Afforestation and Biodiversity: Bryophyte Richness Changes Between Icelandic Forest Types

Kian McDonough
SIT Study Abroad

Follow this and additional works at: https://digitalcollections.sit.edu/isp_collection

Part of the Biodiversity Commons, Botany Commons, Forest Biology Commons, Research Methods in Life Sciences Commons, and the Terrestrial and Aquatic Ecology Commons

Recommended Citation

This Unpublished Paper is brought to you for free and open access by the SIT Study Abroad at SIT Digital Collections. It has been accepted for inclusion in Independent Study Project (ISP) Collection by an authorized administrator of SIT Digital Collections. For more information, please contact digitalcollections@sit.edu.
Afforestation and Biodiversity: 
Bryophyte Richness Changes Between 
Icelandic Forest Types

Kian McDonough

SIT Iceland: Climate Change and the Arctic 
Fall 2022
Acknowledgements
I would like to thank Dan Govoni for his constant support, help, and guidance throughout this project and for his encouragement to pursue this topic. I would also like to thank Faye Kuszewski and Ella Roelofs for their help with idea development, troubleshooting, and moral support – hours of late night discussion furthered this project as well as my own scientific understanding. And finally, I want to thank all the students, families, and mentors that have made my time in Iceland absolutely unforgettable.

Abstract
Forest-dwelling bryophytes (mosses, liverworts, hornworts) greatly contribute to biodiversity and ecosystem function but are largely under-studied in comparison to vascular plants. With Iceland's large-scale afforestation efforts there is a need to understand how different afforestation species are affecting biodiversity, including bryophyte diversity. This study looked at differences in ground-floor bryophyte richness across Sitka spruce, lodgepole pine, and downy birch forests and found that bryophyte richness was highest in the Sitka spruce forests and lowest in downy birch forests. While this suggests a negative correlation between bryophyte richness and light availability, since the conifer species have the densest copy cover, other literature has found a positive correlation between vascular plant richness and light availability. Thus, different forest types may facilitate different vegetation species. Therefore, I suggest that planting forests composed of a variety of monospecific plots may be the best afforestation method for preserving ground-floor biodiversity.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>01</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>02</td>
</tr>
<tr>
<td>Abstract</td>
<td>02</td>
</tr>
<tr>
<td>Introduction</td>
<td>04</td>
</tr>
<tr>
<td>Methods</td>
<td></td>
</tr>
<tr>
<td>a. Study Area</td>
<td>06</td>
</tr>
<tr>
<td>b. Forest Types</td>
<td>07</td>
</tr>
<tr>
<td>c. Sampling Design</td>
<td>10</td>
</tr>
<tr>
<td>d. Data Collection</td>
<td>10</td>
</tr>
<tr>
<td>e. Data Analysis</td>
<td>11</td>
</tr>
<tr>
<td>Ethics</td>
<td>11</td>
</tr>
<tr>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>a. General</td>
<td>11</td>
</tr>
<tr>
<td>b. Cover</td>
<td>12</td>
</tr>
<tr>
<td>c. Richness</td>
<td>13</td>
</tr>
<tr>
<td>Discussion</td>
<td></td>
</tr>
<tr>
<td>a. Cover</td>
<td>14</td>
</tr>
<tr>
<td>b. Richness and Abundance</td>
<td>15</td>
</tr>
<tr>
<td>c. Connections to Literature</td>
<td>15</td>
</tr>
<tr>
<td>d. Implications for Forestry</td>
<td>16</td>
</tr>
<tr>
<td>Acknowledgment of Uncertainty</td>
<td>17</td>
</tr>
<tr>
<td>Conclusions</td>
<td>18</td>
</tr>
<tr>
<td>References</td>
<td>19</td>
</tr>
</tbody>
</table>
Introduction:

