

## Research Paper

## Continental-scale homogenization of residential lawn plant communities



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## ABSTRACT

Residential lawns are highly managed ecosystems that occur in urbanized landscapes across the United States. Because they are ubiquitous, lawns are good systems in which to study the potential homogenizing effects of urban land use and management together with the continental-scale effects of climate on ecosystem structure and functioning. We hypothesized that similar homeowner preferences and management in residential areas across the United States would lead to low plant species diversity in lawns and relatively homogeneous vegetation across broad geographical regions. We also hypothesized that lawn plant species richness would increase with regional temperature and precipitation due to the presence of spontaneous, weedy vegetation, but would decrease with household income and fertilizer use. To test these predictions, we compared plant species composition and richness in residential lawns in seven U.S. metropolitan regions. We also compared species composition in lawns with understory vegetation in minimally-managed reference areas in each city. As expected, the composition of cultivated turfgrasses was more similar among lawns than among reference areas, but this pattern also held among spontaneous species. Plant species richness and diversity varied more among lawns than among reference areas, and more diverse lawns occurred in metropolitan areas with higher precipitation. Native forb diversity increased with precipitation and decreased with income, driving overall lawn diversity trends with these predictors as well. Our results showed that both management and regional climate

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shaped lawn species composition, but the overall homogeneity of species regardless of regional context strongly suggested that management was a more important driver.

### 1. Introduction

The expansion of large areas devoted to single-family residential housing has been postulated to create ecosystems in urban and suburban areas that are much more homogeneous than regional native ecosystems (Kühn & Klotz, 2006; McKinney, 2006; Schwartz, Thorne, & Viers, 2006). This pattern occurs in part because people select a relatively uniform mixture of grass, trees, ornamental plantings, and open areas (Groffman et al., 2014), which homogenizes many plant taxa on multiple spatial scales (McKinney, 2006). Homogenization of urban and suburban plant communities likely occurs through a variety of mechanisms that are both direct and indirect results of human actions. In residential areas, many homeowners obtain plants from nationwide garden and home improvement stores in which sales are dominated by a relatively small pool of plant species (Smith, Thompson, Hodgson, Warren, & Gaston, 2006; Yue & Behe, 2008). However, homogenization is not limited to planted areas or gardens, but also occurs in non-planted urban plant communities, such as spontaneous communities around urban street trees (Del Tredici, 2010; Wittig & Becker, 2010).

Lawns, or the turfgrass-dominated and maintained areas in yards, are a widespread and characteristic element of urban and suburban landscapes. Lawns cover more land than any other irrigated crop in the United States (Milesi et al., 2005; Robbins & Birkenholtz, 2003). Lawns provide ecological services such as water filtration (Beard & Green, 1994), moderation of the urban heat island effect (Hall et al., 2016; Jenerette, Harlan, Stefanov, & Martin, 2011), stormwater management (Mueller & Thompson, 2009), floral resources for pollinators (Larson, Kesheimer, & Potter, 2014), and connectivity between populations or reservoirs of species (Dearborn & Kark, 2010; Stewart et al., 2009), as well as recreational and aesthetic benefits to people and their pets (Beard & Green, 1994; Dearborn & Kark, 2010).

Although lawns are often assumed to be relatively uniform and species-poor, they can be diverse and rich in native species (Bertoncini, Machon, Pavoine, & Muratet, 2012; Thompson, Hodgson, Smith, Warren, & Gaston, 2004) or dominated by non-native species (Stewart et al., 2009). Residential lawns are typically designed to contain a limited number of turfgrass species. They are often maintained to reduce or eliminate weeds, and are continuously shaped through management with mowing, watering, fertilizing and use of pesticides. However, it remains unclear what species are actually present in typical residential lawns across broad regions and what management or

regional environmental drivers may lead to different lawn species compositions.

Lawn management varies within and among cities (Polsky et al., 2014). The ways people choose to manage their lawns varies with characteristics such as resident beliefs and norms, population density, and housing density (Martini, Nelson, Hobbie, & Baker, 2015; Zhou, Troy, Grove, & Jenkins, 2009), and these management choices in turn affect lawn species composition (Bertoncini et al., 2012). Cultural and socioeconomic factors such as family income and resident age also influence urban plant diversity (Hope et al., 2003; Kinzig, Warren, Martin, Hope, & Katti, 2005; Meléndez-Ackerman et al., 2014). The urban “luxury effect” describes the tendency of plant diversity in urban greenspace to increase with increasing socioeconomic status (Hope et al., 2003; Martin, Warren, & Kinzig, 2004). Moreover, urban environments are known to select for species that have functional attributes that allow them to disperse and persist in settings subject to higher pollution levels, heat island effects, altered wind patterns and contrasting dispersal agents (Knapp et al., 2012). At the same time, lawns are subject to the same aspects of the regional climate that affect native communities (Thompson et al., 2004). Interestingly, management practices such as irrigation and fertilization may not be linked to regional abundance of water and nitrogen (Groffman et al., 2016). While there have been a number of studies of controls on lawn species composition in individual cities (e.g., Stewart et al., 2009; Thompson et al., 2004), continental scale patterns of lawn plant species composition associated with climate or large regional variations in lawn management have not been well explored. These patterns are important because they could reveal how management and regional environmental drivers together shape lawn species composition.

In this study, we measured lawn plant species composition across different levels of housing density in seven cities and their associated Metropolitan Statistical Areas (MSAs) spanning climatic zones across the United States. We also measured plant species composition in representative natural reference areas in each MSA. These included, for example, Sonoran desert parks in Phoenix, tallgrass prairie in Minneapolis, and northern hardwood forest in Boston. We determined homeowner income and management practices with a phone survey. Because actions by residents may strongly influence plant species composition in lawns, we hypothesized that the plant species composition, richness and diversity of lawns, both including and excluding planted turfgrasses, would be similar among different MSAs and that lawns across the country would be more similar than reference areas

**Table 1**  
Climate, native vegetation, and number of plots sampled in each MSA. Climate data are 30-year means from 1981 to 2010. Number of sites or locations/transects shows the number of residential lawns and the number of different reference areas and transects sampled, with total number of plots sampled in parentheses. The number of transects in each type of reference vegetation is shown in parentheses after the vegetation type.

Abbreviation	MSA	State	Mean Annual Precipitation (cm)	Annual Mean Daily Temperature (°C)	Number of Sites or Locations/Transects (No. of Plots)		Reference Area Vegetation (No. of Transects)
					Reference	Lawn	
BAL	Baltimore	MD	106	12.8	3/24 (68)	23 (123)	Oak and tulip poplar forest (24)
BOS	Boston	MA	111	10.8	6/21 (63)	31 (186)	Northern hardwood forest (18), pasture (3)
LA	Los Angeles	CA	33	17.0	3/21 (63)	20 (90)	Southern California coastal scrub (21)
MIA	Miami	FL	157	25.1	4/23 (70)	21 (121)	Pine rockland (4), subtropical hardwood hammock (3), coastal hammock (8), pine flatwoods (8)
MSP	Minneapolis – St. Paul	MN	78	7.9	6/24 (66)	21 (126)	Oak savannah (8), tallgrass prairie (4), bluff prairie (4), maple-basswood forest (8)
PHX	Phoenix	AZ	20	23.9	3/24 (72)	28 (130)	Sonoran desert (24)
SLC	Salt Lake City	UT	41	11.6	3/24 (71)	30 (180)	Sagebrush shrub-steppe (24)

across the country. We also hypothesized that residential characteristics would affect lawn species composition regardless of MSA and that lawn species diversity would decrease with urban density, homeowner income and fertilizer use.

