Native Plants for Atlantic Canada Green Roofs

Final Project Report

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Table of Contents

Summary

Due to the rapid expansion of the human population in the last 40 years, urban areas around the globe continue to grow and replace vegetated areas with impervious surfaces (Carter and Butler, 2008). To mitigate environmental problems associated with the loss of vegetated areas, people can improve urban environments by greening rooftops urban areas (Stovin, 2009).
The objective of this project is to develop a native plant mixture for green roofs in Atlantic Canada with how-to protocols including a cost/benefit analysis on plant selection, substrate selection, propagation techniques and indicators of green roof benefits. This protocol will be useful for green roof and nursery industries, landscape architects, planners, community groups and other researchers.
Methodology includes testing of four treatments: two different propagation methods, two different types of growing medium, native plant mixtures with/without *Sedum* species, and plants with/without a living mulch of mosses and lichens. To evaluate these options we collected data on: monetary and time costs of the different treatments, plant growth and flowering, and other green roof functions such as stormwater retention and substrate cooling. With the recent adoption of a green roof by-law in Halifax and Dartmouth (Regional Centre Land Use By-law, 2019), there will be an increased pressure on business and homeowners to install green roofs on buildings. The results in this project are expected to help increase the use of native plants on green roofs to diversify the plant selection available while also identifying effective techniques and substrates.

Introduction

Green roofs are gaining popularity in Atlantic Canada due to their environmental benefits. The region's largest city (Halifax-Dartmouth) is poised for an increase in green roof development, due to the recent development of a green roof by-law and construction standard covering urban core areas. Shallow-substrate (extensive) green roofs constructed to date in the region mainly use mixtures of non-native *Sedum* species, however, there is considerable interest in using native plant species due to increased functionality, aesthetics and a desire to make use of local resources. While our research group has been testing native species on green roofs for over a decade, there are still barriers to widespread adoption of native plants on green roofs in the region. Lack of availability at local nurseries, uncertainty about maintenance requirements, appropriate growing media and compatibility with industry-favoured *Sedums* discourage use of native plants on green roofs. This project aims to reduce these barriers by demonstrating the practicality of a species mixture featuring Atlantic Canada natives.

Green roofs are known to provide benefits to ecosystems in urban areas as vegetated areas become depleted and replaced with impervious surfaces (MacIvor and Lundholm, 2011). These benefits include improved stormwater retention, reduced urban heat island effects, and provide habitat to wildlife (Oberndorfer et al. 2007). Rooftop conditions can be challenging for plant survival and growth depending on their location. Factors affecting plant survival includes drought, moisture, temperatures, high light intensity, and high winds with the risk of physical damage (Dunnett and Kingsbury, 2004). Most suitable plants for shallow-soil green roofs share adaptations that enable them to survive harsh conditions which include stress-tolerant characteristics such as low, mat-forming growth, evergreen foliage, twiggy growth, succulent leaves, good water storage capacity, or CAM (crassulacean acid metabolism) (Lee and Kim, 1994). Due to changing climate conditions that can restrict the use of certain species, it is important to understand which vegetation should be used for installation on green roofs. Due to the shallow substrate depths on green roofs (ranging from 2 to 15 cm), *Sedum* species are used as they often outperform other taxa due to their shallow roots and their water storing capabilities as they are a succulent species (Oberndorfer et al. 2007).

In recent years, native taxa have been evaluated for their potential for use on green roofs due to their adaptation to the existing local climate (Monterusso et al. 2005; Lundholm et al. 2010; Butler et al. 2012; Aloisio et al. 2019). Native, stress-tolerant floras such as dry grassland and coastal and alpine floras of various regions offer opportunities for experiments to be used on green roofs (Oberndofer et al. 2007).

What do we know already?

While green roofs have existed in Halifax for decades, research into plant species selection in Atlantic Canada did not begin until 2006 with Saint Mary's University establishing the Ecology of Plants in Communities research lab. This group has approached plant selection by targeting native species from local coastal barrens environments, species that are presumed to have adaptations to rooftop conditions of shallow soil and high winds from their relatively harsh natural habitat. Early work established the viability of over 20 native species for shallow-substrate (extensive) green roof applications in Halifax (MacIvor and Lundholm, 2011), the role of plant diversity in improving the function of green roofs (Lundholm 2015; Tran et al. 2019), and the potential benefits of lichens and mosses on green roofs (Heim and Lundholm 2013; Haughian and Lundholm, 2020). While this research has often involved both native plants and *Sedums*, we have not explored the value of planting *Sedums* and native species growing together in the same system. We have a great example of a mixed *Sedum* and native plant green roof that has evolved at Saint Mary's since 2010 (Figure 1), but we have not done controlled studies in that system.

Despite over a decade of research that shows certain native plant species to be suitable for green roofs in Atlantic Canada, there is still a lack of uptake locally. Although reasons have not been characterized, this may have been due to the poor availability of native plant species appropriate for extensive green roofs in local nurseries, low knowledge of propagation techniques for native species, landscape designers unaware of the benefits of natives and the green roof industry’s preference for drought tolerant *Sedums*.

Figure 1. Shallow-substrate (extensive) green roofs at Saint Mary's University featuring *Sedums* and native species (established in 2010).

Governance in Nova Scotia

As of November 30th, 2019, the Halifax Regional Municipality developed and passed a By-law titled Regional Centre Land Use By-law for the city of Halifax and downtown Dartmouth. In regards to green roofs, the By-law states any building with a flat roof shall provide soft landscaping (substrate with vegetation) on at least 40% of the roof area. The By-law also indicates that where soft landscaping is required, a minimum number of unique plant species shall be provided. For example, if the area requires at least 10 trees or shrubs, then at least three different tree or shrub species must be used. This ensures the inclusion of species diversity. Although this new By-law is a step in the right direction, there are still many improvements to be made including implementation in other areas of the province, plant and substrate selection suggestions, maintenance requirements and community involvement.

In this study we evaluated top performing Atlantic Canada native plant species which were identified from previous studies (MacIvor and Lundholm, 2011), while also quantifying the costs and benefits of different treatments and propagation techniques. We tested in a fully factorial experiment plug planting versus direct seeding, native plants with or without *Sedums*, commercial extensive roof growing medium versus one made from locally available materials, and with or without a lichen/moss living mulch. Each combination treatment was compared with all others with respect to plant growth, floral cover, soil temperature reductions, and stormwater retention.

Objectives

a) calculate time and financial budgets for direct seeding vs. plug planting approach
b) evaluate options for *ex situ* vs *in situ* green roof establishment
c) determine the benefits/costs of including *Sedums* in mixture with native species
d) determine the benefits/costs of including reindeer lichens (*Cladonia* spp.) and mosses (*Racomitrium lanuginosum*) to fill in any gaps during establishment
e) compare locally sourced growing medium with commercial extensive green roof media in terms of plant establishment rate
f) develop, publish and propagate a concise how-to manual for a diverse set of user groups

Methods

This research project began with seed collection of various plant species (Table 1) including native Nova Scotia species and three non-native *Sedum* species during the 2019 growth season (May – November). Seeds were stored for the direct-seeding treatment and greenhouse propagated for the plug-planting treatment over Fall 2019. The next stages of this experiment included the planting of moss and lichen species in March, 2020 (delayed to June 2020 due to COVID-19) with the full rooftop experiment beginning in May (June, 2020 due to COVID-19) to allow one full growing season for the experiment. A generic modular extensive green roof system was used with species selection based on formally tested and successful growth seasons during previous studies (MacIvor and Lundholm, 2011).

