (Ehrh. ex Hedw.) Loeske	1	0	0	1
Pellia epiphylla (L.) Corda	0	0	0	1
Plagiochila porelloides (Torr. ex Nees) Lindenb. var. *porelloides*	0	0	0	5
Plagiomnium ciliare (Müll. Hal.) T.J. Kop.	0	0	0	2
Plagiomnium cuspidatum (Hedw.) T.J. Kop.	0	2	1	6
Plagiomnium drummondii (Bruch & Schimp.) T.J. Kop.	0	1	0	6
Plagiomnium ellipticum (Brid.) T.J. Kop.	0	2	1	5
Plagiomnium medium (Bruch & Schimp.) T.J. Kop.	0	1	0	5
Plagiothecium cavifolium (Brid.) Z. Iwats.	3	0	1	10
Plagiothecium denticulatum (Hedw.) Schimp.	3	1	1	10

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Plagiothecium laetum Schimp.	4	0	3	34
Plagiothecium latebricola Schimp.	1	0	4	22
Serpoleskea subtilis (Hedw.) Loeske	1	0	0	8
Platygyrium repens (Brid.) Schimp.	1	1	1	2
Pleurozium schreberi (Willd. ex Brid.) Mitt.	5	3	10	65
Pogonatum dentatum (Menzies ex Brid.) Brid.	0	0	0	2
Pohlia cruda (Hedw.) Lindb.	0	0	0	3
Pohlia elongata Hedw. var. *elongata*	0	0	0	1
Pohlia lescuriana (Sull.) Ochi	0	0	0	9
Pohlia nutans (Hedw.) Lindb.	4	3	2	32
Pohlia sphagnicola (Bruch & Schimp.) Broth.	0	0	0	9
Pohlia wahlenbergii (F. Weber & D. Mohr) A.L. Andrews	0	0	0	3
Polytrichastrum alpinum (Hedw.) G.L. Sm.	1	0	0	1
Polytrichum commune Hedw. var. *commune*	2	1	4	22
Polytrichum densifolium Wilson ex Mitt.	3	0	0	2
Polytrichum juniperinum Hedw.	1	1	1	9
Polytrichum longisetum Sw. ex Brid.	1	0	0	3

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Polytrichum pallidisetum Funck	2	0	0	2
Polytrichum strictum Menzies ex Brid.	1	1	0	13
Pseudobryum cinclidioides (Huebener) T.J. Kop.	0	0	0	2
Pseudotaxiphyllum elegans (Brid.) Z. Iwats.	1	0	0	1
Pseudocampylium radicale (P. Beauv.) Vanderp. & Hedenäs	0	0	0	1
Ptilidium ciliare (L.) Hampe	2	2	5	24
Ptilidium pulcherrimum (Weber) Vain.	5	2	9	65
Ptilium crista-castrensis (Hedw.) De Not.	4	3	6	43
Pylaisia intricata (Hedw.) Schimp.	3	2	1	8
Pylaisia polyantha (Hedw.) Schimp.	0	2	0	5
Pylaisia selwynii Kindb.	0	0	0	10
Radula complanata (L.) Dumort.	0	1	0	3
Riccardia latifrons (Lindb.) Lindb.	2	1	0	7
Riccardia multifida (L.) Gray subsp. multifida	0	0	0	2
Rhizomnium punctatum (Hedw.) T.J. Kop.	3	2	1	7
Rhizomnium pseudopunctatum (Bruch & Schimp.) T.J. Kop.	0	0	0	2