## 2. Methods

### 2.1. Lawn selection and sampling

We selected seven cities across the continental United States that represented different climates and vegetation types: Baltimore, MD (BAL), Boston, MA (BOS), Los Angeles, CA (LA), Miami, FL (MIA), Minneapolis-St. Paul, MN (MSP), Phoenix, AZ (PHX), and Salt Lake City, UT (SLC) (Table 1). We first conducted a telephone survey of 9480 residents, equally distributed among six of the seven MSAs (all but SLC), to identify individual residential properties as potential sampling sites (Polsky et al., 2014). Telephone interviews were conducted between November 21 and December 29, 2011. More than 100,000 households were initially contacted, with ~13,500 homes identified where the property contained a front or back yard and the respondent was over 18 years of age. From these households, approximately 70% of homeowners completed a 32 multi-part question telephone survey. Surveyed properties were stratified by urban density (urban, suburban, exurban) and socioeconomic status using the income and lifestyle categories defined by the Potential Rating Index for Zip Markets (PRIZM) (CLARITAS, 2013; Polsky et al., 2014). From the 9480 households surveyed by telephone, we selected 21–31 residential properties per MSA for field sampling. All selected properties were single-family homes with turfgrass lawns. Salt Lake City was not included in the telephone survey and lawns were selected at a later date. In Salt Lake City, 50 letters were randomly sent to homeowners in each of six targeted PRIZM categories asking permission to visit their home for sampling. Within each PRIZM category, we visited 5 homes randomly selected from the positive respondents, for a total of 30 yards.

In addition to site selection, responses to the initial telephone survey in all MSAs except Salt Lake City were used to determine household income and whether or not each household applied fertilizer, pesticides, or water to lawns (Polsky et al., 2014). No information was collected about other lawn management practices.

Within each MSA, we also selected three to six reference areas that contained minimally-managed vegetation. These reference areas were typically parks or publicly-owned reserves that ranged in structure and type, but were chosen to represent the predominant natural vegetation in each MSA (Table 1). In each reference area, we sampled the forest understory or all low-lying vegetation in non-forest communities, including herbaceous plants, woody seedlings, and shrubs less than 1 m tall, but not overhanging trees. We used these measurements to compare species in lawns to those found in unmanaged areas and to test for the possibility that lawns acted as species reservoirs. We also used these communities to test for homogenization of lawns compared with unmanaged vegetation found in remaining natural communities.

To sample each residential property, we placed three  $1 \times 1$  m plots randomly in the turfgrass area of front and back lawns, for a total of six plots per property. Where there was not both a front and back lawn or where lawns were too small to allow placement of three plots, fewer plots were sampled. Within each reference area, we located one to four  $1 \times 1$  m plots along 100 m transects. In most cases, more than one transect was located in the same reference area, but transects were distributed to capture the vegetation composition of the reference area. We selected three to six reference areas per MSA, with a total of 21–24 transects in each MSA. We sampled all areas during the growing season (spring for LA, PHX; summer for BAL, BOS, MIA, MSP, SLC). All sampling in Baltimore, Miami, Minneapolis-St. Paul, and Phoenix and residential sampling in Boston was done in 2012. All Los Angeles lawns and reference areas and Salt Lake City lawns were sampled in 2013, Salt Lake City reference areas were sampled in 2014 and some additional

Boston reference areas were sampled in 2015.

In each plot, we identified plants to species or the lowest possible taxon. The cover of each species within the plot was estimated and species were assigned to a cover class (< 1%, 1–3%, 3–5%, 6–15%, 16–25%, 26–50%, 51–75%, 76–100%). The midpoints of each cover class range were used in further analysis. Species were identified as native or non-native to the state in which they were recorded and were classified by functional group (turfgrass, other graminoid, forb, or shrub/tree) using species data from the USDA PLANTS Database (USDA NRCS, 2015). Nomenclature follows the USDA PLANTS Database.

Climatic data representing 1981–2010 means for annual precipitation and annual mean daily temperature were obtained from NOAA's National Climate Data Center (NOAA, n.d.). Stations located at each city's international airport were used for consistency.

### 2.2. Data analysis

We used species richness and the Shannon-Wiener diversity index to quantitatively compare diversity among MSAs and between lawns and reference areas, and we used the Bray-Curtis dissimilarity index to compare species composition within and among MSAs. The Bray-Curtis index yields a measure of the dissimilarity of communities based on the species present and the Shannon-Weiner index represents the number of species and evenness of a community. We also compared overlap between species lists for lawns in each MSA, with comparisons to reference areas as well. We performed ordinations of the lawn and reference area species data with non-metric multidimensional scaling (NMDS) with the Bray-Curtis dissimilarity index. We ran three NMDS analyses, one considering all species in both residential and reference areas and two considering only residential lawns, one with all species and one with turfgrass species removed from the analysis. We used cover values and species names to create the NMDS. One Boston lawn and one Phoenix lawn that were composed almost entirely of turfgrasses were removed from the analysis without turfgrass species.

As a category for inclusion or exclusion in our analyses, turfgrass species were defined using three sources: a University of California publication on residential turfgrass selection (Harivandi et al., 2001), a lawn grass selection page on a national home improvement store website (Lowe's, n.d.) and a page on types of turfgrasses on a lawn care company website (Scotts Lawn Service, n.d.). Sixteen species were recorded in our plots and considered to be turfgrass species for this analysis (Table S1).

All calculations and analyses were performed in R (R Core Team, 2014). Calculations of NMDS, species diversity, and dissimilarity were performed using the Vegan: Community Ecology package in R (Oksanen et al., 2015). NMDS was calculated with the metaMDS function. For calculations of species richness, diversity and NMDS, a reference area was defined as a reference transect of one to four plots. No significant differences were found between community composition in front and back lawns (Locke, 2017), so lawns were analyzed as a composite of the three to six plots from the front and back lawns of a single residential lot. All plots in each reference and residential area were averaged to give a single species richness and diversity value for each site.

Analyses of income, housing density, and lawn management (fertilizer, pesticide and water application) effects did not include Salt Lake City because it was not included in the original phone survey. We used climate data, lawn management factors, and housing density to create linear models of Shannon-Wiener diversity and species richness using backward elimination to select a subset of significant predictors for each measure of diversity. Differences in species richness and diversity among MSAs were tested using ANOVA with Tukey HSD tests used to determine pairwise differences.

### 3. Results

#### 3.1. Functional group and species composition

The functional group composition of lawns across MSAs was very similar (Fig. 1). Across all MSAs, average turfgrass cover in the sampled areas of lawns was  $76 \pm 30\%$ , and averages for individual MSAs ranged from  $60 \pm 25\%$  to  $98 \pm 11\%$ . Forb cover in lawns varied both between and within MSAs, with  $14 \pm 18\%$  forb cover overall and  $7 \pm 12\%$  to  $33 \pm 28\%$  cover across MSAs. Shrub and tree seedlings were absent from most lawns.

When all plant species were considered, lawns in the four cooler MSAs (BAL, BOS, MSP, SLC) were generally similar to each other and lawns in the three warmer MSAs (LA, MIA, PHX) were distinct from the cool cities but less similar to each other (Fig. 2A). However, when turfgrass species were removed from the NMDS analysis and only spontaneous or unintentionally planted species were included, lawns from all cities grouped very closely together, indicating higher similarity of the spontaneous plant communities than the planted turfgrasses both between and within MSAs (Fig. 2B).

When compared with reference vegetation, lawns in all MSAs had similar species composition and grouped closely together (Fig. 2C). In contrast, species composition of reference areas varied widely by MSA (Fig. 2C).

One notable difference between Miami lawns and lawns in all other MSAs was the proportion of native to non-native species. While lawns in the other six MSAs contained 13–37% native species with an average cover of 3–28%, Miami lawns on average contained 61% native species with 76% native species cover (Fig. 3). Most native cover in Miami lawns was caused by the prevalence of the native turfgrass *Stenotaphrum secundatum* (Walter) Kuntze (St. Augustine grass). However, the number and percentage of species in Miami lawns that were native was

also much higher than in lawns in other MSAs (Fig. 3).