Bryophytes (mosses, liverworts, hornworts) are one of the oldest land plant groups that exist on Earth, originating around 500 million years ago (Heckman, 2001). These archaic species are adapted to living in a variety of harsh conditions and small niches, leading to their presence in almost every area of the terrestrial world (CSIRO, 2021; Kimmerer, 2003; Proctor, 2000). Of the currently known 374,000 plant species on earth, it is estimated that 20,000 are bryophytes (Christenhusz & Byng, 2016; European Commission, n.d.; The Plant List, 2013). Because of their wide distribution and high species variety, bryophytes contribute significantly to overall biodiversity. In forest ecosystems, bryophytes play important roles by providing habitat for insects and microbes, influencing carbon and nutrient cycles, and affecting water balance (Kimmerer, 2003; Odor et al. 2013; Turetsky, 2003). Despite the ecological importance of bryophytes, they are often overlooked in forest management practices.

In Iceland, the topic of forest bryophyte conservation is especially interesting as forest ecosystems have been largely absent from the landscape for the last 100+ years. Before the first settlers arrived in Iceland, it's estimated that 25-30% of the country was covered in trees, but the arrival of people marked the start of deforestation (Blondal, 1987). By the beginning of the 20th century, only 1% of Iceland remained forested (Eyesteinsson, 2009).

However, in the early 1900s, small afforestation efforts began and have since expanded; today 3 to 6 million seedlings are planted every year (Eyesteinsson, 2009; Skograektin, n.d.) There is only one forest-forming tree species native to Iceland, the downy birch (*Betula pubescens*). This species's slow growth, which slows forest regeneration, and crooked trunks, which produce low-quality timber, make them unfavorable for afforestation. Therefore, exotic conifers are predominantly used for forest development. With these wide-scale afforestation efforts and the mass introduction of exotic tree species to the landscape, it’s imperative to understand how different tree species affect Icelandic biodiversity, including bryophytes.

Ecological studies conducted in other parts of the world often cannot be applied to Iceland due to the country’s unique environmental characteristics (i.e. low biodiversity, geothermal activity, poor soil, free grazing sheep, oceanic climate, and extreme topography) (Ministry for the Environment, 2001). Therefore, to understand the effects of Icelandic afforestation on biodiversity, research must be conducted directly in Iceland. Unfortunately,
research on floral and faunal communities in Icelandic forests is extremely limited and there is even less information on forest bryophytes. The only Icelandic research that was found to look directly at the effects of forest type on ground vegetation diversity was a conference paper (Elmarsdottir & Magnusson, 2007) as part of the ICEWOODS project (Elmarsdottir et al. 2007); this study focused more on the effects of afforestation as a whole rather than the effects of various forest species. This paper and others that came out of this project, were focused on total ground vegetation changes rather than looking specifically at bryophytes (Elmarsdottir & Magnusson, 2007; Sigurdsson, 2005). Thus, research on bryophyte diversity changes among Icelandic forest types is effectively non-existent.

Therefore, this study investigates the effect forest type has on ground-floor bryophyte richness by studying soil-dwelling bryophyte composition changes in forests of three different popular afforestation species: downy birch (*Betula pubescens*), lodgepole pine (*Pinus contorta*), and Sitka spruce (*Picea sitchensis*). By understanding richness and total cover of ground-dwelling bryophytes, findings from this study will be able to inform future afforestation efforts. Here I present two hypotheses that will be tested throughout the research process:

**Hypothesis 1.** Bryophyte cover will be negatively correlated with light availability. This is because most bryophytes are more shade tolerant than herbaceous plants, therefore as light increases so should the abundance of herbaceous plants which will compete with bryophytes for resources and space, thus reducing cover. Therefore, bryophyte cover will be greatest in the Sitka spruce forests (lowest available light) followed by lodgepole pine (intermediate available light), and the lowest cover will be in the downy birch (highest available light). See Methods: Forest Types for more information on the light regimes of the different forest types.

**Hypothesis 2.** Bryophyte richness will be positively correlated with light availability. More light allows for greater primary production, thus the forest type with the highest light availability will have the greatest bryophyte richness. Richness in each forest type will therefore rank, downy birch > lodgepole pine > Sitka spruce.
**Methods:**

**Study Area**

Forests in two locations in the south of Iceland, Selfoss and Hveragerði, were chosen for this study. In Selfoss, the forest *Hellisskogur* was selected and in Hveragerði the forest selected is unnamed.

