REFERENCE COMMUNITY: ADAPTING NATIVE PLANTS TO NORTH AMERICAN GREEN ROOFS

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INTRODUCTION

The North American design community typically regards green roofs as inhospitable environments for native plants due to the infrastructure's characteristic thin soils, low organic matter, temperature fluctuations, and wind exposure. Consequently, green roofs are often planted with an industry-standard palette of non-native Sedum and Phedimus species that are adept at withstanding stress, but lack biodiversity and visual interest, and offer little food or shelter to native birds and insects. Regionally specific reference plant communities that thrive in similarly harsh growing conditions can positively influence green roof design throughout North America, and consequently provide ecosystem services, contribute to habitat conservation, and increase human exposure to the beauty and benefits of native plants.

KEYWORDS

North America, green roofs, native plants, reference community, analog community, xeric plants, prairie, savanna, dune, barren, biodiversity, irrigation

THE NEED FOR NATIVE PLANTS

As North America's suburban and urban areas expand and densify, native habitat increasingly comes under threat of degradation or replacement by the built environment. In lieu of curbing development, designers and scientists are beginning to re-conceptualize the design of buildings and constructed landscapes as being part of natural systems, rather than in conflict with them, through the introduction of plant communities native to the region. Adapting native plants to urban open space, streetscapes, and roofs offers multiple benefits, ranging from a re-introduction of natural foliage color into cities, to increased plant biodiversity that provides high-quality food and shelter to native insects, birds, and mammals (Figure 1). The use of native plant species that are naturally resilient to harsh growing conditions can prove additionally beneficial, since these plants may be more apt than their sensitive brethren to withstand drought, survive, and persist in number with minimal maintenance within the built environment.

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FIGURE 1: A native bee pollinating the state-endangered Aster ciliolatus (Lindy's Aster) on a green roof in Syracuse, NY. (Photo: Andropogon)

Since the commercial introduction of thin green roofs to North American around 2000[1], succulent plants from the genera *Sedum* and *Phedimus* (formerly classified within the *Sedum* genus) have dominated rooftop plantings due to their successful proliferation on European green roofs and propensity to tolerate the dry, stressful growing conditions that typify rooftops. Thirty-five *Sedum* species are in fact native to North America, but few tolerate full sun, rendering them widely undesirable to the green roof industry. Consequently, the majority of commonly planted green roof *Sedum* species originate from Europe or Asia. While some of these species are ecologically valuable as host plants for native invertebrates – such as *S. ternatum*, which is pollinated by native bees and serves as the host plant for the Variegated Fritillary and Buckeye butterfly caterpillars – any planting that is limited in genera will be similarly limited in the number of potential ecological interactions it can support. Additionally, low-diversity plantings, typical of *Sedum-Phedimus* dominant green roofs, are likely to be less resilient to disturbances, such as extreme weather fluctuations, because in these assemblages a single species may represent a large proportion of the planting. By contrast, a species lost within a high-diversity assemblage would have less impact on the overall planting and the assemblage would have a greater chance of rebounding after the disturbance.

Deploying native plant assemblages – meaning the intentional planting of a combination of plant species that naturally occur together in a given habitat – may yield additional benefits beyond those typified by selecting individual native species or randomly selecting diverse groupings of plants. Wholescale native plant assemblages provide an ecologically rich urban habitat, and with potential increased plant performance resulting from the species' (and their soil microbes') complementary strategies that may have co-evolved over time. Including threatened or scarce plant communities in constructed landscapes yields the additional benefits of providing habitat for rare animal species that rely upon these environments, exposing people to these plant communities (rather than conducting site visits to fragile ecosystems), and providing unique educational opportunities.

INTEGRATIVE DESIGN

A 9,400-square-foot green roof in Syracuse, New York, built in 2013, at the State University of New York College of Environmental Science and Forestry (SUNY-ESF), supports rare plant assemblages native to New York's grassland and dune regions. The wedge-shaped green roof

1. Snodgrass (2006).

FIGURE 2: SUNY-ESF's LEED Platinum Gateway Center supports a semi-intensive green roof informed by two NY-native, rare plant communities. (Photo: Andropogon)

FIGURE 3: Plant labels educate visitors about the green roof's rare species, while orange flagging delineates research plots. (Photo: Andropogon)

occupies the second floor roof of the university's Gateway Center – a LEED Platinum building that houses a student center, café, bookstore, conference space, and wildlife collection – with a taller building story to the east (Figure 2). As the nation's oldest college dedicated solely to the study of the environment and one of the country's leading environmental education and research institutions, the Gateway Center's design echoes the university's philosophical principle of sustainability. As such, the building's accessible green roof serves as an outdoor laboratory while providing flexible space for students, staff, and visitors across a meandering wood deck (Figure 3).

Meeting the university's building program and performance goals required an integrative design process, in which the client, design team, and end-user maintained a close-knit collaboration from concept development through post-construction. The project's prime designer, Boston-based architecture firm Architerra, Inc., guided this effort, in close coordination with sub-consultant Andropogon Associates, the Philadelphia-based landscape architect of record. Andropogon landscape architect and project manager Darren Damone, PLA, maintained a distinctive connection with the project, as a SUNY-ESF alumnus and New York native. Other design team members included Clark Engineering and Surveying, P.C. (structural engineer), Van Zelm Heywood & Shadford, Inc. (mechanical-electrical-plumbing engineer), and Bryant Associates, P.C. (civil engineer). A multi-faceted client team, led by SUNY-ESF's Assistant Director of Physical Plant for Facilities, Brian Boothroyd, consisted of additional university administrators; select faculty, staff, and students; a stakeholder steering committee; and the New York State University Construction Fund, which financed the project and provided additional guidance.

Together, this robust team collaboratively distilled specific design goals for the Gateway Center building, its green roof, and the surrounding landscape. Andropogon's project involvement with the green roof and on-grade landscape design centered around three main priorities: 1) Improve the campus' physical and social connections; 2) Incorporate didactic (meaning educational) landscape elements that further the university's educational mission; and 3) Use green infrastructure in place of traditional infrastructure to perform services such as stormwater management and building insulation.