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Rhynchostegium serrulatum (Hedw.) A. Jaeger	0	0	0	6
Rhytidiadelphus subpinnatus (Lindb.) T.J. Kop.	0	0	0	3
Rhytidiadelphus triquetrus (Hedw.) Warnst.	0	2	1	3
Sanionia uncinata (Hedw.) Loeske	5	2	6	55
Sarmentypnum exannulatum (Schimp.) Hedenäs	0	0	0	1
Scapania apiculata Spruce	1	0	0	1
Scapania irrigua (Nees) Nees subsp. irrigua	0	0	0	5
Scapania nemorea (L.) Grolle	0	0	0	1
Schistochilopsis incisa (Schrad.) Konstant. var. *opacifolia* (Culm. ex Meyl.) Bakalin	0	0	0	6
Schistostega pennata (Hedw.) F. Weber & D. Mohr	0	0	0	1
Sphagnum angustifolium (Warnst.) C.E.O. Jensen	0	1	1	20
Sphagnum capillifolium (Ehrh.) Hedw.	1	0	1	29
Sphagnum centrale C.E.O. Jensen	0	1	0	3
Sphagnum divinum Flatberg & Hassel	0	1	1	16
Sphagnum fallax H. Klinggr.	1	0	1	12

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Sphagnum fuscum (Schimp.) H. Klinggr.	0	1	0	10
Sphagnum girgensohnii Russow	3	0	3	21
Sphagnum quinquefarium (Lindb.) Warnst.	0	0	0	2
Sphagnum rubellum Wilson	0	0	0	5
Sphagnum russowii Warnst.	1	1	1	19
Sphagnum squarrosum Crome	0	0	0	8
Sphagnum subfulvum Sjörs	0	0	1	0
Sphagnum subtile (Russow) Warnst.	0	0	0	3
Sphagnum tenerum Sull. & Lesq. ex Sull.	0	0	0	1
Sphagnum teres (Schimp.) Ångström	0	0	0	1
Sphagnum warnstorfii Russow	0	0	0	3
Sphagnum wulfiamm Girg.	0	0	1	5
Sphenolobus minutus (Schreb. ex D. Crantz) Berggr.	0	0	0	11
Splachnum ampullaceum Hedw.	0	0	0	1
Straminergon stramineum (Dicks. ex Brid.) Hedenäs	0	0	0	7
Tetraphis pellucida Hedw.	4	2	2	36
Tetraplodon angustatus (Hedw.) Bruch & Schimp.	0	0	0	1

Bryophyte species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Thuidium delicatulum (Hedw.) Schimp.	0	0	0	1
Thuidium recognitum (Hedw.) Lindb.	0	0	0	3
Tomentypnum falcifolium (Renauld ex Nichols) Tuom.	0	0	0	4
Tomentypnum nitens (Hedw.) Loeske	0	0	0	2
Tortella humilis (Hedw.) Jenn.	0	0	0	1
Trichocolea tomentella (Ehrh.) Dumort.	0	0	0	1
Tritomaria exsecta (Schmidel) Schiffn. ex Loeske	1	0	0	2
Tritomaria exsectiformis (Breidl.) Schiffn. ex Loeske	0	0	0	8
Tritomaria laxa (Lindb.) Stotler & Crand.-Stotl.	0	0	0	1
Tritomaria quinquedentata (Huds.) H. Buch subsp. *quinquedentata*	0	0	0	5
Ulota coarctata (P. Beauv.) Hammar	1	0	0	2
Ulota crispa (Hedw.) Brid.	1	0	0	2
Warnstorfia fluitans (Hedw.) Loeske	1	0	0	7

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Abies balsamea (Linnaeus) Miller	69	86	125	275
Acer rubrum Linnaeus	14	14	19	43
Acer spicatum Lamarck	26	31	59	81
Achillea millefolium Linnaeus	1	3	2	10
Actaea pachypoda Elliott	0	0	1	0
Actaea rubra (Aiton) Willdenow	4	9	11	27
Alnus alnobetula subsp. *crispa* (Aiton) Raus	23	14	36	71
Alnus incana subsp. *rugosa* (Du Roi) R.T. Clausen	40	64	89	172
Amelanchier Medikus	54	57	99	169
Anaphalis margaritacea (Linnaeus) Bentham & Hooker f.	3	2	1	9
Andromeda polifolia var. *latifolia* Aiton	1	1	0	5
Antennaria Gaertner	0	1	0	0
Apocynum androsaemifolium Linnaeus	1	3	8	11
Aralia hispida Ventenat	0	0	0	1
Aralia nudicaulis Linnaeus	39	52	92	137
Aronia melanocarpa (Michaux) Elliott	0	0	0	1
Eurybia macrophylla (Linnaeus) Cassini	0	6	6	19