*Selfoss (Hellisskogur):*

*Hellisskogur* has been managed by the Selfoss forestry association since 1985 but planting of the forest didn’t start until 1986 (Skogargatt, n.d.). Up to 51 woody plant species can be found in the forest, but some of the most prevalent trees include birch, spruce, and pine. Much of the site is made up of distinct monospecific stands, but there are a few areas of mixed forest. While the entire designated area of the forest is about 126 ha, a 40 ha section (63.952645,-20.991175) in the eastern part of the forest was looked at for this study. Unfortunately, little is published about the history of management in the forest, but evidence of trimming and brush clearing was observed in various areas during data collection. *Hellisskogur* is a popular recreation area and contains a network of footpaths and roads that are frequented by the public.

*Hveragerði:*

The forest site in Hveragerði (64.003506, -21.173190) lies on a narrow strip of land owned by the Agricultural University of Iceland (AUI) just north of the Horticulture College’s campus. The site is approximately 40 ha. The forest sits adjacent to the geothermal ForHot research site (Sigurdsson, 2016) but there is no geothermal activity present in the site itself. There is no conclusive list of the total species found at the site but the composition is dominated by various spruce, pine, and birch species. The forest is positioned on a steep slope and is broken up into a variety of monospecific forest plots. Very few records exist on the history of the forest but it is estimated that planting started around 1960 and continued into the 1990s (Páll Sigurdsson, personal communication, November 2, 2022). Planting was carried out by students at the Horticulture College. There has been periodic management throughout the forest’s history but most practices have been done for the purpose of teaching students forest thinning and
machinery operation (Páll Sigurðsson, personal communication, November 2, 2022). Several trails can be found in the forest and offer a source of recreation for the public.

Figure 1. The location of the two different sampling locations: Hveragerði and Selfoss. Both locations are in the south of Iceland about 50km from Reykjavik. Two replicates of each forest type were sampled at each location.

**Forest types**

To study the effect of forest type on bryophyte communities, three monospecific species were chosen: downy birch, Sitka spruce, and lodgepole pine. These three species were chosen for several reasons. First, 90% of the trees planted in Iceland’s afforestation efforts consist of only 5 species: downy birch, Siberian larch (L. sibirica var. sukaczewii), Sitka spruce, lodgepole pine, and black cottonwood (Populus trichocarpa) (listed in order from most to least planted) (Eyesteinsson, T. 2009). Thus, the three forest types in this study all rank among the most popular afforestation species in Iceland. Furthermore, downy birch are one of only four trees native to Iceland (Betula pubescens, Sorbus Acuparia, Salix phylicifolia, Populus tremula) and are the only native species that form forests. On the other hand, Sitka spruce and lodgepole pine are exotic species and were not introduced into the country until the early to mid-1900s (Blöndal, 1987). This inclusion of both native and exotic species can provide insight into the effects of non-native tree types on existing ecological communities.
Perhaps the most easily distinguishable feature between the forest types is the fact that downy birch are a deciduous, broad-leaf species while the Sitka spruce and lodgepole pine are evergreen conifers. This distinction, along with other individual characteristics, leads to forests with very different structures. Variation in canopy cover, tree height, diameter at breast height (DBH), ground vegetation, and litter composition can be seen in the different forests. Species composition is widely known to impact a multitude of factors including available light (Prevost & Raymond, 2012), decomposition rates (Ivarson & Sowden, 1959; Prescott et al. 2000), microbial communities (Lejon et al, 2005; Grayston & Prescott, 2003), litter (Facelli & Picket 1991), and soil organic carbon (Angst, 2018; Cha et al. 2019). However, canopy cover may be the factor with the greatest influence on ground vegetation (Emasdottir et al. 2008; Englemark et al 2000; Sigurdsson et al. 2005, Marialigeti et al. 2009). Canopy density and the subsequent amount of available light have been shown to have a significant impact on bryophyte richness. Because of this, the three forest types selected each have varying canopy densities and amounts of light availability. The Sitka spruce plots have the least light penetration (dense canopy cover), followed by the lodgepole pine plots (mid canopy cover), and then downy birch (sparse canopy cover). While canopy openness or gap fraction were not measured for this study, the ranking of light availability in each of the forest types (Spruce < Pine < Birch) is consistent with findings from Barbier et al. 2008.

