27.1: Research Track

# SPONTANEOUS VEGETATION IN THREE TYPES OF ENGINEERED MEDIA

***Anna G. Droz, Reid R. Coffman, Christopher B. Blackwood***
*Kent State University, Kent Ohio, USA*

## Abstract

Spontaneous vegetation in engineered green roof growing media (soil) can be either a nuisance and prove detrimental to a design and construction project or execute the intended outcome of a dynamic vegetative community assemblage. Possessing familiarity with the potential for volunteer plant species in the processes of soil design and selection may be helpful in assisting targeted plant establishment and delivering expected performances. To aid understanding, we recorded the presence and growth of twenty–two weed species emerging across three types of green roofs containing engineered media in an eight-week study and discuss methods of prevention in living architecture projects. The green roof substrate used in the conventional green roof (CGR) and the worm cast compost used in the quasi-traditional green roof (QTR) supported the lowest biomass of spontaneous vegetation when compared to the sandy loam soil used in the blue-green roof (BGR). Media sourcing and quality remain an important facet of green roof design and should be considered in future design applications.

## Introduction

Living architecture projects aimed at consistency with the local environment rely on restoration construction practices involving the use of natural soils and local materials, which assist delivery of ecosystem services, biodiversity goals, and enhance habitat value (Best et al., 2015; Brenneisen 2006; Coffman 2009). Natural soils are able to mimic ground-level conditions in ways that engineered soils cannot, such as supplying a diverse source of organic materials and native soil microbiota (Best et al., 2015). However, natural soils often are more complex and require some alterations in order to ensure they are lightweight and not filled with an abundance of ultrafine particles that can clog drainage systems and inhibit water movement (Best et al., 2015). These soils are essential for bridging the gaps in the creation of more diverse living architecture landscapes, such as prairie restoration and other more intensive style designs.

Besides use of natural soils, employing restoration practices such as seeding of native species can enhance ecological functionality and potentially reduce costs (Sutton 2013). In many cases, local companies providing soil components cannot guarantee that their product is weed-free, nor can they confirm its source. This can lead to spontaneous vegetation that can overwhelm an intended design. Depending on the severity of the problem, this can lead to changes in the aesthetics as well as the functioning of the green roof. However, although conventional roof management focuses on weed prevention (Snodgrass and McIntyre 2010), spontaneous colonization of ruderal plant communities may also be viewed positively, as it has been suggested to improve climate adaptation and the sustainability of long-term management (Dunnett 2015).

The use of native soils or local soil amendments has many pros and cons. It brings natural elements to a system in the form of native organisms and complex organic matter, but it is an unknown quantity in that each soil is different and highly complex in its ability to retain water, particle sizes, and density (Best et al., 2015). Native soils are often used to provide microbial communities, and yet their use requires sterilization for weed seed suppression. However, sterilization of soils also removes beneficial microbes and alters soil physical and chemical properties (Dietrich et al., 2020).

To examine the extent to which spontaneous vegetation (weeds) can occur in green roofs, we compared the performance of an engineered media to two types of natural growth media (worm cast compost and sandy-loam bioretention soil), in three different types of green roof systems (conventional green roof, quasi-traditional green roof, and a blue-green roof) over the course of the 2017 growing season. The goal was to observe how these different roof types support different levels of spontaneous vegetation establishment in terms of the number of plant species (species richness) as well as the total plant biomass. This project was part of a larger long-term study beginning in summer 2015 with the goal to examine the biological interactions between plants, soil microbes, and the intentional design aspects of green infrastructure.

*Study Site and Design*

This experiment took place at the Cleveland Industrial Innovation Center (CIIC), an active industrial complex and brownfield site in Cleveland. This area houses a variety of light industrial businesses with many acres of impermeable surfaces.

