Suitability of Canadian-bred and Native Plant Species for Extensive Green Roofs in Northern Nova Scotia

by

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My Wife, My Mother, My Father: For all of the support. For believing in me.

Nil Magnum Nisi Bonum

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Abstract

Research was conducted to determine individual suitability of native and Canadian-bred selected plants in terms of growth and survivability for local extensive green roofs. The experiment was single-factor (species) with 12 levels (two Sedum spp. [controls]; 10 Canadian-bred or native plant species) in a randomized complete block design with three blocks. Variables measured were percent survival and cover, height, fresh and dry weights, stomatal conductance, transpiration, photosynthetic rate, soil temperature, soil moisture, and reflectance. *Artemisia stelleriana* contributed more to cooling through transpiration than *Sedum floriferum*, and maintained similar soil moisture to *Sedum acre. Lotus corniculatus* was similar to the controls in photosynthetic rate and had higher reflectance than *Sedum acre* in July. With high biomass and photosynthetic rates, *Aster novi-belgii* may contribute more to carbon sequestration and insulation than the controls. *Artemisia stelleriana , Lotus corniculatus*, and *Aster novi-belgii* are suitable species for extensive green roofs in northern Nova Scotia.

List of Abbreviations Used

DAQ	Data Acquisition Device
ºC	degrees Celsius
%	percent
µ	micro
m	milli
mols	moles
cm	centimetres
g	grams
nm	nanometres
LSD	least significant difference
HSD	honestly significant difference
SEM	standard error of the means
Anaphalis	*Anaphalis margaritacea* (L.) Benth.
Arabis	*Arabis sturii* Mottet.
Antennaria	*Antennaria dioica* (L.) Gaertn.
Artemisia	*Artemisia stelleriana* Besser.
Aster	*Aster novi-belgii* L.
Coreopsis	*Coreopsis verticillata* Zagreb.
Echinacea	*Echinacea purpurea* (L.) Moench.
Fragaria	*Fragaria virginiana* Duchesne.
Lotus	*Lotus corniculatus* L.
Monarda	*Monarda punctata* L.
Sedum a.	*Sedum acre* L.
Sedum f.	*Sedum floriferum* L.

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Chapter 1 Introduction

A green roof is a roofing surface covered with substrate and vegetation. There are two main types of green roofs: extensive and intensive. Extensive green roofs are typically comprised of less than 15 cm of growing substrate and planted with low growing perennials. Extensive green roofs can be conventional (planted in place) or modular (comprised of portable modules which fit together to create seamed or seamless roof coverage). Intensive green roofs are comprised of greater than 15 cm of growing substrate, and are generally planted with small trees and shrubs (Kosareo and Ries, 2006). The roof often requires additional support other than that originally allocated during building construction, while extensive green roofs usually do not require additional support and can be retro-fitted to existing roofs (Getter et al., 2009b; Tabares-Velasco, 2009).

Liu and Minor (2005) found that green roofs lowered the energy demand of buildings, reduced storm water runoff, and increased building material longevity by way of easing thermal, ultraviolet and physical stresses. Eumorfopoulou and Aravantinos (1998) reported that green roofs provided insulation to buildings and thus functioned to reduce energy expenditure. Due to evapotranspiration, and the relatively high albedo of vegetation (as opposed to the high absorptive values of the typical urban materials such as concrete and asphalt), the greater the incidence of green roofs, the lower the potential Urban Heat Island Effect (Wolf and Lundholm, 2008). Green roofs can also provide sanctuary for birds and insects, creating intensive ecosystems within urban areas.

Carter and Fowler (2008) noted that green roof incidence and research in North America has increased over the last decade in response to environmental issues. The *Sedum* species used as industry standards for green roofing, *S. album* and *S. acre,* which are native to Europe, were evaluated as green roof plants in Germany and have been used throughout the world. Monterusso et al. (2005) addressed the issue of climatic differences within North America in relation to green roofs by suggesting that an understanding of plant species suitable to green roofs within the wide range of climatic conditions on the continent must be amassed through green roof research specific to climatic locations. Wolf and Lundholm (2008) reported that there was increased consideration given to native plant species as preferable to the standard *Sedum* spp. as they were thought to increase biodiversity of native bird and insect taxa.

As the demand for green roof technology and knowledge increases, so also do the opportunities for local growers. Research into suitable green roof plants for the local modified continental climate of northern Nova Scotia with cold winters and warm summers (Dzikowski, 1985) is necessary to provide valuable plant species survival thresholds in order that a local industry standard of plant options may be defined for growers to successfully penetrate the green roof market.

The project was an initiative of The Canadian Horticulture Research and Innovation Cluster, was funded by Agriculture and Agri-Food Canada, and was administered by Vineland Research and Innovation Centre, Vineland, ON. The objective of this study is to determine individual suitability of native and Canadian-bred selected plants in terms of growth and survivability for local green roofs.

Chapter 2 Literature Review

Green Roof Types

Green roofs consist of a variety of types of vegetation, in different systematic designs, and can be categorized as either "intensive" or "extensive". Intensive green roofs can support plants with large root systems, namely shrubs and trees, and therefore require growing substrate of a depth of 30 cm to 1 m (Cavanaugh, 2008). Intensive green roofs often require more structural support than is typically provided on an existing edifice, and are less economical and eco-friendly than extensive green roofs (U.S. Dept. of Energy, 2004). Extensive green roofs are comprised of substrate less than 15 cm deep that best accommodates low-growing species. Extensive green roofs can be planted in place (conventional) or they can be started elsewhere and brought to the roof after plant establishment (container or modular) (Oberndorfer et al., 2007).

Green Roof Composition

Extensive green roofs are designed to function based on a seven-layer model which encompasses: a platform upon which to build, insulation, a water barrier, protection (which serves to prevent roof damage from roots), drainage, filtration, and a growing substrate layer (Snodgrass and Snodgrass, 2006). The base platform generally consists of metal roof decking which requires little maintenance (Kosareo and Ries, 2006), but can also be comprised of concrete, wood, or plastic, each of which have varying degrees of lifespan and additional structural requirements (Snodgrass and Snodgrass, 2006). The insulation layer is usually polystyrene [(C_8H_8) n] of 85 mm thickness (Kosareo and Ries, 2006) and can be installed below or above the waterproof layer (Snodgrass and Snodgrass, 2006). The water barrier and protective layer (root barrier) are often combined as a single unit (Oberndorfer et al., 2007), while the drainage layer can be comprised of granular constituents (which are heavy and affect load-bearing requirements) or geo-textile drain cores (which are lighter and are available in rolls for easy application) (Luckett, 2009). The filter layer is necessary to contain the substrate while allowing water and air to pass through, and is crucial for preventing build-up of debris in the drainage layer (Greenroofs.com, 2011). The substrate layer, which is comprised of the growing medium for the plants, differs from intensive to extensive roofs. As intensive roofs are deep, support large plant species with considerable root systems (Cavanaugh, 2008), and often require pre-planned load consideration (Tabares-Velasco, 2009), soil media therein resemble rich soils with high organic content. Extensive green roofs contain 75-90% inorganic soil substrate (Beattie and Berghage, 2004) and may include mixtures of expanded shale, clay and slate, volcanic stone, and sand (Snodgrass and Snodgrass, 2006).

Conventional green roofs are constructed using the seven-layer structures in place in a piecewise fashion as a complete system (intensive and extensive), in a combination of piecewise construction of platform and insulation topped with rolled-out units containing the remaining layers (extensive), or as modular extensive roofs wherein the modules are self-contained units comprised of integral seven-layer systems (Oberndorfer et al., 2007). Fig.1 shows an example of the components of an extensive green roof module (LiveRoof®, 2011b).

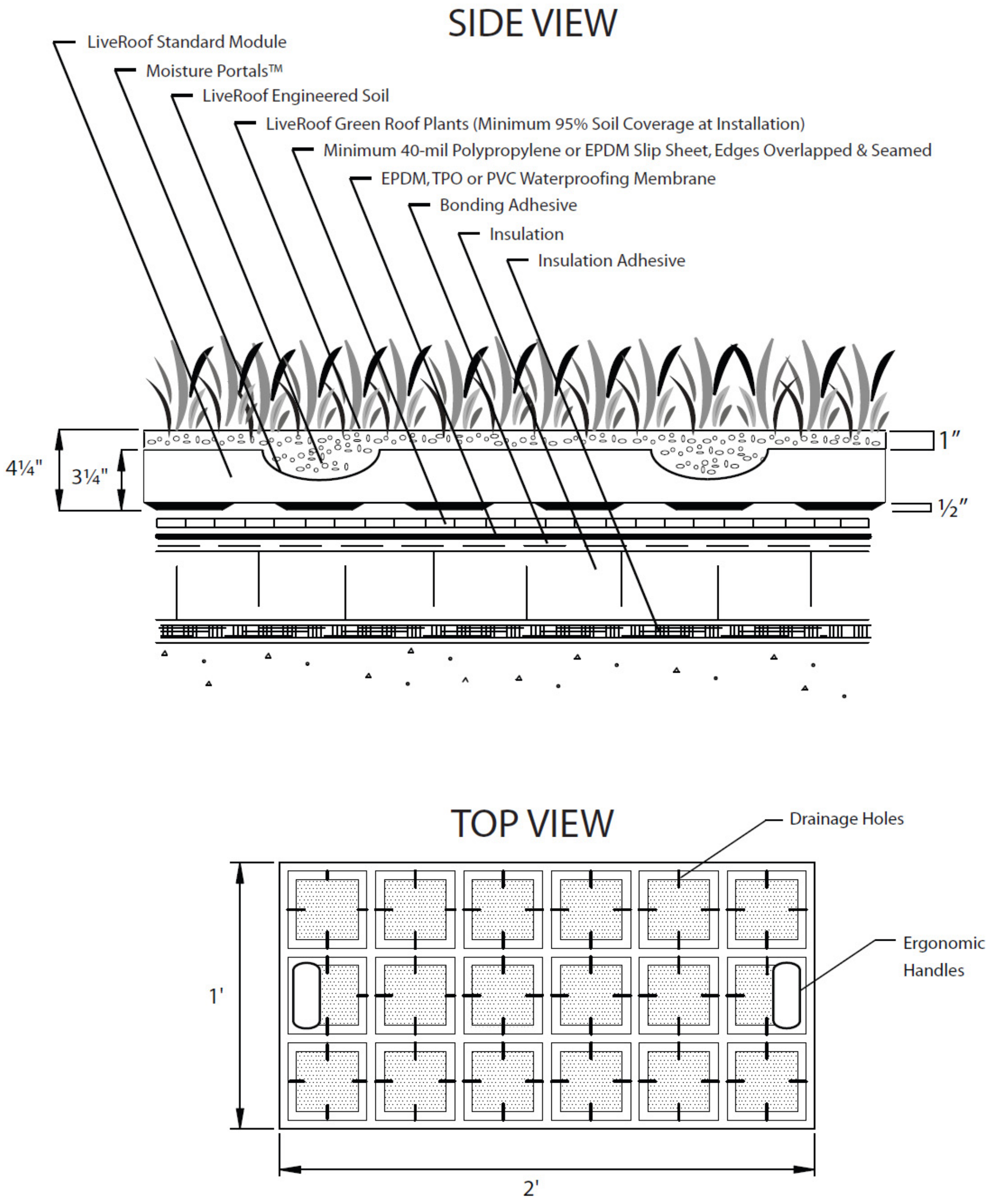

Figure 1. Composition of the LiveRoof**®** green roof modular system (LiveRoof®, 2011)

Benefits of Green Roofs

Green roofs contribute favourably to offsetting environmental impacts incurred in cities and provide aesthetic relief from the urban expanse. Banting et al. (2005, in MacIvor and Lundholm, 2010) noted that 20-30% of all impenetrable urban surfaces which are exposed to the elements are those which make up un-used rooftops. The causes of the Urban Heat Island Effect, or the increase in urban temperatures relative to the surrounding rural area, have been attributed to the replacement of vegetation with impenetrable, dark surfaces (such as concrete, and asphalt), which limit heat-shedding due to reduced evapotranspiration and lower albedo (or reflectance of solar radiation) (Oberndorfer et al., 2007). Applying vegetation to roofs lowers the daytime temperature of the roof surface by intercepting solar radiation, and thus lowers the energy consumption of the building by minimizing air conditioning costs required as a response to the excess solar heat absorbed by the impervious surfaces of a rooftop (Simmons et al., 2008; Snodgrass and Snodgrass, 2006). Green roof applications also prolong the life of roofs by interrupting solar radiation and by mitigating extreme and fluctuating temperatures, all of which degrade a roof surface (Liu and Minor, 2005).

Those dominant surfaces found within cities (such as asphalt and concrete) allow approximately 25% absorption of rainfall, while the forest floor absorbs approximately 95%, and therefore the chances of downstream flooding, erosion, sewage back-up and overflow all increase with rain events in cities (Scholtz-Barth, 2001). The application of green roofs in urban settings mitigates stormwater runoff by sequestering rainfall, and then dissipating it slowly through evaporation, evapotranspiration, and leaching.

Concentrated air pollution, in the form of smog, is detrimental to human health and has been present for centuries in urban settings. Diesel pollutants, and other gaseous air pollutants such as nitrogen oxide and sulphur dioxide can all be significantly reduced by green roofs, and particulates which travel on the wind are reduced by sticking to plants (Currie and Bass, 2008; Getter et al., 2006). As many urban settings cannot feasibly introduce trees as a means of mitigating particulate pollution, using available roof space to accomplish this goal with low growing perennials is a viable alternative. For example, it is estimated that one square metre of green roof can offset the particulate pollutants produced by one car (City of Los Angeles Environmental Affairs Department, 2006), and a study in Washington D.C. estimated that if the roofs in the city were covered in vegetation, nearly 60 metric tons of pollutants from the air could be sequestered annually (Deutsch et al., 2005). The US Environmental Protection Agency (2005) estimated from experimentation that if all roofs in Detroit were green, 252 tons of carbon could be stored, representing an offset of 10,000+ midsized trucks output for a year. Van Renterghem and Botteldooren (2011) summarized from their own research that green roofs can reduce sound pollution by absorption and by providing insulative characteristics, and further, that green roofs may significantly reduce urban noise.

The realization of the loss of biodiversity due to increased implementation of impervious surfaces within cities has been causal in a movement toward conservation, protection, and re-implementation of green space as a counter-measure to restore damage incurred. As urbanization interrupts the rural landscape, it is possible that green roofs contribute toward the rural continuum for wildlife migration through cities, functioning as springboards along the way (Kim, 2004, as cited in Schrader and Boning, 2006). Schrader and Boning (2006) found that extensive green roofs in cities contribute to urban biodiversity, but are not replacements for nature. Birds frequent green roofs for sanctuary and nesting (Baumann, 2006), while many insect and spider species thrive on green roofs, and rare spiders and beetles have also been sighted (suggesting that green roofs may have the potential to support the resurgence of endangered species) (Grant, 2006; Kadas, 2006).

Green Roof Growing Substrate

Traditional garden soils' major constituents are sand, silt, clay and organic matter. Both clay and organic matter are heavy when wet, and organic matter can be unstable and can break down quickly. Green roof growing substrates need to be lightweight to reduce roof load, be stable in order to provide consistent conditions over time, have the capacity to hold nutrients over time, retain plant-necessary water, and evacuate excess water.