**Downy birch site observations**

Downy birch forests were dominated by monocots (grasses and sedges) and a few species of other herbaceous plants. Monocots covered the majority of bryophytes, obstructing them from view. In areas of very dense vegetation, bryophyte cover was sparse. Deciduous litter was present throughout but there was rarely dense accumulation. Ground floor was often characterized by mild hummock formations.

**Lodgepole pine site observations**

In lodgepole pine plots some areas were dominated by monocots while other areas had very few monocots and were dominated by bryophytes carpeting the ground. Areas dominated by bryophytes were often associated with denser canopy cover. Areas dominated by monocots often
had hummock formations. Needle litter was present across most areas and in some places it was dense enough to limit plant growth.

*Sitka Spruce Site Observations*
Sitka spruce plots were frequently very dark and characterized by an extreme lack of herbaceous plants. Most forests appeared to be past the thicket stage and had relatively open understories. However, areas with very high stand density and high needle coverage did occur, and these areas were often devoid of plant growth. The ground floor was typically one continuous carpet of bryophytes with a few horsetails (*Equisetum*) scattered throughout. Needle litter was frequent but less obtrusive than the Lodgepole Pine needles (smaller needle size).

![Figure 2](image_url)

Figure 2. Each column highlights a forest type. Each row highlights a different aspect of the forest. First row is a general image of the forest showing stand density. Second row shows canopy cover from inside the forest, looking up. Third row show ground floor characteristics for each forest type. Birch trees are dominated by grasses, lodgepole pine have a mixture of grasses and bare bryophytes, and Sitka spruce are dominated by a carpet of bryophytes.
**Sampling Design**

At each of the two locations, two plots of each forest type were chosen (2 locations x 2 plots = 4 replicates of each forest type). Visual estimates of canopy cover, stand density, DBH, and management intensity were used to select forest plots with consistent characteristics.

In Selfoss, sampled forest plots averaged 0.271 ha and ranged from 0.06 ha to 0.775 ha. In Hveragerði, average plot size was 0.189 ha and ranged from 0.117 ha to 0.331 ha. In each plot, ten quadrats (20x20cm) were randomly selected through the random generation of an x and y coordinate. Thus, the sample size for each forest type was 40 quadrats.

![Aerial photos of the two sampling locations and the individual plots sampled in each. The image on the left is of Hveragerði and the image on the right is of Selfoss. Images are taken at different scales. B refers to Birch, L to Lodgepole Pine, and S to Sitka Spruce.](image)

**Data Collection**

In each quadrat, bryophyte richness, total bryophyte cover, and dominant species were recorded. In this case, dominance is defined as the species with the greatest percent cover per quadrat. If a species was unable to be identified in the field, a small sample was collected and
stored for later identification. In plots where bryophytes were obscured by monocots, monocots were cut away to reveal the bryophytes. Species were identified using the British Bryological Society’s field guide (British Bryological Society, 2010) and the email discussion group, Bryonet. Fieldwork was conducted at the end of October and the beginning of November in 2022.

**Data Analysis**

Species richness was analyzed using the methods outlined in Chao et al. 2014. Utilizing the iNEXT package in RStudio, rarefaction/extrapolation (RE) curves were generated with each of the three Hill numbers (q=0 for species richness, q=1 for Shannon diversity, q=2 for Simpson diversity). Because the data are sample-size based, the RE curves were generated with the “incidence frequency” parameter. 83% confidence intervals were estimated for the RE curves through 50 replicate bootstrap runs. Non-overlapping confidence intervals indicate statistically significant results and confidence intervals that overlap only at “initial, small sample sizes” are still considered significant (Chao et al. 2014). Visual estimates of significance (overlapping confidence intervals) don’t represent the same levels of significance as traditional statistical tests. For example, 95% confidence intervals may overlap but still show significant differences for $\alpha = 0.05$. It has been found that non-overlapping 83% confidence intervals indicate significant results at an $\alpha$ of 0.05 (Austin & Hux, 2002; Payton et al. 2003; MacGregor-Fors & Payton, 2013).