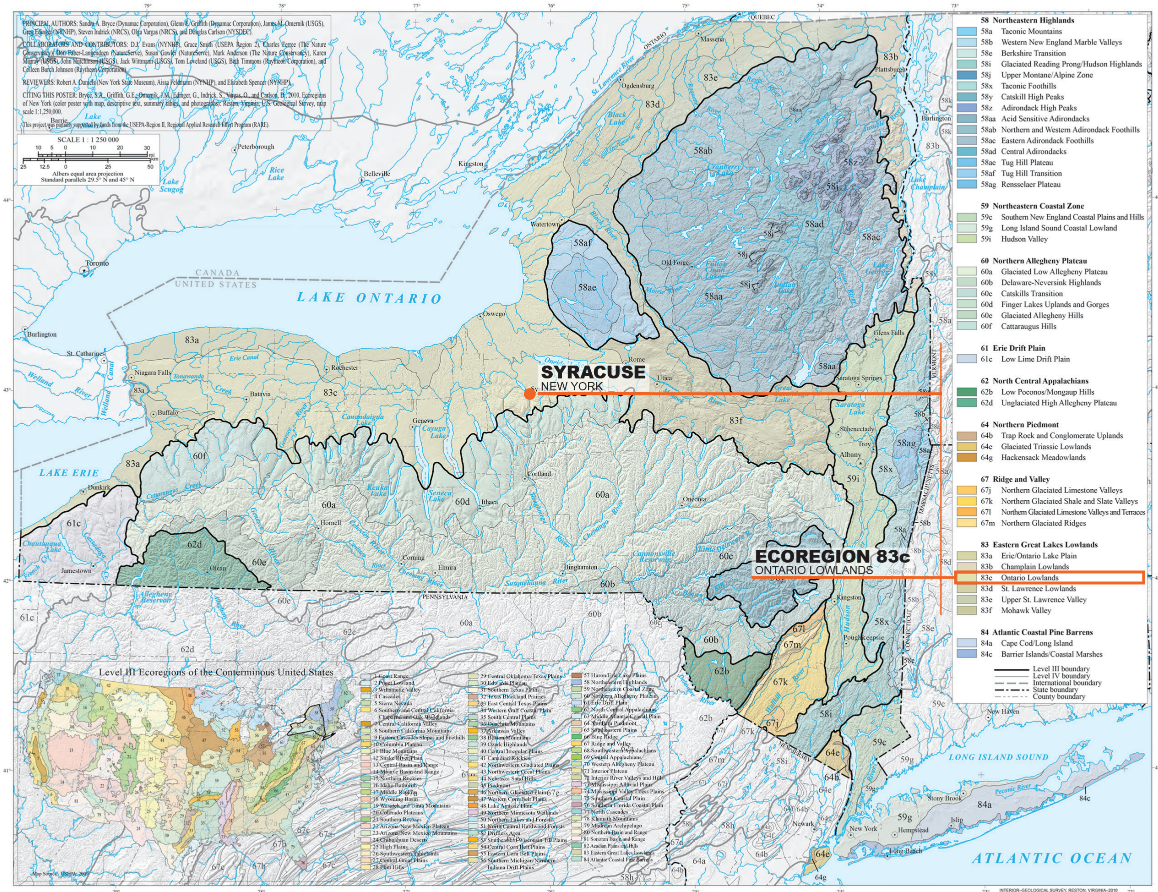
STRESS LOVERS

Sculpted by glacial lakes and flooding, Syracuse lies in Central NY within the Ontario Lowlands of the Eastern Great Lakes Lowlands (ecoregion 83.c)[2], 35 miles southeast of Lake Ontario (Figure 4). As such, the city experiences a lake effect with a climate typified by cloud cover in late fall through early winter, and dense fog with high snowfall during winter. Temperatures range from an average low of 17°F in January to an average high of 82°F in July, with 41.5 inches of precipitation annually, on average[3]. Do native plant communities exist that can survive this cold, damp, overcast climate with the added stresses of thin, nutrient poor soil and high wind found on most roofs? SUNY-ESF Distinguished Teaching Professor, chair of the Department of Environmental and Forest Biology, and Gateway Center design collaborator Donald J. Leopold, PhD studies how wisely selected marginal, native plant communities adapt to the built environment. The marginal habitat concept arises from ecologist Paul Keddy's centrifugal organization model[4], which predicts that low resource, high stress habitats will support high species diversity and low biomass. In these habitats, successful plants perform as "stress tolerators," meaning they are able to tough it out in growing environments typically considered undesirable – such as sandy, rocky, or very shallow soils – while securing a niche that is free from competition with species that typically dominate in fertile soils. Field studies support this theoretical model, suggesting that marginal habitats may serve as appropriate models for green roof design. Based on localized research by Leoplold, the design-research team chose two such marginal plant communities for adaption to the Gateway Center green roof: the alvar grasslands and Lake Ontario dunes.

Alvar habitats persist in thin soils atop shallow limestone or dolostone bedrock, and exhibit extremely high species diversity relative to other North American habitats (Figure 5). In North America, these rare habitats almost exclusively exist within the Great Lakes Basin[5], wherein the predominant vegetation class defines their subtype (or sub-habitat type) as pavement barren, grassland, shrubland, or woodland. These subtypes typically follow successional

2. U.S. Environmental Protection Agency (2009)
3. U.S. Climate Data (2016)
4. Keddy (1990)
5. Reschke (2014)

FIGURE 4: Syracuse, NY is located within ecoregion 8.1.83.83c: the Eastern Temperate Forests, Mixed Wood Plains, Eastern Great Lakes Lowlands, Ontario Lowlands (ecoregion Levels I, II, III, IV). (Map: U.S. Environmental Protection Agency) -- *Journal of Green Building folks, I think this image should be as big as possible to convey that the state is divided into multiple zones. Reading the text is not essential, as we've enlarged the information most relevant to the article.*



trajectories as organic matter accumulates, soil depth increases, and the moisture regime changes over time. Pavement barrens are the most extreme in terms of environmental stress due to their hyper-thin, undeveloped soils. Most alvar habitats experience prolonged droughty conditions because of their mineral-rich soil's inability to hold much moisture, while wet alvar habitats additionally experience inundated conditions in early spring. Alvars therefore mirror green roof conditions because of their low organic content, low nutrient, and rapidly draining soils. Additionally, open-canopy habitats such as pavement barrens, grasslands, and shrublands can experience the high sun and winds that typify most green roofs.

Great Lakes dunes occur along the sandy shores of the Great Lakes, with vegetation characterized by the predominance of shrubs and grasses, and dune stability as the main determinant of vegetation type[6] (Figure 6). *Ammophila breviligulata* (American beachgrass) is one of the most common species, while *Salix cordata* (heartleaf willow), *Artemisia campestris ssp. caudata* (beach wormwood), and *Populus deltoides* (cottonwood) appear less frequently. The dunes' sandy, rapidly draining soils with low organic and nutrient content, coupled with their high sun and wind exposure, position these habitats as another strong analog for green roof design.

