A Comparison of Native and Novel Ecosystems: Green Roof Impacts on Plant Growth and Pest Abundance

by

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Abstract: There is little research that supports the potential of green roofs to provide biodiversity similar to ground-level habitat. This study examined three hypotheses. (1) Due to the similarities in environmental stresses, plants native to the coastal barrens established on green roof ecosystems will display similar growth productivity as plants established in the native environment. (2) Plants established in novel green roof ecosystems are subjected to higher presence of plant enemies (aphid and rust) compared to plants in the native environment. (3) The presence of salt spray at the coastal barrens (the native environment) limits the presence of pests on plant individuals. Plant growth and pest presence were quantified at three different sites, two extensive green roofs with different levels of environmental stresses located in Halifax, NS and one coastal barren site located at Duncan's Cove, NS. Data were collected biweekly on four native plant species over the 2015 growing season. Results indicated the harsher extensive green roof supported growth productivity similar to the plants established in the coastal barrens. Plants established at the coastal barrens had significantly lower abundance of pests than plants established on green roof ecosystems. These results varied depending on what pest or plant species was examined. Artificially created salt spray had some effect on reducing pest presence in the green roof environment however these results were not significant for all species and their associated pests. While the novel green roof environment supported more plant enemies than the native environment of these plant species, the prevalence of aphids and other pests on the roof may yet provide benefits to the ecosystem by increasing insect species diversity. The green roofs ability to support similar plant growth productivity as the native ecosystem, indicate green roofs developed to mimic coastal barrens ecosystems could help increase biodiversity and other beneficial functions.

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1.1 Introduction to Green Roofs

In 2014, 54% of the world population resided in urbanized areas and by the year 2050 this number is predicted to increase to 66% (United Nations, 2014). In more industrialized areas such as North America 83% of the population was already living within urban areas in 2014 (United Nations, 2014). This rapidly increasing urbanization expansion worries many scientists and policy makers due to the negative impacts that may be the resulting fallout (Berndtsson, 2010). Associated with urbanization is an increase in impermeable surfaces and a decrease in green space (Berndtsson, 2010). Green space within urban areas provides key ecosystem services such as air filtration, reductions in the urban heat effect, noise dampening, and storm water management (Bolund & Hunhammar, 1999), as well as general benefits to human health and well-being (Maas et al., 2006). Within highly urbanized areas 32% of horizontal surfaces can be exclusively the roofs of buildings (Oberndorfer et al., 2007). The development of vegetated roofs known as green roofs, is one potential way to alleviate the impacts associated with reductions of green space and increase of impermeable surfaces associated with urbanization (Oberndorfer et al., 2007).

Humans have utilized green roofs since ancient Babylonian times in the form of hanging gardens (Oberndorfer et al., 2007; Berardi et al., 2014). The current day form of green roofs became prominent in 1970s in Germany (Oberndorfer et al, 2007; Berardi et al., 2014). Modern green roofs consist of a vegetation layer, substrate (growing medium), layer for filtration, drainage layer and a membrane layer/root barrier (Berardiet et al., 2014). Green roofs are implemented and developed on roofs for the beneficial ecological and economic services they provide as well as for potential aesthetic reasons

(Oberndorfer et al., 2007). Green roofs have been documented for their ability to reduce storm water run off (Mentens et al., 2006; Stovin et al., 2012, Zhang et al., 2015), reduce heat flux (Liu & Minor, 2005), prolong roof membrane life (Teemusk & Mander, 2009), provide noise insulation, reduce urban heat island effect and provide habitat for organisms (Oberndorfer et al., 2007; Berardi et al., 2014). The ability of green roofs to provide these services is highly dependent but not exclusively on substrate (growing medium) depth (Berardi et al., 2014). Vegetation type is also important in regard to green roof functions (Berardi et al., 2014; Lundholm et al., 2015). Green roofs can be classified into two different categories based on substrate depth, intensive and extensive green roofs (Oberndorfer et al., 2007; Berardi et al., 2014). A substrate depth greater than 20cm in depth categorizes an intensive green roof and a substrate depth of 2-20cm categorizes an extensive green roof. Intensive green roofs can provide increased services compared to extensive green roofs due to the thicker substrate as well support a greater diversity of plants. However, extensive green roofs tend to be cheaper, weigh less and require little to no maintenance (Oberndorfer et al., 2007; Berardi et al., 2014). For these reasons extensive green roofs tend to be more commonly developed on roofs in comparison to intensive green roofs (Getter & Rowe, 2006).

1.2 Green Roof Services

1.2.1 Storm Water Management

The ability of green roofs to reduce storm water runoff is one the most studied services a green roof can provide (Carter & Fowler, 2008). Impermeable surfaces within urban areas pose economic and ecological issues (Berndtsson, 2010; Getter & Rowe,

2006). Rainfall events can cause leaching of toxic contaminates such salts, heavy metals, pesticides and oils into environment as well cause water treatment facilities to run over capacity and cause the overflow of sewers into urban areas (Berndtsson, 2010; Getter & Rowe, 2006). Green roofs can alleviate these impacts through the retention and uptake of water by vegetation and soil (Berndtsson, 2010).

One study combining several roof runoff data sets in Germany determined the annual percent of precipitation runoff for conventional roofs, gravel roofs, intensive green roofs and extensive green roofs (Mentens et al, 2006). Conventional green roofs had the highest percent run off with an average of 81%. Gravel roofs with a substrate depth of 5cm had an average 76% annual runoff. Extensive green roofs with 10cm substrate depth on average had an annual percent run off of 50%. Intensive roofs with an average depth of 21cm had the lowest annual runoff with a value of 25% on average (Mentens et al, 2006). This and several other studies have shown the significant ability of green roofs to reduce the rainfall run off in urban areas (Mentens et al., 2006; Stovin et al., 2012, Zhang et al., 2015).

Research has also provided evidence that plant cover and biomass on green roofs are important drivers of the green roof's ability to reduce storm water runoff (Lundholm et al., 2010). Increased aboveground biomass and plant cover may reduce water evaporation rates from the soil leading to increased storm water runoff for the following rain event. However, it has been shown that greater above ground biomass will cancel out the impact of reduced evaporation rates by increased transpiration rates (Lundholm et al., 2010).

1.2.2: Heat Flux and Energy Savings

Green roofs are also known to be able to reduce heat flux between the roof membranes and provide insulation for the building (Liu & Minor, 2005; Castleton et al., 2010). This means a green roof can help reduce energy costs associated with heating and cooling of the building (Castleton et al., 2010). In the summer the green roof prevents solar radiation from reaching the roof structure of the building and during winter months reduce heat escape from a building (Castleton et al., 2010). A study conducted by Liu & Minor (2005) expressed to what extent extensive green roofs could reduce the heat flux through the roof. They found 70-90% reduction in heat flux during the summer and 10-30% during the summer (Liu & Minor, 2005). Buildings with high roof to wall ratios would benefit the most from the energy savings associated with the development of green roofs (Oberndorfer et al., 2007).

Similar to what was mentioned in the previous section, plant biomass and cover are directly connected to the ability of green roofs to provide thermal functionality (Lundholm et al., 2010; Speak et al., 2013). Damage to vegetation, resulting in lower vegetation cover can decrease thermal functioning of the green roof (Speak et al., 2013). Therefore, increased biomass and plant cover can provide increased cooling of the green roofs surface leading to better overall thermal performance (Lundholm et al., 2010).

1.2.3: Habitat Provision and Native Plants

Along with economic benefits, green roofs may also provide habitat for urban wild life (Oberndorfer et al., 2007; Berardi et al., 2014). Due to the harsh environmental stresses plants are exposed to on green roofs, monocultures of highly drought tolerant *Sedum* species are commonly used in the green roof industry (Cook-Patton & Bauerle,

2012; MacIvor et al., 2015). These monocultures of *Sedum* provide some green roof services however higher diversity vegetation on green roofs is believed to provide greater services (Cook-Patton & Bauerle, 2012). Along with increased storm water management and insulation properties, the ability to support a higher diversity of insect species has also been shown to be improved with more diverse green roof vegetation (Madre et al., 2013). One way to increase the diversity of green roofs is through the habitat template approach (Lundholm, 2006). Using plants adapted to similar environmental stresses to those encountered on green roofs could allow the selection of a larger number of suitable species on green roofs (Lundholm, 2006). Varying substrate depth and drainage across the green roof is also believed to increase habitat provision by providing diverse microhabitats for both fauna and flora (Brenneisen, 2006; Hui & Chan, 2011). While using plant communities adapted to harsh, shallow-soil conditions on green roofs may help select native species that provide ecosystem services on green roofs (e.g. MacIvor and Lundholm, 2011a), green roofs still represent a novel environment where several environmental factors may differ from those found in the native environments of the selected plant species.

Invertebrates have been well documented to colonize green roofs (Kadas, 2006; MacIvor & Lundholm, 2011b; Madre et al., 2013). Birds are also believed to benefit from the development of green roofs by providing food resources, cover from predators and nesting opportunities (Fernandez-Canero & Gonzalez-Redondo, 2010). However, monocultures of *Sedum* green roofs may provide low level of these benefits (Baumann, 2006; Fernandez-Canero & Gonzalez-Redondo, 2010). Highly diverse green roofs have been documented to increase bat presence in urban areas compared to conventional roofs

(Pearce & Walters, 2012). Interestingly *Sedum* monoculture roofs showed no significant difference compared to conventional roofs in terms of the presence of bats (Pearce & Walters, 2012). These studies express the importance of developing diverse green roofs contrary to industrial *Sedum* mat roofs commonly used. This becomes particularly important in the development of polices related to urban habitat provision (Williams et al., 2014).

1.3: Green Roofs and Ground Level Habitats (Comparative Studies)

Comparison studies between ground level habitats and green roof ecosystems are essential for the optimization of green roof policies in regard to biodiversity conservation in urban areas (Williams et al., 2014). Several studies have compared the biodiversity between the novel green roof environment and ground-level habitat but these few studies are inadequate to make conclusions in regard to the ability of green roofs to support biodiversity equivalent to ground-level habitats (Bates et al., 2013; Williams et al., 2014). Studies have examined soil communities (McGuire et al., 2013; Molineux et al., 2015), insect diversity (Kadas, 2006; MacIvor & Lundholm, 2011b), bee diversity (Colla et al., 2009; Tonietto et al., 2011; Ksiazek et al., 2012), and insect host-parasitoid relationships (Quispe & Fenoglio, 2015) in comparison to ground level habitats.

1.3.1: Insect & Invertebrate Diversity

The ability of green roofs to support insect diversity has been a main focus of published research examining green roof biodiversity (MacIvor & Lundholm, 2011b). Bee (Apidae) communities appear to be of particular interest for comparative studies (Colla et al., 2009; Tonietto et al., 2011; Ksiazek et al., 2012). A study conducted by

Colla, et al., (2009) examined the potential of extensive green roofs in Toronto, Canada to support bee communities in comparison to urban ground level habitats. Colla et al. examined two extensive green roofs and four urban ground level sites, a woodlot, a lawn and two unmaintained grassy areas. Results showed that there was no significant difference between the composition of bee communities between the green roof sites and urban ground level sites. However, the abundance of various species was lower on green roof sites in comparison to ground level sites. This study indicates that extensive green roofs might provide similar food resources and nesting opportunities for bee species as urban ground level habitats (Colla et al., 2009).

Tonietto et al., (2011) conducted a comparative study in Chicago, examining bee diversity between novel green roof ecosystems, urban green space and natural tall grass prairies habitats. Native bee communities had higher diversity and abundance in the prairie habitats and urban parks compared to green roof habitat (Tonietto et al., 2011). Similar results were reported by Ksiazek et al., (2012), who found a lower abundance of bees on green roofs in comparison to adjacent ground level habitats (Ksiazek et al., 2012). These studies indicate that extensive green roofs might provide similar food resources and nesting opportunities for Apidae species comparable to ground level habitats however, abundance on green roofs may be lower and species composition may differ significantly, (Colla et al., 2009; Tonietto et al., 2011; Ksiazek et al., 2012). Studies have also documented the importance of native flowering species as well as the height of the green roof from ground level habitat to be important factors in bee species composition and abundance (Tonietto et al., 2011; MacIvor, 2015).

MacIvor and Lundholm (2011b) conducted a more comprehensive study examining insect diversity in general on five intensive green roofs in Halifax, Canada compared to adjacent urban ground-level habitats. This study identified all individuals to morphospecies and beetles were identified to species. Insect diversity and abundance on the green roofs and the ground level habitat were not significantly different. However the abundance and richness of insect species present was less on green roofs in comparison to ground-level habitats (MacIvor & Lundholm, 2011b). Kadas (2006) also studied the ability of green roofs to support insect biodiversity in relation to brown field sites. Coleoptera, Araneae and Hymentoptera species were the focus of this study and it was found that green roofs supported several similar species as ground level brownfield sites. It was also documented that 10% of the species collected on the green roofs were nationally rare (Kadas, 2006). Both of these studies support the notion that green roofs have the ability to support insect and invertebrate diversity similar to ground level urban habitat and may help with conservation goals (Kadas, 2006; MacIvor & Lundholm, 2011b).

1.3.2: Pest Species and Green Roofs

A recent study conducted by Quispe and Fenoglio, (2015) examined the host and parasitoid relationship of a leaf-miner (*Liriomyza commelinae*) in a green roof ecosystem in comparison to urban ground level habitat. This study showed that the leaf-miner (*L. commelinae*) could successfully find host plants on a green roof, however at lower abundance and colonization rates compared to ground level habitats. Lower parasitoid rates on leaf-miner (*L. commelinae*) were found on green roof habitats. Parasitoid species were able to find *L. commelinae* on green roofs however only a few species were found to

be associated with parasitism on green roofs, suggesting that plant pests may be more problematic on green roofs if their own predators or parasites are lower in abundance compared to levels in ground-level habitats (Quispe & Fenoglio, 2015).