Our experimental test setup was built in summer 2015 with 18 plots laid out in a randomized design upon a 45.7 cm thick concrete deck top which caps a subgrade water cistern (Figure 1). Every 1 $m^2$ plot was constructed from plywood and included a Firestone 45 mil EPDM rubber pond liner (Firestone, Michigan, USA) as the waterproofing roof membrane, a layer of filter fabric (SRW, SB3 20 year, Minnesota, USA), and a drain at the bottom to prevent overflow. Plots were originally planted in July 2015 with a mixture of native seeds (Prairie Moon nursery, Winona, MN, USA) and plugs (Emory Knoll Farms, Street, MD, USA), but none survived the initial experimental trial. It should be noted that the roof type includes both growth media and a drainage component. The roof types are described in further detail below (see Table 1 for summary).

Table 1: Summary of roof types, their components and number of replicates.

| | Conventional green roof (CGR) | Quasi-traditional roof (QTR) | Blue-green roof (BGR) |
|---|---|---|---|
| Drainage type | High-density polyethylene filter mat | Dried Phragmites Reed | Reservoir with capillary wick |
| Growing medium | Rooflite® extensive blend | Worm casting compost | Sandy-loam soil and worm casting compost |
| Number of plots | 6 | 6 | 6 |

Figure 1. From left to right: Test site before construction, framework, and waterproofing membrane.

*Constructed roof types*

*Conventional Green Roof (CGR)*
This roof type is modeled after a typical semi-intensive green roof with a drainage layer in the bottom and 15.2 cm of extensive Rooflite® blend (Skyland, Pennsylvania, USA) as the growing medium. Rooflite® is a proprietary blend of engineered media designed for optimal performance on a green roof. The drainage layer used was a high-density polyethylene filter mat (GreenShield Filterdrain 110, Garland, Ohio, USA).

*Quasi-Traditional Green Roof (QTR)*
This roof type is based on early traditional roof designs that have prevailed for centuries in Northern Europe to inexpensively insulate buildings (Coffman 2009; Peck et al., 1999). Local straw or bark is used with on-site soil or compost, and plants are seeded or allowed to colonize naturally from the preexisting seed bank within the soil. For this experiment we used 12.7 cm of dried *Phragmites australis* reed, an aggressive exotic on-site plant, as our straw drainage layer. On top of this drainage, 5.1 cm of compost made from organic worm castings locally sourced from Northeast Ohio (Kurtz Bros., Independence, OH, USA) was layered as the growing medium.

*Blue-Green Roof (BGR)*
The blue-green roof was created from a collaboration among architects, hydrologists, and biologists in 2014 as part of a design competition funded by the EPA-P3 (People, Prosperity, Planet) grant. It is a moveable piece of green infrastructure that can be used in brownfields and other contaminated sites where excavation or remediation of soil is prohibitively expensive. The design features a reservoir for rainwater storage that contains columns of nylon, which act as a capillary wick to allow water to diffuse back into the soil during periods of low precipitation. These plots were filled with 10.2 cm of semi-engineered bioretention grade soil that is similar to a sandy loam, designed in accordance with Ohio Department of Natural Resources standards (Mathews, 2006), and topped with two inches of worm casting compost (Kurtz Bros., Independence, OH, USA).

## Methodology

After planting and seeding at the end of July 2015, plots were watered via drip irrigation for 3 weeks. Growth of plants was observed and recorded for a period of 2 months. Plants were identified using field guides (Del Tredici 2010; Royer and Dickinson 1999) and determined to be unwanted spontaneous vegetation (weed) species, after which all biomass was harvested, separated into above and belowground mass and weighed after drying for 24 hours in an oven at 60°C. Plants were harvested again in November to ensure that all unwanted biomass was removed.

The spontaneous vegetation biomass data and species richness data were analyzed using an ANOVA to determine the effects of different roof types, followed by a post-hoc Tukey's HSD test. A principal component analysis (PCA) was performed to summarize dominant patterns in species composition in the communities that developed. The first two PCA axes were examined to determine if media type or sampling date influenced the species that developed. Statistical analyses were performed in the R version 3.1.3 software package (R Core Team, 2017).

