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Green Roof Thermal and Stormwater Performance Comparisons Between Native and Industry-Standard Plant Species

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There is a demand to use native species on green roofs in North America. However, research is needed to determine which native species are suitable for the green roof environment and how these species impact the ecosystem services attributed to the green roof. This study compared the thermal performance and stormwater mitigation services provided by species native to Nova Scotia, Canada, and those commonly used by the green roof industry. The study was conducted on two extensive green roofs using a vegetated mat system. The native and *Sedum* treatments resulted in similar substrate temperatures and stormwater retention for the majority of the study period. Additionally, the green roof treatments performed significantly better than the conventional roof treatment for the majority of the study period. However, at both study sites the *Sedum* treatment recorded significantly lower average substrate temperatures for the summer of 2014. Since canopy density did not play a significant role in these findings, these results are most likely due to differences in species composition. For stormwater retention, no significant differences were detected between the *Sedum* and native treatments for the entire study period. This is particularly interesting because the substrate cover in the native treatment was significantly lower than in the *Sedum* treatment for the entire study period. It is possible that, as the cover of native species increases, the water retention in these modules will also increase. This study demonstrates that these native species are a viable option for green roofs in a maritime climate.

Keywords

Extensive Green Roof, Storm Water Retention, Thermal Performance, Biodiversity

Acknowledgements

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INTRODUCTION

Compared to neighboring green space, urban centers are associated with increased stormwater runoff, rising temperatures, air pollution and decreased biodiversity (Mentens et al. 2006; Oberndorfer et al. 2007; Currie and Bass 2008; Bowler et al. 2009). Since the world urban population is projected to increase from 3.9 billion in 2014 to 6.3 billion by 2050 (United Nations 2014), there is a need to reduce some of the negative effects associated with urbanization. Numerous studies have demonstrated that green roofs can help mitigate some of these effects and this has lead to an increasing demand for their construction (Oberndorfer et al. 2007). However, more research is necessary to determine which species native to individual ecoregions are suitable for the green roof environment.

Green roofs are composed of layers; they usually contain a waterproof membrane, a root barrier, a drainage layer, a growing medium, and a vegetation layer (Castleton et al. 2010). There are several different ways a green roof can be constructed: complete or "loose laid" systems, where each green roof layer is a fundamental part of the roof; modular, where vegetated trays are installed on top of an existing roof; and pre-vegetated mats, where the vegetation is established off site and rolled onto the roof (Oberndorfer et al. 2007) (Figure 1). Out of these three green roof systems pre-vegetated mats offer instant cover and represent a good choice for windy and sloped locations as the physical structure provided by the mat may reduce erosion. Pre-vegetated mats have also been suggested as one of the best methods for reducing weeds on newly established green roofs (Snoddgrass and Mcintyre 2010). Additionally, since increased plant cover is associated with increased ecosystem services (Ouldboukhitine et al. 2011; Jaffal et al. 2012; Speak et al. 2013; Berretta et al. 2014), this system may provide greater initial benefits than other establishment strategies. However, a study by Emilsson (2008) found that the benefits provided by the pre-vegetated mats were comparable to other establishment strategies by the end of a three-year period.

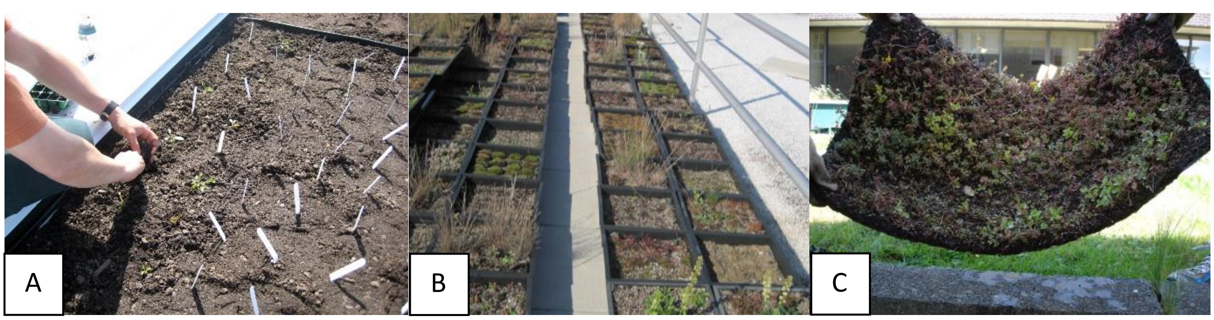


Figure 1. Examples of the three different green roof systems: A) "loose laid" system; B) modular system; C) pre-vegetated mats.

The vegetation used on green roofs can vary but the majority of extensive green roofs are planted primarily with different species of *Sedum* (Cook-Patton and Bauerle 2012). These species are extremely drought tolerant CAM photosynthesizers capable of surviving the harsh rooftop conditions such as drought, high wind, and direct sunlight. However, the majority of *Sedum* species used by the green roof industry are native to Europe and Asia (MacIvor et al. 2013). Since there is a current demand to use native species on green roofs in North America

(Butler et al. 2012), research is needed to determine which native species are suitable to the green roof environment and how these species impact the ecosystem services attributed to the green roof. Determining suitable native green roof vegetation will enhance the choices available to the consumer and the green roof industry.