The percent cover data were arcsine transformed and then analyzed with a parametric ANOVA test. All assumptions were met.

**Ethics:**

While some species had to be removed from the field for identification purposes, all samples were limited to the smallest possible amounts. Additionally, precaution was taken to avoid excessive trampling of field sites.

**Results:**

A total of 11 bryophyte species (9 mosses, 2 liverworts) were recorded. Of these, *Rhytidiadelphus squarrosus* and *Hylocomium splendens* were the most common. They were present in 91.66% (occurrence per forest type: Birch = 97.5%, Lodgepole = 92.5%, Spruce =
85%) and 76.66% (Birch = 57.5%, Lodgepole = 75%, Spruce = 97.5%) of the quadrats respectively. All other species were present in 21% of the quadrats or less with 45.5% of the total species being present in less than 5% of the quadrats.

Figure 4. Shows the two most common bryophyte species *Rhytidiadelphus squarrosus* (left) and *Hylocomium splendens* (right).

**Cover**

No statistical difference was found between the percent bryophyte cover in each of the three forest types ($df = 2$, $F = 0.369$, $p = 0.692$).

Figure 5. Box plot of total percent cover of bryophytes in each of the forest types. No significant difference in percent cover was found between the forest types. Y axis represents the arcsine transformation of the percents.
**Richness**

Sample-size-based RE curves showed the trend of the three Hill numbers \((q = 0, q = 1, q = 2)\) for an artificial increase in sampling units. Because all confidence intervals for the Hill-Shannon and Hill-Simpson diversity indices \((q = 1, q = 2)\) overlapped, there was no statistical difference in bryophyte diversity between the three forest types under these diversity measures. However, there was a significant difference in bryophyte richness between Sitka spruce and downy birch forests under the Hill-Richness index \((q=0)\), as confidence intervals did not overlap for these two forest plots (except at initial, small sampling sizes). Because the confidence intervals of the lodgepole pine rarefaction curve overlapped with both Sitka spruce and downy birch, there was no significant difference in the bryophyte richness between spruce and pine and between pine and birch. That being said, with extrapolation of the data, pine diverges significantly from birch to the point where confidence intervals no longer overlap. Additionally, the overlap between pine and spruce drastically increases to the extent that the two curves have almost the same value. This suggests that as more quadrats are sampled, there might be a significant difference in the bryophyte richness between pine and birch, and the richness in pine and spruce may look very similar. It is important to note that the Hill-Richness metric is very sensitive to rare species and that these species are emphasized in the equation when determining diversity. The large proportion of infrequently occurring species in the raw data likely has a strong influence on the significant results shown under the Hill-Richness metric. The raw data show the rank of bryophyte richness in the three plots as Sitka spruce (10 species) > lodgepole pine (8 species) > downy birch (6 species).
Figure 6. Comparisons of sample-size-based rarefaction (solid line) and extrapolation (dashed line) curves for each of the three Hill numbers for each of the three forest types. q = 0 represents Hill-Richness, q = 1 represents Hill-Shannon Diversity, and q = 2 represents Hill-Simpson Diversity. 83% confidence intervals were generated through a bootstrapping process of 50 replications. If the confidence intervals overlap there is not a significant difference. The only significant difference shown is between Spruce and Birch for q = 0.

