

Water Stress Patterns of Xerophytic Plants in an Urban Landscape

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Abstract. Efficient water use in urban landscapes is a common objective throughout the western United States. Vegetative species promoted for their drought tolerance characteristics are often included in landscapes designed for resource conservation. However, water requirements of most common landscape species have not been quantified. This is especially true for xerophytic species. This lack of landscape plant water requirement data is a significant constraint on the design of efficient irrigation systems and management practices affecting urban landscape water use. Current irrigation practices often fail to consider the unique physiology of xerophytic species, and irrigation scheduling models may not be appropriate for xeric landscapes using xerophytic vegetation as the primary method of reducing water use. This work describes the seasonal patterns of growth and xylem water status for four regionally native xeric shrub species planted in an unirrigated urban landscape in the semi-arid environment of central Oregon. The four species (*Artemisia tridentata*, *Holodiscus microphyllus*, *Ericameria nauseosa*, and *Ribes cereum*) exhibited substantial growth over the course of 18 months without irrigation in a heavily modified urban soil profile. Water potential of the four species was strongly correlated with surface (10 cm) soil moisture ($r \geq 0.90$), less so with reference monthly evapotranspiration ($r \leq 0.55$), and only weakly with water vapor deficit ($r \leq 0.22$). In *A. tridentata* and *H. microphyllus*, xylem water potential became more negative during the growing season and tracked the seasonal decline in soil moisture. In contrast, the xylem water potential of *E. nauseosa* and *R. cereum* tracked soil moisture early in the season but became less responsive to soil moisture in the driest months, suggesting different drought adaptation strategies in these species. Three of the four species showed no visual signs of drought stress and maintained acceptable aesthetics even as soil moisture decreased to less than 10%. However, *R. cereum* exhibited a drought dormancy strategy that made it less aesthetically desirable. These results suggest that extreme xerophytic shrubs provide an opportunity for significant reductions in water use in urban landscapes.

Many urban centers in the western United States are in ecoregions that experience generally low or markedly seasonal patterns of precipitation that create prolonged periods of soil water deficits during the year (Omernik, 2014). As a result, most urban landscapes in the region use seasonal irrigation to maintain plant health and aesthetics. However, urban water use has become contentious. In the western United States, 50% to 60% of residential water is used for outdoor purposes, predominantly urban landscapes (City of Bend, 2011; Mini et al., 2014; St. Hilaire et al., 2008). Consequently, regional public policy has often targeted outdoor water use in urban landscapes as a significant tool for reducing overall municipal water use (English et al., 2002; Glenn et al.,

2015; Hayden et al., 2015; Qaiser et al., 2011; St. Hilaire et al., 2008).

Local and regional governments are increasingly encouraging and even demanding more water-efficient landscape designs. More broadly, there is a growing interest in developing more sustainable urban development. For example, the Living Building Challenge is a performance-based green building certification program managed by the Living Futures Institute in Seattle, WA (McLennan, 2008). A primary design goal of the Living Building Challenge is resource conservation. Landscape designs must balance the water use requirement of the constructed landscape with the quantity of water generated on site from rainfall, storm water storage, or through gray water re-use. Water conservation is inherent in Living Building designs, and structures built under the Living Building Challenge must supply their own resources, including power and water. Each site is unique in its ability to provide these elements.

One approach to reducing the water footprint of urban landscapes is using more species that have unique adaptations for tolerating extended periods of water stress. These species could be used to design landscapes that provide a range of functions such as aesthetics, but that also have very low or even no irrigation requirements. For example, many perennial shrubs native to arid regions of the western United States have extreme drought adaptations that allow them to thrive even in habitats that experience extreme water deficit (Smith et al., 1997).