One method that can be used to choose suitable green roof species is the habitat template approach (Lundholm 2006), where plants that naturally occur in conditions similar to the green roof, (i.e. coastal barrens, rocky outcrops, and dry grasslands) are selected. This method has been successfully implemented in several green roof studies. For example, MacIvor and Lundholm (2011) found that out of the 15 native North American species tested, 12 had 100% survival and two had more than 80% survival. Only one species was unable to survive the entire study period. Additionally, several of these native species outperformed industry standard vegetation in terms of stormwater retention (Lundholm et al. 2010). A study by Farrell et al. (2013) tested 12 species that naturally occur on granite outcrops in southeastern Australia. They found that, overall, these native species were more efficient at reducing stormwater runoff compared to industry standard species.

Different growth forms have also been associated with different ecosystem services. Therefore, a diversity of species may enhance overall green roof function. Both Nagase and Dunnett (2012) and MacIvor and Lundholm (2011) found that graminoids were more efficient at reducing stormwater runoff than succulent or forb species. Madre et al. (2013) found that a diversity of growth forms was associated with increased invertebrate diversity. Additionally, diverse green roofs have been associated with greater aesthetic appeal (Lee et al. 2014) and provision of multiple ecosystem services at the same time (Lundholm 2015). Since green roofs are found in many different ecoregions, creating a list of species suitable to a particular region could be beneficial to the consumer. Testing the ecosystem services provided by these native species could demonstrate that native species can be both an aesthetic and functional alternative/addition to the current green roof vegetative palette.

This manuscript describes two separate studies, on two different extensive green roofs. Each study compares the thermal performance of industry standard species to those native to Nova Scotia. Additionally, one study looks at how these species affect stormwater retention.

METHODS

This study was conducted between August 2013 and October 2014 on two experimental extensive green roofs (Figure 2). The study period was broken into four seasons: summer (June, July, August), autumn (September, October, November), winter (December, January, February) and spring (March, April, May). During this timeframe, the highest average monthly air temperature was 20.3 °C and the lowest was -3.3 °C. The greatest total monthly precipitation was 215.7 mm and the lowest was 35.8 mm (Environment Canada, 2014) (Appendix 1). Before installation, vegetated mats were grown for two seasons (2011-2012) in field conditions at Tasbo Farms, Greenwich, Nova Scotia (45°06'51.0"N 64°25'57.9"W). Originally, ten native species and 10 *Sedum* species were seeded onto the mats (Table 1). The native species were chosen because they naturally occur in conditions similar to the green roof (coastal barrens) and due to their success in previous green roof experiments (Lundholm et al. 2010; MacIvor and Lundholm

2011). The *Sedum* species used were provided as a seed mixture by the green roof company Vitaroofs, (Vitaroofs Seed Mix, Vitaroofs, Mississauga, Ontario).

Table 1. *Sedum* and native species used in this study. The *Sedum* species were provided by the green roof company Vitaroofs. The Native species were either collected as seed from local field sites or harvested from previous studies conducted by Saint Mary's University.

***Sedum* Treatment**		**Native Treatment**	
Species Name	**Growth Form**	**Species Name**	**Growth Form**
Sedum acre	Succulent	*Sibbaldiopsis tridentata*	Creeping Shrub
Sedum aureum	Succulent	*Campanula rotundifolia*	Forb
Sedum album	Succulent	*Plantago maritima*	Forb
Sedum floriferum	Succulent	*Sagina procumbens*	Forb
Sedum kamtschaticum var. ellacombianum	Succulent	*Solidago bicolor*	Forb
Sedum middendorffianum	Succulent	*Danthonia spicata*	Graminoid
Sedum pulchellum	Succulent	*Deschampsia flexuosa*	Graminoid
Sedum reflexum	Succulent	*Festuca rubra*	Graminoid
Sedum sexangulare	Succulent	*Luzula multiflora*	Graminoid
Sedum spurium	Succulent	*Rhodiola rosea*	Succulent

