2.1: Research Track

INVESTIGATING THE EFFECT OF SUBSTRATE TYPE AND SPECIES MIX ON PLANT COVER ON A MANHATTAN, KANSAS GREEN ROOF

Allyssa Decker [a]***, Lee R. Skabelund*** [b]

[a] *Dept. of Environmental Science, Dickinson College, Carlisle, PA, USA;* [b] *Dept. of Landscape Architecture and Regional & Community Planning, Kansas State University, Manhattan, KS, USA*

Abstract
Plant selection is a critical step ensuring the success of a green roof. Many studies outline beneficial characteristics for green roof species, but knowledge on species mixes is limited. To address this knowledge gap, experimental green roofs were constructed atop Seaton Hall at Kansas State University in the summer of 2017. This two-year study focuses on an extensive green roof (with depths ranging from 2.4 to 5.2 inches). This green roof consists of 4 blocks containing two different substrate types (a locally blended substrate and a regionally mixed commercially supplied substrate), planted with three different species mixes (A: an all *Sedum* spp. mix, B: a *Sedum* and native grasses mix, and C: a native graminoid and forbs mix). Each species mix consists of six different species. Plant cover was measured at the end of the 2018 and 2019 growing season. In 2018 there was an effect of substrate type and species mix on plant cover, and by the end of the 2019 growing season there was still an effect of species mix on plant cover, with mixes B and C yielding greater cover than mix A. The results of this study indicate that with the right specifications, locally blended green roof substrates can perform just as well as commercially supplied green roof substrates and plant mixes incorporating native plant species can outperform *Sedum* spp. mixes in terms of plant cover.

Key Words: experimental green roof, plant cover, prairie species, species mix, substrate type

Introduction
One of the most critical design steps for ensuring green roof success is plant selection (Dvorak and Volder, 2010). When selecting green roof species, one must consider its regional context, local climate, and microclimate (Metselaar, 2012). Extensive green roof microclimates can be

characterized by periodic drought and rapid fluctuations in soil moisture levels impacting shallow substrates and making drought tolerance and avoidance a critical component for green roof plant species (Wolf and Lundholm, 2008). For selected plants to be successful in shallow green roof designs, valuable adaptations include crassulacean acid metabolism (CAM) photosynthesis pathways, drought avoidance and tolerance, woody growth, water storage organs, and other traits that that reduce water loss and heat gain (Larson et al., 2000). Furthermore, plants selected for green roof designs are more likely to be successful if the selected plant species are easily propagated, establish rapidly, and achieve high groundcover density (Getter and Rowe, 2006). Previous literature indicates that *Sedums*, stress-tolerant grasses, and herbaceous dicots that are adapted to the usually harsh conditions of a shallow green roof are preferred for planting (Durham et al., 2007; Emilsson et al., 2007; Köhler, 2006; VanWoert et al., 2005; Wolf and Lundholm, 2008). Nevertheless, each region needs to be studied regarding the most appropriate substrate types and species mixes if designers are to create regenerative living green roofs.

Sedum species are common selections for green roof plantings for various reasons. The *Sedum* genus exhibits beneficial growth habits and physiological characteristics that aid in their success on green roofs. *Sedums* easily establish through plugs, cuttings, and seeds making them easy to propagate and quick to establish. Sedum species utilize the CAM photosynthesis pathway allowing them to fix CO_2 during the day when soil moisture is low (Silvola, 1985). At night *Sedum* spp*.* limit the amount of plant-water lost through the stomata. Although *Sedum* species have proven to be great contenders for green roof plantings, more diverse plantings utilizing native species may be more appropriate for green roofs depending on the specific design goals.