A roadblock to designing landscapes with extremely low water input is our generally limited understanding of how xeric-adapted species respond to declining water availability. In addition, the few data that exist generally come from field studies of plants in minimally disturbed natural habitats (Ehleringer et al., 1991; Mata-González et al., 2014; Volo et al., 2014; Webb et al., 1978). Urban contexts likely pose a unique set of environmental challenges that could interfere with the drought adaptations of xerophyte species. For example, urban soils are often compacted or have more restrictive soil volumes relative to rural or wildland soils (Craul, 1991). Compacted soils can negatively affect root growth and reduce the water-holding capacity of soils (Benbough et al., 2005; Eavis, 1972; Sims and Singh, 1978). Almost no data describe the ecophysiological response of xerophytic species in actual urban landscapes. This lack of information makes it difficult to develop appropriate plant palettes and appropriate recommendations for their management.

In this study, we evaluated the drought response of xerophytic plant species in an established urban landscape designed to emulate the ecological functions of a sagebrush steppe plant association in the East Cascades Slopes and Foothills ecoregion. The landscape was designed to meet the water conservation standards under the Living Building Challenge, and it was actively used by the landowners during the course of the study. We measured the water status and growth patterns of four native shrub species, and we tested the association between xylem water potential, monthly evapotranspiration (ET), soil moisture level, and vapor pressure deficit (VPD). We also subjectively evaluated the aesthetic quality of the species through interviews with the property owners.

Materials and Methods

Study site. We conducted the study at Desert Rain, a residence and demonstration site located in the urban core of Bend, OR (lat. 44°3'10.87"N, long. 121°19'17.67"W) (Fig. 1). Bend is a city of ≈80,000 that is located in the East Cascades ecoregion (Omernik 2014) at an elevation of 1115 m. The climate is semi-arid (Fig. 2). Summers are typically warm and dry, with an average daytime temperature of 25 °C (June–September). Winters are normally cold, with annual precipitation falling as rain or snow. The average winter daytime temperature

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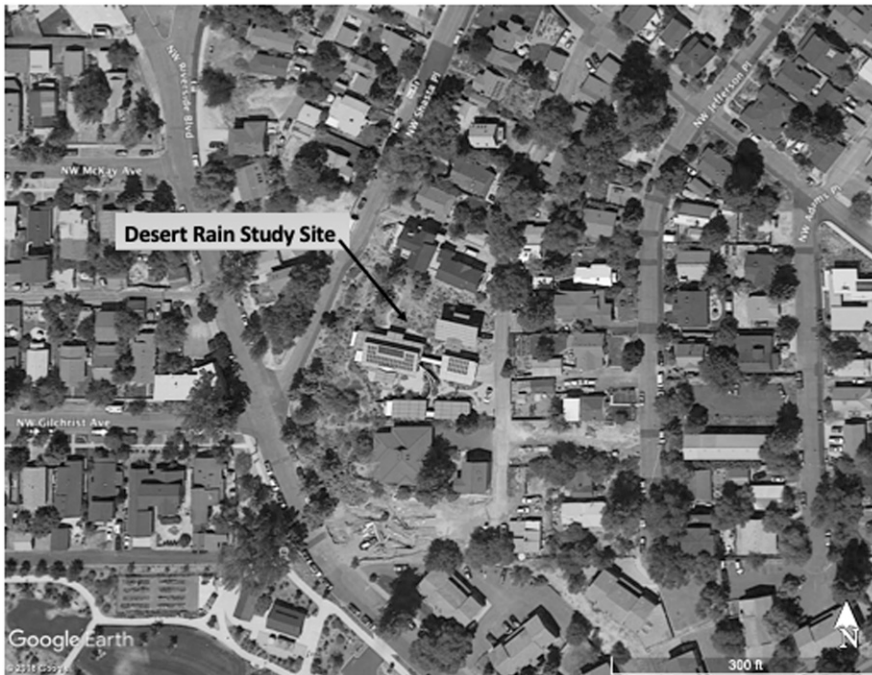


Fig. 1. Study site location showing the urban setting within the city of Bend, OR (lat. 44°3' 10.87" N, long. 121°19' 17.67" W).

