

Assessing the homogenization of urban land management with an application to US residential lawn care

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Changes in land use, land cover, and land management present some of the greatest potential global environmental challenges of the 21st century. Urbanization, one of the principal drivers of these transformations, is commonly thought to be generating land changes that are increasingly similar. An implication of this multiscale homogenization hypothesis is that the ecosystem structure and function and human behaviors associated with urbanization should be more similar in certain kinds of urbanized locations across biogeophysical gradients than across urbanization gradients in places with similar biogeophysical characteristics. This paper introduces an analytical framework for testing this hypothesis, and applies the framework to the case of residential lawn care. This set of land management behaviors are often assumed—not demonstrated—to exhibit homogeneity. Multivariate analyses are conducted on telephone survey responses from a geographically stratified random sample of homeowners ($n = 9,480$), equally distributed across six US metropolitan areas. Two behaviors are examined: lawn fertilizing and irrigating. Limited support for strong homogenization is found at two scales (i.e., multi- and single-city; 2 of 36 cases), but significant support is found for homogenization at only one scale (22 cases) or at neither scale (12 cases). These results suggest that US lawn care behaviors are more differentiated in practice than in theory. Thus, even if the biophysical outcomes of urbanization are homogenizing, managing the associated sustainability implications may require a multiscale, differentiated approach because the underlying social practices appear relatively varied. The analytical approach introduced here should also be productive for other facets of urban-ecological homogenization.

sustainability science | land-change science | urban ecology | private land management

Changes in land use and cover have transformed the biosphere (1, 2). Land changes should remain a key influence on the global environment, although the dominant source of these transformations will likely shift from agricultural expansion to urbanization (1, 3–7). Global-scale urbanization may be homogenizing ecological structure and function (cf. refs. 8–10). The composition of plant species, soil nutrient profiles, and presence or extent of surface water bodies appears to be increasingly similar across cities, even in dissimilar biophysical settings (10–14). Such trends are potentially worrisome in sustainability terms because they suggest large-scale and possibly irreversible transformations in biogeochemical cycling and trace gas fluxes are underway. Sustainability science therefore needs an improved

understanding of the causes and consequences of urban land management (15). This knowledge should be grounded in the geographic patterning—that is, homogeneous versus differentiated—of human land management practices at household, neighborhood, metropolitan, and even continental scales (16, 17).

Sustainability, Lawn Care, and Urban Ecological Homogenization

The environmental management of an expanding private urban land base is not well understood. Of primary concern are residential lawn and yard care, due to the apparently widespread practice of excessively fertilizing and irrigating turfgrass (18–20). Such behaviors are concerning because lawns not only cover a larger extent of land than any other irrigated crop in the United States (19, 20), but also are expected to expand in coming decades (21). Thus, the potential homogenization of residential lawn care has emerged as a major concern for carbon, nitrogen, phosphorus, and water flows (22–24). The conventional wisdom asserts that a singular human–environment process—urbanization—is generating similar human behaviors (such as lawn care

Significance

This paper offers conceptual and empirical contributions to sustainability science in general and urban-ecological studies in particular. We present a new analytical framework for classifying socioecological measures along a homogenization-differentiation spectrum. This simple 2×2 matrix highlights the multiscale nature of the processes and outcomes of interest. Our application of the conceptual framework produces needed empirical insights into the extent to which land management appears to be homogenizing in differing biophysical settings. Results suggest that US lawn care behaviors are more differentiated in practice than in theory. Thus even if the biophysical outcomes of urbanization are homogenizing, managing the associated sustainability implications may require a multiscale, differentiated approach.

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practices), regardless of the biophysical setting, that produce similar environmental outcomes. This relationship (sometimes implicit), the so-called “homogenization hypothesis” (9, 10, 25–27), has yet to be rigorously tested regarding lawn care practices. The production of similar landscapes in differing biophysical settings might be associated with different, not similar, behaviors. Producing the same English manor-style yards from the native landscapes in Phoenix and Boston would require different activities (adding or removing trees, respectively) due to the differing initial conditions.