It is suggested by some researchers that using diverse species mixes can enhance green roof function and resilience (Bousselot et al., 2020; Lundholm et al., 2010). An in-depth review of ecological literature conducted by Cook-Patton and Bauerle (2012) concluded that diverse green roof plantings maximize the number of environmental services provided by a mixed-species green roof. However, the researchers also stressed that “empirical research linking plant biodiversity with green roof performance is limited” (Cook-Patton and Bauerle, 2012, 85). Thus, green roof plant diversity experiments are required to determine what type of diversity (namely functional group, functional plant trait, phylogenetic, structural diversity) improve green roof functions and to ascertain how mixed-species plant communities influence the ecosystem services provided (Cook-Patton, 2015). Nagase and Dunnett (2010) noted that diverse plant mixes (containing species with different functional diversities and structural complexities) are more advantageous than monocultures in terms of both survivability and visual rating under dry conditions, and dry conditions are a common characteristic of most green roofs at various times of the year, including those in Manhattan, Kansas.

In a study by Lundholm and Williams (2015), it was emphasized that there is much more to understand about the benefits of green roof plant species mixes and how these diverse plant communities can influence green roof sustainability and ecosystem functions. Studying the relationships between biotic and abiotic factors, and their shared effects on provision of green roof ecosystem services, is crucial for deciphering how green roof ecosystems are likely to function and change over time (Lundholm and Williams, 2015).

North American green roof research has increased markedly during the past decade. There have been numerous studies assessing single species suitability for green roof plantings, testing the effects of growth media, measuring stormwater retention, and evaluating the environmental benefits provided by *Sedum* green roofs. However, there have not been many studies focusing on green roof diversity as a primary variable (Butler and Orians, 2011; Dunnett et al., 2008; Heim and Lundholm, 2014; Kolb and Schwarz, 1986; Lundholm et al., 2010; MacIvor and Lundholm, 2011; Nagase and Dunnett, 2010; Nagase and Dunnett, 2013). Finding a native plant regime capable of thriving on Kansas green roofs roof may provide many of the ecological benefits outlined above.

Some green roof benefits can be directly linked to plant cover. Plant cover is crucial to protect green roof ecosystems from the harsh urban environmental conditions. For example, green roofs species can shelter the substrate from direct sunlight and wind (Cascone, 2019). Green roof plants can also contribute significantly to the stormwater reduction and retention capabilities of green roofs (Vijayaraghavan, 2016). The extent to which plant cover reduces runoff depends highly on plant height, diameter, and root and shoot biomass. Nagase and Dunnett (2012) found that grasses were more effective at reducing green roof runoff than forbs and *Sedums*.

At the start of this study, it was unclear as to what substrate characteristics and plant species mixes were ideal to provide nearly full-cover vegetation on green roofs in Manhattan, Kansas. And, since plant cover is closely linked to green roof benefits, plant cover was selected as an indicator of green roof suitability for the selected species mixes chosen and planted in this study. The primary objective of this two-year study was to understand the effect of two different substrate types on plant cover for three mixed-species plantings in the 4-inch substrate profile on the Kansas State University, College of Architecture, Planning and Design Experimental Green Roof (APD-EGR).

The primary research questions were:

1. How does the performance of the three plant mixes (A: all *Sedums*, B: *Sedums* and native grasses, and C: native grasses and forbs) on the APD-EGR differ in each substrate in terms of plant cover?
2. How does species mix affect plant cover within each substrate type?

It was hypothesized that:

a) Cover will be greater in the rooflite® Extensive MC substrate due it being a well-tested commercially available green roof product.
b) Cover will be greater for the all-*Sedum* mix for both substrate types (Kansas BuildEx and rooflite® Extensive MC) due to *Sedum* species adaptations to survive extreme stress.