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Athyrium filix-femina (Linnaeus) Roth ex Mertens	13	23	35	47
Betula alleghaniensis Britton	0	0	1	2
Betula glandulosa Michaux	0	0	0	3
Betula papyrifera Marshall	62	78	120	228
Betula pumila Linnaeus	1	3	1	5
Botrypus virginianus (Linnaeus) Michaux	1	1	1	2
Caltha palustris Linnaeus	0	1	1	6
Carex Linnaeus	47	68	87	190
Caulophyllum thalictroides (Linnaeus) Michaux	0	0	0	1
Chamaedaphne calyculata (Linnaeus) Moench	13	12	8	32
Chamaenerion angustifolium (Linnaeus) Scopoli subsp. *angustifolium*	13	15	27	60
Circaea alpina Linnaeus	4	1	8	11
Cirsium Miller	0	0	1	2
Claytonia caroliniana Michaux	0	0	0	1
Claytosmunda claytoniana (Linnaeus) Metzgar & Rouhan	5	13	8	18

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Climacium dendroides (Hedw.) F. Weber & D. Mohr	1	1	1	4
Clintonia borealis (Aiton) Rafinesque	53	72	105	210
Comarum palustre Linnaeus	0	1	1	1
Comptonia peregrina (Linnaeus) J.M. Coulter	2	1	3	6
Coptis trifolia (Linnaeus) Salisbury	51	60	97	189
Corallorhiza maculata (Rafinesque) Rafinesque	0	2	0	0
Cornus alternifolia Linnaeus f.	4	6	4	2
Cornus canadensis Linnaeus	58	74	129	267
Cornus sericea Linnaeus	9	9	18	22
Corylus cornuta Marshall	22	28	41	63
Cypripedium acaule Aiton	4	4	16	28
Dendrolycopodium obscurum (Linnaeus) A. Haines	32	35	50	91
Diervilla lonicera Miller	39	37	63	117
Diphasiastrum complanatum (Linnaeus) Holub	2	3	2	8
Diphasiastrum digitatum (Dillenius ex A. Braun) Holub	0	0	0	1

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Dryopteris carthusiana (Villars) H.P. Fuchs	32	50	82	139
Dryopteris cristata (Linnaeus) A. Gray	1	0	1	0
Endotropis alnifolia (L'Héritier) Hauenschild	1	1	2	5
Epigaea repens Linnaeus	9	7	10	17
Equisetum Linnaeus	18	31	50	84
Equisetum sylvaticum Linnaeus	10	14	15	48
Eupatorium perfoliatum Linnaeus	0	0	0	1
Eriophorum Linnaeus	0	0	2	6
Eurybia macrophylla (Linnaeus) Cassini	30	42	60	101
Fallopia cilinodis (Michaux) Holub	0	0	1	0
Fragaria Linnaeus	2	10	15	28
Fraximus nigra Marshall	1	0	0	2
Galium labradoricum (Wiegand) Wiegand	1	0	1	0
Galium Linnaeus	15	26	41	64
Galium triflorum Michaux	2	3	3	7
Gaultheria hispidula (Linnaeus) Muhlenberg ex Bigelow	41	51	96	229
Gaultheria procumbens Linnaeus	3	2	9	8

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Geocaulon lividum (Richardson) Fernald	3	0	2	7
Geum macrophyllum Willdenow	1	0	0	0
Geum rivale Linnaeus	0	1	1	2
Goodyera R. Brown	0	0	1	3
Goodyera repens (Linnaeus) R. Brown	4	4	2	14
Goodyera tesselata Loddiges	0	0	0	1
Gymnocarpium dryopteris (Linnaeus) Newman	0	0	0	4
Gymnocarpium disjunctum (Ruprecht) Ching	10	20	41	57
Heracleum maximum W. Bartram	0	0	0	3
Hieracium Linnaeus	1	7	4	10
Huperzia lucidula (Michaux) Trevisan	12	7	16	29
Ilex mucronata (Linnaeus) M. Powell, V. Savolainen & S. Andrews	30	24	46	92
Ilex verticillata (Linnaeus) A. Gray	0	0	0	1
Impatiens capensis Meerburgh	2	3	2	10
Iris versicolor Linnaeus	1	2	0	4
Kalmia angustifolia Linnaeus	52	52	86	232
Kalmia polifolia Wangenheim	8	7	6	26