6.. Reschke (2014)

FIGURE 5: Marginal alvar grassland habitats support highly diverse plant communities in thin soil above bedrock. (Photo: Andropogon)

FIGURE 6: Central New York's Great Lake's dune community served as a reference community for portions of SUNY-ESF's Gateway Center green roof. (Photo: Andropogon)

UP ON THE ROOF

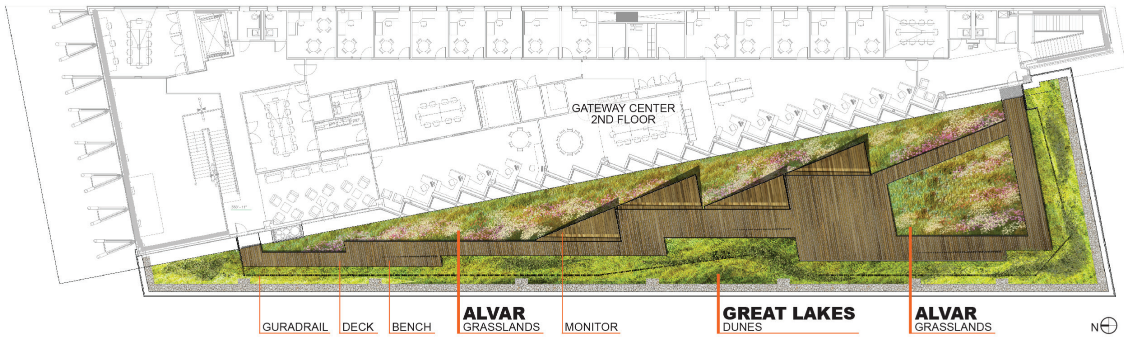
Selecting potential plant species for the Gateway Center green roof began with SUNY-ESF faculty, research students, and Andropogon landscape architects and researchers jointly engaging in field visits to the alvar grasslands and Great Lakes dunes to experience the habitats firsthand. During these visits, the team conducted geo-located quadrat sampling of vegetation composition, dispersal, and density, to inform the green roof planting design (Figure 7). They also noted soil conditions, soil depth to bedrock, aesthetic character, and overall structure and patterns in abiotic and biotic elements for design and functional inspiration. The team then compiled a preliminary green roof plant list that reflected a complete "wish list" of species observed in the field. To more accurately predict each species rooftop performance, the team developed a plant trial strategy that played out on a rooftop adjacent to the Gateway Center, which was under construction at the time. In 2010, SUNY-ESF faculty and students built a series of wooden frames and filled each test plot with the intended green roof profile and media depths (Figure 8). Limited species availability from local plant nurseries caused the team to procure the rarest plants from specialized nurseries, the National Resource Conservation Service Plant Materials Centers, and in-house propagation from privately collected specimens. Species survival monitoring and qualitative plant health assessment occurred continually for 18-months, with a final evaluation in summer 2011. The team then distilled the final plant list based on the plant trial results and anticipated nursery availability. This process exemplifies the project's adaptive design process wherein the client's well-researched input and active green roof plant trials continually informed the design (Figure 9-10).

FIGURE 7: SUNY-ESF researchers and Andropogon representatives conducted geo-located quadrat sampling of vegetation composition, dispersal, and density in the alvar grasslands to inform the Gateway Center green roof planting design. (Photo: Andropogon)

FIGURE 8: In 2010, SUNY-ESF researchers conducted plant trials to help inform the Gateway Center green roof plant list (Photo: SUNY-ESF)

The Getaway Center's construction team included Turner Construction Company (construction manager), Murnane Building Contractors (general contractor), Watson Farms (landscape and green roof contractor), and Recover Green Roofs (green roof planting contractor). Once the Gateway Center's waterproofing membrane was installed and tested using electronic leak detection, a layer of extruded polystyrene insulation with drainage channels was laid. Then, the roof's accessible wood decking was built with sleepers that extended toward the parapet to provide an anchor point for the guardrail base. This method avoided the need for roof penetrations (at the guardrail base), which have a higher risk of leaking than the flat seams and field of the waterproofing membrane. Next, Watson Farms secured perforated edging at the deck's margin to contain the vegetated roof areas, and then laid a geosynthetic sheet drain followed by a needle-punched geotextile. The contractor then installed "false terrain" by stacking extruded polystyrene insulation, cut to reflect specified contour geometries, followed by another needle-punched geotextile, and then large, natural stones positioned according to Andropogon's green roof layout plan (Figure 11). Watson Farms then installed green roof media, via blower truck, to specified, varied depths throughout the green roof to mimic irregular growing conditions typical of the reference comminutes. Though not apparent

FIGURE 9: The Gateway Center green roof references alvar grassland plants close to the building and Great Lakes dune plants outboard of the meandering wood deck. (Image: Andropogon).



from the surface, this media depth ranged from 6-to-18-inches, while the false terrain strategically accentuated or hid these thicknesses. The media consisted of a mix of lightweight mineral aggregate, sand, and compost, with a moderate particle size distribution, relatively low organic content, moderate water holding capacity, and low transmissivity. After the media was compacted with hand tamping, the contractor installed a spun jute wind blanket with wide apertures, meant to stabilize the surface of the media and then photodegrade once the plant roots established. During planting, several professors, including Leopold, were physically present and attentive due to the plant palettes' complexity (Figure 12-13). The planting plan and schedule intricately specified plant species, placement, and quantity, reflective of the caliber of research that the team deployed to inform the design. No permanent irrigation was installed, although the plants were hand watered during the first growing season to ensure establishment.

FIGURE 10: One-meter by 1-meter quadrat sampling helped Andropogon designers and SUNY-ESF researchers better understand alvar grassland plant communities. (Photo: Andropogon)

Realizing the Gateway Center's green roof design intent as an outdoor laboratory involved overcoming some obstacles. Leopold and his team largely engaged in post-occupancy research surrounding plant establishment (stem counts, dieback, vigor, and species migration), including a complete vegetation survey conducted in 2014, one-year after the green roof installation.