Aphids (Aphididae) have also been documented to feed on green roof vegetation in large numbers (Kadas, 2006; Martin & Hinckley 2007; Coffman & Waite, 2011). In Coffman and Waite's (2011) study aphids and leafhoppers were the most abundant category of species found on the two green roofs studied (34.1% and 38.8%). The presence of aphids on green roofs could have both negative and positive benefits (MacIvor & Ksiazek, 2015). Aphids in high numbers are known to be damaging to forb plant species in native environments due to their feeding habits. However, aphids also provide important food sources for ladybird beetles (MacIvor & Ksiazek, 2015). High abundance of both adult and larval ladybird beetles in relation to aphid presence has been observed in studies examining green roofs (Kadas, 2006; Appleby-Jones, 2014). Green roofs have been observed to support pest species however there is limited research on this topic, especially in regard to comparative studies (MacIvor & Ksiazek, 2015). Quispe and Fenoglio's 2015 study was one of the first quantitative documentations of pest species on green roofs in comparison to ground level habitat. As the number of green roofs increase it is important to understand how green roofs will impact the presence of pest species in urban environments. The prevalence of pests on green roofs is also relevant to the provision of ecosystem services. If green roofs plants have high pest loads, this may have implications for the functioning and long-term sustainability of the systems. Increasing insect diversity in urban areas is believed to be in association with increased pest control by increasing beneficial insects (Hunter & Hunter, 2008). However, Quispe and

Fenoglio's (2015) study showed that some parasitoids might not be able to utilize food resources on green roofs due to the height of buildings. More research is needed to determine how green roofs may impact pest-predator relationships and the abundance of insect herbivores on green roofs.

No studies have quantified the presence of aphids on green roof plants despite frequent observations of aphid presence in green roof systems (Kadas, 2006; Martin & Hinckley 2007; Coffman & Waite, 2011; MacIvor & Ksiazek, 2015). Quantifying aphids on plants established in green roof ecosystems is important for understanding how plant productivity may be impacted by presence of these pests if in high numbers. Insect herbivores aren't the only plant pests present on green roofs. Rust fungal pathogens of plants have also been documented to be a pest in the green roof environment (Heim, 2013). In ground-level studies, both aphids and rust have been documented to negatively impact productivity of plants (Barlow et al., 1977; Barlow & Messmer, 1982; Godoy et al., 2006).

As discussed in a previous section, plants native to coastal barrens habitats have been documented to make excellent candidates for green roof species due to the predicted similar environmental stresses experienced at these two environments (Wolf & Lundholm, 2008). However, past work on local green roofs suggest that pest abundance may be higher on green roofs than in the natural environment where the plants originate. Some speculate that some difference between the natural environment on the coastal barrens and the green roof environment may result in greater pest pressure on green roof plants. One environmental stressor stands out as a possible candidate for novel effects on native plants: ocean salt spray exposure is common in populations of plants growing close

to the coast but is generally not present in the green roof environment. Due to the presence of ocean salt spray from breaking waves, plants established close to the coast have to be salt tolerant. When these plants are removed from their native habitat and grown in a novel ecosystem such as green roofs it is unknown how this new environment will impact the species in regards to productivity and susceptibility to pests. The reduction of salt spray may result in increased pest numbers, if the salt spray in coastal environments keeps pest populations to low levels.

In this study I investigated vegetation growth and presence of common pests in two contrasting green roof ecosystems (one with greater sun and wind exposure, and a second with more shade and shelter from wind) and compared these with plants of the same species growing in a natural setting, the coastal barrens. A manipulative experiment was also conducted to examine the influence of salt spray as a factor with the potential to reduce rust and aphid presence. It was hypothesized that (1) novel green roof ecosystems can support equal plant growth productivity as the species' native coastal environment. (2) Abundance of aphids and rust on host plant species is greater in green roof ecosystems in comparison to the plant species' native coastal environment. (3) Application of salt spray to green roof pants can reduce the presence of pests on plant surfaces.

2.1: Methods

2.1.1: Part I: Plant Performance of Native Barren Species in Green Roof Ecosystems

Plant species were chosen on their ability to survive in a green roof ecosystem. Native plant species selected are native to coastal barren habitats in Nova Scotia, Canada.

The species chosen were as follows; *Rhodiola rosea*, *Sibbaldiopsis tridentata, Plantago maritima* and *Solidago bicolor.* All of these species have grown successfully on local green roofs for the previous 10 years (Lundholm et al., 2010; MacIvor and Lundholm 2011a). Performance of the four species was recorded from May 21, 2015 until October 23, 2015 every second week.

2.1.2: Experimental Setup

Coastal Barrens Site

Chebucto Head, located in Duncan Cove, Nova Scotia, Canada was chosen as the site to represent the native habitat of the plants used in the experiment (Figure 1). Chebucto Head site is a coastal barrens habitat and was chosen on the basis that all four species can be commonly found in this location. Individuals for the experiment were selected on May 20, 2015. *P. maritima, S. tridentata* and *R. rosea* were all tagged by loosely tying a string and duck tape tag around the base of the plant. *S. bicolor* replicates was tagged by inserting a bamboo skewer into the substrate next to the individual due to the small size of the plants early in the growing season. Later in the growing season *S. bicolor* was tagged using the same method as the other three species. Thirty individuals of each species were identified and tagged while walking down the coastline. All individuals had to be a minimum of 1 meter apart to reduce chances of identical plants being tagged. *P. maritima* and *R. rosea* individuals were located growing in cracks and in thin substrate along the rocky outcrop of the coastline and were all approximately 15m from the high tide line.

S. bicolor and *S. tridentata* were identified and tagged in substrate along a path just above the rock outcrop. Due to *S. bicolor* being so small at the beginning of the

growing season, dead flower shoots from the previous year's growing season was used to locate the species. A coin was flipped to determine whether odd or even numbered plant individuals would be included in experiment. The coin flip resulted in all odd number individuals to be used in the experiment. Due to the difficulty in correctly identifying *S. bicolor* so early in the growing season all 30 tagged individuals' growth and pest measurements were taken. Once the *S. bicolor* species could be identified the coin flip results were applied to these individuals. Some *S. bicolor* individuals were lost due to the removal of the bamboo skewer by an unknown cause. This resulted in some even number individuals being used in the experiment.

Figure 1. Chebucto Head located at Duncan's Cove NS, Canada. Photo Taken May 21, 2015

Library Green Roof Site

The Library green roof site is an experimental intensive green roof constructed on top of the Patrick Power Library located at Saint Mary's University, Halifax Nova Scotia, Canada (44°39′N, 63°35′W) (Figure 2). The green roof is situated one story above ground level and is sheltered by 1-3 story buildings surrounding three sides of green roof. All four plant species analyzed on the Library green roof were originally grown from seeds collected at Chebucto Head. Species' replicates for on the Library green roof were used as the controls for Part II. Setup for the species *R. rosea* occurred on May 22, 2015. *R. rosea* individuals were sampled within a pre-existing experiment on the roof. This experiment was raised approximately one meter above the green roof with an average soil depth of 11.5cm. The pre-existing experiment consisted of six 1 m x 1 m. plots that contained native coastal barren species. Two plots contained four individuals and the remaining four plots contained three individuals. The individual plants used in the experiment were selected at random with a minimum of 30 cm distance between plants. The raised plots were weeded on weekly basis to remove non-native invasive species to reduce interspecific competition because in the native environment *R. rosea* experience minimal competition.

S. tridentata, P. maritima and *S. bicolor* were transplanted into 36 cm x 36 cm modules (Polyflat®, Stuewe & Sons Inc., Oregon, United State) with a depth of 12 cm and placed next to the raised plots containing the *R. rosea.* The bottom of the modules allowed for free drainage of water and was lined with 36 cm x 36 cm root barrier and water retention mat (EnkaRetain and Drain 3111®, Colbond Inc., North Carolina, United States). The soil used for transplanting was Sopraflor X (Soprema Inc., 20

Drummondville, Quebec, Canada) and was filled up the modules to the top. This is the same substrate used in both green roofs for all species. The modules were arranged into four groups each two modules wide and five modules in depth. Each module contained one replicate of the three species. *S. tridentata* and *S. bicolor* were transplanted on May 22, 2015 from experimental modules on the Atrium green roof. The individual plants were chosen at random. Due to the scarcity of established *P. maritima* plants on the green roofs, the individuals had to be transplanted from trays of seedlings grown from seed during the winter months. *P. maritima* was transplanted on May 25, 2015. This species was transplanted two days later then other species to limit transplant shock due to two consecutive cold days. The largest individuals which were not flowering were chosen to be used in the experiment. Replicates were replaced if the cause of death appeared to be the direct result of the plant not being able to withstand the transplant.

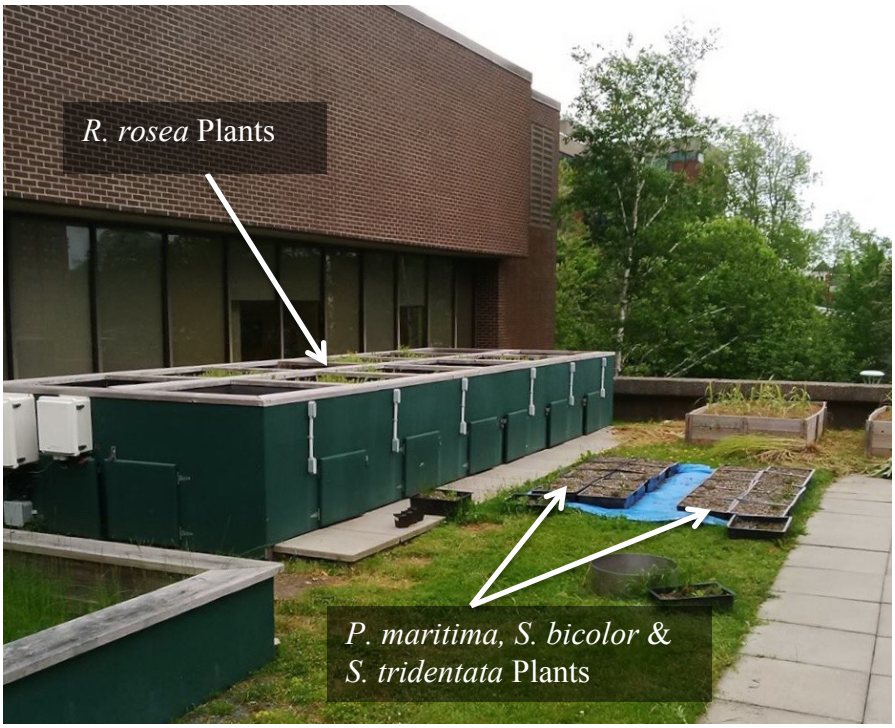

Figure 2. The Library green roof site located at Saint Mary's University, Halifax Nova Scotia, Canada (44°39′N, 63°35′W). Taken June 23, 2015.

Atrium Green Roof Site

The Atrium green roof is an experimental extensive green roof located on Saint Mary's Campus, Halifax, Nova Scotia, Canada (44◦39′ N, 63◦35′ W) (Figure 3). The green roof is four stories above ground level and plant communities on this green roof experience relatively harsh environmental conditions. The Library and Atrium green roofs were considered two distinct sites due to predicted different level of environmental stresses experienced on the separate green roofs. Previous work has suggested that the Library green roof is more sheltered from environmental extremes, being more shaded and protected from wind by adjacent buildings, whereas the Atrium green roof has greater sun and wind exposure (Lundholm et al., 2014). Similar to the Library green roof, all four

species of plants examined on the Atrium green roof were originally grown from seeds, which were collected at Chebucto Head. Each plant species on the Atrium green roof had ten replicates. Ten established *R. rosea* were selected from a pre-existing experiment and tagged with a bamboo skewer and duck tape tag. The pre-existing experiment consisted of 24 61 cm x 61cm plots with varying soil depth and established native coastal barren species. For this experiment *R. rosea* was selected from plots with a soil depth of 10 cm. Due to the low number of *R. rosea* present on the Atrium green roof it was not possible to select individuals at random. Instead each plot with a soil depth of 10 cm contained two *R. rosea* individuals that were sampled.

P. maritima replicates were selected from individuals already established on the Atrium green roof in modules, identical to the ones used on the Library green roof. The six modules were then moved next to the larger plots containing *R. rosea. S. tridentata* and *S. bicolor* replicates were identified on the adjacent extensive green roof. Native coastal barren plant species as well as many mosses and lichens dominated this green roof. The green roof's average substrate depth was 7 cm. All replicates were located on the eastern side of the green roof closest to the other location of the experiment with *R. rosea* and *P. maritima*. *S. tridentata* and *S. bicolor* were selected at random however a minimal distance of 1 meter between selected individuals was required for *S. tridentata* due to its ability to grow using rhizomatous growth. All species were tagged by inserting a bamboo skewer with a duct tape tag into the substrate directly next to the replicate. Throughout the duration of the experiment crows would pull out the bamboo skewers marking the replicates. To counter this, overhead pictures of all the replicates were used to identify the same individual again. Multiple methods of tagging were used at the same

time to limit the removal of the tags. Coffee stir sticks labeled with the replicated identification and 2 inch nails inserted deeply into the substrate were used along with the bamboo skewers. A summary of the different settings for each species analyzed can be found in Table 1.

Figure 3. Atrium green roof located Saint Mary's Campus, Halifax, Nova Scotia, Canada (44◦39′ N, 63◦35′ W). Picture taken August 15, 2014.

Table 1. A summary of the setting in which the analyzed plant species were established in on the Library green roof, Atrium green roof and Chebucto Head (native environment).