Bray-Curtis dissimilarity among lawn species composition in different MSAs was significantly positively correlated with differences in precipitation (Mantel test,  $r = 0.38$ ,  $p = 0.001$ ) and temperature (Mantel test,  $r = 0.59$ ,  $p = 0.001$ ), and with increasing geographic distance between MSAs (Mantel test,  $r = 0.51$ ,  $p = 0.001$ ). This indicated that lawn species composition became less similar with greater climatic difference and greater geographic distance. Similarities between some MSAs with very different temperatures (e.g., PHX-MSP, BOS-MIA) were higher with turfgrasses removed, indicating that the spontaneous plant community was more similar than the planted turfgrasses (Table S2).

On average, 18% (range 3–48%) of species were shared among lawns (Table S3). For most MSAs, lawns shared more species with lawns in other MSAs than they did with the associated reference areas (Fig. 4). Miami, however, shared more species with Miami reference areas than with lawns in any other city. Less than 25% of species in lawns in each MSA were also found in the reference vegetation of that MSA (Fig. 4), and less than 30% of species recorded in the reference areas were found in lawns in that MSA (Fig. S1). Overall, more species were shared among lawns in different MSAs than among reference areas in different MSAs. A total of 93 species were found in lawns in multiple MSAs, while only 32 species were found in reference areas in more than one MSA and no species were found in reference areas in more than three MSAs.

Lawns in the seven MSAs shared a few very common species (Table S4). *Poa pratensis* was the most commonly recorded species, and was found in lawns in Salt Lake City (100% of lawns), Boston (97%), Baltimore (96%), Minneapolis-St. Paul (95%), and Los Angeles (10%). All lawns in Boston, Minneapolis-St. Paul, and Salt Lake City contained one or more species of *Poa*, and Miami was the only MSA without *Poa* in any lawns. *Schedonorus arundinaceus* (Schreb.) Dumort. (Tall fescue)

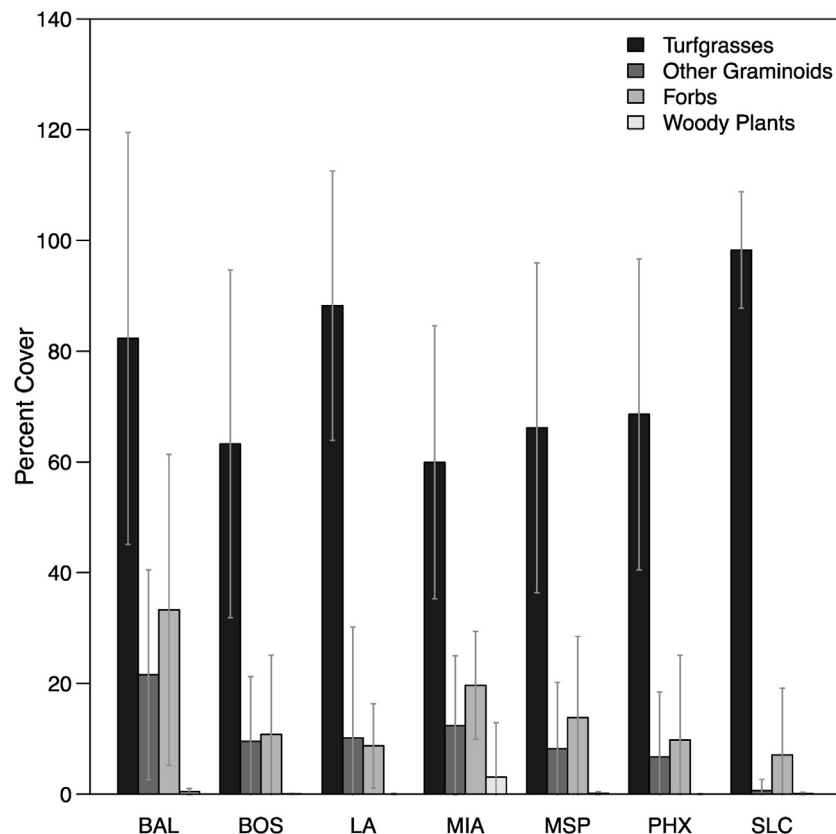


Fig. 1. Average cover (as percent of area sampled) of plant functional groups in lawns within each Metropolitan Statistical Area. Error bars shown are standard deviation. Cover was the average of the summed cover of all species in the functional group in a plot and may be greater than 100.

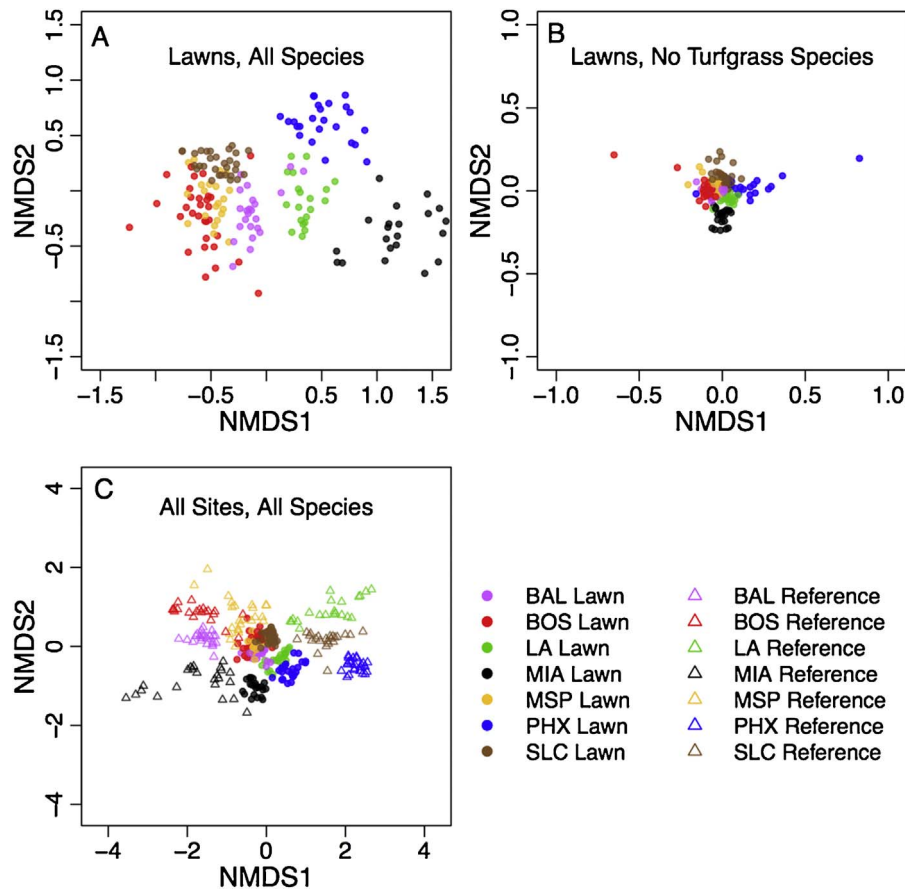


Fig. 2. Non-metric multidimensional scaling (NMDS) of lawn and reference vegetation in seven Metropolitan Statistical Areas across the US. Panels show NMDS of lawns only with all species (A) or excluding turfgrass species (B), and of lawns plus reference areas with all species included (C).

was prevalent in Baltimore (100% of lawns) and Los Angeles (95%) and also occurred in Salt Lake City (53%) and Minneapolis-St. Paul (24%). *Festuca rubra* L. (Red fescue) was common in lawns in Minneapolis-St. Paul (100%) and Salt Lake City (70%). *Festuca* species were also prevalent in lawns in Boston (90%), Baltimore (35%) and Los Angeles (20%). *Lolium perenne* L. (Perennial ryegrass) was found in lawns in Boston (90%), Salt Lake City (50%), Phoenix (24%), Minneapolis-St. Paul (10%), and Baltimore (9%). *Cynodon dactylon* (L.) Pers. (Bermudagrass) was the most widespread graminoid species, and occurred in all lawns in Phoenix and in a few lawns in five of the six other MSAs (all except MSP). While a few Miami lawns contained *C. dactylon*, the most common turfgrass there was *Stenotaphrum secundatum*, which was found in all Miami lawns and also found in lawns in Los Angeles (20%) and Phoenix (20%).