FIGURE 11: False terrain and large natural stones at the Gateway Center green roof helped create green roof microclimates, similar to conditions found in marginal reference communities. (Photo: Andropogon)

FIGURE 12: Plant spacing on the Gateway Center green roof ranged from 8-to-12-inches on center, depending on the species. (Photo: Andropogon)

FIGURE 13: Natural stone on the green roof mimics the alvar grassland reference community's shallow bedrock, even once the plants mature. (Photo: Andropogon)

Supporting studies included monitored soil biology (total and active bacteria, total and active fungi, protozoa, nematodes, mycorrhizal colonization, and soil moisture); entomology (pollinator species, pollinator quantity, and number of flower visits); weather patterns (precipitation, air temperature, and wind speed); roof temperature; and plant community composition in response to supplementary irrigation.

The composition monitoring involved dividing the roof's vegetated areas into plots of roughly equal size and delineating them with short stakes and flagging. While the study has revealed valuable preliminary results, the green roof's irregular geometry, media depth, and microclimate complicated the research by creating confounding variables and minimizing opportunity for the replication of identical treatments across multiple plots. Furthermore, the use of temporary plot delineation for a multi-year study, particularly in a climate that experiences heavy snow, is risky compared to a permanent, built-in-place means of visual differentiation. Some of these challenges could have been circumvented with more in-depth designer-researcher coordination during the green roof's design.

IN THE FIELD

Armed with lessons learned from the Gateway Center, SUNY-ESF is currently collaborating with Andropogon and Ellenzweig Architecture & Planning to complete the design of the campus' second research green roof, "v2.0," slated for completion in 2019. The 1,700-square-foot outdoor laboratory will adorn a portion of the university's new Academic Research Building, approximately 500-feet east of the Gateway Center. In an effort to provide programming that complements (rather than duplicates) that of the Gateway Center, as well as infrastructure that caters to university researchers' needs, the Academic Research Building green roof is designed to flexibly accommodate rigorous scientific studies that are already planned and future research efforts yet to be conceived. The design provides four hydrologically isolated research plots of equal area, each with an internal roof drain and consistent media depth, with delineation between the plots expressed on the surface using walkway pavers atop a narrow curb. A permanent irrigation system with an independently operable zone in each plot will further the design's effectiveness, by providing supplemental water to each plot on an as-needed basis. These features are intended to accommodate studies ranging from stormwater performance to long-term effects of vegetation on media composition, with a minimum of three test plots and one control plot per study. Additional walkways, two small gathering spaces, and a cascading series of rooftop bogs separated by weir walls further enrich the green roof design.

FIGURE 14: Andropogon and SUNY-ESF-led field visits to PA serpentine barrens provided an opportunity for invited industry and academic experts to experience the rare habitat firsthand and discuss potential applications to green roof design. (Image: Andropogon)

The plant selection process for the Academic Research Building began with field visits to the alvars at Lucky Star Ranch in Chaumont, NY, and several serpentine barren sites in southeastern PA. The field visits were attended by industry and academic experts from a diverse spread of disciplines, including ecology, botany, geology, horticulture, landscape architecture, and green roof media manufacturing (Figure14). The field trips served as an opportunity to visually explore these unique habitats, dive into multi-disciplinary discussions about the abiotic and biotic conditions shaping these communities, and gain insight into how those understandings might be applied to innovative green roof design. Due to the diversity of fields represented, participants had the opportunity to discuss plant selection, soil factors (including how and whether to model the green roof media on the reference community soils), and hydrology.

Serpentine barrens, similar to alvars, characteristically contain very shallow bedrock and relatively undeveloped soils that drain rapidly and have low organic and nutrient content. Also like alvars, serpentine communities can be categorized as barrens, grasslands, shrublands, or woodlands. Two unique constraints that affect plant communities on serpentine outcrops are the high magnesium to calcium ratio of the geologic parent material, and the relatively high concentration of nickel. The resultant chemical composition of serpentine soils proves toxic to many plants, so the plant species that inhabit the barrens exhibit specialized stress tolerance mechanisms, leading to a diverse and specialized mix of plants within serpentine sites. Historically, the use of fire by indigenous peoples maintained barrens and grasslands by preventing the accumulation of organic matter, which would otherwise promote succession to wooded conditions. In the absence of periodic fire, the influx of organic matter from surrounding wooded sites is now a primary challenge to the conservation of serpentine sites, particularly within the eastern U.S. Similar to alvar and dune communities, serpentine barrens serve as an excellent green roof reference community because of their rocky, rapidly draining soils with low nutrients and organic matter, and their exposed conditions. It is worth noting that while serpentine barren plants exist in soil conditions that would be toxic to many plants, they do not *require* such conditions, rather, they tolerate such conditions. As such, recreating the serpentine soil chemistry in order to use serpentine plant species on a green roof is not necessary.

To create a preliminary plant list for the Academic Research Building green roof, SUNY-ESF PhD student and this paper's co-author, Toby Liss, initially reviewed a catalog of characteristic serpentine barren flora developed by ecologist and conservation biologist Roger Latham, PhD. Liss then collected available data about each species' typical distribution, sun and moisture tolerances, and habitat, and then assigned scores to tolerance, distribution, and habit based on suitability to green roof conditions. She then summed the scores and ranked the species accordingly. Species that scored within the top 50% of the list (excluding trees, large shrubs, and species already tested thoroughly on green roofs) were selected for a plant trial, with final culling based on commercial availability as landscape plugs or quarts (Figure 15). The plant trial, which will run from 2016-2017, utilized the same plot design and test location as the Gateway Center trail, and results will similarly inform the final green roof plant list.

SELECTING A REFERENCE PLANT COMMUNITY

The concept of adapting native plant assemblages to green roofs extends far beyond the bounds of Central NY. Reference plant communities that occupy dry, nutrient poor, windy

FIGURE 15: SUNY-ESF PhD student Toby Liss ranked potential species for the Academic Research Building plant trial and then tested those that ranked highly and were available through procurement during an ongoing 2016-2017 study. (Data: Liss 2016a)

SUNY-ESF ACADEMIC RESEARCH BUILDING 2016-2017 PLANT TRIAL SPECIES LIST

Species selected for plant trial based on ranked scoring system | Species successfully procured & planted in trial

