Ten-year persistence of native plant species on a green roof in Northeast US

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ABSTRACT

We evaluated persistence of 28 northeastern or Midwestern US native plants for 10 y after installation on the green roof of the Wellesley College Water Treatment Facility. After 10 y, 50% of the original 28 species had perished and 29% had greatly expanded their presence on the green roof. *Allium cernuum* Roth (nodding onion; Liliaceae), *Antennaria plantaginifolia* (L.) Richardson (pussytoes; Asteraceae), *Arctostaphylos uva-ursi* (L.) Spreng. (kinnikinnick; Ericaceae), *Campanula rotundifolia* L. (bluebell bellflower; Campanulaceae), *Carex pensylvanica* Lam. (Pennsylvania sedge; Cyperaceae), *Eurybia divaricata* (L.) G.L. Nesom (white wood aster; Asteraceae), *Fragaria virginiana* Duchesne (Virginia strawberry; Rosaceae), (*Oligoneuron album* (Nutt.) G.L. Nesom (prairie goldenrod; Asteraceae), *Schizachyrium scoparium* (Michx.) Nash (little bluestem; Poaceae), *Solidago sciaphila* Steele (shadowy goldenrod; Asteraceae), and *Symphyotrichum laeve* (L.) A. Löve & D. Löve (smooth blue aster; Asteraceae) were able to persist and grow in response to the challenging green roof conditions, and we recommend them for use on green roofs. Twenty-seven emergent species were present on the green roof at the end of the study. Emergent *Solidago* L. (goldenrod; Asteraceae) species, *Solidago caesia* L. (wreath goldenrod), *Solidago odora* Aiton (anisescented goldenrod), and *Solidago rugosa* Mill. (wrinkleleaf goldenrod) should be investigated further for their suitability in green roof installations.

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Photos by Kristina N Jones

Green roofs comprise a living plant community and a growth substrate. The benefits of green roofs include reduction of storm water surge, energy conservation, and remediation of the urban heat island effect (Getter and Rowe 2006). Green roofs can be aesthetically pleasing and have been documented to provide habitat for arthropods and ground-nesting birds (Baumann 2006; Kadas 2006; Schindler and others 2011).

Sedum species are commonly used on green roofs because they are drought tolerant and can withstand exposure to the challenging rooftop conditions of full sun, heat, cold, and wind (Snodgrass and Snodgrass 2006). Significant research on sedums has been conducted to evaluate their growth and survival in response to changing substrate, fertility, and irrigation both in direct roof installations and green roof module production (VanWoert and others 2005; Durham and others 2006, 2007; Barker and Lubell 2012; Lubell and others 2013). The use of native plants on green roofs is of interest to support wildlife and to increase species diversity in light of recent concerns over installation of sedum monocultures (Sutton and others 2012). Several studies have evaluated growth and performance of native plant species for green roof applications (Monterusso and others 2005; Bousselot and others 2010; MacIvor and Lundholm 2010); however, little work has been done to understand the long-term survival of native plants on green roofs. Understanding long-term changes to species composition is important for managing a green roof to maintain species diversity (Dvorak and Volder 2010). The objective of this study was to assess the long-term (10-y) survival of 28 northeastern or Midwestern US native plant species on the green roof located atop the Wellesley College Water Treatment Facility building in Wellesley, Massachusetts.

MATERIALS AND METHODS

We selected 28 northeastern or Midwestern US native species (Table 1; full plant nomenclature included in table) from drought-tolerant offerings available through Prairie Moon Nursery (Winona, Minnesota), Prairie Nursery (Westfield, Wisconsin), and New England Wild Flower Society (Framingham, Massachusetts). Plants received were mostly bareroot, but some were in 7.6 cm (3 in) or 1.9 l (2 qt) pots. The growth medium, provided by Richard White Sons (Auburndale, Massachusetts), consisted of 3 parts expanded shale and 1 part compost. The medium was installed at 15 cm (5.9 in) depth in a continuous, 55 m^2 (592 ft^2) section of roof on the Wellesley College Water Treatment Facility building in Wellesley Massachusetts, on 20 April 2006. For planting, the roof was divided into 4 equal-sized sections, and in each section we installed a single patch of each of the 28 species. Depending on the species size, form, and habit, 1 to 4 individual plants were installed per patch.