Table 1: Native, *Sedum*, moss and lichen species used in this project. All species used have been previously tested and had successful growth and survival rates on green roofs in the Maritimes.

Type	Species Name	Common Name	Growth Form	Ecosystem Services Provided	Harvest Period/Collection
Native Species	*Solidago bicolor*	Silverrod	perennial herb	pollinator resources, enhances stormwater retention[1], visual appeal	August - October
	Symphyotrichum novi-belgii	New York Aster	perennial herb	pollinator resources, enhances stormwater retention, visual appeal	November
	Luzula multiflora	Common wood rush	perennial	Low water requirement	August - October
	Oenothera biennis	Evening Primrose	biennial herb	Pollinator resources[2], visual appeal	August - October
	Danthonia spicata	Oatgrass	perennial bunchgrass	low water requirements[1]	July - August
	Festuca rubra	Red Fescue	perennial sod grass	enhances stormwater retention [3]	August
	Rhodiola rosea	Roseroot	perennial succulent	pollinator resources, visual appeal, microclimatic cooling[1]	July - August
	Plantago maritima	Seaside plantain	perennial herb	carbon storage[20]	September
	Sibbaldiopsis tridentata	Three-toothed cinquefoil	creeping shrub	pollinator resources, visual appeal	August
***Sedum* Species**	*Sedum acre*	Goldmoss stonecrop	perennial herb	microclimatic cooling[4]	August - September
	Sedum album	White stonecrop	perenial herb	canopy density, microclimatic cooling[5]	September
	Sedum sexangular	Tasteless stonecrop	perenial succulent	microclimatic cooling[6]	August - September
Moss Species	*Racomitrium lanuginosum*	Woolly moss	Moss	Weed reduction, lower substrate temperature[7]	March

Lichen Species	Cladonia spp.	Reindeer Lichen	Lichen	Weed reduction[8], lower substrate temperature[7]	March

Treatments

Four experimental factors were evaluated throughout this experiment. These include 1) an establishment method of direct seeding vs. plug planting; 2) comparison of two substrates: locally made growing medium vs. commercial green roof medium; 3) inclusion of *Sedum* species vs. no *Sedum* species; and lastly 4) inclusion of lichen/moss vs. no lichen and moss. This will result in a total of 16 combinations of treatments (Appendix A1).

Table 2: Composition of locally sourced substrate. Amount per module was calculated based on parts. For example, one batch of soil would include 5.5 parts pea stone, 1.5 parts perlite, 2 parts sand and 1-part organic matter to fill 10 modules.

Composition	Percentage (%)
Pea Stone	55%
Perlite	15%
Sand	20%
Compost	10%

a)

b)

Figure 2. a) local soil mixture; b) commercial soil mixture.

Roof Set-up and Modular System

This project consisted of 180 modules (16 treatment combinations x 10 replicates per treatment combination and one control per replicate) (Appendix A1). Modules are square trays measured at 36x36x12 cm; each module was assigned to one of the 16 treatment combinations (Appendix A1). Before the addition of growing medium and plant material, a water retention layer including a site of attachment for plants was added into each module. Substrate was then added with a depth of 10 cm per module. Each module in the direct-seeding treatment received a standard amount of seed from the same species. Depending on the desired combination, moss, lichen, *Sedum,* plugs, direct seeding, local substrate and commercial substrate was added accordingly (Appendix A1). Modules were divided into three rooftop locations on the Saint Mary's University campus in Halifax, Nova Scotia. The first location will receive four of the ten replicates of each treatment combination resulting in 64 modules. This will be located one floor above ground-level with partial shade and shelter from surrounding wind (Appendix A2). The other two sites will be on a roof four floors above ground-level and will represent a more typical green roof. The second site had partial shade with the third completely exposed. These sites had three replicates of each treatment combination for a total of 48 modules each (Appendix A2).

2. Research progress made to date

Objectives of Project

1. Calculate time and financial budgets for direct seeding vs. plug planting approach.

   In order to determine the best method for plant growth, two establishment methods were tested. These methods included growing plugs in a greenhouse during the winter then planting at the time of set-up as well as directly placing seeds into soil at the time of set-up. Time and financial budgets were recorded to determine effectiveness of plant growth and how the plants relate to each recording. Data have not yet been analyzed due to delays to the project caused by the COVID-19 pandemic.

Figure 3. Direct seeded modules (top); plug planted module (bottom).

2. Determine the cost and benefits of including *Sedums* in mixture with native species.

Sedum species were incorporated into plant mixtures as they can have superior survival in low substrate levels (as low as 2 to 3 cm) (Oberndorfer et al., 2007) with native plant species to increase ecosystem service provisioning and biodiversity (Lundholm, 2015). These were propagated from existing *Sedum* species at Saint Mary's University. Data have been collected and analyzed; results are summarized in the next section.

3. Determine the benefits/costs of including reindeer lichens (Cladonia spp.) and mosses (*Racomitrium lanuginosum*) to fill in any gaps during establishment.

Moss and lichen species (*Racomitrium lanuginosum and* Cladonia spp) were added to the plant mixtures as they have been found to survive harsh green roof environments. We were not allowed to enter the university campus to establish these treatments outdoors in March as planned so we had to delay planting the lichen and moss fragments until June. Nevertheless, measurements were taken on the treatment combinations with the lichen/moss treatment for the duration of the growing season.

Figure 4. Modules planted with lichen and moss fragments to establish living mulch treatments.

4. Compare locally sourced growing medium with commercial extensive green roof media in terms of plant establishment rate.

In Nova Scotia, commercially prepared growing media specifically engineered for green roofs come primarily from Quebec. We compared a product long used by the research group, Sopraflor X™ which is a substrate formulated according to the requirements and criteria of the German FLL guidelines for non-irrigated and low maintenance green roof systems (©Soprema, Lachance Quebec, Quebec). Taylor Hicks formulated her own growing medium targeting the approximate composition of various materials as in the Sopraflor X™ soil and the FLL guidelines from recycled or locally sourced material to be used as an option for green roof installment in Nova Scotia. All data for this comparison have been collected and analysed (see Results section).

Figure 5. Green roof modules containing the local growing medium (left) and the commercial growing medium (right).

5. Measure indicators of green roofs benefits

In order to determine the benefits being provided by plant selection, propagation method, and substrate selection, various indicators of green roof benefits will be measured to determine their success. These include substrate temperature, water retention, canopy density, heights, and floral display for aesthetics. Data has been collected for this objective.