In addition to turfgrasses, three common lawn weeds were prevalent in multiple MSAs: *Taraxacum officinale* F.H. Wigg. (Common dandelion; BAL, BOS, LA, MSP, PHX, SLC), *Oxalis stricta* L. (Common yellow oxalis; BAL, BOS, MIA, MSP, SLC), and *Trifolium repens* L. (White clover; BAL, BOS, MSP, SLC). At least one species of *Oxalis* was found in lawns in every MSA, while no reference areas in any MSA contained any *Oxalis* species.

### 3.2. Species richness and diversity

Combined, lawns from all seven MSAs contained a total of 353 species from 74 families, while reference areas contained 397 species from 93 families. Forb and graminoid species diversity were higher in lawns (215 forb species, 18 turfgrass species, 54 other graminoid species) than in reference areas (199 forb species, 5 turfgrass species, 64 other graminoid species), while many more woody species were present in reference areas (130 species) than in lawns (66 species).

While functional group and species composition were more homogeneous in lawns than in reference areas, Shannon-Wiener diversity and species richness varied more in lawns across MSAs than in reference areas (Fig. 5). Lawns across MSAs differed significantly in both diversity ( $F_{[6,164]} = 13.95$ ,  $p < 0.0001$ ) and species richness ( $F_{[6,164]} = 20.6$ ,  $p < 0.0001$ ). There were no significant differences in diversity between reference areas in different MSAs ( $F_{[6,154]} = 1.84$ ,  $p = 0.1$ ), although richness did differ slightly ( $F_{[6,154]} = 6.11$ ,  $p < 0.0001$ ).

Although turfgrasses formed the dominant proportion of total cover in lawns in all MSAs (Fig. 1), they were only a small part of species richness. Lawns in each MSA had 1–5 turfgrass species compared with 1–25 non-turfgrass species. On average, lawns contained 1–3 turfgrass species and 4–15 non-turfgrass species. Trends in species richness and diversity did not change when turfgrasses were removed from consideration.

### 3.3. Climate and management effects

Some of the variation in lawn richness and diversity among MSAs was explained by differences in climate. Annual precipitation explained some differences in lawn species richness ( $r^2 = 0.38$ ) and diversity ( $r^2 = 0.21$ ), with higher plant species richness and diversity in wetter MSAs, while reference site diversity and richness remained relatively constant over the gradient (Fig. 5). Annual mean temperature did not explain differences in richness in lawns ( $p > 0.1$ ) and was a poor predictor of richness in reference areas ( $r^2 = 0.04$ ) and diversity in lawns ( $r^2 = 0.03$ ) or reference areas ( $r^2 = 0.02$ ).

Lawn species diversity did not differ with urban density ( $F_{[2,132]} = 1.79$ ,  $p = 0.2$ ; Fig. S2). Species richness and diversity decreased with increasing household income (richness  $F_{[5,107]} = 3.30$ ,  $p = 0.008$ ; diversity  $F_{[5,107]} = 2.79$ ,  $p = 0.02$ ; Fig. 6).

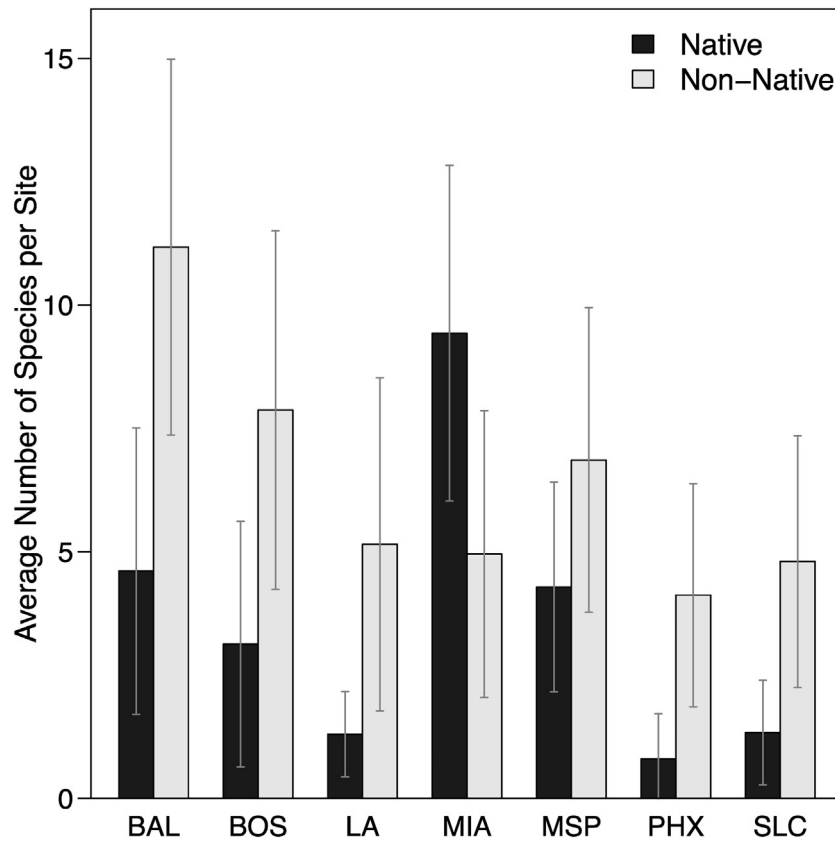


Fig. 3. Average number of native and non-native species per site in lawns of each Metropolitan Statistical Area. Species were considered native if they were native to the state in which they were observed. Error bars are standard deviation.

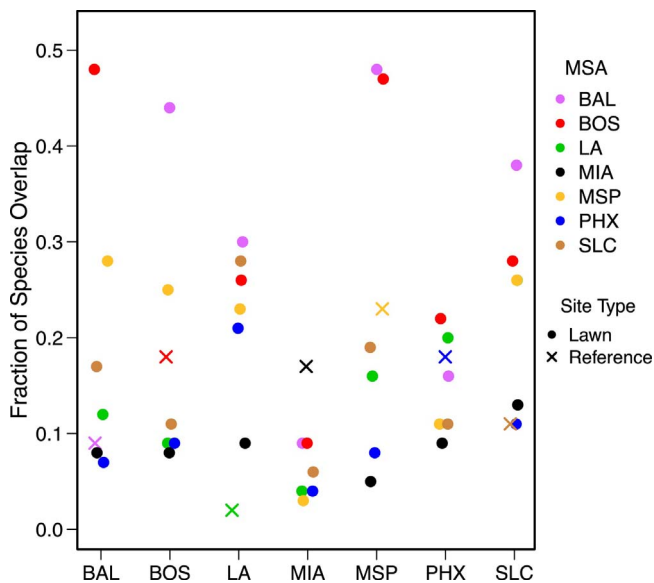


Fig. 4. Fraction of species shared among lawns and reference areas across seven Metropolitan Statistical Areas (MSAs). Points show the fraction of all species in lawns in that MSA that are shared with lawns in other MSAs, with species shared with the corresponding reference area shown for comparison.