**Results**

Across both harvests, 22 total species of spontaneous vegetation were identified. The most prevelant species was purple amaranth (*Amaranthus blitum*), which occurred in 12 out of 18 total plots on both harvest dates. Purple amaranth also had the highest total abundance, followed by Barnyardgrass (*Echinochloa crus-galli*) and Pale smartweed (*Polygonum lapathifolium*) (Table 2). None of the originally intended planted specimens were positively identified as surviving the experimental period, likely due to the high levels of spontaneous vegetation that overwhelmed the plots in a relatively short period of time.

Media type and time of sampling both had a significant impact on species richness, or the number of species found per plot ($P < 0.05$, Figure 2). The date × media type interaction was also significant ($P < 0.05$). The conventional green roof (CGR) plots had significantly lower species richness on both harvest dates than the quasi-traditional green roof (QTR) and blue-green roof (BGR) plots. The September harvest date for the blue-green roof had the highest amount of biomass compared to the other treatments.

The first two PCA axes showed that there was a clear effect of date on the species composition of the plots (Figure 3). The PCA also showed a media type effect on species composition, with the QTR and BGR plots clustered apart from the CGR plots. The November harvest date also showed clustering among the QTR and BGR plots, but the CGR plots were much more scattered, indicating less consistency in the CGR community in November. We would expect to see these results as not only were the supplier of the soils for QTR and BGR the same, but they also both contained the same compost.

Weeds like *Amaranthus blitum* exclusively occurred in the QTR and BGR plots in large quantities, while *Euphorbia maculata*, a common green roof weed, was found only in the CGR. These results indicate that growth media played an important role in forming the plant community composition on both harvest dates.

Total plant biomass was significantly affected by both sampling date and media type, as well as a date × media type interaction ($P < 0.05$, Figure 4). The findings showed greater biomass of spontaneous vegetation in BGR, when compared to the other two roof types, suggesting that the bioretention soil was able to support the highest amount of vegetation. The engineered media in the CGR and the compost of the QTR supported a significantly lower abundance of spontaneous vegtation.

Table 2. Spontaneous vegetation species identified and average total dry biomass[1] in each green roof type.

| Species Name | Native Status[2] | Conventional Green Roof, g $m^{-2}$ | Quasi-Traditional Green Roof, g $m^{-2}$ | Blue-Green Roof, g $m^{-2}$ |
|---|---|---|---|---|
| Purple amaranth (*Amaranthus blitum*) | Introduced | 0 | 2.46 | 46.27 |
| Burgundy red astilbe (*Astilbe arendsii*) | Cultivar (no data) | 0 | 0 | 0.04* |
| Smooth brome (*Bromus inermis*) | Both | 0 | 0.08* | 0.80* |
| Oak-leaved goosefoot (*Chenopodium glaucum*) | Introduced | 0.002* | 0.13 | 2.27 |
| Yellow nutsedge (*Cyperus esculentus*) | Both | 0 | 0.22* | 0.61 |
| False nutsedge (*Cyperus strigosus*) | Native | 0.31 | 0.71 | 0.40 |
| Smooth crabgrass (*Digitaria ischaemum*) | Introduced | 0 | 0.20 | 5.63 |
| Hairy crabgrass (*Digitaria sanguinalis*) | Introduced | 0.002* | 0.08* | 1.82 |
| Barnyardgrass (*Echinochloa crus-galli*) | Introduced | 0 | 0.47 | 8.73 |
| Spotted spurge (*Euphorbia maculata*) | Native | 0.11 | 0 | 0 |
| Misc. plant matter | - - - - - | 4.29* | 1.11* | 6.70* |
| Green carpetweed (*Mollugo verticillata*) | Native | 0 | 0 | 0.07* |
| Yellow woodsorrel (*Oxalis stricta*) | Native | 0.12 | 0 | 0.002* |
| Witchgrass (*Panicum capillare*) | Native | 0 | 0.11 | 0.75 |
| Fall panic grass (*Panicum dichotomiflorum*) | Native | 0 | 0 | 0.26 |
| Common reed (*Phragmites australis*) | Both | 0.17 | 0 | 0.07 |
| Pale smartweed (*Polygonum lapathifolium*) | Native | 0 | 0.23 | 8.32 |
| Common purslane (*Portulaca oleracea*) | Both | 0 | 0.01 | 0.20 |
| Foxtail (*Setaria viridis*) | Introduced | 0 | 0.41 | 1.52 |
| Black nightshade (*Solanum nigrum*) | Introduced | 0 | 0 | 0.08 |
| Field sowthistle (*Sonchus arvensis*) | Introduced | 0 | 0 | 0.02* |
| Common dandelion (*Taraxacum officinale*) | Both | 0.14* | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Rough cocklebur (*Xanthium strumarium*) | Native | 0 | 0.13 | 0 |