Results

General

Despite significant delays associated with the closing of the SMU University campus from end of March to early June 2020, we were able to keep alive the plants started from seed (plug treatment) during fall 2019 and plant these out in June 2020. Unfortunately, we were not able to plant the lichens and mosses until June 2020 as well (we were not allowed to begin new experiments but could maintain previously established plants). There was very little growth of the lichen and moss components after planting. These should have been planted in March to take advantage of high moisture conditions in late winter/early spring. We consider the results concerning all the treatment combinations to be inconclusive, in other words, the effects of any ground covering function of soil lichens and mosses could not be evaluated as there was almost no ground coverage. We had a similar issue with the direct seeding treatment: we could not seed the green roof modules until June, whereas we intended to seed these in April at the latest. Overall, the plug-planted treatments did the best as we were able to plant large, greenhouse-grown plugs in early June which is pretty close to optimal for outplanting these species in Halifax (we might have done this as early as mid-May if we had campus access so we do not think we have lost much of the growing season with the plug treatment)(Figure 6). All results presented here factor out any site effects attributable to the three locations our modules

Plug treatments had large plants already established in June, providing high cover and biomass and relatively tall plants (Figure 6). Direct seeded treatments were less successful; while some species germinated fairly quickly in the seeded treatments, others had little germination by the end of the growing season. The two growing media we tested showed largely similar performance in terms of supporting plant growth and flowering, but also in terms of providing other benefits associated with green roofs: soil temperature reductions and retention of stormwater. While there are some deficits we uncovered in terms of stormwater capture with the growing medium the researchers created ourselves, this is likely due to a substitution of a single ingredient in the medium (pea gravel instead of a more porous aggregate material) or the inclusion of sand. We think it is highly likely that there are other local products available that could fill this need with some additional research.

Figure 6. Tall, well-established plants from plug treatment in early July 2020 (treatments: *Sedum* + Natives; commercial growing medium).

Biomass

The biomass estimates we obtained are technically estimates of how much plant material is in the plant canopy. Plug planted establishment led to the greatest biomass values in July and there were few differences among the other treatment combinations (Figure 7); by August all species produced good amounts of canopy biomass in the plug propagation treatments (Figure 8). When we compared the individual species contributing to the biomass in each module, Evening primrose, a biennial forb, stood out as having the high biomass values across the whole growing season with roseroot (a perennial succulent) producing the lowest aboveground biomass (about 6x lower values by the end of the growing season)(Figure 8). Whether *Sedums* were included or not neither increased nor decreased biomass, indicating that *Sedums* can be combined with our native species mix with no penalty to overall biomass in the system, at least during the first growing season. Likewise, biomass production from both growing media produced essential the same amount of biomass growth in the modules by the end of the growing season (Figure 7).

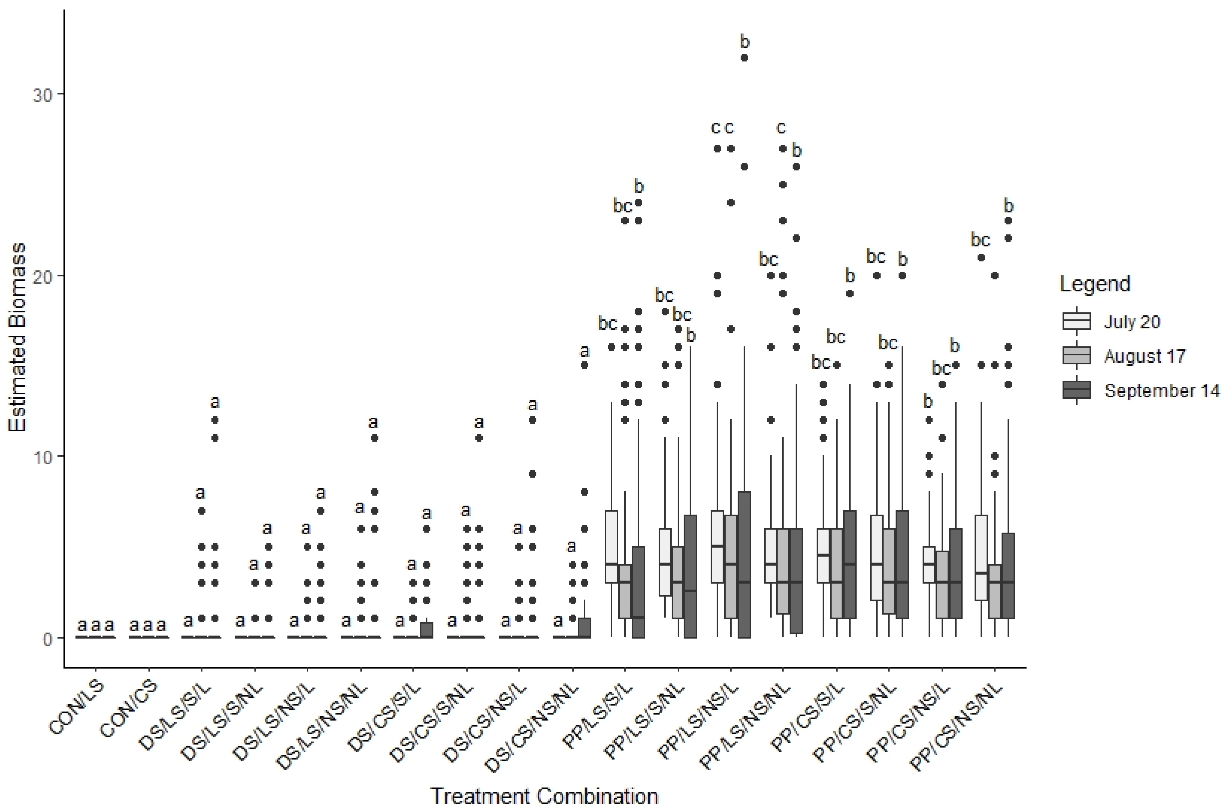


Figure 7. Total estimated biomass by treatment combination: CON= controls (no plants); DS (direct-seeded) vs PP (plug-planted); LS (local growing medium) vs CS (commercial growing medium); S (*Sedum* included) vs NS (no *Sedums*); L (lichen/moss added) vs NL (no lichen/moss).