Site	Species	Transplanted	Setting	Avg. Soil Depth (cm.)
Library Green Roof	*R. rosea*	No	100 cm x 100 cm plots containing native plant species	11.33 ± 0.27
	P. maritima	Yes	36 cm x 36 cm Module containing three individuals	11.05 ± 0.12
	S. bicolor	Yes	36 cm x 36 cm Module containing three individuals	10.6 ± 0.14
	S. tridentata	Yes	36 cm x 36 cm Module containing three individuals	10.85 ± 0.16
Atrium Green Roof	*R. rosea*	No	61 cm x 61 cm plots containing native plant species	9.98 ± 0.23
	P. maritima	No	36 cm x 36 cm modules containing native plant species	7.82 ± 0.30
	S. bicolor	No	EGR dominated by native coastal barren plant species	7.35 ± 0.31
	S. tridentata	No	EGR dominated by native coastal barren plant species	6.99 ± 0.26
Chebucto Head	*R. rosea*	No	Narrow cracks and shallow substrate on exposed bedrock, approx. 15m from high tideline	3.48 ± 0.53
	P. maritima	No	Narrow cracks and shallow substrate on exposed bedrock, approx. 15m from high tideline	3.61 ± 0.74
	S. bicolor	No	Directly above bedrock outcrop, found in dense vegetation	14.53 ± 1.04
	S. tridentata	No	Directly above bedrock outcrop, found in dense vegetation	10.21 ± 1.57

EGR, extensive green roof

2.1.3: Plant Growth Measurements

Plant growth measurements for all species began on May 21,2015. Sequential measurements were made every two weeks until October 23, 2015. Plant growth was measured different ways and depended on the species being analyzed. *R. rosea* growth

performance was assessed by the number of stems per plant and the length of the longest stem present. *P. maritima* was assessed by recording the length and width of the longest leaf on the plant. The number of leaves present on the individual was recorded as well. *S. bicolor* growth was recorded by measuring the length and width of the longest leaf on the plant and the number of leaves present. If a leaf's length was less then 1.0cm it was not included in this assessment. For *S. tridentata* the length and width of the longest leaf and the number of leaves per plant were recorded. The ability of *S. tridentata* to grow via rhizomes made it difficult to identify distinct individuals in natural populations at Chebucto Head. To compensate for this an individual plant was considered to be anything connected to the central stem that tag was tied to. A plant health score was recorded for all species assessed every two weeks (Heim and Lundholm, 2014). Time of flowering was recorded as well.

2.1.4: Pest Abundance Measurements

Aphids on *R. rosea* were recorded by tagging three stems on each individual with a coloured thread at random. Each second week the number of aphids per stem was counted and recorded. This gave an average number of aphids per stem on the plant. Analyzing aphid abundance in this manner allowed for the comparison between individuals with different stem counts because the larger the plant the more aphids the plant can host. Aphids on *S. tridentata, S. bicolor* and *P. maritima* were recorded by counting the total number of aphids present on the entire individual. Observations of the aphids' location on the plant were recorded as well.

Fungus (Rust) on *S. bicolor* was quantified using a percent cover key developed by, Godoy, Koga, and Canteri, (2006) (Figure 4). Pictures were taken of the leaf with the highest intensity of rust coverage every two weeks from May 21, 2015 until October 23, 2015. At the end of the growing season the pictures were compiled and using Godoy et al's (2006) key, a percentage of rust cover was designated for the individual at that time interval. The number of leaves infected with rust was also recorded.

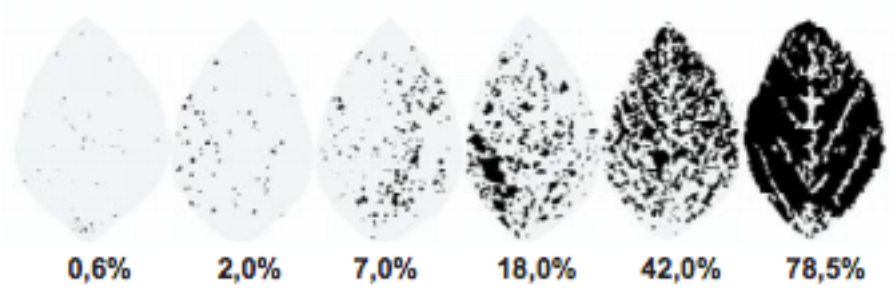

Figure 4. Percent cover key of rust severity developed by Godoy et al., (2006)

2.1.5: Pest Identification

Aphids (family Aphidae) were collected during the growing season on all host plant species at each site and preserved in 70% ethanol. Due to time constraints identification of the aphids collected was not possible. Aphids were left in ethanol for later identification. Orange rusts present on *S. bicolor* was identified to be within the genra *Coleosporium*, *Puccinia* or *Uromyces* (Heim, 2013).

2.1.6: Soil Depth

Soil depth directly below all the individual plants sampled at all three sites was measured. Some replicates for *R. rosea* and *P. maritima* at Chebucto Head grew in cracks in the bedrock where accurate soil depth measurements were impossible. These replicates

were considered to be established in a substrate depth of 0 cm. The length of the bamboo skewer used to determine soil depth prevented precise values for some *S. bicolor* and *S. tridentata* replicates located at Chebucto Head because the substrate depth was occasionally greater than the length of the skewer. In such cases the full length of the skewer was used as the soil depth and a note was made recording what individuals had this error.

2.1.6: Statistical Analysis

In order to compare the magnitude of different dependent variables against site as a main factor, One-Way ANOVA Tests were used. Each plant species was analyzed separately (see Table 2). For pest abundance measurements the maximum aphid count and rust percent cover recorded on each replicate was statistically analyzed. As well, the sum of aphid density and rust percent cover over the study period on each replicate were analyzed as indices of overall pest loads during the growing season. Tukey Pairwise Comparison tests were used to determine which sites differed significantly if the main site effect was significant. Transformations were applied to the data to meet the ANOVA assumptions. If transformations were insufficient to transform the data to meet the assumptions required for One-way ANOVA test a Kruskal-Wallis Test was conducted as well. The main transformation used was logarithm base ten however if logarithm did not work the square root transformation was applied. Minitab 17 (Minitab® 17.1.0, State College, Pennsylvania) was used to conduct statistical analysis of the data collected.

Table 2. The variables recorded to detect significant differences in plant size and the associated species in which they were recorded for. An "**x**" denotes if the species was analyzed for that variable. Maximum values recorded for each replicate were the only values statistically analyzed. For each time interval leaf area was calculated by multiplying the largest leaf's length by width. Then the maximum value for each replicate was statistically analyzed.

Variables of Plant Size	***R. rosea***	***P. maritima***	***S. bicolor***	***S. tridentata***
Number of Stems per Individual	**x**			
Number of Leaves per Individual		**x**	**x**	**x**
Largest Stem's Height (cm)	**x**			
Largest Leaf's Length & Width (cm)		**x**	**x**	**x**
Leaf Area (cm^2)		**x**	**x**	**x**

Leaf area was calculated by multiplying length by width to give an index of leaf surface area. Leaf area growth rates were calculated using equation 1 (Harper, 1977). Positive leaf area growth rates were calculated from the first data sample (May 21,2015) until the plant leaf reached its maximum area. Negative leaf area growth rates were calculated from the maximum leaf area recorded until the last data sample on October 23, 2015. For *R. rosea* replicates T2 was considered to be September 25, 2015 because following this date replicates at all three sites experienced significant reductions in aboveground biomass attributed to the plants going into dormancy for the winter. If a plant had zero leaves for T2, ln $(cm^2{}_{T1})$ was replaced with 0. For *R. rosea* the height of the largest stem determined the growth rates since no leaf measurements were recorded for this species. The second growth rate was calculated to show the decline in growth after the summer peak and to see if one of the sites had a longer growing season.

$$Growth\ rate = (\ln(cm^2{}_{T2}) - \ln(cm^2{}_{T1}))/\#\ of\ days \quad (1)$$

2.2.1: Part II: Salt Spray and Pest Presence Experimental Setup

The ability of salt spray to reduce the presence of pests on native salt tolerant species was assessed on the Library green roof located at Saint Mary's University, Halifax NS. To make data collection as efficient as possible the same species used in Part I were used in Part II. These species included *Rhodiola rosea*, *Sibbaldiopsis tridentata, Plantago maritima* and *Solidago bicolor.* Experimental setup and transplanting processes for Part II were identical as Part I, as seen in Table 3. However, in addition to the 10 controls replicates, 10 more replicates were added for salt treatments. For *R. rosea* replicates were required to be a minimum of 30cm apart. Replicates were then randomly assigned to be a salt treatment or represent a control. Due to the location of *S. tridentata, P. maritima* and *S. bicolor* replicates on the green roof they were subjected to shade late in the day. To compensate for this a coin was flipped to determine if odd or even number replicates would receive the salt treatment. This allowed for an even distribution of the replicates throughout the four groups of 2x5 module layout.

Table 3. A summery of settings for four plant species examined in Part II. All plant species examined in Part II were established on the Library green roof. Each of the four species had salt treatments (n=10) and controls (n=10).

Species	Transplanted	Setting	Avg. Soil Depth (cm.)
R. rosea	No	100 cm x 100 cm plots containing native plant species	11.33 ± 0.27
P. maritima	Yes	36 cm x 36 cm Module containing three individuals	11.05 ± 0.12
S. bicolor	Yes	36 cm x 36 cm Module containing three individuals	10.6 ± 0.14
S. tridentata	Yes	36 cm x 36 cm Module containing three individuals	10.85 ± 0.16

2.2.2: Concentrations of Salt Spray Present in the Native Environment

Determining the salt concentration that plants in the salt spray zone are subjected to at Chebucto Head was attempted, however the results failed to show salt concentrations present in the environment. Due to restrictions in time, the concentration of salt that plants are exposed to in their native environment was determined by examining several peer-reviewed articles. Oosting and Billings (1942) provided the data used to determine the concentration for the experimental salt treatment. Their study was selected on the basis that it was conducted on the Eastern shore of North America in relative close proximity to Nova Scotia and provided different levels of salt concentration in respect to the high tide zone. The value chosen was 22.9 mg/dm^2 per day (Oosting & Billings, 1942). This was the average between the two sites studied by Oosting and Billings and at similar distance from the high tide line as *R. rosea* at Chebucto Head (approximately 15 m). Since *R. rosea* and *P. maritima* found at Chebucto Head are both similar distances from the high tide zone, it was predicted that both of these species were exposed to 22.9 mg/dm^2 per day in the natural environment. Salt spray exposures for *S. bicolor* and *S. tridentata* at Chebucto Head was predicted to be a value five times less at 4.58 mg/dm^2 per day. The 4.58 mg/dm^2 was determined by analyzing salt concentrations present in the soil at Chebucto Head. A previous study conducted at Chebucto Head showed that *S. bicolor* and *S. tridentata* commonly were established in soils that had salt concentrations five times less in comparison to the soils *R. rosea* and *P. maritima* were established in (Lundholm, J., unpublished data).

2.2.3: Salt Spray Treatments and Controls

The salt treatment replicates were subjected to salt spray by spraying the plant directly with a hand held spray bottle containing a salt solution. Controls were sprayed with distilled water to eliminate the possibility of the spray impacting pest presence. Salt solutions were prepared by mixing Kosher Sea Salt and distilled water at a concentrations of 9.160g/liter for *R. rosea* and *P. maritima* and 1.832g/liter for *S. bicolor* and *S. tridentata.* These concentrations allowed for 3 sprays of the hand held spray bottle to equal 22.9mg of salt dissolved in the spray for *R. rosea* and *P. maritima* and 4.58 mg for *S. bicolor* and *S. tridentata*. The plants were then sprayed with salt at a particular distance so the area of the spray on average equaled 1dm^2. Salt treatments were sprayed with salt and controls with distilled water every second day. Following rainfall events the plants were exposed to salt spray or distilled water. This was done to counter salt that washed off the plant surfaces from the rainfall. Salt treatments began on June 9, 2015 and continued until October 8, 2015. On July 29, 2015 the concentrations of salt being exposed to the plants were doubled for all species however the frequency of salt spray application remained constant. The doubling of salt spray concentrations occurred because the current concentrations at that time appeared to have no impact on the presence of pests on *S. bicolor* and *S. tridentata.* The doubled concentrations also made the salt exposure more comparable to findings of Oosting & Billings, 1942 because their data suggested 22.9 mg/dm^2 per day and 4.58 mg/dm^2 per day. This experiment applied 22.9 mg/dm^2 and 4.58 mg/dm^2 of salt every second day rather then every day as suggested by Oosting & Billings. Spraying the plants everyday for the full growing season was not possible due to time restraints. At the beginning of the experiment it was feared that by

increasing the concentration to compensate for lower frequency of salt addition it might negatively impact growth and may result in plant death.

2.2.3: Pest Abundance Measurements

The methods used to determining pest abundance were identical to the methods proposed previously in Part 1 section 2.1.4.

2.2.4: Statistical Analysis

For Part II Two-Sample T-Tests were exclusively used to test for significant differences between salt-treated and control populations. Logarithmic transformations were also applied to the data if assumptions were not met. Similar to Part I, only the maximum aphid count and rust percent cover recorded on each replicate was statically analyzed, as well, the sum of aphid counts and rust percent cover over the study period on each replicate. Minitab 17 (Minitab® 17.1.0, State College, Pennsylvania) was the software used to perform the statistical tests.

3: Results

3.1: Part I: Plant Performance of Native Barren Species in Green Roof Ecosystems

3.1.1: Maximum Leaf/Stem Length

P. maritima plants on the Library green roof had significantly larger leaves in comparison to both the Atrium green roof and the Chebucto Head coastal barrens (Figure 5A). The Atrium green roof and coastal barren site exhibited no significant difference of means. The One-way ANOVA analysis of difference of means showed at least one site being significantly different (R-sq(adj)=34.70%; $P<0.000$). No significant difference was

found between means of the three different sites for *S. tridentata* (Figure 6A). Similar to *P. maritima,* the One-way ANOVA analyzing *S. bicolor* maximum leaf length showed a significant difference between one or more of the sites (R-sq(adj)=30.09%; P=0.001) (Figure 7A). *S. bicolor* plants on the Library green roof had significantly larger mean leaf length in comparison to the Atrium green roof. There was no significant difference between the coastal barrens and the two green roof sites (Figure 7A).