1. September and November harvest date totals were combined. * indicates species that increased in biomass between the September and November harvest.
2. Native status obtained from the plants.usda.gov website (USDA-NRCS, 2018). The term "Both" indicates that within the state of Ohio, there are both native and introduced varieties of a given species.

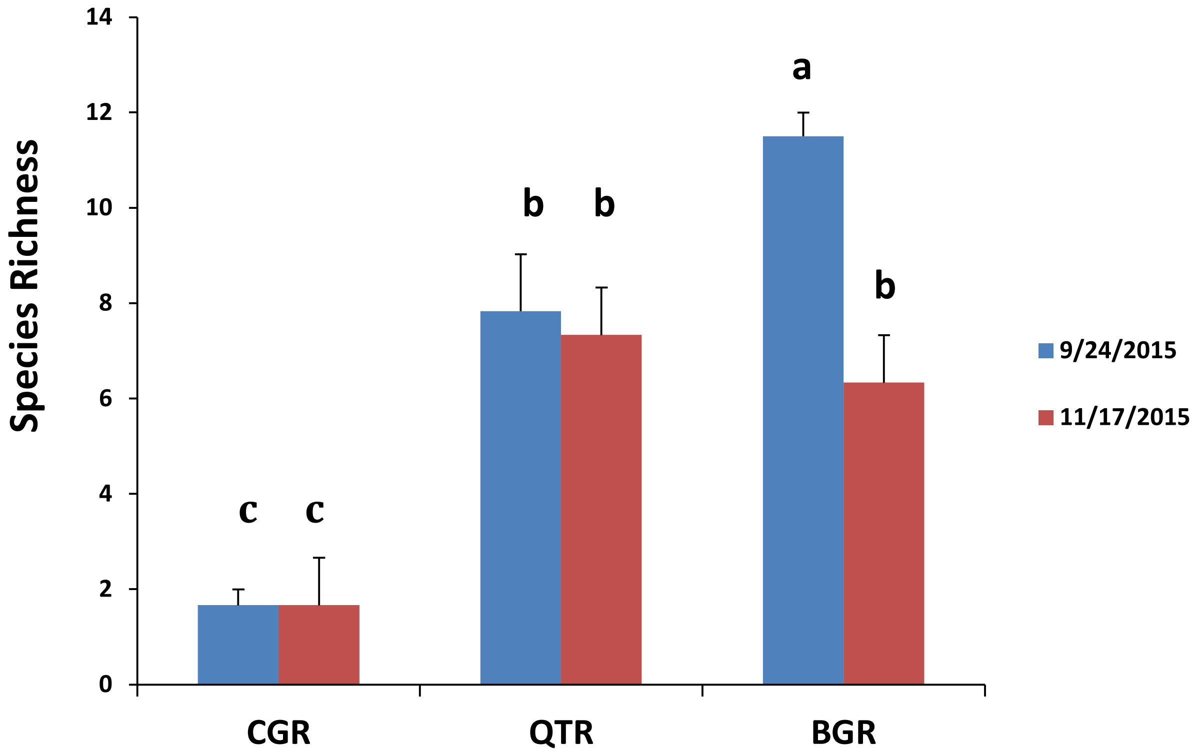


Figure 2. Species richness on each harvest date (average ± standard error). Bars with different letters indicate treatments that were significantly different from one another in *post-hoc* Tukey's HSD test. CGR = Conventional Green Roof, QTR = Quasi-Traditional Green Roof, and BGR = Blue-Green Roof.