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Lactuca canadensis Linnaeus	0	0	0	1
Larix laricina (Du Roi) K. Koch	10	19	19	48
Linnaea borealis Linnaeus	43	52	98	191
Lonicera canadensis Bartram ex Marshall	11	16	24	38
Lonicera dioica Linnaeus	1	0	0	1
Lonicera villosa (Michaux) Roemer & Schultes	1	4	3	10
Dendrolycopodium dendroideum (Michaux) A. Haines	0	0	0	3
Lycopodium clavatum Linnaeus	9	7	16	37
Lycopus uniflorus Michaux	0	0	0	1
Lysimachia borealis (Rafinesque) U. Manns & Anderberg	47	67	117	204
Maianthemum canadense Desfontaines	62	82	128	260
Maianthemum racemosum (Linnaeus) Link	1	1	2	1
Maianthemum trifolium (Linnaeus) Sloboda	16	17	22	66
Matteuccia struthiopteris (Linnaeus) Todaro	0	1	0	0
Melampyrum lineare Desrousseaux	3	5	8	8
Mertensia paniculata (Aiton) G. Don	1	1	0	1
Mitella nuda Linnaeus	9	14	25	46

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Moneses uniflora (Linnaeus) A. Gray	2	4	3	1
Monotropa uniflora Linnaeus	3	2	7	11
Myrica gale Linnaeus	2	1	0	2
Nabalus Cassini	3	1	1	2
Neottia cordata (Linnaeus) Richard	0	0	0	2
Oclemena acuminata (Michaux) Greene	11	22	11	31
Onoclea sensibilis Linnaeus	1	0	1	0
Orthilia secunda (Linnaeus) House	4	4	6	21
Osmorhiza claytonii (Michaux) C.B. Clarke	0	0	0	1
Osmundastrum cinnamomeum (Linnaeus) C. Presl	0	0	1	3
Ostrya virginiana (Miller) K. Koch	0	0	0	2
Oxalis montana Rafinesque	9	19	43	49
Parathelypteris noveboracensis (Linnaeus) Ching	0	2	6	6
Petasites frigidus var. *palmatus* (Aiton) Cronquist	4	10	20	44
Phegopteris connectilis (Michaux) Watt	1	4	5	14
Picea abies (Linnaeus) H. Karsten	0	0	0	1
Picea glauca (Moench) Voss	24	33	54	83

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Picea mariana (Miller) Britton, Sterns & Poggenburgh	78	85	146	322
Picea rubens Sargent	0	0	1	1
Pinus banksiana Lambert	29	31	61	140
Pinus resinosa Aiton	0	0	0	1
Pinus strobus Linnaeus	3	1	0	8
Platanthera orbiculata (Pursh) Lindley	0	0	1	1
Platanthera Richard	0	0	0	1
Polypodium virginianum Linnaeus	0	2	2	2
Populus balsamifera Linnaeus	3	7	3	18
Populus grandidentata Michaux	1	0	0	0
Populus tremuloides Michaux	41	53	72	148
Potentilla norvegica Linnaeus	0	1	0	0
Prunus pensylvanica Linnaeus f.	32	34	63	112
Prunus virginiana Linnaeus	4	12	12	19
Pteridium aquilinum (Linnaeus) Kuhn	26	28	38	86
Pyrola asarifolia Michaux	1	3	2	5
Pyrola elliptica Nuttall	4	2	6	18
Pyrola Linnaeus	4	2	7	10