A One-way ANOVA test showed a significant difference in means for the maximum height recorded on *R. rosea* for the 2015 growing season at the three sites, (R-sq(adj)=26.58%; P=0.003). *R. rosea* was significantly larger on both the green roof sites in comparison to the Coastal Barrens (Figure 8A). *R. rosea* grown on the two green roofs showed no significant difference.

3.1.2: Maximum leaf/stem count

P. maritima grown on the Library green roof had a significantly larger number of leaves present in comparison to plants grown at the Atrium green roof and the coastal barrens (R-sq(adj)=32.22%; P=0.001). There was no significant difference in the number of leaves between the Atrium green roof and the coastal barrens, as seen in figure 5B. For *S. tridentata* there was no significant difference in the maximum number of leaves between the Atrium green roof and Chebucto Head (Figure 6B). Similar to *P. maritima*, One-way ANOVA test and Tukey pairwise tests on S. *bicolor* showed individuals established on the Library green roof had a larger number of maximum leaves recorded (R-sq(adj)=52.85%; P<0.000). As well the Atrium green roof and coastal barrens showed no significant difference between the means at these two locations, as seen in figure 7B.

No significant differences were found for *R. rosea* in regard to mean maximum stem count per plant (Figure 8B).

3.1.3: Leaf Area

Leaf area of the largest leaf for *P. maritima* was significantly larger for plants growing on the Library green roof in comparison to the other two sites as seen in Figure 5C (R-sq(adj)=31.45%; P=0.001). The Atrium green roof and Chebucto Head means were not significantly different. For species *S. tridentata* leaf area was not found to be significantly different between any of the sites (Figure 6C). *S. bicolor* One-way ANOVA Test results showed a significant difference between all three sites (R-sq(adj)=43.39%; P<0.000) (Figure 7C).

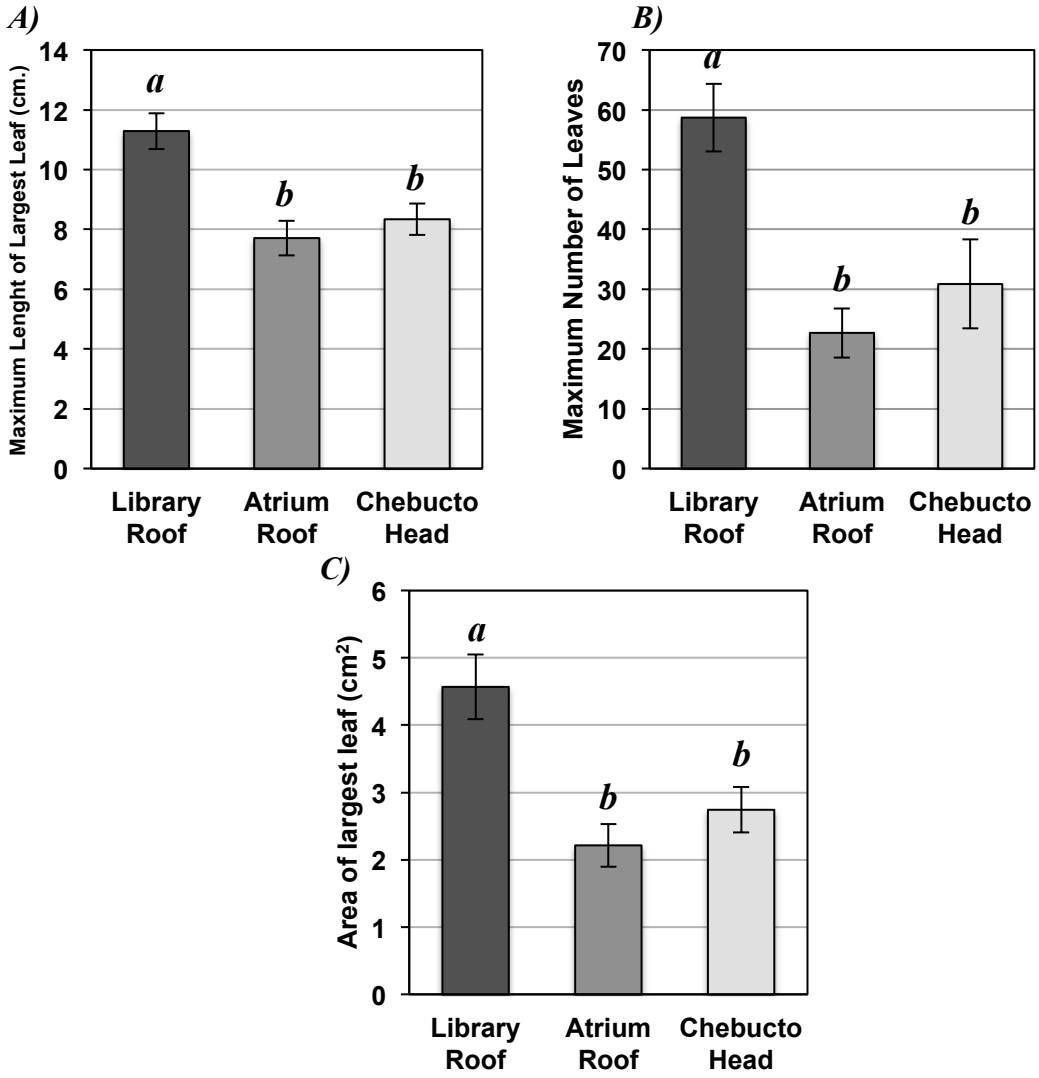

Figure 5. Mean maximum (A) length of largest leaf, (B) leaf count, and (C) leaf area for ***P. maritima*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different.

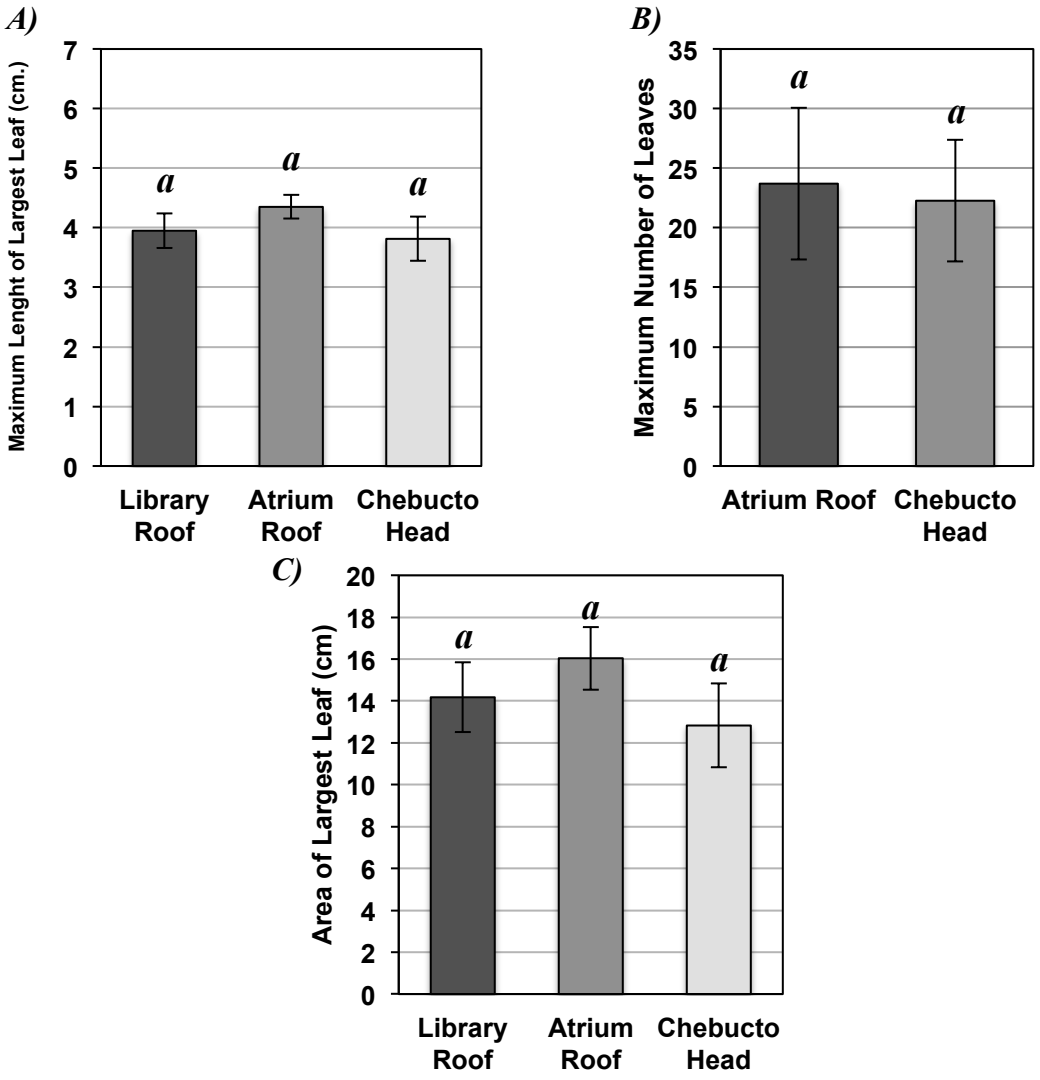

Figure 6. Mean maximum (A) length of largest leaf, (B) leaf count, and (C) leaf area for ***S. tridentata*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different. The number of leaves on *S. tridentata* plants at the Library roof site was omitted from the final results due to error in identifying the central stem. Therefore, the number of leaves at this site could not be compared confidently with the other sites, as the data was not completely homogenous.

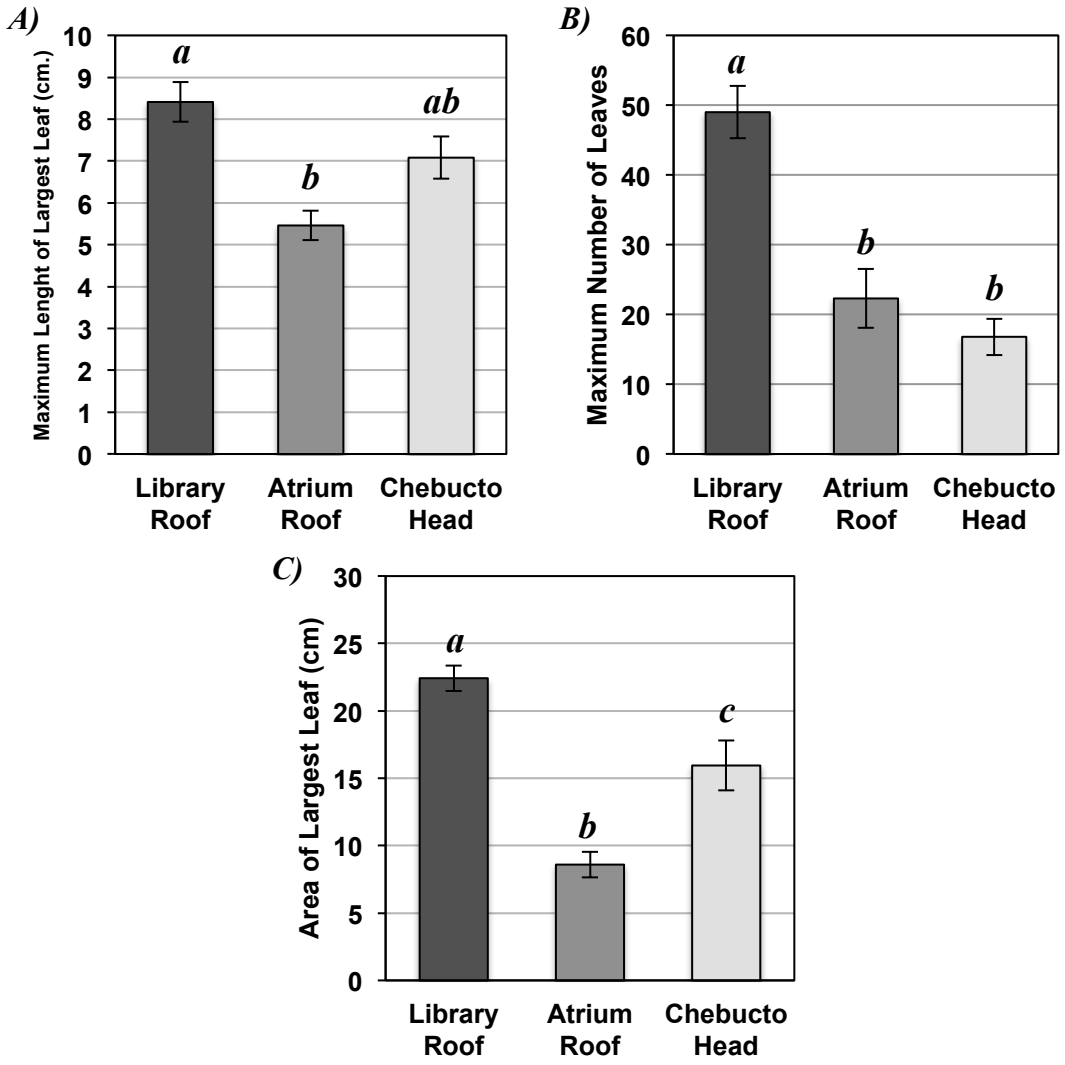

Figure 7. Mean maximum (A) length of largest leaf, (B) leaf count, and (C) leaf area for ***S. bicolor*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different.