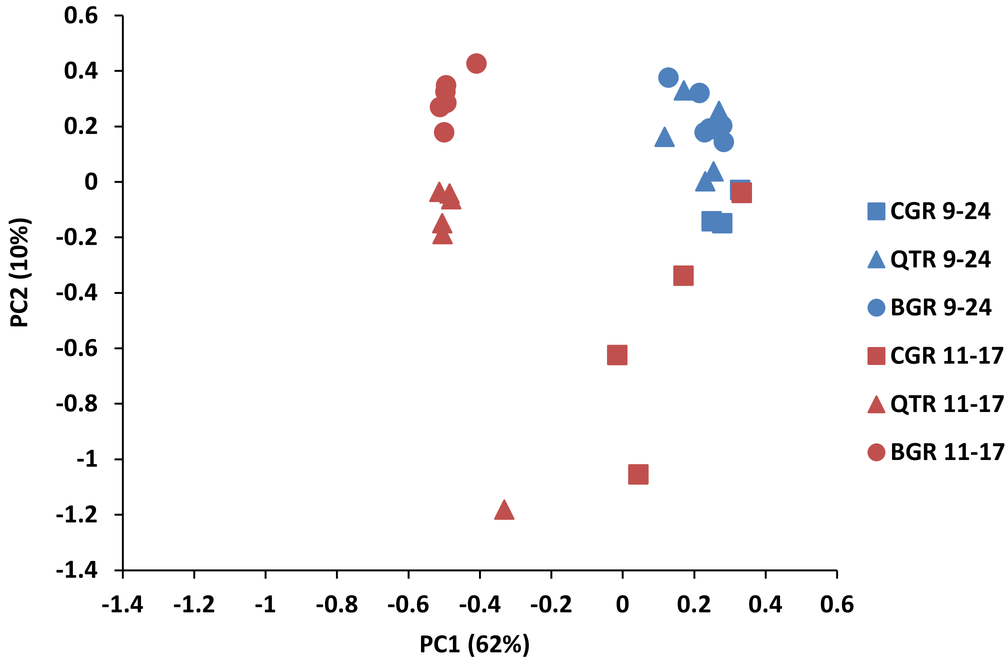


Figure 3. PCA showing the visual representation of each plot's plant community and how they relate to each other. Communities that are more similar to each other will be in closer proximity to one another. CGR = Conventional Green Roof, QTR = Quasi-Traditional Green Roof, and BGR = Blue-Green Roof.