Methods

Experimental Layout

The APD-EGR was constructed atop the East Wing of Seaton Hall at Kansas State University (KSU) in Manhattan, Kansas (39° 11′ 30″ N, 96° 35′ 30″ W). Three experimental green roof beds with depths of 4, 6, and 8 inches were completed in the summer of 2017. This two-year study focuses on the 4-inch green roof. The measured substrate depths within the 4-inch bed after completion of the 4-inch green roof construction ranged from 2.4 to 5.2 inches. The Kansas BuildEx and rooflite® Extensive MC substrates were selected for this study because they were used for other green roof implemented at Kansas State University and have proved to be a suitable growing medium for *Sedum* species and selected Kansas native prairie plant species. The first substrate used in this study is Kansas BuildEx, a locally blended substrate. The second substrate used for this study is rooflite® Extensive MC, a regionally mixed commercially supplied substrate. Each substrate was planted with three different species mixes (A: an all-*Sedum spp.* mix composed of six species; mix B, a *Sedum* and native grasses mix composed of two *Sedum* species and four species of graminoids; and mix C, a native grasses and forbs mix composed of four species of grasses and two species of native wildflowers). To depict end-of-season plant growth in the 4-inch APD-EGR photos from September 3, 2018 (a) and September 11, 2019 (b) are shown below in Figure 1.

a)

b)

Figure 1. Photos of 4-inch APD-EGR (looking east away from one-story, dark gray metal storage and mechanical rooms) on September 3, 2018 (a) and September 11, 2019 (b). Photos by Lee Skabelund.

This study utilizes a strip plot design within a randomized complete block design, containing four blocks that each consist of six (approximately 4’ x 4’) experimental cells. The experimental cells are separated by aluminum dividers and the only portion of the experimental cells that are not separated are the expanded shale leveling and drainage layer, which lies at the lowest level of each planting area. The horizontal strips of the design are the three different multi-species mixes (mixes A, B, and C) while the vertical strips of the design are the two different substrate types (Kansas BuildEx and rooflite® Extensive MC) (Figure 2). The species used in each mix are listed in Table 1.

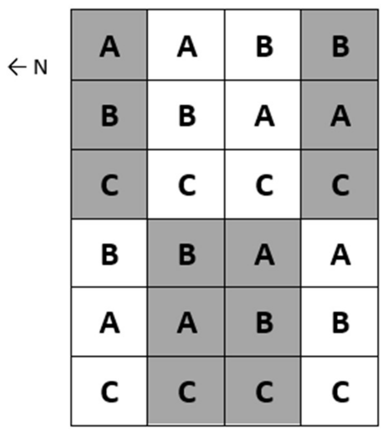

Figure 2. Randomized species mix and substrate type layout in a 4-inch profile. Shaded boxes represent experimental cells that consist of Kansas BuildEx substrate while non-shaded areas represent experimental cells that consist of rooflite® Extensive MC substrate. A, B, and C represent the plant mixes: All *Sedum*, *Sedum* and native grasses, and native grasses and forbs.

Table 1. Species used for each of the APDesign research green roof plant mixes.

Mix A: All *Sedum*	**Mix B: *Sedum* and native grasses**	**Mix C: Native grasses and forbs**
1. *Sedum album* var. *murale*	1. *Bouteloua curtipendula*	1. *Carex brevoir*
2. *Sedum ellacombeanum*	2. *Bouteloua dactyloides*	2. *Dalea purpurea*
3. *Sedum hybridum*	3. *Bouteloua gracilis*	3. *Koeleria pyramidata*
4. *Sedum kamtschaticum* var. *floriferum*	4. *Schizachyrium scoparium*	4. *Packera obovata*
5. *Sedum sexangulare*	5. *Sedum reflexum*	5. *Schizachyrium scoparium*
6. *Sedum spurium*	6. *Sedum ruprestre*	6. *Sporobolus heterolepis*

Substrate Descriptions

Bulk densities for Kansas BuildEx and rooflite® Extensive MC are 1.46 g/cm^3 and 0.97 g/cm^3 respectively. Kansas BuildEx and rooflite® Extensive MC substrate have major differences in the values for sand (particles 0.063 - 2.0 mm) and particles larger than 2.0 mm (Table 2). Kansas BuildEx is approximately 68% sand 25% larger particles (> 2.0 mm) and rooflite® Extensive MC is approximately 52% sand and 41% larger particles (> 2.0 mm). Kansas BuildEx has the potential to have greater effect on plant cover because fine particles have the ability to increase nutrient uptake and translocation (Zhao et al., 2012).

