

Research paper

When the economic engine stalls – A multi-scale comparison of vegetation dynamics in pre- and post-recession Phoenix, Arizona, USA



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HIGHLIGHTS

- We examined plant community change through a decade of boom-bust economics.
- We found plant species diversity increased for all land uses at multiple scales.
- And homogenization of species composition occurred on urban and agricultural sites.
- Planners should consider socioeconomic trends since ecological change may result.

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ABSTRACT

Often, we think of cities as designed landscapes, where people manage everything from water to weeds. But we do not fully understand what happens to these extensively managed landscapes when there is an abrupt disruption in economic activity. Considering the ability of cities to support plant biodiversity and their importance as human habitat, we studied pre- and post-recession landscapes across a gradient of human influence by asking: How did vegetation change over time from before the housing bubble to after the nadir of the Great Recession? And how did vegetation vary across sites at regional versus residential scales? This investigation used long-term vegetation data to examine diversity trends and responses to a novel economic disturbance in an urban social-ecological system. Overall, we found that plant species diversity increased through time across scales, while species composition homogenized in urban and agricultural areas. Residential yards, however, initially had high compositional heterogeneity which then increased over time. Changes in residential diversity were driven by substantial increases in the role of annual plants. This research improves our understanding of spatiotemporal vegetation dynamics in a coupled human-natural system, and specifically how urban vegetation dynamics are linked to anthropogenic influence. Ultimately, we recommend that city planners and managers consider economic trends when approaching community projects because of the interconnectedness of ecology and socioeconomics in urban landscapes.

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1. Introduction

Vegetation has long been recognized as a primary contributor to ecosystem functioning and stability (Cardinale et al., 2011; de Mazancourt et al., 2013; Grime, 1998) as well as to human health and well-being (Bolund & Hunhammar, 1999; Harlan, Brazel,

Prashad, Stefanov, & Larsen, 2006). While the majority of studies examining vegetation composition and dynamics have been in natural systems, a growing number are now aimed at understanding these same phenomena in social-ecological systems (SESS) including urban ecosystems (Johnson, Tauzer, & Swan, 2015; Kremer, Hamstead, & McPhearson, 2013). Previous studies have shown linkages between vegetation diversity and socioeconomics in urban areas, and the phrase “luxury effect” was coined to encapsulate the idea that higher socioeconomic status corresponds to the higher observed plant diversity in wealthier residential areas (Hope et al., 2003). In Phoenix, Arizona, USA, neighborhood socioeconomic

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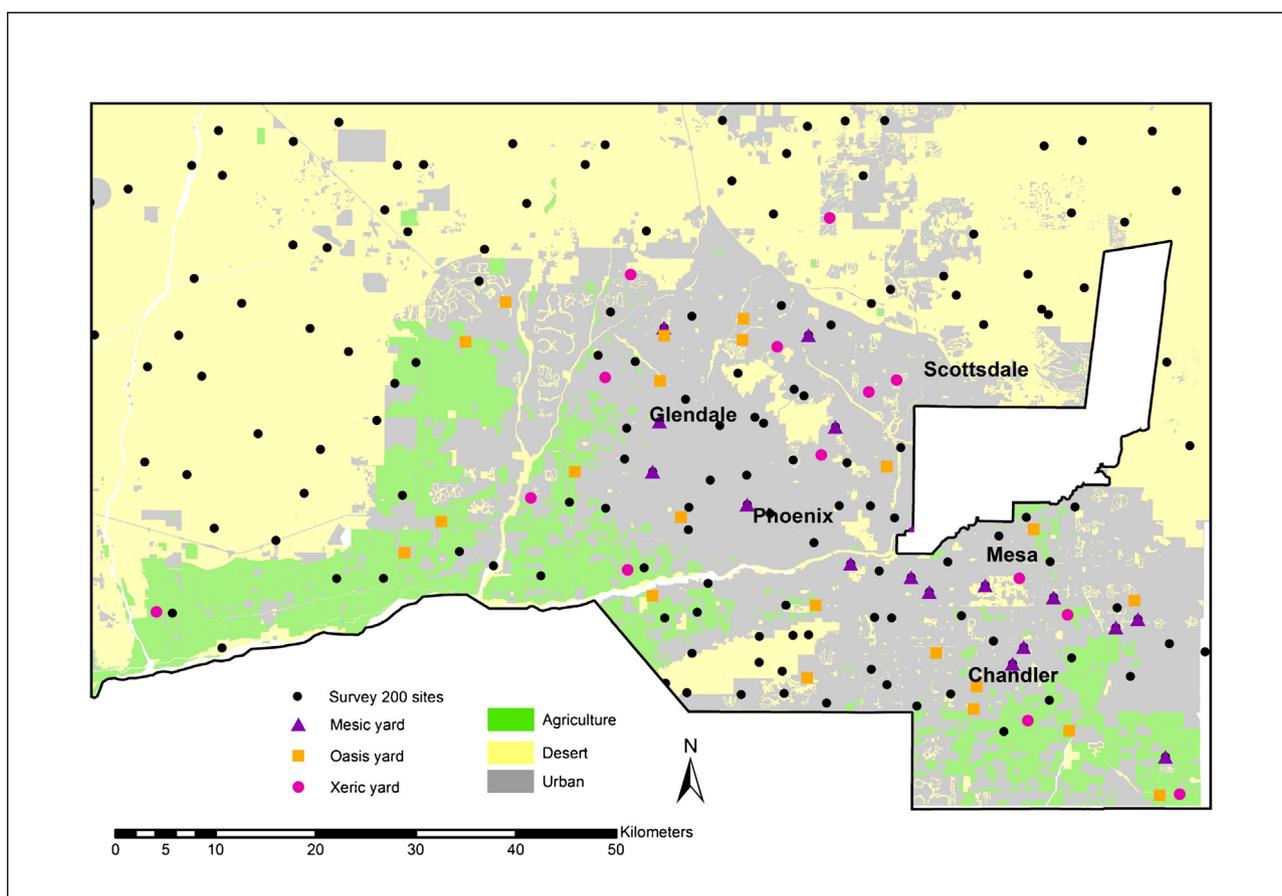