The roof of the water treatment facility is primarily flat, except for an imperceptible slant toward the north. Elevation of the site is 37 m (122 ft) above sea level. The facility is built into a steep slope so that the roof of the building adjoins a paved path at grade to the south, and then the ground falls away steeply to the north. The north side of the roof is 2.8 m (9 ft) above ground level and contains drainage openings along the edge. Nearby woodlands to the south, east, and west protect the site from strong winds and provide some partial shade on the south and east side of the roof in early morning and late afternoon. The roof is highly visible from the south by people using the path, which borders the Wellesley College Botanic Gardens.

After planting, the green roof received no supplemental water or fertilization, and we conducted minimal weed control. We did, however, physically remove volunteer, or emergent, plants of the woody tree species *Acer rubrum* L. (red maple; Aceraceae), *Pinus strobus* L. (eastern white pine; Pinaceae), and *Prunus serotina* Ehrh. (black cherry; Rosaceae); the invasive woody shrub, *Frangula alnus* Mill. (glossy buckthorn; Rhamnaceae); and the large, tap-rooted *Daucus carota* L. (Queen Anne's lace; Apiaceae) because, if left in place, they could damage the roof structure. Average annual precipitation for the years 2006 to 2016 was 100 cm (39 in), with a low of 61 cm (24 in) in 2015 and a high of 127 cm (50 in) in 2008 (TWC 2017).

In July 2016, 10 y after the green roof was installed, we assessed plant survival (Figure 1, Figure 2). The green roof was sectioned into 9 belt transects, 1 m (3.3 ft) wide, and each transect was meticulously surveyed for all plants present. We recorded the presence or absence of each of the 28 original native species per transect. For each of the 28 species, we determined plant status based on the total number of transects in which the species were found, where presence in 7 to 9 transects indicated the plant had expanded greatly, 5 to 6 transects indicated the plant had expanded slightly, 1 to 3 transects indicated the plant had declined, and 0 transects indicated the plant had perished. Over the 10-y study period, emergent species, both native and nonnative, colonized the green roof, and their presence in transects was noted. For emergent species, we described plant status as *present* for plants found in 1 to 5 transects and *thriving* for plants found in 6 to 9 transects.

RESULTS AND DISCUSSION

After 10 y, 50% of the original 28 species had perished and could no longer be found on the green roof (see Table 1). Similar mortality rates were found for studies of green roof succulent plant taxa, for which 53% of species had perished after 2 y (Durhman and Rowe 2007), and 42% of species had perished after 4 y (Getter and Rowe 2009). In a 6-y green roof plant evaluation, Schneider and others (2014) reported 5% of succulent species had perished and 62% of creeping forb species had perished. Failure of creeping forbs was attributed to taproot

TABLE 1

US native range, natural site conditions, number of transects plant present (July 2016), and plant status for all 28 original species installed on the green roof of the Wellesley College Water Treatment Facility (April 2006).