In general, residential landscapes of varied baseline biophysical conditions (e.g., climate) may exhibit similar ecological characteristics (e.g., soil carbon levels), despite being potentially produced by different land management practices (e.g., high versus low lawn fertilization) and preferences (e.g., social pressures favoring or discouraging native vegetation aesthetics). The presence of homogeneity should be tested, not assumed. A full understanding of continental-scale human–environment processes must, *contra* the conventional wisdom, allow for the plausible cases where either similar biophysical outcomes across differing environmental conditions are the product of differing human behaviors, or where differing biophysical outcomes are the product of similar human behaviors. Coupled with the homogenization hypothesis, these alternative propositions of differentiation collectively represent a major and under-studied research agenda in urban ecology. To date, the social and natural sciences literatures on lawn care have tested for the homogeneity of biophysical outcomes from lawn care practices, assuming—not testing—an underlying homogeneity of lawn care practices (9, 10, 25–27).

As a first step toward testing the homogenization hypothesis regarding both lawn care practices and associated outcomes, this paper formally examines lawn care practices across biophysical and social gradients. A multiscale analytical framework is presented, which should be applicable to urban ecological topics beyond lawn care. The framework classifies land management patterns as either similar or not within cities (i.e., along a social gradient holding biophysical conditions constant), and as either similar or not between cities (i.e., along a biophysical gradient holding social classification constant) (see refs. 8, 9, and 27). The research design thus permits a dual scale analysis (within and across cities) of the extent to which residential land management practices are or are not homogenizing. The multivariate framework is applied to two residential land management practices measured by a nationally representative telephone survey ($n = 9,480$) of US residents with yards.

An Analytical Framework for Investigating Socioecological Homogenization and Differentiation

If homogenization is present, then land management practices should not be statistically linked with biophysical or social factors. This broad framing suggests that an empirical analysis could

take several different forms. One could correlate a biophysical measure with a measure of land use or land cover. For example, comparing relative humidity in a city’s irrigated neighborhoods to nearby native ecosystem locations might indicate that lawn humidity measures are similar across the irrigated neighborhoods but different from the city’s native setting. This result would suggest urban homogenization at the city scale. If the irrigated humidity measures across multiple cities vary less than do their associated native ecosystems, then homogenization would be present at the multicity scale. One could also associate a biophysical measure with a measure of land management, or integrate a measure of social conditions with a measure of land management in varying biophysical settings. For instance, if, holding biophysical conditions constant (i.e., at the local-scale), fertilization is more common among households with high income than with low income, then a preliminary inference is that fertilization cost produces a differentiated landscape of land management behaviors—there is no homogeneity. Similarly, if, holding household income constant, fertilization is more common in some cities than in others, then a preliminary explanation is that climate or soil quality differentiates land management at the multicity scale.

There are four potential combinations of homogenization or differentiation (see cells A–D Table 1). Two scales of analysis are highlighted in each case because at any given point in time an urbanization process—even one that is homogenizing—may generate different patterns at different scales (15). Cell A reflects the case where land management appears similar at both the city- and multicity scales. This case would present *prima facie* evidence supporting the homogenization hypothesis. In cell B, a city presents internal similarities but important differences compared with the other cities. For instance, regardless of income class, a substantial majority of city 1 survey respondents might report that they irrigate their lawns, whereas the same proportion in city 2 might report not irrigating, again regardless of income class. The conclusion would be city-scale homogenization but multicity differentiation. The remaining two possible combinations, cells C and D, represent cases exhibiting local differentiation. Cell C cities exhibit differences locally, but similar differences are observed in other cities. The same within-city differentiation of fertilization behaviors across a population density gradient might be observed in both cities 3 and 4. By contrast, in cell D there is no apparent association at either scale. In this case land management practices differ within and between cities, thereby providing evidence for both city-scale and multicity differentiation.

Materials and Methods: Comparing Fertilization and Irrigation Practices Across Biophysical and Social Gradients

This paper illustrates the utility of the analytical framework (Table 1) by examining associations among social characteristics, biophysical conditions, and land management practices in six US cities. Since the cities (Boston,

Table 1. Analytical framework for classifying types and drivers of urban homogenization and differentiation

		Similarity across cities?	
		Yes	No
Similarity within city?	Yes	A: Multicity and local homogenization. City exhibits similarities locally and with at least one other city.	B: Multicity differentiation and local homogenization. City exhibits similarities locally but differences with other cities.
	No	C: Multicity homogenization and local differentiation. City exhibits differences locally and similarities in the differences with at least one other city.	D: Multicity and local differentiation. City exhibits differences locally and with other cities.