The German FLL (Landscaping and Landscape Development and Research Society) association has developed guidelines for green roof specifications, which are followed worldwide, including the "**E2396-11** Standard Test Method for Saturated Water

Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems" (ASTM, 2012) which enables companies to create their own substrate mixtures according to policy (Greenroofs.com, 2011). For example, LiveRoof® Engineered Green Roof Soil™ guarantees that their substrate mix is in accordance with the FLL guidelines, is ~94 % inorganic, and at a depth of 10 cm and when saturated, weighs between 131.8 and 141.6 kg m^{-2} (LiveRoof®, 2011a).

The green roof substrate components of shale, clay, slate, and volcanic stone are chosen for unique attributes which are favourable to rooftop applications (Snodgrass and Snodgrass, 2006). Volcanic stone (mostly pumice) is lightweight and porous, and though dense and impervious in their natural state, shale, clay and slate are expanded via microwave heating and rotary kiln-firing to become lightweight, porous aggregates (WIPO, 2011).

The organic portion (up to 6%) of green roof substrate is usually humus (Philippi, 2002). Humus delivers nutrients to plants, functions as an adhesive which maintains soil structure allowing for the necessary microenvironment present in healthy soils, and becomes the catch for applied slow-release fertilizers and water (Bot, 2005).

Generally, designing the substrate composition for extensive green roofs becomes a balancing act which addresses the variables of weight requirement, water-holding capacity, root aeration and proliferation, stability, price and availability of components.

Green Roof Plant Environment

Extensive roofs are subject to harsh and extreme conditions, including high desiccating winds, high winds accompanied by pelting precipitation, intense solar radiation at high temperatures, and extremely low temperatures. Getter et al. (2009a) note that it is difficult to pick plant species for extensive roofs as the harsh environment of shallow substrate and elevation make for frequent periods of drought. The environment on an extensive roof is poor for plant growth as the limited plant-available water, wide temperature range, and exposure generate a demanding and disturbed setting. Plant species, which thrive on extensive green roofs, must exhibit traits of simple and/or self-propagation, quick and shallow establishment, and high leaf area index (LAI) (Getter et al., 2006). The faster the growth and canopy coverage, the sooner the risks of wind- and precipitation-driven erosion, and weed colonization are minimized (Getter et al., 2006).

Standard Green Roof Species

Research of plant species suitable to extensive green roofs has focused largely on drought tolerant plants (of the family Crassulaceae) and full-sun exposure. As the soil substrate is shallow in extensive green roofs and is subject to occasional drought conditions, it is crucial that green roof plants can tolerate such adversity. Plants which thrive in such settings exhibit adaptations such as water-storing leaves, stems, and bulbs; and root proliferation (Lundholm and Marlin, 2006). Add the ability to exhibit Crassulacean Acid Metabolism (which slows evapotranspiration), to propagate vegetatively, and to grow prostrate: succulent plants come to mind (Emilsson and Rolf, 2005). Succulent plants excel at water retention, and *Sedums* have been used as the standard of succulents because they tolerate drought, shallow substrate conditions, and many display CAM photosynthesis (Getter and Rowe, 2008; Getter et al., 2006). *Sedums* are short plants and grow prostrate, therefore increasing canopy size and protecting the substrate from erosion. In Germany, *S. album* was the most persistent of all plants tested on all types of green roofs, and it was found growing spontaneously on green roofs, further supporting adaptability of the species (Getter and Rowe, 2008). Monterusso et al. (2005) found that all of nine *Sedum* species tested in Michigan (*S. acre, S. album, S. kamtschaticum, S. ellacombeanum, S. pulchellum, S. reflexum, S. spurium Bieb, S. spurium L.,* and *S. middendorffianum* 'Diffusium') successfully survived and thrived over a three year experiment and were deemed suitable to Midwestern green roofs. In testing species suitability for extensive green roofs, Getter and Rowe (2008) found that *S. floriferum,* and *S. stefco,* were also suitable to the Midwestern US climate.

Native Green Roof Species

Of the plants tested, Bousselot et al. (2010) noted that although succulent plants performed significantly better than native plants, those native plants, which were tested, had become adapted to native environments with high precipitation and deep soils, and she posed that plants grown in the Rocky Mountains with shallow, fast-draining soils, and high exposure may be better candidates for extensive green roof testing. Of plant species fitting these criteria, five of six species they tested (*Antennaria pervifolia* [forb/herb]*, Bouteloua gracilis* [graminoid]*, Delosperma cooperi* [forb/herb]*, Opuntia fragilis* [decumbent cactus]*,* and *Sedum lanceolatum* [forb/herb]) were found to be acceptable for extensive green roof application in Colorado, all of which, with the exception of *Delosperma cooperi,* are native plants.

Because of the harsh climatic conditions present on green roofs, many plant species are not considered; however, the use of native plants is encouraged to promote diversity and an integrated management approach to pest control. As many wetland plant species exhibit plasticity with regards to water shortage, it is supposed that some of these species may be suitable for extensive green roofs in wet climates, and MacIvor et al. (2011) found that wetland species *Kalmia polifolia* (rhizomatous shrub)*, Scirpus cespitosus* (graminoid) and *Vaccinium macrocarpon* (stolonifereous shrub) had greater than 75% survival rates after one winter, however, the dryland species (*Sibbaldiopsis tridentate* (rhizomatous shrub)*, Danthonia spicata* (cespitose grass)*, and Empetrum nigrum* (stoloniferous shrub) exhibited greater coverage.

An experiment within a maritime climate experiencing warm, wet summers (Sheffield, UK), tested plant species accustomed to dry habitats with ornamental characteristics in 10 cm of substrate, with the results that *Armeria maritima 'Alba'*(compact perennial [clump]), *Festuca ovina* (graminoid), and *Stachys byzantina* (herb) species actually increased in numbers after five years (Dunnett et al., 2008). Another study, in Michigan, showed that the US native plant, *Talinum calycinum* (upright succulent) was a good choice for an extensive roof exposed to sun (Getter et al., 2009a).

Ecoregions are areas within a geographical domain whose ecosystems function similarly, and the North American continent has been divided into hundreds of ecoregions, all of which exhibit different traits (Dvorak and Volder, 2010).

Monterusso et al. (2005) evaluated the establishment and persistence of 18 plants native to Michigan and found that *Allium cernuum* L. (forb/herb), *Coreopsis lanceolata* L. (forb/herb), *Opuntia humifosa* Raf. (decumbent cactus), and *Tradescantia ohiensis* L. (forb/herb) were suitable to grow on non-irrigated extensive green roofs in that semi-arid ecoregion (Southern Michigan/Northern Indiana Drift Plains Ecoregion) (Midwest

PARC, 2011), while MacIvor and Lundholm (2010) found that the graminoids (*Carex argyranthra, Carex nigra*, *Danthonia spicata, Deschampsia flexuosa, Festuca rubra, and Luzula multiflora)*, the tall forbs (*Aster novae-belgii, Solidago bicolour,* and *Solidago puberula*), the creeping shrubs (*Arctostaphylos uva-ursi, Empetrum nigrum, Sibbaldiopsis tridentata*, and *Vaccinium marcocarpon*) and the creeping forb (*Fragaria virginiana*), native to Atlantic coastal regions, were suitable as green roof plants in the wet Atlantic Coast Ecoregion. They also suggested that graminoids largely out-performed the other plant forms tested, but qualified by noting that differences exist within life-form groups. Lundholm et al. (2009) found that out of ten native plants (of local coastal barren habitats) tested in Halifax, Nova Scotia, eight (grasses: *Danthonia spicata* and *Deschampsia flexuosa*, the creeping forb: *Sagina procumbens*, creeping shrubs: *Empetrum nigrum*, *Gaultheria procumbens*, and tall forbs: *Campanula rotundifolia*, *Plantago maritime*, and *Solidago bicolour*) had greater than 90% survival over a two year study, similar to the survival rates of the non-native succulents and grass which were tested .

Some plant species perform well on green roofs over a wide range of climatic conditions, while other species with narrower tolerance thresholds perform well within smaller ranges of climatic conditions. Researching native plants within different ecoregions highlights physiological attributes which may lead to new species choices for local green roofs. Local research shows success with each of the life-forms of graminoids, shrubs and forbs, however, differences within forms and even families necessitates that more research be conducted to determine a broad range of acceptable local green roof plants. Further research may lead to the use of plant species with various adaptations which promote biodiversity and integrated pest management.

Selected Plant Characteristics

Anaphalis margaritacea (L.) Benth., *Arabis sturii* Mottet., *Antennaria dioica* (L.) Gaertn., *Artemisia stelleriana* Besser., *Aster novi-belgii* L., *Coreopsis verticillata* L., and *Echinacea purpurea* (L.) Moench. were the herbaceous perennials of the Asteraceae Family used in this experiment. *Fragaria virginiana* Duchesne. (Rosaceae), *Lotus* *corniculatus* L. (Fabaceae), and *Monarda punctata* L. (Lamiaceae) comprised the remaining herbaceous perennial species used in the experiment.

It should be noted that the following characteristics (specifically height, growth rate and drought tolerance) are derived from observations of the species in their native environments, and parameters are likely narrowed in an extensive green roof setting.

A. sturii Mottet., hardy to zone 4a, is a creeping, mat-like plant with a slow growth rate that requires full exposure and tolerates medium-to-coarse soil (Horticopia.com, 2011 and ZipcodeZoo.com, 2012).

A. margaritacea (L.) Benth., hardy to zone 3, is an upright plant growing to 90 cm in height with a rapid growth rate, requiring full exposure and medium-coarse soil. It spreads by rhizomes and seeds and is moderately drought tolerant (USDA, Natural Resources Conservation Service. 2012a).

A. dioica (L.) Gaertn., hardy to zone 3, forms a dense, creeping mat. It has a moderate growth rate, can tolerate some shade, but prefers full exposure. It can tolerate a wide range of soils, reproduces sexually and by stolon (NC State University, 2012; Roland et al., 1998).

A. stelleriana Besser, hardy to zone 2, is a robust, low lying, highly branched plant which requires full exposure, coarse to sandy soils and reproduces sexually (Roland et al., 1998).

A. novi-belgii L., hardy to zone 3, is an upright plant with a moderate growth rate which can reach 180 cm in height, requires full exposure and fine- to medium-coarse soil, spreads by rhizomes and seed, and is drought intolerant (USDA, Natural Resources Conservation Service, 2012b).

C. verticillata (L.), hardy to zone 3, is an upright plant which can reach 60 cm, has a fast growth rate, requires full exposure, and tolerates a wide range of soils and pH. It is spread by rhizomes and can tolerate drought (Ohio State University, 2012).

E. purpurea (L.) Moench., hardy to zone 3, can reach 90 cm in height, has a fibrous root system which requires a medium-to-rich soil with good drainage and full exposure. It can tolerate pH > 6.0, is drought tolerant, and can be propagated sexually or by division (Agriculture and Agri-Food Canada, 2012; Natural Resources Canada, 2012; Manitoba Agriculture, Food and Rural Initiatives, 2012).

F. virginiana Duchesne, hardy to zone 3, is a creeping plant with a moderate growth rate that requires full exposure and a variety of soil textures, is spread by stolons and is moderately drought tolerant (UBC, 2012 and Native Plant Database, 2012a).

L. corniculatus L., hardy to zone 2, is a semi-erect plant with a moderate growth rate which requires full exposure and prefers loam soil. It is spread by seed, and is moderately drought tolerant (CIAT/FAO, 2012 and USDA, Natural Resources Conservation Service, 2012c and Global Invasive Species Database, 2012).

M. punctata L., hardy to zone 4, is an upright plant reaching up to 60 cm, with a fast growth rate and a full exposure requirement. It requires medium textured soil, is spread by seed and rhizomes, and is moderately tolerant of drought (Missouri Botanical Garden, 2012a and University of Florida, 2012).

Physiological Research of Selected Plants

Chapin (1995), in his research on the colonizing plants of Mount St. Helens, found that the stomatal conductance of *A. margaritecea* decreased at a water potential of -1.0 to -1.1 MPa., and surmised that although the plant does not use water particularly efficiently, it does have a highly branched root system which may add to its ability to source water in scarce conditions. Archibald (2005) noted in her work on seed production protocol for *Anaphalis margaritecea* L., that the species is a fast colonizer and may inhibit noxious weed invasion while protecting soil from erosion.

Hygen (1953) found that stomatal closure in *A. dioica* resulted in a 90-95 percent reduction in transpiration, and compared this efficiency to that of *Empetrum nigrum*.

Zollinger et al. (2006) found that *E. purpurea* exhibited no significant effects when watered once weekly, however, when the interval was stretched to 2 and 4 weeks, it underwent wilting, stem dieback and leaf burning, and stomatal conductance and photosynthesis were reduced by 72-81%. They suggested that the species not be used as a landscape plant under drought conditions.

Geater et al. (1997) found that *F. virginiana* grown at 23 and 29°C had more fresh weight gain, more runners, more runner plants, greater leaf area, and greater root dry mass than plants grown at 35°C. Serce et al. (2002) found that the CO_2 assimilation rate of *F. virginiana*, when grown at a daytime/nighttime controlled temperature regime of

30/25°C, maintained 76% of the optimal, making it the choice species of strawberries tested at high temperatures.

In their work to test if *L. corniculatus* could locally adapt to different soils and climates, Macel et al. (2007) found weak evidence supporting adaption to soil, and none to climate.

The Ecoregions of Halifax and Truro

In their review of green roof vegetation in North American ecoregions, Dvorak and Volder (2010) found that although green roof technology is on the rise on the continent, only 17 ecoregions out of hundreds have been researched adequately to determine acceptable extensive green roof vegetation standards, and summarized by noting that understanding of the topic is very limited. Further, they recommended that more research be reported in peer-reviewed journals across the ecoregions.

Nova Scotia, part of the Atlantic Maritime Ecozone, includes eight ecoregions (which are further divided into ecodistricts with the exception of the Atlantic Coast Ecoregion) which are defined by landform, climate, flora, soils, water, and usage (Agriculture and Agri-Food Canada, Environment Canada, 1999). Halifax, of the Atlantic Coast Ecoregion in South-eastern Nova Scotia, is an area with high rainfall and cool temperatures (Dzikowski, 1985). The ecoregion accumulates 1472 growing degree days (the lowest in the province) based on 5ºC, and has a growing season of 202 days (Agriculture and Agri-Food Canada, 1999). Truro, of the Nova Scotia Highlands Ecoregion, 100 km north-east of Halifax in Northern Nova Scotia, receives high snowfall, some of the coldest winter temperatures in the province, and has warm summers (Dzikowski, 1985). Truro is within the St. Mary's Block Ecodistrict, accumulates 1506 annual growing degree-days based on 5ºC and has a growing season of 193 days (Agriculture and Agri-Food Canada, 1999).

Due to their tolerance of drought conditions, industry standard extensive green roof plants have traditionally been succulents, largely of the species *Sedum*. While *Sedums* are obviously superb at coping with the crucial plant growth-limiting factor of drought, it is important to consider factors such as pest management, climatic differences, and biodiversity when evaluating potential alternative species for extensive green roofs.

As the green roof industry has expanded from Central Europe to Scandinavia, Asia, South America and North America, so too have the variations in climatic conditions, and research finds that plant species local to those areas where the roofs will be implemented may be better suited to the roofs. Research with native plant species on green roofs has been documented in only a small portion of ecoregions across the North American continent, and although research has been conducted in Halifax, Nova Scotia, the differences in climatic conditions between coastal Halifax and the Northern mainland of the province justify that native and Canadian-bred plant species extensive green roof research be conducted at Truro.

