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Landscape Sustainability in a Sonoran Desert City

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The objective of this paper is to discuss concepts of landscape sustainability in the Phoenix metropolitan area. Phoenix is situated in the greater Salt River Valley of the lower Sonoran Desert in the southwest United States. In this paper I use the ecological frameworks of ecosystem services and resiliency as a metric for understanding landscape sustainability. An assessment of landscape sustainability performance benchmarks were made by surveying research findings of scientists affiliated with the Central Arizona Phoenix Long Term Ecological Research Project (CAP LTER). In Phoenix, present day emphases on cultural, aesthetic, and habitat formation ecosystem services within an arid ecoregion of low natural resilience coupled to a complex matrix of socioeconomic stratification, excessive landscape water use and pruning practices has had the undesired effect of degrading landscape sustainability. This has been measured as mixed patterns of plant diversity and human-altered patterns of carbon regulation, microclimate control, and trophic dynamics. In the future, sustainable residential landscaping in desert cities such as Phoenix may be fostered through use of water-conserving irrigation technologies, oasis-style landscape designs motifs, recycling of landscape green waste, and conservative plant pruning strategies.

Keywords

Ecosystem services, human landscape preferences, landscape design, landscape management, microclimate, resiliency, socioeconomics, urban heating, water availability and quality

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Abstract

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INTRODUCTION

Human activities impact nearly all terrestrial ecosystems, now altering ecological and biogeochemical processes at a global scale and at unprecedented rates (Vitousek et al. 1997). Cities are profound modifications of the earth's surface (Redman 2006), and in the early part of this century more people will live in urbanized than rural environments (United Nations Statistics Division). Because of these demographic trends, daily interactions with "nature" for the majority of people on earth will soon be in an environment largely designed and structured for concentrated human living. Within the United States, public focus on global environmental issues such as climate change and ecosystem degradation is increasing the number of urban ecosystems services that are perceived as fundamental for people's quality of urban life beyond only landscape amenity and access to 'nature' (Contanza et al. 1997; de Groot et al. 2002). Thus, a holistic knowledge of the impact of landscape design and management practices on overall urban ecosystem function is essential to ensure that urban landscapes, particularly the vast portion of landscapes that are structured in residential land uses, are conceived and managed in a sustainable manner (Harrison et al. 1987).

Cities first arose as complex social structures nearly 10,000 years ago. Sustainable cities in arid ecoregions of the world may at first glance seem paradoxical, but many of the earliest cities were in arid climates near reliable fresh river water resources (Redman 2006). From 750 to 1250 AD, an estimated 250,000 Hohokam Native Americans resided in central Arizona's fertile Salt River Valley region at the northeast fringe of the lower Sonoran Desert (Anderies 2006). These peoples were able to flourish for centuries in this arid ecoregion because of perennial streams and rivers that flowed into the Salt River Valley from the nearby moisture-laden Mogollon Rim plateau and White Mountain regions to the northeast. However, sometime around the 14th century AD the Native American peoples in this ecoregion vanished for reasons still unclear (Andrews and Bostwick 2000).

Today, the Phoenix metropolitan area is situated within the Salt River Valley in Maricopa and Pinal Counties, Arizona, USA. It consists of 13 contiguous municipalities covering an area of 37,750 km^2, has an estimated population of approximately 4.2 million, and an estimated moderate population density of 98 per km^2 (US Census Bureau). Although the modern day ascent of Phoenix to become a major metropolitan center has occurred mostly during the second half of the 20th century, present day irrigation delivery systems in this a regional desert oasis city are patterned in part after those of the earlier Hohokam peoples (Keys et. al. 2007).

FACTORS THAT LIMIT LANDSCAPE SUSTAINABILITY IN PHOENIX

In this paper, I borrow from the Brundtland Commission's 1987 definition of sustainability as a system that meets the needs of the present without compromising the needs of future generations (United Nations Economic Commissions for Europe). I define sustainable urban landscapes as those that are designed, installed and managed by people in ways that over the course of time are able to improve human health, quality of life and commerce without excessive consumption of natural resources. Within this context, ecosystems services can provide a measurable framework for assessing landscape site sustainability. Ecosystem services have been defined as the capacity of natural processes and components to provide goods and services that satisfy human needs either directly or indirectly (de Groot et al. 2002). The importance of ecosystem services to urban landscapes sustainability is framed by the unique interactions of natural and built systems and should be weighted according to local ecoregion and ecosystem resiliency factors.