RANK	SCIENTIFIC NAME	COMMON NAME(S)
1	*Minuartia michauxii*	rock sandwort
2	*Phlox subulata*	moss phlox, moss-pink, creeping phlox
3	*Panicum philadelphicum*	Philadelphia panic-grass
3	*Sporobolus neglectus*	small rush grass, small dropseed
3	*Asclepias verticillata*	whorled milkweed
5	*Asclepias viridiflora*	green milkweed, green comet milkweed
5	*Sporobolus vaginiflorus*	poverty dropseed, sheathed rush grass, sheathed rush, sheathed dropseed
5	*Symphyotrichum ericoides*	white heath aster
5	*Trichostema brachiatum*	false pennyroyal
6	*Lilium philadelphicum*	wood lily
7	*Lespedeza capitata*	round-headed bush-clover, round-headed lespedeza
7	*Lobelia spicata var. spicata*	spiked lobelia, palespike lobelia
7	*Phemeranthus teretifolius*	round-leaf fameflower, quill fameflower
8	*Dichanthelium acuminatum*	tapered rosette grass, Lindheimer panic-grass
8	*Dichanthelium dichotomum*	cypress panic-grass, annulus panic-grass, Yadkin river panic-grass
8	*Lespedeza virginica*	slender bush-clover, slender lespedeza
8	*Phlox pilosa*	downy phlox, prairie phlox, fragrant phlox
8	*Viola sagittata*	arrow-leaf violet
9	*Aristida oligantha*	prairie three-awn
9	*Asclepias purpurascens*	purple milkweed
9	*Carex glaucodea*	blue sedge
9	*Paspalum setaceum*	paspalum
9	*Sorghastrum nutans*	Indian-grass
10	*Antennaria plantaginifolia*	plantain-leaf pussytoe, woman's-tobacco
10	*Bouteloua curtipendula*	side-oats grama, tall grama
10	*Carex retroflexa*	reflexed sedge
10	*Cyperus lupulinus*	Great Plains flatsedge, sand sedge
10	*Lechea minor*	thyme-leaf pinweed
11	*Aletris farinosa*	white colicroot
11	*Cerastium velutinum var. villosissimum*	serpentine chickweed, long-haired barrens chickweed
11	*Lonicera dioica*	wild honeysuckle
11	*Vernonia glauca*	Appalachian ironweed, tawny ironweed, broadleaf ironweed
12	*Andropogon gyrans*	Elliott's beardgrass
12	*Chamaecrista fasciculata*	partridge-pea, prairie senna
12	*Comandra umbellata*	bastard toadflax
12	*Juncus secundus*	lopsided rush
12	*Oenothera fruticosa ssp. glauca*	sundrops, narrow-leaf evening-primrose
12	*Spiranthes vernalis*	spring ladies'-tresses, grass-leaved ladies tresses
12	*Stylosanthes biflora*	pencil-flower
13	*Castilleja coccinea*	Indian paintbrush
13	*Cerastium velutinum*	barrens chickweed, field chickweed
13	*Desmodium marilandicum*	Maryland tick-clover, smooth small-leaf tick-trefoil
13	*Houstonia caerulea*	bluets, Quaker-ladies, azure bluet
13	*Luzula multiflora*	field woodrush, common woodrush
13	*Sabatia angularis*	common marsh-pink, rose-pink
13	*Tridens flavus*	purpletop
14	*Pycnanthemum tenuifolium*	narrow-leaf mountain-mint, slender mountain-mint
14	*Sisyrinchium mucronatum*	needletip blue-eyed-grass
15	*Cirsium horridulum*	yellow thistle, horrible thistle
15	*Cystopteris fragilis*	fragile fern
15	*Desmodium paniculatum*	panicled tick-trefoil
15	*Galium boreale*	northern bedstraw
15	*Heliopsis helianthoides*	ox-eye, smooth ox-eye
15	*Liatris spicata*	blazing-star
15	*Muhlenbergia mexicana*	Mexican muhly, satingrass
15	*Polygala verticillata*	whorled milkwort
15	*Scleria triglomerata*	whip-grass, whip nut-rush
15	*Scutellaria serrata*	showy skullcap
15	*Setaria parviflora*	perennial foxtail, marsh bristle-grass
15	*Shepherdia canadensis*	buffalo-berry, buffaloberry
15	*Smallanthus uvedalius*	bear's foot, leaf cup
15	*Solidago bicolor*	silver-rod, white goldenrod
15	*Symphoricarpos albus*	common snowberry
16	*Arabis lyrata*	lyre-leaf rockcress, lyrate rockcress
16	*Ceanothus americanus*	New Jersey tea
16	*Linum intercursum*	sandplain wild flax
16	*Polygonum tenue*	slender knotweed, pleat-leaf knotweed
16	*Potentilla canadensis*	dwarf cinquefoil
16	*Rosa carolina*	pasture rose, Carolina rose
n/a	*Calamintha arkansana*	calamint
n/a	*Symphyotrichum depauperatum*	serpentine aster

growing environments exist throughout the North America, from west coast cliffs and savannas, to Midwestern prairies, to east coast dunes and barrens. Each of these communities can serve as a potential analog for green roofs. While these reference communities share certain growing condition regime characteristics with one another, each is appropriate for adaption to green roofs within a unique geographic region, with minimal overlap. The key to selecting a functionally appropriate reference community for a specific green roof therefore lies in: 1) Recognizing that no "one-size fits all" approach exists wherein a single reference community can be effectively applied to any green roof across the country; and then 2) Wisely selecting a reference community based upon shared growing condition characteristics between the community and the planned green roof.

FIGURE 16: The U.S. Environmental Protection Agency partitions North America into 25 Level II ecoregions, or ecological regions. (Image: U.S. Environmental Protection Agency via Commission for Environmental Education)

To better understand the geographic pockets of shared growing conditions within North America, Andropogon looked to the U.S. Environmental Protection Agency (EPA)'s ecoregion maps. Ecoregions are ecological regions, each composed of areas with similar ecosystems, identified by "analyzing patterns of biotic and abiotic phenomena, both terrestrial and aquatic… [including] geology, landforms, soils, vegetation, climate, land use, wildlife, and hydrology."[7] As opposed to other regional divisions that serve hyper-specific purposes or align to political boundaries (such as U.S. Department of Agriculture plant hardiness zones, U.S. Forest Service Regions, or U.S. Census Tracts), the EPA developed these maps of amalgamated data to offer a spatial framework for cross-disciplinary research, resource and wildlife management, and assessment. Four layers of ecoregion maps exist, designated with Roman numerals as Levels I through IV, with increasing degrees of specificity. Level I paints broad strokes across ecosystem types to achieve 12 ecoregions within the continental U.S. With increasing granularity, Levels II, III, and IV contain 25, 105, and 967 ecoregions, respectively (Figure 16). For each ecoregion at every level, the EPA describes the typical physiology, geology, soils, climate, natural vegetation, and land cover/land use.