Objective

The objective of this study is to determine individual suitability of native and Canadian-bred selected plants in terms of growth and survivability for local green roofs.

Hypotheses

H_0 (null hypothesis): There was no significant difference in growth and survival among Canadian-bred and native species and the industry standard *Sedum* spp.

H_A (alternative hypothesis): There were significant differences in growth and survival among Canadian-bred and native species and the industry standard *Sedum* spp.

Chapter 3 Materials and Methods

The experiment was a single-factor experiment with 12 levels in a randomized complete block design with three blocks. The factor was species. Two levels were *Sedum* species, and 10 levels were Canadian-bred or native plant species.

Each block of the experiment included LiveRoof® modules consisting of LiveRoof® Engineered Green Roof Soil™ at a depth of 10 cm (LiveRoof®, 2011a). As Liveroof® is an established company specializing in extensive green roofs which conforms to the industry-standard FLL guidelines, the use of their substrate and modular system to conduct this experiment was acceptable, as the study focussed on the growth and survivability of plant species in green roof substrate on extensive green roofs, not the mixing of substrate nor the construction of modules. The experiment included 36 modules (10 species x 3 replications of native or Canadian-bred species [Table1], and 2 x 3 samples of *Sedum* species [*S. acre* L. and *S. floriferum* 'Weihenstephaner Gold' Fetthenne gelb.]). An experimental unit consisted of one module.

Ten Canadian-bred or native plant species as well as two species of *Sedum* as controls were chosen to be used in the green roof experiment (Table 1).

Plants were propagated from seed, cuttings, or divisions. *A. margaritacea*, *A. dioica*, *A. stelleriana*, *E. purpurea,* and *M. punctata* were sourced from Jelitto seeds [Postfach 1264, D-29685 Schwarmstedt, Germany], and *L. corniculatus* was sourced from Co-op Atlantic. *A. sturii*, *S. acre, S. floriferum,* and *A. novi-belgii*, were propagated from cuttings, the first three from Darwin Carr of the NSAC, and the latter from Hillendale Perennials of Hilden, Nova Scotia. *C. verticillata* was purchased as divisions from Bunchberry Nurseries of Annapolis Royal, Nova Scotia; and *F. virginiana*, by division from Hillendale Perennials. All plants were established in the NSAC Plant Science greenhouses, and subsequently transferred to the LiveRoof® modules at 15 plants per module. The planted modules were set outside at ground level to harden-off and establish in the spring of 2011 and then transferred to the roof on May 28.

In the experiment, all perimeter modules (Fig. 2) were used as guard modules, and 12 of the 14 interior modules were randomized and allocated as experimental units(during the establishment year, sampling units were comprised of the five plants in the centre row of each module: in year two, sampling comprised the entire module). Guard modules and non-sampled modules consisted of two non-sampled replicates of all 12 species in the experiment for a total of 24 modules. Blocks were separated by 2 metres (Fig. 2).

Table 1. Canadian-bred and Native plant Extensive Green Roof Species

	Species	Common name
1	*Anaphalis margaritacea* (L.) Benth.	Pearly Everlasting
2	*Arabis sturii* Mottet.	Mountain Rock Cress
3	*Antennaria dioica* (L.) Gaertn.	Pussytoes
4	*Artemisia stelleriana* Besser.	Beach Wormwood
5	*Aster novi-belgii* L.	New York Aster
6	*Coreopsis verticillata* L.	Tickseed
7	*Echinacea purpurea* (L.) Moench.	Purple Coneflower
8	*Fragaria virginiana* Duchesne.	Wild Strawberry
9	*Lotus corniculatus* L.	Birdsfoot Trefoil
10	*Monarda punctata* L.	Bee Balm
11	*Sedum acre* L.	Common Stonecrop
12	*Sedum floriferum* L.	Golden Stonecrop

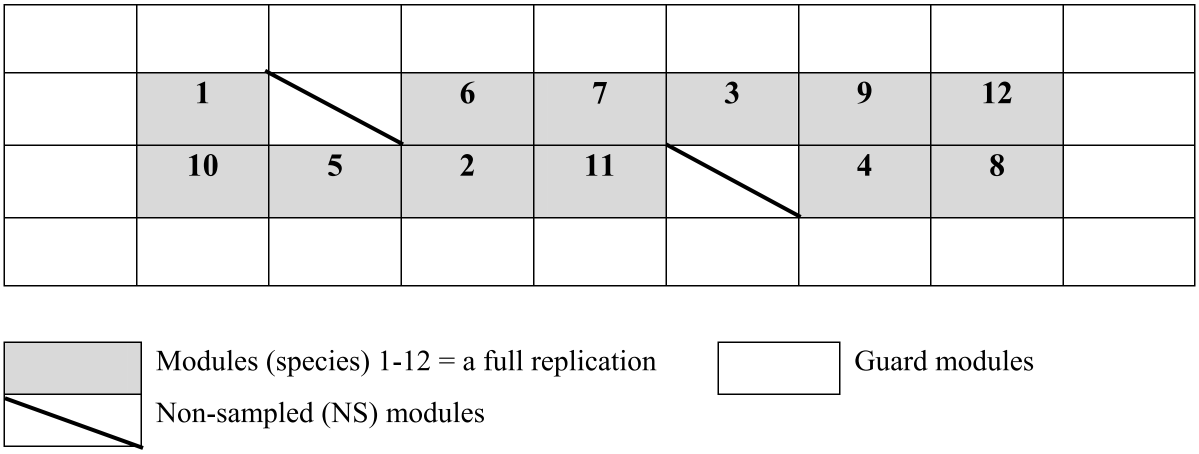

Figure 2. Experimental layout

Data collection

Prior to the establishment of plants in the modules, soil samples were taken to determine the soil composition. In year one (2011), measured parameters included: width, height, percent canopy cover, vigour, soil moisture, air temperature, and soil temperature. During the summer of 2011, measurements taken on the 5 centre plants of each experimental unit (module) were: width (at broadest point) and height (at tallest point from the soil surface). Percent canopy cover (by visual estimation) and vigour (visually on a rating of 1-5, 1 being dead and 5 being excellent) were taken on the entire module.

From August 17, 2011 until May 28, 2012, soil moisture, air temperature, and soil temperatures were recorded on block three. While soil moisture was recorded on *S. floriferum*, *A. margaritecea*, *L. corniculatus*, and *A. novi-belgii,* soil temperature was recorded on all species of block three. Air temperature was recorded adjacent to the block in a single open-ended hollow, north-facing spruce box (12 x 12 x 8 cm on the outside, ¾ inch lumber) for the entire duration of the experiment.

Data Acquisition Devices (DAQ) were used to monitor soil moisture, air and soil temperatures. The first set of DAQ hardware used in the experiment were the 6220 and 6210 DAQ devices, the LM-35 Precision Centigrade Temperature Sensor, Type T thermocouple wiring (National Instruments, Quebec City, QU) and the EC-5 soil moisture probes (Decagon, from Hoskin Scientific Inc., Burlington, ON). The computer was an HP Compaq D5-30 CMT, with a Pentium IV 2.66 GHz processor with 512 MB RAM. This combination of devices was used during the summer 2011 through to May of 2012 for establishment and winter survivability data. The placements of the thermocouples and soil moisture probes were then shifted. The thermocouples were placed to collect data on each of three blocks of four treatments (*L. corniculatus, A. novi-belgii, A. stelleriana, and S. acre*). The soil moisture probes were placed to collect data on each of three blocks of *L. corniculatus* and *A. stelleriana.* This configuration was maintained until the completion of the experiment on September 15, 2012.

The second DAQ device, used from May 2012 – September 15, 2012, was a CR800 Data Acquisition Device, PS100 and CH100 Power Supply and Charging Regulators, A100 Null Modem Adaptor, and A105 Additional 12V Terminals Adapter, ENC14/16 Environmental Enclosure, and the CS616 Water Content Reflectometers (Campbell Scientific Canada Corp., Edmonton, Alberta. Copyright 2002-2011). The reflectometers were used to measure volumetric water content of *A. novi-belgii* and *S. acre*.

All DAQ measurements were compiled as daily averages of hourly samples, and summer 2011 to May 2012 data included daily temperature highs and lows.

In the spring of 2012, percent survival was recorded (number of original plants which survived divided by the total number of original plants). From May 28, 2012 until September 15, 2012, soil temperature and moisture were recorded for *A. novi-belgii*, *A. stelleriana*, *L. corniculatus*, and *S. acre* at each of the 3 blocks.

The summer 2012 percent canopy coverage of each experimental unit was determined using overhead photographs taken with a Canon E0S Digital Rebel camera (Canon Inc. 2003. Shimomaruko 3-chrome, Ohta-ku, Tokyo 146-8501, Japan), in combination with WinDIAS 3. Version 3.1 Leaf Image Analysis System (Copyright Delta-T Devices Ltd. ©2009-2009). Photos were taken on June 28, July 27, and September 6, 2012.

On August 21 through and including August 26, 2012 the LCA-4 Portable Photosynthesis System, with the PLC-4 Portable Leaf Chamber (ADC Bioscientific, Hoddesdon, UK.) was used to measure photosynthetic rate, stomatal conductance, and transpiration rate. The August measurements were taken on successive sunny days within an hour of solar noon following a rain event on August 20. Measurements were conducted on one leaf per applicable (broadleaf plants) experimental unit for each of three blocks in the experiment. All photosynthetic data were sampled from one newly-expanded leaf per module (with the exception of *Monarda* in August as the only new growth were flower parts) in order to rule out factors such as immature, rapidly expanding, or old, senescing leaves which could lead to false conclusions. Data were collected on *A. margaritecea*, *A. stelleriana*, *A. novi-belgii*, *E. purpurea*, *F. virginiana*, *L. corniculatus*, *M. punctata*, and *S. floriferum*. The remaining species did not lend favorably to data collection with the leaf chamber as they were either too small (*C.verticillata*, *S. acre*) or were too close to the ground, or too bunched (*A. dioica*, *A. sturii*) to capture.

Analytical Spectral Devices (ASD) FieldSpec® 3 spectroradiometer (ASD Inc., Boulder, CO) was used to determine the full spectral range, visible range, and near infrared range of reflectance of all plant species in each of three replicates in the experiment on July 3, 2012 and September 12, 2012. Graphs were generated using View Spec Pro 6.0 software.

At the completion of data collection (September 12, 2012), a destructive harvest was completed on all experimental sampling units. Fresh weight (at harvest) and dry weights (after 7 days at 55°C in drying oven) of above-ground biomass were measured. Once above-ground biomass was removed, roots were removed from modules, washed to remove all substrate, and dry weights were recorded (after 5 days at 55°C in drying oven).

Statistical Methods

Data were tested for assumptions of analysis of variance using Proc Univariate of SAS v. 9.3 (SAS Institute Inc., Cary, NC). Outliers were removed where appropriate. Data that met assumptions were analyzed using Proc Mixed of SAS v. 9.3. Blocks were treated as random variables and species were treated as fixed variables. Means were compared by LSD or Tukey's HSD, depending on the number of levels. Data collected as repeated measures were analyzed using the repeated statement in Proc Mixed of SAS v. 9.3. Non-parametric data were analyzed using Proc Npar1way of SAS v. 9.3.

Experimental model

$Y_{ij} = \mu + \rho_i + \alpha_j + \varepsilon_{ij}$

Where Y_{ij} = the observation in the ith block (i = 1-3) for the level j (j= 1-12) of species, μ the overall mean effect, ρ_i = effect of block i, α_j = the effect of the jth level of species, and ε_{ij} represents the experimental error.

Chapter 4 Results and Discussion

In the establishment year, the data for vigour did not have homogeneous variance, thus assumptions were not met: therefore the non-parametric Kruskal-Wallis test was used. The *P* value for the chi-square approximation is less than 0.0001 indicating differences among treatments. An index of 1-5 was used, with 1 representing dead plants and 5 representing excellent vigour. *Echinacea*, *Monarda* and *Anaphalis* had lowest mean vigour, while *Lotus* and *Sedum f.* had the highest (Table 2).

The harsh summertime solar conditions on the roof made it a challenge for plant establishment unless they were under constant mist-irrigation (this experiment had once-daily irrigation, either by precipitation or by nozzle during the establishment year). The *Sedum* spp., vigorous at 90%, were, as expected, according to industry standards. That *Artemisia*, *Coreopsis* and *Lotus* were over 80% was a positive sign for those species so early in the trial, as high vigour is indicative of the plants' successful establishment in the constrained conditions of the extensive green roof. The low vigour in *Echinacea* may have been an indicator of its inability to thrive in the shallow substrate. This species is reported to reach 130 cm in height (Kwantlen Polytechnic University, 2012d), but it was hypothesized that phenotypic plasticity might be exhibited in this member of the Asteraceae family, potentially allowing the species to grow to a height relative to the available soil depth. Phenotypic plasticity is the ability of an organism to alter its physiology or morphology in response to the environment. Mitchell and Bakker (2010), from the University of Washington, found that 5 of 6 asters tested demonstrated plasticity with regards to shoot and root growth and varying levels of N. It was phenotypic plasticity, present in Asteraceae (which may be a crucial trait for determining suitability of plant species to shallow substrate experiments), which was the deciding factor in choosing *Echinacea* for testing in the extensive green roof experiment.

Table 2. Establishment year vigour

Species	**Vigour (index of 1-5)**
1. *Anaphalis*	3
2. *Antennaria*	4
3. *Arabis*	4
4. *Artemisia*	4
5. *Aster*	4
6. *Coreopsis*	4
7. *Echinacea*	3
8. *Fragaria*	4
9. *Lotus*	5
10. *Monarda*	3
11. *Sedum a.*	4
12. *Sedum f.*	5

Standard error of the mean ± 0
Kruskal-Wallis Test *P* value < 0.0001

In the establishment year there was a significant interaction between species and day on percent cover (Table 3). Lotus (D3), Sedum f. (D2, D3), Sedum a. (D2, D3), *Fragaria* (D2), and Aster (D3) reached full coverage while on D1 all species (with the exception of Sedum f.) attained less than 50% coverage.

It is possible that those species which had lower percent cover (*Antennaria*, *Arabis*, *Artemisia*, and *Echinacea*) by the end of the growing season could have reached much higher cover given a different establishment protocol. At the individual level, an establishing plug, surrounded by expanded shale, slate and clay, which retain more heat and lose more moisture from solar radiation than surrounding vegetation, stands less of a chance of establishing in the harsh green roof environment than does the plug with proximal neighbours, which interrupt and reflect more solar radiation, thus retaining more soil moisture, creating a microclimate conducive to establishment.

Table 3. Effect of species and day on percent cover during establishment year

Species	**Day**^{z}		
	D1	**D2**	**D3**
Anaphalis	28^y*k*^{x}	82*d-g*	85*c-f*
Antennaria	10*mn*	25*kl*	48*h-j*
Arabis	10*mn*	40*j*	55*hi*
Artemisia	no data	45*j*	58*h*
Aster	15*m*	85*cde*	92*abc*
Coreopsis	8*n*	74*g*	87*cd*
Echinacea	15*m*	42*j*	45*ij*
Fragaria	22*l*	94*abc*	90*bcd*
Lotus	no data	77*efg*	100*ab*
Monarda	28*k*	77*efg*	90*bcd*
Sedum a.	45*j*	92*abc*	98*ab*
Sedum f.	77*fg*	100*a*	100*ab*
Standard error	**2**	**3**	**4**

[z] where calendar day (mm/dd)for D1 = 07/10, D2 = 08/16, D3 = 10/03
[y] Units are %
[x] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.