Table 0. Particle size distribution for selected substrates.

Particle Size (mm)	BX	RL
Clay < 0.002	2.9	1.3
Silt 0.002 - 0.0063	4.5	5.8
Sand 0.063 - 2.0	67.6	52.4
Particles[1] > 2.0	25	40.5

Note: BX denotes Kansas BuildEx and RL denotes rooflite® Extensive MC substrate. Includes both mineral and organic components[1].

Green Roof Management

Irrigation protocol

The APD-EGR was watered on an as-needed basis throughout the course of the study. The irrigation protocol was to ensure plants received approximately one inch of water weekly via rainfall and/or supplemental irrigation. After rainfall events, irrigation was not provided until soil moisture levels reached the critical value of 0.05 cm3/cm3 (as set by the research team following more than a year of observing soil moisture sensors deployed on other Kansas State University green roofs and monitored using METER 5TM soil moisture sensors). A nearby spigot (potable water) or collected rainfall in a cistern nearby was used for irrigation. A hand wand paired with a flow meter was used for irrigation to allow for accurate measurement of supplemental water applied to the green roof. Each green roof cell was water individually for the same set period (ranging from 20 to 60 seconds per cell depending on the amount of water required to meet the approximately one-inch-per week protocol).

Weeding protocol

Weeding occurred approximately on a bi-weekly basis to allow for coverage of planted species to be tracked. Weeding was especially important before coverage photos were taken. When weeding the APD-EGR, all non-originally planted species were pulled and removed from the green roof cells. Additionally, all grass seedlings were pulled due to the difficulty identifying small grass seedling species. All seedlings of the originally planted forbs were not weeded to allow for measurement of forb reproduction.

Plant Cover Measurements

For this study, plant cover was defined as the of the substrate surface covered by living plant material (Cook-Patton and Bauerle, 2012). Plant cover was measured at the end of the 2018 and 2019 growing seasons. Here, growing season is defined as the time between last spring frost (typically in mid-April) and first autumn frost (typically in late-October). Plant cover was captured using overhead photography for each of the green roof cells.


Figure 3. Capturing overhead plant cover images. Photo by Lee Skabelund on June 15, 2018**.**

Photos were cropped to contain only the contents each individual cell. Once the photos were cropped, they were uploaded to ImageJ, a Java-based image processing program developed at the National Institutes of Health and the Laboratory for Optical and Computational Instrumentation (Rashband, 2018). After uploading a photo to the ImageJ software, cover was measured following the protocol developed by Butler (2009). To measure cover in ImageJ, the image was broken into hue, saturation, and brightness by selecting HSB stack. From here, the image threshold was changed to black-and-white and the threshold levels were adjusted so the substrate surface and dead plant material appeared white and living plant material was black. Next, the analyze and measure functions were used to measure percent cover. Figure 4 shows examples of cropped plant cover photos from each of the species mix and substrate type factor combinations taken during the first growing season in September 2019. Note that “plant cover” is represented by the plants that cover the soil surface when looking directly down at the plot; this is not just measuring cover directly above the soil surface.

Figure 4. Overhead photos of example species mix/substrate type combinations. The side-by-side images of the three six-species plant mixes were taken September 12, 2018. The photos on the left are of species planted in the Kansas BuildEx substrate, while photos on the right are of species planted in the rooflite® Extensive MC substrate. The two photos on the top are of cells planted with six *Sedum* species (mix A), the two photos in the middle are of cells planted with two *Sedums* and four native grass species (mix B), and the two photos on the bottom are of cells planted with four native grasses and two native forbs (mix C). All photos were taken by Allyssa Decker.

Data Analysis

To assess growth, a linear mixed model was fit to the plant cover measured at the end of each growing season (2018 and 2019). The MIXED and LSMEANS (least square means) procedures in SAS version 9.4 were used to fit the model and compute the least square means of fixed effects ($\alpha = 0.05$).