Fig. 1. Map representing the spatial distribution of Survey 200 sites in Phoenix Metro and surrounding area (N = 204). Colored points indicate residential sites surveyed in 2010 by landscaping type.

status predicts perennial diversity (Martin, Warren, & Kinzig, 2004) and spatially structures plant and bird diversity (Kinzig, Warren, Martin, Hope, & Katti, 2005).

In natural systems, drought or insect outbreaks are examples of exogenous disturbances that structure plant communities (Pickett & White, 1985). Non-urban SESs including forests, rangelands, and fisheries are increasingly stressed by global changes (Foley et al., 2005; Vitousek, Mooney, Lubchenco, & Melillo, 1997). Urban SESs are not exempt from comparable disturbances. In urban SESs, like the Phoenix metropolitan area (hereafter Metro Phoenix), natural disturbances are often mitigated by human actions such as supplemental watering and the use of pesticides. This results in highly managed and relatively stable urban landscapes (Knapp et al., 2012). Management itself, however, can be considered to be a form of disturbance (Ripplinger, Franklin, & Edwards, 2015), and management decisions are often influenced by socioeconomic drivers. For example, the recent housing recession that began in 2006 – sometimes termed The Great Recession – impacted the burgeoning Metro Phoenix area leading to high rates of foreclosure and unemployment. Viewed through the lens of the press-pulse disturbance (PPD) framework (Collins et al., 2011), management and design activities in cities act as press-disturbances that provide sustained controls on diversity and composition of urban plant communities, while a sudden, unexpected shock like the Great Recession acts as a socioeconomic pulse-disturbance that can potentially affect urban vegetation from local to regional scales.

Urban ecological homogenization occurs when urban landscapes – even those designed to have different functions or satisfy different landscaping preferences – look more like each other than they do the surrounding natural landscapes (McKinney, 2006;

Trentanovi et al., 2013). Under urban ecological homogenization (Knapp et al., 2012), natural vegetation assemblages are replaced by designed vegetation assemblages and urban ground cover like lawns or other types of gravel/bark cover (Cadenasso, Pickett, & Schwarz, 2007; Walker, Grimm, Briggs, Gries, & Dugan, 2009). The homogenization of urban biota has been attributed to transported landscapes (Anderson, 1952), the commercial nursery trade, real estate developer decisions, homeowner values and desires, and government and non-government regulations. National home improvement retailers contribute to homogenization by making available a globally derived, standardized stock of nursery plants, selected for gardening hardiness zones and homeowner appeal. Introduced ornamental species increase the occurrence of non-native and invasive species in cities (Reichard & White, 2001) and in-turn affect urban biodiversity and vegetation homogeneity. By designing ‘dreamscapes’ and establishing the initial conditions for housing developments (Larsen & Harlan, 2006), developers initially determine the underlying style and structure of residential landscapes. Homeowner’s associations (HOAs), increasingly common in rapidly developing regions, often have landscaping requirements that may be legally enforced, sometimes resulting in fines and in extreme cases even foreclosure (Lerman, Turner, & Bang, 2012; McKenzie, 1994). HOA regulations affect both landscaping form and function, as well as the plant species used. These homogenizing processes are driven by human decisions, including top-down HOA regulations and bottom-up homeowner decisions (Walker et al., 2009).

Phoenix, Arizona was historically viewed as a verdant refuge from the Sonoran Desert, with its green lawns and shade trees, and flood-irrigated cotton fields and citrus orchards that still sur-

round the Metro Phoenix core (Fig. 1). Well-watered landscapes were seen as a necessity until the advent of affordable air conditioning in the 1970s. Since then, landscape designs have become more popular that include desert-adapted plants and emphasize water-conservation over cooling of the urban environment via evapotranspiration (Larson, Casagrande, Harlan, & Yabiku, 2009; Martin, Peterson, & Stabler, 2003). Nowhere are these mesic vs. xeric landscaping motifs as apparent as they are in residential yards, where landscaping designs either mimic the desert landscape, take after lush lawns of wetter climates, or blend the two motifs (Martin et al., 2003).

Plant functional groups can be defined as groups of species with similar capacities to respond to environmental pressure and disturbance (Walker et al., 1999). Annual plant species are one such group, characterized by rapid germination, short lifespans, and adaptation to unpredictable rainfall (Gurevitch, Scheiner, & Fox, 2002). Non-native plant species are another such group that has proliferated with increasing urbanization (Kowarik, 1995; Ricotta, Godefroid, & Rocchini, 2010). Non-natives have a strong influence on biodiversity of urban floras (Lososova et al., 2012). These two functional groups deserve special consideration since annual species have adaptations allowing them to exhibit rapid responses to change in environmental pressures, while non-native plant species have been linked with loss of diversity and biotic homogenization (McKinney 2006; Winter et al., 2009).