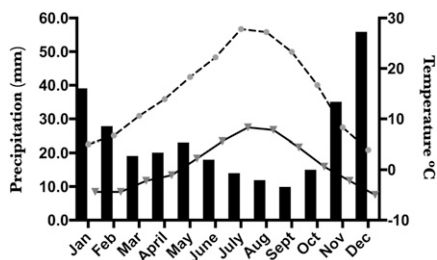


Fig. 2. Climograph for Bend, OR. Mean monthly precipitation (bars), mean daily high temperature (dotted line), and mean daily low temperature (solid line) are historical averages (1954–2015).

is 6 °C (November–February). The average annual precipitation is 289 mm.

Dominant soils at the study site are the *Wanoga* (35%) and *Fremkle* (30%) series *Vitrixerands* of the order *Andisols*, described as moderately deep, well-drained sandy loam on volcanic uplands (Natural Resources Conservation Service, 2014) containing an average 60% ash in the upper 35–60 cm and a high humus content in the surface horizon (Krasilnikov, 2009). The mean annual soil temperature is 7.2 °C. The remaining soils are classified as Rock Outcrop (Natural Resources Conservation Service, 2014). The slope varies from 0% to 20% in the study area, with north/northwest aspect predominance.

The study landscape covers $\approx 168 \text{ m}^2$, which is approximately 5% of the entire property. The design intent was to emulate the structural and vegetative components of the sagebrush steppe plant association that is characteristic of the site while enhancing the aesthetic considerations typical of a managed urban landscape. Construction in-

cluded the creation of rock outcrops, drainage patterns, and spatial distribution of plants to create spatially patchy zones of elevated resources known as resource islands; these comprise a critical structural and functional component of sagebrush steppe communities (Halvorson et al., 1994). The study portion of the landscape was unirrigated. No irrigation system was installed, nor has the study site received supplemental irrigation. The overall designed landscape at the site included 38 native plant species representing a range of functional forms, including 12 shrub species, 22 forbs, and 4 species of grasses.

Study plants. Four shrub species native to the East Cascades ecoregion were used for this study: *Artemisia tridentata* Nutt ssp. *wyomingensis* Beetle & Young (ARTRW8), *Holodiscus microphyllus* (prev. *dumosus*) var. *glabrescens* (HODU), *Ericameria nauseosa* (Pall. Ex Pursh), G.L. Nesom & Baird (ERNA10), and *Ribes cereum* Douglas var. *cereum* (RICE) (Natural Resources Conservation Service, 2006). All four species are associated with dry habitats and are occasionally used as ornamentals with low water requirements (CalFlora, 2018). All plants were propagated locally from propagules collected within the same East Cascades ecoregion as the study site (Omernik, 2014), and they were planted as 1-gallon nursery stock. Each individual plant was inoculated with a commercially available endo-ecto mycorrhizal inoculant (Mycorrhizal Applications, Grants Pass, OR) and watered once during landscape construction.

Ten months after the landscape was planted, we identified four target individuals of each species for study. Each individual was located in the same soil and microclimate conditions and within 5 m of an installed weather station.

Physical measurements. In Aug. 2015, we installed a HoboWare model U30 weather station datalogger (Onset Computer Corporation, Bourne, MA) at the study site. The station was situated within 5 m of the study plants. We used the station to record volumetric soil water at 10-cm, 30-cm, and 60-cm depths with dielectric aquameter probes (Onset Computer Corporation, Bourne, MA), precipitation, and ambient air temperature. Readings were collected every 5 min and averaged every 2 h, resulting in 12 records every 24 h.