The household surveys showed that all lawns in Phoenix and Los Angeles received supplemental water, as did most lawns in the other MSAs. Thirty eight percent of the 141 lawns for which survey data were available received fertilizer, pesticide and water, while 18% received fertilizer and water, 11% received pesticide and water, 2% received fertilizer and pesticide, 18% received only water, 4% only fertilizer, 2% only pesticide, and 7% had no additions. Lawn diversity was lower

(model  $r^2 = 0.14$ ) when fertilizer ( $p = 0.01$ ) and water ( $p = 0.0004$ ; Fig. 7) were applied.

The observed differences in species richness with climate and income were primarily related to differences in the number of native forbs. Native forb richness increased significantly with increasing precipitation ( $r^2 = 0.39$ ,  $p < 0.00001$ ; Fig. S3). Species richness of non-native forbs and native graminoids also increased, but native forbs increased the most rapidly (Fig. S3). Income was the only variable that explained more than 10% of the variance in native forbs ( $r^2 = 0.23$ ,  $p < 0.00001$ ). Shannon-Wiener diversity and lawn plant species richness were both best described by a linear combination of precipitation, temperature, fertilizer application and household income (diversity  $r^2 = 0.40$ , richness  $r^2 = 0.49$ ; Table 2). Fertilizer application and increasing temperature and income were associated with lower plant species richness and diversity, while increasing precipitation was associated with greater species richness and diversity.

#### 4. Discussion

##### 4.1. Homogenization of lawn flora

Lawns across the country had highly similar functional group and species composition. As expected, lawns across the U.S. were much more similar than were corresponding reference areas of unmanaged vegetation. This pattern supported the idea that by creating lawns in areas of residential land use across the U.S., humans have caused ecological homogenization at the continental scale (Groffman et al., 2014; McKinney, 2006) that creates and maintains similar ecosystems across a broad range of ecoregions.

More surprisingly, the similarity of the spontaneous vegetation in lawns across the country indicated that homogenization was related to factors beyond the similarity of human planting practices, as has been

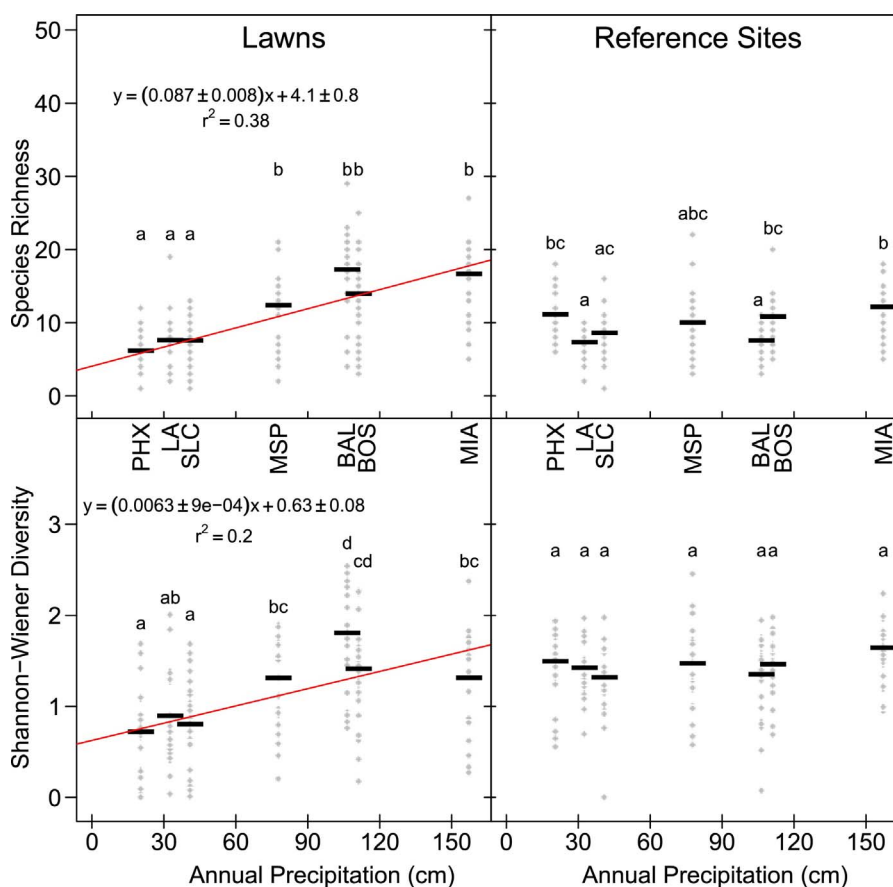


Fig. 5. Species richness and Shannon-Wiener diversity index in lawns and reference area vegetation in seven Metropolitan Statistical Areas (MSAs) plotted across a precipitation gradient. Points show richness and diversity values for each lawn and thick dashes show the average value for each MSA. MSAs that did not differ significantly (Tukey HSD,  $p > 0.05$ ) are marked with the same letter.

found for spontaneous communities around street trees (Wittig & Becker, 2010). Some of these species are common weeds present in turfgrass seed sources (Stewart et al., 2009) and may be maintained in the soil seed bank from past as well as current lawn cultivation. It is also likely that factors such as lawn maintenance (e.g., mowing), urban temperature, and disturbed soils create a distinct environment in which certain species are successful (Bertoncini et al., 2012).

Many of the common species found in lawns in this study were common to lawns beyond these seven MSAs. Lawns in Ohio also contained common turfgrass species such as *Poa pratensis* and *Schedonorus arundinaceus* (as *Festuca arundinacea*) as well as weed species such as *Taraxacum officinale* and *Trifolium repens* (Cheng, Richmond, Salminen, & Grewal, 2008). Thompson et al. (2004) found species including *Taraxacum* sp., *Festuca rubra*, *Lolium perenne*, and *Trifolium repens* with the highest cover in lawns in Sheffield, UK. *Lolium perenne* and *Trifolium repens* were found in more than half of surveyed lawns in Paris, France (Bertoncini et al., 2012) and more than 80% of lawns in Christchurch, New Zealand (Stewart et al., 2009). These similarities indicate that lawn species homogenization may extend more broadly within the U.S. as well as beyond North America.

Lawn species composition was more similar among lawns in different MSAs when only spontaneous species were considered than when all species were considered. This result indicated that lawns in different MSAs commonly contained different turfgrasses, but supported a more similar mix of spontaneous species. One explanation for this difference may be that there is regional variation in recommendations provided by home improvement stores, lawn care professionals, and turfgrass extension programs for what species of turfgrass to plant. In addition, turfgrass species originally planted by housing

developers may vary regionally.

One positive aspect of the homogeneity of the spontaneous lawn flora is the abundance and ubiquity of the flowering forbs *T. officinale*, *T. repens*, and *Oxalis stricta*, which may act as floral resources for urban pollinator populations (Larson et al., 2014; Lerman & Milam, 2016). The presence of these species in the majority of lawns surveyed indicates that this may be a prominent service provided by lawns as a whole, and therefore the use of lawn floral resources by urban pollinator communities warrants further study.

#### 4.2. Drivers of lawn diversity and composition

Plant species richness and diversity in lawns were more strongly associated with annual precipitation than with mean annual temperature. However, lawns in warm and cool MSAs grouped separately when species composition was considered. This indicated that temperature was correlated with species composition but not overall diversity. The reduction in diversity at the drier end of the continental precipitation gradient was largely caused by the presence of fewer native forbs. Native forbs in drier areas may be unsuited to the supplemental irrigation applied to all lawns in Los Angeles and Phoenix. In wetter climates, native forbs adapted to local conditions may be better suited to, and more able to invade, lawn environments. Alternatively, differences in management (e.g., increased herbicide use) could be responsible for reductions in lawn native forb diversity in drier MSAs. Common forb species found in most lawns are likely adapted to the lawn environment rather than local climates, so may be able to persist in lawns across the precipitation gradient. Thompson et al. (2004) also found local climate to be a primary determinate of lawn species composition along an altitude gradient in Sheffield, UK.