Scientific name	Family	Common name	US native range	Natural site conditions	No. of transects plant present	Plant status
Allium cernuum Roth	Liliaceae	nodding onion	Throughout, except New England	Dry woods; rock outcroppings; prairies	6	Expanded slightly
Allium stellatum Fraser ex Ker Gawl	Liliaceae	autumn onion	North and south central	Dry fields; prairies; rocky areas	0	Perished
Anemone caroliniana Walter	Ranunculaceae	Carolina anemone	North and south central and most of southeast	Prairies; barrens; open rocky woods	0	Perished
Antennaria plantaginifolia (L.) Richardson	Asteraceae	pussytoes (or woman's tobacco)	Throughout eastern half	Cliffs; balds; ledges; woodlands	8	Expanded greatly
Arctostaphylos uva-ursi (L.) Spreng.	Ericaceae	kinnikinnick	Throughout, except south central and southeast	Mountain summits, plateaus and ridges; sand plains and barrens	7	Expanded greatly
Campanula rotundifolia L.	Campanulaceae	bluebell bellflower	Throughout, except most of southeast	Cliffs; ledges; dry fields; river shore outcrops	9	Expanded greatly
Carex eburnea Boott	Cyperaceae	bristleleaf sedge	Throughout most of eastern and central	Open woodlands; cliffs; outcrops	0	Perished
Carex pensylvanica Lam.	Cyperaceae	Pennsylvania sedge	Throughout eastern half, except FL and south central	Dry woodland; sandy grassland	5	Expanded slightly
Dennstaedtia punctilobula (Michx.) T. Moore	Denstaedtiaceae	eastern hay-scented	Throughout most of eastern half	Fields; forests; rocky slopes	2	Declined
Eurybia divaricata (L.) G.L. Nesom	Asteraceae	white wood aster	Throughout northeast and most of southeast	Woodlands	6	Expanded slightly
Fragaria virginiana Duchesne	Rosaceae	Virginia strawberry	Throughout	Fields; open hillsides; roadsides	9	Expanded greatly
Geum triflorum Pursh	Rosaceae	old man's whiskers	Throughout western half, north central, and NY	Prairies; woodlands	1	Declined
Houstonia longifolia Gaertn.	Rubiaceae	longleaf summer bluet	Throughout most of eastern half	Woodlands; fields; shores of rivers or lakes	0	Perished
Hylotelephium telephium (L.) H. Ohba	Crassulaceae	witch's moneybags	Introduced throughout eastern half, except deep south	Floodplains; forests; fields	0	Perished
Hypoxis hirsuta (L.) Coville	Liliaceae	common goldstar	Throughout eastern half, except FL	Woodlands; forest edges; fields	0	Perished
Muhlenbergia cuspidata (Torr. ex Hook.) Rybd.	Poaceae	plains muhly	Throughout most of central	Prairies	0	Perished
Oligoneuron album (Nutt.) G.L. Nesom	Asteraceae	prairie goldenrod	Throughout most of eastern and central	Cliffs; balds; ledges; woodlands; shores of lakes or rivers	7	Expanded greatly

(continued)

TABLE 1 *(continued)*

US native range, natural site conditions, number of transects plant present (July 2016), and plant status for all 28 original species installed on the green roof of the Wellesley College Water Treatment Facility (April 2006).

Scientific name	Family	Common name	US native range	Natural site conditions	No. of transects plant present	Plant status
Schizachyrium scoparium (Michx.) Nash	Poaceae	little bluestem	Throughout, except NV and OR	Cliffs; balds; ledges; ridges; meadows and fields; woodlands	9	Expanded greatly
Sedum nevii A. Gray	Crassulaceae	Nevius' stonecrop	Only AL, MS, TN	Woodlands	0	Perished
Sedum ternatum Michx.	Crassulaceae	woodland stonecrop	Throughout most of eastern half	Woodlands	0	Perished
Silene virginica L.	Caryophyllaceae	fire pink	Throughout eastern half, except New England	Woodlands	0	Perished
Sisyrinchium albidum Raf.	Iridaceae	white blue-eyed grass	Throughout most of eastern half, only CT and ME in New England	Woodlands; sandy fields; roadsides	0	Perished
Solidago sciaphila Steele	Asteraceae	shadowy goldenrod	Only IA, IL, MN, WI	Cliffs; outcrops; bluffs	9	Expanded greatly
Sporobolus heterolepis (A. Gray) A. Gray	Poaceae	prairie dropseed	Throughout most of eastern and central	Ledges; ridges; woodlands	0	Perished
Symphyotrichum laeve (L.) A. Löve & D. Löve	Asteraceae	smooth blue aster	Throughout	Woodlands; fields; roadsides	8	Expanded greatly
Vaccinium angustifolium Aiton	Ericaceae	lowbush blueberry	Throughout northeast, midatlantic, and north central	Balds; mountain summits; fields; woodlands	3	Declined
Verbena stricta Vent.	Verbenaceae	hoary verbena	Throughout most	Meadows and fields	0	Perished
Viola pedata L.	Violaceae	birdfoot violet	Throughout eastern half	Grassland; meadows; fields	0	Perished

Sources: Descriptions are based on literature sources: Gleason and Cronquist (1991); Magee and Ahles (1999); Barker (2004); Haines (2011); USDA NRCS (2017).