Results

2018 Growing Season

There was a significant effect for both the main effects (species mix and substrate type) on plant cover for the 2018 growing season (Table 3) with an alpha level of 0.05. When looking at the main effect of species mix on plant cover at the end of the 2018 growing season, mixes B and C (the *Sedum* and native grasses mix, and the all-natives mix) yielded greater cover than mix A (the all-*Sedums* mix). When averaging across both substrates, cover for mix A was 28%, cover for mix B was 45%, and cover for mix C was 45% (Figure 5). When looking at the main effect of substrate type on plant cover at the end of the 2018 growing season, cover in the Kansas BuildEx cells yielded a greater cover than rooflite® Extensive MC, with plant covers of 44% and 34% respectively (Figure 5).

Table 3. Type 3 test of fixed effects for 2018 end of season cover.

Type 3 Test of Fixed Effects				
Effect	**Num df**	**Den df**	**F value**	**Pr>F**
Mix	2	6	19.85	**0.0023***
Substrate	1	3	14.48	**0.0319***
Mix*Substrate	2	6	0.84	0.4765

An asterisk (*) shows a significant effect on plant cover (α=0.05).

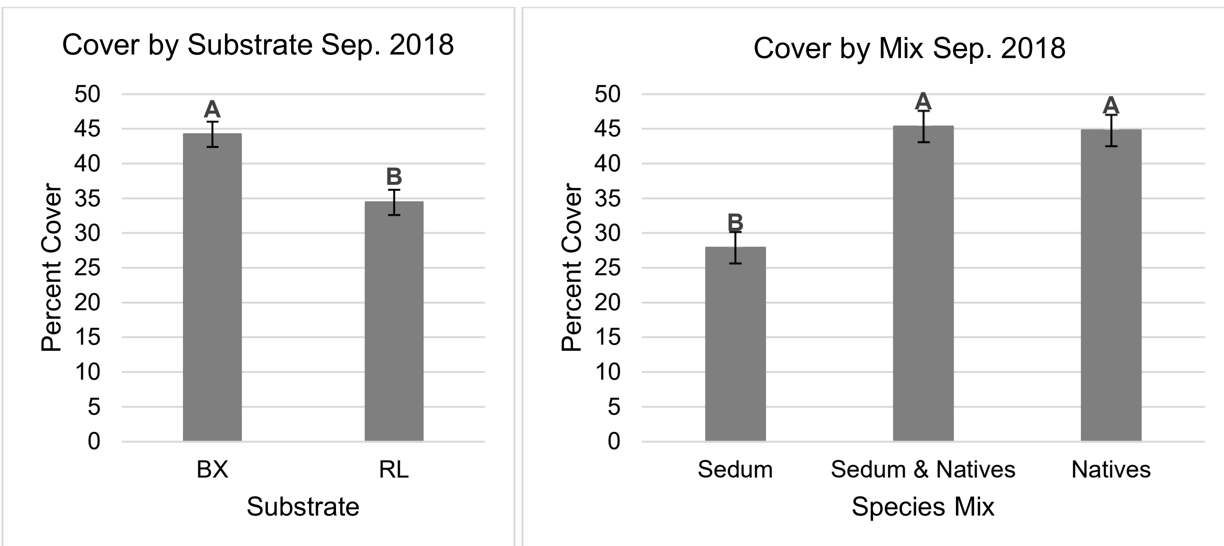

Figure 5. Cover by substrate (left) and my mix (right) for 2018. BX denotes Kansas BuildEx and RL denotes rooflite® Extensive MC. n = 24, α > 0.05 Error bars represent ± one SE. Means that do not share a letter a significantly different.

2019 Growing Season

By the end of the 2019 growing season there was only a significant effect for the main effect, species mix, on plant cover (Table 4) with an alpha level of 0.05. Like the 2018 growing season, mixes B and C (the *Sedum* and native grasses mix, and the all natives mix) yielded greater cover than mix A (the *Sedums* mix) at the end of the 2019 growing season. When averaging across both substrates, cover for mix A was 32%, cover for mix B was 58%, and cover for mix C was 52% (Figure 6).