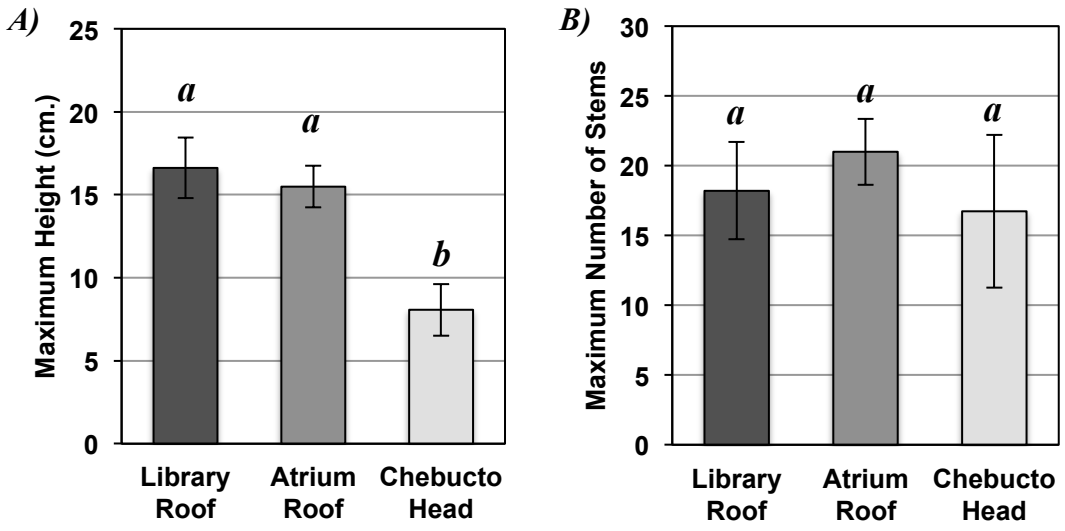

Figure 8. Mean maximum (A) height of the largest stem, and (B) number of stems for ***R. rosea*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different. One *R. rosea* individual located at the coastal barrens site was omitted from final results due its significantly larger height believed to be the result of the low light and shelter microenvironment it was growing in.

3.1.4: Growth rates

One-way ANOVA analysis showed no significant difference in growth rate among sites, from the beginning of the experiment (May 21,2015) to the point of maximum leaf area for *P. maritima*, as seen in Figure 9A. *S. tridentata* growth rate was significantly larger at Chebucto Head in comparison to the Atrium green roof and the Library green roof (R-sq(adj)=17.62%; P=0.017) (Figure 10A). *S. bicolor* had significantly higher growth rate at Chebucto Head in comparison to both of the green roof sites (R-sq(adj)=49.52%; P<0.000) (Figure 11A). The two green roof sites exhibited no significant difference in growth for this species.

For *P. maritima* no significant difference in leaf area reduction rates was detected between the three sites (Figure 9B). A Kruskal-Wallis Test found a significant difference in the reduction of leaf area for *S. tridentata* between the two different green roof sites and Chebucto Head (P=0.018) (Figure 10B). After using Mann-Whitney Tests between each site the Library roof was considered to be the site significantly different then the other two sites. Simular to *P. maritima, S. bicolor* leaf area reduction rates exhibited no significant differences between the three sites (Figure 11B).

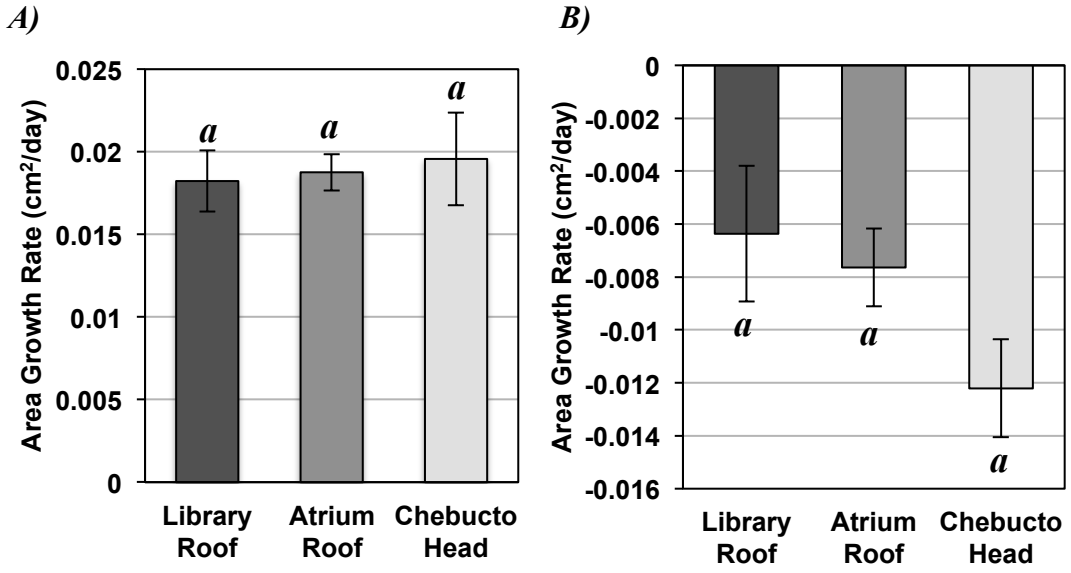

Figure 9. (A) Mean leaf area growth rates calculated from May 21, 2015 to maximum height recorded and (B) mean leaf area reduction rates calculated from the maximum leaf area recorded for that individual to October 23, 2015 for for ***P. maritima*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different.

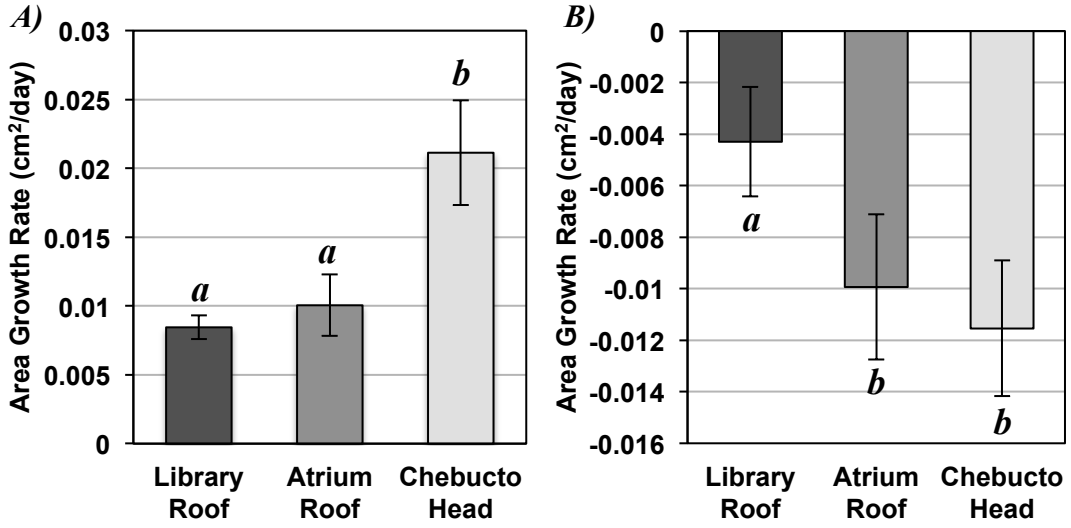

Figure 10. (A) Mean leaf area growth rates calculated from May 21, 2015 to maximum height recorded and (B) mean leaf area reduction rates calculated from the maximum leaf area recorded for that individual to October 23, 2015 for ***S. tridentata*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different.

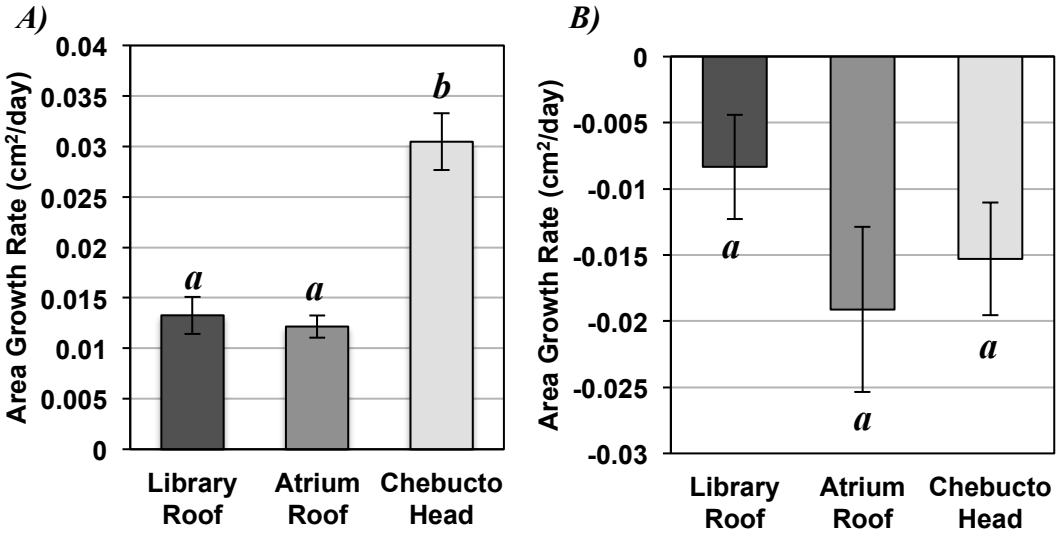

Figure 11. (A) Mean leaf area growth rates calculated from May 21, 2015 to maximum height recorded and (B) mean leaf area reduction rates calculated from the maximum leaf area recorded for that individual to October 23, 2015 for ***S. bicolor*** plants located at two different green roof sites and Chebucto Head coastal barrens site from May 21, 2015 to October 23, 2015. For each graph, bars that share a letter are not significantly different.

A One-Way ANOVA test showed no significant difference between the three sites in regard to the means of positive growth rate of *R. rosea* stems (Figure 12A). However a significant difference was found for negative growth rates of *R. rosea* using a Kruskal-Wallis Test (P=0.010). Using Mann-Whitney Tests it was determined that the Atrium green roof negative growth rate was significantly larger then the Library green roof and Chebucto Head growth rates (Figure 12B).

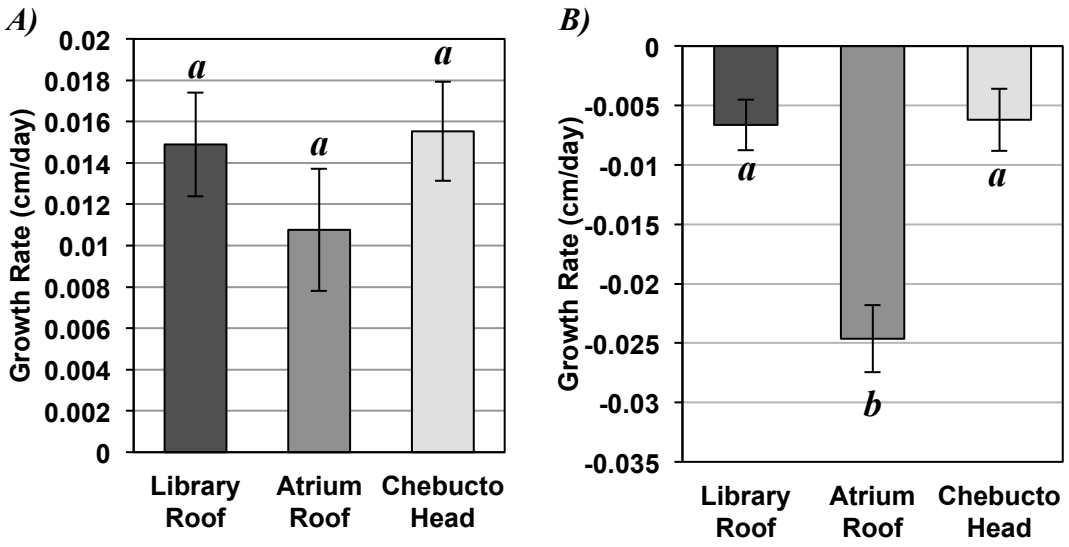

Figure 12. (A) Mean positive growth rate of the largest ***R. rosea*** stem per plant calculated from May 21, 2015 to maximum height recorded and (B) mean negative growth rate of the largest ***R. rosea*** stem per plant calculated from maximum height to September 25, 2015 at two different green roof sites and Chebucto Head coastal barrens site. For each graph, bars that share a letter are not significantly different.

3.1.5: Aphid Pest Presence

The number of aphids was significantly higher on plants established on the green roofs in comparison to the native environment, the coastal barrens. Aphids were found on

all species examined, however only aphids present on *R. rosea* and *S. tridentata* replicates were analyzed. The number of aphids recorded on the other species, *S. bicolor* and *P. maritima* was very low at all sites. However, it is important to note that the few aphids recorded on *S. bicolor* and *P. maritima* plants were only found on plants established on the green roofs.

The total number of aphids recorded on *R. rosea* differed significantly among sites (Figure 13A; R-sq(adj)=53.64%; P<0.000). The Kruskal-Wallis Test also conducted on this data due to lack of normality resulted in a P-value of <0.000. Maximum aphid counts also differed in the same way among the three sites (Figure 13B; R-sq(adj)=53.64%; P<0.000). A Kruskal-Wallis Test exhibited similar P-value as well (P<0.000).