Survival data taken in May 2012 did not have homogeneous variance, thus assumptions were not met: therefore the non-parametric Kruskal-Wallis test was used. The *P* value for the chi-square approximation was 0.0022 indicating significant differences among treatments. *Antennaria*, *Arabis, Aster*, *Coreopsis*, *Lotus*, *Sedum a.* and *Sedum f.* had highest mean survival, while *Anaphalis, Monarda* and *Echinacea* had the lowest (Table 4).

Antennaria, Arabis and *Artemisia* had high winter survival (Table 4) without reaching high percent cover during the establishment year (Table 3). If the priority for the green roof is to realize green roof benefits (as described in Benefits of Green Roofs section of the Literature Review, Chapter 2) as quickly as possible, then adjustments in establishment protocol may be required.

Echinacea had poor cover in the establishment year (Table 3) and had poor winter survival, adding to its lack of suitability to the shallow substrate. Conversely, Monarda attained high percent cover (Table 3) but marginal (67%) (Table 4) winter survival percentage. Environment Canada Daily Data Reports for January and February 2012 Debert, Nova Scotia Weather Station show minimum temperatures of less than -18°C for

Table 4. Percent winter survival, May 2012

Species	**Mean survival (%)**
Anaphalis	69 (±18)[z]
Antennaria	100 (±0)
Arabis	100 (±0)
Artemisia	95 (±4)
Aster	100 (±0)
Coreopsis	100 (±0)
Echinacea	49 (±21)
Fragaria	80 (±10)
Lotus	100 (±0)
Monarda	67 (±12)
Sedum a.	100 (±0)
Sedum f.	100 (±0)

[z] Standard error of the mean

January 22, 23, and February 3-6, and there were also a number of freeze-thaw cycles in January, February and March (Environment Canada National Climate Data and Information Archive, 2012a). Given this information from Environment Canada, it may be that a minimum temperature threshold occurred, below which, plants died.

Cover differed significantly among species for the 2012 season (Table 5). *Sedum f.*, *Artemisia*, and *Sedum a*. reached significantly higher mean coverage than all other treatments except for *Lotus* and *Aster*. *Lotus* had significantly higher percent cover than *Monarda*, *Antennaria*, *Arabis*, *Fragaria*, *Coreopsis*, and *Echinacea*.

The greater the percent cover of vegetation on a green roof, the greater the potential to interrupt, intercept, or reflect solar radiation which otherwise contributes to the Urban Heat Island Effect, and more locally, to the degradation of the building roof and to the energy costs (air-conditioning) of a building (Simmons et al., 2008; Snodgrass and Snodgrass, 2006). Considering percent cover in 2012, there were no differences between *Artemisia*, *Aster*, *Lotus* and the control *Sedum* spp. (Table 5) in exhibiting high coverage, and thus, these species should be considered for the extensive green roof in realizing reduced replacement and energy costs.

Given the similarity in percent cover reached by *Antennaria*, *Arabis* and *Artemisia* by D3 of the establishment year (Table 3), as compared to that of the percent cover of 2012 (Table 5), it may be concluded that *Artemisia*, once established, grows more quickly than either *Antennaria* or *Arabis.*

Percent cover differed significantly by date (Table 6). D2 had significantly higher percent cover across all treatments than either D1 or D3.

That D2 was significantly higher in percent cover (Table 6) than the other dates is logical, as late June (D1) in Nova Scotia is early in the growing season (meaning there is much growth left to come at this stage), and by September (D3), many perennial plant species have flowered and seeded, growth has slowed, and photosynthates are being sent into the crown to build reserves of energy in the storage organs.

July and August are the warmest months in Nova Scotia (Nova Scotia Museum of Natural History, 2012), and percent cover was highest during those months, thus enabling all species to intercept maximum solar radiation.

Table 5. The effect of species on percent cover, September 2012

Species	**Percent cover (%)**
Anaphalis	54.98*bcd*[z]
Antennaria	52.34*d*
Arabis	46.43*d*
Artemisia	87.06*a*
Aster	82.19*abc*
Coreopsis	43.00*d*
Echinacea	28.27*d*
Fragaria	45.59*d*
Lotus	82.34*ab*
Monarda	54.93*cd*
Sedum a.	82.56*a*
Sedum f.	87.94*a*

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ±10.02

Table 6. The effect of date on percent cover in 2012

Day[z]	**Cover (%)**
D1	58.94*b*[y] (± 4.71)[x]
D2	67.59*a* (± 4.87)
D3	60.38*b* (± 4.64)

[z] Calendar day (mm/dd) for D1 = 06/28, D2 = 07/27, D3 = 09/06
[y] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
[x] Standard error of the mean

Height differed significantly among species in September 2012 (Table 7). *Aster*, *Echinacea* and *Monarda* were not significantly different in height from one another, but were significantly taller than all other treatments. *Artemisia*, *Anaphalis*, *Lotus* and *Coreopsis* were not significantly different in height from one another, but were significantly taller than *Sedum f.*, *Sedum a.*, *Arabis*, *Fragaria* and *Antennaria*.

A possible benefit of including the taller plants (*Aster*, *Echinacea* and *Monarda*) in the green roof is to retain snow. The dead fibrous upright stalks left in the winter allow for snow capture, increasing the potential to protect not only the overwintering crown of the plants, but to insulate and to lessen the heat loss of the building upon which the green roof is constructed. The shorter plant species are less exposed than taller plant species to the harsh winds present on the roof, and therefore may be more prone to the stress incurred by extremely high temperatures during summer as canopy cooling may not as easily take place by air displacement via wind.

The three different heights of the experiment species may lend favourably to experimentation in polyculture, where over-, mid- and under-storey plants may coexist on the roof in a situation wherein they exploit each others' weaknesses to the advantage of the roof. That is, a mid-storey species may capture or reflect incoming radiation that is not captured or reflected by the taller species, alleviating solar degradation and air-conditioning costs. An under-storey species may need shade protection from a taller species to thrive in the green roof environment, and in turn, may effectively aid in alleviating water stress for the taller species by decreasing evaporation of plant-available water through substrate coverage. Lundholm et al. (2010) found that polyculture combinations held more water, reflected more incoming radiation, and lowered roof surface temperatures as well as the best monoculture treatments. Sutton et al. (2012 cited Sutton, 2010) noted that the microclimate created by *Aster* spp., *Dalia* spp., and *Artemisia* spp. was conducive to the growth and establishment of *Bouteloua* spp., supporting the suitability of *Artemisia* and *Aster* to polyculture green roofs.

Fresh weight differed significantly among species (Table 8). *Sedum f.* was significantly heavier than all other species, *Artemisia* was significantly heavier than all species except *Sedum f.*, and *Aster* (which was of similar weight). *Aster*, *Sedum a*., and

Lotus were similar in fresh weight, and were significantly heavier than *Anaphalis*, *Arabis*, *Antennaria*, *Monarda*, *Echinacea*, *Coreopsis*, and *Fragaria*.

Table 7. The effect of species on height, September 2012

Species	**Height (cm)**
Anaphalis	32.5*b*[z]
Antennaria	1.0*c*
Arabis	5.0*c*
Artemisia	35.0*b*
Aster	58.0*a*
Coreopsis	29.2*b*
Echinacea	52.5*a*
Fragaria	4.0*c*
Lotus	30.0*b*
Monarda	50.8*a*
Sedum a.	6.5*c*
Sedum f.	7.7*c*

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ±4.0 with the exception of *Echinacea* where SEM = ±5.0

In their work on simulated extensive green roofs, Nagase and Dunnett (2012) found that plant species which were taller and heavier performed better in reducing storm water runoff than shorter species with less mass. *Artemisia* was significantly heavier than *Sedum a*. in shoot fresh, dry and root dry weights (Tables 8, 9, 10); lending to its suitability to the green roof for the purpose of water retention. *Aster* and *Lotus*, also high in shoot and root weight (Tables 8, 9, 10) are good candidates for effective green roof storm water management.

In considering carbon sequestration as a benefit of green roofs, total biomass and photosynthetic pathways are crucial considerations. Getter et al. (2009b) noted that plants which exhibit C3 and C4 photosynthesis assimilate 1/2 to 2/3 more carbon than those plants which exhibit CAM photosynthesis. Kluge (1977) found *Sedum acre* to be a facultative CAM plant, that is, it exhibited CAM photosynthesis under water stress. Though there is no available literature on the photosynthetic pathway of *Sedum floriferum*, research done by Gravett and Martin (1992) indicates that the *Sedum* spp. can be either CAM- cyclers (where the stomata are open during the day to capture CO_2), strictly CAM (where the stomata are open during the night to capture CO_2) (Harris and Martin, 1991), or some combination of the two. Regardless, as *Lotus* (Oregon State, 2012) is a C3 plant, and *Artemisia* and *Aster* and (which are high in total biomass) are

Table 8. The effect of species on final shoot fresh weight, September 2012

Species	**Weight (g)**
Anaphalis	157.5d[z]
Antennaria	126.9d
Arabis	134.0d
Artemisia	730.0b
Aster	556.3bc
Coreopsis	87.3d
Echinacea	92.1d
Fragaria	65.8d
Lotus	381.5c
Monarda	126.4d
Sedum a.	520.9c
Sedum f.	985.9a

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ±70.8 with the exception of *Echinacea* where SEM = ±86.7

likely C3, suitability to the green roof with regards to carbon sequestration of these species is considerable.

Shoot dry weight differed significantly among species (Table 9). *Sedum f.* had significantly heavier dry shoots compared to all other species, *Artemisia* and *Aster* had heavier dry shoots than all other species except *Sedum f.* *Sedum a.* was significantly heavier than all remaining species except *Lotus*. *Lotus* was similar in dry shoot weight to *Arabis*, and significantly heavier than all remaining species. There were no significant differences between *Anaphalis*, *Antennaria*, *Monarda*, *Coreopsis*, *Fragaria* and *Echinacea*, and all were significantly lighter than all other species except *Arabis*.

Table 9. The effect of species on final shoot dry weight, September 2012

Species	**Weight (g)**
Anaphalis	57.9*e*[z]
Antennaria	53.7*e*
Arabis	59.0*de*
Artemisia	227.1*b*
Aster	216.1*b*
Coreopsis	36.7*e*
Echinacea	20.6*e*
Fragaria	29.4*e*
Lotus	126.9*cd*
Monarda	44.6*e*
Sedum a.	135.1*c*
Sedum f.	320.8*a*

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ± 23.4

Root dry weight differed significantly among species (Table 10). There were no significant differences detected among *Sedum f.*, *Aster* and *Lotus*, but all had significantly heavier root dry weight than all other treatments. *Artemisia* had significantly heavier dry root weight than *Coreopsis*, *Sedum a.*, *Arabis*, *Monarda*, and *Echinacea,* but was similar to *Anaphalis*, *Fragaria* and *Antennaria*.

Table 10. The effect of species on final root dry weight, September 2012

Species	**Weight (g)**
Anaphalis	66.5*bc*[z]
Antennaria	43.4*bcde*
Arabis	31.1*cde*
Artemisia	77.5*b*
Aster	139.4*a*
Coreopsis	35.2*cde*
Echinacea	12.5*e*
Fragaria	53.5*bcd*
Lotus	137.8*a*
Monarda	18.1*de*
Sedum a.	34.9*cde*
Sedum f.	172.1*a*

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ±13.1

Photosynthetic parameters (photosynthetic rate, transpiration rate, and stomatal conductance) were measured on July 11, 2012 and again on consecutive sunny and windy (maximum daily gusts of 31- 35 kph) days from August 21- 25, 2012 following rain events of 49.4 mm (August 16) and 13.7 mm (August 20) (Environment Canada National Climate Data and Information Archive, 2012b). This ensured moist soil at the beginning, followed by a depletion of soil moisture over time for the 5 days of data collection; the objective was to observe how the plant species behaved as plant available water became scarcer. The July data were not included in the statistical analysis (as values may have eliminated or altered detection of any patterns over the 5 day August collection after the rain event), and were used to compare general photosynthetic parameters between mid- and late summer.

As this climate data was taken approximately 17 km from the experiment site, at the Debert, Nova Scotia weather station, it is likely that wind speeds and precipitation amounts differed between Debert and the experiment site; however, these data are adequate for observance of general patterns.

It should be noted that all data obtained by use of the photosynthesis system fell within the range of parameters given in the appendix of the manufacturer standards, with the exception of those in Tables 11 and 15 (transpiration data) which are above the typical 0-1 range.

There was a significant interaction between species and day for transpiration rate (Table 11). There were significant differences among species on all days with the exception of D5. There were significant differences within species by day for *Artemisia*, *Echinacea*, and *Fragaria*. There were no significant differences detected between *Anaphalis*, *Aster*, *Lotus*, *Monarda*, and the control *Sedum f.* in transpiration rate.

In realizing benefits of a green roof, consideration must be given to the potential of heat-shedding via transpiration: as water follows a gradient from high to low humidity and is carried from the soil through the roots, xylem, and stomata into the air as vapour, heat (required to change the state of water to vapour) goes with it (Nobel, 1970). Therefore, considering only the benefit of cooling, *Artemisia*, *Echinacea* and *Fragaria* are good potential green roof plants based on their high transpiration rates (Table 11). The situation is dichotomous in that the shallow extensive green roofs' limiting factor is often drought due to insufficient plant-available water, and thus, without a waste-water cistern available to the green roof, plants high in transpiration are often poor choices.

That a plant will deplete available water quickly via the transpirational stream, is not in itself, reason enough to assume plant failure on the extensive green roof; drought tolerance must also be considered. In a water-stress experiment (unpublished data, 2011) including four groups of 30 plants per species which were watered every 2, 4, 8 and 16 days under cool greenhouse conditions, *Artemisia* exhibited traits which support the high transpiration rates monitored in this experiment: the plant exhibited great capacity for fast cover in a frequently irrigated phase, and extreme resistance to desiccation during drought.

Should water conservation be considered paramount on the extensive green roof, then *Anaphalis*, *Aster*, *Lotus*, and *Monarda*, based on their similarity in low transpiration rates to the industry standard *Sedum f.*, should be considered as suitable species for the extensive green roof.

Table 11. The effect of species and day on transpiration rate, 2012

Species	**Transpiration rate by day**[z] **(mmols m^{-2} s^{-1})**					**Pr > F**
	D1	**D2**	**D3**	**D4**	**D5**	
Anaphalis	0.12[y]*i*[x]	0.11*i*	0.12*i*	0.07*i*	0.09*i*	0.9999
Artemisia	1.98*de*	2.07*de*	2.02*de*	1.67*ef*	0.85*ghi*	0.0139
Aster	0.59*hi*	0.60*hi*	0.56*hi*	0.24*i*	0.43*hi*	0.8695
Echinacea	3.57*ab*	4.35*a*	3.04*bcd*	2.41*cde*	1.47*efgh*	<.0001
Fragaria	3.21*bc*	3.32*abc*	2.07*de*	1.61*efg*	0.64*hi*	<.0001
Lotus	0.46*hi*	0.64*hi*	0.27*i*	0.30*i*	0.13*i*	0.7267
Monarda	0.57*hi*	0.29*i*	0.62*hi*	0.59*hi*	0.29*i*	0.8351
Sedum f.	0.21*i*	0.05*i*	0.07*i*	0.16*i*	0.08*i*	0.9943
Pr > F	<.0001	<.0001	<.0001	<.0001	0.1621	

[z] Where calendar day (mm/dd) for D1= 08/21, D2= 08/22, D3= 08/23, D4= 08/24, D5= 08/25

[y] Where units of are mmols m^{-2} s^{-1}

[x] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.