In ecological terms, resiliency has been defined as the tendency for ecosystems to maintain their integrity when subject to disturbance (Holling 1973). Phoenix landscapes are nested within a fragile Sonoran Desert ecosystem that is of relative low biological resilience (Liu et al. 2007; Walker et al. 2006). Mean annual precipitation and evapotranspiration in the Sonoran Desert vicinity of Phoenix are 180 mm and 1200 mm, respectively. Recovery of Sonoran Desert ecosystem diversity and function after natural disturbances such as fire might require some 60 to 100 years. In contrast, the relatively lush landscapes of this rapidly expanding urban area are normally irrigated, generally have greater vegetative cover, and have plant diversities that are site independent and highly variable (Martin 2001; Hope et al. 2003; Walker and Briggs 2007).

The recent and rapid formation of modern day Phoenix has occurred largely because of past affordable land costs and abundant supplies of fresh water from regional rivers. In this rapidly growing city, native Sonoran Desert vegetation has been replaced with built structures and lush landscapes comprised of a diverse mixture of mostly non-native plant taxa (Martin et al. 2003 and 2004b). Unlike cities in more mesic climates, Phoenix has relatively little natural invasion of woody native or non-native flora across the urban boundary. Because of the affordability and abundance of natural resources, past efforts by people to optimize landscape water use and management practices have been lacking. This has had the unintentional effect of degrading landscape sustainability even though landscapes in Phoenix may be viewed within an anthropogenic context as having relatively greater resilience than that of the surrounding Sonoran Desert ecoregion.

In the past, residential landscape sustainability in Phoenix has been tightly coupled to an abundance of affordable land and water resources. In the future, landscape sustainability may be improved through discovery of new landscape design and management practices which more efficiently utilize natural resources. In the following discussion, I review water availability, human demography and socioeconomics, human landscape preferences, urban heating, landscape design and microclimate, and landscape management practices as important factors affecting sustainability of managed landscapes in Phoenix. Research findings of scientists affiliated with the Central Arizona Phoenix Long Term Ecological Research Project (CAP LTER) are used to discuss landscape sustainability, ecosystem services and resiliency. At the conclusion of this discussion, I propose a framework for future sustainable landscaping in Phoenix by making conceptual recommendations for ecoregion specific landscape design and management practices.

Water availability

During the 20th century, construction of local water storage reservoirs along the Salt and Verde River drainageways of central Arizona and the Central Arizona Project (CAP), a canal system that transports water approximately 250 Km from the Colorado River of western North America, have underpinned the rapid re-inhabitation of this ancient population center. From 1985 to 1994, total consumptive water use in greater Phoenix increased by about 26% (Arizona Department of Water Resources). Even so, fresh water capture and regeneration potentials in central Arizona at the start of the 21st century still exceed consumptive demand despite recent rapid increases in urban population and consumptive water use, mostly because of declining local agriculture water use.

Looking to the future, increasing population and overall consumptive water use in Phoenix will most certainly occur. Recent projections of the growth of Phoenix suggest that by the year 2030 the metropolitan population will reach 8.5 million and will consume all of the currently secured 2.4 million-acre-feet (MAF) of water now deliverable to the metropolitan area (Holway 2006). Currently secured water supplies for the greater Phoenix region include 1) state

regulated withdrawals of ground water, 2) Salt and Verde River surface water reservoirs, 3) Central Arizona Project (CAP) canal flows from the Colorado River, and 4) small amounts of effluent generated as a byproduct of human consumption of potable water. Sustainment of water supplies to the Phoenix ecoregion to support future population increases beyond the year 2030 might include additions of water rights leased from adjacent Native American communities, increases in CAP canal capacity to increase transfers of Colorado River water, increasing use of water effluent, and possible desalination (Holway 2006). These projections do not include potential supply reductions or disruptions caused by long-term regional drought, high rates of silt deposition into Colorado River reservoirs, or the potential impacts of global climate change (Reisner 1993; Golden et al. 2006).

Irrigation of outdoor landscaping in Phoenix has been shown to account for 45% to 70% of total residential water consumption (Arizona Department of Water Resources). More irrigation waters were applied to landscapes dominated by turf grass than landscapes that consisted of desert-adapted vegetation (Figure 1). In addition, house-to-house variability of landscape water use has been shown to be greater than the mean differences in landscape water use related to landscape design type (Martin et al. 2004b). Based on these findings, future water conservation efforts based solely on ordinances and recommendations of low water-use plants without concomitant changes in irrigation scheduling are not likely to be successful. Further improvements in sustainable landscape water use in Phoenix could involve greater optimization of landscape water delivery to evapotranspirational demand through increased use of Smart Water Application Technologies (SWAT™). SWAT™ is a national initiative designed to achieve exceptional landscape water use efficiency through the use of irrigation technologies and irrigation scheduling based on applied measures of local evapotranspiration. Reports from the US Bureau of Reclamation (2007) document landscape irrigation water savings through the use of Smart irrigation controllers of up to 159 liters per day for the residential landscape and 2,063 liters per day for commercial landscapes.