The Great Recession dealt a particularly severe blow to the Metro Phoenix housing market, leading to a contraction in development, higher rates of unemployment, and ultimately, a collapse of the real estate market. In 2010 alone, there were 2.9 million foreclosure filings nationwide, roughly 6% of which were Arizona properties (analytics from realtytrac.com). For the regional scale, we expected that urban vegetation would undergo the greatest change and become more homogeneous due to the collapse of the housing market, as compared to agricultural and desert areas which we expected to be unaffected by the housing market. This hypothesis is supported by an understanding that human structuring of ecosystems is greater in urban areas than in desert or even agricultural systems.

Residential neighborhoods are one of several types of urban landscapes nested within an urban system. Of the different types of urban land uses, residential households are among the most intensively managed, and linkages between socioeconomic status and urban vegetation are well supported (Grove et al., 2006; Hope et al., 2003; Larson et al., 2009). For the residential level, we expected that three common residential landscaping types – mesic, xeric, and oasis, a hybrid of the other two – would be characterized by different species and diverge from one another over time. In particular, xeric yards should be more resilient to the lack of watering and other yard maintenance than water-intensive mesic and oasis yards, and accordingly should change less following the Great Recession. Finally, we expected increased plant biodiversity and homogenization in residential areas, due to expansion in spontaneous annuals and non-native plants as a result of abandonment and neglect of residential yards due to the Great Recession.

By using a core dataset from the Central Arizona-Phoenix Long-Term Ecological Research project (CAP LTER), we examined and compared how designed urban landscapes and their surrounding desert and agricultural counterparts varied in diversity and community composition, recognizing that they are influenced by anthropogenic and biophysical factors to different degrees and at different scales. Specifically, we addressed the following questions:

(1) In what ways did vegetation change over time, from before the housing bubble to after the Great Recession? At regional vs. residential scales?

- (2) Do urban plant communities become more homogeneous following socioeconomic disturbance? How do trends compare across scales?
- (3) What are the similarities and differences among plant communities at three regional land use types (i.e. Agricultural, Desert, and Urban); similarly, how did plant communities vary among three residential land use types (i.e. Mesic, Oasis, Xeric)?

2. Methods

2.1. Study area and sampling design

Metro Phoenix is home to nearly five million people and until 2008 was among the fastest growing metropolitan areas in the U.S. (US Census Bureau, 2000). The CAP LTER research program focuses on a region of 6400 km² in central Arizona that encompasses the entire Phoenix metropolitan area, as well as adjacent agricultural land and native Sonoran Desert landscapes (Grimm, Grove, Pickett, & Redman, 2000). Mean annual precipitation for the region is typically 20.2 cm; mean annual maximum temperature is 29.8 °C and mean annual minimum temperature is 12.3 °C (wrcc.dri.edu/summary/climsmphx.html). Mean winter precipitation for the region is typically 61 mm, although highly variable, and in the years of this study winter precipitation was 57 mm and 55 mm for 2000 and 2010 respectively (ag.arizona.edu/azmet/az-data.htm).

As part of the CAP LTER program, a regional survey of plant communities is conducted during late spring every five years at 204 sites (Grimm, Hope, Gries, & Martin, 2010). These “Survey 200” plot locations were selected using stratified random sampling in order to capture a gradient of human influence across Urban, Agriculture, and Desert land uses across the Metro Phoenix area (Fig. 1). To do so, one 30 × 30-m plot was randomly placed within each 4 × 4-km tessellation-grid square in the urban area and one survey point within one of three of these squares in the desert surrounding the urban area. Vegetation species composition and abundance data were collected for each 30 × 30-m plot during each survey (see Hope et al., 2003 for full description). We standardized all vegetation records using the Taxonomic Name Resolution Service (TNRS; Boyle et al., 2013), then analyzed abundance data for herbaceous, succulent, and woody plants using survey data from 2000 and 2010, bracketing the Great Recession.

Urban landscapes are predominantly planned landscapes, but design and management happen at different levels. Top-down controls include zoning, city planning, and homeowner association covenants, conditions, and restrictions. Bottom-up drivers include individual landscaping decisions, and socioeconomic status (Walker et al., 2009). There is no single appropriate scale for this type of analysis, so we focused our analyses at two spatial scales: (1) at the regional level where policy-makers manage resources for the general public, and (2) at the residential level where landscaping is managed on individual properties. At the regional level urban planning and design interacts with biophysical processes and urban governance. At the residential level householders make decisions about landscaping choices based on personal preferences and socioeconomics.

Broad regional land use categories were the basis of stratified sampling and were used to describe each Survey 200 site (i.e. Desert, Agricultural, Urban) (Hope et al., 2003). Then, finer-scale within-urban residential categories were designated by CAP LTER scientists to describe household-level landscaping (i.e. Mesic, Oasis, Xeric). At the regional level, Desert sites included intact Sonoran Desert as well as mountain park preserves within the urban matrix. Agricultural plots consisted of both subsistence and cash crops, including cotton, alfalfa, citrus, and cattle. Urban sites included the following land uses: commercial/industrial, transportation, city

parks, and residential. At the residential level, Mesic ground cover primarily consists of lawn and lacks gravel swaths. Mesic yards often have broadleaf trees and shrubs and are characterized by low water use efficiency. Xeric plots are usually covered in gravel or another form of mulch and lack lawns (turf grass). Xeric yards are often drip-irrigated and have desert-adapted, low water-use vegetation. Oasis plots are a mixture of the Mesic and Xeric landscaping motifs (Martin et al., 2003).