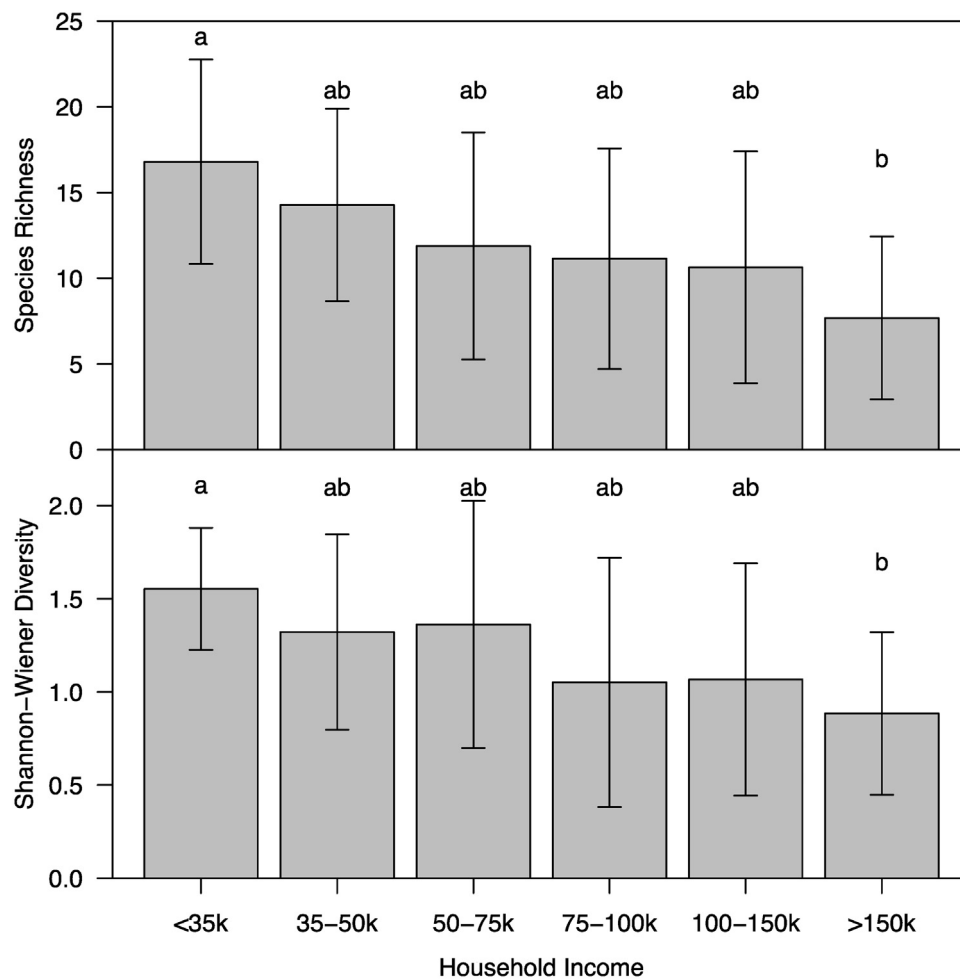


Fig. 6. Species richness and Shannon-Wiener diversity index in lawns of households with different annual income levels. Bars show mean values for six Metropolitan Statistical Areas (BOS, BAL, LA, MIA, MSP, PHX). Error is standard deviation. Income categories are less than \$35,000 ( $n = 10$ ), \$35,000–\$50,000 ( $n = 11$ ), \$50,000–\$75,000 ( $n = 26$ ), \$75,000–\$100,000 ( $n = 22$ ), \$100,000–\$150,000 ( $n = 25$ ), and more than \$150,000 ( $n = 19$ ). Significant differences (Tukey HSD,  $p < 0.05$ ) are marked with different letters.

Overall species diversity across lawns in all MSAs was lower than diversity across all reference areas. Similar to a previous study that compared household yard diversity to reference areas in Minneapolis-St. Paul, MN (Knapp et al., 2012), individual lawn diversity was lower than diversity in the associated reference areas in most MSAs, and species in the lawns and those in the reference vegetation overlapped little. This result indicated that lawns as a whole had limited ability to act as species reservoirs or corridors for native species (Dearborn & Kark, 2010). Miami, the only subtropical and peninsular location, was an exception to this general pattern. The dominant turfgrass in Miami, *Stenotaphrum secundatum*, was a native tropical species and differed from the dominant turfgrasses in any other MSA. Miami lawns also contained far more non-turfgrass native species than lawns in any other MSA. Tropical and subtropical lawns generally may be more hospitable to native species, and therefore may be more important as urban reservoirs of native species than lawns in temperate cities (Cook, Hall, & Larson, 2012; Stewart et al., 2009).

The lawns sampled in this study were only a single component of the assemblages of plant species that occurred in urban, suburban, and exurban residential yards. Other cover types that include gardens, plantings, and patches of more natural vegetation were common as well. We found that while overall species diversity was lower in lawns than in reference areas, forb and graminoid diversity was higher. It is likely that if entire yards were considered together with lawns, continental-scale plant species diversity of residential parcels would be higher than in reference areas (Cook et al., 2012; McKinney, 2008; Smith et al., 2006).

Species diversity was lower in lawns with higher household income and in fertilized lawns. Other studies have shown higher fertilization rates in higher income households (Fraser, Bazuin, Band, & Grove, 2013; Zhou et al., 2009), but we did not find this correlation to be significant. Fertilization may reduce diversity by favoring the growth of a small number of species, and it is also possible that there was high covariation between application of fertilizer and herbicides, the use of which was not included in our survey. The association of decreasing lawn species diversity with increasing income was opposite the effect observed in studies focused on urban gardens as a whole (Hope et al., 2003). This trend appeared to indicate a preference among residential homeowners for diverse gardens but more uniform and weed-free lawns (Larson & Brumand, 2014; Larson et al., 2016), which may be more effectively achieved when household income is higher. Questions about mowing regimes were not included in the resident surveys in this study, so the possible effects of mowing on lawn diversity and species composition cannot be excluded. While many differences in diversity can be explained by the variables considered here, additional consideration of lawn mowing may provide further insight. However, prior studies have shown little effect of mowing on lawn species composition (Thompson et al., 2004).

We did not find that residential density was significantly related to lawn diversity, contrary to findings by others that distance from the city center and position along urban-rural gradients were significant predictors of diversity (Bertoncini et al., 2012; McKinney, 2002; Pickett et al., 2011). However, we did not consider either highly urban residences (that were not single-family homes) or very rural residences