Discussion:

Cover

No difference was found between bryophyte cover in each of the forest types thus the results fail to support Hypothesis 1. Initial observations showed bryophytes dominating the ground in Sitka spruce forests but not in downy birch (Figure 2). This was not because of the absence of bryophytes but rather the high abundance of monocots in the downy birch forests which effectively covered the bryophyte layer from view. This higher herbaceous plant presence in the downy birch forests can most likely be linked to greater light availability (Stone & Wolfe 1996, Elmarsdottir & Magnusson 2007, Barbier et al 2008). Literature has shown that herbaceous plants are competitors to bryophytes and can outcompete them for resources and space, leading to reductions in bryophyte cover (Lobel et al 2006, Ingerpuu 2002, Ingerpuu et al 2003, He 2016). However, while herbaceous plants can limit bryophyte growth, environmental
factors may have a greater effect on bryophyte cover than herbaceous plant competition. Available light has been shown to be positively correlated with bryophyte growth and subsequently bryophyte cover (Tinya et al 2009, Marialigeti 2009). Thus, the greater light availability in the birch forests can lead to both negative pressures (more herbaceous plants) as well as positive pressures (increased bryophyte growth) that affect bryophyte cover. Ultimately, more data must be collected before any conclusions can be made on the factors influencing bryophyte cover.

Richness and Abundance

Bryophyte richness was found to be higher in Sitka spruce forests than in downy birch forests (no significant difference between spruce/lodgepole or birch/lodgepole) and extrapolation curves indicate that with further sampling, bryophyte richness in Sitka spruce and lodgepole pine forests may be largely similar. These results reject Hypothesis 2 and indicate that Icelandic bryophyte diversity is higher in conifer forests than it is in deciduous, downy birch forests.

Changes in relative abundance (incidence data) of sampled bryophyte species indicate that concentrations of species fluctuated depending on forest type. For example, the relative abundance of \textit{H. Splendens} is 40\% lower in downy birch than it is in Sitka spruce, while \textit{R. squarrosus} is 12.5\% higher in downy birch than it is in Sitka Spruce. Thus, each species has its own unique positive or negative correlations between the forest types, dependent on different environmental characteristics (Ingerpuu et al. 2005; Vellak et al. 2003; Virtanen et al. 2002).

Connections to Available Literature

Few studies have looked specifically at the topics addressed in this paper. Thus, there is an opportunity to synthesize these results, with literature that looks at ground vegetation diversity as a whole, and generate ideas about how bryophyte diversity and total ground vegetation diversity are related in Icelandic forests. Previous studies have indicated that ground vegetation richness is positively correlated with light availability (Englemark et al. 2001; Hedwall et al. 2018; Humphrey et al. 2002; Odor et al. 2013; Tinya et al. 2009; Tyler 1989). In the Icelandic context, these results were upheld in Elmarsdottir & Magnusson, 2007, in which they showed that there is higher ground vegetation richness in downy birch forests than in conifer forests. Observations of higher herbaceous plant abundance in downy birch forests also support these
results. However, in Elmarsdottir & Magnusson, 2007, bryophyte richness was not separated from total ground vegetation richness. Thus, my results, which looked specifically at bryophyte richness, present contrasting information. While total ground vegetation richness may be highest in downy birch forests and forests with high light availability, bryophytes don’t follow this trend. If we assume that total ground vegetation consists of bryophytes, vascular plants, and lichens, this indicates that vascular plant and lichen richness is negatively associated with conifer forests and/or positively associated with downy birch forests, while bryophyte richness is positively correlated with conifer forests and/or negatively correlated with downy birch forests.

Implications for Forestry

The results of this study suggest that to best promote bryophyte diversity, afforestation efforts should emphasize the planting of conifer (specifically Sitka spruce) forests. This will create habitats that allow for maximum bryophyte richness. However, it's important to note that most of the conifer plots in this study appeared to be past the thicket stage and, within plots, areas with extremely dense canopy cover and a thick litter layer often showed very little bryophyte growth. This suggests that while conifer forests can harbor the greatest bryophyte richness, if stand density and canopy cover are too dense, there may be a suppression of bryophyte growth. Thus, management practices such as thinning, trimming, and low-density planting may be essential to determining whether or not conifer forests promote maximum bryophyte diversity. That being said, more research is needed before any conclusion can be drawn.