2.2. Data analysis

2.2.1. Measuring diversity with richness, indicator species

In order to examine diversity changes from 2000 and 2010 at both regional and residential land use levels, we computed plant species richness of each of the 204 survey sites in each time period, then calculated the mean and standard error of species richness for sites within each land use. To determine which species dominated different land use types, we used species importance values. Importance Values (IVs) were calculated as average abundance of each species in each land use type (Aho, Roberts, & Weaver, 2008). We then computed a Bray-Curtis distance matrix of all pairs of sites for both survey years, which was then used to quantify vegetation homogeneity (similarity) and for multivariate analysis of site composition and change.

2.2.2. Calculating dominance of annuals and non-natives

Short-lived annual species have adapted to respond to resource pulses, such as increases in resources and decreases in competitors, and they typically exhibit traits for rapid and widespread seed dispersal (Gurevitch et al., 2002). Annual plants are not often used for landscaping in Phoenix and therefore annuals in the urban area represent opportunistic “weedy” pioneers that might typically be managed against in a well-maintained yard. Also, non-native plant species represent a functional group of interest because of the central role they are known to play in urban floras (Kowarik, 1995). To determine the dominance of high-turnover annual species and non-native species, we summed the number of annuals and non-natives per land use, then calculated their dominance as percentage of the total species pool per land use type. Percentages were calculated for 2000 and 2010 separately.

2.2.3. Vegetation composition using non-metric multidimensional scaling

We determined how community composition varied among study sites for the two survey periods by using non-metric multidimensional scaling (NMDS). NMDS, an unconstrained ordination method, is a multivariate analysis based on species abundance data associated with survey sites, indirectly reflecting environmental processes that structure vegetation communities (Causton, 1988). Species abundance values were not transformed for the NMDS analysis. We used the Bray-Curtis dissimilarity metric and 999 permutations. Analyses were performed with default options for the metaMDS function in the ‘vegan’ package in R (Oksanen et al., 2011). Permutational multivariate analysis of variance (PERMANOVA) calculates the significance of the resulting ordination models (Anderson, 2001). We used PERMANOVA to test for significant differences in species composition among residential land use types as well as changes in vegetation between 2000 and 2010 within land use types. We used the Adonis function in the R package ‘vegan’ for PERMANOVA calculations of overall model significance, with Bray-Curtis as the dissimilarity measure (Clarke & Gorley, 2006; Magurran, 1988).

Table 1 Dominance calculations for annual species and non-native species. Species pool (Total N), count of non-native species (N), non-native species as a percentage of total species pool for each land use (%Tot LU), change in the dominance of non-native species from 2000-to-2010 (Δ Non-Native), count of annual species (N), annual species as a percentage of total species pool for each land use (%Tot LU), and change in the dominance of annuals from 2000-to-2010 (Δ Annuals). Results given for 2000 and 2010, by land use type at both regional and residential levels.

REGIONAL	Total (N)	Non-native (N, %Tot LU)	Δ Non-Native	Annuals(N, %Tot LU)	Δ Annuals	RESIDENTIAL	Total (N)	Non-native (N, %Tot LU)	Δ Non-Native	Annuals(N, %Tot LU)	Δ Annuals
2000											
Agriculture	29	10 (34.5%)	NA	13 (44.8%)	NA	Mesic	126	58 (46.0%)	NA	23 (18.3%)	NA
Desert	124	12 (9.7%)	NA	56 (45.2%)	NA	Oasis	104	52 (50.0%)	NA	18 (17.3%)	NA
Urban	233	117 (50.2%)	NA	56 (24.0%)	NA	Xeric	96	55 (57.3%)	NA	11 (11.5%)	NA
2010											
Agriculture	69	34 (49.3%)	143%	63 (91.3%)	204%	Mesic	188	110 (58.5%)	127%	76 (40.4%)	221%
Desert	257	29 (11.3%)	117%	173 (67.3%)	149%	Oasis	251	125 (49.8%)	100%	80 (31.9%)	184%
Urban	464	213 (45.9%)	91%	198 (42.7%)	178%	Xeric	180	88 (48.9%)	85%	68 (37.8%)	330%

2.2.4. Estimating homogenization in plant communities

Using the Bray-Curtis index, we calculated spatial homogeneity of plant communities as:

$$\text{homogeneity} = 1 - (\text{dissimilarity in species composition})$$

This metric equates to the inverse of community heterogeneity (Collins, 1992). We aggregated results by sites of the same land use type and survey year. Analyses were done using the 'vegan' and 'labdsv' packages in R (R Development Core Team 2011).

