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Research Paper

A multi-city comparison of front and backyard differences in plant species diversity and nitrogen cycling in residential landscapes

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ABSTRACT

We hypothesize that lower public visibility of residential backyards reduces households' desire for social conformity, which alters residential land management and produces differences in ecological composition and function between front and backyards. Using lawn vegetation plots (7 cities) and soil cores (6 cities), we examine plant species richness and evenness and nitrogen cycling of lawns in Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, Los Angeles (LA), and Salt Lake City (SLC). Seven soil nitrogen measures were compared because different irrigation and fertilization practices may vary between front and backyards, which may alter nitrogen cycling in soils. In addition to lawn-only measurements, we collected and analyzed plant species richness for entire yards—cultivated (intentionally planted) and spontaneous (self-regenerating)—for front and backyards in just two cities: LA and SLC. Lawn plant species and soils were not different between front and backyards in our multi-city comparisons. However, entire-yard plant analyses in LA and SLC revealed that frontyards had significantly fewer species than backyards for both cultivated and spontaneous species. These results suggest that there is a need for a more rich and social-ecologically nuanced understanding of potential residential, household behaviors and their ecological consequences.

1. Introduction

The spatial extent of private residential land use, which includes yards, is rapidly expanding in the United States (Brown, Johnson, Loveland, & Theobald, 2005). Lawns, the dominate component of most residential yards, cover ~163,800 km^2 of 48 contiguous United States

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(Milesi et al., 2005), which is larger than the entire state of Georgia. Americans spent nearly $50 billion on lawn care, supplies, and equipment in 2013 and 2014 (ESRI, 2016), suggesting that residential ecosystems are resource-intensive. However, the spatial variation of yard management practices and intensity remains uncertain at multiple scales: variations within parcels between frontyards versus backyards, among neighborhoods within a metropolitan region, and among metropolitan regions in different climatic regions (Groffman et al., 2014; Groffman et al., 2017; Larson et al., 2015; Polsky et al., 2014). Given the vast extent of lawns and their potential environmental consequences, more research is needed to understand the geographic variations, drivers, and outcomes of yard care.

Despite a growing literature examining the social drivers of urban and suburban land management (Cook, Hall, & Larson, 2012; Robbins, 2007), surprisingly little attention has been paid to the variation within residential parcels. Robbins (2007) has hypothesized that self-presentation and social norms may affect how residents maintain their frontyard because of its public visibility. A potential corollary to this observation is that less-visible backyards are guided by a different set of socially-driven land management principles that do not include an outward display of 'fitting in' with a particular neighborhood aesthetic (Larsen & Harlan, 2006). For example, backyards may be used for growing food, recreation (Harris et al., 2012), or other purposes. Differences between front and backyard residential land may have implications for its ecological structure and function. For instance, several studies have shown lower vegetation species richness (Dorney, Guntenspergen, Keough, & Stearns, 1984) and more ornamental plants in frontyards (Daniels & Kirkpatrick, 2006; Vila-Ruiz et al., 2014), and better habitat features for birds in backyards (Belaire et al., 2015).

Building on previous work to understand the social drivers and ecological properties of residential land management (Larson, Casagrande, Harlan, & Yabiku 2009; Stehouwer, Nassauer, & Lesch, 2016; Larsen and Harlan, 2005), we hypothesize that frontyards are simpler and more clean-cut, reflecting an American aesthetic perceived as a shared neighborhood ideal and norm (Jackson, 1987; Robbins, 2007), while backyards are wilder and more diverse, reflecting an array of personally-held values and/or priorities. In this paper, our objective is to better understand the relationships among public visibility, social norms, ecosystem processes, and biodiversity by measuring ecological differences between front and backyards across climatically diverse regions. To achieve this objective, we evaluate variations between front and backyards with multiple measures of ecological structure, function and plant diversity. We analyze plant species in lawns in seven cities, soil properties related to nitrogen cycling processes in six cities, and entire-yard plant species differences between front and backyards in two of those cities (Salt Lake City and Los Angeles). In our entire-yard analyses for Salt Lake City and Los Angeles, we compare differences in cultivated (intentionally planted by people) and spontaneous (self-regenerating) plant species richness.

1.1. Theoretical underpinnings

We employ two social science theories to explore variations in residential land management: reference group behavior theory and its extension the ecology of prestige, and the moral economy. Reference group behavior theory posits that individuals seek membership in and identify with social groups they perceive as desirable and adopt the values, judgments, standards, attitudes, behaviors, and norms of those social groups (Hyman, 1942; Merton & Kitt, 1950). The extension of reference group behavior theory to residential land management is an ecology of prestige (Grove et al., 2006). Ecology of prestige theory posits that residential yardcare expenditures and behaviors are motivated in part by group identity and perceptions of inclusion in distinct lifestyle groups (Grove et al., 2006; Zhou, Troy, Grove, & Jenkins 2009). Because neat, picturesque, safe, and inviting landscapes may require substantial financial inputs, they may indicate to casual observers that residents belong to a certain socioeconomic class (Nassauer, 1988, 1995), or social group. This is "cues to care" concept. Research in Baltimore, MD (Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007), New York, NY (Grove, Locke, & O'Neil-Dunne, 2014) and Philadelphia, PA (Locke, Landry, Grove, & Roy Chowdhury, 2016) show that the distribution of existing vegetative cover, as well as the space potentially available for expanding vegetation on residential lands, are better correlated with different lifestyle measures (e.g. family size, marital status, housing styles) than with measures of socioeconomic status alone.