To assess possible changes in soil structure resulting from construction activities, we measured soil bulk density and porosity from samples collected at the study site and from a relatively undisturbed reference site within the same East Cascades ecoregion and soil series (lat. 44°0' 53.29" N, long. 121°17' 14.80" W). The same ecological site type is reported for both the study and reference site. The dominant plant association for both sites is *Juniperus occidentalis* Hook/*Pinus ponderosa* Lawson & C. Lawson/*Festuca idahoensis* Elmer spp. *idahoensis* (Natural Resources Conservation Service, 2014). Soil samples at both sites were collected across a depth profile using an AMS Bulk Density Soil Sampling Kit (AMS, Inc. American Falls, ID). Samples were taken at 10-cm, 30-cm, and 60-cm depths at the reference site and 10-cm and 30-cm depths at the study site. Samples from the 60-cm depth were unattainable at the study site due to shallow bedrock. Ten 90.59-cm³ samples were collected for each depth at the study site and the reference site. We estimated gravimetric soil moisture content by weighing samples at field capacity, drying each sample in a microwave for three cycles of 5 min, and weighing the dried samples. We estimated soil bulk density by dividing the dry soil weight by volume and soil porosity according to the method of Thien and Graveel (2002).

Reference evapotranspiration. We obtained average monthly reference evapotranspiration (ET_{ref}) from the AgriMet Cooperative Agricultural Weather Network (Palmer 2008) calculated for the Bend, OR station (lat. 44°2' 5.0" N, long. 121°19' 12.972" W, elevation: 1103 m) located 0.62 km south of the study property. Calculations used the ASCE standard Penman-Monteith model (2013). We estimated the maximum mid-day vapor pressure deficit (VPD_d) following the method of Murray (1967), with saturated vapor pressure estimates calculated following the method of Jensen et al. (1990).

Plant performance. We measured monthly mid-day xylem water potential (Ψ) for each target individual using a model 1505D pressure chamber (PMS Instrument Company, Albany, OR). Five replicated measurements were performed for each individual plant during each sample period. Measurements throughout the study period were performed for the same individual plants. A similar approach using comparable levels of individual replication has been used to measure in situ water potential in other landscape ornamental plants (Nardini et al., 2015; Sjöman et al., 2018).

We estimated the change in the aboveground biomass of the target individuals over the course of 18 months because they were planted in the landscape. Because removing entire plants from the created landscape was not approved by the property owner, we estimated the aboveground biomass of the established target plants using the reference unit technique (Bonham, 2013). We destructively harvested a representative 10% sample of the canopy of each target individual. The representative samples were dried, weighed, and used to estimate the aboveground biomass of whole plants by extrapolation (Evans et al., 2013). Because we did not have initial size estimates of the nursery stock when it was planted in the landscape, we established an initial baseline using comparable nursery stock. This stock was the same size [1.0 gallon (3.8 L)] and grown in the same nursery under the same conditions as the stock planted in the landscape. We destructively sampled 10 individuals representative of this reference nursery stock. All aboveground biomass was removed, dried at 116 °C for 48 h, and weighed.

We assessed the rooting depth of each target individual by excavating root systems of individual plants to a depth of 60 cm, when possible. Excavation of deeper soil layers was inhibited by the shallow parent material characteristic of the study site. We traced tap and fibrous roots back to the crown of the plant to ensure that measurements were for the correct species. Roots extending beyond 60-cm depths were noted.

Aesthetic quality. Plant health and aesthetic quality were qualitatively assessed by the lead author and the homeowners. Owners were informally interviewed twice per month regarding perceived landscape health and visual quality.

Statistical analysis. We described the associations between monthly xylem pressure and volumetric soil water content at each measured depth using the Pearson correlation. The same method was used to test the association between monthly xylem pressure with ET_{ref} and VPD. We tested whether soil properties across the depth profile at the study and reference sites differed from each other using a two-way analysis of variance. Statistical tests were conducted using GraphPad Prism version 7.0 (GraphPad Software, La Jolla, CA).

Results

Patterns of plant water stress. The xylem water potential of *A. tridentata* and *H. dumosus* became more negative over the summer in relation to the spring, and it continued to have a sharp decline during the fall. The water potential of *R. cereum* and *E. nauseosa* also became more negative over the summer with respect to the spring, but the decline during the fall was not as pronounced. *Ribes cereum* and *E. nauseosa* also had generally less negative xylem water potential during the season than *A. tridentata* and *H. dumosus* (Fig. 3). The xylem water potential of the four

species was strongly correlated with soil moisture content at all three depths, but primarily at the shallower layers (Table 1). However, the water potential of both *A. tridentata* and *H. dumosus* more closely tracked the seasonal decline in soil moisture than did *R. cereum* or *E. nauseosa* (Fig. 3). The xylem water potential was only weakly correlated with ET_{ref} and VPD_d in all four species (Table 1). ET_{ref} reached its maximum observed levels in early summer and then declined over the next 4 months (Fig. 4).