3. Results

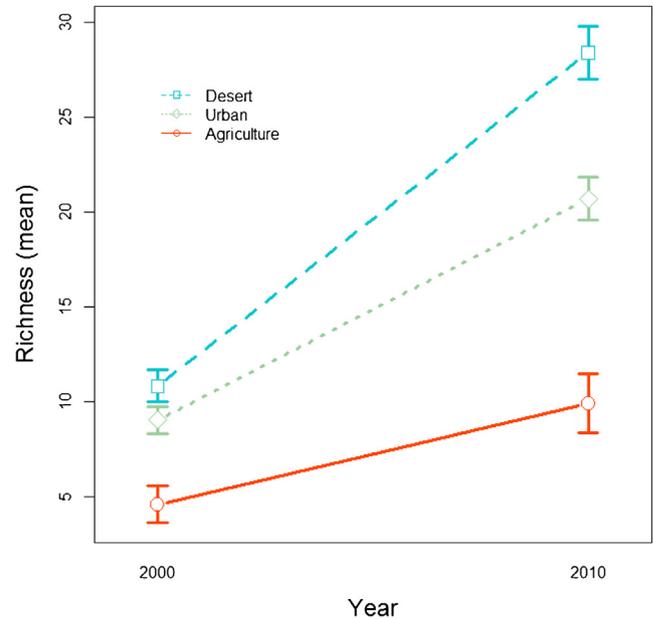
3.1. Plant community and homogenization dynamics from 2000 to 2010

At the coarsest level of analysis – regional – survey sites showed a systematic change from 2000 to 2010. Mean plant species richness increased from pre- to post-recession for Agricultural (+5 species), Desert (+18 species), and Urban sites (+12 species) (Fig. 2a). Regional NMDS results (stress=0.2512) revealed that Desert sites were composed of a consistent set of species across years and were largely distinct in their community composition from Agricultural and Urban sites, as indicated by the clustering of Desert sites from both years on Axis 1 (Fig. 4a). Agricultural sites were compositionally similar to Urban sites across years, although they had less variation in composition than Urban sites (Fig. 4a). Compositional shifts along Axis 2 were also evident between 2000 and 2010 for all three regional land use types (Fig. 4a). The differences among regional-level land uses and between years were significant, with ~12% of sums of squared differences explained by regional land use (PERMANOVA model with Bray-Curtis dissimilarity: $r^2 = 0.129$; $p < 0.001$) and ~7% sums of squared differences explained by survey year ($r^2 = 0.072$; $p < 0.001$).

For residential yard types, mean plant species richness increased from pre- to post-recession for all three residential types, but most dramatically for Mesic sites (+14 species, Fig. 2b), as predicted. Richness increased to a lesser extent on Xeric (+11 species) and Oasis (+9 species) sites as well. Although Mesic sites experienced the greatest overall increase in richness (Fig. 2b), Xeric sites had the greatest increase in dominance of annual species (Table 1). Similar species occurred in the plant communities at all three residential site types (Fig. 4b) but were slightly different between the survey years. Residential NMDS results (stress=0.2869) highlighted differences in composition across years (PERMANOVA model with Bray-Curtis dissimilarity: $r^2 = 0.085$; $p < 0.001$) but not among residential land use types (Fig. 4b). Within-year compositional similarities existed among Mesic, Oasis, and Xeric sites for both 2000 and 2010 surveys.

Levels of homogenization were significantly different for regional land uses pre- and post-recession (Fig. 3a). Homogeneity on Agricultural and Urban sites increased ($\text{Hom}_{\text{Agri}} 0.0063 \pm 0.002$, $T = 3.33$, $p < 0.01$; $\text{Hom}_{\text{Urban}} 0.0038 \pm 0.001$, $T = 6.37$, $p < 0.01$ per 900 m²) but remained significantly lower than on Desert sites ($\text{Hom}_{\text{Desert}} -0.0022 \pm 0.001$, $T = -3.29$, $p < 0.01$ per 900 m²) (Fig. 3a). Increases in Urban and Agricultural homogeneity are particularly notable, given the decrease in homogeneity observed at Sonoran Desert sites. Across all residential yard types, plant community homogeneity increased from pre- to post-recession (Fig. 3b). Oasis yards were slightly less homogeneous ($\text{Hom}_{\text{Oasis}} 0.0033 \pm 0.002$, $T = 1.93$, $p = 0.056$) than Mesic and Xeric yards ($\text{Hom}_{\text{Mesic}} 0.0025 \pm 0.001$, $T = 1.86$, $p = 0.066$; $\text{Hom}_{\text{Xeric}} 0.0043 \pm 0.002$, $T = 2.41$, $p = 0.017$), and Xeric yards had the steepest increase in homogeneity (Fig. 3b).

(a) REGIONAL



(b) RESIDENTIAL

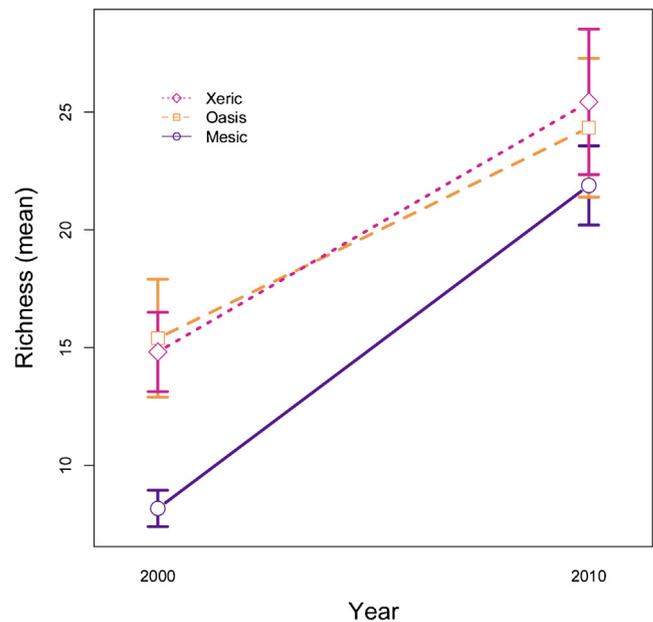


Fig. 2. Mean (plus standard error) plant species richness of Survey 200 sites in 2000 and 2010 by (a) regional and (b) residential land use type.