While ecology of prestige theory explains yardcare practices in terms of goal seeking, moral economy theory explains yardcare practices in terms of avoiding disapproval or sanctions. In this case, the idea of a moral economy explains household behavior in terms of shame or guilt because they failed to meet their neighbors' expectations if they do not maintain a particular lawn appearance (Robbins, 2007). Whether motivated by anxiety, shame, or guilt (moral economy), or by pride or desire to uphold the image of the neighborhood (ecological prestige), or a mix of both, neighbors can be an important reference group for landscaping practices. For instance, several studies have shown that neighborhood social norms influence household land management behaviors (Carrico, Fraser, & Bazuin, 2012; Fraser, Bazuin, Band, & Morgan Grove, 2013; Larson & Brumand, 2014; Nassauer, Wang, & Dayrell, 2009). In a cross-site study of yard care behaviors among ~7000 households, [authors name blinded for review] found that when residents know more neighbors by name, the odds of their irrigating and fertilizing any part of their parcels – front or back – is ~8% greater.

In both cases, ecology of prestige and moral economy theories, explanations of yardcare behaviors depends upon self-presentation; and self-presentation can only occur where it is visible (Nassauer et al., 2014). Thus, the social pressure to maintain group conformity and a particular aesthetic may be reduced when yardcare practices, such as those in a backyard, are no longer visible. However, little is known if or how social norms and residential land management is spatialized within parcels, from publically-visible frontyards to relatively more concealed, private backyards.

1.2. Empirical foundations

A review of more than 250 research papers on residential lands in urban areas found that, "most residential vegetation studies focus on frontyards because they are readily surveyed through field observations" from the public-right-of way and not requiring homeowner permission (Cook et al., 2012: 24). The few explicit comparisons between urban residential front versus backyards show substantial differences in vegetation structure. For example, across neighborhoods in Syracuse NY, there was 1.5–2.4 times more vegetated area and 0.9–1.8 times more tree canopy in backyards compared to frontyards (Richards, Mallette, Simplson, & Macie, 1984). Care for shrubs in frontyards was observed to be more intense than for backyard shrubs, and food-producing gardens were found to be absent from most front and side yards, but common in backyards (Richards et al., 1984). A study in Shorewood, WI found high species richness in frontyards (30 tree species) compared to backyards (21 species; Dorney et al., 1984). However, the number of trees was higher in backyards due to greater seedling survival of spontaneous regeneration near fences, garages, and other structures in these more private spaces (Dorney et al., 1984). In a suburb of Chicago, neighbors' yards and socioeconomic characteristics best explained residents' frontyard vegetation, while perceptions of and habitat resources for birds were most important for backyard vegetation structure and wildlife-friendly attributes (Belaire et al., 2015). A study of ten suburbs around Hobart, Tasmania, Australia, showed similar species richness across front and backyards when controlling for yard size, but the *types* and *purpose* of vegetation was significantly different (Daniels & Kirkpatrick, 2006). For example, there was more shrub cover in front than in backyards, and "simple native gardens, woodland gardens and exotic shrub gardens were concentrated in frontyards. Productive gardens, flower and vegetable gardens, no input exotic gardens and shrubs and bush trees gardens were concentrated in backyards" (Daniels & Kirkpatrick, 2006: 346). This study also found that the proportion of showy (intended to be aesthetically pleasing) front gardens to non-showy backyards was negatively correlated with suburb age; in newer developments, the difference between the front and back vegetation species was more pronounced (Daniels & Kirkpatrick, 2006). In San Juan, Puerto Rico, there was significantly greater diversity and abundance of ornamental plants in frontyards than backyards, and there were more cultivated edible food species in backyards than frontyards across six neighborhoods representing different architectural styles (Vila-Ruiz et al., 2014).

Studies comparing soil properties and processes between front and backyards have been extremely limited in comparison to studies of vegetation. Martinez, Bettez, and Groffman (2014) analyzed bulk density, organic matter, nitrate, potential net nitrogen mineralization and nitrification, microbial respiration, potential nitrous oxide production, and root mass in exurban, suburban, and urban watersheds in the Baltimore, MD region, and found no significant difference between front and backyards. Yesilionis et al. (2015) found significantly higher concentrations of calcium (26%), magnesium (10%) and higher pH (6.2 vs 5.7) in soils in frontyards compared to backyards in Baltimore County, likely due to higher application of lime in frontyards.

Focusing on the social dimensions of yard care in Phoenix, AZ, Larsen and Harlan (2006), found that front yard landscaping styles signaled social status and/or adherence to social norms, while residents' preferences and values were expressed in backyards. This work points to sub-parcel differences in yard care driven by neighborhood-level social processes, consistent with reference group behavior theory, the moral economy, and the ecology of prestige. Another study in Phoenix found that residents had distinctly different rationales for yard management across front and backyards, even when residents had different yard types (i.e. mesic, oasis, xeric, patio courtyard; Larson et al., 2009). Importantly, there was a gap between preferences and actual yard care, attributable to social norms (Larson et al., 2009). Long-time residents reported more mesic lawns in back than in front, and would prefer even more mesic lawn in back than front with less xeric desert landscaping (Larson et al., 2009). Significant differences in preferences for large trees in front yards and neatness, privacy and wildlife in backyards were found in suburban Michigan (Stehouwer et al., 2016). These findings are consistent with the Zone of Care concept (Nassauer et al., 2014), which "is the area of the parcel under frequent visible maintenance […including] areas that are regularly mown or maintained as food or ornamental gardens" developed to explain exurban land management in Michigan. These similar findings about landscape preferences, and the importance of the sub-parcel scale across climatically dissimilar Phoenix and Michigan suggest more generalizable relationships. But cross-site comparisons with standardized methods are needed to further understand the structure and function of front versus backyards, and across a variety of climatic conditions.