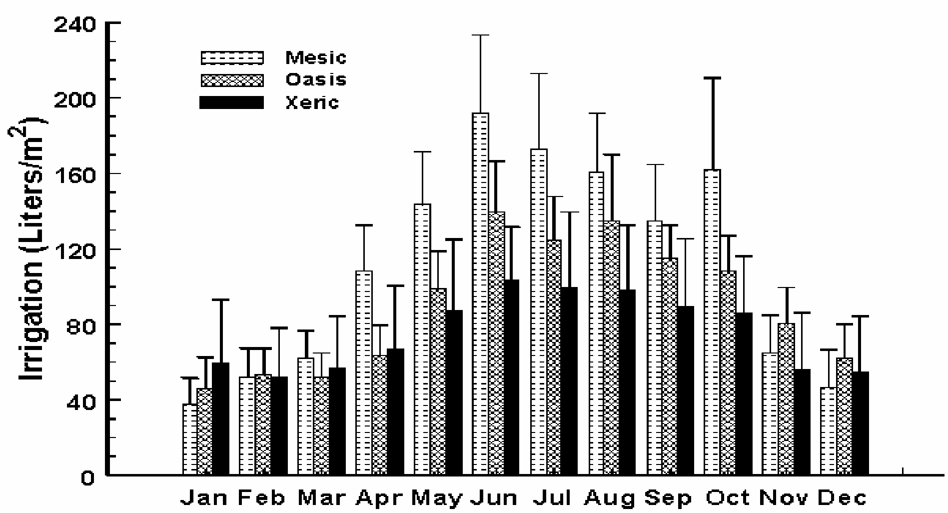

Figure 1. Effect of landscape design type on mean monthly residential landscape irrigation application volumes in Phoenix, Arizona, 1998-2003 (From Martin et al. 2004).

Human demography and socioeconomics

Landscaping, or the practice of creating, installing and managing outdoor living environments for the enhancement of everyday quality of life, is shaped by a complex interwoven mosaic of socio-economic values, the needs of society, and technology (Motloch 1991). Before 1960 and the advent of the common use of air conditioning, one of the principle ways that Phoenix landscapes served the needs of society was to make outdoor living spaces more habitable by ameliorating high summer temperatures through shading and evapotranspirational cooling. To accomplish this, flood irrigation techniques were commonly practiced and landscapes consisted of abundant turfgrass and fast-growing shade trees. After 1960, the functional role of outdoor landscapes waned as Phoenicians generally spent a greater portion of time inside climate-controlled environments. Especially after 1990, landscape function as a measure of the value of outdoor living space was superseded by landscape form driven by increased public interests in water conservation and preservation of Sonoran Desert flora. Evidence for this change in the role of outdoor landscapes may be seen in the contemporary widespread planting of native and desert-adapted trees and shrubs and the covering of landscape surfaces with decomposed granite instead of turfgrass. This paradigm shift in pubic landscape values may signal a change in people's attitudes toward their immediate outdoor environment. In this new era, the role of outdoor amenity landscapes may be to visually enhance the human living experience from inside while reflecting an attempt to conserve natural resources and offer city dwellers an opportunity to comfortably experience 'nature'.

From a traditional ecological perspective, urbanization and human landscaping practices have been considered disturbance events and the use and management of exotic landscape plants have not been perceived as relevant to the ecology of natural systems beyond their potential for habitat invasion or degradation. Recently, ecologists have come to appreciate the unique diversity patterns of urbanized areas (Kinzig et al. 2005; Cook and Faeth 2006; Liu et al. 2007). Compared with the surrounding Sonoran Desert, artificial or 'built' landscapes in the greater Phoenix area form an urban forest characterized by a patchwork mosaic of higher plant species richness and vegetative cover (Peterson et al. 1999).