This general form of the table should be replicated for each measure. Within each table, a city is placed in exactly one cell of the table based on the results of two statistical tests of association: a within-city test comparing survey responses across social variable classifications, holding location constant (compare with the six tests shown in Fig. 1); and a between-cities test comparing survey responses across locations, holding social variable classification constant.

Baltimore, Miami, Minneapolis–St. Paul, Phoenix, and Los Angeles) represent variation in biophysical conditions, little variation in land management across cities would suggest multicity homogenization because residential land management by a given group appears similar regardless of the differing climate or other environmental conditions. Similarly, little variation within cities would suggest city-scale homogenization because land management appears similar regardless of local social conditions. Conversely, and following the same logic, significant variation in land management across cities would suggest that biophysical factors are producing multicity differentiation, whereas significant variation within cities would suggest that social factors are yielding city-scale differentiation.

Self-reported measures of yard fertilization and irrigation from the survey are correlated here with factors commonly understood to differentiate residential land management. These two activities are selected because they are relevant to the dominant biophysical concerns associated with contemporary lawn and yard care: impacts on local and regional carbon, nitrogen, phosphorus, and water cycling (19, 20, 28). For practical reasons of survey validity, the survey asked respondents if they had fertilized or irrigated their lawn in the past year with yes/no binary responses, rather than the quantity or frequency of resource use. Accordingly, the survey responses provide a first-order understanding of biophysically relevant land management; specific water and nitrogen cycling concerns should be modeled with more refined measures of human behavior. The hypothesized drivers of yard fertilization and irrigation practices—one from the biophysical domain and three from the social domain—are drawn from the land-change science literature (1, 2). The rationale for specifying climate as a biophysical driver is self-evident. Urban residents might tailor their land management (vegetation types, extent, care) to suit their locally varying potential evapotranspiration or other climatic or biophysical conditions. The six cities examined here represent a variety of climates: humid, semiarid, and arid plus cold, temperate, and hot.

As with the biophysical drivers, if a homogenization toward increasingly intensive yard care practices has occurred, then the practices should not exhibit statistically significant correlations with the social drivers. By contrast, if homogenization is either incomplete or absent altogether, then differences in population density should correlate with variation in industrial lawn care practices due to differences in land availability and social norms in exurban, suburban, and urban areas (18, 19). Socioeconomic status (SES) is specified to account for the affluence and status effects thought to influence the social stratification of cities and suburbs (29–32). This theoretical position recognizes the importance of not only income but also education level, profession, ethnicity, and race. Such factors may be correlated with urban land management in ways that differ from population density, or from income alone (33). The expectation is that, as with population density, for households with yards to manage, higher SES levels should be associated with higher levels of fertilization and irrigation.

Finally, it is possible to observe a checkerboard (i.e., differentiated) pattern of fertilization and irrigation practices across places even after accounting for population density and SES (15, 34). Life stage is specified to account for variations in residential land management practices associated with the number and ages of people living at the home where the fertilization and irrigation is being examined. Life stage is operationalized with a categorical variable created through a cluster analysis of several continuous variables that include family size and ages of family members (cf. refs. 30, 35, and 36–38). The underlying premise is that the management of lawns, gardens, and recreational features on residential land is a product of the demand for such land features and the time available for associated management activities—and that such demand or time available varies over time with the changing composition and ages of the household members. In short, land management may not depend on cost constraints as much as it does on a household's social identity, what has been termed an “ecology of prestige” (37, 39). This logic applies to a cross-sectional view of households across a region, as well as to a single household observed over time. In sum, the research design explicitly accounts for potential cross-city variations in climate and in three socioeconomic variables. Other unobserved city-specific factors that might influence household-level lawn care practices (e.g., soil nutrient profiles, governance rules and sanctions) are not examined in this study.