Based upon this literature review, we propose three hypotheses and their supporting rationale:

1) Lawns and soils: Frontyard lawns will have lower plant diversity, higher plant species evenness, and higher rates of nitrogen cycling than backyard lawns. This was hypothesized because if resources such as time and money are limited, residents seeking to produce the idealized "American" lawn will prioritize creating an orderly lawn in the public-facing frontyard than in the more private backyard spaces.
2) Lawns across study locations: The difference between front and back lawns in plant species richness, evenness, and nutrient cycling will be greater in areas where greater human inputs are needed to create and maintain lawns (Phoenix, Los Angeles, Salt Lake City), than in regions more hospitable to lawn vegetation (Baltimore, Boston, Miami, and Minneapolis-St. Paul). In other words, climate may interact with yard management priorities; with limited resources, effort will be focused on the publically-visible front versus private, less-visible backyards.
3) Entire-yard vegetation: Cultivated (intentionally planted) species richness will be higher in frontyards, while spontaneous (self-regenerating) plant species richness will be higher in backyards. The rationale is that relatively weed-free frontyards with ornamental species will be valued in more publicly visible frontyards while weeds will be tolerated in less visible backyards.

2. Methods

We examined plant diversity and soil nitrogen cycling in seven metropolitan statistical areas (MSAs or "regions"): Boston, MA (BOS), Baltimore, MD (BAL), Miami, FL (MIA), Minneapolis-St. Paul, MN (MSP), Phoenix, AZ (PHX), Los Angeles, CA (LA), and Salt Lake City (SLC). Lawns were the portion of the entire yard that was mowed and maintained, containing a mix of grasses and forbs. We analyzed lawn plant species richness and evenness for all seven MSAs, soil nitrogen cycle in six MSAs (all but SLC), and entire-yard (i.e., not just the lawn but also inclusive of gardens, trees, shrubs, etc.) plant species richness in two MSAs (LA and SLC) across front and backyards. In the entire-yard analyses, we compared cultivated (intentionally planted by people) and spontaneous (self-regenerating) plant species. Entire-yard vegetation species data were collected in LA and SLC because investigators were interested in differences between front and backyards.

2.1. Study design

The Potential Rating Index of Zip Code Markets (PRIZM; Claritas, 2008) was used to inform a stratified random sample of Census block groups, and to select properties to survey. Specifically, block groups of high or low socioeconomic status across an urban-rural gradient (urban, suburban, or exurban) were selected in the MSAs. Telephone interviews (~1600 per city) were completed to understand residents' characteristics and their yard management practices (Groffman et al., 2016; Polsky et al., 2014). From among those respondents, 21 to 31 single-family homes with lawns per metropolitan region, stratified by socioeconomic status and location along the urban to rural gradient, were chosen for field sampling of vegetation and soils (see Trammell et al., 2016, Wheeler et al., 2017). Sites to match this design were selected in Salt Lake City (SLC) by field reconnaissance without the telephone survey.

2.1.1. Lawns

Following the methods described by Wheeler et al. (2017), three 1 m^2 plots were randomly placed in the turfgrass area of front and back lawns, for a total of six plots per property. When lot size and/or shape did not allow for three plots in a particular front or backyard, fewer plots were sampled. Plants in each plot were identified to the species level, or the lowest possible taxon. Species richness and evenness were calculated by averaging plot data for the front and backyards for each home visited, making richness a continuous variable. Lawn species evenness was calculated using Simpsons' inverse evenness (1/D):

$$\frac{1}{D} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

where s is the number of plant species and p is the proportion of individuals of one particular species divided by the total number of individuals.

2.1.2. Soils

Only two of the six subplots were sampled for soils. Only residential

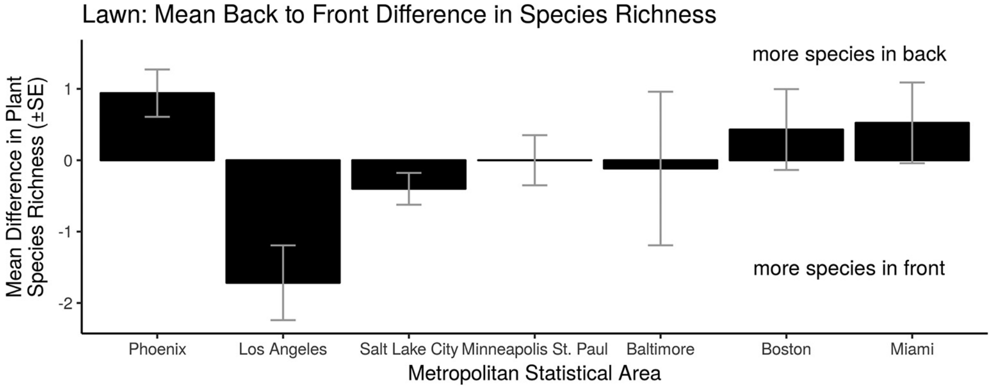

Fig. 1. Average plant species richness found in lawns, by front and backyard by MSA. MSAs are ordered from lowest annual precipitation (left) to highest (right; NOAA., n.d.).

sites with matched front vs. back pairs were analyzed, producing a lower number of observations for soils relative to vegetation (above). A soil impact corer (JMC ESP slide hammer) was used to extract 1-m cores from undisturbed portions of the lawn directly into plastic sleeves. Cores were capped and transported to the laboratory in coolers and stored at 4 °C until they could be processed. Laboratory methods followed those used by Raciti et al. (2011a,b) to measure microbial biomass carbon and nitrogen content, microbial respiration, potential net nitrogen mineralization, potential net nitrification, potential denitrification, and pools of extractable ammonium and nitrate. Because the focus here is on human activities that may influence biogeochemical cycling, analyses were restricted to the top 10 cm of the cores. These measures were chosen because they provide a suite of indices of soil microbial carbon and nitrogen cycle processes that are sensitive to land management (Brady & Weil, 1996).