During the last few years, researchers have begun to frame a mechanistic understanding of the drivers of urban plant diversity distribution. The compositional structure of landscape plantings in Phoenix is sharply segmented by property boundaries often demarcated by 1.5- to 2.5-m concrete block walls. In addition, the structural composition of residential landscape is affected by a strong positive relationship between urban neighborhood socioeconomic status and vegetation richness up to an apparent limit of diversity complexity of about 20 different woody plant genera per 1000 m^2 of landscaped area (Hope et al. 2003; Martin et al. 2004a). As a result, Phoenix residents in high socioeconomic neighborhoods are more likely to enjoy rich assemblages of vegetation in their neighborhoods than people who live in neighborhoods of low socioeconomic status. The newest residential neighborhoods were found to have the highest vegetation abundance suggesting generally that as residential landscapes in Phoenix age, rates of landscape plant mortality are higher than rates of plant replacement.

The plant community composition of residential Phoenix landscapes is apparently driven by "luxury" and legacy effects. Phoenicians who benefit the most from landscape vegetation are apparently those who reside in the wealthiest and/or newest residential neighborhoods (Hope et al. 2006). These differential accesses to 'nature' by urban residents may have environmental justice implications. Residents in older neighborhoods of lower socioeconomic status are most likely to have landscapes of low diversity and abundance that are less able to deliver regulation, habitat, production, and information ecosystem service functions (de Groot et al. 2002).

Human landscape preferences

A variety of factors influence the dichotomy of human landscape preference. If environmental attitudes translate into environmental behaviors, then evaluating and educating people's attitudes and preferences toward landscapes could result in more sustainable landscape management practices. Since the advent of the Xeriscape™ concept in 1981 (Colorado Water Wise Council), residents of greater Phoenix have been presented with local public campaigns promoting desert-adapted or water-conserving landscape plants or municipal financial rebates for conversion high water-use landscapes to desert landscapes having a blend of water-conserving trees and shrubs (Arizona Department of Water Resources). Despite public campaigns for reductions of landscape water use, surveys of greater Phoenix residents consistently show that people prefer greenspaces with many textures and colors to open bare landscapes (Martin et al. 2003; Larsen and Harlan 2006; Yabiku et al. 2008).

Phoenix residents preferred high-water-use landscapes over dry landscapes for their own yards, even though they considered desert landscapes to be aesthetically pleasing (Yabiku et al 2008). For the front yard, both the legacy of where homeowners had previous lived and their preferences for landscape design type were significant predictors of landscape behavior, but in the backyard, only the homeowner's landscape preference had a significant influence (Larson and Harlan 2006; Figure 2). Women and long-term residents of the Phoenix area were significantly more averse to dry landscapes (Yabiku et al. 2008). Apart from the concern for young children, it is still unclear why gender differences in landscape preference exist. For both genders, stronger environmental attitudes did not lead to a preference for desert landscape designs, but did lead to compromises on the amount of turf grass preferred in lush landscapes. The two traits that homeowners considered most important for their landscape were ease of maintenance (64%) and landscape aesthetics (38%). Water conservation was third most important (26%), while landscape design type (22%) and plant growth habit (19%) were of less importance (Martin et al. 2003).