Plant growth and health. Significant biomass production was recorded for all four study species after 18 months of growth. Each shrub had an aboveground biomass ranging from 5.1 to 14.1 g when planted and exhibited production rates from 400% to 1200% (Table 2). The rooting depth for each individual plant exceeded 60 cm within 18 months.

Aesthetic quality. Three of the study species, *Artemisia tridentata*, *H. dumosus*, and *E. nauseosa*, did not exhibit any visual indicators of drought stress and retained their aesthetic value throughout the growing season, even as volumetric soil moisture declined to less than 10%. In contrast, *R. cereum* dropped much of its leaves during late summer and displayed signs characteristic of a summer

deciduous strategy for surviving drought. Generally, the homeowners were very pleased with the visual quality and apparent health of the landscape and the rapid growth of the plants. However, they did express concern about the visual stress of the *Ribes* in August and September.

Soil characteristics. Soil characteristics at the study site were generally similar to those at a nearby reference site (Table 3). There were no significant site or site × depth interaction effects for any of the measured soil variables ($P > 0.1$).

Discussion

The species examined in this study exhibited the ability to tolerate extended periods of drought. Despite receiving no supplemental irrigation, all four species established and grew substantially over 18 months. This ability likely reflects a range of morphological adaptations as well as isohydric and anisohydric responses that are typical of many perennials from this ecozone. These adaptations include modified leaf morphology, extensive or deep root systems, and various forms of drought dormancy (Chaves et al., 2003). All four species displayed rapid root growth exceeding a 60-cm depth within

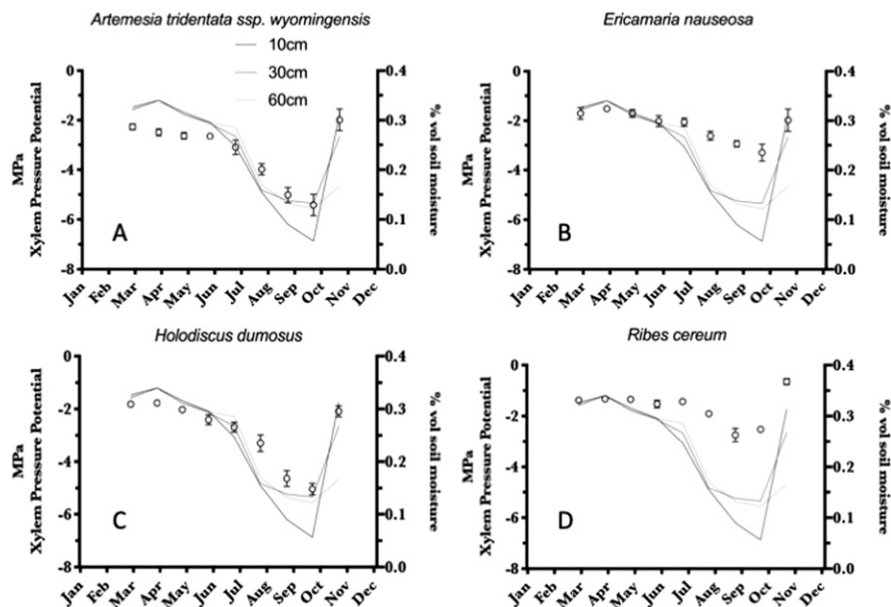


Fig. 3. Monthly xylem water potential (open circles) over the course of 1 year for four xerophyte plant species in an urban residential landscape in Bend, OR: (A) *Artemisia tridentata*; (B) *Ericameria nauseosa*; (C) *Holodiscus dumosus*; and (D) *Ribes cereum*. Volumetric soil moisture values at 10, 30, and 60 cm are plotted as lines.