Figure 1. Wellesley College Water Treatment Facility green roof in August 2008.

Figure 2. Wellesley College Water Treatment Facility green roof in August 2017.

morphology and insufficient water supply in extensive green roofs. Monterusso and others (2005) followed survival of 18 native species on a simulated green roof system over 3 y and found that 67% of species had perished. Single-year studies by Bousselot and others (2010) and MacIvor and Lundholm (2011) that included non-succulent, mostly native species found little or no mortality, in contrast to this and other long-term green roof studies.

Dennstaedtia punctilobula, *Geum triflorum*, and *Vaccinium angustifolium* declined in number since the time of green roof installation (see Table 1). *Dennstaedtia punctilobula* and *G. triflorum* tolerate dry, well-drained soils, but in such situations these plants typically benefit from afternoon shade, which was not provided on the green roof. Decline of these species may have resulted from constant exposure to full sun. Established plantings of *V. angustifolium* may demonstrate drought tolerance (Dirr 2009); however, to become established, recently installed plants benefit from a consistent supply of water, which is not typically available on nonirrigated green roofs (Schneider and others 2014). *Vaccinium angustifolium* planted in green roof modules that were set on top of a pre-existing green roof and that received no supplemental irrigation had only 1.82%

TABLE 2

Number of transects plant present, plant status, and US native species status for emergent species found on the green roof of the Wellesley College Water Treatment Facility (July 2016).

Scientific name	Family	Common name	No. of transects plant present	Plant status	US native species
Ageratina altissima (L.) R.M. King & H. Rob.	Asteraceae	white snakeroot	1	Present	Yes
Carex L.	Cyperaceae	sedge	2	Present	Unknown
Chamaesyce maculata (L.) Small	Euphorbiaceae	spotted sandmat	1	Present	Yes
Daucus carota L.	Apiaceae	Queen Anne's lace	4	Present	No
Erechtites hieraiifolius (L.) Raf. ex DC.	Asteraceae	American burnweed	3	Present	Yes
Euthamia graminifolia (L.) Nutt.	Asteraceae	flat-top goldentop	2	Present	Yes
Frangula alnus Mill.	Rhamnaceae	glossy buckthorn	1	Present	No
Galium aparine L.	Rubiaceae	stickywilly	4	Present	Yes
Hieracium aurantiacum L.	Asteraceae	orange hawkweed	1	Present	No
Hieracium sabaudum L.	Asteraceae	New England hawkweed	8	Thriving	No
Lactuca biennis (Moench) Fernald	Asteraceae	tall blue lettuce	6	Thriving	Yes
Oxalis stricta L.	Oxalidaceae	common yellow oxalis	7	Thriving	Yes
Panicum virgatum L.	Poaceae	switchgrass	3	Present	Yes
Parthenocissus quinquefolia (L.) Planch.	Vitaceae	Virginia creeper	7	Thriving	Yes
Parthenocissus tricuspidata (Siebold & Zucc.) Planch	Vitaceae	Boston ivy	4	Present	No
Poa pratensis L.	Poaceae	Kentucky bluegrass	1	Present	Yes
Potentilla simplex Michx.	Rosaceae	common cinquefoil	1	Present	Yes
Prunus serotina Ehrh.	Rosaceae	black cherry	1	Present	Yes
Solidago L.	Asteraceae	goldenrod	1	Present	Unknown
Solidago L.	Asteraceae	goldenrod	2	Present	Unknown
Solidago caesia L.	Asteraceae	wreath goldenrod	4	Present	Yes
Solidago odora Aiton	Asteraceae	anisescented goldenrod	5	Present	Yes
Solidago rugosa Mill.	Asteraceae	wrinkleleaf goldenrod	4	Present	Yes
Symphyotrichum ericoides (L.) G.L. Nesom	Asteraceae	white heath aster	2	Present	Yes
Trifolium repens L.	Fabaceae	white clover	6	Thriving	No
Vicia cracca L.	Fabaceae	bird vetch	6	Thriving	No
Viola L.	Violaceae	violet	1	Present	Unknown