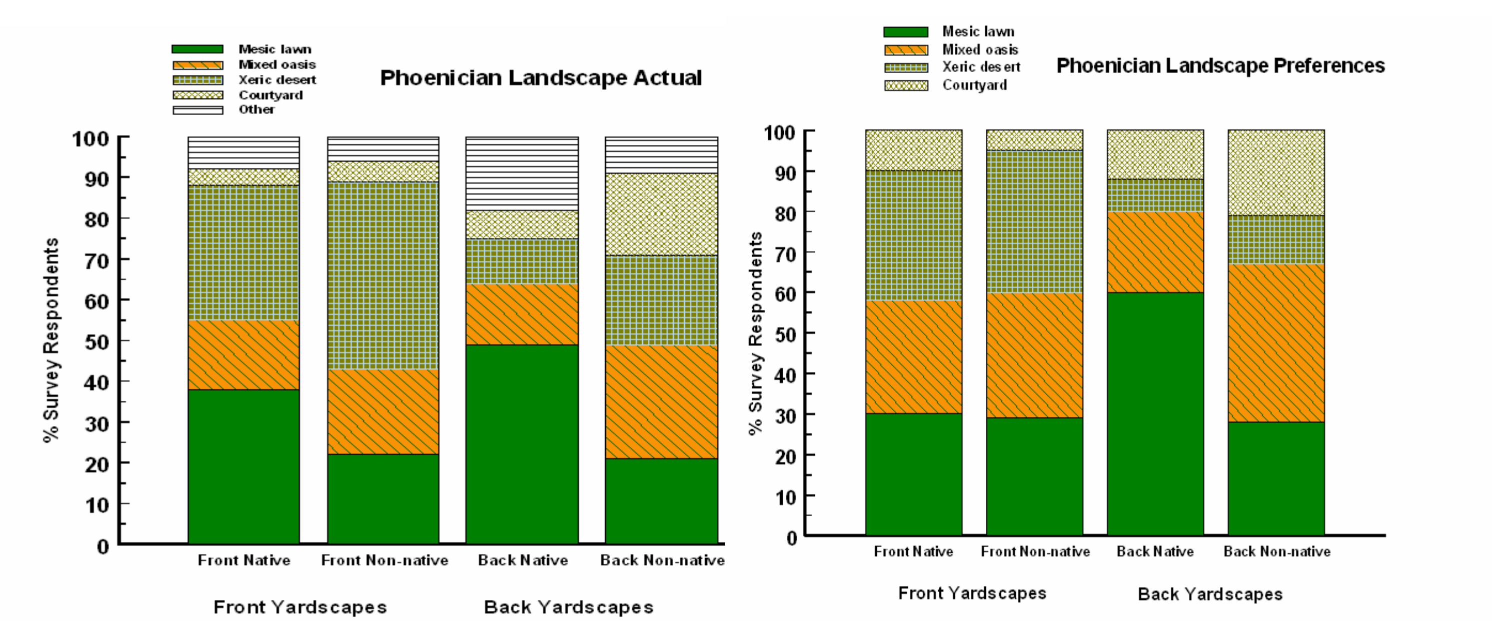

Figure 2. Front and back yardscape in Phoenix, AZ, A) actual, B) homeowner preferences of native and non-native Phoenician residents distributed by landscape design motif (From Larson and Harlan, 2006).

One prevailing dogma has been that people relocating to Arizona from less arid climates, such as in the eastern United States, would prefer lush landscapes because they are legacies of a former home which makes them reluctant to accept the principles of desert landscape design that are more popular among long-standing Arizona residents. In each of the three survey studies referenced above (Martin et al. 2003; Larsen and Harlan 2006; Yabiku et al. 2008), researchers found that contrary to popular ideology there is a positive correlation between length of Phoenix residency and increased preference for landscapes with lush green elements. These findings underscore the importance in Phoenix of turfgrass lawns as an important and serviceable element of residential landscapes, especially backyard private areas.

Urban heating, landscape design and microclimate

Urban heating in the greater Phoenix region is now well documented (Baker et. al. 2002; Martin et al. 2000; Stabler et al. 2005; Golden et al. 2006). Compared with the surrounding Sonoran Desert terrain, the Phoenix urban heat island has been characterized to have higher summer nighttime temperatures and slightly lower summer temperatures during the day (Brazel et al. 2007). This nighttime heating effect is caused by the higher heat storage capacity of the urban built environment that enhances delayed remittance of long-wave radiation. Lower daytime temperatures are largely a result of higher latent heat transfer fluxes caused by the evapotranspirational cooling of landscape vegetation and evaporation of water from swimming pools and urban lakes (Guhathakurta and Gober 2007). Moreover, the pattern of undercanopy urban microclimates (surface to 5 m height) in the greater Phoenix area is related to urban land use and consequent socioeconomic composition of the urban fabric (Harlan et al. 2006). In areas of high structural and low vegetation densities such as in the Phoenix urban core and areas of low socioeconomic status, urban heating is most pronounced because evaporational cooling from latent heat transfer fluxes is minimal and urban heat storage capacity by built surfaces is high (Harlan et al. 2008). In contrast, single family unit residential neighborhoods with high vegetative cover, moderate to high irrigation inputs and high socioeconomic status are observably cooler.

Figure 3. Images showing residential neighborhood landscape design experiment treatments in qPhoenix, AZ described by Martin et al. (2007). A = mesic treatment; expansive turfgrass and overhead sprinkler irrigation. B= oasis treatment; turfgrass and overhead sprinkler irrigation mixed with landscape trees and shrubs, drip irrigation and decomposing granite mulch. C= xeric treatment; desert adapted trees and shrubs, drip irrigation and decomposing granite mulch, D= native treatment; Sonoran Desert native trees and shrubs, no irrigation and decomposing granite mulch. Digital images captured by Chris Martin.