2.1.3. Entire-Yard vegetation

In Los Angeles (LA) and Salt Lake City (SLC), an inventory of all plants in the whole yard was conducted – not restricted to the lawn – and the plant's location in the front and backyard was recorded. We term this "entire-yard vegetation". Species were identified to the lowest possible taxon, which occasionally included the cultivar level. Species were marked as cultivated, spontaneous, or uncertain. Cultivated plant species were intentionally planted by people, in contrast to spontaneous species which were not planted by a human. Analyses were conducted with the unknown species classified as spontaneous and then again as cultivated. The results were not sensitive to this choice, and we report the analyses where species classified as uncertain were re-classified as spontaneous.

2.2. Statistical analyses

All lawn and soil dependent variables were log-transformed after adding one to normalize variance. There was no evidence for zero-inflation. Entire-yard analyses of species richness were conducted using a generalized mixed effects model with a Poisson family link to avoid log-transforming count data (O'Hara & Kotze, 2010). Linear mixed effects models were fit where the front/back variable interacted with the encompassing region. Random intercepts for site were also included to explicitly account for the paired nature of the non-independent samples at each site (Eq. (1)). This random intercept for site is equivalent to a paired *t*-test (Wickham, 2014). Each dependent variable was regressed against back vs front, their interaction with their containing region, and with random effects for site:

$$Y_{ij} = \gamma_{00} + \gamma_{10} backFront_{ij} + \gamma_{01} region_{0j} + \gamma_{11} backFront_{ij} \times region_{0j} + u_{0j} + e_{ij} \quad (1)$$

where Y_{ij} is species richness, evenness, or nitrogen cycle process variables in plot (or core, or yard) i, at residence j. γ_{00} is the intercept and mean value found in backyards in Baltimore. γ_{10} is the back/front categorical variable (with back as the reference) at residence j, γ_{01} is the categorical variable for region (with Baltimore as the reference), γ_{11} is the back/front – region interaction term. u_{0j} represents the random effects per residence, and e_{ij} are the observation-level residuals. γ_{10} is the primary variable of interest. σ^2 is the variance within residences, and τ_{00} is the variance across residences.

Confidence intervals and p-values were calculated assuming a normal-distribution, treating the t-statistics as Wald z-statistics. The intraclass correlation coefficient (ICC) is "the proportion of the variance explained by the grouping structure in the population" (Hox, 2002: 15). Following Byrnes (2008), the R^2 approximation was computed using the correlation between the fitted and observed values, which is the proportion of explained variance in the random effect after adding covariates or predictors to the model. A simplified version of the $\Omega_0{}^2$ value is calculated as (1 – (residual variance/response variance), as suggested by Xu (2003) and Nakagawa and Schielzeth (2013). $\Omega_0{}^2$ statistic is therefore the proportion of the residual variation explained by the covariates. The statistical analyses were performed in R version 3.4.1 (R R Core Team, 2017), using the contributed packages shown in Appendix A.

3. Results

3.1. Hypothesis 1 – Lawns: differences in plants and soils between front and back

There were no statistically significant differences between front and backyards for lawn plant species richness (Fig. 1), evenness (Table 1), or soil process variables (γ_{10}; Table 2) when controlling for region. Thus, Hypothesis #1 was not supported. The R^2 value for plant species richness and evenness models were 0.89 and 0.80, respectively. Relative to the base case of Baltimore, front and backyard lawns in Los Angeles, Minneapolis-St. Paul, Phoenix, and Salt Lake City all had lower plant species richness (Table 1). Plant species evenness in lawns was higher in Salt Lake City, Los Angeles, and Phoenix, statistically equivalent in Minneapolis-St. Paul, and lower in Boston and Miami when compared to Baltimore (Table 1).

Before comparing concentrations, soil densities were examined. There were no differences in soil bulk density (which can influence comparisons between sites) between front and backyards ($F_{1,148} = 2.54$, $p = 0.11$). But there were differences in bulk density between MSAs ($F_{5,148} = 7.32$, $p = < 0.001$), with no interaction ($F_{5,148} = 1.39$; $p = 0.23$) with front versus backyard. The soil analyses were not as robust as the lawn analyses, likely because of the smaller sample sizes. The R^2 values for the soil nitrogen cycle variable models

Table 1
Linear mixed model output for vegetation species richness and evenness found in lawns by front and backyard and seven regions. Dependent variables were log transformed after adding one; bold terms are significant at the 95% level.