Standard error of the means = ±0.34

There was a significant interaction between species and day on stomatal conductance (Table 12). There were significant differences among species on all days with the exception of D5. There were significant differences within species by day for *Artemisia*, *Echinacea*, and *Fragaria.* There were no significant differences detected between *Anaphalis*, *Aster*, *Lotus*, *Monarda*, and the control *Sedum f.* in stomatal conductance.

Although *Artemisia*, *Echinacea* and *Fragaria* had higher stomatal conductance than the other species for the first four days following the rain event, by D5 conductance slowed to the point that showed no significant difference among species (Table 12), suggesting similar water stress response in the form of stomatal closure among species. Similar stomatal response (and concomitant transpiration rate) (Table 11) across species during water shortage (D5) may negate the need to consider transpiration rate as a parameter to determine plant suitability to the green roof, as evaporation of soil water in the days leading to the low moisture conditions may equal the water used by *Artemisia*, *Echinacea* and *Fragaria* (Ács, 2003; Voyde et al., 2010), with the result that the low transpiration rates of the other species were of no consequence. In their work quantifying evapotranspiration on green roof substrate using succulents in New Zealand, Voyde and others (2010) found that in conditions with water abundance, transpiration rate accounted for up to 48% of the total evapotranspiration, and in conditions of water shortage evapotranspiration and evaporation were not significantly different as plants conserved water.

Table 12. The effect of species and day on stomatal conductance

Species	**Stomatal conductance by day[z](μmols m^{-2} s^{-1})**					**Pr > F**
	D1	**D2**	**D3**	**D4**	**D5**	
Anaphalis	10.0[y]*k*[x]	10.0*k*	10.0*k*	10.0*k*	10.0*k*	0.9994
Artemisia	120.0*de*	80.0*efg*	80.0*efg*	90.0defghi	30.0*jkl*	0.0029
Aster	20.0*hijk*	20.0*jkl*	20.0*hijk*	10.0*k*	20.0*jkl*	0.9815
Echinacea	220.0*b*	280.0*a*	130.0*cde*	140*cde*	50.0*fghijk*	<.0001
Fragaria	190.0*bc*	150.0*cd*	20.0*ef*	80.0*efghj*	20.0*ikl*	<.0001
Lotus	20.0*hijk*	20.0*hijk*	10.0*k*	20.0*hijk*	0.00*k*	0.8689
Monarda	40.0*fghijk*	10.0*k*	30.0*ghijk*	10.0*k*	0.01*k*	0.4144
Sedum f.	10.0*k*	10.0*k*	10.0*k*	10.0*k*	10.0*k*	0.9996
Pr > F	<.0001	<.0001	0.0004	.00046	0.7501	

[z] Calendar day (mm/dd) for D1= 08/21, D2= 08/22, D3= 08/23, D4= 08/24, D5= 08/25
[y] Where units of are μmols m^{-2} s^{-1}
[x] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ±0.02

Photosynthetic rate differed significantly by day (Table 13). The photosynthetic rates on D1 and D2 were significantly higher than D4 and D5.

As expected, as days without irrigation continued, photosynthetic rate decreased Table 13). As plant-available moisture decreases, stomata close as a drought-response in order to conserve water. This disables the carbon-harvesting ability of the plant, and CO_2 becomes a limitation to biomass creation via photosynthesis.

Table 13. The effect of day on photosynthetic rate

Day	Photosynthetic rate (μmols m^{-2} s^{-1})
08/21	2.82*a*[z] ± 0.43
08/22	2.71*a* ± 0.39
08/23	2.07*ab* ± 0.44
08/24	1.44*b* ± 0.49
08/25	1.09*b* ± 0.38

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.

Photosynthetic rate differed significantly by species (Table 14). *Anaphalis*, *Artemisia*, and *Aster* had significantly higher photosynthetic rates than *Echinacea*, *Fragaria*, *Lotus*, *Monarda* and *Sedum f.*

The photosynthetic rates measured in this experiment are quite low according to the LCA-4 Portable Photosynthesis System manual which states the typical range at 0-100 μmols m^{-2} s^{-1}. This may be due to a physiological response across species to the conditions of the extensive green roof; generally, shallow porous substrate, high wind, high temperatures, and low moisture. In their work on stress-induced dormancy in orchids, Shefferson et al. (2005), found that dormancy may be an alternative which allows plants to mitigate stressful environments without risking plant death. In their work with perennial grasses, Volaire and Norton (2006) note that a defining criterion of summer dormancy is a slowing or stoppage of normal leaf growth and production. Further, they found that summer dormancy resulted in increased survival after drought conditions.

Should this low photosynthetic rate across species be indicative of induction of dormancy, then perhaps consideration should be given to the studying of genetic predisposition toward dormancy for the extensive green roof. Certainly, this response supports attributes observed in Asteraceae regarding phenotypic plasticity.

Table 14. The effect of species on photosynthetic rate, August 2012

Species	**Photosynthetic rate (µmols m^{-2} s^{-1})**
Anaphalis	0.*16b*[z] ± 0.67
Artemisia	4.03*a* ± 0.60
Aster	1.05*b* ± 0.63
Echinacea	5.64*a* ± 0.80
Fragaria	3.86*a* ± 0.58
Lotus	0.57*b* ± 0.60
Monarda	0.77*b* ± 0.69
Sedum f.	0.12*b* ± 0.71

[z] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.

July 11, 2012 was similar to August 20- 24 in maximum temperature and wind speed, but had 9.7 mm of rainfall in the week before the data collection as compared to the 65 mm received in the week before the August data collection (Environment Canada National Climate Data and Information Archive, 2012b and c), so despite the generally less favourable conditions for growth in the week prior to the July data collection, photosynthetic parameters were lower in August.

By general observation, growth rate in July was high, plants were lush, and active leaf expansion occurred. In August, although the growth rate was noticeably slower, new leaf growth and expansion were present.

Monarda, which was among *Artemisia*, *Echinacea* and *Lotus* in highest values for the photosynthetic parameters in July (Table 15), and among the lowest in August (Tables 11-14), appeared to be the only obvious species whose low photosynthetic rates were directly related to senescence. As the upper leaves on the flower stalks had turned from green to pink and white (an adaptation of the leaves which, from a pollinator's perspective, allowed them to function as flower parts, thus limiting the expenditure of resources required for floral production), and the only visible growth were small, newly formed petals, measurements were taken on the healthiest green leaves directly below the flowers as there were no obvious newly formed leaves.

Despite having similar environmental conditions and less rainfall, July photosynthetic parameters (Table 15) were higher than those in August (Tables 11-14), lending to the possibility that limited resources (substrate volume for root expansion) and adverse conditions (large fluctuations in temperature) other than plant-available water may have triggered dormancy at some point between the July and August measurements.

Table 15. Average values of photosynthetic parameters, July 11, 2012

Species	**Transpiration rate (mmols $m^{-2} s^{-1}$)**	**Stomatal conductance (µmols $m^{-2} s^{-1}$)**	**Photosynthetic rate (µmols $m^{-2} s^{-1}$)**
Anaphalis	0.33	10.0	0.80
Artemisia	1.88	14.0	5.84
Aster	0.60	30.0	1.23
Echinacea	4.34	200.0	13.11
Fragaria	3.43	210.0	8.17
Lotus	0.61	200.0	0.78
Monarda	3.76	180.0	11.28
Sedum f.	0.12	10.0	0.20

There were significant correlations between environmental and photosynthetic parameters (Table 16). Soil moisture had a positive correlation with transpiration and stomatal conductance ($P = 0.0046$), and a marginally positive correlation ($P = 0.08$) with net photosynthesis. Average air temperature had marginally negative correlations with stomatal conductance ($p = 0.075$) and transpiration ($P = 0.0641$). Maximum soil temperature had negative correlations with photosynthetic rate, stomatal conductance, and transpiration rate ($P = 0.0050$, 0.001, and 0.0004 respectively). Stomatal conductance and transpiration were positively correlated (0.95, $P < 0.0001$). Net photosynthesis had positive correlations with transpiration and stomatal conductance (0.82, $P = 0.0001$).

As expected, when soil moisture was depleted, transpiration rate, stomatal conductance, and photosynthetic rate decreased (Table 16; Fig. 3, 4, 5). Hall et al. (1993) note that soil moisture decreases, stomata close and photosynthetic rate lessens. Also, as expected, stomatal conductance and transpiration decreased as air temperature increases. Maximum soil temperature, closely related to air temperature, supports the air temperature correlation in its negative correlation with stomatal conductance, transpiration rate and photosynthetic rate. As soil temperature increases, so does evaporation from the soil surface, and with a depletion of plant-available water, the decrease in water potential in the roots creates a feed-forward response to close stomata. As the stomata close, decreases occur in stomatal conductance, water loss by diffusion as transpiration, and biomass production via conversion of the carbon in CO_2 to carbohydrates in the photosynthetic processes. That stomatal conductance and transpiration were highly correlated is expected as 75% of the water loss in plants due to evaporation, and 90-95% of the water loss in leaves occurs via diffusion through the stomata (Hopkins and Hüner, 2009), and thus stomatal regulation largely regulates transpiration.

Table 16. Correlation between environmental and photosynthetic parameters

		Net photosynthesis	**Stomatal conductance**	**Transpiration**
Soil moisture	Correlation[z]	0.28	0.46	0.44
	P- value	0.08	0.0046	0.0046
Average temperature[y]	Correlation	-0.19	-0.28	-0.28
	P- value	0.2148	0.0750	0.0641
Maximum temperature[x]	Correlation	-0.42	-0.49	-0.51
	P- value	0.0050	0.001	0.0004
Minimum temperature[w]	Correlation	0.18	0.01	0.17
	P- value	0.2319	0.9379	0.2696
Transpiration	Correlation	0.82	0.95	
	P- value	<0.0001	<0.0001	
Stomatal conductance	Correlation	0.82		
	P- value	<0.0001		

[z] Correlation = correlation coefficient (r)
[y] Average temperature = average air temperature for the day
[x] Maximum temperature = maximum temperature of the soil for the day
[w] Minimum temperature = minimum temperature of the soil for the day

Fig. 3, 4 and 5 show the correlations based on the mean values of the transpiration, stomatal conductance and photosynthetic rate for each day in order that patterns for the individual species could be observed for the five days of data collection.

Generally, *Artemisia* had higher transpiration rates, stomatal conductance and photosynthetic rates than *Aster* or *Lotus* (Fig. 3, 4 and 5). All three species show the trend of lower values of all three parameters as days increase without irrigation. Despite higher values, *Artemisia* shows similar (even higher) soil moisture levels than the other two species by D5, supporting the hypothesis that soil-water evaporation may negate the effects of high stomatal conductance, transpiration and photosynthetic rates across these species. Percent cover (Table 5) did not vary significantly among these species, but the unmeasured parameter of distance from soil to leaf cover may have; as *Artemisia* is more prostrate with larger leaves than either *Aster* or *Lotus*, there is a potential decrease in the interaction between the soil surface and the air, and thus, soil evaporation from those two species may have been more accessible. This factor may play to the need of the extensive green roof designer to include combinations of plants of different morphology in the interest of preserving limited water, further supporting the work of Lundholm et al. (2010) in their work on functional group combinations.

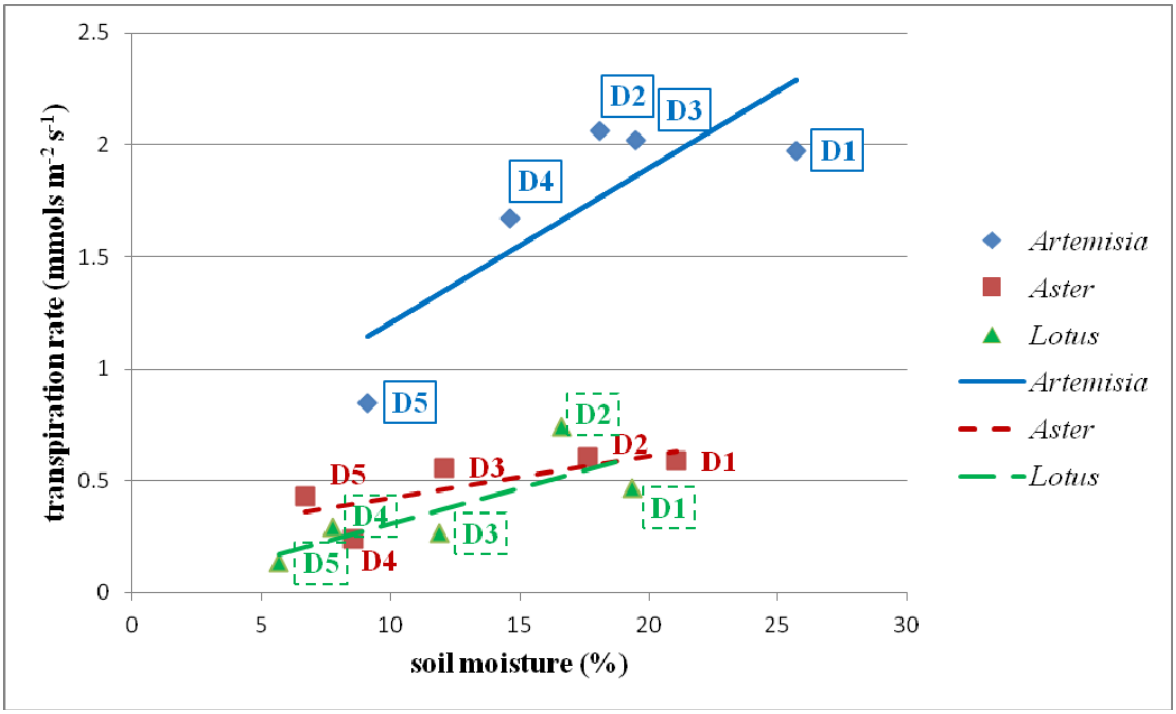

Figure 3. Correlation of mean soil moisture and transpiration over 5 days (D1= 08/21, D2 = 08/22, D3 = 08/23, D4 = 08/24, D5 = 08/25)

The high stomatal conductance of *Artemisia* (Fig. 4) on D1 and its relatively steep decline over the five days (as compared to *Aster* and *Lotus*) may suggest an increased ability over the other species to take advantage of soil-available water when it occurs. This makes sense as this species, *Artemisia stelleriana* Besser., is a plant found primarily in the sand dunes of coastal regions, and therefore would be forced to evolve to become efficient at water scavenging in a desiccating environment with fast-draining soil.