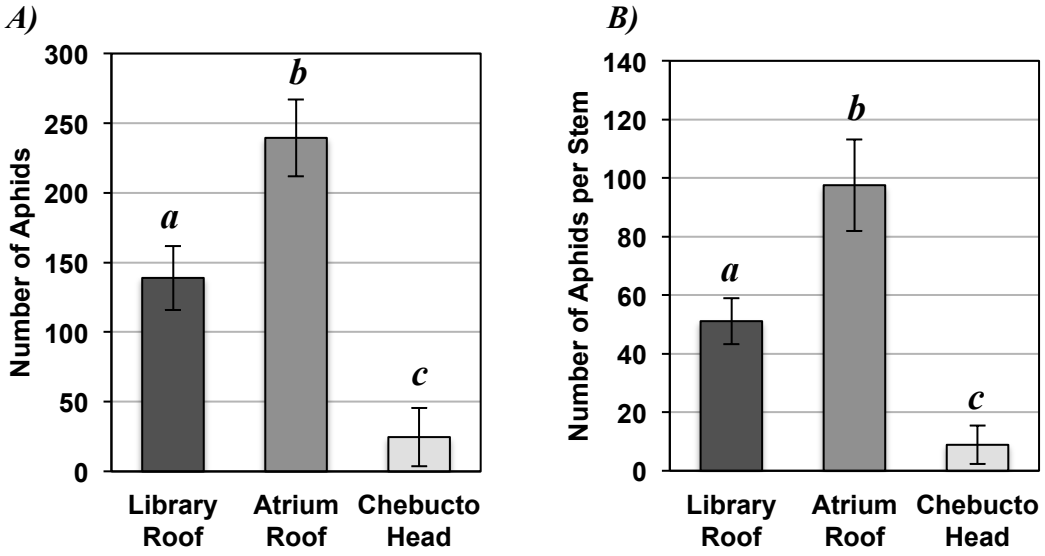

Figure 13. (A) Mean summation of aphid counts over the growing season and (B) mean maximum number of aphids recorded on a single stem of *R. rosea* from May 21, 2015 to October 7, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. For each graph, bars that share a letter are not significantly different.

From May 21, 2015 to October 7, 2015 the number of aphids present on one stem of a *R. rosea* plant differed among sites (Figure 14). The Atrium green roof had two large peaks on the dates of June 17, 2015 and September 11, 2015. Following these peaks there was a substantial decrease in aphid counts directly after. For both instances, observations were made of increased presence of Coccinellidae adults and larvae the green roof. Syrphidae larvae were also observed following the June 17, 2015 peak. The Library green roof *R. rosea* had only one peak of aphid count on July 15th and then slowly decreased as the growing season progressed. Chebucto Head plants had the least number of aphids and no distinct peak of aphid counts were observed.

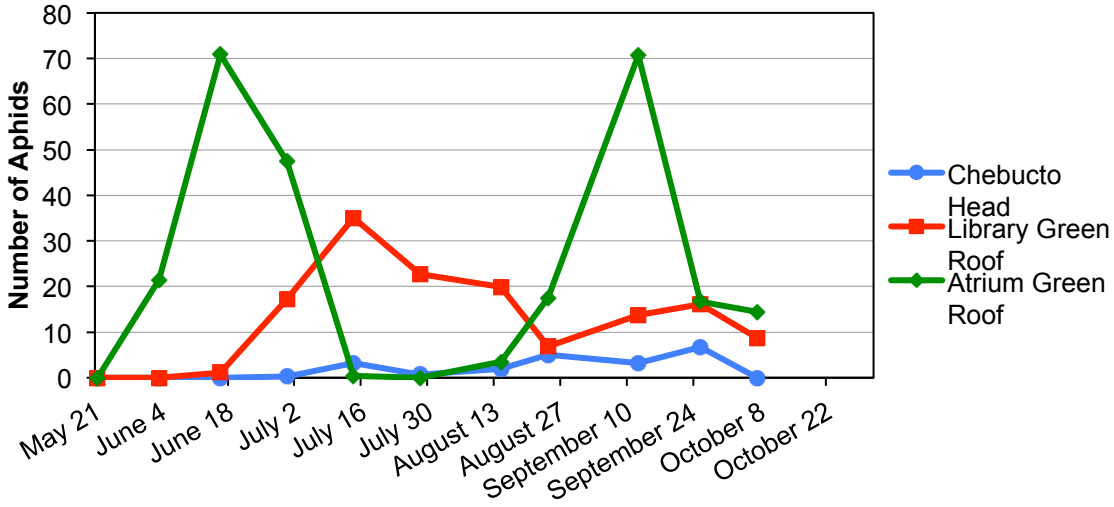

Figure 14: Mean number of aphids on one stem per *R. rosea* plant over the duration of May 21, 2015 to October 7, 2015 located at two different green roof sites and Chebucto Head coastal barrens site.

A One-way ANOVA test showed a significant difference between the means of summed aphid counts on *S. tridentata* plants over the growing season (R-sq(adj)=52.50%; P<0.000). Similarly, a One-way ANOVA test detected a significant difference in the

maximum count of aphids record on *S. tridentata* plants (R-sq(adj)=46.76%; P<0.000). The Library green roof had significantly more aphids in regard to both maximum counts and summation over the growing season in comparison to the Atrium green roof and Chebucto Head (Figure 15). Due to the large variance in standard deviations of the data for both sets of data, a Kruskal-Wallis Test was also conducted. The result was a P-value less the 0.000 for both total abundance and maximum aphid counts.

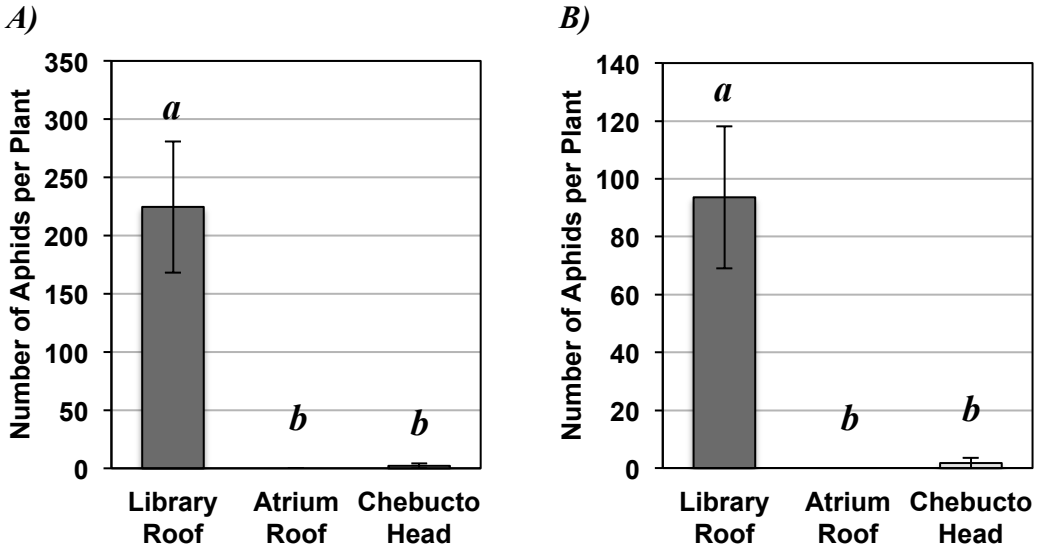

Figure 15. (A) Mean summation and (B) mean maximum count of aphids per *S. tridentata* plant recorded from May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. For each graph, bars that share a letter are not significantly different.

3.1.6: Rust Pest Presence

Orange rust was found only on *S. bicolor* species. The rust was present at all sites examined however the severity of infection varied significantly. The Library green roof had significantly larger means for maximum percent coverage of rust on the most infected

leaf in comparison to the other two sites (Figure 16A; R-sq(adj)=45.06%; P<0.000). Due to the lack of normality a Kruskal-Wallis Test was also conducted and resulted in a p-value of <0.000. The total of rust percent cover over the growing season was significantly larger on the Library green roof compared to the other two sites (R-sq(adj)=42.02%; P<0.000). A Kruskal-Wallis Test was also performed because One-Way ANOVA assumptions were not met (p value <0.000).

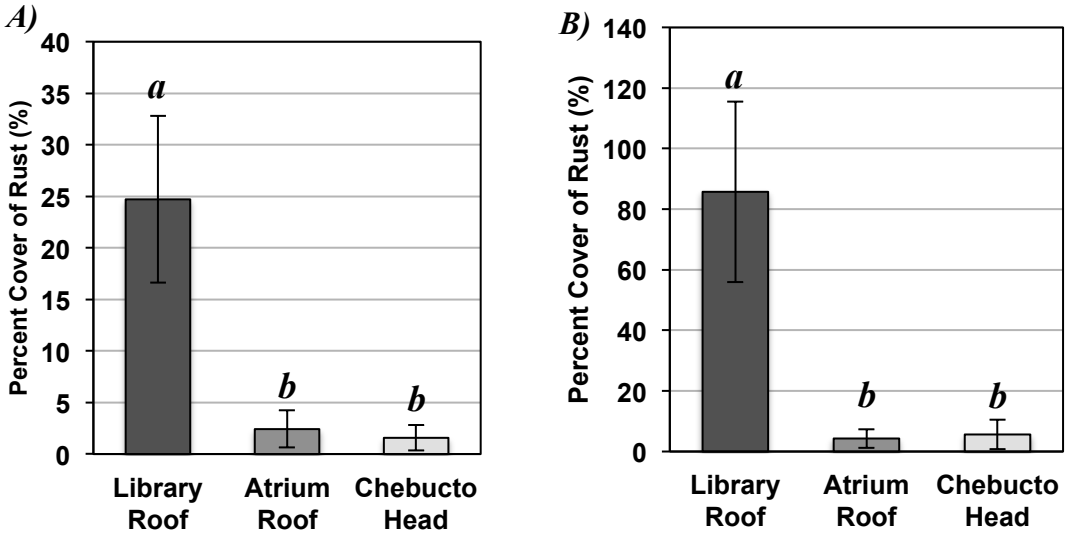

Figure 16. (A) Mean maximum rust percent cover on most infected leaf and (B) mean summation of rust percent cover on *S. bicolor* recorded from May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. For each graph, bars that share a letter are not significantly different

Over the duration of the experiment (May 21, 2015 to October 23, 2015) a rust percentage cover values began to increase near the end of the growing season (Figure 17). The Library green roof had substantial more rust in comparison to the other two sites. The Atrium green roof and Chebucto Head exhibited a similar trend.

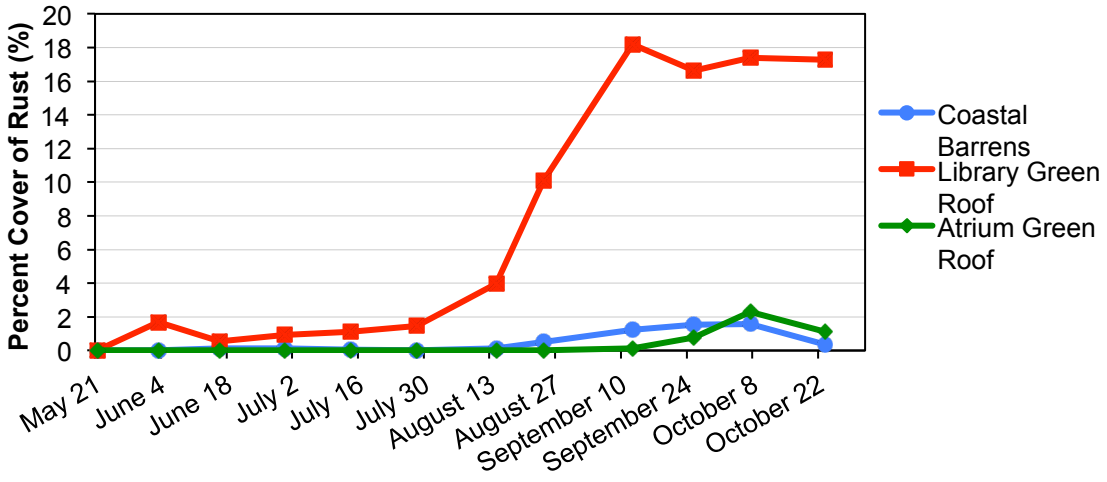

Figure 17. Mean bi-weekly percent coverage of rust on the most infected *S. bicolor* leaves located at two different green roof sites and Chebucto Head coastal barrens site, for the duration of May 21, 2015 to October 23, 2015.

3.1.7: Soil Depth

Plants species were established in similar soil depths on the green roofs (Table 4). The Library green roof had substrate on average larger then Atrium green roof for all species. Chebucto Head soil depths varied between each species with both *P. maritima* and *R. rosea* growing in very shallow soils compared with the green roof settings. In some cases a substrate depth of zero was assigned since the plants were established in narrow cracks in the bedrock and accurate depths could not be measured. The results of One-Way ANOVA tests and Kruskal-walis tests used to determine significant differences in soil depths between each species are listed in table 4.

Table 4. Average soil depth measured in centimeters directly below the plant replicates at two different green roof sites and Chebucto Head coastal barrens site. Cells with the same letter are not significantly different between sites. One-Way ANOVA tests and Tukey Pairwise Comparison tests were used to calculate significant differences for plant species *P. maritima*, *R. rosea* and *S. bicolor*. Kruskal-walis test was used for the plant species *S. tridentata.*

Species	Library Roof (cm.)	Atrium Roof (cm.)	Chebucto Head (cm.)	R-sq (adj)	p-value
P. maritima	**A** 11.05 ± 0.12	**B** 7.82 ± 0.30	**C** 3.61 ± 0.74	71.62%	0.000
S. tridentata	**A** 10.85 ± 0.16	**B** 6.99 ± 0.26	**AB** 10.21 ± 1.57	N/A	0.024
R. rosea	**A** 11.33 ± 0.27	**A** 9.98 ± 0.23	**B** 3.48 ± 0.53	86.48%	0.000
S. bicolor	**A** 10.6 ± 0.14	**B** 7.35 ± 0.31	**C** 14.53 ± 1.04	54.31%	0.000

3.1: Part II: Salt Spray and the Reduction of Pest Presence

A Two-Sample T-test showed individuals treated with salt-water spray equivalent to ocean spray had a decreased maximum number of aphid counts per stem of *R. rosea* (P=0.042) (Figure 18A). However the summed abundance of aphids over the whole season was not statistically significant between treatments (P=0.053) (Figure 18B). No significant differences were found when analyzing aphid counts before or after the increase in concentration on July 29, 2015.