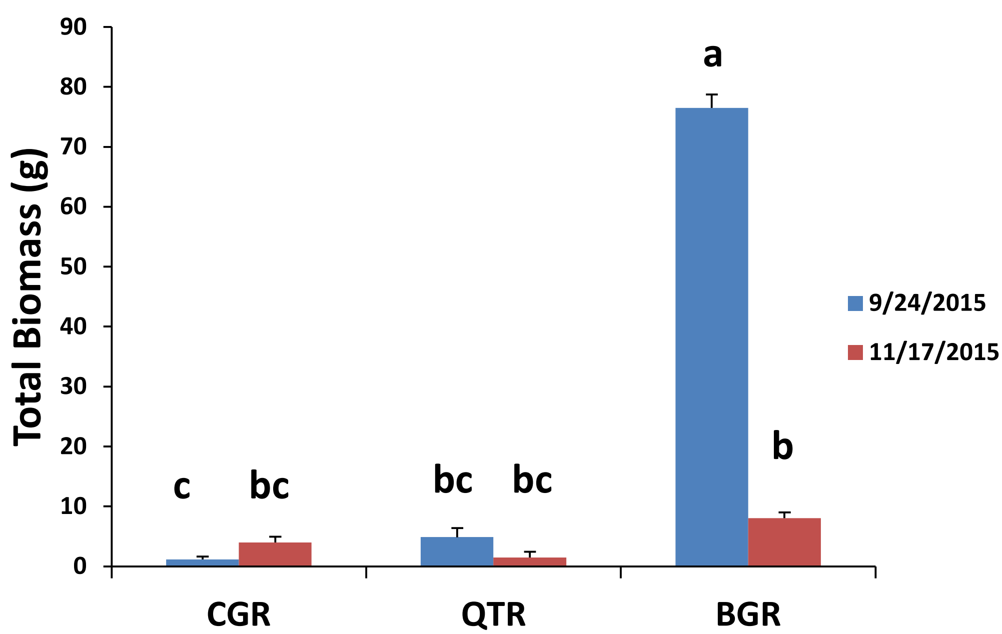


Figure 4. Total biomass of all harvested spontaneous vegetation (average ± standard error). Numbers include both above and belowground biomass. Bars with different letters indicate plots that are significantly different from one another in *post-hoc* Tukey's HSD test. CGR = Conventional Green Roof, QTR = Quasi-Traditional Green Roof, and BGR = Blue-Green Roof.

*Discussion*

Our experimental observations highlighted the importance of confirming the quality of source media, which interfered with the design and functioning of the project. The local soil supply company was not able to verify the source of its purchased soil materials, nor could they certify any of the products were weed-free. As a result of this, it is likely that many of the species of spontaneous vegetation were already present in the media before our experiment began. Other spontaneous vegetation may have established via wind or birds, both common methods of seed dispersal, as the location was exposed to wind pressure and was next to a congregation point for local seagulls (Deng and Jim 2016). The local soils used in the QTR and BGR plots appeared to facilitate ruderal community establishment quite well, as suggested by Dunnett (2015) who relates the use of local soil to plant community recruitment, higher trophic diversity, and aesthetics in spontaneously developing roofs. Dunnett (2015) argues this alternative approach is more ecologically oriented, supporting regional biodiversity, and providing a visually appealing aesthetic.

Compared to the conventional green roof system, the quasi-traditional and blue-green roofs represent much newer roof system types that do not yet have a standardized set of designs. Reference materials such as the FLL green roof guidelines (2018), have been designed for conventional type green roof systems, and therefore the designs for the QTR and BGR are still experimental. It is likely that QTR and BGR style roofs may need further refinement in terms of optimization for the substrate, water retention, and other design elements in order to perform as effectively as FLL standard green roofs.

On both harvest dates, the growth media of the conventional green roof (CGR) had lower species richness and a different community composition when compared to the quasi-traditional green roof (QTR) and blue-green roof (BGR). The total biomass of spontaneous vegetation was higher in the BGR than the QTR and CGR, likely due to the fact that its properties represented an intermediate between the three different growing media with both abundant organic matter and enhanced drainage and water-supplying capabilities. Although we did not measure water retention in this study, soil moisture levels observed in subsequent research showed that the BGR plots had the least amount of extreme drying and rewetting events (Droz et al., 2021), leading to a more favorable environment for potential spontaneous vegetation. Both types of media in the QTR and BGR came from the same local soil supplier and had shared components (compost), explaining the similarities between the plant communities of those treatments. Conversely, the engineered media in the conventional green roof came from a separate company and was very different in components than those in the other two types of media. The species found in our experimental plots were fairly typical of common weeds found in the Ohio region and previously recorded in North American green roofs. However, regardless of the soil type, six of the species that were present in our plots were typical of previously recorded green roof weeds. Specifically, *Taraxacum officinale, Oxalis stricta, Euphorbia maculata, Setaria viridis*, *Digitaria ischaemum*, and *Digitaria sanguinalis,* which have been previously defined by Snodgrass and McIntyre (2010) as ‘problem weeds’.