χ^2 tests of association are performed both within each city and across all six cities. The within-city tests compare survey responses across categories of each of the three social variables holding climate constant; the across-city tests compare responses across climates holding the social category constant. Within-city tests that reject the null hypothesis of no association ($\alpha = 0.05$) provide evidence for differentiation in residential land management as a function of the specified social gradient; failing to reject the null provides evidence supporting within-city homogenization. Across-city patterns are tested for a given survey question and social gradient by comparing survey responses across cities for each gradient category. Any group of ≥ 2 cities for

which all categories of a given gradient exhibit across-cities similarities is classified as multicity homogeneous, i.e., either cell A or C. All other cities are classified as multicity differentiated, i.e., either cell B or D. This testing framework identifies if any of a given city's within-city patterns—be it homogenized or differentiated—is repeated in one or more other cities, for each combination of survey question and social gradient. Thus, for each combination of survey question and social variable, the left column cells must contain either 0 or >1 city; each right-column cell can contain 0–6 cities (Table 1). The larger a city set in the left column of the matrix, the stronger the statistical support for homogenization: for these cities each category of the social gradient must be statistically identical across all cities in the set. As such, the *ex ante* probability of placing a city in the left column is lower than in the right column, and larger city sets in the left column are less likely to be observed than are smaller city sets.

Results

For the full national sample ($n = 9,480$), 79% of respondents report having irrigated and 64% having fertilized their lawn or yard in the past year. However, conclusions about homogenization cannot be drawn without formally parsing responses by city location and potential social driving factor, as suggested by Table 1. For example, all six within-city tests of the fertilization survey question and population density social factor provide evidence for within-city differentiation ($P < 0.05$ for all 6 cities; Fig. 1). These cities would therefore be classified as either cell C or D, depending on the nature of their across-city patterns. The across-city patterns are illustrated in Fig. 1 by inspecting Los Angeles and Miami: even though the fertilization patterns differ across urban, suburban, and rural locations within the two cities ($P < 0.05$ in each case), the corresponding urban rates appear similar, as do suburban rates, and rural rates. The across-cities tests confirm the visual impressions: there is no fertilizing difference between Los Angeles and Miami for each population density category ($P > 0.05$ in all three across-cities cases). Thus, for this illustration, Los Angeles and Miami are placed in cell C, locally differentiated but multicity homogeneous (see Table 2). This city set includes only these two cities because for the other cities there is at least one population density category for which there

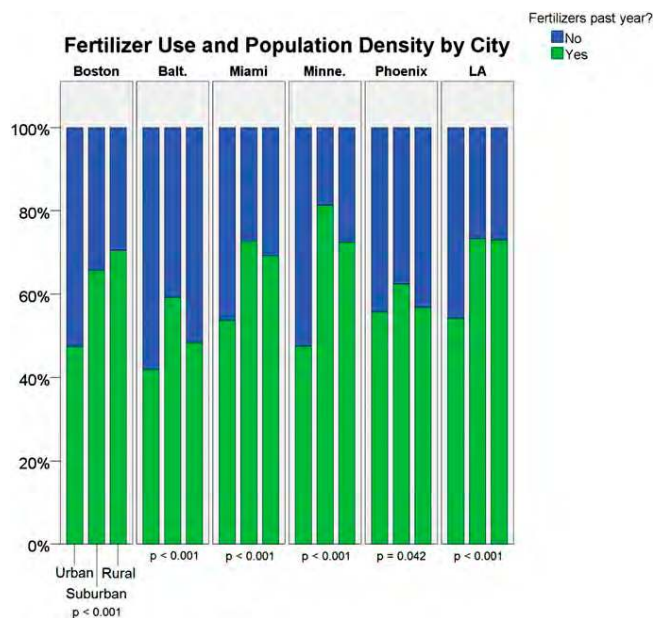


Fig. 1. Analysis of fertilizer use survey responses by city and by population density class (urban, suburban, and rural). Total sample size = 9,480 households, distributed similarly across each city. χ^2 tests of association with P values < 0.05 for each city indicate a statistical association between population density and self-reported fertilizer use in the past year.

is a statistically significant fertilization difference. For instance, even though Phoenix exhibits fertilizing similarities with Miami for one category (urban residents; $P = 0.578$), Phoenix is not classified with Miami in cell C because the two cities differ on at least one of the other two population density categories.