survival after one growing season (MacIvor and Lundholm 2014). *Vaccinium angustifolium* also benefits from soil pH in the range of 4.5 to 5.5 (Dirr 2009), but green roof growing media pH tends to be significantly higher since it is largely composed of expanded shale, which has a pH of 8.0 (Sloan and others 2010). Shrestha and Lubell (2015) studied native shrub establishment in a full sun landscape site with dry, compacted soil of pH 6.1 and found that plants of *Vaccinium corymbosum* L. (highbush blueberry; Ericaceae) exhibited dramatic decreases in plant size (82%).

Allium cernuum, Carex pensylvanica, and *Eurybia divaricata* expanded slightly to occupy 5 to 6 belt transects on the green roof, whereas *Antennaria plantaginifolia, Arctostaphylos uva-ursi, Campanula rotundifolia, Fragaria virginiana, Oligoneuron album, Schizachyrium scoparium, Solidago sciaphila*, and *Symphyotrichum laeve* expanded greatly to occupy 7 to 9 belt transects and were the dominant species on the green roof (see Table 1). For most of these species, expansion occurred by seed, but *Arctostaphylos uva-ursi* likely spread by vegetative rhizomes. *Campanula rotundifolia* and *Fragaria virginiana* likely expanded by both seed and vegetative runners. In our study, 29% of species initially installed greatly expanded their presence on the green roof, which is similar to a study of 12 *Sedum* taxa in which 33% of species grew to dominate the green roof study platforms (Getter and Rowe 2009). Monterusso and others (2005) evaluated, over 3 growing seasons, *Allium cernuum, Fragaria virginiana, Schizachyrium scoparium*, *Symphyotrichum laeve*, and 15 other Michigan natives grown in experimental green roof platforms elevated 1.4 m (4.6 ft) above ground. By the end of the study *Fragaria virginiana, Schizachyrium scoparium*, and *Symphyotrichum laeve* had perished, which contradicts our findings for these 3 species, while *A. cernuum* had 96% survival. These losses in the Michigan study may be attributed to insufficient water supply or overwintering stress.

By the end of our study, 27 emergent species were present on the green roof, and 6 of these species were thriving and had spread to occupy 6 to 8 belt transects (Table 2). We do not recommend most of the emergent species for use on green roofs, since they lack ornamental appeal, are not native, or are woody, such as *Parthenocissus tricuspidata*. The emergent *Solidago* species, *S. caesia, S. odora*, and *S. rugosa,* have horticultural merit and were found in 4 to 5 belt transects of the green roof. These observations warrant greater investigation of the *Solidago* genus for suitability in green roof installations. This list of likely emergent species may be useful for managers of green roofs who need to develop maintenance plans to prevent or slow the establishment of unwanted species.

Despite drought tolerance in their wild environments, *Dennstaedtia punctilobula*, *Geum triflorum,* and *Vaccinium angustifolium* do not appear to be good candidates for nonirrigated green roofs because they declined during the 10-y period. We recommend *Allium cernuum, Antennaria plantaginifolia, Arctostaphylos uva-ursi, Campanula rotundifolia, Carex pensylvanica*, *Eurybia divaricata, Fragaria virginiana, Oligoneuron album, Schizachyrium scoparium, Solidago sciaphila*, and *Symphyotrichum laeve* for green roofs because they were able to persist and grow in response to the challenging green roof conditions of full sun, minimal water, and exposure to heat, cold, and wind. The majority of successful species, which expanded greatly, are found in highly exposed natural environments including cliffs, balds, ledges, and mountain summits and ridges (see Table 1). When selecting novel species to trial in green roof situations, it may be beneficial to target species that inhabit the aforementioned exposed environments. This list of native species adds to the palette of suitable plant options for green roofs to support increasing species diversity, which in turn may enhance the resiliency of green roofs to changes in climate over time.

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