In Phoenix, CAP LTER researchers are studying the long-term effects of landscape design on ecosystems services by transforming residential yards in a local neighborhood into one of four local design archetypes (Yabiku et al. 2008; Figure 3). These four design archetypes are: 1) a mesic design consisting of expansive areas of well-irrigated turfgrass; 2) an oasis design consisting of a mixture of small areas of well-irrigated turf grass interspersed with drip-irrigated landscape trees and shrubs and decomposed granite mulch; 3) a xeric design consisting of drip-irrigated, desert-adapted trees and shrubs and decomposed granite mulch; and 4) a native design consisting of non-irrigated Sonoran Desert native trees and shrubs and decomposed granite mulch. During 2007, a direct relationship was found between landscape design type and landscape surface cover, rhizosphere soil temperatures and outdoor surface temperatures of residential houses (Martin et al. 2007). Rhizosphere soil temperatures (30 cm below surface) in landscapes dominated by sprinkler irrigated turfgrass were cooler compared with landscapes dominated by the regionally common decomposed granite surface mulch (Figure 4). Additionally, afternoon and evening summertime outdoor surface temperatures of residences embedded within turfgrass landscapes were cooler than surface temperatures of residences surrounded by low water use desert adapted vegetation and decomposed surface mulch cover (Table 1). These findings again highlight the importance of latent heat transfer and turfgrass in the creation of cooler Phoenix microclimates. Based on these findings, future sustainable strategies for landscape design in Phoenix should include the optimization of size, placement, and management of turfgrass areas within residential land uses rather than the wholesale abolition of turfgrass as a landscape element in favor of an environmentally warmer, composite, structured desert landscape archetype.

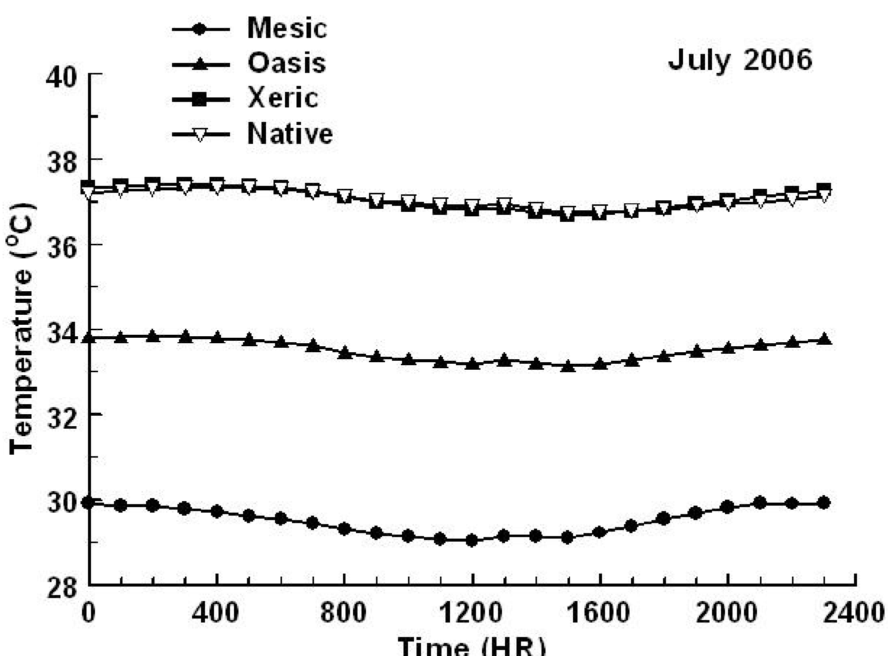

Figure 4. Effect of landscape design treatments on diel mean soil temperatures (30 cm depth) for July 2006 in Phoenix, Arizona. Landscape design treatments described in Martin et al. (2007).

In Phoenix, maximizing vegetative cover as an ecosystem service to ameliorate urban heating and regulate atmospheric gases is exacerbated by the high amounts of supplemental water required to sustain landscape vegetative cover in an arid climate (Figure 1). The combination of efficient landscape irrigation systems such as drip or trickle and use of desert native or adapted landscape vegetation have been shown to reduce demand for landscape irrigation. In Phoenix

these water conserving landscapes are normally interspaced with heat retaining structured surfaces such as concrete, asphalt, and inorganic landscape surface covers such as decomposed granite rock mulch (Celestian and Martin 2004; Singer and Martin 2008). Recently, organic mulches such as recycled shredded landscape tree trimmings were shown to have nearly the same effect on lowering undercanopy temperatures as turfgrass (Singer and Martin 2008). These findings support increased local recycling of landscape waste as landscape surface mulch to improve carbon regulation and urban climate ecosystem service performance without increasing landscape consumptive water use.