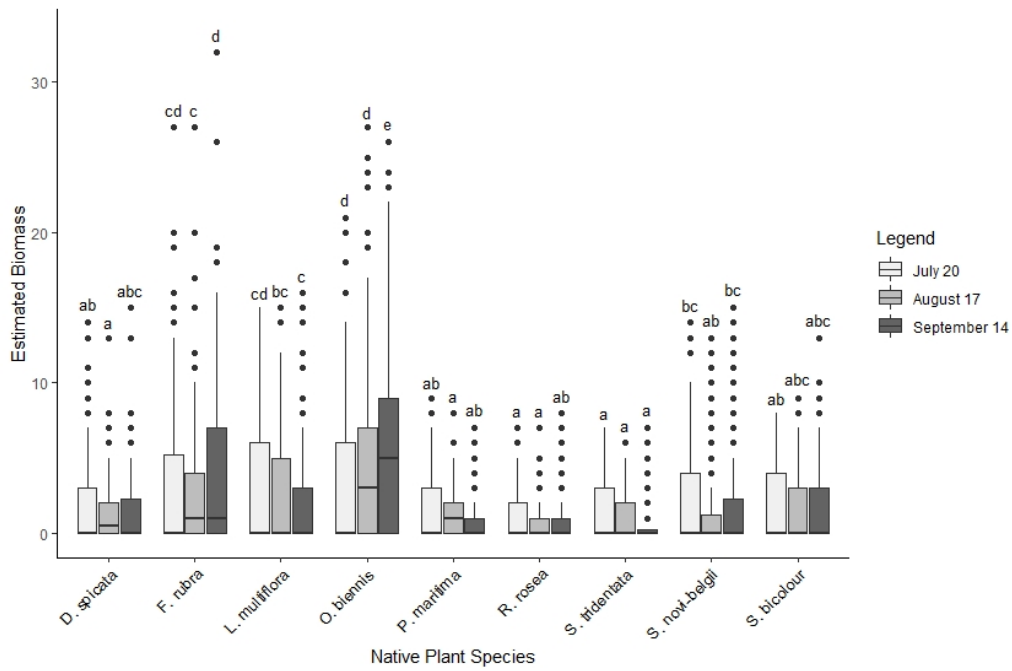


Figure 8. Biomass summarized across treatments, by native species. (*D. spicata*: Oatgrass; *F. rubra*: Red Fescue; *L. multiflora*: Common Wood Rush; *O. biennis*: Evening Primrose; *P. maritima*: Seaside Plantain; *R. rosea*: Roseroot; *S. tridentata*: Three-toothed Cinquefoil; *S. novi-belgii*: New York Aster; *S. bicolor*: Silverrod). Within a date, treatments sharing letters are statistically equivalent.

Plant Heights

Again, whether plugs or seeds were planted made the biggest difference in plant heights by the end of the growing season. All the plug treatments had greater average plant heights than the seeded treatments (Figure 9). Whether *Sedums* were included or not did not seem to make a difference in average plant height in the plug-planted treatments, but in the seeded treatments, no *Sedum* modules tended to have taller plants probably as small seedlings would have been in direct competition with the low growing *Sedums*. There was also a trend for plants in the commercial growing medium to be taller especially in the seeded treatments. The tallest species were Evening Primrose and Red Fescue (Figure 10).

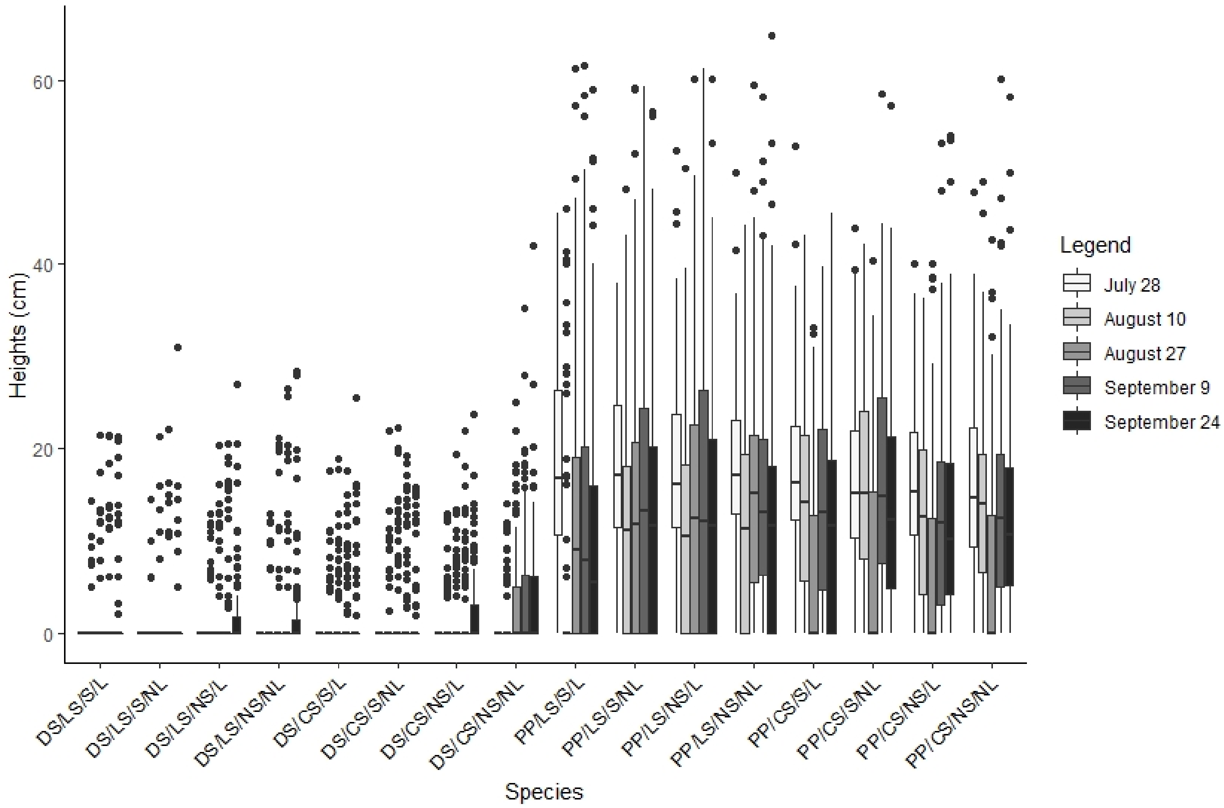


Figure 9. Total estimated biomass by treatment combination: CON= controls (no plants); DS (direct-seeded) vs PP (plug-planted); LS (local growing medium) vs CS (commercial growing medium); S (*Sedum* included) vs NS (no *Sedums*); L (lichen/moss added) vs NL (no lichen/moss).