Table 1. Degree of correlation between measured xylem water potential, monthly cumulative reference evapotranspiration (ET_{ref}), and mean daily vapor pressure deficit (VPD_d) for four xerophyte plant species in an urban residential landscape in Bend, OR.^z

Water potential	Pearson correlations				
	Soil moisture (%)			ET_{ref}	VPD_d
	10 cm	30 cm	60 cm		
ARTRW8	0.98	0.92	0.74	-0.55	-0.14
ERNA10	0.98	0.97	0.88	-0.52	-0.22
RICE	0.90	0.80	0.56	-0.52	-0.09
HODU	0.99	0.94	0.82	-0.52	-0.18

^zValues are Pearson correlation coefficients. ARTRW8 = *Artemisia tridentata* ssp. *wyomingensis*; ERNA10 = *Ericameria nauseosa*; RICE = *Ribes cereum*; HODU = *Holodiscus dumosus*.

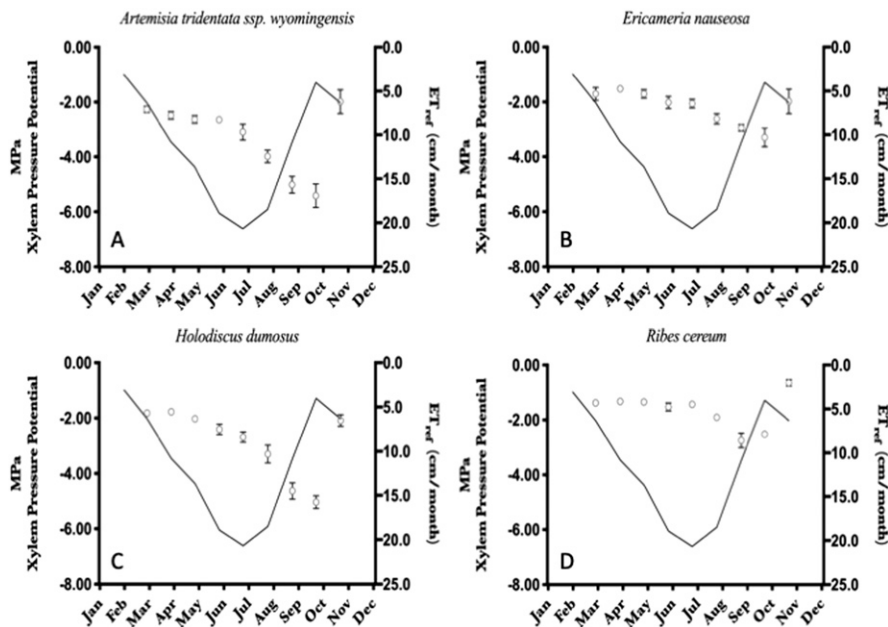


Fig. 4. Monthly xylem water potential (dots) over the course of 1 year for four xerophyte plant species in an urban residential landscape in Bend, OR: (A) *Artemisia tridentata*; (B) *Ericameria nauseosa*; (C) *Holodiscus dumosus*; and (D) *Ribes cereum*. The solid line indicates the 2004–16 historic mean of monthly cumulative reference evapotranspiration (ET_{ref}).

Table 2. Estimated change in aboveground biomass (g) of four xerophyte plant species over 18 mo. planted in an unirrigated urban residential landscape in Bend, OR. Biomass estimates are presented for the replicated 10% reference unit and the derived total plant estimate.^z

Species	Change in aboveground biomass				
	Reference unit (g)	Total plant (g)	Nursery stock, 1-gallon (g)	Increase (%)	
ARTRW8	6.6 ± 0.1	66.25	5.13 ± 0.2	1,191	
ERNA10	7.6 ± 0.4	75.55	14.13 ± 0.9	434	
RICE	7.1 ± 0.5	70.50	6.38 ± 0.4	1,005	
HODU	6.0 ± 0.2	60.03	5.38 ± 0.4	1,020	

^zValues are means ± sd (n = 4). HODU = *Holodiscus dumosus*; ERNA10 = *Ericameria nauseosa*; ARTRW8 = *Artemisia tridentata* ssp. *wyomingensis*; RICE = *Ribes cereum*.