Table 1. Effect of residential landscape design and type on morning (0800 to 0900 HR), afternoon (1430 to 1530 HR), and evening (2100 to 2200 HR) house surface temperatures in Phoenix, AZ during June 2007.

Landscape Treatment	Morning	Afternoon	Evening
Mesic	40.5 a	42.3 d	29.2 b
Oasis	42.3 a	43.8 c	30.8 a
Xeric	40.2 a	45.3 b	31.3 a
Native	40.9 a	46.8 a	30.7 a

Values are treatment means, n=24. Values followed by the same letter are not significantly different, Tukey's HSD test, alpha=0.05.

Landscape management practices

Sustainability of landscape vegetation in Phoenix is inordinately dependent on horticultural management practices because of the desert climate. In particular, the capacity for Phoenix landscapes to provide regulation, habitat, and information ecosystem functions is directly impacted by irrigation rates and pruning regimens. Present day landscapes in Phoenix are designed with a bias toward aesthetical cultural services. In the rapidly evolving economy of Phoenix, this means that landscapes are designed and installed to give aesthetic information prematurely through increased plant frequency (landscapes installed with plants spaced closely) and irrigation rates intended to promote fast plant growth. These practices inevitably lead to frequent and sometimes excessive pruning regimens to control plant size (Figure 5), and ultimately to a degrading of regulation and habitat functions and landscape resilience.

Figure 5. Image showing effect on shrub form of typical frequent shearing pruning practices in Phoenix, AZ. Digital image captured by Chris Martin.

In a five-year outdoor experiment, replicated landscapes were planted with trees and shrubs to mimic the density and representative taxa of vegetation in "xeric style" residential plots surveyed in the Phoenix metropolitan area to determine effects of irrigation rate and pruning practices on landscape productivity (Martin and Stabler 2002; Martin et al. 2003; Stabler 2003). Mean annual carbon sequestration potential was estimated to be 2215 g or 1183 g C/m^2 when irrigated at high (1954 mm/yr) or low (814 mm/yr) rates, respectively. Assuming 0.28 m^2 of leaf area per m^2 of land area in a typical single family residential site in Phoenix (Stabler 2003), these values suggest maximum gross annual landscape productivity of 620 and 331 g C m^{-2} land area under high rate and low rate irrigation regimes, respectively (Martin and Stabler 2002). Based on these figures, high irrigation application rates similar to those monitored by Martin et al. (2004b) in the estimated 1168 km^2 of residential land use in the greater Phoenix ecoregion (Stefanov et al. 2001) might increase gross primary production in the ecoregion by over 200,000 metric tons per year relative to lower irrigation application rates. In comparison, mean annual carbon sequestration potential of unirrigated Sonoran Desert sites has been measured at 424 g C per m^2 leaf area (Martin and Stabler 2002) which when scaled to show maximum gross annual productivity for non-irrigated Sonoran Desert woody vegetation is about 34 g C m^{-2} land area or 10 to 20 times lower than a normally irrigated Phoenix residential landscape (Stabler 2003).

While increased CO_2 sequestration in Phoenix landscapes is a beneficial ecosystem service, the cost in water use must also be considered. The combined effects of drip irrigation rate and pruning can have significant effects on Phoenix shrub productivity, green waste generation, shrub water use efficiency, and soil salinity (Table 2). Water use efficiency and soil salinity were highest and lowest, respectively, when shrubs were drip irrigated at the lowest rate and not pruned (Table 2). Since electrical conductivity of Phoenix irrigation water typically ranges from 0.6 to 1.0 dS/m, it is not surprising that soil salinity would be increased by higher irrigation rates. These findings show that low irrigation rates and infrequent or no pruning can increase efficient use of water resources and limit green waste produced by Phoenix landscapes.

Table 2. Effects of five years (1999 to 2003) of drip irrigation rate and pruning treatments on total above ground net primary productivity (APP), green waste generation (GW), and water use efficiency (WUE) of two landscape shrubs[Z], and soil electrical conductivity.