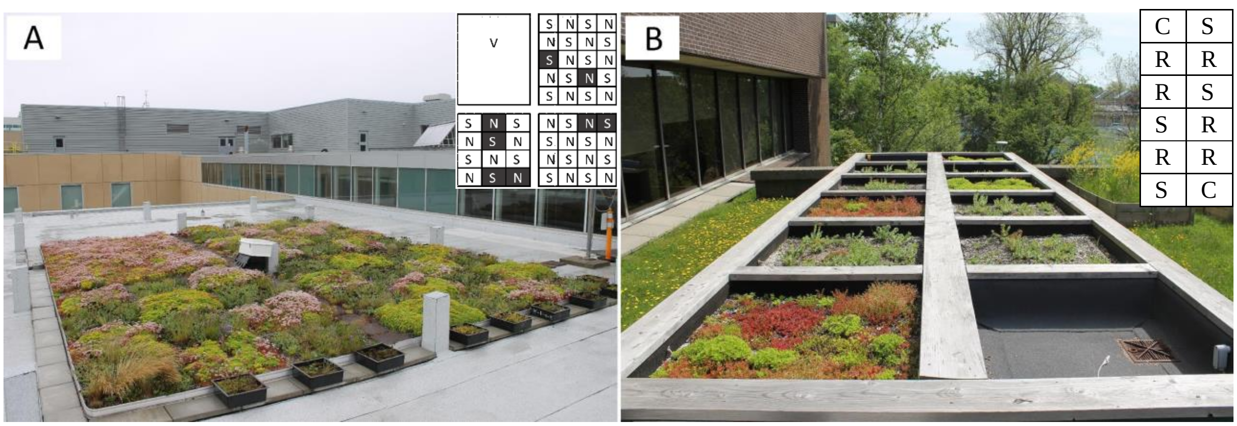


Figure 2. Extensive green roof at NSCC (A) and SMU (B) taken during the 2014 growing season. For the NSCC green roof only highlighted panels where analyzed. For the SMU green roof all panels were analyzed. A vegetation key is provided for both roofs: N = Native, S = *Sedum*, V = Vitaroof green roof display, R = *R. rosea* and C = Conventional roof.

Green Roof Construction

A 75 m^2 green roof was installed the last week of June 2013 on an 8.2 m high unheated roof at the Nova Scotia Community College (NSCC) in Dartmouth, Nova Scotia, Canada (44°39"N 63°33"W). The green roof was surrounded by 140 mm of aluminum edging (Vitaroofs 7000, Vitaroofs, Mississauga, Ontario) and a patio stone ballast (12" x 24" x 1.8" Utility Stones, natural colour, 20.1 kg, Shaw Brick, Lantz, Nova Scotia). Black rubber blocks (3 cm x 3 cm x 1 cm high) were installed under each patio stone (four for each stone) to allow for drainage

underneath the stones. From bottom to top the roof layers consisted of a root barrier (Vitaroofs 7090, Vitaroofs, Mississauga, Ontario), a drainage/filter layer (Vitaroofs 7060, Vitaroofs, Mississauga, Ontario), filter fabric (Vitaroofs 7080, Vitaroofs, Mississauga, Ontario), and a substrate layer with a depth of 10 cm (Vitaroofs 7400, Vitaroofs, Mississauga, Ontario) (Appendix 2). Microblend ™ (113.4 kg) (Rexius Forest By-Products, Inc., Eugene, OR, USA), a sediment reduction device, was blended into the substrate. Before installation of the vegetated mats the substrate was rolled with a weighted lawn roller to help remove air pockets. To ensure this green roof contained the same design features used by our industry partner a drip irrigation was installed on top of the substrate, under the plant mats (Rainbird, Tucson, Arizona, USA). To allow easy accesses to green roof plots, two perpendicular rows of recycled rubber flagstone pavers (Rubber Designs, Ranger, GA, USA.) 18"x18" intersected the middle of the green roof installation (Appleby-Jones 2014).

48 green roof mats (1m x 1m) were installed on top of the substrate. Of these mats, 24 contained *Sedum* species and 24 contained native species. The mats alternated one *Sedum* and one native mat. Adjacent to these 48 mats, 15 m^2 of commercial *Sedum* mats were installed by Vitaroofs, the project's industry partner, to provide a visual sample of their product on a green roof. On August 2, 2013, one heat flux transducer (HFT3, Campbell Scientific, Edmonton, AB), and two temperature probes (105T thermocouple, Campbell Scientific, Edmonton, AB) were installed in four *Sedum* and four native mats, 40 cm from the edge of each mat. A heat flux plate and temperature probe were buried at the base of the substrate layer and a second temperature probe was buried just under the vegetative mat (Figure 3). Data were recorded at 15 minute intervals. All plant growth and ecosystem services reported in this study for the NSCC green roof are from these eight mats.

