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Short communication

Mosses inhibit germination of vascular plants on an extensive green roof

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ABSTRACT

Mosses are capable of tolerating harsh conditions, and are commonly found on both conventional bare roofs and engineered green roofs. Intentional planting of mosses on green roofs has shown that mosses can improve ecosystem services such as stormwater retention and microclimate cooling. Past studies of moss interactions with vascular plants on green roofs and in other habitats demonstrate both positive and negative effects on juvenile and adult tracheophytes. Moss can aid vascular plants by buffering environmental extremes, facilitating seed establishment, and improving nutrient and water availability. Conversely, moss can also hinder young seedling germination by blocking access to the soil column and/or light. In the green roof context, few studies have examined the relationship between moss and vascular plant germination. Since mosses commonly colonize green roofs it is important to understand the effects of established moss colonies on incoming plant propagules. The purpose of this study was to examine how four moss species, *Atrichum undulatum* (Hedw.) P. Beauv., *Polytrichum commune* Hedw., *Polytrichum piliferum* Hedw., and *Racomitrium lanuginosum* (Hedw.) Brid. affected the germination of weedy and native vascular plant seeds in a green roof system. Seeds were added to six pre-established moss treatments: monocultures of each moss species, a mixture which included all four moss species, and a substrate only control in pots on a rooftop. Overall, the control (moss-free) treatment resulted the highest germination rates for the majority of seeded species examined, an indication that for these vascular plants, mosses tend to inhibit germination of incoming seeds.

1. Introduction

Green roofs have become a useful way to mitigate some of the negative impacts of urbanization. They are more reflective than conventional shingle roofs, and contain vegetation that reduces heat transfer into the building throughout the summer (Bowler et al., 2009; Jaffal et al., 2012; Lundholm et al., 2010; Oberndorfer et al., 2007). Vegetation acts positively to cleanse the air through converting carbon dioxide to oxygen, as well as to cool the roof by providing shade and removing heat with the water that vaporizes during evapotranspiration (Kawakami et al., 2012). Green roofs also retain rainwater that would otherwise flow off the hard surfaces of the buildings and pavement below, contributing to erosion and treatment costs (Lundholm et al., 2010; Mentens et al., 2006; Oberndorfer et al., 2007; Stovin, 2010).

The height and relative isolation of green roofs exposes their vegetation to relatively harsh conditions including, drought, high wind speeds, temperatures and light intensities (Oberndorfer et al., 2007). Therefore, plants selected for this environment have to be well adapted to these stresses in order to survive. Many moss species can tolerate these harsh conditions, and are commonly found in rooftop settings (Anderson et al., 2010; Glime, 2013; Seaward, 1979). Additionally, previous research has found that moss can be planted together with vascular plants to optimize storm water retention and reduce substrate temperature (Anderson et al., 2010; Heim & Lundholm, 2014; Heim et al., 2014). However, mosses may not always have a positive impact on neighboring vascular plants. For example, Heim et al. (2014) found that companion planting with moss species negatively affected the growth of some vascular species and enhanced the growth of others. More research is needed to determine the positive and negative relationships between moss and vascular vegetation in the green roof setting.

Previous studies have demonstrated both negative and positive effects of moss on vascular plants. Moss can aid vascular plants by buffering environmental extremes in stressful conditions, trap seeds and facilitate their establishment, and improve nutrient and water availability (Gornall et al., 2011; Rayburn et al., 2012; Sand-Jensen & Hammer, 2012). Conversely, many studies have found that moss can also hinder young seedling germination (Donath & Eckstein, 2010; Jeschke & Kiehl, 2008; Soudzilovskaia et al., 2011; Van Tooren 1990; Zamfir, 2000). Jeschke & Kiehl (2008) found that a dense moss layer acted as a barrier preventing seeds from reaching the soil and reduced light exposure to seedlings. Another study found that the emergence of

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seedlings was related to seed size, where larger seeds had a greater advantage when emerging from the moss canopy (Donath & Eckstein, 2010). Seedling shape can also be a contributing factor. A narrow vertical first leaf will emerge easier than horizontal dicots (Zamfir, 2000). Thus, the nature of moss-vascular plant interactions varies according to the species involved, their growth form, seed characteristics, and resource requirements (Heim et al., 2014).

In the green roof context, few studies have examined the relationship between moss presence and vascular plant germination. Green roofs are artificial ecosystems featuring novel combinations of biota and environmental conditions and simplified biotic communities (Lundholm & Walker, 2018). The differences between green roofs and natural habitats where mosses have been intensively studied are great, so it is difficult to directly apply ground-level research to the green roof context. Since mosses commonly colonize green roofs it is important to understand the relationship these organisms have with different vascular species. For example, particular moss species may inhibit weedy vegetation while encouraging desired native vegetation. The purpose of this study is to examine how different species of moss will affect the germination of native and weedy vascular vegetation in a green roof setting in Halifax, Nova Scotia.

2. Methods

Moss species were transplanted as clumps in November 2013 into 13.5 cm^3 pots, containing a root barrier/drainage layer (EnkaRetain and Drain 3111®, Colbond Inc., NC, USA) and 11 cm of Sopraflor X substrate (Soprema Inc., Drummondville, QC, CA). Seeds were added to pots in June 2014 with treatments monitored from June to August 2014. To prevent disturbance, bird netting was used to shield treatments. Pots were arranged in a random block design. Treatments were watered to field capacity at the beginning of the study and during prolonged drought (if moss/vegetation was browning). During this timeframe the total precipitation was 191.3 mm and the average temperature ranged between 15.4 °C and 20.2 °C (Environment Canada, 2017).