Most practitioners will consider it costly and impractical to sterilize or remove dormant seeds in growth media before use on large scale properties. The options for landowners include: solarization, mulching, steam sterilization, landscaping fabric, or hand weeding, each of which are heavily dependent on the resources available to a given property manager. Solarization involves covering an area with plastic in order to trap solar radiation and kill seeds using heat. Solarization can be useful in large areas because it is relatively cheap and does not rely on chemicals, but it depends on correct seasonal timing in order to bring temperatures up to the appropriately high levels and may not be as effective in areas with little sunshine (Culman et al., 2006; Horowitz et al., 1983). Mulching has potential to be effective, but needs to be more specifically engineered for the green roof setting, as typical landscaping mulch will not stay put on a roof, leading to undesirable movement (Nagase et al., 2013). Sterilization using steam or autoclave can also kill weed seeds, but the process fundamentally alters the chemical and microbial properties of the soil in a way that may be detrimental (Tanaka et al., 2003). Landscaping fabric is a low cost, low impact weed control method that minimizes bare spots for outside colonizers and smothers weeds beneath it. However, the fabric itself is vulnerable to degradation over time, allowing light and stubborn weed species to penetrate the fabric, and its low aesthetic appeal leaves it as only a temporary solution in the beginnings of establishment (Derr and Appleton 1989; Pickering 2004). Some green roof installers also use biodegradable erosion protection fabrics as an alternative to landscaping fabric to perform both wind and weed protection (GRHC 2016). Hand weeding has the fewest drawbacks, but it requires a large amount of manual labor and is dependent on the ability of maintenance staff to correctly identify plants at all stages of growth in order to avoid removing desirable plants in the weeding process (Snodgrass and McIntyre 2010).

Whether a roof design uses engineered or natural growing media, the success of a green roof depends on the quality of the soil purchased and the strength of the maintence plan. Although in many circumstances, it may be unfeasible for soil suppliers to control for weeds, it makes sense for them to be transparent about the source and limitations of the substrate they sell so that practitioners can construct a sound maintenance plan. A good maintenance strategy utilizes multiple methods of weed control in order to ensure the original vision of the designer is met. Practitioners should keep in mind that every green roof is unique, and no one approach will work for every roof. Following the end of this experiment, 14 new plant species were seeded and successfully established at the Cleveland Industrial Innovation Center the subsequent summer (See Droz et al., 2021). We attribute the success to the use of a combination of techniques from solarizing all plots, changing the timing of seeding to correspond with natural seeding cycles, covering open soil areas with landscaping fabric, hand weeding, and planting a small number of plugs in order to hold space while seeds grew. In addition, the use of overhead watering over drip irrigation likely played a role, as on average, 2017 represented a drier year than 2018 (Rowe et al., 2014).

Continued research should focus on additional methods to remove weeds from the seedbank, as well as how different types of management and the timing of these methods work, specifically in the unique environmental setting provided by green roofs. There is a popular and persistent belief that it is feasible to construct a maintenance-free green roof – but that simply is not possible in a dynamic biological system. However, with appropriate planning it may be possible to reduce roof maintenance through an improved understanding of the life cycle of common weeds and a clean source of growing media.

## Acknowledgements

We would like to thank our colleagues at Kent State University for helping to construct the green roof test plots, specifically Jessie Hawkins, Timo Ong, and the students of the College of Architecture and Enivornmental Design's Living Architecture Innovation class. Thanks to Melissa Davis at the Kent State University greenhouse for plant identification resources and insight. Thanks to Dan T. Moore and the team at the Cleveland Industrial Innovation Center for permitting us to build, store supplies, and use equipment on site. The development of the blue-green roof was made possible by the Environmental Protection Agency's People, Prosperity and the Planet (EPA-P3) Grant [#83570001].

## References

Best, B.B., Swadek, R., and Burgess, T. 2015. Soil based green roofs Chapter 6, in *Green Roof Systems* edited by Richard Sutton. Springer. 139-174.