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Ranunculus abortivus Linnaeus	0	0	0	1
Ranunculus acris Linnaeus	0	1	3	7
Ranunculus Linnaeus	0	0	2	3
Rhododendron canadense (Linnaeus) Torrey	0	0	0	2
Rhododendron groenlandicum (Oeder) Kron & Judd	42	58	82	221
Rhus typhina Linnaeus	0	0	1	0
Rhytidiadelphus triquetrus (Hedw.) Warnst.	5	16	11	11
Ribes americanum Miller	0	0	1	0
Ribes cynosbati Linnaeus	0	0	3	3
Ribes glandulosum Grauer	29	41	62	114
Ribes hirtellum Michaux	0	1	0	1
Ribes lacustre (Persoon) Poiret	9	12	17	42
Ribes triste Pallas	11	18	33	42
Rosa acicularis Lindley	3	3	5	17
Rubus allegheniensis Porter	0	1	0	0
Rubus chamaemorus Linnaeus	4	1	0	2
Rubus idaeus Linnaeus	13	33	55	85
Rubus pubescens Rafinesque	17	42	63	109

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Rubus repens (Linnaeus) Kuntze	0	0	1	1
Salix Linnaeus	54	65	103	251
Sambucus canadensis Linnaeus	0	0	2	1
Sambucus racemosa Linnaeus	9	15	26	28
Sarracenia purpurea Linnaeus	0	0	0	1
Scutellaria lateriflora Linnaeus	1	0	0	0
Senecio Linnaeus	0	0	0	2
Solidago Linnaeus	3	6	8	21
Solidago macrophylla Banks ex Pursh	6	8	20	27
Solidago rugosa Miller	3	5	14	16
Sonchus Linnaeus	0	0	0	1
Sorbus americana Marshall	29	39	58	91
Sorbus decora (Sargent) C.K. Schneider	27	29	52	91
Spinulum annotinum (Linnaeus) A. Haines subsp. *annotinum*	19	39	52	79
Spiraea alba var. *latifolia* (Aiton) Dippel	1	1	1	5
Stellaria Linnaeus	0	1	1	2
Stereocaulon paschale (L.) Hoffm.	1	0	3	4

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Streptopus amplexifolius (Linnaeus) de Candolle	8	10	9	6
Streptopus lanceolatus (Aiton) Reveal var. *lanceolatus*	21	27	47	70
Symphyotrichum puniceum (Linnaeus) Á. Löve & D. Löve var. *puniceum*	2	3	11	10
Taraxacum officinale F.H. Wiggers	0	0	0	9
Taxus canadensis Marshall	4	7	18	28
Thalictrum dioicum Linnaeus	0	0	1	1
Thalictrum pubescens Pursh	3	6	4	14
Thuja occidentalis Linnaeus	3	1	6	16
Trifolium Linnaeus	0	0	0	2
Trillidium undulatum (Willdenow) Floden & E.E. Schilling	3	2	2	2
Trillium cernuum Linnaeus	1	1	0	7
Trillium erectum Linnaeus	2	4	2	4
Vaccinium angustifolium Aiton	58	65	107	240
Vaccinium myrtilloides Michaux	60	71	116	276
Vaccinium oxycoccos Linnaeus	8	7	9	20
Vaccinium vitis-idaea Linnaeus	0	0	0	2

Vascular plant species	**Broadleaf**	**BroadConif**	**ConifBroad**	**Coniferous**
Viburnum cassinoides Linnaeus	48	58	68	168
Viburnum edule (Michaux) Rafinesque	10	19	39	52
Viburnum opulus var. *americanum* Aiton	1	1	0	3
Vicia cracca Linnaeus	0	0	2	8
Viola Linnaeus	27	54	61	124
Viola pubescens Aiton	1	0	0	0

APPENDICE G: ANOVA RESULTS FOR EXCLUSIVE BRYOPHYTE SPECIES RICHNESS

Parameters and interactions	F-value	p-value
N = 89		
Forest age	72.21	<0.001
Surface deposits	0.7	NS
Stand type	0.71	NS
Forest age*surface deposits	1.71	NS
Forest age*type of stand	1.49	NS
Surface deposits*type of stand	>0.01	NS
Forest age*surface deposits*type of stand	0.57	NS