3.2. Variation in plant communities among regional land uses – 2010

In the post-recession surveys (2010), plant species richness differed significantly among the three regional land use types (Fig. 2a). Species richness was highest on the Desert sites (28 ± 1 species, $T = -10.64$, $p < 0.01$ per 900 m²), and lower on both anthropogenic site types (Agri: 10 ± 1 species, $T = -1.14$, $p < 0.26$; Urban 21 ± 1 species, $T = -8.01$, $p < 0.01$ per 900 m²). Homogeneity was higher on Desert sites despite having the highest species richness, indicating lack of dominance among Desert sites that was lacking in Urban and Agricultural areas (Fig. 3a). The increases in homogeneity

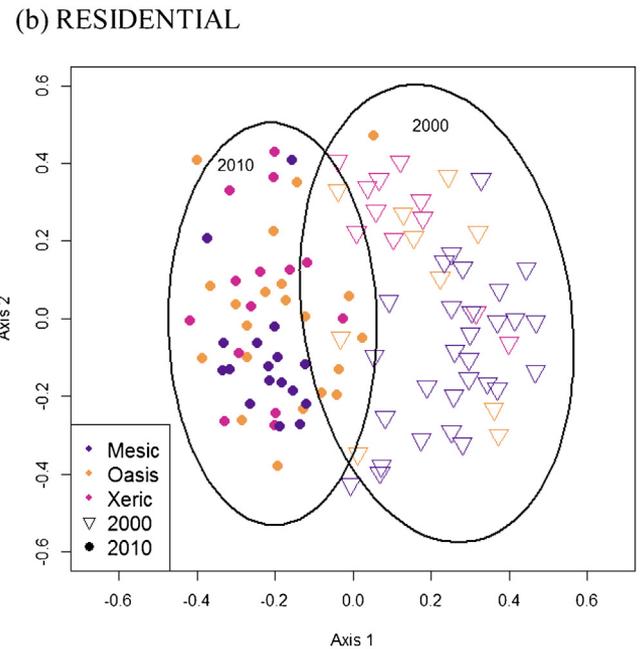
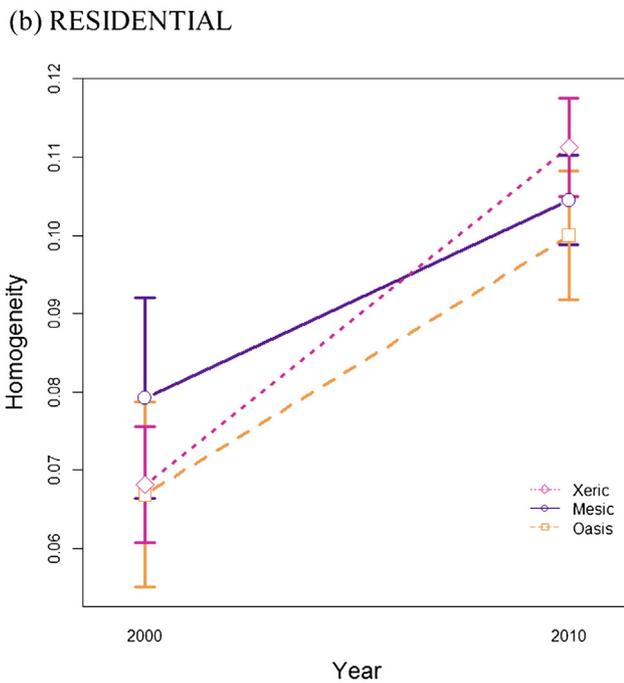
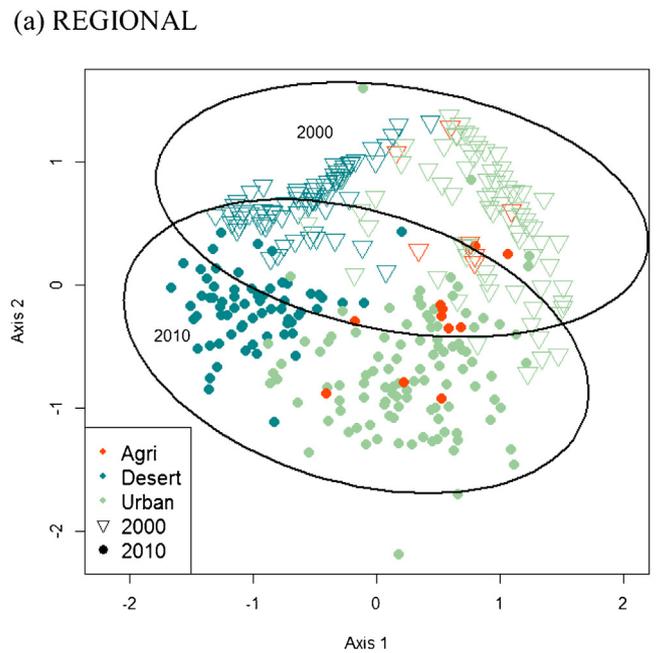
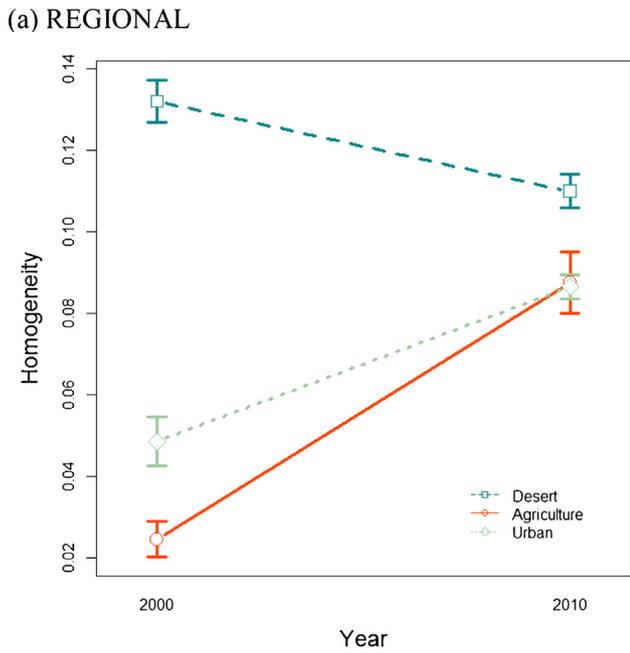