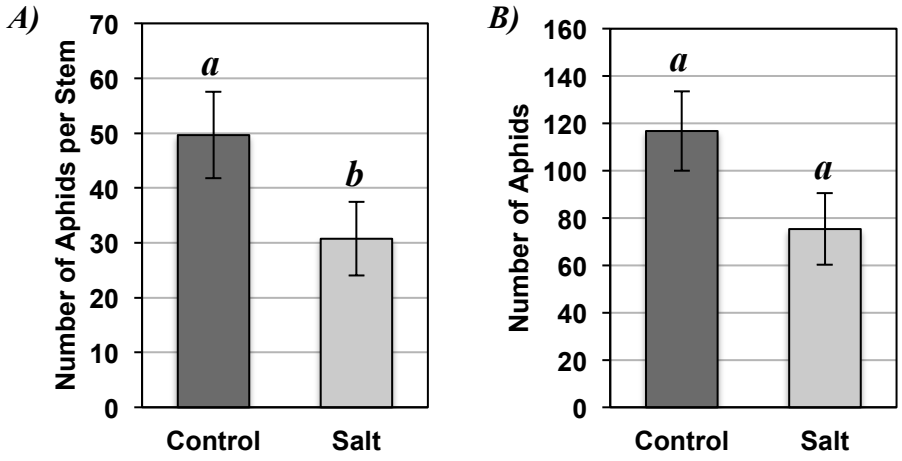

Figure 18. (A) Mean maximum number of aphids and (B) mean summation of aphid counts per stem of *R. rosea* plants present on the salt-sprayed treatment and controls recorded from May 21, 2015 to October 7, 2015. For each graph, bars that share a letter are not significantly different.

For *S. tridentata* the salt treatments had no impact on aphid counts (Figure 19). A Two-Sample T-test showed no significant difference in the ability of the lower concentration salt to the decrease aphid presence on *S. tridentata*. The mean for both maximum count and summation over the growing season were actually larger for the salt treatments. No significant differences were found when analyzing aphid counts before or after the increase in concentration on July 29, 2015.

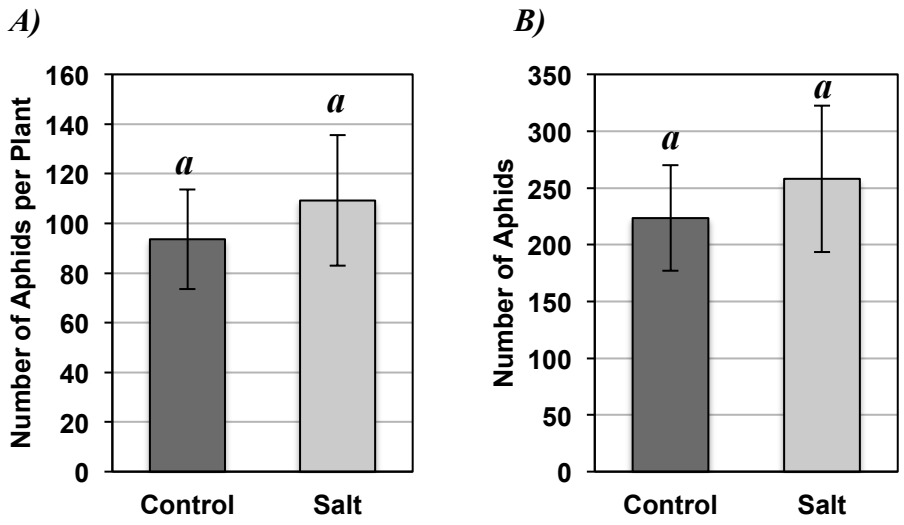

Figure 19. (A) Mean maximum number of aphids and (B) mean summation of aphid counts per plant of on *S. tridentata* present on the salt-sprayed treatments and controls recorded from May 21, 2015 to October 7, 2015. For each graph, bars that share a letter are not significantly different.

Two-Sample T-tests presented no significant ability of salt spray to decrease percent cover of rust on *S. bicolor* leaves (Figure 20). However the means for both maximum and summation of percent cover was found to be lower for salt spray treatment. No significant differences were found when analyzing rust percent cover before or after the increase in concentration on July 29, 2015.

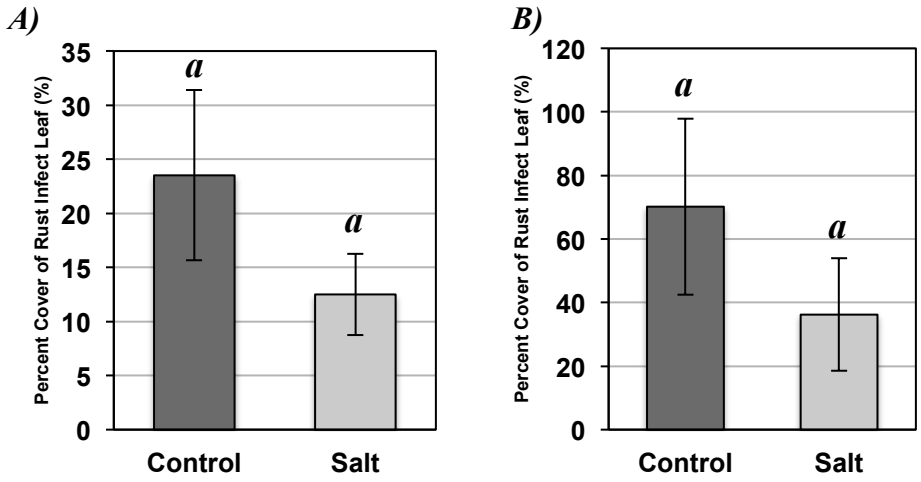

Figure 20. Mean maximum rust percent cover on most infected leaf and (B) mean summation of rust percent cover on *S. bicolor* on salt-sprayed treatments and controls recorded from May 21, 2015 to October 7, 2015. For each graph, bars that share a letter are not significantly different.

4: Discussion

4.1: Part 1: Plant Performance of Native Barren Species in Green Roof Ecosystems

4.1.1: Plant Size

Results indicated growth for all four species was not inhibited when grown in a green roof ecosystem compared to the plant species' native environment, the coastal barrens. For almost all variables of growth, the Library green roof and the Atrium green roof plants were significantly larger or displayed no significant difference in comparison to Chebucto Head. For both species *S. bicolor* and *P. maritima* the Library green roof had significantly larger leaf area and number of leaves compared to the coastal barrens site. *R. rosea* had significantly larger stems on both of the green roofs as well compared to the coastal barrens.

The Atrium green roof was statistically similar to the coastal barrens site in growth in general. For species *S. bicolor, S. tridentata* and *P. maritima* no significant difference was found between the Atrium green roof and Chebucto Head in regard to the length of leaves and number of leaves. For every measured variable of growth of *S. tridentata* there was no significant difference found between any of the sites. Similar, stem count for *R. rosea* exhibited no significant difference between the three sites.

The lack of competition for resources needs to be considered as a confounding variable for species *S. bicolor, P. maritima* and*, S. tridentata*, in regards to plant size. The replicates established at the other two sites experienced intraspecific and interspecific competition (Table 1). Therefore, the larger size of the plants on the Library green roof could have been influenced by the lower levels of competition for resources between individuals and not directly connected to the different environmental conditions. However, *R. rosea* on the Library green roof and all species on the Atrium green roof and Chebucto Head can be compared confidently.

The overall trend of the results indicated the Library green roof was able to support larger plants in comparison to the Atrium green roof and Chebucto Head. Interestingly, in general the assumed more environmentally harsh Atrium green roof in terms of plant size was very similar to the coastal barrens with only two exceptions such as the height of *R. rosea* and the area of *S. bicolor* leaves. The ability of these plants grown in a novel green roof ecosystem to be comparable in size or larger then plants established the native environment supports the habitat template approach proposed by Lundholm (2006) for plant selection. For *R. rosea* and *P. maritima*, the substrate depth data suggest one possible reason for larger plants in the green roof environment: the

native environment for these species has lower average soil depths, so the deeper substrate could have allowed plants to grow larger. However, we cannot be sure that the difficulties in measuring substrate depth in rocky environment did not yield underestimates of the amount of soil actually available for plants in the barrens. The green roof substrates are largely homogeneous and free of large rocks. This study at least indicates that these plant species can survive in the green roof ecosystem and are not negatively impacted by the harsh associated environmental stresses. This is important when constructing green roofs in order to support habitat provisioning and increasing diversity in urban areas, as vegetation cover and plant diversity is strongly connected to the ability of green roofs to provide these ecosystem functions (MacIvor et al., 2011; Cook-Patton & Bauerle, 2012; Madre et al., 2013).

4.1.2: Plant Growth Rates

Overall, there was a large variation in terms of how the three sites impacted growth rates of the four species. However in general the trend for positive growth rate was highest at the Chebucto Head. Both *S. tridentata* and *S. bicolor* plants exhibited significantly larger growth rate at the Chebucto Head. No significant difference was detected for *R. rosea* and *P. maritima* but the growth rate on average was larger than at the two green roof sites. This larger growth rate experienced at the coastal barrens may be in association with the growing season starting later than the green roofs sites. The earlier growing season may have lead to an underestimation of growth rates for plants examined on the green roofs, as some growth may have occurred before the initial size measurements. The initial plant size recordings were the smallest at Chebucto Head compared to other sites. This was not tested for significance but with each species

displaying this similar trait it strengthens the notion of a later start of the growing season at the coastal barrens. Another factor that should be mentioned is the abnormally harsh and long winter Nova Scotia experienced prior to the 2015 growing season. This potentially had a significant impact on the observed later growing season recorded at all three sites.

The more sheltered Library green roof had an extended growing season and was expressed by a lower negative growth rate as plant size declined from summer to fall (Figure 21, 22 & 23). However, only one species*, S. tridentata* showed a significant difference (Figure 22). Extending the data collection a month longer may have strengthened these results and a significant difference may have been detected for *P. maritima* and *S. bicolor* but due to time restrictions this was not possible. *R. rosea*'s earlier growing season allowed for observations of plant growth to be recorded over the entire 2015 season. The Atrium green roof replicates experienced a statistically significant reduction in height compared to the other two sites (Figure 24). This may have been the consequence of the high density of aphids present during this period or the harsher environmental conditions (Figure 14).

The lack of a significant difference between negative growth rate for species *P. maritima, S. tridentata* and *S. bicolor* plants established on the Atrium green roof and the coastal barrens coincides with the data observed for plant size. This further strengthens the previous conclusion that the Atrium green roof is similar to Chebucto Head in terms of its ability to support coastal barrens species.

Overall the species' growth rates observed in this study imply that plants grown on the green roofs may have similar or longer growing seasons than in these species'

native habitat. Suggesting that the green roofs in this study may be a less severe environment. This could be in association to the lack of coastal effects and the presence of the urban heat island effect, which could allow from warmer temperatures resulting in an earlier growing season. This coupled with the previous discussed results of plant size signifies the green roofs constructed to mimic coastal barrens ecosystems may be possible and support equal or greater vegetation growth and an increased growing season. Plants present on the green roof increase the functionality of a green roof (MacIvor et al., 2011). Therefore, an increased growing season is substantially important.

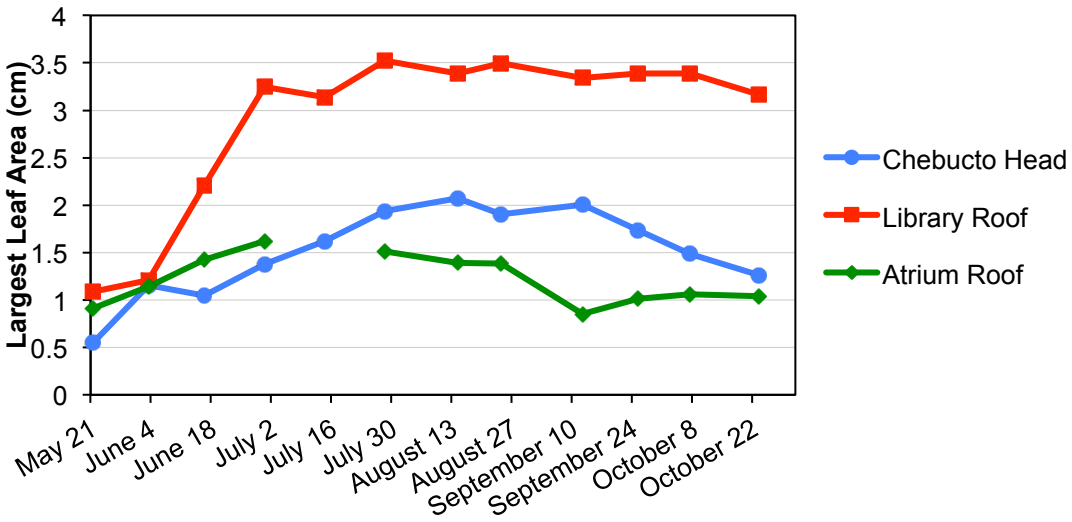

Figure 21. Mean leaf area of largest leaf (length *x* width) of *P. maritima* plants over the duration of May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site.