APPENDICE H: ANOVA RESULTS FOR INDICATOR BRYOPHYTE SPECIES RICHNESS

Parameters and interactions	F-value	p-value
N = 89		
Forest age	3.58	<0.02
Surface deposits	3.01	NS
Stand type	11.08	NS
Forest age*surface deposits	1.09	<0.002
Forest age*type of stand	2.49	NS
Surface deposits*type of stand	1.45	NS
Forest age*surface deposits*type of stand	0.65	NS

APPENDICE I: ANOVA RESULTS FOR MEAN BRYOPHYTE SPECIES RICHNESS

Parameters and interactions	F-value	p-value
Forest age	21.19	<0.001
Surface deposits	1.78	NS
Stand type	2.5	NS
Forest age*surface deposits	3.67	<0.006
Forest age*type of stand	1.12	NS
Surface deposits*type of stand	2.08	NS
Forest age*surface deposits*type of stand	3.12	NS

APPENDICE J: ANOVA RESULTS FOR TREE SPECIES RICHNESS

Parameters and interactions	F-value	p-value
Forest age	5.49	<0.001
Surface deposits	2.28	<0.05
Stand type	2.1	NS
Forest age*surface deposits	1.33	NS
Forest age*type of stand	0.95	NS
Surface deposits*type of stand	1.52	NS
Forest age*surface deposits*type of stand	0.57	NS

APPENDICE K: ANOVA RESULTS FOR SHRUB SPECIES RICHNESS

Parameters and interactions	F-value	p-value
Forest age	5.15	<0.001
Surface deposits	1.42	NS
Stand type	0.64	NS
Forest age*surface deposits	1.47	NS
Forest age*type of stand	1.54	NS
Surface deposits*type of stand	0.74	NS
Forest age*surface deposits*type of stand	1.02	NS

APPENDICE L: ANOVA RESULTS FOR HERBACEOUS SPECIES RICHNESS

Parameters and interactions	F-value	p-value
Forest age	2.01	NS
Surface deposits	1.38	NS
Stand type	3	0.03
Forest age*surface deposits	0.93	NS
Forest age*type of stand	0.41	NS
Surface deposits*type of stand	0.67	NS
Forest age*surface deposits*type of stand	0.74	NS

APPENDICE M: ANOVA RESULTS FOR EXCLUSIVE VASCULAR PLANT SPECIES RICHNESS

Parameters and interactions	F-value	p-value
Forest age	26.73	<0.001
Surface deposits	0.22	NS
Stand type	1.97	NS
Forest age*surface deposits	0.77	<0.001
Forest age*type of stand	4.25	NS
Surface deposits*type of stand	1.11	NS
Forest age*surface deposits*type of stand	0.63	NS

APPENDICE N: ANOVA RESULTS FOR THE PH VALUES IN BRYOPHYTES INDICATOR SPECIES

Parameters and interactions	F-value	p-value
N = 89		
Forest age	3.61	<0.01
Stand type	0.83	NS
Surface deposits	0.22	NS
Forest age*type of stand	0.36	NS
Forest age*surface deposits	0.36	NS
Surface deposits*type of stand	0.07	NS
Forest age*surface deposits*type of stand	0.04	NS

APPENDICE O: ANOVA RESULTS FOR THE LIGHT INDEX VALUES IN VASCULAR PLANT INDICATOR SPECIES

Parameters and interactions	F-value	p-value
N = 722		
Forest age	11.71	<0.001
Stand type	0.71	NS
Surface deposits	0.99	NS
Forest age*type of stand	1.19	NS
Forest age*surface deposits	1.87	0.03
Surface deposits*type of stand	0.61	NS
Forest age*surface deposits*type of stand	1.19	NS

APPENDICE P: ANOVA RESULTS FOR THE MOISTURE INDEX VALUES IN VASCULAR PLANT INDICATOR SPECIES

Parameters and interactions	F-value	p-value
N = 722		
Forest age	9.41	<0.001
Stand type	1.45	NS
Surface deposits	1.8	NS
Forest age*type of stand	1.47	NS
Forest age*surface deposits	1.46	NS
Surface deposits*type of stand	2.27	<0.005
Forest age*surface deposits*type of stand	0.82	NS

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