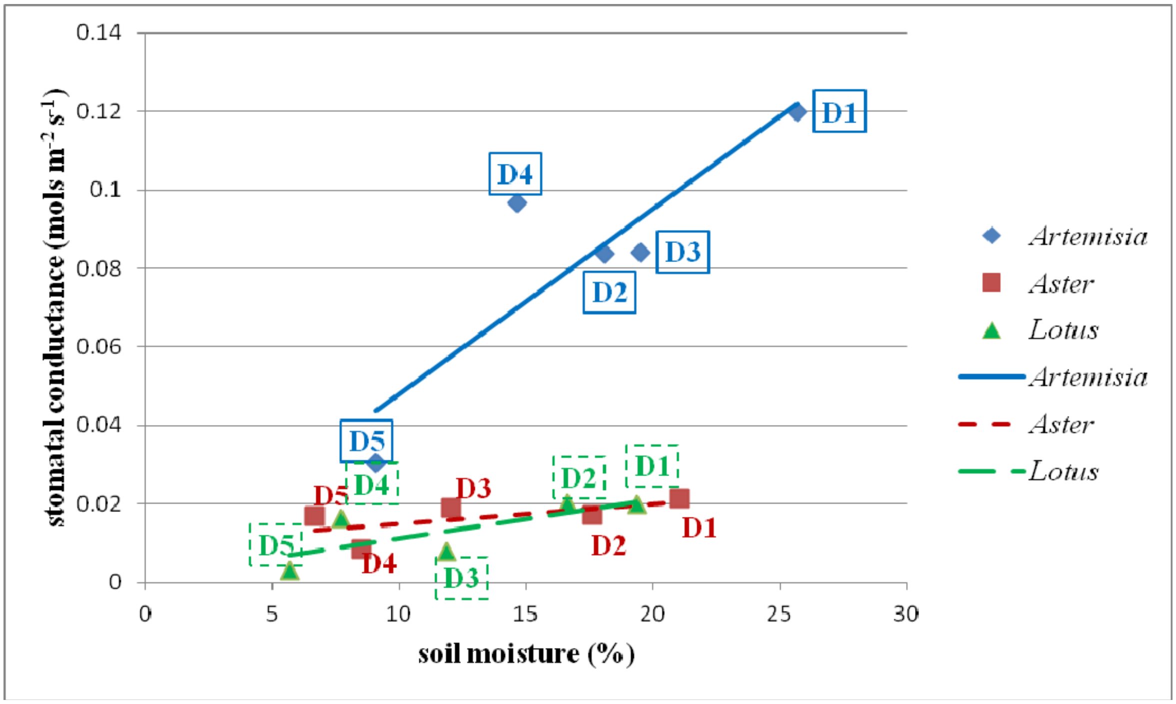

Figure 4. Correlation of mean soil moisture and stomatal conductance over 5 days (D1= 08/21, D2 = 08/22, D3 = 08/23, D4 = 08/24, D5 = 08/25)

That Artemisia has a higher photosynthetic rate than the other two species (Fig. 5) over the five days also supports the hypothesis above, fixing carbon to increase biomass with the ultimate goal of setting seed to reproduce in a water-limited, stressful environment.

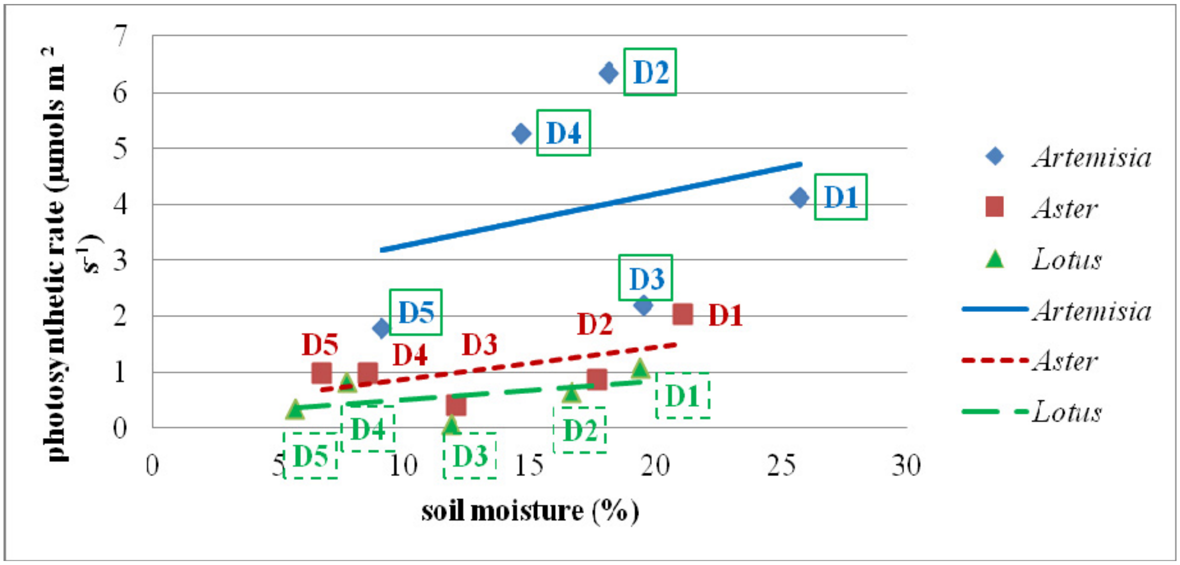

Figure 5. Correlation of mean soil moisture and photosynthetic rate over 5 days (D1= 08/21, D2 = 08/22, D3 = 08/23, D4 = 08/24, D5 = 08/25)

Maximum soil temperature differed significantly among species (Table 17). Soil maximum temperature beneath *Artemisia* was significantly lower than that of *Aster* and *Lotus*. There was no difference in soil maximum temperature beneath *Aster*, *Lotus* and *Sedum a*.

The results of the effect of species on maximum temperature (Table 17) and soil moisture (Table 18) are further validated by the effect of species on percent cover, as all four species tested for soil moisture reached percent covers with which there were no differences at almost full coverage (Table 5), thus establishing a true basis from which to discuss the contribution of these species to the benefits of green roofs.

Reduced surface/soil/substrate temperature of the green roof lowers energy costs associated with the use of air conditioning in response to increased ambient heat due to solar radiation (Snodgrass and Snodgrass, 2006; Simmons et al., 2008). As there was no difference between *Artemisia* and the industry standard *Sedum a.* in attaining the coolest soil of the species tested (Table 17), *Artemisia* may be a suitable species to mitigate energy costs associated with solar heat.

Table 17. The effect of species on maximum soil temperature, 2012

Species	**Soil maximum temperature (°C)**
Artemisia	25.6*b*^{z}
Aster	27.5*a*
Lotus	27.8*a*
Sedum a.	25.9*ab*

^{z} Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = 0.6

Soil moisture differed significantly among species (Table 18). *Aster* and *Lotus* had significantly drier soils than *Sedum a*. There was no difference in soil moisture between *Artemisia* and *Sedum a*.

Canopy closure lowers soil water loss (Hopkins and Hüner, 2009). As drought stress due to water scarcity is often the factor which leads to the incompatibility of a species on an extensive green roof, any increase in the retention of soil moisture can be crucial to plant survival. Therefore, as there were no significant differences in percent cover between the species tested (Table 5), we can infer that *Artemisia* is as suitable as the control *Sedum a.* in retaining soil moisture (Table 18).

Table 18. The effect of species on soil moisture, 2012

Species	**Soil moisture (%)**
Artemisia	10.8ab^z
Aster	10.5b
Lotus	9.0b
Sedum a.	13.6a

^{z} Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ according to Fisher's protected LSD.
Standard error of the means = ± 0.9

The Shortwave infrared range (1350- 2500 nm) is not presented in this study as it is the presence of water in the vacuoles of plant tissue that determines the reflectance in this portion of the spectrum (Samson, 2000), and the variable water content of the shallow extensive green roof presents too many factors to elicit a true result with such a limited frequency of data collection.

Species photos (Fig. 6-29) are presented in pairs to highlight visual differences in change over time between the reflectance dates (July 3, and September 12).

July *Anaphalis* is in a vegetative state, lush and dark green, while September *Anaphalis* is laden with reproductive structures and vegetative structures are yellowing and thinner than that of July (Fig. 6 and 7). July *Antennaria* is covered in reproductive structures, with a blue hue to the vegetation, while September *Antennaria* is a lush green devoid of blue (Fig. 8 and 9). July *Arabis* is a lush green while September *Arabis* has yellowed, with no sign of reproductive structures on either (Fig. 10 and 11). July *Artemisia* is lush vegetation with a blue hue, and September *Artemisia* is a mottled blue and white and green mix with some light coloured reproductive structures (Fig.12 and 13). July *Aster* is lush and green, while September *Aster* has much red and reproductive structures are present (Fig.14 and 15). July *Coreopsis* is slightly darker green than the September *Coreopsis*, which has a yellower appearance (Fig. 16 and 17). July *Echinacea* is lush and dark green and in a vegetative state while September *Echinacea* vegetation has yellowed and dominant white-pink flowers are present (Fig. 18 and 19). July *Fragaria* is lush and green vegetation, while September *Fragaria* has much red and some yellowing (Fig. 20 and 21). July *Lotus* is lush and green, while September *Lotus* has lost some brilliance and exhibits intermittent tan-colour where dead tissue is present (Fig. 22 and 23). July *Monarda* shows lush green vegetation, and September *Monarda* shows very little green with dominant reproductive structures in white to pink (Fig. 24 and 25). July *Sedum a.* is covered in yellow flowers while September *Sedum a.* is green combined with washed-out green/brown (Fig. 26 and 27). July *Sedum f.* is dominated by lush green vegetation with intermittent red to yellow flowers, while September *Sedum f.* is a lighter and duller green vegetation (Fig. 28 and 29).

Figure 6. July *Anaphalis* (Golf ball diameter = 4.27 cm)

Figure 7. September *Anaphalis* (Golf ball diameter = 4.27 cm)

Figure 8. July *Antennaria* (Golf ball diameter = 4.27 cm)

Figure 9. September *Antennaria* (Golf ball diameter = 4.27 cm)

Figure 10. July *Arabis* (Golf ball diameter = 4.27 cm)

Figure 11. September *Arabis* (Golf ball diameter = 4.27 cm)

Figure 12. July *Artemisia* (Golf ball diameter = 4.27 cm)

Figure 13. September *Artemisia* (Golf ball diameter = 4.27 cm)

Figure 14. July *Aster* (Golf ball diameter = 4.27 cm)

Figure 15. September *Aster* (Golf ball diameter = 4.27 cm)

Figure 16. July *Coreopsis* (Golf ball diameter = 4.27 cm)

Figure 17. September *Coreopsis* (Golf ball diameter = 4.27 cm)

Figure 18. July *Echinacea* (Golf ball diameter = 4.27 cm)

Figure 19. September *Echinacea* (Golf ball diameter = 4.27 cm)

Figure 20. July *Fragaria* (Golf ball diameter = 4.27 cm)

Figure 21. September *Fragaria* (Golf ball diameter = 4.27 cm)

Figure 22. July *Lotus* (Golf ball diameter = 4.27 cm)

Figure 23. September *Lotus* (Golf ball diameter = 4.27 cm)

Figure 24. July *Monarda* (Golf ball diameter = 4.27 cm)

Figure 25. September *Monarda* (Golf ball diameter = 4.27 cm)

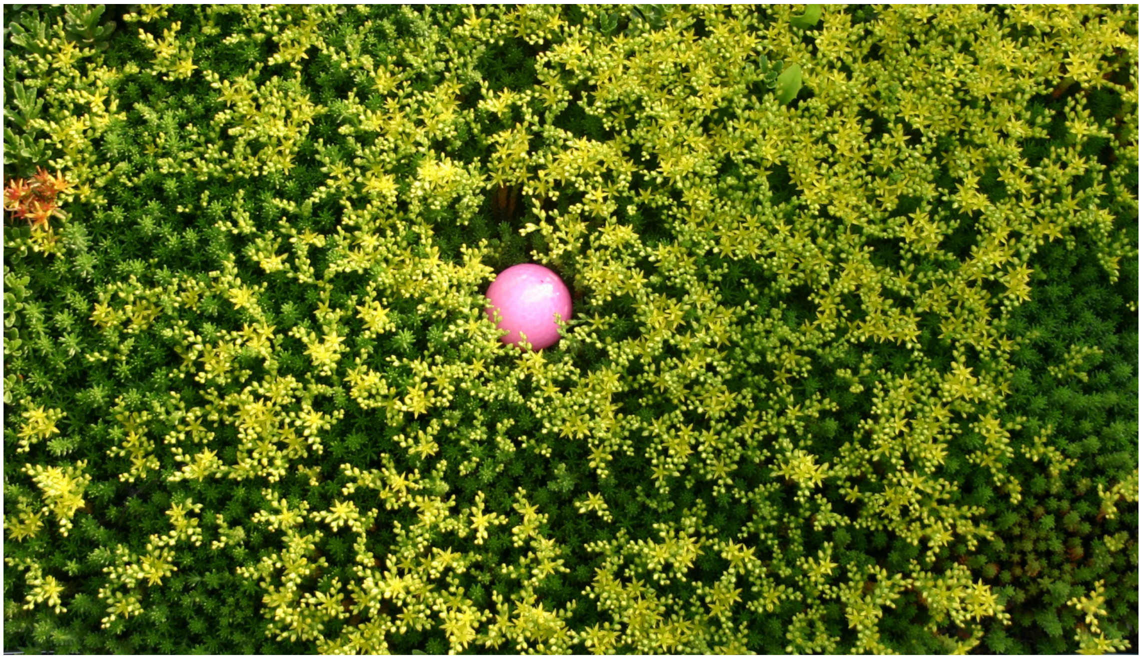

Figure 26. July *Sedum a.* (Golf ball diameter = 4.27 cm)

Figure 27. September *Sedum a.* (Golf ball diameter = 4.27 cm)

Figure 28. July *Sedum f.* (Golf ball diameter = 4.27 cm)

Figure 29. September *Sedum f.* (Golf ball diameter = 4.27 cm)

There was a significant interaction among date, species and wavelength on reflectance for the 600 – 750 nm range (Table 19). There was a significant interaction between date and species over time for all other ranges, and a significant effect of wavelength on reflectance.

Table 19. Summary of *P*-values from ANOVA for reflectance from test species

Effect	***P* > F**			
	400-550 nm	**600-750 nm**	**800-1050 nm**	**1050-1350 nm**
date (D)	0.1752	0.3695	0.1851	0.3568
species (S)	**<.0001**	**<.0001**	**<.0001**	**<.0001**
wavelength (W)	**<.0001**	**<.0001**	**0.0103**	**<.0001**
D × S	**<.0001**	**<.0001**	**<.0001**	**<.0001**
D × W	0.3140	**<.0001**	0.2723	0.6461
S × W	0.6460	**0.0067**	1.0000	1.0000
D × S × W	0.9993	**0.0212**	1.0000	1.0000

For the range of 400 – 550 nm, July *Echinacea* and *Lotus*, and September *Artemisia* and *Monarda* had significantly higher reflectance than all other species for both months with the exceptions of September *Antennaria*, *Aster* and *Echinacea* (Fig. 30). *Echinacea* had significantly higher reflectance than *Sedum a*. July *Anaphalis* was significantly higher in reflectance than all other species for both months, and there were no significant differences between all remaining species for either month.

Absorption of pigments crucial to photosynthesis largely occurs in the visible range, of which, the majority (chlorophyll a, chlorophyll b, α-carotenoid, β-carotenoid, anthocyanin, lutein, and violaxanthin) fall between 400 and 550 nm (Zwiggelaar, 1998), accounting for low reflectance (less than 30 %) in these wavelengths. As *Monarda* began to senesce (beginning in mid-late July in this experiment), the dominant colours gradually changed from green to pink and white as chlorophyll synthesis ceases (Samson, 2000), dramatically altering reflectance, adding to its suitability for green roofs with regards to reflectance. In this range, *Echinacea* was the only species which had higher reflectance than *Sedum a.* for both months, giving some merit to this species with regards to suitability to the green roof.