Table 3. Representative soil properties across a depth profile (10–60 cm) at an urban residential study site in Bend, OR (Desert Rain) and a nearby undisturbed reference site (reference site).^z

	10 cm		30 cm		60 cm	
	Study site	Reference site	Study site	Reference site	Study site	Reference site
Bulk density (g·cm ⁻³)	1.05 ± 0.19	1.04 ± 0.07	1.27 ± 0.23	1.23 ± 0.04	—	1.39 ± 0.13
Soil porosity (%)	0.60 ± 0.07	0.61 ± 0.03	0.52 ± 0.09	0.54 ± 0.02	—	0.47 ± 0.05

^zValues are mean ± sd (n = 5). The study site had shallow bedrock at 60 cm. Soil properties of deeper layers could not be assessed.

1 year of planting, surpassing the 15- to 30-cm average rooting depth commonly seen in non-xerophyte landscape ornamentals (St. Hilaire et al., 2008). Roots of the target individuals were even observed penetrating small cracks in the underlying bedrock.

There were also marked differences in the drought responses of the four study species. *Artemisia tridentata*, *Holodiscus dumosus*, and *Ericameria nauseosa* exhibited no visual indication of drought stress and retained their aesthetic value even as volumetric soil moisture declined to less than 10%. In contrast, *Ribes cereum* exhibited marked drought dormancy, losing most of its leaves during late summer and early autumn.

Landscape water requirement. Such drought tolerance adaptations are likely a main reason

why the seasonal pattern of xylem water potential and visual indicators of water stress did not track ET_{ref} or VPD_a . This lack of correlation between plant water demand and ET_{ref} complicates efforts to estimate the irrigation demand of a landscape (Kjelgren, 2016). Most currently available tools for estimating the landscape water demand are modified versions of models that were originally developed for estimating crop water requirements in agricultural systems (Farag et al., 2011; Gober et al., 2011; Nouri et al., 2013). These models assume that water demand and evapotranspiration are closely correlated. A typical approach estimates water demand as a fractional proportion of ET_{ref} . The proportion is estimated using adjustment factors to account for species differences in water demand as

well as a range of other processes and factors, such as microclimate, soil cover, and the stage of plant growth that potentially modify water flux from the landscape (Grabow et al., 2013; Pannkuk et al., 2010; Radwan et al., 2010). Although earlier approaches often included a large number of adjustment factors, more recent approaches such as the Simplified Landscape Irrigation Demand Estimator (SLIDE) use only a small number of plant factors to estimate water demand (Kjelgren, 2016). However, the suitability of ET -based approaches for estimating the water demand of xeric vegetation is questionable (Mata-González et al., 2005). The extreme morphological and physiological adaptations to water stress that these species exhibit are likely not fully accounted for in the ET_{ref} adjustment factors used in landscape irrigation models (Ferguson, 1987; Mata-González et al., 2005; Smith and Smith, 2013).

We estimated the water demand for our study landscape using three widely available irrigation scheduling models: 1) EPA WaterSense New Home Specifications (EPA, 2014), 2) Hunter Run-Time Calculator (Hunter Industries, 2018), and 3) The Simplified Landscape Irrigation Demand Estimator (SLIDE) (Kjelgren, 2016). These models were selected because of their accessibility (e.g., online availability) and their wide acceptance in the landscape industry. Each model is based on ET_{ref} but uses different species-specific adjustment values. Models also differ regarding the type and number of adjustment factors related to other parameters such as vegetation density. We parameterized the models based on 0.1 ha of landscaped area at the study site. Details and summary model calculations are available elsewhere (Martinson, 2018). The three different models provided estimates of the landscape water demand that ranged from 336.9 m³/season for WaterSense to 79.5 m³/season for Hunter and 61.52 m³/season for SLIDE. The different results largely reflect the water demand relative to ET_{ref} that each model estimated for xerophytic vegetation. Differences in water demand estimates across various models have been shown to largely reflect differences in plant-specific or landscape-specific adjustment factors for ET_{ref} (Kjelgren et al., 2015). The results of our study suggest that even the low water demand estimates provided by existing models may overestimate the demand for many extreme xerophyte species.