Table 2 shows all 36 classifications (2 survey questions \times 3 social gradients \times 6 cities). Results are characterized by summarizing the strength of support for homogenization, by identifying which factors can help explain any observed homogenization, and by highlighting two particularly noteworthy outcomes. First, cell A classifications constitute the strongest possible evidence in support of homogenization, and those in D the strongest possible evidence for differentiation (i.e., the weakest evidence for homogeneity). Results in cells B and C indicate mixed evidence for homogenization and differentiation. Using this grouping schema, overall we find limited evidence for complete homogenization (only 2 of the total 36 classifications appear in cell A), but substantial evidence for partial homogenization (22 cases in cells B and C). These findings lend limited support to the popular, yet to-date untested, notion that urbanization is a homogenizing process, but strong evidence that homogenization is not as complete or pervasive as the conventional wisdom would suggest.

The varying levels of support for homogenization (24 cases in cells A–C) are explained by parsing these results along the biophysical and social driver gradients. The strongest possible support for homogenization (cell A) is found only for the fertilization–life-stage combination in Boston and Miami. These results therefore do not explain the fertilization patterns in these two cities, but it is fair to rule out climate and life stage as driving forces. The 22 cases exhibiting a mix of homogeneity and differentiation permit hypothesizing which factors are driving the survey patterns. The 13 cases exhibiting multicity differentiation but local homogeneity (cell B) are not associated with the specified social factor but are interpreted here preliminarily to be

associated with differences in climate (although unspecified city-specific factors may also be implicated in the associations). The life-stage factor shows the greatest evidence for this outcome, and population density the least. The remaining 9 cases exhibit multicity homogeneity but local differentiation (cell C). These cases are not associated with climate because the responses do not vary across cities, but the responses are clearly associated with the social factors. SES exhibits the greatest frequency of this outcome, with the remaining cases split evenly across the population density and life-stage social factors.

Finally, two specific results deserve particular mention. Los Angeles exhibits notable consistency in its classifications: 4 of its 6 classifications appear in cell C, suggesting that in most cases the lawn care differences observed within Los Angeles are also observed in some of the other cities. This result suggests significant homogenization across the climate gradient for this city; Los Angeles behaviors appear representative of behaviors elsewhere. However, the results cannot identify if the country is emulating Los Angeles or vice versa. There is also one instance where all cities are classified in the same cell: the irrigation–life-stage combination (cell B). Thus, life stage is not a significant predictor of irrigation practices in any of the six cities, but climate is a significant predictor in all of the cities.

Discussion

The results in Table 2 highlight four notable features of the analytical framework proposed in Table 1. First, the classification schema identifies which specific combinations of cities, social factors, and survey questions cluster to confirm expectations, and which generate unexpected findings. For instance, it might not be surprising to observe that for the two driest cities—Phoenix and Los Angeles—irrigation varies positively with SES within both of these cities, and that the specific within-city relationship is statistically indistinguishable across the two cities (cell C in Table 2). By

Table 2. Classification of within- and across-cities test results into Table 1 general format for two survey questions (fertilizing and irrigation)

		Similarity across cities?			
		Yes		No	
Similarity within City?	Yes	A: Multi-City & Local Homogenization		B: Multi-City Differentiation & Local Homogenization	
		Fertilizing 1. P.D.: ☐ 2. SES: ☐ 3. L-S: (Boston, Miami)	Irrigation 1. P.D.: ☐ 2. SES: ☐ 3. L-S: ☐	Fertilizing 1. P.D.: ☐ 2. SES: Boston 3. L-S: Baltimore	Irrigation 1. P.D.: ☐ 2. SES: Baltimore, Boston, MSP 3. L-S: Baltimore, Boston, MSP, LA, Miami, Phoenix
	No	C: Multi-City Homogenization & Local Differentiation		D: Multi-City & Local Differentiation	
		Fertilizing 1. P.D.: (LA, Miami) 2. SES: (LA, Miami, MSP) 3. L-S: (LA, MSP)	Irrigation 1. P.D.: ☐ 2. SES: (LA, Phoenix) 3. L-S: ☐	Fertilizing 1. P.D.: Baltimore, Boston, MSP, Phoenix 2. SES: Baltimore, Phoenix 3. L-S: Phoenix	Irrigation 1. P.D.: Baltimore, LA, Miami, Phoenix 2. SES: Miami 3. L-S: ☐

By construction, each city must appear exactly once for a given combination of city, survey question, and social variable. Cities in left column are grouped to reflect their shared test results of no association (i.e., of homogeneity). P.D., population density; SES, socio-economic status; L-S, life stage. See *Materials and Methods* for elaboration.

contrast, it is not intuitively apparent why self-reported fertilization practices are statistically indistinguishable by life stage for cities of differing climates (Boston and Miami; cell A in Table 2). Such findings suggest the need for additional research into the multiscaled influences on residential land management (15).