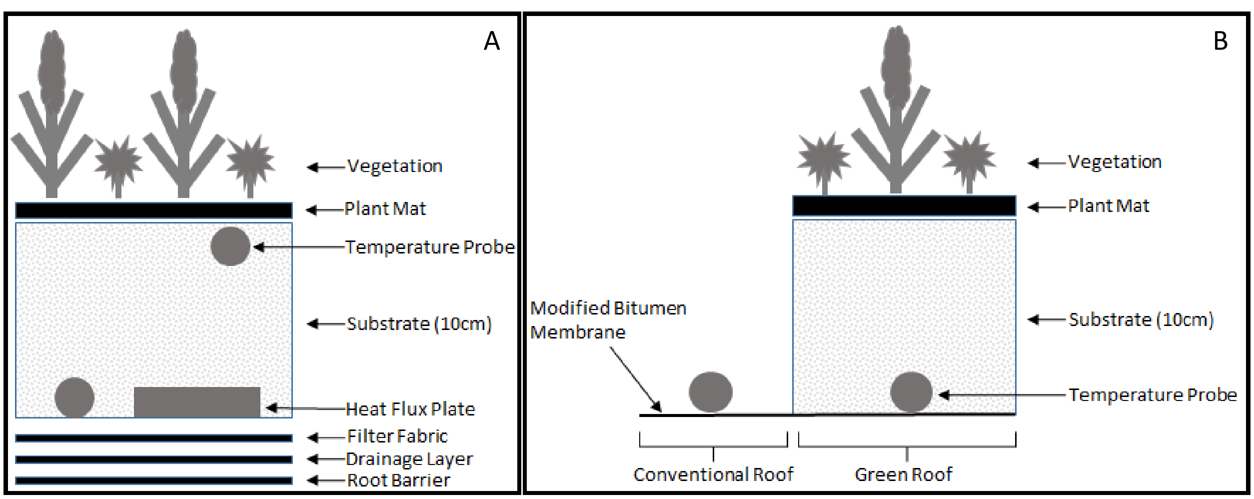


Figure 3. Section diagram of the NSCC green roof (A) and the SMU green roof (B).

The majority of the *Sedum* mats had at least 80% cover at the time of installation. However, plant cover on the native mats was very low, with the majority of cover from *R. rosea*. To address this, ten *Danthonia spicata*, ten *Sibbaldiopsis tridentata,* five *Campanula rotundifolia* and varied quantities of *R. rosea* (quantity varied to ensure mats had equivalent individuals) were

randomly planted into each native mat. After transplanting, the native mats had ~ 30% canopy cover. Native transplants were harvested from previous experiments conducted at Saint Mary's University. After planting, the roof was watered four times a week from June 28, 2013 to September 9, 2013. After this date, the roof only received moisture through natural rainfall events. Mats were weeded weekly throughout the growing season.

In order to understand how *R. rosea* (The species with the greatest cover on the vegetated mats grown in the field (Appleby-Jones 2014)) compared to industry standard species (in terms of stormwater retention and substrate temperature) a second green roof was established at Saint Mary's University (SMU) located in Halifax, Nova Scotia, Canada (44°39'N, 63°35'W). The SMU green roof was originally constructed in the summer of 2008 on a pre-existing sod roof approximately 5 m above ground-level. This study was conducted using 12 1 m x 1 m panels installed on top of a 1 m high rectangular raised platform, in two rows of six panels each, clad around the sides with plywood to shelter the area under the panels from the wind (details in Lundholm et al. 2014). Each panel was fitted with a roof drain (TE525M, Texas Electronics, Dallas, Texas) and temperature sensors (105T thermocouple, Campbell Scientific, Edmonton, AB). The roof drain was connected to a pipe leading to a tipping bucket rain gauge which quantified the flow rate of runoff. Substrate temperature (°C) was measured by sensors placed at the base of the substrate layer (Figure 3 (see Lundholm et al 2014 for the section diagram of the non-vegetated green roof layers.). All sensors were connected to a data logger which recorded substrate temperature every 15 minutes and the total volume passing through the tipping buckets every 5 minutes.

The SMU green roof study consisted of three treatments, a *R. rosea* treatment (n=6), a *Sedum* treatment (n=4) and a conventional roof treatment (n=2). The conventional roof treatment consisted of a thin layer of dark grey modified bitumen membrane applied to the plywood base. The temperature sensors in the conventional treatment were shielded with aluminum foil. Substrate and vegetation mats were added in the first week of July 2013. The substrate was composed of ½ Sopraflor X (Sopraflor X, Soprema Inc., Drummondville, Quebec) and ½ Vitaroofs 7400 growing medium (Vitaroofs 7400, Vitaroofs, Mississauga, Ontario) with a substrate depth of 10 cm. Soprema X consists of crushed brick, blond peat, perlite, sand, and vegetable compost with a total porosity between 50-60% and a bulk density between 1100-1200 kg/m^3 (Sopraflor X, Soprema Inc., Drummondville, Quebec) (Appendix 2). To avoid surface runoff all vegetated treatments were surrounded by a 14 cm high parapet and the conventional roof was surrounded by a 28 cm high parapet. Before measurements were taken, this study went through a vegetation establishment period (July 2013). Dead vegetation was replaced and all treatments were watered to saturation once a week. After July 2013 precipitation only occurred through natural rain events. Additionally, vegetated mats were weeded once a week throughout the growing season.

Monitor plant growth and ecosystem function

For the NSCC green roof canopy cover and canopy density were collected once in July and October 2013 and once in June, July and August 2014. For the SMU green roof canopy cover and canopy density were collected once in July 2013 and once in May, June, July and August 2014. Percent canopy cover was estimated by analyzing photographs with ImageJ (Image

Processing and Analysis in Java, http://imagej.nih.gov/ij/). Canopy density was estimated through the point interception method (Floyd and Anderson 1987) using a 1m x 1m grid containing 16 equally spaced interception points. Each time the living aboveground biomass touched a rod placed at these interception points it was recorded.