Table 4. Type 3 test of fixed effects for 2019 end of season cover.

Type 3 Test of Fixed Effects				
Effect	**Num df**	**Den df**	**F value**	**Pr>F**
Mix	2	6	51.49	**0.0002***
Substrate	1	3	0.64	0.4836
Mix*Substrate	2	6	0.28	0.7680

An asterisk (*) shows a significant effect on plant cover (α=0.05).

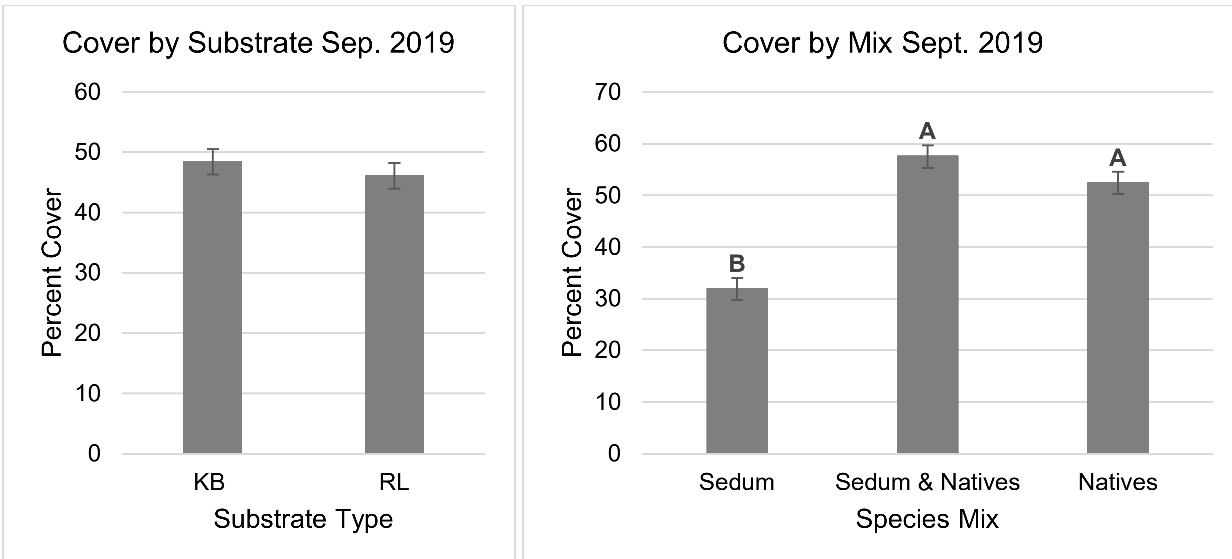

Figure 6. Cover by substrate (left) and mix (right) for 2019. BX denotes Kansas BuildEx and RL denotes rooflite® Extensive MC. n = 24, α > 0.05. Error bars represent ± one SE. Means that do not share a letter a significantly different.

Discussion and Conclusions

It was hypothesized that during this two-year study the *Sedum* spp. mix (A) would yield a greater plant cover than the *Sedum* and native grasses mix (B) and all-natives mix (C) because of the low growing and mat forming nature of *Sedum* species and because of their adaptations for surviving extreme stress. However, by the end of the 2018 and 2019 growing seasons the *Sedum* and native grass mix and the natives only mix had significantly greater percentages of plant cover than the *Sedum* spp. mix. These findings suggest that with the employed irrigation protocol native plants can perform just as well or better than *Sedum* species, which is also supported in other green roof studies (Bousselot et al., 2009; Klein and Coffman, 2015; MacIvor and Lundholm, 2011; Schroll et al, 2009; Wolf and Lundholm, 2008). The results of this study also show that there does not need to be a divide between *Sedum* green roofs and native green roofs. Both *Sedum* and natives can be incorporated together for green roof plantings to help provide better cover and structural complexities for green roof designs and green roof mixes incorporating native plant species can outperform *Sedum* spp. mixes in terms of plant cover.