Many studies, including Elmarsdottir & Magnusson, 2007, have suggested that planting mixed forests, of deciduous and conifer species, is the best way to promote biodiversity (Elmarsdottir & Magnusson, 2007; Felton et al. 2013; Lindenmayer & Hobbs, 2003, Nichols et al. 2006). While mixed forests have been shown to support a large number of unique species, most studies only compare mixed forests to monoculture forests, thus indicating there are only two viable forest designs. However, the results of this study suggest that a new and different forest design may facilitate the maximum vegetation richness.

I hypothesize that forests made up of many monospecific stands may be the best way to promote vegetation richness at a landscape scale. To facilitate maximum bryophyte richness monospecific conifer forests should be planted. To facilitate high vascular plant and lichen
richness, downy birch forests should be planted. Therefore, if a forest is made up of individual plots of conifers and individual plots of downy birch it would, in theory, preserve all the species that only grow in conifers as well as the species that prefer downy birch. This creates the largest possible vegetation diversity over the forested landscape.

Mixed conifer-birch forests may limit the growth of certain bryophyte species that are dependent on the light and climate regimes of pure conifer forests (Heinrichs et al. 2019). Thus, mixed forests can suppress the diversity potential of Icelandic forests. That being said, in small fragmented forest plots where the forest area is not large enough to support many individual monospecific plots, mixed forests may provide the highest vegetation richness. By providing a variety of habitats and light regimes, mixed forests can support some bryophyte species, some vascular plants, and some lichens, therefore leading to high vegetation diversity (albeit not the maximum) (Cavard et al. 2011; Gong et al. 2021; Hedwall et al. 2018). Therefore, small afforestation efforts may benefit from a mixed forest structure. However, for large-scale afforestation projects, I propose a landscape of monospecific stands, as it will ensure that bryophyte richness is preserved while also providing habitat for organisms that thrive in downy birch forests.

**Acknowledgment of Uncertainty:**

While this study provides important findings, improvements can be made for future research. Increasing the number of sampling locations (include locations in the north, east, and west), the number of forests sampled, and the number of quadrats sampled per forest, will all increase the confidence in the results. Additionally, only one of the three Hill indices (q=0) showed significant results. With increased sampling, we may see greater distinctions in all of the diversity estimators. This study only looked at soil-dwelling bryophytes, but to accurately understand total bryophyte richness, bryophytes growing on trees (epiphytic), rocks (lithophytic), and dead wood (epixylic) should be studied. Also, this study did not collect data on possible factors influencing richness. Data should be collected on canopy gap fraction/canopy cover, tree height, basal area, stand density, soil pH, litter cover, and soil moisture in order to confidently understand why bryophyte richness changes between forests and to inform management practices. Finally, collecting data on bryophyte richness in mixed forest vs monospecific plots can provide conclusive evidence on how to best structure forest plantings.
Conclusions:
Despite large-scale afforestation efforts in Iceland, little is known about how different afforestation species affect biodiversity. Understanding how bryophyte richness varies in different forest types helps to answer a small part of this larger question. The higher bryophyte richness found in conifer forests indicates that afforestation with conifer species can promote bryophyte diversity. However, more information is needed on the environmental factors that are driving this bryophyte richness in order to accurately develop sustainable forest management practices. Literature on positive correlations between total vegetation richness and light availability combined with this study's finding that conifer forests have higher bryophyte richness indicates that large forests made up of a mosaic of monospecific conifer plots and monospecific birch plots may provide the greatest vegetation diversity at a landscape scale. Future research must look at how other individual floral and faunal communities are affected by various afforestation practices to ensure that the development of Iceland’s forests promote biodiversity.
References


Heinrichs, S., Ammer, C., Mund, M., Boch, S., Budde, S., Fischer, M., ... & Schall, P. (2019). Landscape-scale mixtures of tree species are more effective than stand-scale mixtures for biodiversity of vascular plants, bryophytes and lichens. *Forests, 10*(1), 73.