For the SMU green roof stormwater retention (the amount of rainfall in mm retained by each treatment) was determined using the following formula, where rain is the amount of rainfall in mm recorded by the weather station and runoff is the water in mm recorded by the tipping buckets (Carsen et al. 2013):

$$\text{Retention} = (\text{rain} - \text{runoff})/\text{rain}.$$

A storm event was considered complete once all tipping buckets registered 0 mm. Storm intensities were determined based off information provided by a weather station positioned adjacent to the SMU green roof.

Statistical Analysis

One-way ANOVAs were used to compare percent canopy cover and canopy density between treatments. ANCOVAs were used to analyze substrate temperature (covariate: canopy density) and total stormwater retention (covariates: canopy density; time since the last rain event ≥ 5 mm). Comparisons between treatments were made through a Tukey Post-Hoc test. All statistical tests were performed in R v 3.1.1 (The R Project for Statistical Computing, http://www.r-project.org/)

RESULTS

Canopy Density and Percent Canopy Cover

At the NSCC green roof the average percent canopy cover of the *Sedum* treatment was significantly greater than in the native treatment for the entire study period (p<0.009). The average percent canopy cover for the *Sedum* treatment at the beginning of the study (July 2013) was 83%, and by August 2014 the average percent canopy cover was 97%. For the native treatment, the average percent canopy cover at the beginning of the study was 29%, and by August 2014 the average percent canopy cover was 71% (Appendix 3). For every data collection period, except July 2014 (p=0.054), the canopy density of the *Sedum* treatment was significantly greater than the native treatment (p<0.030).

For every data collection period at the SMU green roof, the percent canopy cover and canopy density of the *Sedum* treatment were significantly greater than the *R. rosea* treatment (p<0.001). The average percent canopy cover for the *Sedum* treatment at the beginning of the study (July 2013) was 69%, by August 2014 the average percent canopy cover was 97%. For the *R. rosea* treatment the average percent canopy cover at the beginning of the study (July 2013) was 26%, by the end of the study the average percent canopy cover was 36% (Appendix 3).

Substrate Temperature (°C) and Heat Flux (W/m^2)

At the NSCC green roof the average substrate temperature in the native treatment was significantly warmer than the *Sedum* treatment for summer 2014 (p=0.007). The maximum substrate temperature for the native treatment was significantly warmer than the *Sedum* treatment for summer 2014 (p=0.036) and autumn 2014 (p=0.004). For minimum substrate temperature no significant differences were detected between treatments for the entire study period (p>0.05) (Figure 4). For average heat flux the native treatment had significantly greater heat flux than the *Sedum* treatment for summer 2014 (p=0.007) (Figure 4). Due to instrument malfunction, the data logger was inoperative between February 26 and June 7, 2014. Therefore, data from spring 2014 were not available for analysis.

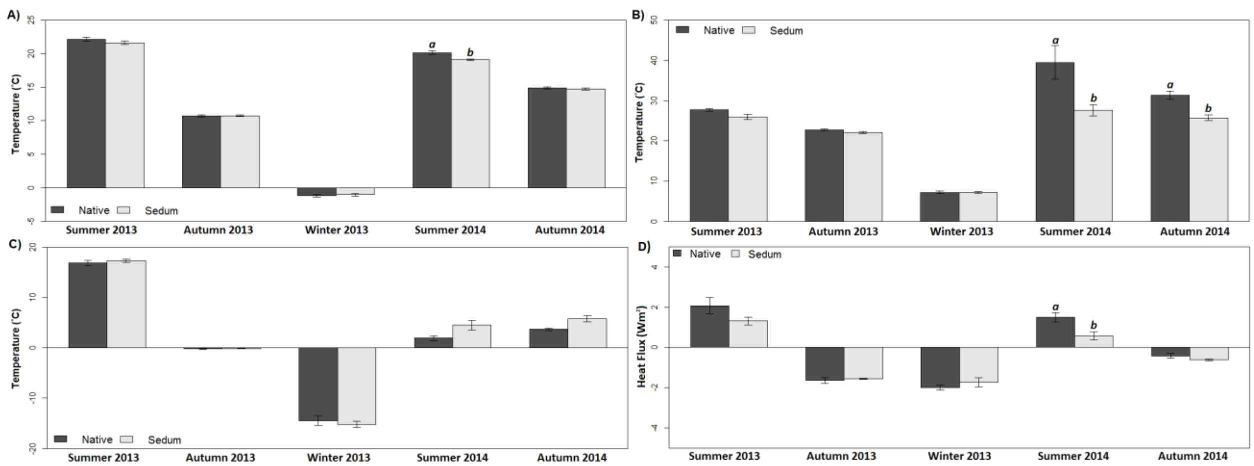


Figure 4. Average (A), maximum (B), and minimum (C) substrate temperature (°C) and average substrate heat flux Wm^2 (D) at the NSCC green roof. Those bars that share a letter are not significantly different (within the same season).