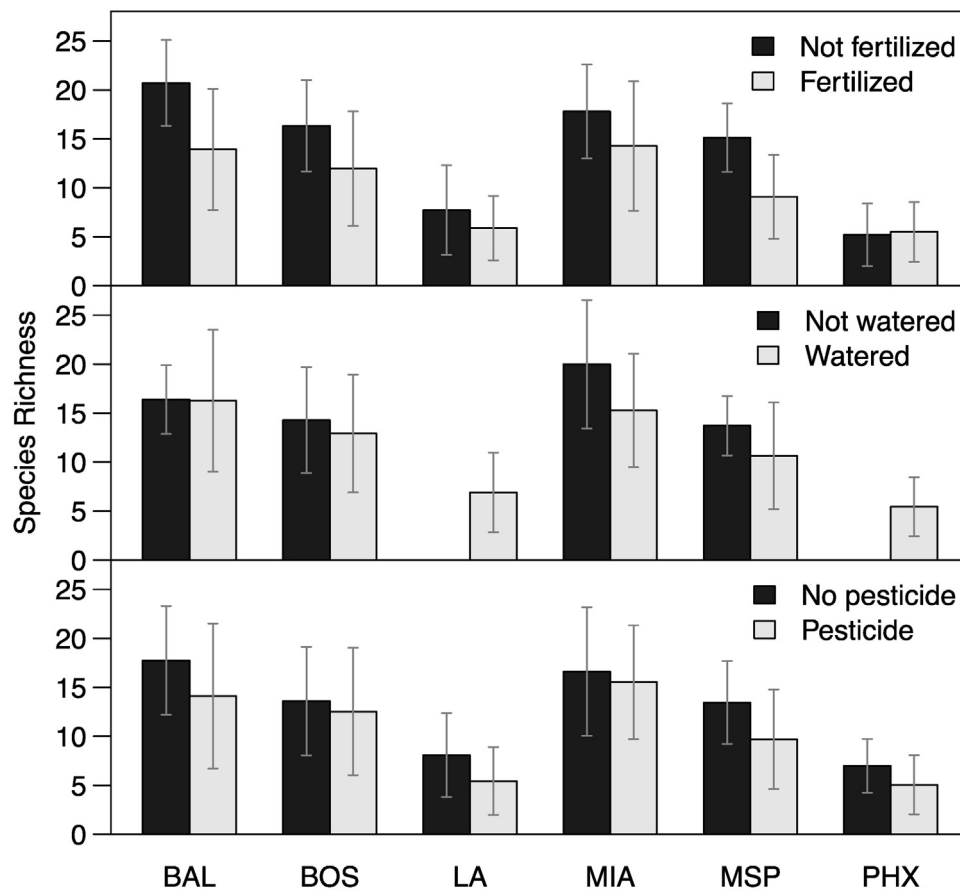


Fig. 7. Species richness in lawns receiving or not receiving fertilizer, water or pesticide in each MSA. Error is standard deviation.

Table 2

Linear models of Shannon-Wiener diversity and species richness with climate, management and income as independent variables.

	Coefficient	Std Error	p-value
Model: Shannon-Wiener Diversity = Precipitation + Temperature + Fertilizer + Household Income			
Intercept	1.8	0.2	< 0.00001
Precipitation (cm)	0.004	0.001	0.00004
Temperature (°C)	-0.033	0.007	0.00002
Fertilizer Applied	-0.3	0.1	0.004
Household Income	-0.000003	0.000001	0.003
Adjusted R <sup>2</sup>	0.40		
Model: Species Richness = Precipitation + Temperature + Fertilizer + Household Income			
Intercept	13	2	< 0.00001
Precipitation (cm)	0.07	0.01	< 0.00001
Temperature (°C)	-0.19	0.07	0.009
Fertilizer Applied	-3	1	0.001
Household Income	-0.00003	0.00001	0.004
Adjusted R <sup>2</sup>	0.49		

that were outside MSAs. A larger range of housing density and land uses may have captured a greater influence of urban density on lawn diversity.

Lawns have been shown to provide a variety of services such as heat reduction and stormwater management in residential yards (Beard & Green, 1994; Mueller & Thompson, 2009), and our results support the potential ability of lawns to sustain urban pollinators (Larson et al., 2014; Lerman & Milam, 2016). However, because of consistent and very low levels of species overlap in lawns and reference areas and the high proportion of non-native species in lawns in most places in the U.S., we found that the role of lawns as reservoirs of native

species is low. Plant diversity in lawns could be increased by reduction or elimination of lawn fertilizer application, but these changes are unlikely to significantly increase the connection between lawns and the regional flora. Rather, increased regional species presence in lawns would require a more dramatic rethinking of lawn design in U.S. residential landscapes.

## 5. Conclusions

This study showed that human actions in residential lawns created a continental-scale lawn flora that was much more similar than the regional understory flora of minimally-managed reference areas. This national lawn flora was far more diverse than the idealized monoculture and contained nearly as many species as reference area understories across the U.S. However, most species represented were non-native and not place-specific, limiting the ability of lawns to act as species reservoirs. These results show that while lawns contain a wider-than-expected array of species, these species largely belonged to a continental-scale homogenized lawn community that was shaped by both climatic factors and lawn management.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.landurbplan.2017.05.004>.