Fig. 3. Mean and standard error of within-group spatial homogeneity of Survey 200 sites in 2000 and 2010 by (a) regional and (b) residential land use type. Homogeneity calculated with a Bray-Curtis distance matrix of all possible pairs of plots within each land use type. Higher values of homogeneity index indicate higher spatial homogeneity.

Fig. 4. Non-metric multidimensional scaling (NMDS) plots of Survey 200 sites by (a) regional and (b) residential land use type, using plant species abundance and Bray-Curtis dissimilarity. Stress values for Regional and Residential were 0.2512 and 0.2869, respectively, where values <0.3 confirm the suitability of using a two-dimensional representation in the ordination plot. Stress values equate to the variance unexplained by the NMDS. Symbols represent site location; symbol colors represent land use type and symbol shape represents year surveyed.

ity on anthropogenic land uses after the recession resulted from the shifts in dominance of annual and non-native plant species (Table 1); annuals increased by 204% in Urban and 178% on Agricultural sites, while non-natives decreased by 91% in Urban and increased by 143% on Agricultural sites.

Different key species were associated with each of the three regional land uses in 2010 (see Appendix S1 in Supplementary material). The species of highest importance ($IV \geq 6$) for Desert sites were all native perennials, including one tree species (*Parkinsonia microphylla*), and two shrub species (*Condea emoryi*, *Ephedra* spp.). Rather than the crop species themselves, the most impor-

tant species on Agricultural sites was *Cupressus sempervirens*, an introduced ornamental tree commonly used in windblocks or as hedgerows between fields. Few cultivated species had consistently high abundance across Agricultural sites because there are many different cash and subsistence crops grown in and around Phoenix and because of the limited extent of this class in the sampling scheme. The one exception was *Citrus* spp., due to their widespread planting in agricultural settings as well as urban landscapes. The two most important species in Urban sites were trees with high horticultural value (*Parkinsonia aculeata*, *Beaucarnea recurvata*).

3.3. Variation in plant communities among residential yards – 2010

Post-recession species richness at the residential level was higher on average than at the regional level. Lowest richness in 2010 was on the Mesic sites (22 ± 3 species, $T=5.08$, $p < 0.01$) (Fig. 2b). Highest richness was found on the Xeric sites (25 ± 3 species, $T=2.98$, $p < 0.01$), and richness on the hybrid landscapes of Oasis sites was 24 ± 2 species ($T=2.63$, $p < 0.01$), but these small differences among yard types were not significantly different. The increase in homogeneity on residential yards (Fig. 3b) resulted in part from the shifts in dominance of annual and non-native plant species following the recession (Table 1); annuals increased by 330% in Xeric and 184% in Mesic yards, while non-natives decreased by 85% in Xeric but increased by 127% in Mesic yards.

Species importance values (IVs) quantified differences in abundant species for the three residential land use site types (see Appendix S1). Species of highest importance ($IV \geq 6$) on Mesic sites consisted of both native and introduced species. They included three ornamental tree species (*Acacia farnesiana*, *Beaucarnea recurvata*, and *Ebenopsis ebano*), a horticultural shrub species (*Gardenia jasminoides*), and one succulent genus (*Agave* spp.). The most important species on Oasis sites included the popular golden barrel cactus (*Echinocactus grusonii*) introduced from Mexico, the deciduous fruit tree (*Prunus persica*), and two introduced tree species (*Callistemon viminalis*, *Phoenix roebelenii*). Primarily native species were important on Xeric sites, as might be expected in a desert-like landscape, though none of them were cactus species but instead trees (*Parkinsonia aculeata*, *Parkinsonia florida*, and *Populus fremontii*). Also important at Xeric sites was the introduced tree genus *Eucalyptus*.