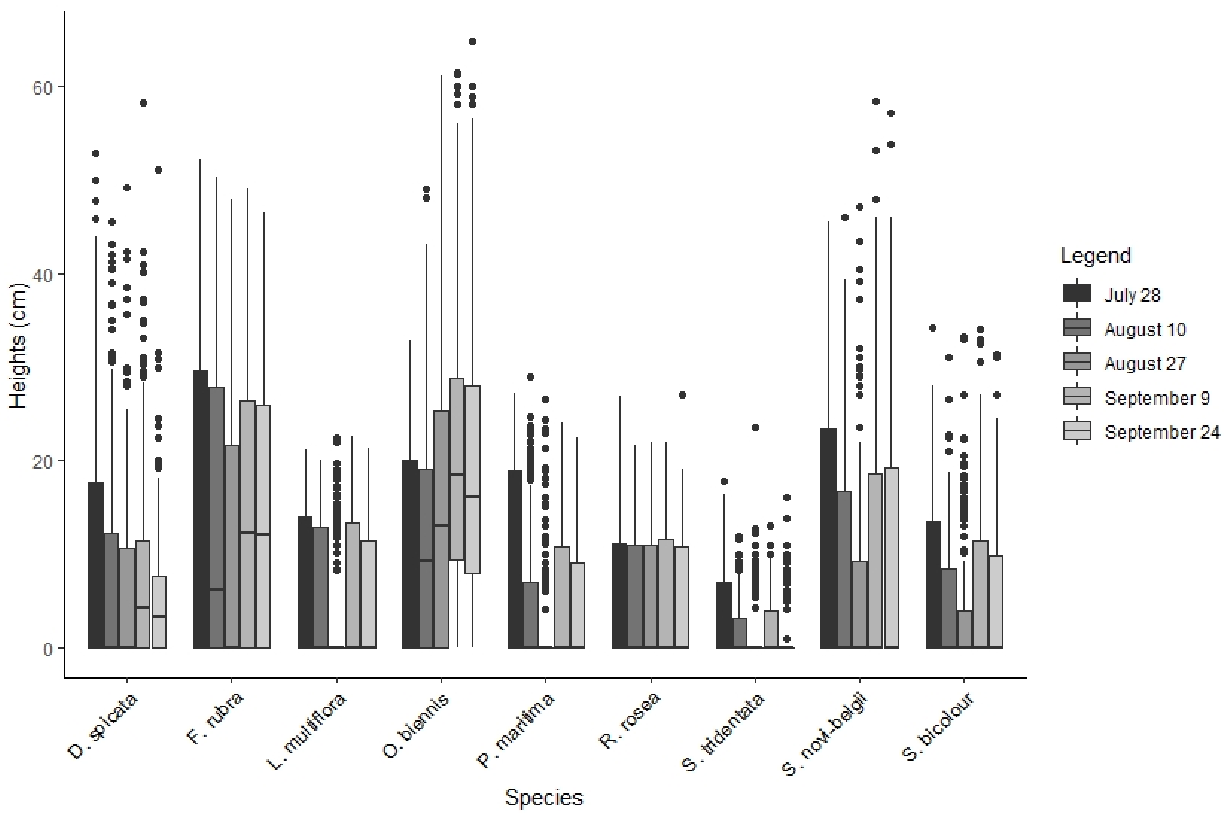


Figure 10. Heights summarized across treatments, by species. (*D. spicata*: Oatgrass; *F. rubra*: Red Fescue; *L. multiflora*: Common Wood Rush; *O. biennis*: Evening Primrose; *P. maritima*: Seaside Plantain; *R. rosea*: Roseroot; *S. tridentata*: Three-toothed Cinquefoil; *S. novi-belgii*: New York Aster; *S. bicolor*: Silverrod)

Flower coverage

Flower coverage tended to be higher overall for the plug treatments except in *Sedum* treatments which showed some flower coverage at the end of July even in the direct seeded treatments (Figure 11). Treatments with *Sedums* had greater flower coverage in July (Figure 12). Different species flowered at different times (Figure 12) showing the value of species diversity and including *Sedums* (which tended to flower in mid-summer) with the native mixture (where most species flowered later). Even within the purely native mixtures, there were noted differences in flowering time between Evening Primrose (mainly August) and the Aster and Goldenrod (mainly September). Growing medium did not make a difference for flower coverage. It should be noted that there are earlier flowering species in the native mixture but they did not flower very much in this experiment. For example, Three-toothed Cinquefoil tends to flower in July and can be quite prolific in our other green roofs but this species is a long-lived creeping shrub that likely needs more time to establish before it starts flowering.

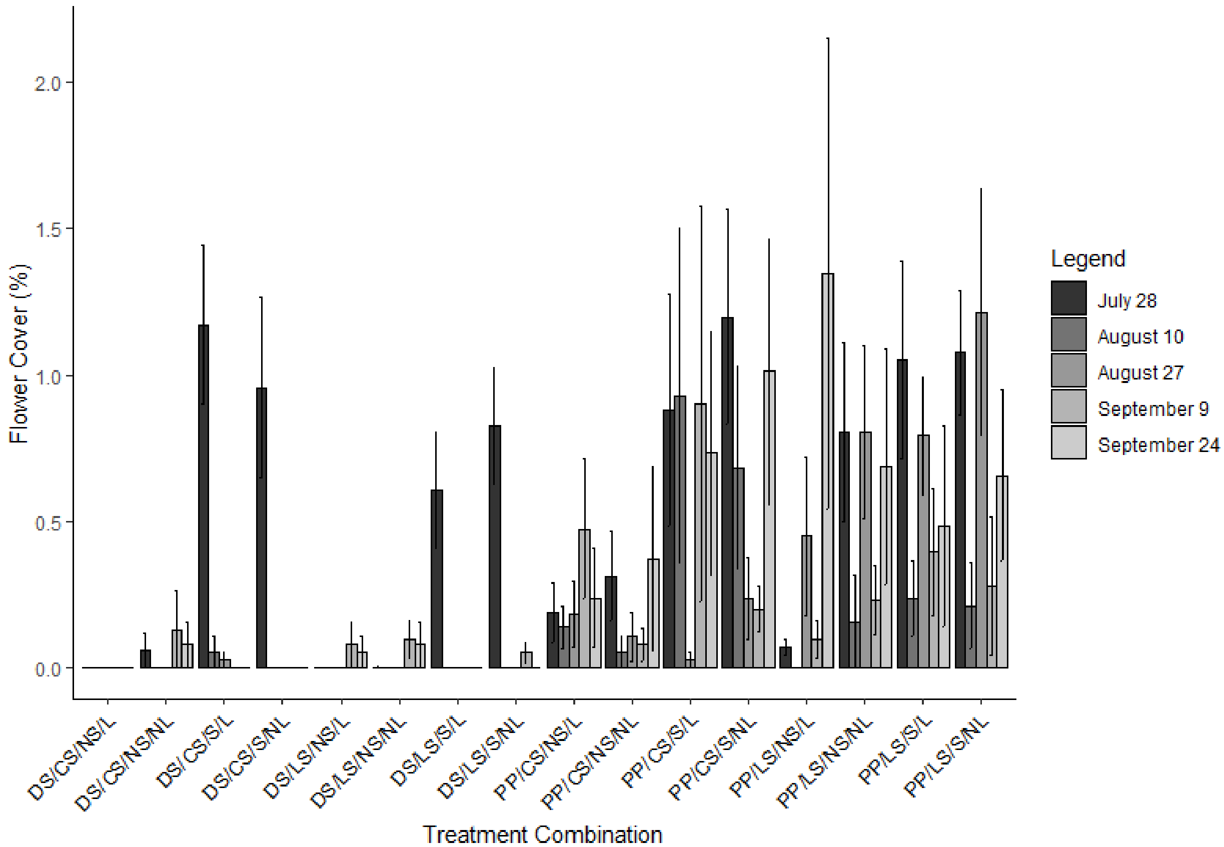


Figure 11. Flower cover by treatment combination: CON= controls (no plants); DS (direct-seeded) vs PP (plug-planted); LS (local growing medium) vs CS (commercial growing medium); S (*Sedum* included) vs NS (no *Sedums*); L (lichen/moss added) vs NL (no lichen/moss).