For the SMU green roof the substrates in the *R. rosea* and *Sedum* treatments were significantly cooler than the conventional roof membrane for spring (*Sedum* p=0.006; *R. rosea* p=0.048) and autumn 2014 (both p<0.001), and warmer than the conventional roof for winter 2013 (both p<0.001). For the summer of 2014, all treatments were significantly different from each other (both p<0.001), with the *Sedum* treatment showing the lowest average temperature and the conventional roof recording the largest. The maximum temperatures in the *R. rosea* and *Sedum* treatments were significantly lower than the control treatment for the entire study period (all p<0.001; except winter 2013 *R. rosea* compared to conventional roof p=0.004). For minimum substrate temperatures the *R. rosea* and *Sedum* treatments both had significantly lower substrate temperatures than the conventional roof for summer 2013 (both p<0.001), summer 2014 (both p<0.001), and autumn 2014 (both p<0.001), and warmer than the control for autumn 2013 (both p<0.001), winter 2013 (*Sedum* p<0.001; *R. rosea* p=0.004), and spring 2014 (*Sedum* p=0.002; *R. rosea* p<0.001) (Figure 5).

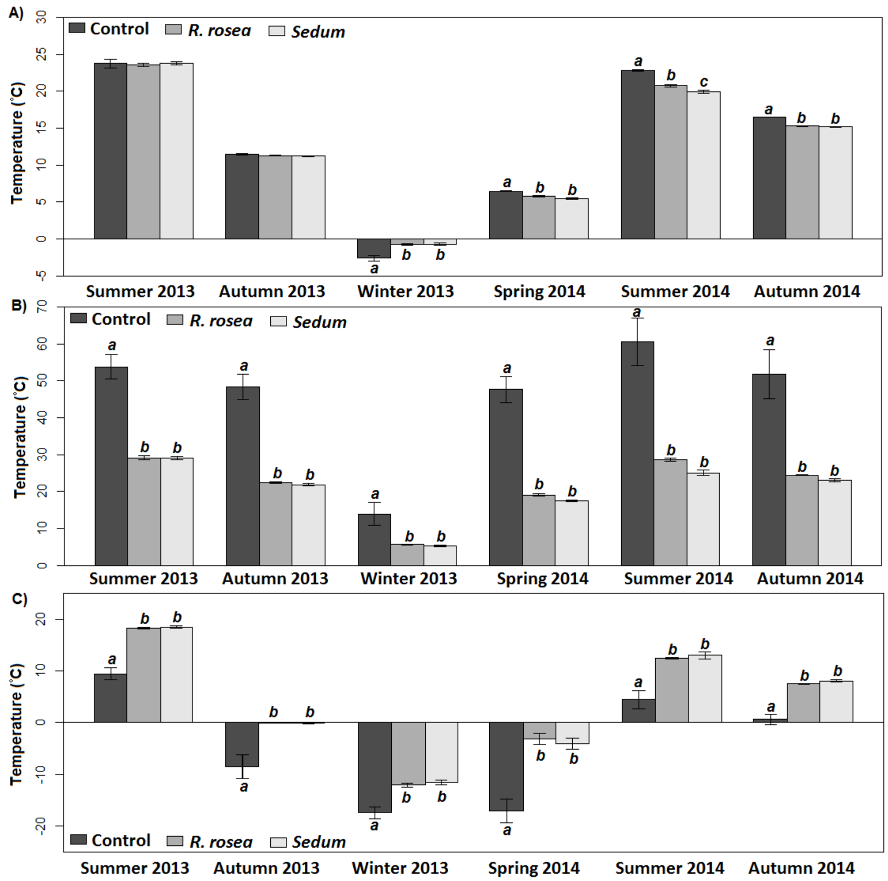


Figure 5. Substrate temperature (°C) at the SMU green roof depicting the average (A), maximum (B), and minimum (C) substrate temperatures for the conventional roof control, the *R. rosea* treatment, and the *Sedum* treatment. Those bars that share a letter are not significantly different (within the same season).

Stormwater Retention (%)

For the SMU green roof, the two vegetated treatments had significantly more stormwater retention than the conventional roof treatment for storm intensities with 1-4 mm (both $p<0.001$), 5-9 mm (both $p<0.001$), 10-19 mm (both $p<0.001$) of rainfall (Figure 6). For storm intensities with 5-9 mm ($p=0.030$), 10-19 mm ($p<0.001$), 20-29 mm ($p=0.002$) and 40-49 mm ($p=0.005$) of rainfall, the duration since a previous storm event (of at least 5 mm) there was a significantly positively correlation with total stormwater runoff. Canopy density also significantly affected total stormwater runoff for storm intensities with 20-29 mm ($p=0.014$), and 60-69 mm ($p=0.024$) of rainfall.