	Species Richness in Lawns			Species Evenness in Lawns		
	β	*95% CI*	*p*	*β*	*95% CI*	*p*
Fixed effects						
Intercept: Baltimore Back-Yard (γ_{00})	2.15	1.99 to 2.32	< **.001**	0.39	0.34 to 0.44	< **.001**
Front vs Back (γ_{10})						
Frontyard contrast	−0.06	−0.20 to 0.08	.402	0.01	−0.04 to 0.06	.616
Region: Baltimore as Reference (γ_{01})						
Boston contrast	−0.16	−0.38 to 0.05	.128	−0.08	−0.14 to −0.02	**.010**
Los Angeles contrast	−0.96	−1.21 to −0.72	< **.001**	0.10	0.03 to 0.17	**.005**
Miami contrast	−0.14	−0.38 to 0.09	.224	−0.09	−0.15 to −0.02	**.009**
Minneapolis-St. Paul contrast	−0.38	−0.61 to −0.15	**.001**	−0.02	−0.09 to 0.04	.461
Phoenix contrast	−0.81	−1.04 to −0.59	< **.001**	0.07	0.00 to 0.13	**.042**
Salt Lake City contrast	−0.86	−1.07 to −0.65	< **.001**	0.09	0.03 to 0.15	**.004**
Front vs Back – Region interactions (γ_{11})						
Front – Boston	−0.03	−0.21 to 0.16	.780	0.01	−0.05 to 0.07	.805
Front – Los Angeles	0.45	0.23 to 0.67	< **.001**	−0.10	−0.17 to −0.03	**.007**
Front – Miami	−0.05	−0.25 to 0.14	.591	−0.01	−0.08 to 0.05	.673
Front – Minneapolis-St. Paul	0.06	−0.13 to 0.26	.519	−0.00	−0.07 to 0.06	.935
Front – Phoenix	0.04	−0.18 to 0.26	.714	−0.00	−0.08 to 0.07	.921
Front – Salt Lake City	0.15	−0.04 to 0.33	.115	−0.04	−0.10 to 0.03	.255
Random effects						
σ^2	0.050			0.006		
$\tau_{00,\ \mathrm{Site}}$	0.096			0.006		
N_{Site}	171			171		
ICC_{Site}	0.657			0.514		
Observations	317			317		
$R^2/\Omega_0{}^2$	.890/.879			.800/.769		

ranged from a low of 0.314 (biologically available N) to a high of 0.720 (microbial biomass).

3.2. Hypothesis 2 – Lawns: differences between front and back across climatic sites

The mixed model outputs did not provide evidence to support the second hypothesis, i.e., difference between front and back lawns would be greater in areas where greater human inputs are needed to create and maintain lawns (Phoenix, Los Angeles, and Salt Lake City). The exception was a significant difference between front and backyards in Los Angeles (Table 1). In Los Angeles, overall lawn plant species richness was higher in front ($M = 4.17$, $SD = 1.91$) than in backyards ($M = 2.71$, $SD = 1.34$), while evenness was lower in frontyards ($M = 0.49$, $SD = 0.12$) than in backyards ($M = 0.64$, $SD = 0.21$). We expected the opposite, i.e., lower plant species richness and higher evenness (Hypothesis 1) in frontyards than in backyards.

The regression-adjusted estimates, which explicitly incorporate the paired nature of the data via the site-specific random intercept u_{0j}, reinforced the descriptive statistics reported above (Table 1). Frontyards in LA had back-transformed (i.e. exponentiated) 1.57 times more plant species in frontyard lawns than backyard lawns and frontyard lawns were ~10% less even (Table 1). There were few significant differences in soil nitrogen processes by region, and those differences did not suggest an underlying pattern (Table 2). None of the soil nitrogen cycling variables had a significant interaction between front/back and region (Table 2).

3.3. Hypothesis 3: Entire-Yard vegetation and differences between front and back

Because larger yards may have more species of plants, species richness and yard size were examined first. Yard size was not significantly related to species richness in front (LA: $r = -0.08$, $p = 0.73$, SLC: $r = 0.21$, $p = 0.28$) or backyards (LA: $r = 0.17$, $p = 0.47$, SLC: $r = 0.26$, $p = 0.17$). There were significant differences in entire-yard plant species richness, with backyards having more cultivated and spontaneous species (Table 3). We originally expected more cultivated species in visible frontyards, owing to ornamentals, and higher spontaneous species richness in backyards because residents may be more tolerant of weeds in these less-visible spaces. The unadjusted average difference in cultivated entire-yard species richness from backyard to frontyard was 10.19 species in LA and 1.67 species in SLC (Fig. 2A). The average difference in spontaneous vegetation species richness between backyards and frontyards was more modest, but still present in LA (4.14) and SLC (3.20; Fig. 2B). Because the species richness data represent counts, a generalized mixed model with a Poisson family and log link function was specified. Regression-adjusted estimates showed significantly lower cultivated and spontaneous species richness in frontyards compared to backyards (Table 3, Fig. 2). These regression analyses explicitly take into account the paired nature of the data and found statistically significant differences between front and backyard cultivated and spontaneous vegetation species richness (Table 3). On average frontyards had 35% fewer cultivated and 28% fewer spontaneous vegetation species than backyards in LA. Salt Lake City had significantly fewer cultivated species than LA, and there was a significant interaction effect for region; the difference between cultivated front and back species richness was smaller in Salt Lake City than in Los Angeles (Table 3, Fig. 2). There was no significant region-front vs back interaction for spontaneous species richness (Table 3, Fig. 2). In summary, frontyards had fewer species than backyards (for both cultivated and spontaneous species), SLC had fewer species than LA generally, and differences between front and backyard cultivated species richness were smaller in SLC than in LA. Descriptive statistics of lawn, soils, and whole-yard vegetation by front and backyards can be found in Supplemental Tables 1–4.

Table 2
Linear mixed model output for indicators of the nitrogen cycle by front and backyards by six region. Dependent variables were log transformed after adding one; bold terms are significant at the 95% level.