Second, using this matrix permits analysts to work productively with cases of no statistical association. Cases classified in cells A, B, or C have at least one test that fails to reject the null hypothesis of no association. The framework presented here renders such results meaningful: a nonsignificant association suggests that the land management behavior is not driven by the specified social factor.

Third, the matrix formally identifies the extent to which the homogenization-differentiation patterns vary by spatial scale (cf. refs. 15 and 40–42). Even though cases of complete homogeneity or differentiation in lawn care practices do not exhibit differences across scales, the other cases (cells B and C) do exhibit scale-specific differences. Thus, scale matters, but not in all cases.

Fourth, the matrix can accommodate biophysical, social, and combinations of biophysical and social data. In this paper the biophysical measures were implicit, but one could specify explicit biophysical measures. The matrix can also accommodate different sources of extensive and intensive data. An example of an intensive data source is ethnographic surveys of homeowners to understand psychological and sociocultural factors affecting lawn care practices (cf. refs. 19, 26, 27, and 43–47). An example of extensive data is landscape metrics derived from high-resolution remotely sensed imagery, which can be used to characterize biophysical features that shape or reflect the lawn care decision-making process (cf. refs. 30, 35, 36, 48, and 49). Several of these data types have been collected and incorporated (9, 17), which adds to the present analysis of lawn care practices an associated analysis of lawn care outcomes.

Conclusions

Advancing toward urban sustainability in the 21st century will require understanding the extent to which urbanization may be producing socially and environmentally homogeneous or differentiated landscapes at neighborhood, metropolitan, national, and continental scales. This paper introduces and applies a formal analytical framework for detecting socioecological homogenization or differentiation at two spatial scales. This approach carries significant potential for advancing sustainability science. To fully realize this potential, the framework needs to be animated with repeated observations. Robust inferences about trends in homogenization or differentiation over time are not possible without observations over time. This framework should be able to detect whether a place is trending toward or away from homogenization (or is stable). The urban ecological homogenization hypothesis implies that cases exhibiting a combination of similarities and differentiation today will exhibit only similarities tomorrow. Cases classified in cells B and C today would be expected to migrate to A in the future. However, the emergence of locally tailored urban sustainability policies and practices may lead to less not more homogenization (e.g., refs. 18, 39, and 50–53). From this perspective, *contra* the homogenization hypothesis, cities classified in cells B and C may migrate to D not A. Applying the framework presented here to repeated measures can identify the presence (if any) and direction of trends.

This call for repeated observations of both biophysical and social variables is not new (cf. refs. 54–56). Cross-sectional analyses such as the one presented here are common out of necessity, for cost reasons. Long-term monitoring of biophysical variables is relatively rare, with the US National Science Foundation (NSF) Long Term Ecological Research (LTER) (<http://lternet.edu>) program being an outstanding exception to this rule. The repeated collection of social measures relevant for urban ecosystems is even less common. However, understanding the social and ecological dynamics that lead to urban homogenization

or differentiation requires a sustained program of repeated observations of urban land use, land cover, and land management. Establishing such a monitoring program is therefore a pressing need for the next generation of sustainability science program development.

Sampling and Data Collection. To reflect the theoretical interests in population density, SES, and life stage, the first sampling stage identified types of neighborhoods shared among all cities that reflect as much variation as possible in these three variables. Each city was stratified using the PRIZM scheme (30, 37, 38, 57), which classifies all US Census Block Groups (CBGs) based on an analysis of the CBG's population density, SES, and life stage. Fourteen PRIZM segments were chosen based on the PRIZM data available in July 2011. CBGs included must have $\geq 90\%$ of its surface area within the city's boundary. The selected PRIZM segment codes are: 02, 06, 07, 10, 11, 13, 14, 15, 20, 25, 29, 34, 54, and 61. Each segment is a collection of CBGs in the United States that share three characteristics: similar population density (classified based on the original continuous measure in declining order of density as urban, suburban/second city, or town and rural), SES (high or low), and life stage (younger years, family life, or mature years). For practical reasons, the sampling frame does not contain all possible pairwise combinations of classes from the three social dimensions. The six selected combined social groups in the sampling frame include: urban–family, urban–mature, suburban–family, suburban–mature, rural–younger, and rural–family. Accordingly, the sample excludes groups representing urban–younger, suburban–younger, or rural–mature. The six groups vary on the SES measure as follows: for population density, urban high and low SES, suburban high and low SES, and rural high SES; and for life-stage, younger high SES, family high and low SES, and mature high SES.