Andropogon developed a Green Roof Reference Community Table (Figure 17) to provide guidance as to which reference plant communities serve as appropriate analogs for green roofs throughout North America. The table is organized by Level I ecoregion and then subdivided by Level II to provide an accurate, yet not overwhelmingly granular tool intended to offer landscape architects, ecologists, and horticulturalists a conceptual starting point for the design and plant selection of native plant green roofs. The table synthesizes original research by Andropogon's Integrative Research Department and SUNY-ESF's Department of Environmental and Forest Biology as well as studies within the literature ("Research" column), while providing inferences based on scientific reasoning and for regions that lack published research on green roof plant performance ("Inference" column).

For example, the Table shows that Lake Ontario dunes, alvar grasslands, and serpentine barrens – analog communities for SUNY-ESF's Gateway Center and/or Academic Research Building – may serve as appropriate reference for green roofs within the Eastern Temperate Forest, Mixed Wood Plains ecoregions (Level I, II), as supported by the authors' original research[8] and that of SUNY-ESF researchers[9]. Studies published by other researchers suggest that the shortgrass prairie may serve an appropriate reference for green roofs in the Eastern Temperate Forest, Central USA Plains ecoregions (Level I, II)[10]. It's worth noting that while ecoregion Levels I and II generally provide sufficient specificity for urban projects, the more detailed Level III is required for projects that seek Sustainable SITES Initiative rating, and Level IV is critically informative for ecological restoration efforts, which may benefit further from increased granularity by specifying site specific ecotypes and genotypes. By contrast, projects that seek LEED and/or Living Building Challenge certification can utilize plant species outside of the local ecoregion, since these certification systems rely upon political boundaries for plant origin.

Although recreating a reference community may present an appealing design approach that highlights a particular plant community, from a scientific perspective, precisely duplicating these habitats is not necessary to increase ecological value. Many marginal habitats support

7. U.S. Environmental Protection Agency (2016)
8. Liss (2016a), Liss (2016b)
9. Leopold et al. (2011)
10. Ksiazek (2014)

FIGURE 17: The author's Green Roof Reference Community Table synthesizes research and provides inference into which reference communities may be suitable for application to native plant green roofs in each of North America's Level II ecoregions. (Image: Andropogon)

GREEN ROOF REFERENCE COMMUNITY TABLE

R = Research I = Inference

ECOREGION LEVELS (I & II)		REFERENCE COMMUNITY	DESCRIPTION	DATA SOURCE R	I	Reference	LOCATION
1	**ARCTIC CORDILLERA**	N/A	N/A				
2	**TUNDRA**	N/A	N/A				
3	**TAIGA**	N/A	N/A				
4	**HUDSON PLAIN**	N/A	N/A				
5	**NORTHERN FORESTS**						
5.1	Softwood Shield	N/A	N/A				
5.2	Mixed Wood Shield	Limestone cliff	Exposed limestone bedrock, thin soils, high wind		X	Lundholm (2006)	N/A
		Talus slope	Rocky deposit or accumulation		X	Lundholm (2006)	N/A
5.3	Atlantic Highlands	Coastal barren	Rocky, thin soils, soil moisture variability, high winds	X		Ranalli (2009)	Nova Scotia
5.4	Boreal Plain	N/A	N/A				
6	**NORTHWESTERN FORESTED MOUNTAINS**						
6.1	Boreal Cordillera	N/A	N/A				
6.2	Western Cordillera	Coastal savanna	Mountain shrub	X		Sutton et al. (2012)	Salt Lake City, UT
7	**MARINE WEST COAST FOREST**						
7.1	Marine West Coast Forest	Coastal savanna	Coastal savanna	X		Sutton et al. (2012)	San Bruno, CA
		Coastal savanna	Coastal savanna	X		Dvorak & Davis (2010)	Corvallis, OR
8	**EASTERN TEMPERATE FOREST**						
8.1	Mixed Wood Plains	Alvar grassland	Limestone or dolostone bedrock, thin or absent soil	X		Leopold et al. (2010)	Syracuse, NY
		Alvar grassland	Limestone or dolostone bedrock, thin or absent soil	X		Liss (2016b)	Syracuse, NY
		Alvar	Limestone or dolostone bedrock, thin or absent soil		X	Lundholm (2006)	N/A
		Lake Ontario dune	Sandy, well-drained, neutral to alkaline soil	X		Leopold et al. (2010)	Syracuse, NY
		Limestone cliff	Exposed limestone bedrock, thin soils, high wind		X	Lundholm (2006)	N/A
		Serpentine barren	Shallow bedrock, thin soils, low nutrient soils		X	Liss (2016a) - results forthcoming	Syracuse, NY
		Pitch pine-scrub oak barren	New England xeric	X		Andropogon (2016), Swain (2016)	Boston, MA
		Acidic rock cliff	New England acidic shady cliff	X		Andropogon (2016), Swain (2016)	Boston, MA
		Talus slope	Rocky deposit or accumulation		X	Lundholm (2006)	N/A
8.2	Central USA Plains	Shortgrass prairie	Semiarid prairie, dominated by shortgrass spp.	X		Ksiazek (2014)	Glencoe, IL
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	St. Charles, IL
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Glenview, IL
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Chicago, IL
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Chicago, IL
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Glencoe, IL
8.3	Southeastern USA Plains	Cedar glade	Shallow limestone bedrock, thin soils, sparse cedar spp.	X		Sutton et al. (2012)	Nashville, TN
		Cedar glade	Shallow limestone bedrock, thin soils, sparse cedar spp.		X	Lundholm (2006)	N/A
		Granite barren	Exposed granite bedrock, shallow soils		X	Lundholm (2006)	N/A
8.4	Ozark Ouachita-Appalachian Forests	N/A	N/A				
8.5	Mississippi Alluvial & Southeast USA Coastal Plains	Cedar glade	Shallow limestone bedrock, thin soils, sparse cedar spp.		X	Lundholm (2006)	N/A