	Microbial biomass (ug C/g soil)			Respiration (ug C/g soil/day)			Mineralization (ug N/g dry soil/day)			Nitrification (ug N/g dry soil/day)		
	β	*95% CI*	*p*	*β*	*95% CI*	*p*	*β*	*95% CI*	*p*	*β*	*95% CI*	*p*
Fixed effects												
Intercept: Baltimore Back-Yard (γ_{00})	6.30	5.84 to 6.75	< **.001**	2.33	2.04 to 2.63	< **.001**	0.04	−0.21 to 0.29	.748	0.23	−0.04 to 0.50	.102
Front vs Back (γ_{10})												
Frontyard contrast	−0.05	−0.55 to 0.44	.828	0.06	−0.27 to 0.38	.732	0.01	−0.31 to 0.32	.962	−0.02	−0.36 to 0.33	.918
Region: Baltimore as Reference (γ_{01})												
Boston contrast	−0.28	−0.81 to 0.24	.292	−0.13	−0.47 to 0.22	.464	0.28	−0.01 to 0.57	.059	0.14	−0.18 to 0.45	.385
Los Angeles contrast	−0.42	−1.10 to 0.26	.227	0.48	0.04 to 0.93	**.032**	−0.25	−0.62 to 0.13	.198	−0.59	−1.00 to −0.19	**.004**
Miami contrast	−0.16	−0.78 to 0.45	.607	0.10	−0.30 to 0.50	.627	0.28	−0.06 to 0.62	.101	0.06	−0.31 to 0.42	.764
Minneapolis-St. Paul contrast	−0.91	−1.51 to −0.30	**.003**	−0.30	−0.69 to 0.09	.133	0.14	−0.19 to 0.47	.403	−0.01	−0.37 to 0.35	.972
Phoenix contrast	−1.32	−1.98 to −0.66	< **.001**	−0.54	−0.97 to −0.11	**.015**	−0.02	−0.39 to 0.34	.903	−0.05	−0.44 to 0.34	.812
Front vs Back – Region interactions (γ_{11})												
Front – Boston	0.10	−0.48 to 0.68	.733	0.08	−0.30 to 0.47	.662	−0.02	−0.38 to 0.35	.921	−0.05	−0.45 to 0.36	.819
Front – Los Angeles	−0.03	−0.77 to 0.72	.945	−0.47	−0.96 to 0.02	.062	0.33	−0.14 to 0.80	.172	0.48	−0.04 to 1.00	.069
Front – Miami	0.15	−0.52 to 0.82	.663	0.08	−0.36 to 0.52	.717	0.23	−0.20 to 0.65	.290	0.36	−0.11 to 0.83	.135
Front – Minneapolis-St. Paul	−0.10	−0.76 to 0.56	.771	−0.03	−0.47 to 0.40	.891	−0.13	−0.54 to 0.29	.552	−0.12	−0.58 to 0.34	.620
Front – Phoenix	0.28	−0.44 to 1.00	.443	0.09	−0.38 to 0.57	.705	0.02	−0.44 to 0.47	.938	−0.25	−0.76 to 0.25	.327
Random effects												
σ^2	0.320			0.139			0.128			0.156		
$\tau_{00,\ Site}$	0.216			0.088			0.034			0.033		
N_{Site}	80			80			80			80		
ICC_{Site}	0.403			0.389			0.211			0.176		
Observations	160			160			160			160		
R^2/Ω_0^2	.720/.681			.699/.650			.516/.462			.477/.435		

	Denitrification (ng N/g soil/hour)			Ammonium (ug N/g dry soil)			Biologically available N (ug N/g dry soil)		
	β	*95% CI*	*p*	*β*	*95% CI*	*p*	*β*	*95% CI*	*p*
Fixed effects									
Intercept: Baltimore Back-Yard (γ_{00})	5.09	3.98 to 6.21	< **.001**	1.24	0.85 to 1.63	< **.001**	3.80	3.32 to 4.28	< **.001**
Front vs Back (γ_{10})									
Frontyard contrast	−0.06	−1.53 to 1.42	.941	−0.14	−0.62 to 0.34	.578	−0.04	−0.69 to 0.62	.915
Region: Baltimore as Reference (γ_{01})									
Boston contrast	−0.54	−1.83 to 0.74	.409	−0.32	−0.78 to 0.14	.168	−0.10	−0.66 to 0.46	.730
Los Angeles contrast	−0.55	−2.36 to 1.25	.548	−0.18	−0.77 to 0.41	.550	0.01	−0.71 to 0.73	.973
Miami contrast	−0.39	−1.86 to 1.08	.601	−0.58	−1.11 to −0.05	**.031**	0.17	−0.48 to 0.82	.611
Minneapolis-St. Paul contrast	−0.11	−1.54 to 1.31	.876	−0.50	−1.02 to 0.02	.061	−0.04	−0.68 to 0.59	.894
Phoenix contrast	−3.14	−4.77 to −1.50	< **.001**	−0.43	−1.00 to 0.14	.136	−1.22	−1.91 to −0.52	< **.001**
Front vs Back – Region interactions (γ_{11})									
Front – Boston	−0.27	−1.97 to 1.44	.760	0.23	−0.33 to 0.79	.430	0.18	−0.58 to 0.94	.637
Front – Los Angeles	0.39	−1.89 to 2.66	.737	−0.15	−0.87 to 0.57	.691	0.38	−0.60 to 1.36	.449
Front – Miami	−0.20	−2.16 to 1.75	.839	0.50	−0.15 to 1.16	.129	0.26	−0.62 to 1.15	.557
Front – Minneapolis-St. Paul	0.31	−1.57 to 2.20	.745	−0.01	−0.65 to 0.63	.975	−0.13	−0.99 to 0.74	.773
Front – Phoenix	1.08	−1.11 to 3.27	.335	−0.24	−0.94 to 0.46	.496	0.58	−0.37 to 1.52	.233
Random Parts									
σ^2	2.352			0.301			0.553		
$\tau_{00,\ Site}$	0.259			0.099			0.044		
N_{Site}	78			80			80		
ICC_{Site}	0.099			0.247			0.073		
Observations	142			160			160		
R^2/Ω_0^2	.355/.332			.553/.458			.314/.300		

4. Discussion

4.1. Lawns: differences in plants and soils between front and back

Plant species richness and evenness, and soil nitrogen fluxes in lawns were analyzed for differences between front and back yards, and across regions in different climates. We expected to find lower plant species richness, higher plant species evenness, and higher rates of nitrogen cycling in lawns in frontyards when compared to backyards (Hypothesis 1). The rationale was that, driven to maintain the idealized "industrial" lawn (Robbins, 2007), households would devote more resources (i.e. time and money) into creating a monoculture lawn where it can be more readily seen – in the frontyard – and tolerate more weeds in backyards. We also reasoned that increased inputs of water and fertilizers in frontyards would significantly drive the nutrient fluxes in those spaces. Our robust, high R^2 mixed models did not support those expectations. There were no detectable differences between front and backyard lawns, or the soils beneath them.