Using these selected social groups, >100,000 households were contacted between November 21 and December 29, 2011, across the six cities. Institutional Review Board approval was obtained on May 5, 2011 for project CHRBS: B11-205, from the University of Vermont Committee on Human Subjects. Of the contacted households, 13,590 qualified: the respondent was over 18 y of age, and his/her single-family home has a front- or backyard. The response rate, after informed consent was obtained, for the computer-assisted telephone survey (37 multipart questions) was $\sim 70\%$; the city-specific response rates ranged from 66% to 73%. The resulting 9,480 completed surveys are roughly equally distributed across both the six social groups and six cities. At the 95% confidence level, survey responses can be generalized to the broader population of continental US single-family home residents with a precision ranging from $\pm 0.44\%$ to $\pm 1.01\%$, depending on the observed responses for a given survey question.

Data Analysis. χ^2 tests of association were performed both within each city and across cities. A test that fails to reject the null hypothesis of no association ($\alpha = 0.05$) supports homogenization at the scale of the test, either local or multicity. The criteria for determining cell placement for each combination of city, social variable, and survey question are:

A: within-city test, $P \geq 0.05$; and for ≥ 2 cities the across-cities tests for each social category, $P \geq 0.05$;

B: within-city test, $P \geq 0.05$; and for all across-cities tests for each social category, $P < 0.05$;

C: within-city test, $P < 0.05$; and for ≥ 2 cities the across-cities tests for each social category, $P \geq 0.05$; and

D: within-city test, $P < 0.05$; and for all across-cities tests for each social category, $P < 0.05$.