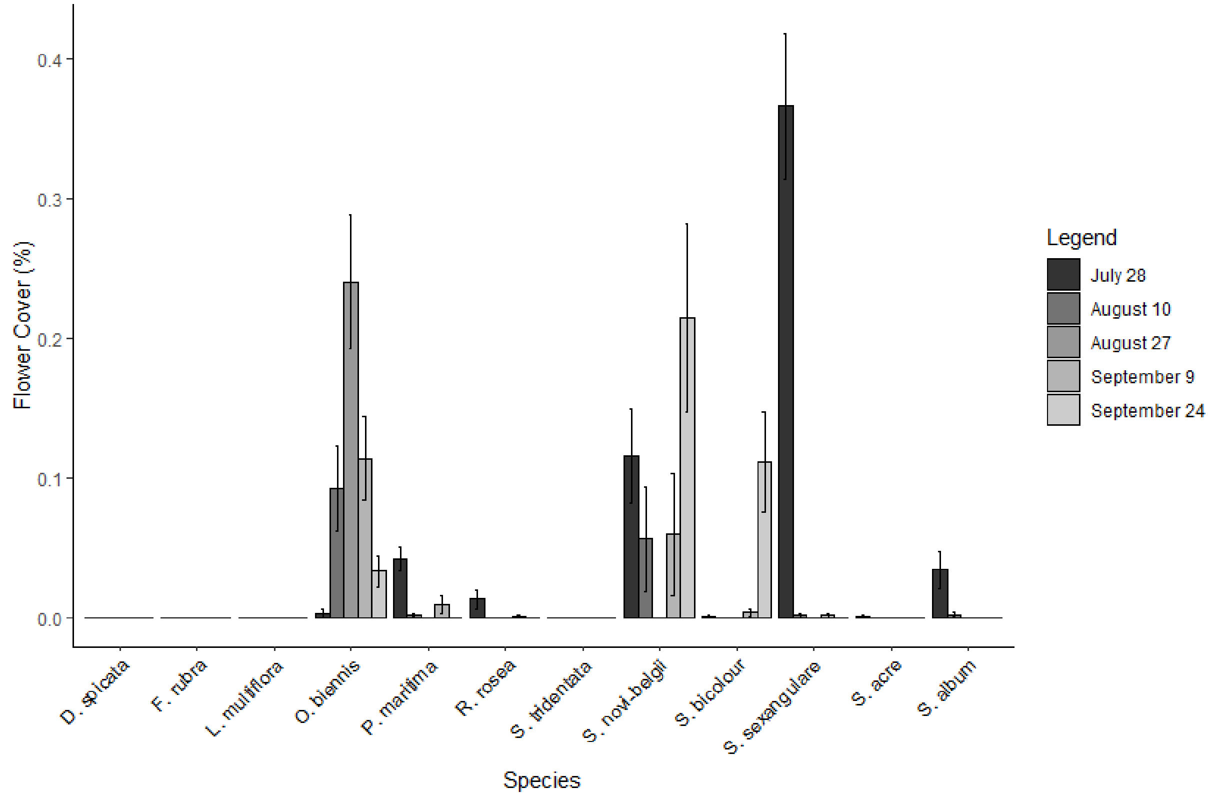
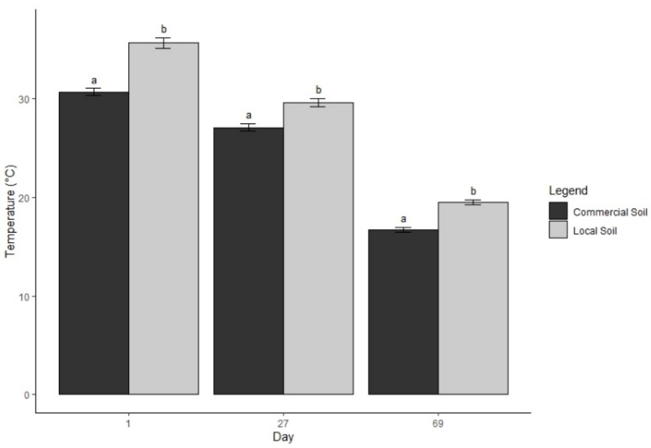


Figure 12. Flower coverage summarized across treatments, by species. (*D. spicata*: Oatgrass; *F. rubra*: Red Fescue; *L. multiflora*: Common Wood Rush; *O. biennis*: Evening Primrose; *P. maritima*: Seaside Plantain; *R. rosea*: Roseroot; *S. tridentata*: Three-toothed Cinquefoil; *S. novi-belgii*: New York Aster; *S. bicolor*: Silverrod)

Growing medium temperature

The local growing medium was consistently hotter across treatments by 5 degrees in July and 2 degrees in September (Figure 13a). It is not clear which properties of the growing medium contributed to this difference. *Sedum* inclusion made no difference to growing medium temperature (Figure 13b). Due to the effects of plant biomass on shading, plug-planted treatments were generally cooler across the three dates when temperature was sampled (Figure 13c).



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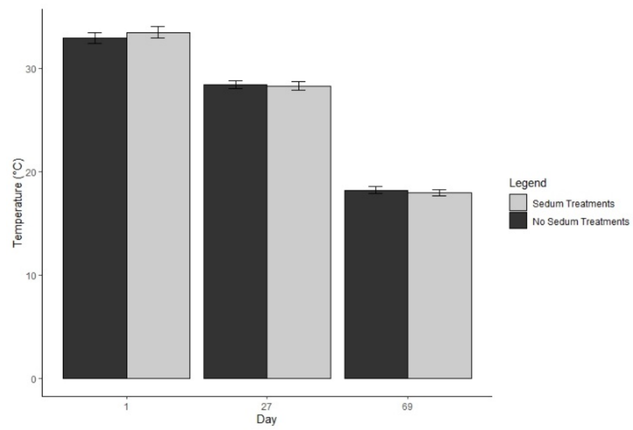

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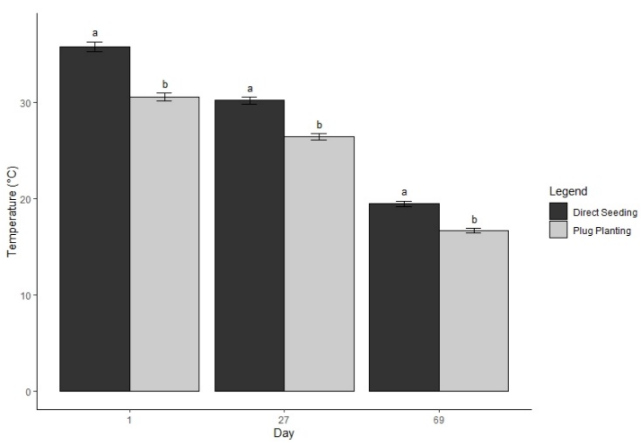


c)

Figure 13. Average substrate temperature: pairwise treatment comparisons: a) Commercial vs Local growing medium; b) *Sedum* vs no *Sedum*; c) Direct-seeded vs Plug-planted; Day 1: July 21, 2020, Day 27: August 17 and Day 69: September 28, 2020. Within a variable and date, different letters indicate a statistically significant difference.