## References

- Beard, J. B., & Green, R. L. (1994). The role of turfgrasses in environmental protection and their benefits to humans. *Journal of Environmental Quality*, 23(3), 452–460.
- Bertoncini, A. P., Machon, N., Pavoine, S., & Muratet, A. (2012). Local gardening practices shape urban lawn floristic communities. *Landscape and Urban Planning*, 105, 53–61. <http://dx.doi.org/10.1016/j.landurbplan.2011.11.017>.
- CLARITAS (2013). CLARITAS PRIZM Market Segmentation. Retrieved April 24, 2015 from: <http://www.claritas.com/MyBestSegments/Default.jsp>.
- Cheng, Z., Richmond, D. S., Salminen, S. O., & Grewal, P. S. (2008). Ecology of urban lawns under three common management programs. *Urban Ecosystems*, 11, 177–195. <http://dx.doi.org/10.1007/s11252-008-0048-9>.
- Cook, E. M., Hall, S. J., & Larson, K. L. (2012). Residential landscapes as social-ecological systems: A synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosystems*, 15, 19–52. <http://dx.doi.org/10.1007/s11252-011-0197-0>.
- Dearborn, D. C., & Kark, S. (2010). Motivations for conserving urban biodiversity. *Conservation Biology*, 24, 432–440. <http://dx.doi.org/10.1111/j.1523-1739.2009.01328.x>.
- Del Tedici, P. (2010). Spontaneous urban vegetation: Reflections of change in a globalized world. *Nature and Culture*, 5(3), 299–315. <http://dx.doi.org/10.3167/nc.2010.050305>.
- Fraser, J. C., Bazuin, J. T., Band, L. E., & Grove, J. M. (2013). Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization. *Landscape and Urban Planning*, 115, 30–38. <http://dx.doi.org/10.1016/j.landurbplan.2013.02.013>.
- Groffman, P. M., Cavender-Bares, J., Bettez, N. D., Grove, J. M., Hall, S. J., Heffernan, J. B., et al. (2014). Ecological homogenization of urban USA. *Frontiers in Ecology and the Environment*, 12, 74–81. <http://dx.doi.org/10.1890/120374>.
- Groffman, P. M., Grove, J. M., Polsky, C., Bettez, N. D., Morse, J. L., Cavender-Bares, J., et al. (2016). Satisfaction, water and fertilizer use in the American residential macrosystem. *Environmental Research Letters*, 11(3), <http://dx.doi.org/10.1088/1748-9326/11/3/034004>.
- Hall, S. J., Learned, J., Rudell, B., Larson, K., Cavender-Bares, J. J., Bettez, N., et al. (2016). Convergence of microclimate in residential landscapes across diverse cities in the United States. *Landscape Ecology*, 31, 101–117. <http://dx.doi.org/10.1007/s10980-015-0297-y>.
- Harivandi, M. A., Gibeault, V. A., Henry, M. J., Wu, L., Geisel, P. M., & Unruh, C. L. (2001). *Turfgrass selection for the home landscape, vol. 8035*. University of California Agriculture and Natural Resources Publication.
- Hope, D., Gries, C., Zhu, W., Fagan, W. F., Redman, C. L., Grimm, N. B., et al. (2003). Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Sciences*, 100(15), 339–347. [http://dx.doi.org/10.1007/978-0-387-73412-5\\_21](http://dx.doi.org/10.1007/978-0-387-73412-5_21).
- Jenerette, G. D., Harlan, S. L., Stefanov, W. L., & Martin, C. A. (2011). Ecosystem services and urban heat riskscape moderation: Water, green spaces, and social inequality in Phoenix, USA. *Ecological Applications*, 21, 2637–2651. <http://dx.doi.org/10.1890/101493.1>.
- Kühn, I., & Klotz, S. (2006). Urbanization and homogenization – Comparing the floras of urban and rural areas in Germany. *Biological Conservation*, 127, 292–300. <http://dx.doi.org/10.1016/j.biocon.2005.06.033>.
- Kinzig, A. P., Warren, P., Martin, C., Hope, D., & Katti, M. (2005). The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*, 10(1), 23–36.
- Knapp, S., Dinsmore, L., Fissore, C., Hobbie, S., Jakobsdottir, I., Kattge, J., et al. (2012). Phylogenetic and functional characteristics of household yard floras and their changes along an urbanization gradient. *Ecology*, 93(8), 83–98. <http://dx.doi.org/10.1890/11-0392.1>.
- Larson, K. L., & Brumand, J. (2014). Paradoxes in landscape management and water conservation: Examining neighborhood norms and institutional forces. *Cities and the Environment (CATE)*, 7(1).
- Larson, J. L., Kesheimer, A. J., & Potter, D. A. (2014). Pollinator assemblages on dandelions and white clover in urban and suburban lawns. *Journal of Insect Conservation*, 18(5), 863–873. <http://dx.doi.org/10.1007/s10841-014-9694-9>.
- Larson, K. L., Nelson, K. C., Samples, S. R., Hall, S. J., Bettez, N., Cavender-Bares, J., et al. (2016). Ecosystem services in managing residential landscapes: Priorities, value dimensions, and cross-regional patterns. *Urban Ecosystems*, 19(1), 95–113. <http://dx.doi.org/10.1007/s11252-015-0477-1>.
- Lerman, S. B., & Milam, J. (2016). Bee fauna and floral abundance within lawn-dominated suburban yards in Springfield, MA. *Annals of the Entomological Society of America*, 109, 713–723. <http://dx.doi.org/10.1093/aesa/saw043>.
- Locke, D. H. (2017). *A new look at residential ecosystems management: Heterogeneous practices and the landscape mullets concept*. Worcester, Massachusetts: Clark University [178 pp (PhD dissertation)].
- Lowe's. (n.d.). Choose the right grass for your lawn. Retrieved April 1, 2015 from: <http://www.lowes.com/projects/lawn-and-garden/choose-the-right-grass-for-your-lawn/article>.
- Martin, C. A., Warren, P. S., & Kinzig, A. P. (2004). Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning*, 69, 355–368. <http://dx.doi.org/10.1016/j.landurbplan.2003.10.034>.
- Martini, N. F., Nelson, K. C., Hobbie, S. E., & Baker, L. A. (2015). Why Feed the Lawn? Exploring the influences on residential turf grass fertilization in the Minneapolis-Saint Paul metropolitan area. *Environment and Behavior*, 47(2), 158–183. <http://dx.doi.org/10.1177/0013916513492418>.
- McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *Bioscience*, 52(10), 883–890. [http://dx.doi.org/10.1641/0006-3568\(2002\)052\[0883:UBAC\]2.0.CO;2](http://dx.doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2).
- McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*, 127, 247–260. <http://dx.doi.org/10.1016/j.biocon.2005.09.005>.
- McKinney, M. L. (2008). Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*, 11, 161–176. <http://dx.doi.org/10.1007/s11252-007-0045-4>.
- Meléndez-Ackerman, E. J., Santiago-Bartolomei, R., Vila-Ruiz, C. P., Santiago, L. E., García-Montiel, D., Verdejo-Ortiz, J. C., et al. (2014). Socioeconomic drivers of yard sustainable practices in a tropical city. *Ecology and Society*, 19(3), 20–32. <http://dx.doi.org/10.5751/ES-06563-190320>.
- Milesi, C., Running, S. W., Elvidge, C. D., Dietz, J. B., Tuttle, B. T., & Nemani, R. R. (2005). Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environmental Management*, 36(3), 426–438. <http://dx.doi.org/10.1007/s00267-004-0316-2>.
- Mueller, G. D., & Thompson, A. M. (2009). The ability of urban residential lawns to disconnect impervious area from municipal sewer systems. *Journal of the American Water Resources Association*, 45(5), 1116–1126. <http://dx.doi.org/10.1111/j.1752-1688.2009.00347.x>.
- NOAA. (n.d.). Data tools: 1981–2010 normals. Retrieved February 19, 2015 from: <http://www.ncdc.noaa.gov/cdo-web/datatools/normals>.
- Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., et al. (2015). *Vegan: Community ecology package*. R package version 2.2-1 <http://CRAN.R-project.org/package=vegan>.
- Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E., et al. (2011). Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management*, 92(3), 331–362. <http://dx.doi.org/10.1016/j.jenvman.2010.08.022>.
- Polsky, C., Grove, J. M., Knudson, C., Groffman, P. M., Bettez, N., Cavender-Bares, J., et al. (2014). Assessing the homogenization of urban land management with an application to US residential lawn care. *PNAS*, 111(12), 4432–4437. <http://dx.doi.org/10.1073/pnas.1323995111>.
- R Core Team (2014). *R: A language and environment for statistical computing*. Vienna, Austria: Version 3.1.2. R Foundation for Statistical Computing. URL <http://www.R-project.org/>.
- Robbins, P., & Birkenholtz, T. (2003). Turfgrass revolution: Measuring the expansion of the American lawn. *Land Use Policy*, 20, 181–194. [http://dx.doi.org/10.1016/S0264-8377\(03\)00006-1](http://dx.doi.org/10.1016/S0264-8377(03)00006-1).
- Schwartz, M. W., Thorne, J. H., & Viers, J. H. (2006). Biotic homogenization of the California flora in urban and urbanizing regions. *Biological Conservation*, 127, 282–291. <http://dx.doi.org/10.1016/j.biocon.2005.05.017>.
- Scotts Lawn Service. (n.d.). Types of turfgrasses for lawns and landscaping. Retrieved April 1, 2015 from: <https://www.scottslawnservice.com/sls/templates/index.jsp?pageUrl=slsturfgrassbasics>.
- Smith, R. M., Thompson, K., Hodgson, J. G., Warren, P. H., & Gaston, K. J. (2006). Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity. *Biological Conservation*, 129, 312–322. <http://dx.doi.org/10.1016/j.biocon.2005.10.045>.
- Stewart, G. H., Ignatieva, M. E., Meurk, C. D., Buckley, H., Horne, B., & Braddick, T. (2009). Urban biotopes of aotearoa New Zealand (URBANZ) (I): Composition and diversity of temperate urban lawns in Christchurch. *Urban Ecosystems*, 12, 233–248. <http://dx.doi.org/10.1007/s11252-009-0098-7>.
- Thompson, K., Hodgson, J. G., Smith, R. M., Warren, P. H., & Gaston, K. J. (2004). Urban domestic gardens (III): Composition and diversity of lawn floras. *Journal of Vegetation Science*, 15(3), 373–378.
- USDA NRCS. (2015). The PLANTS Database. National Plant Data Team, Greensboro, NC USA. Retrieved April 27, 2015 from: <http://plants.usda.gov>.
- Wittig, R., & Becker, U. (2010). The spontaneous flora around street trees in cities – A striking example for the worldwide homogenization of the flora of urban habitats. *Flora*, 205, 704–709. <http://dx.doi.org/10.1016/j.flora.2009.09.001>.
- Yue, C., & Behe, B. K. (2008). Estimating U.S. consumers' choice of floral retail outlets. *HortScience*, 43(3), 764–769.
- Zhou, W., Troy, A., Grove, J. M., & Jenkins, J. C. (2009). Can money buy green? Demographic and socioeconomic predictors of lawn-care expenditures and lawn greenness in urban residential areas. *Society and Natural Resources*, 22, 744–760. <http://dx.doi.org/10.1080/08941920802074330>.