A significant constraint to improving estimates made by water demand models is the lack of empirical data to parameterize them. However, ongoing research is beginning to provide empirical estimates of water use for common landscape types and species, at least for regions with Mediterranean-type climates (Reid and Oki, 2008, 2016; Snyder and Ackley, 2015).

Urban landscapes. In created urban landscapes, severe disturbances associated with construction activities can alter conditions such as exposure, soil compaction and chemistry, wind patterns, hydrologic function, and biotic

communities, resulting in highly modified environments (Craul, 1991; Lorenz and Lal, 2009). Altered conditions could interfere with xerophyte drought adaptations. For example, increases in soil bulk density can negatively affect root growth through the rhizosphere by reducing pore space and the ability of soil to hold plant-accessible moisture (Benbough et al., 2005). However, the species in this study performed similarly to those in less disturbed contexts. The rooting depth of the study species during the first year was deep, despite the shallow soils and rocky substrate. All study species developed fibrous roots exceeding 50 cm, consistently accessing higher moisture levels at greater depths than normally expected in urban landscapes or designed for in urban irrigation systems. These rooting depths were similar to those that have been observed for other xeric-adapted species in undisturbed natural landscapes in the Owens Valley of California (Mata-González et al., 2014). This might be a primary reason why the study species performed so well. Another reason is that soils at the study site were very similar to those of a nearby reference site; however, soils at the study site were shallower. Although bulk density has been shown to increase at construction sites (Evanylo et al., 2016), we found no statistically significant differences in bulk density between the study site and the reference site.

The specific construction techniques used at the study site might be a reason for the relatively low bulk density. Site construction included extensive subsurface excavation for infrastructure unique to a Living Futures residence. The extent of the excavation exceeded levels commonly associated with residential construction and may have decreased soil organic matter while mitigating soil compaction. Another mitigating factor was that the study site landscape was designed to emulate the structural and spatial characteristics of reference communities. The landscape included a diverse and purposely chosen association of plant functional types that included grasses and forbs. The physical facilitation and spatial patterning of these different components are known to be critically important to the ecological function of plant associations in semi-arid environments (Jackson and Caldwell, 1993). Results of this study suggest that designing and constructing urban landscapes in ways that emulate the species composition and structural patterning of less disturbed xeric plant communities may result in similar functional aspects and ecological processes, such as hydraulic lift and nutrient cycling, that will result in reduced water use requirements for landscapes.

Summary. Xerophyte species can be a suitable landscape choice in arid and semi-arid environments, and even in urban residential landscapes. However, current landscape management approaches will need to be adjusted to achieve the maximum water-savings benefit from their use. Current water demand models can overestimate water demand in instances

when there is little correlation between plant water demand and ET_{ref} for xerophyte species. Furthermore, conventional landscape management assumes an average shrub rooting depth of 15–30 cm (St. Hilaire et al., 2008), and models developed to encourage irrigation efficiency are based on average rooting depths, soil characteristics, and application efficiency of the irrigation system (Connellan, 2013; Ferguson, 1987; Irrigation Association, 2014; Jensen et al., 2016; Nouri et al., 2013; White, 2013). A constraint to developing better management guidelines for xerophyte species is that few studies have described their drought physiology in the context of ornamental landscapes. Additional work is needed to quantify the drought stress response of most landscape species, most notably species with aesthetic values and physio-biochemical adaptations that can contribute to a significant reduction in water use in urban landscapes.

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