Stormwater retention

Retention of stormwater varied considerably depending on when the trial was done. In July, there was a significant interaction between growing medium and propagation method treatments: the commercial growing medium promoted greater retention than the local growing medium but only in the direct seeding treatments (Figure 14). Plug-planted treatments outperformed direct seeding treatments, except in the commercial growing medium (Figure

14). In August, only propagation method made a difference to retention, with direct seeded treatments outperforming plug planted treatments (Figure 15c). There were no differences related to whether *Sedums* were included or not (Figure 15b) across all sampling times. In September, commercial growing medium outperformed the local medium and plug-planted treatments outperformed direct seeded treatments (Figures 15a and 15c). In general, it is expected that vegetation with more biomass (e.g. plug-planted treatments in this study) will use more water from the soil, leading to greater retention when it rains. This is often an inconsistent result in green roof studies, as bare growing medium has a high retention capability, and the presence of plants can reduce that capacity when roots occupy soil pore space that could hold water. In our case, sometimes the directed seeded treatments had higher retention than the plug treatments sometimes it was the opposite. This likely depends on different antecedent weather conditions that result in greater or less soil moisture prior to our experimental addition of water in order to calculate retention. One potential reason for generally higher retention rates in the commercial substrate is the presence of a more porous aggregate material in the commercial mix (expanded slate) allowed greater retention; the use of sand in the local mix may have also reduced the water holding capacity of this growth medium. Other components of the local mixture deserve further experimentation as well.

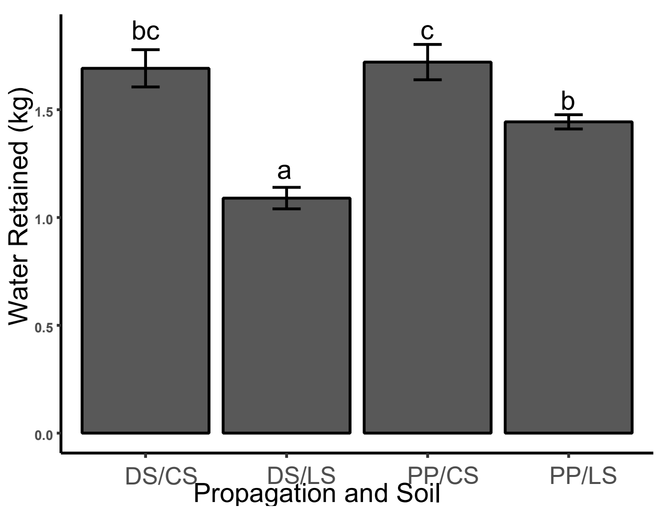
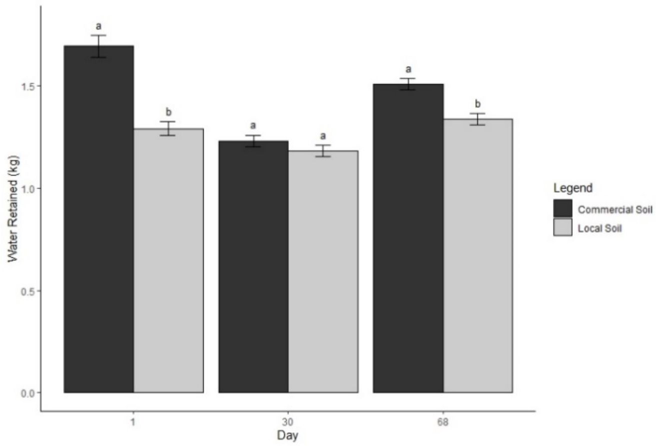


Figure 14. Stormwater retention (July measurement): treatment combination comparisons: DS (direct-seeded) vs PP (plug-planted); LS (local growing medium) vs CS (commercial growing medium). Bars sharing letters are statistically equivalent.



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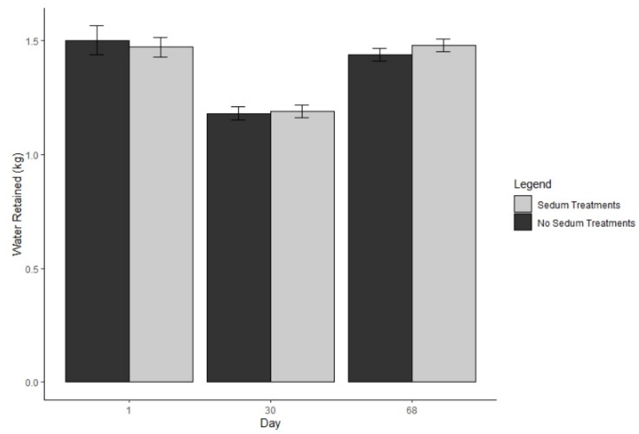

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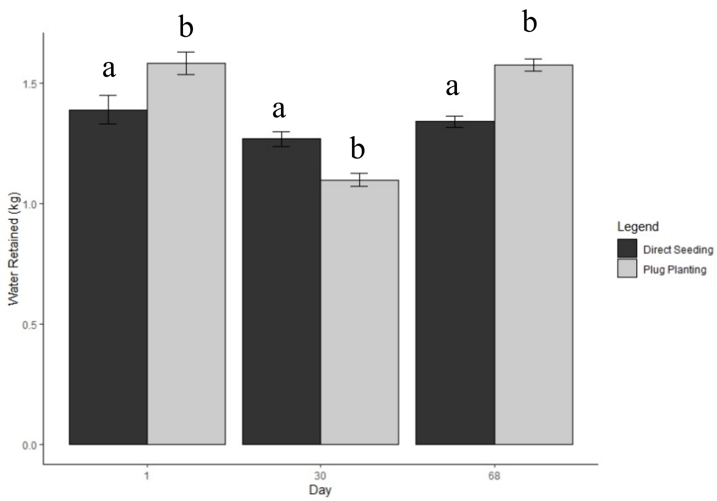

c)

Figure 15. Stormwater retention: pairwise treatment comparisons: a) Commercial vs Local growing medium; b) *Sedum* vs no *Sedum*; c) Direct-seeded vs Plug-planted; Day 1 is July 22, 2020, day 30 is August 21, 2020 and day 68 is September 28, 2020. Within a variable and date, different letters indicate statistically significant differences.

Remaining Components

While data collection is complete, we have several analyses left to complete due to delays to the whole project due to the pandemic. Soil analyses to allow comparison of the nutrient composition of the local vs. commercial soil still needs to be completed. There were observations that the direct seeded treatments had higher weed colonization but we have not yet analyzed these data. The time budget for the two propagation treatments need to be calculated as well. Outreach and publication activities have also all been delayed: preparation of the manual/brochure, and public presentations. Our results are certainly clear enough to publish in a peer-reviewed journal. We will target the Journal of Living Architecture and aim to have a paper submitted by August 2022.