Treatment[Y] Irrigation rate/pruning	**APP** (Kg/shrub)	**GW** (Kg/shrub)	**WUE**[X]	**EC** (dS/m)
High/no prune	4.83 ab[W]	0.44 c	0.52 b	3.8 a
High/6 weeks	5.76 a	2.94 a	0.60 b	1.5 b
Low/no prune	3.57 b	12.0 b	0.87 a	0.7 d
Low/6 weeks	2.82 c	0.34 b	0.71 ab	1.8 b

[Z] The two landscape shrubs were clones of *Nerium oleander* and *Leucophyllum frutescens*.
[Y] Treatments: High irrigation rate = 1954 mm/year; low irrigation rate = 814 mm/year; pruned every 6 weeks = sheared into a symmetrical rounded shape approximately 1 m in height; no prune = control.
[X] WUE=APP/(total liters of water applied per shrub/1000).
[W] Values are treatment means, n=36 for irrigation, n=24 for prune every 6 weeks, n=12 for no prune. Values followed by the same letter are not significantly different, Tukey's HSD test, alpha=0.05.

The enhanced productivity and intensive management of Phoenix landscapes impacts habitat formation and alters controls of trophic dynamics. Generally, landscape productivity gains tend to dampen seasonal and yearly fluctuations in macro- and micro-fauna species diversity, elevate abundances, and alter feeding behaviors of some key urban species (Faeth et al. 2005). Moreover, compared with the surrounding Sonoran Desert, Phoenix landscapes have abundant resources and reduced predator risks. Reduced predation risk has been shown to elevate the abundance of urban birds and alter their foraging behavior such that they exert increased top-down effects on arthropods (Warren et al. 2006). Finally, population dynamics and tree root colonization patterns of soil borne arbuscular mycorrhizal fungi in Phoenix landscapes has been shown to be reduced likely by landscape irrigation and higher levels of soil nutrients, especially soil P (Stabler et al. 2001).

CONCLUSION

Ecosystem services provide an integrated framework for assessing the nature and value of an ecosystem to human society. In this paper, I have proposed that landscape sustainability in Phoenix may be understood through the ecological contexts of ecosystem services and resilience. Public attitudes and policies toward landscape sustainability in Phoenix have been dynamic and have changed from a focus on information and regulation functions prior to the wide spread use of air conditioning and landscape irrigation in the 1960s, to an emphasis on information and habitat functions from the 1960s to 1990s. In Phoenix, present day emphases on cultural, aesthetic, and habitat formation ecosystem services within an arid ecoregion of low natural resilience coupled to a matrix of socioeconomic status, irrigation rate and pruning practices has had the undesired effect of degrading landscape sustainability.

In cities, landscape sustainability is affected by a myriad of influences at multiple scales. At large spatial scales, sustainability of landscapes is broadly influenced by policy makers and urban planners via decisions about urban development, socioeconomic land use, and various land management decisions intended to conserve natural resources or preserve open space. At smaller spatial scales of individual property units, landscape sustainability is influenced directly by individual decisions and actions on choice of plant taxa, vegetation density, and management practices. It is within this context that I propose that individual landscape managers in desert cities such as Phoenix may improve landscape sustainability by implementing the following practices:

1) Utilize water-conserving irrigation technologies such as Smart controllers to optimize rates of landscape water delivery to evapotranspirational demand.

2) Give preference to oasis landscape designs motifs that use strategic size and placement of turfgrass surrounded by native and desert-adapted trees and shrubs. Use of native and desert-adapted trees and shrubs will balance landscape water conservation with the ecosystem services of CO_2 sequestration, provide shade for microclimate control, encourage native wildlife habitat formation, and provide cultural and aesthetic functions. Public appreciation for turfgrass remains high. Where appropriate and functional, the presence of turf grass especially during the warm desert summer months is able to provide evapotranspirational cooling in landscapes as well as give cultural inspiration and historic inference.

3) Establish a goal of 100% recycling of landscape green waste on site. Organic surface mulches encourage water retention, soil formation, nutrient recycling, and inhibit soil heating.

4) Implement infrequent, conservative plant pruning schemes that are tailored to the patterns of vegetative and reproductive growth of individual landscape plant species on a landscape site. The concurrent use of conservative landscape water use and pruning strategies can result in lower rates of green waste production and salt deposition in landscape soil.

Finally, present day concerns about global rises in atmospheric CO_2 levels, urban heating, and the future adequacy of natural resource supplies has caused a resurgence of public interest in optimizing regulation function ecosystem services. Because of this landscape ecosystem services and resilience in rapidly expanding desert cities such as Phoenix will likely be increasingly measured against the future inflation of land and water costs. The implications of this socio-environmental paradigm will likely further sharpen public awareness and concerns about the importance of landscape water conservation, design, and management practices in creating sustainable landscapes that sequester atmospheric carbon and moderate urban climate, and will continue to increase demand for use of native and desert-adapted trees and shrubs in Phoenix landscapes.

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