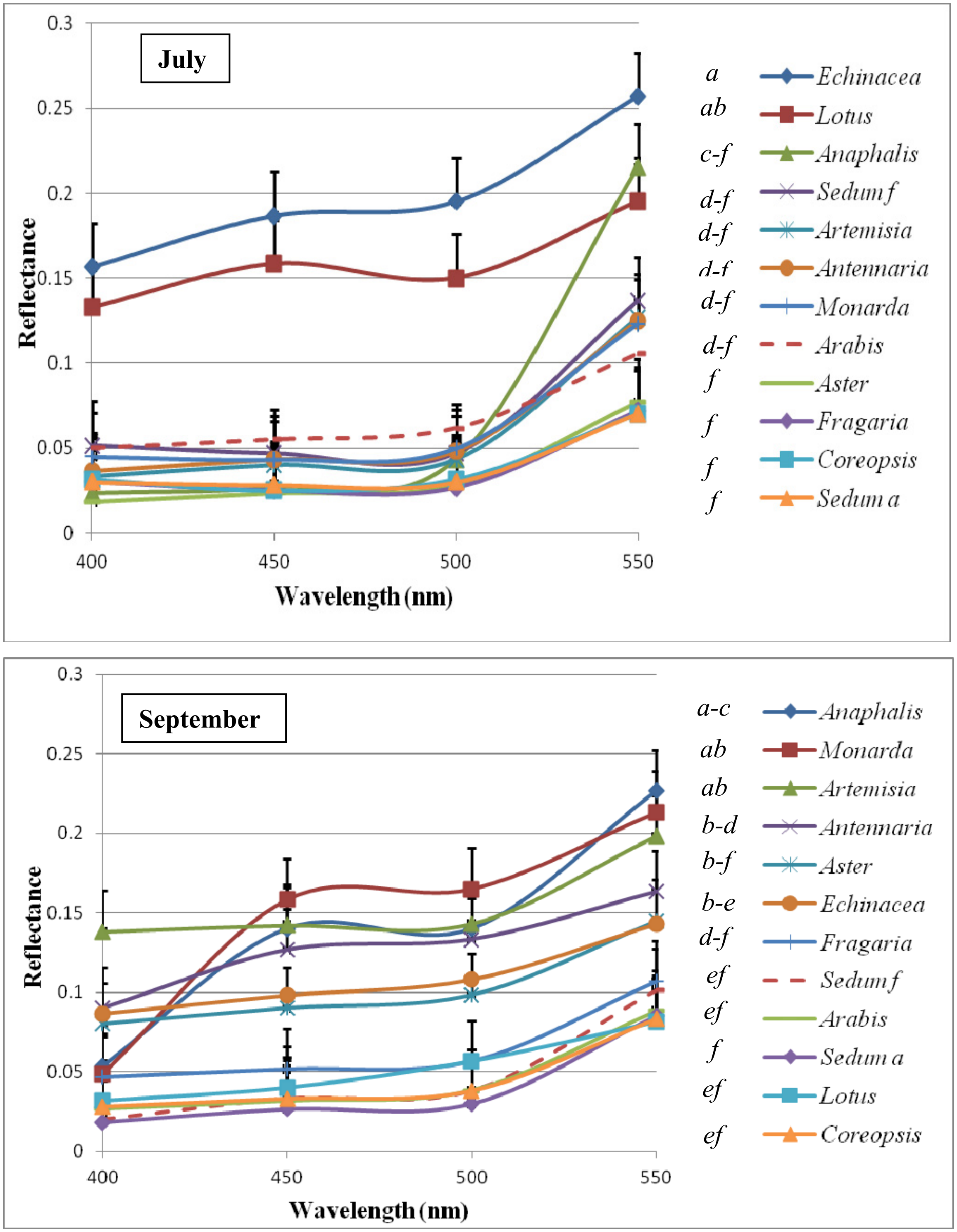

Figure 30. Reflectance of test species for 400 – 500 nm. Error bars are standard error of the means. Lines with the same letters are not significantly different at $P \leq 0.05$ according to Tukey's HSD test.

There were no significant differences in reflectance among species for 600, 650, and 700 nm, but there were significant differences in reflectance among species at 750 nm (Fig. 31). July *Anaphalis* and *Echinacea* were significantly higher in reflectance than *Sedum a*. for both months, while there were no differences between all other species and *Sedum a.* for both months excluding July *Antennaria*, *Aster*, and *Artemisia*. *Antennaria*, *Arabis*, *Artemisia*, *Aster*, *Coreopsis*, *Fragaria*, *Lotus*, *Monarda* and *Sedum f.* had similar reflectance for both months.

Chlorophyll a and b absorb at 650, and 670 - 680 nm respectively (Zwiggelaar, 1998), possibly accounting for the continuation of the relatively low reflectance in the 600, 650, and 700 nm ranges of the visible spectrum for both July and September.

The near-infrared range of 750 – 1400 nm is free of the principle absorbers (pigments in the visible range [350 – 750 nm], and water in the mid-infrared range [> 1400 nm]) in plants, and therefore, high reflectance values are present. Separation of percentages of reflectance by species is dependent on factors like leaf morphology (generally flat reflect more than cylindrical), structure (primarily, the orientation of mesophyll cells), orientation and coverage (Ollinger, 2010). The cuticular waxes of adaxial, or top surfaces of leaves allow penetration of solar radiation in the near-infrared range due to transparency, accounting for the high reflectance associated with scattering in the mesophyll. Differences in concentration and size of cells and tissue in the mesophyll of leaves account for much variation in reflectance among species. Species with leaves which are oriented such that many abaxial surfaces are exposed to sunlight can lower reflectance due to the impervious nature of the back epidermis; sunlight does not reach the mesophyll layer for high reflectance (Baranoski and Rokne, 1997).

Such orientation variation among species and within species over time may contribute to understanding the reasoning behind higher reflectance at 750 nm for *Anaphalis* in July than that for the control *Sedum a*. in either month; the leaf surfaces of *Anaphalis* in July were more prostrate than in September, and back surfaces were not visible, however *Sedum a*. had a different geometry and thus the orientation was such that many abaxial surfaces may have been exposed to sunlight, lowering the potential reflectance. *Echinacea* appeared similar in leaf orientation on both months, so the reasoning for the lower reflectance in September may be due to other factors.

July *Echinacea* had significantly higher reflectance for the 800 – 1050 nm range than all other species in both months with the exceptions of *Artemisia*, *Aster*, *Sedum f.*, July *Anaphalis*, *Antennaria*, and *Lotus* (Fig. 32). There were no significant differences in reflectance among *Artemisia*, *Aster*, July *Anaphalis*, *Antennaria*, *Echinacea* and *Lotus* and the control *Sedum f.* and September *Sedum a*.

Water absorption occurred at ~940 nm, possibly accounting for the pattern of lower reflectance present in Fig. 32. (Noble and Li, 2012).

For the range of 1100 – 1350 nm, July *Artemisia* and *Echinacea* were significantly higher in reflectance than July *Fragaria*, *Aster*, *Sedum a*., and September *Coreopsis* (Fig. 33). No species were significantly different from *Sedum f.*

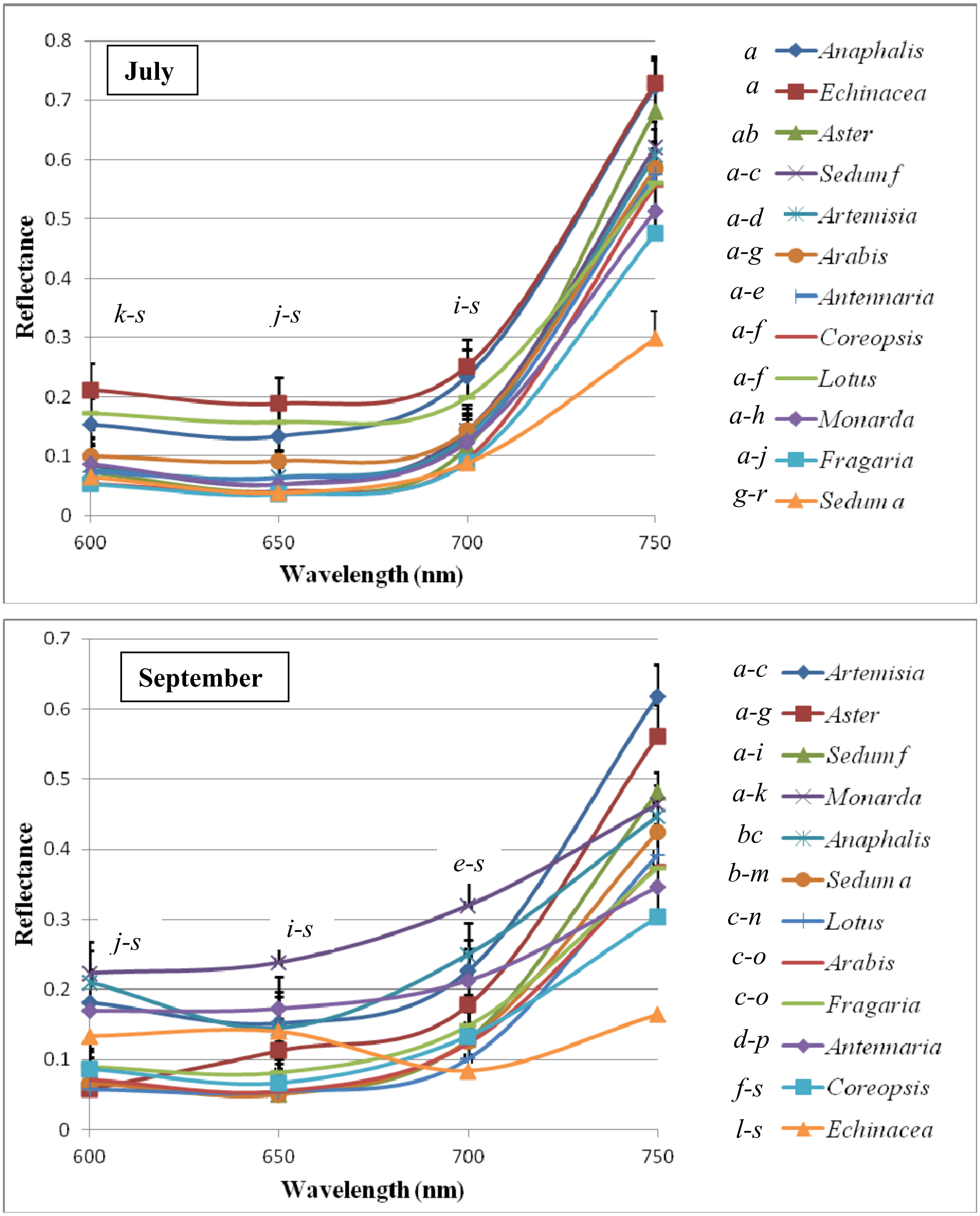

Figure 31. Reflectance of test species for 600 – 750 nm. Error bars are standard error of the means. Lines with the same letters are not significantly different at $P \leq 0.05$ according to Tukey's HSD test.

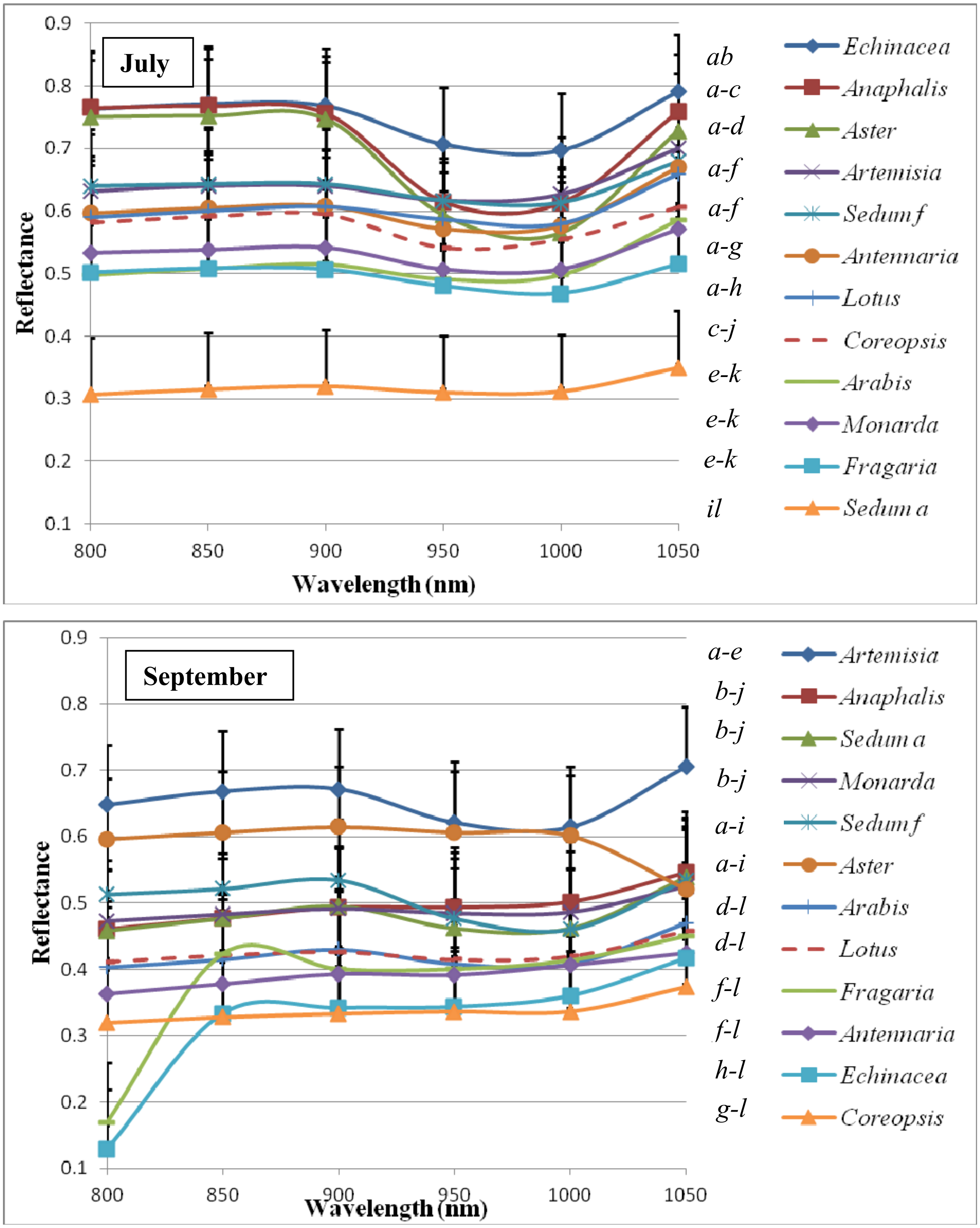

Figure 32. Reflectance of test species for 800 – 1050 nm. Error bars are standard error of the means. Lines with the same letters are not significantly different at $P \leq 0.05$ according to Tukey's HSD test.