Summary of Recommendations

Our results show that the tested mixture of native plants is completely compatible with *Sedums*; there were no performance deficits when *Sedums* were included for key variables related to plant growth, building cooling and stormwater retention. *Sedums* and native species can be productively combined in the Atlantic Canada setting. While previous work in our research group has shown advantages of native species over *Sedums*, this has mainly been done via growing them separately whereas our study combined multiple *Sedums* with multiple native species. The main advantage of including *Sedums* in the mixture that we found was in flowering. It is worth including *Sedums* for their earlier flowering times than many natives, although there are native species that do flower at the same time. Practitioners may also wish to incorporate *Sedums* as an insurance policy along with natives that might be more drought tolerant in the long run. This study also shows the value of including a range of native species with different flowering times in order to prolong the duration of open flowers on the roof. This has spin off benefits for both aesthetics and value for pollinators that visit the roof.

While plug planting was definitely the quickest way to establish large, healthy plants at the beginning of the growing season, direct seeding is likely cheaper in terms of time and monetary costs. We think that the direct seeded treatments will eventually catch up to the plug-planted treatments but it is not clear how long that might take. We recommend plug planting despite potentially higher costs.

We showed that a local growing medium mixed to approximate commercially available green roof growing media could function equivalently in terms of plant size and flower production. There were significant deficits in the cooling and stormwater retention functions in the local growing medium compared with the commercial one in our study. Further tests of local materials will be necessary to create a local alternative to commercial engineered mixes. Due to delays associated with access to our research sites during the pandemic we were not able to test the value of including a moss/lichen living mulch in our green roof system.

Use of LACF/FAPC Funds

We used the funds awarded by LACF to partially cover the summer student Catlin Bradbury's salary and materials for the rooftop project in including commercial growing medium and local products use to make a custom growing medium.

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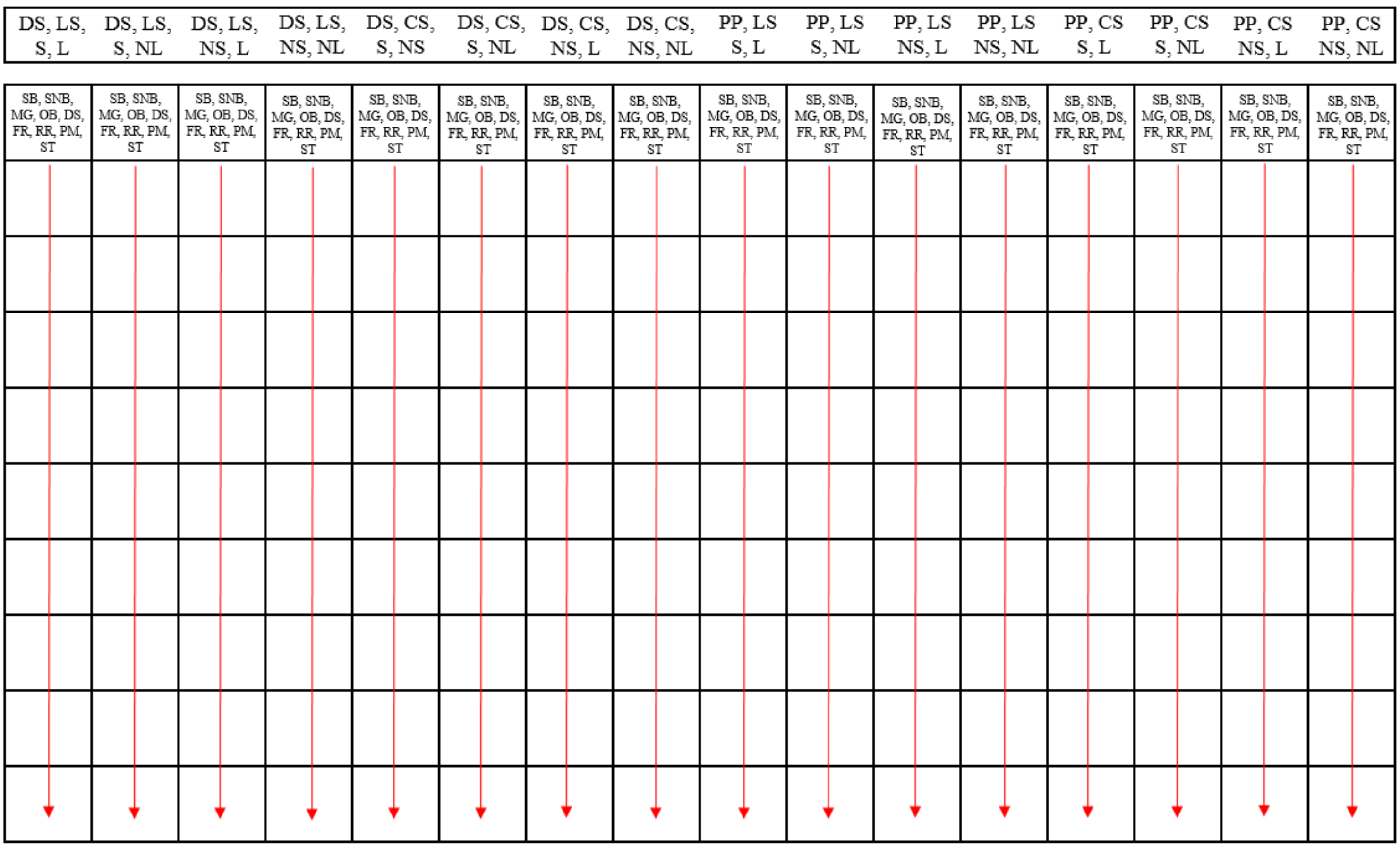
Appendices

A1: Treatment combinations: Experimental set-up for the 16 treatment combinations used throughout this project. Red arrows represent the continuation of 10 replicates. The top row of codes represents treatment combinations and the second row represents native species. Each square is one module. Note: all MG species were replaced with LM. Order of modules was randomized within each of the three sites.

16 Treatment Combinations
DS: Direct Seeding
PP: Plug Planting
LS: Local Substrate
CS: Commercial Substrate
S: *Sedum*
NS: No *Sedum*
L: Lichen/Moss
NL: No Lichen/Moss

9 Species
SB: *Solidago bicolor*
SNB: *Symphyotrichum novi-belgii*
LM: *Luzula Multiflora*
OB: *Oenothera biennis*
DS: *Danthonia spicata*
FR: *Festuca rubra*
RR: *Rhodiola rosea*
PM: *Plantago maritima*
ST: *Sibbaldiopsis tridentata*



A2: Study site locations. a) Study site #1: one story above ground and has surrounding walls providing partial shade; b) Study site #2: 4 stories above ground, partial shade; c) Study site #3: 4 stories above ground, full sun exposure.

a)

c)

A3: Additional photos


DS/LS/NS/NL – 4-1