Table 3
Generalized mixed model output for entire-yard vegetation species by front and backyard by region.

	Cultivated Plant Species Richness				Spontaneous Plant Species Richness			
	β	*exp(β)*	*exp(95% CI)*	*p*	*β*	*exp(β)*	*exp(95% CI)*	*p*
Intercept – Los Angeles, Back-Yard (γ_{00})	3.22	24.94	18.81 to 33.05	< **.001**	2.59	13.31	9.91 to 17.89	< **.001**
Front vs Back (γ_{10})								
Frontyard contrast	−0.42	0.65	0.58 to 0.74	< **.001**	−0.33	0.72	0.61 to 0.85	< **.001**
Region: Los Angeles as Reference (γ_{01})								
Salt Lake City contrast	−0.37	0.69	0.48 to 1.00	**.050**	−0.22	0.80	0.54 to 1.18	.262
Front vs back – Region interactions (γ_{11})								
Front – Salt Lake City	0.34	1.41	1.19 to 1.67	< **.001**	0.06	1.06	0.85 to 1.33	.594
Random effects								
$\tau_{00,\text{ Site}}$	0.394				0.403			
N_{Site}	51				51			
ICC_{Site}	0.283				0.287			
Observations	102				102			
Deviance	270.817				193.644			

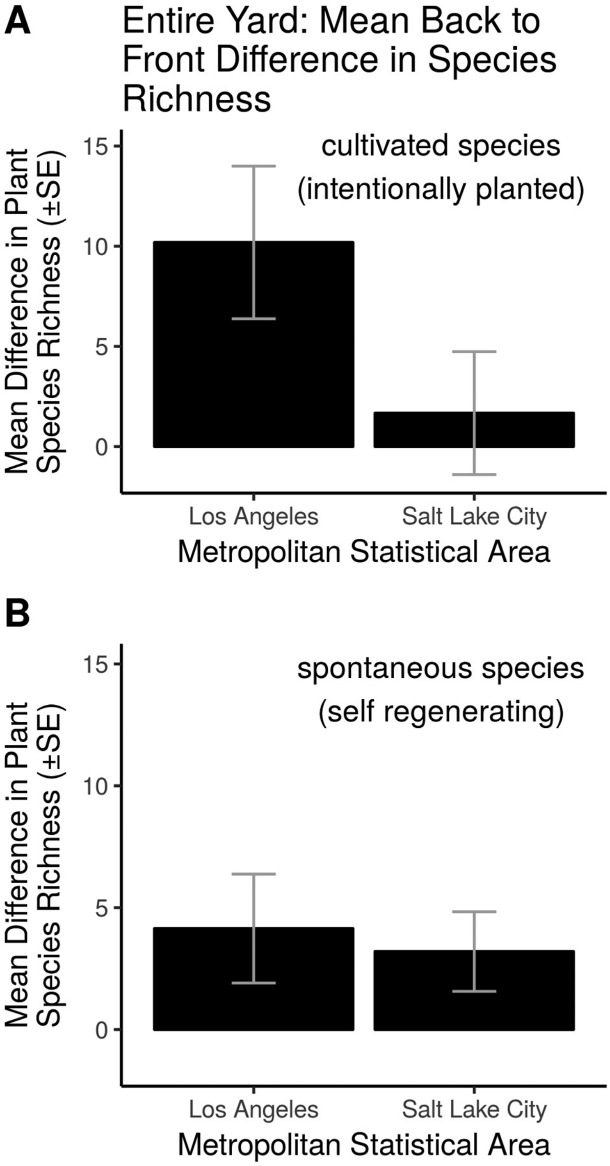

Fig. 2. Average cultivated (A) and spontaneous (B) plant species richness found across entire-yards, by front and backyard by MSA.

The lack of differences between lawns in front and backyards that we observed may be due to residents managing their lawns the same in the front and the back, or because management inputs do not alter the measured indicators. It is also possible that lawns have become "industrialized" in the true sense of the word: a standard set of mechanized practices that are widely adopted. In this case, if lawns have become industrialized, then it is likely that a relatively same set of management practices are applied to front and backyards (Hypothesis 1) and for different climates (Hypothesis 2), and thus, no significant differences would be observed.

4.2. *Lawns: differences between front and back across climatic sites*

We did observe some variation in lawn species richness and evenness by city (Table 1), possibly driven by different climates and/or other unmeasured factors. We expected to find differences between front and backyards to be greater in regions with climates that require greater inputs to create and maintain a lawn (e.g., relatively arid Phoenix, Los Angeles, Salt Lake City; Hypothesis 2). In other words, we anticipated a significant interaction effect where less-lawn accommodating climates (hot and dry) exacerbate the differences across front and backyards. However, Hypothesis 2 was rejected, and the only significant front/back-regional interactions were found for lawn plant species richness and evenness in Los Angeles. In Los Angeles, we found greater lawn plant species richness and lower evenness in frontyards, the opposite of our expectation. No other front/back-regional interactions were found for either lawn plants or nitrogen cycling in soils.