ECOREGION LEVELS (I & II)		REFERENCE COMMUNITY	DESCRIPTION	DATA SOURCE R	I	Reference	LOCATION
9	GREAT PLAINS						
9.2	Temperate Prairies	Sand prairie	Semiarid prairie, sandy soil	X		Sutton et al. (2012)	Lincoln, NE
		Bluff bedrock prairie	Shallow sandstone bedrock, sandy soils, dry	X		Sutton et al. (2012)	Minneapolis, MN
		Bluff bedrock prairie	Shallow sandstone bedrock, sandy soils, dry	X		Sutton et al. (2012)	Minneapolis, MN
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Minneapolis, MN
		Tallgrass prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Minneapolis, MN
9.3	West-Central Semi-Arid Prairies	Northern Rocky Mountain Subalpine-Upper Montane Grassland	Dry soils, often south-facing slopes, dominated by perennial grasses and forbs		X	NatureServe Explorer (2016)	N/A
		Northwestern Great Plains Mixedgrass Prairie	Fine and medium-textured soils, greater than 50% cool-season grass cover		X	NatureServe Explorer (2016)	N/A
		Rocky Mountain Alpine Fell-Field	Shallow, stony, low organic matter, poorly developed soils, high wind, 15-50% plant cover, exposed rock		X	NatureServe Explorer (2016)	N/A
		Rocky Mountain Subalpine-Montane Mesic Meadow	Mesic meadow rich with forb species, contains graminoid species		X	NatureServe Explorer (2016)	N/A
		Western Great Plains Sand Prairie	Sand prairie, dominated by graminoid species with shifting relative dominance due to wind disturbance		X	NatureServe Explorer (2016)	N/A
		Western Great Plains Tallgrass Prairie	Mesic prairie, dominated by tallgrass species				
		Northern Great Plains Fescue-Mixed Grass Prairie	Level sites, hilltops, or upper slopes with clay, silty clay, or loam soils that may be solonetzic, with an impervious subsoil hardpan caused by excess sodium		X	NatureServe Explorer (2016)	N/A
9.4	South Central Semi-Arid Prairies	High plains	High plains	X		Sutton et al. (2012)	Denver, CO
		Flint Hills prairie	Semiarid prairie, dominated by tallgrass spp.	X		Sutton et al. (2012)	Manhattan, KS
		Mid-grass prairie	Semiarid prairie, dominated by mid-grass spp.	X		Sutton et al. (2012)	Austin, TX
9.5	Texas-Louisiana Coastal Plain	N/A	N/A				
9.6	Tamaulipas-Texas Semiarid Plain	N/A	N/A				
10	NORTH AMERICAN DESERTS						
10.1	Cold Deserts	Desert cliff	Shallow soils, dry, fluctuating temperatures, slow-growing vegetation		X	Lundholm (2006)	N/A
10.2	Warm Deserts	Desert cliff	Shallow soils, dry, fluctuating temperatures, slow-growing vegetation		X	Lundholm (2006)	N/A
11	MEDITERRANEAN CALIFORNIA						
11.1	Mediterranean California	Coastal savanna	Coastal dunes, sandy soil, dry	X		Sutton et al. (2012)	San Francisco, CA
12	SOUTHERN SEMI-ARID HIGHLANDS						
12.1	Western Sierra Madre Piedmont	Semi-desert grassland	Grassland dominated by perennial grasses, some shrubs, forbs, succulents, annuals		X	The Nature Conservancy (2006)	N/A
12.2	Mexican High Plateau	N/A	N/A				
13	TEMPERATE SIERRAS	N/A	N/A				
14	TROPICAL DRY FORESTS	N/A	N/A				
15	TROPICAL WET FORESTS	N/A	N/A				

species that exist in broad distribution and can be highly functional beyond their native local. Constructed landscapes that incorporate native plants are therefore likely to provide increased habitat value to native animal species relative to similar landscapes planted exclusively with non-natives. Furthermore, aesthetic advantages may result from combining complementary native species from multiple reference communities.

Certain areas of North America may lack suitable reference communities for native plant green roofs altogether. The Green Roof Reference Community Table lists six Level I ecoregions and seven additional Level II ecoregions as "N/A," meaning that the authors were not successful in identifying any naturally occurring analog plant communities. These regions predominantly occur at high latitudes with cold climates (e.g. Tundra, Taiga) or tropical, near-equatorial regions (e.g. Tropical Wet Forests).

If reference communities do in fact exist in these areas, it's conceivable that the search criteria characteristics could differ from that of reference communities in, for example, temperate regions.

THE IRRIGATION QUANDARY

Logic dictates that most reference plant communities suitable for adaption to harsh green roof conditions, particularly those that are drought tolerant, do not require irrigation (Figure 18). The Gateway Center green roof design and client team relied upon this assumption when electing not to install a permanent irrigation system, which proved to be a suitable decision until 2016. Syracuse, like most of the country, experienced prolonged droughts during the spring and summer of 2016, with the longest period without measured precipitation from June 23 to July 8 and the greatest proportion of precipitation-free days during a single month in August, with 77% of precipitation-free days[11]. During these dry spells, many of the Gateway Center's green roof plants declined or died.

FIGURE 18: Despite the Gateway Center green roof's drought tolerant reference plant communities, installation of a permanent irrigation system (for periodic use) would have been cost effective for multiple reasons. (Photos: Andropogon)

To quantify the effect of supplementary irrigation on plant survival and vegetation composition Liss engaged in a Gateway Center green roof hand-watering study. During drought conditions in 2016, half of the roof's plots received a watering treatment to simulate average local conditions while other plots received no supplemental watering. Liss completed a vegetation survey prior to the irrigation treatment, and plans to conduct a follow-up survey during the summer of 2017 in order to assess any shifts in vegetation composition that may result from the irrigation treatments. Although the authors recommend installing a permanent irrigation system in new green roofs, managers of existing, un-irrigated green roofs should not be

11. WeatherSpark (2016)

discouraged. The Gateway Center study relied solely upon a hose bib, which presents an easy method for replicating the experimental effort on other green roofs.

In the natural environment, plant loss due to prolonged drought is normal and communities are typically large enough to rebound over time. In the urban environment, significant plant death can be more problematic due to aesthetic expectations, required stormwater management performance, and the financial realities of replacing plants (particularly in difficult-to-access locations). SUNY-ESF's Academic Research Building design and client team therefore chose to include a permanent irrigation system in their "v2.0" green roof design, to be used as both a "safety blanket" in times of prolonged drought, and as a tool to aid rooftop research efforts that include supplementary water as a variable.

Installing permanent irrigation systems in green roofs informed by reference plant communities is beneficial due to additional intertwined aesthetic, environmental, and financial factors. Studies suggest that green roof irrigation leads to increased plant coverage, due to more rapid plant establishment[12 13]and increased survivorship during drought[14]. This increased plant coverage means that more plants are *transpiring* (releasing water vapor into the atmosphere), which moderates air temperatures directly above the vegetation and directly affects the green roof's overall stormwater performance. Water holding capacity also impacts stormwater performance, and a three-year study in Chicago at one of the world's largest research green roofs found that: 1) Green roof media's water holding capacity increased significantly once plants fully established; and 2) Moist green roof media retained more additional stormwater than dry media[15].