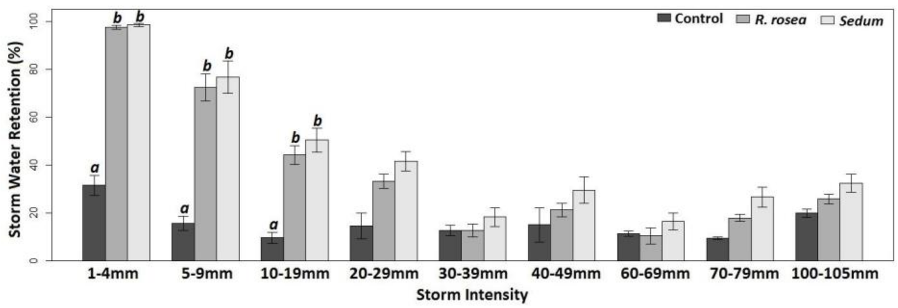


Figure 6. Average stormwater retention (%) for varying storm intensities at the SMU green roof for the conventional roof, the *R. rosea* treatment, and the *Sedum* treatment. Those bars that share a letter are not significantly different (within the same rainfall intensity).

DISCUSSION

Overall, substrate temperature and stormwater retention, for the native and *Sedum* treatments at NSCC and the *R. rosea* and *Sedum* treatments at SMU, were comparable for the majority of the study period. Additionally, both vegetated treatments at SMU performed significantly better than the conventional roof treatment, a result consistent with numerous other green roof studies (Simmons et al. 2008; Castleton et al. 2010). These results indicate that the native species tested here can provide benefits similar to standard green roof vegetation, making them a viable option for the green roof industry.

In terms of temperature, the *Sedum* treatment did perform significantly better than the native treatment at NSCC and the *R. rosea* treatment at SMU during the summer of 2014 and at NSCC for autumn 2014, although the actual differences were minimal. During this timeframe the canopy density for the *Sedum* treatment was significantly greater than the native treatments (except at NSCC for summer 2014). However, when an ANCOVA was performed we found that canopy density was not statistically significant as a covariate. This indicates that these results are most likely due to differences in species composition. In this case the *Sedum* treatment (containing 10 succulents) outperformed the native treatment (containing 4 forbs, 4 graminoids, 1 creeping shrub, 1 succulent) and the *R. rosea* treatment (containing 1 succulent). Similar results were observed in a study by Lundholm et al. (2010), where the combination of succulent species outperformed combinations containing graminoids, forbs, and succulents in terms of thermal performance. Additionally, both of the *Sedum* species used by Lundholm et al. (2010) resulted in lower substrate temperatures than the succulent *R. rosea*. Differences in reflectivity, which is associated with thermal performance, have also been observed between different plant species (MacIvor and Lundholm 2011; Zhao et al. 2014). For example, Zhao et al. (2014) found differences in the reflectivity of the foliage in six different *Sedum* species.

No significant differences in stormwater runoff were detected between the *Sedum* and *R. rosea* treatment for the entire study period. This is particularly interesting because the substrate cover in the *R. rosea* treatment was significantly lower than the *Sedum* treatment for the entire study period. Usually, lower substrate coverage is associated with lower water retention (Berretta et al. 2014). It is possible that as the cover of *R. rosea* increases the water retention in these modules will also increase due to greater uptake by the vegetation (Wolf and Lundholm 2008).

For storm intensities less than 7.5 mm, previous research found that green roofs were able to retain almost 100% of stormwater (Carter et al. 2006; Volder and Dvorak 2014). Another study by Carsen et al. (2013), found that for storm events less than 10 mm, the green roof retained roughly 75-90% of the total precipitation. In this study, storm intensities less than 7.5 mm resulted in 76%-100% retention. However, one storm event in the 7.5 mm range does not fit this trend, with a retention of 6%. Since this result was observed one day after a rain event with 43.2 mm of rainfall, this most likely reduced the holding capacity of the substrate prior to the second event. For storm intensities with more than 58 mm of rainfall, previous research has found retention values between 30-60% of the precipitation volume (Carsen et al. 2013; Volder and Dvorak 2014). This study showed lower levels of retention, with 13%-28% of the total precipitation retained. Overall this study observed an average of 67% retention across the study period. When compared to previous research this value is on the higher end of what has been reported (values ranging between 12%-82.8% (VanWeort et al. 2005; Carsen et al. 2013; Volder and Dvorak 2014)). Additionally, this study showed that the duration since a previous storm event had a significant effect on total stormwater runoff. This is most likely due to changes in the storage capacity in the substrate. Previous green roof research also reported this trend (Stovin, 2010; Berretta et al. 2014; Volder and Dvorak 2014).