4.3. *Entire-yard vegetation and differences between front and back*

Residential yards, which include lawns, gardens, trees, and shrubs contain many more plant species than turfgrass. We expected to find greater cultivated plant (intentionally planted) and lower plant species (self-regenerating) richness in frontyards when compared to backyards (Hypothesis 3). The idea was that residents may plant more ornamental species in public frontyards and tolerate more weeds in private backyards. However, we found greater richness for both cultivated and spontaneous vegetation species in backyards in LA and SLC compared to frontyards (Table 3, Fig. 2). It is possible instead that residents are seeking tidier appearances in front, and more utilitarian uses in back. The difference was larger in LA than SLC. While these results are consistent with our predictions, we recognize that our expectations from moral economy and ecology of prestige theory, where households seek to fit into a residential land management aesthetic deemed socially desirable in a particular neighborhood, may not be sufficient. For example, residents might cultivate plants in backyards for utilitarian or functional purposes, such as food cultivation (Daniels & Kirkpatrick, 2006; Vila-Ruiz et al., 2014) or providing bird habitat (Belaire et al., 2015). Future work should more closely examine vegetation traits and management preferences more directly. There may be additional explanations of household motivations to explain variations in residential land management between front and backyards.

In summary, Hypotheses 1 and 2 were rejected and mixed for Hypothesis 3: both cultivated and spontaneous species richness was higher in back yards. Lawns and the soils beneath them do not appear to have sub-parcel differences from publically-visible frontyards to relatively more concealed, private back yards. Nitrogen cycling is not as clearly visible as entire-yard vegetation. There were significant differences in entire-yard species richness. Visibility may therefore be an important component of residential land mangers' decision making. Social pressures may be playing a role in creating the observed differences in entire-yard vegetation, but further research is needed.

Based upon our results, we offer several social and ecological methodological considerations. First, direct social measurements should be made that explicitly link household and neighborhood social norms, perceptions of social norms, and group identity. Additionally, environmental knowledge, preferences, motivations, and management behaviors should be assessed in the context of front and backyards. This could be done through a combination of open-ended, qualitative surveys and photo-elicitation techniques (see Larson et al., 2009; Nassauer et al., 2009, 2014).

Ecological data collections and analyses – remotely-sensed and field surveys – should expand from a focus on lawns to a consideration of entire yards. In the case of remote sensing, there is a need for the development of methods to partition individual parcels into front and backyards and to quantify morphological differences in structure between front and backyards within and among parcels and neighborhoods. Findings from this approach could help assess front and backyard differences at the parcel scale and the degree to which neighbors mimic each other at the neighborhood scale. Future analyses should more explicitly take into account, plant traits and uses. In addition to plant surveys and soil measurements, field surveys should include additional ecological phenomenon that might vary with differences in residential land management. This list includes additional taxa such as birds, insects, amphibians, and mammals and processes such as temperature, humidity, evapotranspiration, and carbon cycling in order to further assess the consequences of residential yard management.

5. Conclusions

Prior research consistently suggests that social norms may be a key driver of yard care behaviors (Bormann, Balmori, & Geballe, 2001; Carrico et al., 2012; Fraser et al., 2013; Larson & Brumand, 2014; Nassauer et al., 2009; Robbins, 2007). 'Fitting in' with a neighborhood may be accomplished by altering visible aspects of residential yards to conform to neighborhood aesthetics and social group expectations. However, previous research has not distinguished between front and backyards and considered whether such social norms would have the same influence on backyards, where land management would be beyond public observation and scrutiny. We hypothesized that the influence of social norms on land management would be affected by whether land management practices could be publicly observed or not. Based upon this hypothesis, we predicted that there would be differences in land management between front and backyards that would have ecological consequences: plant diversity and evenness, and rates of nitrogen cycling.

While we did not directly measure social norms at either the household or neighborhood level, we did measure the predicted ecological outcomes. Although we found no differences in plant diversity and evenness or rates of nitrogen fluxes for lawns in front and backyards (which are less visible), we did find differences for both cultivated and spontaneous plant species when sampling was inclusive of the entire yard: lawns, gardens, trees, shrubs and other portions of yards. The species of vegetation within lawns and the soils beneath them are not as readily visible as entire-yard vegetation species. The lack of differences between lawns and soils, and the significant difference in the more prominent and more-visible entire-yard vegetation point to the importance of landscape aesthetics. The cues to care (Nassauer, 1988, 1995) and zone of care concepts (Nassauer et al., 2014) may help explain and reconcile the null findings for lawns and soils, and the significant differences across entire-yard vegetation. Ultimately, with an expanded portfolio of methods and explanations, future research could have important implications for understanding the social-ecological dynamics, consequences, and opportunities for residential land management, one of the most dominant landscape types in the United States.

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Appendix A. Contributed R packages used for statistical analyses

Package name	Citation	Purpose
cowplot	(Wilke, 2017)	graphing
dplyr	(Wickham, Francois, Henry, & Müller 2017)	data manipulation
ggplot2	(Wickham, 2009)	graphing
lme4	(Bates, Maechler, Bolker, & Walker, 2015)	fitting mixed models
sjPlot	(Lüdecke, 2017)	calculating fixed effects significance values and model diagnostics, and formatting outputs

tidyr	(Wickham & Henry, 2017)	data manipulation
vegan	(Oksanen et al., 2017)	vegetation analyses

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2018.05.030. Additional data used in this paper are available via Groffman et al. (2018).

The reproducible R code used for this paper is available from the corresponding author at dexter.locke@gmail.com.

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