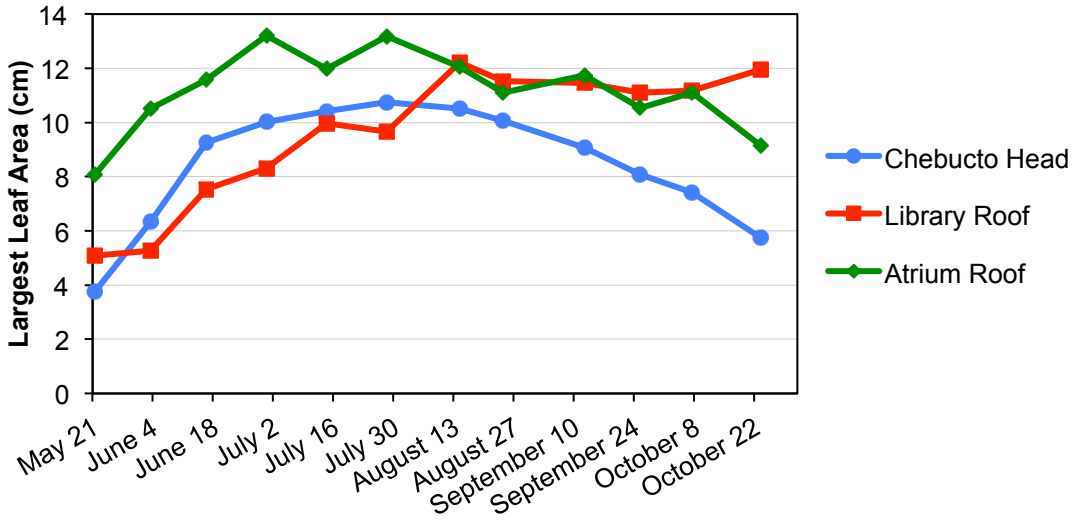

Figure 22. Mean leaf area of largest leaf (length *x* width) of *S. tridentata* plants over the duration of May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. The mean positive leaf area growth rate of Chebucto Head individuals was significantly larger then the other two sites. Post maximum leaf size the Library green roof had significantly smaller reduction in leaf size compared to the other sites

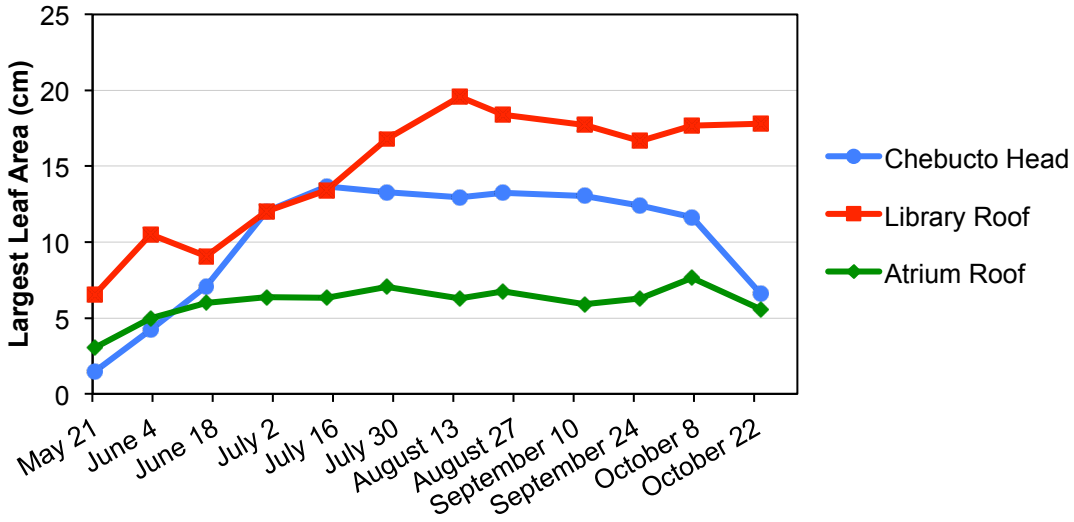

Figure 23. Mean leaf area of largest leaf (length *x* width) of *S. bicolor* plants over the duration of May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. The mean positive leaf area growth rate of Chebucto Head individuals was significantly larger then the other two sites.

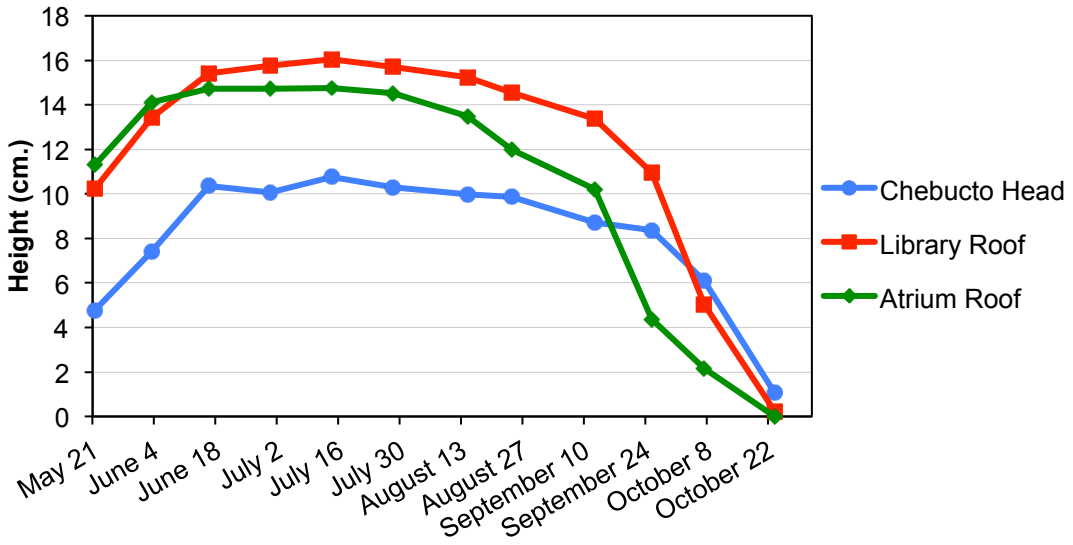

Figure 24. Mean height of largest stem of *R. rosea* plants over the duration of May 21, 2015 to October 23, 2015 located at two different green roof sites and Chebucto Head coastal barrens site. Post maximum height the Atrium green roof had significantly larger reduction in steam size compared to the other sites.

4.1.3: Pest Presence

For all species impacted by pests the Library green roof replicates had significantly larger pest presence compared to the coastal barrens habitat as seen in Figures 13, 15 and16. However, pests associated with *S. bicolor* and *S. tridentata* on the Atrium green roof were not significantly different than at the coastal barrens. Due to the close proximity and frequent exchange of modules between the two roofs prior to the 2015 growing season it was predicted that both roofs would be significantly higher in pest abundance than the coastal barren site. These results were not observed. For rust and aphids the difference may have been the consequence of the predicted more intense solar radiation and wind speed on the Atrium green roof since the Library green roof is more

sheltered by surrounding buildings. The elevation of the 4-story Atrium green roof may have been a factor that could have reduced the ability of aphids to reach and utilize the vegetation on the roof. This was observed in Quispe and Fenoglio, (2015) study where a lower abundance of a different insect herbivore (leaf-miner, *Liriomyza commelinae*) was found on the green roofs compared to ground level. The Library green roof is only one story above ground level therefore it would have been more accessible to aphid colonization.

Contrary to observed results for aphids on *S. tridentata* replicates, the Atrium replicates for *R. rosea* had significantly larger quantities of aphids in terms of both maximum count and abundance than any other site (Figure 13). It is puzzling as to why this may be the case. MacIvor & Ksiazek (2015) notes aphids can be transported by wind due to their small size. This may have been a factor for the increased presence of aphids on *R. rosea* on the Atrium roof compared to the Library roof but why was this not the case for *S. tridentata*? Theoretically larger plants can support greater densities of aphids but a significant difference in plant heights was not observed between the two roofs. As well aphids were commonly observed in high densities only utilizing the new growth of *R. rosea* so height should not have been a factor. Time limitations prevented identification of the aphid species observed on the plant host species. However, when the aphids were collected for later identification they were separated based on color and other morphological features. It was noted that similar species were found on both *R. rosea* and *S. tridentata.* However, on *R. rosea* two differently colored aphids were observed (yellowish green and bluish green), suggesting multiple species of aphids may have been present on *R. rosea* plants. On *S. tridentata* replicates, only bluish green aphids were

observed. Differentiating the aphids based on these features suggests different aphid species may have been found on the different host plant species. This may have ultimately lead to the differences observed in aphid quantities between the two different plant species on the same green roof site. It would be beneficial to determine if the aphids found were different species as host specificity occurs within the Aphididae family and this may have played a role in the observed outcome (Powell et al., 2006).

The presence of aphids on green roofs can create both positive and negative consequences (MacIvor & Ksiazek, 2015). Plant growth and survival may be negatively impacted by the presence of aphids (MacIvor & Ksiazek, 2015). This was observed on June 20, 2015 where a *R. rosea* stem on the Atrium green roof was recorded as having 300-400 aphids on a single stem and the following data collection week the stem was dead. The high presence of aphids may have also influence significantly larger rate of die off experienced by Atrium *R. rosea* individuals. However despite the high presence of aphids on the Atrium green roof *R. rosea* replicates, the plants still had significantly larger height compared to the Chebucto Head individuals which had fewer aphids. Similar to the observations made by other studies, ladybird beetles in both life stages were present on both roofs (Kadas, 2006; Martin & Hinckley 2007; Coffman & Waite, 2011; MacIvor & Ksiazek, 2015). These predators first appeared when aphids were in large quantities on *R. rosea* plants established on the Atrium green roof. Syrphidae larvae was also observed consuming aphids during this time period. These observations were made when the aphid populations were at the top of the first peak shown in Figure 14. Following the initial observation of these beneficial insects the aphid populations began to decrease. This may imply that the presence of aphids may also play an important role

by providing a food resource for higher trophic level species, increasing diversity of insects on green roofs by supporting predatory insects. More research is needed to determine the extent of the negative impact these aphids on *R. rosea* have on plant performance.

4.1.4: Environmental Variables and Limitations of the Study

The observational nature of this study limits our ability to make firm conclusions and the direct causes of the relationships observed are left to speculations and assumptions. Further research monitoring the different environments may further strengthen these speculations. Monitoring wind speeds, temperature, soil moisture, and solar radiation would be beneficial in determining how environmentally different the sites are. Soil depth was the only environmental variable quantified in this study (Table 1). The data suggested in terms of soil depth Chebucto Head was more environmentally harsh for species for species *R. rosea* and *P. maritima* compared to the other two green roof sites. However, for *S. tridentata* the coastal barren site was similar to the green roofs. *S. bicolor* replicates on the coastal barrens were established in deeper substrate than the green roof sites. Previous research has suggested that the air temperature at Chebucto Head during the summer is cooler then the Library green roof (Ranalli, 2009). It was shown that from July to October 2007, Chebucto Head had a mean air temperature of 15.7°C with a range of 3.6 -30.8°C and the Library green roof had a mean air temperature of 17.7°C with a range 5.0 -34.4°C (Ranalli, 2009). Both of theses variables should be taken into consideration when examining the growth aspects of the four species at the different sites.

4.2: Part II: Salt Spray and the Reduction of Pest Presence

Both the coastal barrens and green roofs environments express similar substrate depths and exposure to wind (Lundholm, 2006). However due to the distance from the ocean salt spray exposure from the ocean is not evident on the green roof systems studied here. This study suggests that ocean salt spray may not be a driving force for the observed reduction of the presence of pests on native plant species in the salt spray zone. Only *R. rosea* salt treated replicates had significantly lower aphid numbers (Figure 18). These values were still considerably larger then what was observed at Chebucto Head (Figure 13). Rust on *S. bicolor* was less on salt treated plants however this was not significantly different (Figure 20). Aphid presence on *S. tridentata* was not significantly different between the treatments and was actually greater on salt treated replicates.

Evidence in Part I shows the lack of aphid presence on *S. tridentata* at the coastal barrens yet the salt treatments with similar salt exposure showed no impact on aphid counts on the green roofs. This suggests another factor is present in reducing the presence of aphids in the native environment. Natural ecosystems are naturally self-regulating and a possible higher diversity of predatory insects result in control of pest species populations (Altieri, 1999; Hunter & Hunter, 2008). Since the green roof is an environment isolated from natural habitats that contains novel features, the level of predation may be lower in comparison. Quispe and Fenoglio (2015) study on parasitism on green roofs suggests this. It is possible that predation is the driving factor in the reduction of pests in the barrens.

5: Conclusion

This study is one of the first studies to document and compare the growth performance and pest presences on native plant species between two environmentally different green roofs and the plants' native ecosystem. The results of this study suggest that green roofs may be able to support similar plant sizes as in their native environment, the coastal barrens. These results support the habitat template approach of selecting similar environments to green roofs for plant selection (Lundholm, 2006). However, these plants may become more susceptible to pest damage due to the increased presence of pests in the novel green roof ecosystem. The presence of these pests can also be considered beneficial for increasing diversity by supplying a food source for predators (MacIvor & Ksiazek, 2015). It was thought a possible reason of elevated pest presence was from the reduction of salt spray exposure however results in Part II suggest this may not be the case.

When developing green roofs for the use of diversity conservation goals, it is unknown what extent green roofs can provide this service due to the lack of scientific research (Bates et al., 2013; Williams et al., 2014). This study supports the notion that green roofs may be able to increase plant species diversity in urban areas with green roofs designed to mimic the coastal barrens. Other research has also expressed the ability of green roofs to support adjacent similar ground level diversity. However, research has indicated these communities may differ in composition and abundance (Colla et al., 2009; McGuire et al., 2013; Molineux et al., 2015). More information is still needed to determine what impact increasing green roofs in urban areas will have on mediating the loss of green space in association to increased urbanization (Berndtsson, 2010; Bates et

al., 2013; Williams et al., 2014). Green roofs are known to provide key ecosystem services in urban areas such as storm water management, increased insulation, and reduction of urban heat island effect yet the biodiversity potential of green roofs is still relatively unknown.

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