Previous research indicates that some native species in specific ecoregions can outperform industry standard species (MacIvor and Lundholm 2011; Farrell et al. 2013). However, for the majority of the study period, few differences were observed between the native and industry species for the tested ecosystem services. This is itself an interesting finding as the cover in the native treatments was significantly lower for the entire study period. As cover in the native treatments increase the ecosystem services provided by these species should also increase (Emilsson 2008; Jaffal et al. 2012; Speak et al. 2013; Berretta et al. 2014).

This study demonstrates that the native species tested are a viable option for green roofs in a maritime climate. Since there is an increasing demand for native species on green roofs (Butler et al. 2012), our findings that the performance of thermal and stormwater functions is similar between *Sedum*s and native species suggest that the use of these species could enhance the design options for the consumer.

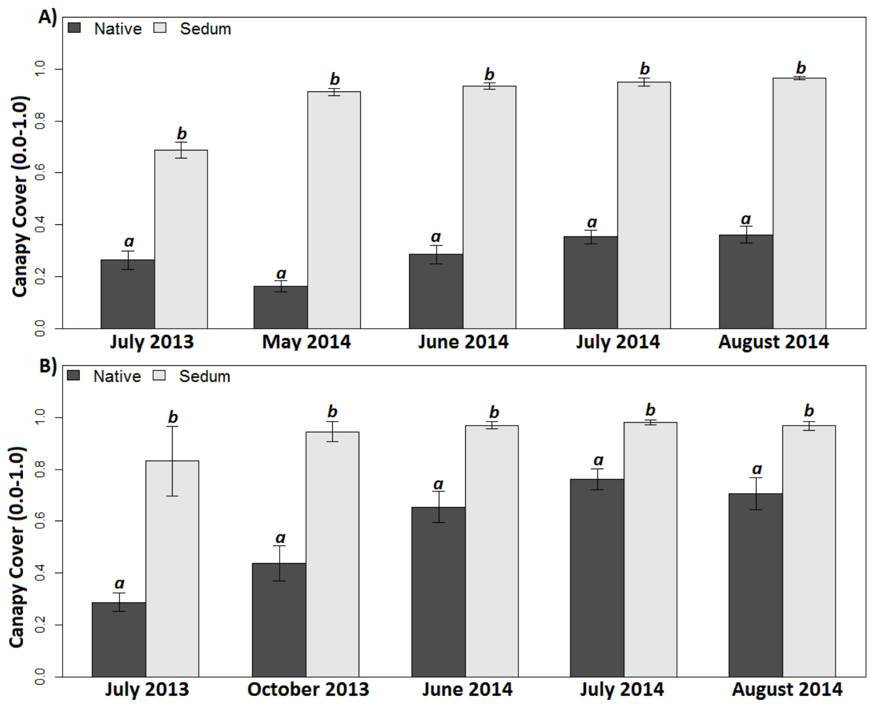
APPENDIX

Appendix 1. Climate summary for study period (July 2013 - October 2014). Obtained from the Shearwater RCS, Nova Scotia weather station (44°37N, 63°30W) (Environment Canada, 2014).

Date	Mean Temp (°C)	Total Precip. (mm)
July 2013	20.3	77.8
Aug. 2013	18.3	76.4
Sep. 2013	15.6	118.4
Oct. 2013	10.5	155.3
Nov. 2013	4.1	148.1
Dec. 2013	-2.2	215.7
Jan. 2014	-2.8	168.4
Feb. 2014	-3.3	123.4
Mar. 2014	-2.4	166.3
Apr. 2014	4.8	140.6
May 2014	8.8	46.3
June 2014	14.8	134.4
July 2014	18.5	35.8
Aug. 2014	18.8	56.6
Sep. 2014	15.7	144.2
Oct. 2014	12.2	94.5

Appendix 2. Soil analysis conducted on the green roof substrate Vitaroofs 7400 substrate and Soprema X. Analysis conducted by the Nova Scotia Department of Agriculture, Quality Evaluation Division, Truro, N.S., Canada (n=3). Vitaroofs substrate consisted of 29.9% gravel, 69.5% sand, and 0.6% silt and clay (Stantec Materials Testing Lab, Dartmouth, N.S.).

	Vitaroofs	Soprema X
pH	8.376	7.2
Organic Matter (%)	27.7	7
P2O5 (kg/ha)	700.333	916.7
K20 (kg/ha)	2957.0	1698
Ca (kg/ha	7774.667	5128.3
Mg (kg/ha)	1026.333	721.3
Na (kg/ha)	2437.333	321.7
Sulphur (kg/ha)	37.666	480.3
Al (ppm)	135.0	568
Fe (ppm)	178.333	147.3
Mn (ppm)	36.666	29
Cu (ppm)	2.583	1.3
Zn (ppm)	19.023	7.2
B (ppm)	4.22	1.2
Nitrate–N (ppm)	13.633	117.7



Appendix 3. Percent canopy cover of the Sedum and Native treatments for the 2013 and 2014 growing season. A) SMU Percent canopy cover B) NSCC percent canopy cover of the no amendment controls. Bars with different letters were significantly different (within a month).

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