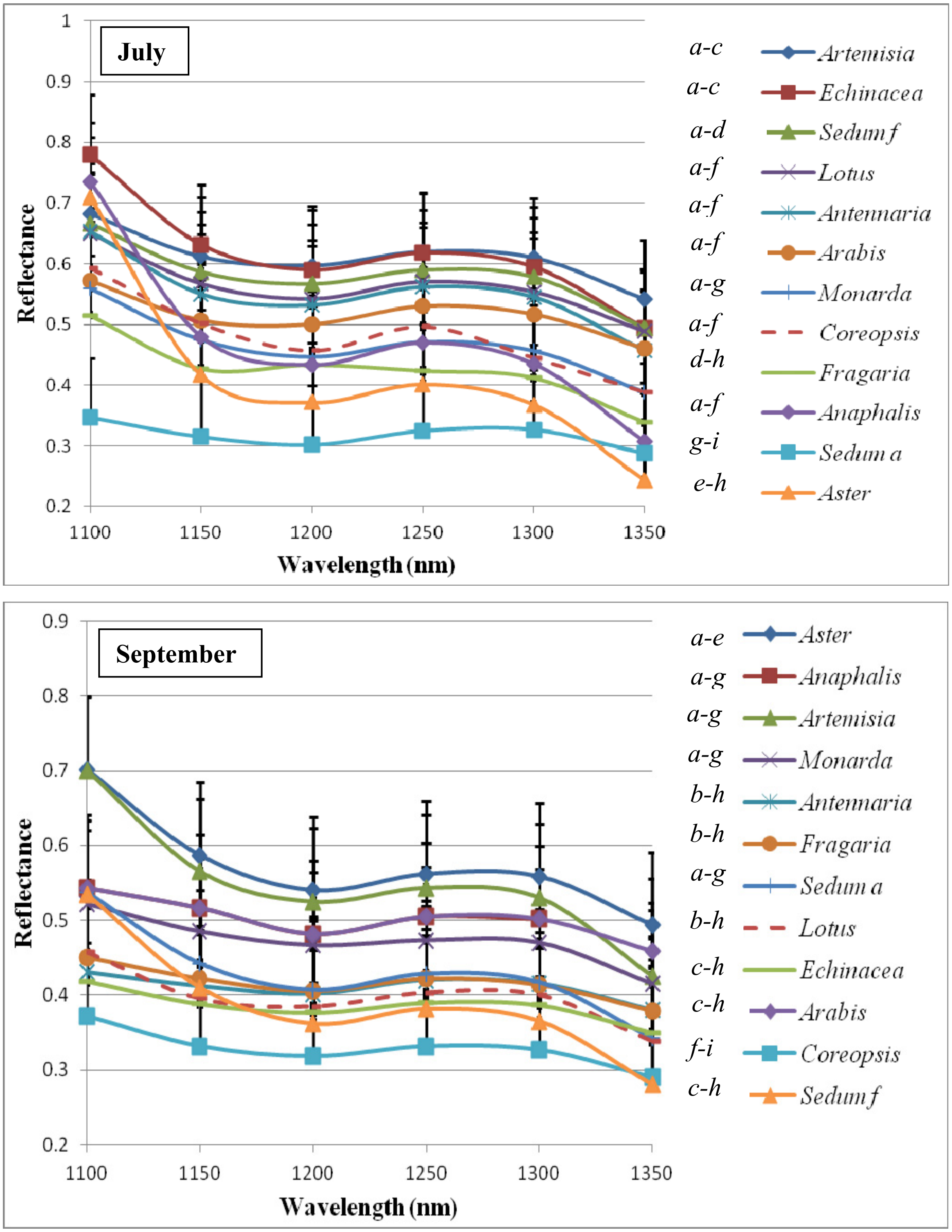

Figure 33. Reflectance of test species for 1100 – 1350 nm. Error bars are standard error of the means. Lines with the same letters are not significantly different at $P \leq 0.05$ according to Tukey's HSD test.

Chapter 5 Conclusion

Justification for allocation of time and resources into the creation and implementation of extensive green roofs has been shown through experimentation. Green roofs have been shown to lessen the Urban Heat Island Effect, lower building energy costs, mitigate storm water runoff and the associated deleterious effects, sequester carbon and airborne pollutants, dampen sound pollution, and increase biodiversity and pollination.

Empirical data collected in this study largely focussed on benefits associated with the reduction of the Urban Heat Island Effect and building energy costs, namely the photosynthetic parameters (however, data were not collected on *Antennaria*, *Arabis*, *Coreopsis*, or *Sedum a*. due to an incompatibility with the leaf chamber) soil temperature and moisture (collected for *Artemisia*, *Aster*, *Lotus* and *Sedum f.*), reflectance and percent cover. Carbon and pollution sequestration were addressed by way of fresh and dry weights.

Suitability of Species to the Extensive Green Roof in Northern Nova Scotia

Artemisia stelleriana was the best performing plant species compared to the control *Sedum* spp. in meeting the requirements of the green roof. Despite having attained only 55% cover by the season's end of the establishment year it reached similar percent cover as both *Sedum* spp. by the end of year two, had similar soil temperatures and soil moistures, had similar or better reflectance values, and scored between the controls for fresh and dry weights. Despite having similar soil moistures as the controls, *Artemisia* had higher transpiration rates (which contribute to roof cooling). That it was able to contribute more to cooling through transpiration than *Sedum f.*, and maintained similar soil moisture to *Sedum a*., may point to superiority in protecting the soil from evaporation. The observed drought tolerance of *Artemisia* makes it an ideal candidate for extensive green roofs in Northern Nova Scotia.

Lotus corniculatus attained similar percent cover to the control *Sedum* spp., had similar shoot weights to *Sedum a*., similar root weights to *Sedum f.,* similarly low photosynthetic rates to both controls (which, given the dichotomous nature of the water conservation necessity versus the heat-shedding contribution of transpiration, could also be considered a benefit) and was higher than *Sedum a*. in reflectance in July. That *Lotus* (Fabaceae family) can fix nitrogen is worthy of consideration on extensive green roofs given the limited resources afforded the shallow substrate with relatively low organic matter.

Aster novi-belgii attained similar percent cover to the *Sedum* spp., had higher shoot weights than *Sedum a*. but lower than *Sedum f*., had highest root weights along with Sedum f., and higher photosynthetic rates than either control. As well as the correlated benefit of heat- shedding via transpiration, higher photosynthetic rates also contribute to increased carbon sequestration and pollutant capture through increased biomass. *Aster* is also taller than the controls, and with considerable dead fibrous tissue left erect above-ground during the winter, the potential to provide insulative properties via snow capture and thus mitigate heat loss through the roof exists with this species. This plant is suitable for the extensive green roof in Northern Nova Scotia.

Anaphalis margaritacea had higher photosynthetic rates than the controls, scored in between the *Sedum* spp. in root dry weight, and was similar to or better than the control plants in reflectance. *Anaphalis* had a relatively low winter survival rate at ~69%, but an adjustment to establishment density may increase survival and percent cover, making it a species worthy of consideration for the extensive green roof in Northern Nova Scotia.

Antennaria dioica had higher root dry weight than *Sedum a*., and had similar reflectance values to the controls. *Antennaria* is a slow growing plant which shows great potential in mitigating the Urban Heat Island Effect and building energy expenditure via its solar reflectance properties should establishment criteria be altered successfully to attain canopy closure.

Monarda punctata performed similarly to the controls in root dry weight, photosynthetic rate, and reflectance. Despite high percent cover in the establishment year followed by poor winter survival and poor percent cover for 2012, the facility of the plant to attract pollinators was exceptional. Aptly named Bee Balm, this plant was laden in bees from late July until the experiment ended in September 2012. During the establishment year, the perennial did not flower, and bee presence was not unusual, leading me to conclude that if not for the typical benefits such as the mitigation of the

Urban Heat Island Effect and building energy reduction, *Monarda* should be used on extensive green roofs in Northern Nova Scotia to encourage pollinators.

Coreopsis verticillata had similar high root weight to *Sedum a*., and showed similar reflectance values to the controls. *Coreopsis* had poor cover in 2012 despite 100% winter survival and relatively high coverage by the end of the establishment summer (~87%), suggesting plant failure due to unknown factors such as exposure, substrate depth or composition. The reflectance attributes that it possesses provide little true value because a closed canopy could not be attained, and thus, a high percent of incoming solar radiation would pass through the leaves and reach the soil substrate. This species is thus deemed unsuitable for the monoculture extensive green roof in Northern Nova Scotia.

Arabis sturii had comparable winter survival and reflectance values to the controls, and similar shoot and root dry weight to *Sedum a*. It may be that for a long-lived, low- maintenance extensive green roof, this species may contribute to the inherent benefits; when set against the upkeep requirements of some of the species which are heavy users of nutrients, *Arabis* may be preferable in the long term. I am hesitant to deem this plant unsuitable for the green roof due to its slow growth, however, due to the lack of empirical support evident in the results, this species under these parameters is unsuitable.

Fragaria virginiana had beneficial similarities to the control *Sedum* spp. in root dry weight, photosynthetic rate, and reflectance values. Percent cover was among the lowest. Within the constraints of the variables which were measured, *Fragaria* is not suitable to the extensive green roof in Northern Nova Scotia.

Echinacea purpurea was similar to the controls in root dry weight and photosynthetic parameters. It was significantly higher in reflectance than *Sedum a.* for more than half of the tested ranges; the only criterion where it proved better than a control. *Echinacea* had the lowest establishment year coverage, winter survival, percent cover in 2012, and vigour. Although its height was reduced from published values, vigour suffered concomitantly and therefore phenotypic plasticity was not present, and short stature was likely due to stress. As its transpiration rates were the highest of all species, an increase in the planting density (which might lead to greater coverage) would lead to depleting the soil moisture, causing drought conditions, thus decreasing, rather than increasing its performance on the roof. *Echinacea* is unsuitable for extensive green roofs in Northern Nova Scotia.

Recommendations

Establishment protocol:

As there were no literature standards for establishing these species in the LiveRoof® modules (which were shallow and unique in composition), the decision of the number of plants per module (15 plants per, which equals 42 plants/m^2), regardless of species, was to test at a specific level upon which informed recommendations could be made at the end of experimental observations.

Determining the appropriate size that the establishing plant should attain before the transfer to the roof is crucial. Testing the success of species survival on the roof by varying seedling/transplant/cutting size before transfer may improve percent cover and survival.

Using this model (that is, the LiveRoof® modules consisting of LiveRoof® Engineered Green Roof Soil™ at a depth of 10 cm [LiveRoof®, 2011a]), *Anaphalis margaritacea* (L.) Benth. and *Antennaria dioica* (L.) Gaertn. planting densities should be increased to 20 plugs per module (30 cm x 60 cm).

Considering the high establishment percent cover attained by *Monarda* following the low survival rate in 2012, and the fact that local temperatures fell within the hardiness zone deemed suitable for *Monarda*, it may be that protocol for hardiness thresholds for green roofs in Northern Nova Scotia must be created separately from the usual species zone hardiness in order that shallow, less-protected root zones are considered.

Further research:

There is very little literature available on the species used in this experiment, and less on their application to extensive green roofs. Development of a pool of knowledge on the successful species of this experiment would further specify their suitability. Changes may include:

- The utilization of the LCA-4 Portable Photosynthesis System to measure the photosynthetic parameters more often over a variety of environmental conditions and times to obtain detailed physiological patterns of these species in response to drought, wind, heat and cool.
- Determination of specific growth dynamics of individual species over the growing season via data collection on new growth and leaf expansion would enhance the ability to explain the data collected with the LCA-4 Portable Photosynthesis System.
- The weekly use of the Analytical Spectral Devices (ASD) FieldSpec® 3 spectroradiometer (ASD Inc., Boulder, CO) to develop a continuum of reflectance by species to obtain an accurate picture of the reflectance properties over the entire growing season.
- The addition of soil moisture probes and thermocouples to monitor all species in order to develop water usage and conservation, and temperature statistics.
- An increase in the number of modules and the number of blocks to add to the accuracy of ruling out errors attributable to environmental factors such as the presence of microclimates, and heat-shedding inconsistencies of the building beneath the experiment.
- In addition to the average temperature variable which was written over each 24-hour period, an average temperature over daylight hours (or approximately 7 a.m. until 7 p.m.) could have increased correlations with stomatal conductance, transpiration and photosynthetic rate.
- The accumulation of data on the successful species in this experiment over a longer period to assess whether factors like high root volume and high transpiration rates impact negatively with regards to substrate and plant replacement, and ultimately economic viability of the extensive green roof.

Applying species in polyculture to the green roof may enhance the benefits based on:

- The water usage and conservation properties employed by over-, mid-, and under-storey plants evident in natural ecosystems.
- The coordination of species by high reflectance properties over time (that is, when one species' high reflectance fades, another species' high reflectance begins).

Percent cover plays a role in maintaining precious soil moisture on the roof, but determining if low transpiration rates in given species are rendered insignificant by the offset of evaporation is crucial to understanding whether high transpiration rates are beneficial to the roof for heat-shedding, or whether they are detrimental to the survival of the biota of the roof due to the exacerbation of drought conditions. Considering the results found in New Zealand regarding the lack of difference in evapotranspiration and evaporation under water shortage conditions in two succulents, it may be that once water shortage occurs on the green roof, evaporation, rather than species' specific stomatal conductance and transpiration rates, becomes the major limiting factor; and plant species' variables such as percent cover, canopy geometry and soil protection need to be quantified to limit evaporative losses. However, more work needs to be done with non-succulents to determine if these patterns hold true for differences in photosynthetic pathways and plant life forms.

Identifying the photosynthetic pathways (C3, C4, CAM, or facultative CAM) of potential extensive green roof species would increase predictability of the physiological responses which could occur on the roof, and would aid in the design of green roofs with regards to shade, exposure, and water usage.

Additional research into the quantification of biomass production via photosynthetic rate and transpiration rate needs to be conducted. It is unclear in the long term whether high shoot and perhaps more importantly, high root biomasses are sustainable given the limited resources of substrate volume on the extensive green roof; for the longer a green roof exists with minimal inputs and maintenance, the lower the environmental impact and cost, and thus the greater the justification for its implementation.

Determining species- or family-specific leaf orientation and geometric attributes, and identifying patterns therein which contribute to or detract from high reflectance, could provide valuable plant selection information for researchers and growers without necessitating the purchase of expensive radiometric devices.

Opportunities for growers:

Given the results of this study, and following the establishment protocol therein, local growers in Northern Nova Scotia could exploit *Artemisia stelleriana* Besser. as a viable extensive green roof species which shares many of the attributes inherent to the industry standard *Sedum* spp.

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Appendix 1. Soil test report for 2011 and 2012

	2011		2012	
Parameter	**Analysis**	**Rating**	**Analysis**	**Rating**
pH	7.7		7.4	
Organic matter (%)	6.9		6.5	
P205 (kg/ha)	99	L-	903	H
K20 (kg/ha)	267	M	241	M
Ca (kg/ha)	3599	M+	4398	H-
Mg (kg/ha)	1126	E	1087	E
Na (kg/ha)	72		41	
Sulfur (kg/ha)	28		18	
Al (ppm)	212.78		279.24	
Fe (ppm)	181		220	
Mn (ppm)	35		39	
Cu (ppm)	1.35		1.56	
Zn (ppm)	6.0		7.2	
B (ppm)	0.90		0.74	
CEC (meq/100 g)	14.2		15.9	
Base Sat. K(%)	2.0		1.6	
Ca (%)	63.3		68.9	
Mg (%)	33.0		28.4	
Na (%)	1.1		0.6	
H (%)	0.6		0.5	