4. Discussion

In this observational study, we compared the diversity and composition of plant communities before and after the Great Recession, investigating multi-scale vegetation patterns along a gradient of human influence. Our findings illustrate the numerous ways that vegetation composition and diversity changed from 2000 to 2010. These changes could be explained by various factors, i.e. biophysical variability (e.g., seasonal precipitation), the 'press' of human management and landscaping preferences, or the 'pulse' of an exogenous disturbance (e.g., the Great Recession). Precipitation variation is a key driver of vegetation abundance and composition, particularly in arid climates (Gurevitch et al., 2002). However, in urban ecosystems, supplemental watering mitigates the effects of an arid climate, and decouples vegetation from desert precipitation regimes. Specific to our study, antecedent precipitation in 2000 and 2010 (57 mm and 55 mm, respectively) fell slightly below average (61 mm) in both survey years, so it is unlikely that precipitation levels contributed to increased plant diversity or differences in composition between survey years. Human preference has been proposed as a strategic filter of urban floras (Williams et al., 2009), e.g. professional and hobbyist gardeners are likely to prefer particular traits, like large flowers (Knapp et al., 2012). But human preference does not explain the >180% increase in annual species nor the ranking of two noxious weeds among indicator species for residential yards (Appendix S1 in Supplementary material). The Great Recession resulted in high rates of home abandonment and job loss, which would logically promote increased plant richness through lack of weed removal, as well as increased homogeneity due to the greater distribution of annual plant species among sample sites.

The luxury effect hypothesis predicts higher diversity will correspond to higher income (Hope et al., 2003, 2006). However, following decreases in income and home values with the Great Recession, we found increased plant species richness and homogeneity in Urban and Agricultural locations despite the fact that the housing market hit record lows and the 2010 survey followed four years of recession. Post-recession differences could have been caused by background changes like increased species richness, observed even in Desert plant communities. However, annual plant species increased disproportionately at Urban and Agricultural locations following the Great Recession (Table 1) while the dominance of non-native species decreased in Urban locations despite increasing in Desert locations. The changes in Metro Phoenix plant communities following the Great Recession were not congruent with the luxury effect hypothesis.

At a glance, the three different types of residential land uses appear to be quite different from one another. For example, Xeric yard designs often consist of sparse shrubs and rocky ground cover, while Mesic yards have grassy expanses and verdant trees (Martin et al., 2003). But the landscaping plants used in these designs were more likely chosen for ease of maintenance or to control for water use (Larson et al., 2009), and not for their provenance or biodiversity. So despite the varying physical appearances of these residential land uses and uneven dominance of non-native species (Table 1), we found the diversity and plant community composition of the three residential site types was similar (Figs. 2 b and 4 b), even while the dominance of annual species greatly increased from 2000 to 2010 (Table 1).

Urban landscapes can be designed to perform very different functions (e.g. agricultural production vs. transportation corridor) or to satisfy different aesthetics (e.g. lush, mesic yard vs. water-wise xeric yard), but when those landscapes become more like each other than the surrounding natural landscapes, their ecology has homogenized (McKinney, 2006; Trentanovi et al., 2013). Urban landscapes consist of numerous land uses and large, diverse species pools. And yet, our homogeneity analysis revealed significant increases in ecological homogeneity of Urban and Agricultural locations as well as residential locations following the Great Recession (Fig. 3a and b).

The unexpected compositional similarity we uncovered between Xeric yards and other residential landscape types has not been found in previous studies (Hope et al., 2003, 2006; Martin et al., 2004; Walker et al., 2009). We expected that water-wise Xeric yards were designed to mimic the arid Sonoran Desert, and so would be compositionally distinct from other residential landscapes and more similar to Desert sites. In a cross-scale comparison, we found that Xeric locations had different key species than Sonoran Desert locations (Appendix S1 in Supplementary material) (only *Parkinsonia* spp. and the invasive *Cenchrus setaceus* in common among abundant species ($IV > 4$)) (Howery et al., 2009), with more non-native species and fewer annual species than Desert locations (Table 1). Similar studies have recently shown how during homogenization of urban areas, natural vegetation assemblages were replaced by popular vegetation assemblages and lawns or other types of gravel/bark ground cover (Cadenasso et al., 2007; Walker et al., 2009). While other studies have focused on comparisons among cities, we observed the homogenizing influence of the Great Recession within a single city – across regional anthropogenic land uses and following an economic disturbance. Our results add momentum to the call for a better understanding of the processes leading to homogenization of vegetation and driving temporal dynamics of urban ecosystems over time and at multiple scales.

5. Conclusion

While the diversity and distribution of plants in urban systems cannot be understood without considering human behavior (Williams et al., 2009) – such as the cultivation of horticultural plants or suppression of ‘weedy’ species – it is important to recognize that socioeconomic distress reduces the ability to act on landscaping preferences. As shown here, the urban fabric as a whole became more compositionally homogeneous and supported proportionally fewer non-native plant species than before the Great Recession. Despite the reduction in non-native species, residents of mesic yards experienced more non-native species and a different flora with higher diversity; conversely, residents of xeric yards experienced lower non-native species richness and higher total species diversity. Our study suggests that flexible management strategies will be required to maintain urban green space that will support diverse plant and animal populations regardless of socioeconomic instability effects on urban residents.

Our results identify opportunities for additional research into empirically detecting drivers of changes in urban plant communities and further identifying pulse disturbances relevant to urban ecosystems. The ramifications of changes to urban flora following economic disturbance are social as well as ecological. We recommend that urban planners and managers be cognizant of trends in the global and local economy beyond their effects on development, because ecology and socioeconomics are strongly interconnected within and across urbanizing landscapes.

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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.2016.05.009>.

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