All species used in this study were chosen due to their success in previous green roof experiments and/or due to their success in ground-level habitats that are similar to the green roof environment (Heim et al., 2014). The seeds and moss used in this study were collected from one of three sites across Nova Scotia: 1. Chebucto Head: coastal barrens (44°30′N, 63°31′W), 2. Saint Mary's University (44°39′N, 63°35′W), and 3. Gravelly roadside habitat (44°37′N, 63°41′W). The moss species used included: *Atrichum undulatum, Polytrichum commune, Polytrichum piliferum*, and *Racomitrium lanuginosum*. The native plant species included: *Anaphalis margaritacea, Plantago maritima, Luzula multiflora, Solidago bicolor,* and *Festuca rubra*. The weedy species included: *Plantago major, Rumex crispus, Erysimum cheiranthoides, Senecio viscosus,* and *Polygonum persicaria* (Appendix A). This study consisted of 12 treatments (n = 5): native seeds planted in a moss monoculture (one for each moss species), a mixed treatment containing all four mosses, and a bare soil treatment (which acted as a control); and weed seeds planted in the same six treatments as the native seeds (i.e. native and weed seeds were not sown together) (Fig. 1). This study aimed to have at least 10 seedlings of each species sprouting in each treatment. The number of seeds required to yield such results was determined through an indoor germination trial (Appendix A). The number of germinating seeds for each treatment was counted three times a week. At the end of the study an ANOVA and Tukey post hoc test was used to compare average germination and the number of days it took for germination to occur for all treatments (R Project for Statistical Computing version 3.1.1).

3. Results

For average germination, significant differences were observed between treatments ($p = 3.23e-05$). Overall, no *A. margaritacea* seeds germinated in the *P. piliferum* or *R. lanuginosum* treatments or for *S. bicolor* in the *R. lanuginosum* treatment. For germination, no significant differences were observed between treatments for *F. rubra, P. maritima*, and *R. crispus*. Significantly greater germination was observed in the control treatment compared to all other treatments for *A. margaritacea*, *L. multiflora*, and *P. major*. Both *P. persicaria* and *S. viscosus* had significantly greater germination in the control treatment than the *P. piliferum* and *P. commune* treatments. Compared to all other treatments *E. cheiranthoides* had significantly greater germination in the *A. undulatum* and control treatments. Compared to all but the *A. undulatum* treatment, *S. bicolor* had significantly greater germination in the control treatment. Additionally, *S. bicolor* in the *A. undulatum* treatment had significantly greater germination than in the other treatments. Finally, *S. bicolor* in the mixed moss treatment had significantly greater germination than in the *R. lanuginosum* treatment (Fig. 2a).

For the average number of days until germination, significant differences were observed between treatments ($p < 2e-16$). No significant difference was observed between treatments for *E. cheiranthoides, F. rubra, L. multiflora, P. maritima, R. crispus, S. bicolor,* and *S. viscosus*. Compared to all other treatments *A. margaritacea* germinated significantly later in the *A. undulatum* and control treatments. *P. persicaria* germinated significantly later in the *A. undulatum* and control treatments than in the *P. piliferum* treatment. Finally, *P. major* seeds germinated significantly later in the control treatment than in the *P. piliferum* treatment (Fig. 2b).

4. Discussion

Overall, the substrate only control was the preferred treatment for the majority of species examined. This coincides with many other studies that have shown mosses do not facilitate but rather inhibit germination of seedlings (Jeschke & Kiehl, 2008; Zamfir, 2000). This impediment could be the result of many factors such as the moss acting as a barrier preventing seedlings from reaching the soil or emerging from the moss canopy (Jeschke & Kiehl, 2008). It was observed that during the study *P. piliferum* and *P. commune* tended to dry out faster and appeared to have lower moisture in the soil than the controls. This could have negatively impacted seedling germination. However, no moisture data was recorded. Therefore, more research is needed to confirm this speculation.

Out of all the mosses, the *A. undulatum* treatment supported the highest germination of vascular plants. This species is not as tall as *P. commune* or *P. piliferum* and it is not as dense as *R. lanuginosum*. The *A. undulatum* treatments had a relatively short and loose canopy which may have promoted better germination by increasing the chance of seeds reaching the soil. It was observed that in the mixed moss species treatments, seedlings commonly grew among the stems of this species of moss rather than in the others. The *R. lanuginosum* and *P. commune* treatments had the lowest germination rates. For *R. lanuginosum* this result could be due to its high stem density. The few seedlings that grew in the *R. lanuginosum* treatment were commonly found along the edge of the pot or in cracks that occurred within the moss canopy where bare substrate was exposed. *P. commune* was the tallest moss species examined, and researchers observed that these pots tended to dry out fairly easily. Overall, the moss treatments resulted in fewer seedlings germinating than the bare soil control pots. This suggests that mosses could play a beneficial role on green roofs by inhibiting the growth of weeds, and therefore minimize the amount of weeding maintenance required. However, in addition to inhibiting weed growth moss will likely also inhibit the germination of desired vegetation. This implies that green roofs in regions that tend to encourage moss development should avoid establishing vegetation that solely relies on seed germination for long term persistence (e.g. annual species).

The low germination of *P. maritima* in all treatments was likely due to dry storage conditions before germination. After this study had taken place, germination research was conducted on *P. maritima,* determining