It was also hypothesized that plant cover would be greater for the mixes planted in rooflite® Extensive MC substrate than those planted in Kansas BuildEx substrate due to rooflite® Extensive MC being a commercially available substrate. However, for the 2018 growing season

Kansas BuildEx yielded greater cover than rooflite® Extensive MC and by the end of the 2019 growing season there was no difference in plant cover between the two substrates. The results of this study indicate that with the right specifications, locally blended green roof substrates can perform just as well as commercially supplied green roof substrates. When investigating shallow green roof profiles, the limiting factor for plant survival and growth is often water availability (Dvorak and Volder, 2010; Nagase and Dunnett, 2010). The 2019 growing season received much more rainfall than the 2018 growing season, making water stress less of a limiting factor for the plant mixes used on the APD-EGR. During the 2019 growing season, substrate characteristics may not have been as critical of a factor in explaining plant cover in a 4-inch depth. Green roofs are fully exposed to the surrounding environment and variability in weather patterns between the two years can have a significant impact on survival and growth of the selected plant species on the APD-EGR.

This study shows that native planting palettes can perform exceptionally well in extensive, semi-intensive and intensive green roof systems with supplemental irrigation. Cover remained higher in all natives mix than in all *Sedum* mix, further showing that native graminoids and forbs are great contenders for green roof plantings in the Flint Hills Ecoregion and areas with similar climates. Also, these findings show that locally blended substrates can yield equal or higher plant cover for native and *Sedum* green roof species. These findings show that selected native species are still great candidates for extensive green roof plantings in full-sun settings with early evening shade in the summer months. This study emphasizes the importance of understanding the relationship between substrate type and plant performance.

Limitations and Future Considerations

A limitation of this study is that this was an irrigated study. Considering that not all green roof managers want to irrigate, it would be beneficial to continue monitoring plant cover under a little to no irrigation regime. Additionally, plant cover was only recorded at the mix level, not the species level due to the selected method of analysis. Some of the species may have had greater growth in terms of cover throughout this two-year study and knowledge of species cover throughout the year could help guide species selection for future green roof designs in the Flint Hills ecoregion or in regions with a similar climate. Moreover, overhead photography can be a time-consuming tool for measuring individual plant cover, but it would be great method for measuring individual plant cover on smaller studies. Although aerial photography was taken of the APD-EGR using an unmanned aerial system (UAS) July 12, 2018 and October 27, 2018, this data has not been closely analyzed. It is possible that aerial photography can be effectively used to monitor plant cover through time, however, there are challenges related to flying a UAS on campus (related to permissions and insuring safety, a licensed and expert UAS pilot, and access to programs and expertise for data interpretation).

References

Bousselot J.M., J.E. Klett, and R.D. Koski. 2009. “High elevation semi-arid taxa: evaluations on an extensive green roof.” Atlanta, GA: The Cardinal Group. Seventh Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show Toronto.

Bousselot, J., V. Russel, L. Tolderlund, S. Celik, B. Retzlaff, S. Morgan, I. Buffam, R. Coffman, J. Williams, M. E. Mitchell, J. Backer, J. DeSpain. 2020. “Green roof research in North America: A recent history and future strategies.” *Journal of Living Architecture,* 7: 27-64.

Butler, C. 2009. Instructions for measuring percent plant cover using Image J. Unpublished Oct. 12, 2009 notes.

Butler, C. and C.M. Orians. 2011. "*Sedum* cools soil and can improve neighboring plant performance during water deficit on a green roof." *Ecological Engineering*, 37: 1796-1803.

Cascone, S. 2019. "Green roof design: State of the art technology and materials." *Sustainability,* 11 (3020):1-28.

Cook-Patton, S.C. and T.L. Bauerle. 2012. "Potential benefits of plant diversity on vegetated roofs: A literature review." *Journal of Environmental Management,* 106: 85-92.