Brenneisen, S. 2006. "Space for urban wildlife: designing green roofs as habitats in Switzerland." *Urban Habitats,* 4(1): 27-36.

Coffman, R. 2009. "Elevating Habitat: Creating biodiversity through quasi-traditional green roof design." *Landscape Architecture Magazine,* 99(1): 72-77.

Culman, S.W., Duxbury, J.M., Lauren, J.G., Thies, J.E. 2006. "Microbial community response to soil solarization in Nepal's rice–wheat cropping system." *Soil Biology and Biochemistry*, 38(12): 3359-3371.

Del Tredici, P. *Wild Urban Plants of the Northeast: A Field Guide*. Cornell University Press. 2010.

Deng, H., and Jim, C.Y. 2017. "Spontaneous plant colonization and bird visits of tropical extensive green roof." *Urban Ecosystems*, 20.2: 337-352.

Derr, J.F., Appleton, B.L. 1989. "Weed control with landscape fabrics." *Journal of Environmental Horticulture,* 7(4): 129-133.

Dietrich, P., Cesarz, S., Eisenhauer, N. and Roscher, C. 2020. "Effects of steam sterilization on soil abiotic and biotic properties." *Soil Organisms,* 92.2: 99-108.

Droz, A.G., Coffman, R.R., Fulton, T.G., and Blackwood, C.B. 2021. "Moving beyond habitat analogs: Optimizing green roofs for a balance of ecosystem services." *Ecological Engineering,* 173: 106422.

Dunnett, N., 2015. Ruderal Green Roofs Chapter 10, in *Green Roof Systems* edited by Richard Sutton. Springer. 233-255.

FLL, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau 2018. Green Roof Guidelines: Guidelines for the planning, construction and maintenance of green roofs.

Green Roofs for Healthy Cities (GRHC). 2016. Green roof design and installation resource manual.

Horowitz, M., Regev, Y., Herzlinger, G. 1983. "Solarization for weed control." *Weed Science,* 31(2): 170-179.

Mathews, J. 2006. "Rainwater and land development: Ohio's standards for stormwater management, land development and urban stream protection." Ohio Department of Natural Resources, Division of Soil and Water Conservation.

Nagase, A., Dunnett, N., Choi, M.S. 2013. "Investigation of weed phenology in an establishing semi-extensive green roof." *Ecological Engineering,* 58: 156-164.

Peck, S.W., Callaghan, C., Bass, B., Kuhn, M.E. 1999. "Research report: greenbacks from green roofs: forging a new industry in Canada." Ottawa, Canada: Canadian Mortgage and Housing Corporation (CMHC).

Pickering, D.L. 2004. "Covering the *Spartina* threat: An alternative control method for non-native *Spartina patens* in a west coast salt marsh." In *Conference on Invasive Spartina*.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Rowe, D.B., Kolp, M.R., Greer, S.E., and Getter, K.L. 2014. "Comparison of irrigation efficiency and plant health of overhead, drip, and sub-irrigation for extensive green roofs." *Ecological Engineering*, 64: 306-313.

Royer, F., Dickinson, R. 1999. *Weeds of the Northern U.S. and Canada: A Guide for Identification*. University of Alberta.

Snodgrass, E.C., McIntyre, L. 2010. *The green roof manual: a professional guide to design, installation, and maintenance.* Timber Press.

Sutton, R.K. 2013. "Seeding green roofs with native grasses." *Journal of Living Architecture,* 1-20. https://doi.org/10.46534/jliv.2013.01.01.015

Tanaka, S., Kobayashi, T., Iwasaki, K., Yamane, S., Maeda, K., Sakurai, K. 2003. "Properties and metabolic diversity of microbial communities in soils treated with steam sterilization compared with methyl bromide and chloropicrin fumigations." *Soil Science and Plant Nutrition*, *49*(4): 603-610.

USDA, NRCS. 2018. The PLANTS Database (http://plants.usda.gov, 7 January 2018). National Plant Data Team, Greensboro, NC 27401-4901 USA.