Green roof plant coverage and soil moisture also influence building energy use. Up on the roof, water held within the green roof media displays thermal massing and insulative effects, meaning that the surface and sub-surface temperatures of a healthy green roof fluctuate more slowly than that of a bare membrane roof, particularly during cold months[16]. Resulting tempered air temperatures around rooftop unit (RTU) and air handling unit (AHU) air intakes can additionally affect building energy use, by decreasing the energy required to heat and cool the indoor air in winter and summer, respectively. While little field research exists on this topic, the Chicago study measured these properties and found the most significant effects (and consequent energy savings) in RTUs during the winter[17](Figure 19). These findings are particularly significant for multi-story buildings, which can benefit from reduced heating and cooling demand but do not significantly benefit from a green roof's thermal massing and insulative effects due to their high building volume to roof surface area ratio.

At a neighborhood or citywide scale, increased plant coverage can prove additionally beneficial by contributing to urban heat island (UHI) effect reduction. UHI is a growing concern in cities, where on warm days, dense urban areas can be 3-8˚F warmer than nearby rural areas, causing increased energy demand, poor air quality, thermal discomfort, loss of life, and increased carbon dioxide emissions[18]. Strategies that landscape architects can employ on the roof to mitigate UHI, and thus reduce its secondary effects, include: 1) Increasing surface albedo (the proportion of light or radiation reflected by a surface) by applying light colors

12. Price (2011)
13. Durhman (2006)
14. Liss (2016b)
15. Walmart Corporation (2013)
16. Walmart Corporation (2013)
17. Walmart Corporation (2013)
18. McPherson (1994)

FIGURE 19: RTU air intakes within green roof areas result in energy savings that vary seasonally, with largest savings during winter months. (Photos: Andropogon)

to roofs; and 2) Increasing vegetated areas and thus evapotranspiration. Widespread use of these strategies can profoundly affect UHI mitigation. A study conducted by the University of Maryland on the U.S. Coast Guard Headquarters green roofs in Washington, D.C. found that during peak times, the green roofs were 15˚F cooler than the non-vegetated roofs of a similar, nearby office complex. The researchers' findings also suggest that different types of green roofs have varied mitigation potential. For instance, the meadow plantings (grass dominated planting with some forbs) on the U.S. Coast Guard Headquarters green roofs provided the lowest temperatures when compared to nearby *Sedum-Phedimus* and non-vegetated roofs[19].

When it comes to dollars and cents, installing a permanent irrigation system during construction can be a smart financial decision. This idea holds particular weight when considering the green roof's maintenance and lifecycle costs, which may be more relevant to owner-managed projects rather than to those built and then quickly sold by developers. For example, during the summer drought of 2016, SUNY-ESF Department of Environmental and Forest Biology representatives hand watered select treatment plots within the Gateway Center's 4,900-square foot vegetated rooftop area. Students performed most of the watering as an unpaid task, which totaled approximately 30 hours from June through August for 2,365-square feet of vegetated area. Had paid university's employees hand watered the green roof plots instead, the cost would have equaled $464, or $980 for the full vegetated area (based on Onondaga County's 2016 landscape maintenance prevailing wage rate of $15.46 per hour[20]), or $0.07 per square foot per month, on average. By contrast, the installed cost of a typical sub-surface drip irrigation system with a complete valve assembly and automatic controller would have cost approximately $1.27 per square foot[21]. Based on these figures, the payback period for a permanent irrigation system would have been 18 months of watering, or roughly six summers if irrigation only takes place seasonally. Installing a permanent irrigation system during construction would have therefore been more cost effective than hand watering the Gateway Center green roof, particularly when considering the added cost of replacement plants and increased wage rates during the course of the green roof's life.

19. Ellis and Reilly (2015)
20. New York State Department of Labor (2016)
21. Miller (2012)

The U.S. General Services Administration – which owns and manages 1,126,550-square-feet of green roof throughout the country – has reached similar conclusions based on a cost-benefit analysis study of green roofs[22] (Figure 20). Through a comprehensive study, they found that although there are increased construction and maintenance costs associated with green roofs with and without irrigation, the longevity of the green roofs offsets these costs. They estimate that a conservative payback of a typical green roof is 6.2 years in the U.S., assuming that an average green roof has a life expectancy of 40 years and a conventional roof has a life expectancy of 17 years (due to the need for more frequent waterproofing membrane replacement[23]. Using harvested rainwater, rather than municipal water, can further make the case for green roof irrigation by reducing operating costs.

FIGURE 20: The U.S. Coast Guard Headquarters at St. Elizabeth's Campus – owned by the U.S. General Services Administration – supports 400,750-square-feet of green roof, designed by Andropogon (Image: Perkins+Will)

GREATER IMPLICATIONS

Expanding the design and scientific communities' knowledgebase about native plant green roofs requires a recognition that native plant assemblages, informed by appropriate reference communities, can survive on rooftops. While this approach remains relatively novel, the infrastructure's unique ecological and didactic benefits elevate the need for its implementation throughout North America. Expanding this concept globally by applying this paper's ecoregion-based model for selecting appropriate reference communities to green roofs around the world would further build knowledge while increasing habitat value and ecosystem services within the built environment. Amassing a global ecoregion-driven database of native

22. U.S. General Services Administration (2011)
23. U.S. General Services Administration (2011)

plant reference communities, akin to that produced by the authors for North America, would further strengthen this approach, particularly if the tool were open-source.

Effectively pursuing native plant green roofs, particularly those used for research, requires that designers, scientists, and clients work collaboratively from pre-design through post-occupancy to understand the design, construction, management, and performance of native plant green roofs. Much like an integrated project delivery process in which an end-user might provide input during design meetings, researchers can play a key role by communicating their infrastructural and programmatic needs during the design phase. Collectively, the team can then navigate cost, schedule, and other obstacles of designing for landscape performance monitoring to deliver a native plant green roof that meets the design and research objectives. This discussion should explicitly address irrigation, with recognition that a permanent irrigation system for use in experiments and/or during prolonged drought is cost effective and favorable for plant and building performance.

Sharing research findings with a broad audience proves equally important in cultivating a comprehensive understanding of native plant green roofs and their multi-faceted aesthetic, environmental, and economic contributions to urban and suburban environments. Communicating these findings through digital and print media that is accessible to professionals from diverse disciplines further benefits the greater good by perpetuating opportunities for cross-disciplinary understanding and collaboration.

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