Dunnett, N., A. Nagase, R. Booth and P. Grime. 2008. "Influence of vegetation composition on runoff in two simulated green roof experiments." *Urban Ecosystems,* 11: 385-398.

Durhman, A.K., D.B. Rowe and C.L. Rugh. 2007. "Effect of substrate depth on initial growth, coverage, and survival of 25 succulent green roof plant taxa." *HortScience,* 42: 588-595.

Dvorak, B. and A. Volder. 2010. "Green roof vegetation for North American ecoregions: A literature review." *Landscape and Urban Planning,* 96: 197-213.

Emilsson, T. 2008. "Vegetation development on extensive vegetated green roofs: influence of substrate composition, establishment method and species mix." *Ecological Engineering,* 33(3-4): 265-277.

Heim, A. and J.T. Lundholm. 2014. "Species interactions in green roof vegetation suggest complementary planting mixtures." *Landscape and Urban Planning,* 130: 125-33.

Klein, P.M. and R. Coffman. 2015. "Establishment and performance of an experimental green roof under extreme climatic conditions." *Science of The Total Environment,* 512-513 (April): 82-93.

Kolb, W. and T. Schwarz. 1986. "New habitats on the roof: The possibilities for the provision of extensive verdure." *Anthos,* 1: 410.

Köhler M. 2006. "Long-term vegetation research on two extensive green roofs in Berlin." *Urban Habitats,* 4: 326.

Lundholm, J.T., J.S. MacIvor, Z. Macdougall, and M. Ranalli. 2010. "Plant species and functional group combinations affect green roof ecosystem functions." *PLoS One,* 5 (3): 1-11.

Lundholm, J.T., and N.S. Williams. 2015. "Effects of vegetation on green roof ecosystem services." In *Green Roof Ecosystems.* Edited by Richard Sutton, 211-232. Springer International Publishing.

MacIvor, J.S. and J. Lundholm. 2011. "Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate." *Ecological Engineering,* 37 (3): 407-417.

Metselaar, K. 2012. "Water retention and evapotranspiration of green roofs and possible natural vegetation types." *Resources, Conservation and Recycling,* 64: 49-55.

Nagase, A. and N. Dunnett. 2010. "Drought tolerance in different vegetation types for extensive green roofs: Effects of watering and diversity." *Landscape* and *Urban Planning,* 97(4): 318-327.

MacIvor, J.S. and J. Lundholm. 2011. "Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate." *Ecological Engineering,* 37: 407-417.

Nagase, A. and N. Dunnett. 2013. “Establishment of an annual meadow on extensive green roofs in the UK.” *Landscape Urban Plan*ning, 112: 50-62.
Schroll E., J. Lambrinos and D. Sandrock. 2009. “Irrigation requirements and plant survival on northwest green roofs.” Atlanta, GA: The Cardinal Group. Seventh Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show Toronto.
Silvola, J. 1985. “Photosynthesis measurements on a CAM plant, *Sedum telephium* (Crassulaceae).” *Annales Botanici Fennici,* 22 (3): 195-200.
VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh and L. Xiao 2005. "Watering regime and green roof substrate design affect *Sedum* plant growth." *HortScience* 40: 659-664.
Vijayaraghavan, K. 2016. “Green roofs: a critical review on the role of components, benefits, limitations and trends.” *Renewable and Sustainable Energy Reviews,* 57: 740-753.
Wolf, D., and J.T. Lundholm. 2008. “Water uptake in green roof microcosms: effects of plant species and water availability.” *Ecological Engineering,* 33: 179-186.
Zhao, L.J., J.R. Peralta-Videa, M.H. Ren, A. Varela-Ramirez, C.Q. Li, J.A. Hernandez-Viezcas, R.J. Aguilera, and J.L. Gardea-Torresdeya. 2012. “Transport of Zn in a sandy loam soil treated with ZnO NPs and uptake by corn plants: electron microprobe and confocal microscopy studies.” *Chemical Engineering,* 184: 1-8.