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- Turner BL, 2nd, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. *Proc Natl Acad Sci USA* 104(52):20666–20671.
- Rindfuss RR, Walsh SJ, Turner BL, 2nd, Fox J, Mishra V (2004) Developing a science of land change: Challenges and methodological issues. *Proc Natl Acad Sci USA* 101(39):13976–13981.
- Seto KC, Güneralp B, Hutyra LR (2012) Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc Natl Acad Sci USA* 109(40):16083–16088.
- Grimm NB, et al. (2008) The changing landscape: Ecosystem responses to urbanization and pollution across climatic and societal gradients. *Front Ecol Environ* 6(5):264–272.
- Grimm NB, et al. (2008) Global change and the ecology of cities. *Science* 319(5864):756–760.
- Foley JA, et al. (2005) Global consequences of land use. *Science* 309(5734):570–574.
- Seto KC, et al. (2012) Urban land teleconnections and sustainability. *Proc Natl Acad Sci USA* 109(20):7687–7692.
- Pouyat RV, Yesilonis ID, Golubiewski NE (2009) A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosyst* 12:45–62.
- Groffman PM, et al. (2014) Ecological homogenization of urban USA. *Front Ecol Environ* 12(1):74–81.
- McKinney ML (2006) Urbanization as a major cause of biotic homogenization. *Biol Conserv* 11(2):247–260.
- Kendal D, Williams NS, Williams KJ (2012) A cultivated environment: Exploring the global distribution of plants in gardens, parks and streetscapes. *Urban Ecosyst* 15(3):637–652.
- Williams NS, et al. (2009) A conceptual framework for predicting the effects of urban environments on floras. *J Ecol* 97(1):4–9.
- Schwartz MW, Thorne JH, Viers JH (2006) Biotic homogenization of the California flora in urban and urbanizing regions. *Biol Conserv* 127:282–291.
- Steele MK, et al. (2014) Convergent surface water distributions in U.S. cities. *Ecosystems*, 10.1007/s10021-014-9751-y.
- Chowdhury RR, et al. (2011) A multi-scalar approach to theorizing socio-ecological dynamics of urban residential landscapes. *CATE* 4(1):Article 6. Available at <http://digitalcommons.lmu.edu/cate/vol4/iss1/6>.
- Meyer WB, Turner BL, eds (1994) *Changes in Land Use and Land Cover: A Global Perspective* (Cambridge Univ Press, Cambridge, UK).
- Grove JM, Pickett STA, Whitmer A, Cadenasso ML (2013) *Long Term Socio-Ecological Research: Studies in Society-Nature Interactions Across Spatial and Temporal Scales*, eds Singh SJ, Haberl H, Chertow M, Mirtl M, Schmid M (Springer, Dordrecht, The Netherlands), pp 369–408.
- Bormann FH, Balmori D, Geballe GT (2001) *Redesigning the American Lawn: A Search for Environmental Harmony* (Yale Univ Press, New Haven, CT), 2nd Ed.
- Robbins P (2007) *Lawn People: How Grasses, Weeds, and Chemicals Make Us Who We Are* (Temple Univ Press, Philadelphia).
- Milesi C, et al. (2005) Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environ Manage* 36(3):426–438.
- Alig RJ, Kline JD, Lichtenstein M (2004) Urbanization on the US landscape: Looking ahead in the 21st century. *Landsc Urban Plan* 69(2):219–234.
- Groffman PM, Williams CO, Pouyat RV, Band LE, Yesilonis ID (2009) Nitrate leaching and nitrous oxide flux in urban forests and grasslands. *J Environ Qual* 38(5):1848–1860.
- Raciti SM, Groffman PM, Fahey TJ (2008) Nitrogen retention in urban lawns and forests. *Ecol Appl* 18(7):1615–1626.
- Runfola DSM, et al. (2013) A growing concern? Examining the influence of lawn size on residential water use in suburban Boston, MA. *Landscape and Urban Planning* 119:113–123.
- Pouyat RV, et al. (2007) *Terrestrial Ecosystems in a Changing World*, eds Canadell P, Pataki DE, Pitelka L (Springer, Berlin).
- Harris EM, Martin DG, Polisky C, Denhardt L, Nehring A (2012) Beyond 'lawn people': The role of emotions in suburban yard management practices. *Prof Geogr* 65(2):345–361.
- Harris EM, et al. (2012) Heterogeneity in residential yard care: Evidence from Boston, Miami, and Phoenix. *Hum Ecol* 40(5):735–749.
- Milesi C, Elvidge C, Nemani RR (2009) *Remote Sensing of Global Croplands for Food Security* (CRC Press, Boca Raton, FL), pp 217–236.
- Logan JR, Zhou M (1989) Do suburban growth controls control growth? *Am Sociol Rev* 54:461–471.
- Troy AR, Grove JM, O'Neil-Dunne JP, Pickett STA, Cadenasso ML (2007) Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environ Manage* 40(3):394–412.
- Vemuri AW, Grove JM, Wilson MA, Burch WR (2009) A tale of two scales: Evaluating the relationship among life satisfaction, social capital, income, and the natural environment at individual and neighborhood levels in metropolitan Baltimore. *Environ Behav* 43(1):3–25.
- Pickett STA, et al. (2011) Urban ecological systems: Scientific foundations and a decade of progress. *J Environ Manage* 92(3):331–362.
- Logan J, Molotch HL (1987) *Urban Fortunes: The Political Economy of Place* (Univ of California Press, Berkeley, CA).
- Cook EM, Hall SJ, Larson KL (2012) Residential landscapes as social-ecological systems: A synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosyst* 15(1):19–25.
- Zhou W, Troy A, Grove JM, Jenkins JC (2009) Can money buy green? Demographic and socioeconomic predictors of lawncare expenditures and lawn greenness in urban residential areas. *Soc Nat Resour* 22(8):744–760.
- Giner N, Polisky C, Pontius RG, Runfola D (2013) Understanding the social determinants of lawn landscapes: A fine-resolution spatial statistical analysis in suburban Boston, Massachusetts, USA. *Landsc Urban Plan* 111:25–33.
- Grove JM, et al. (2006) Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems* 9:578–597.
- CLARITAS (2013) *CLARITAS PRIZM Market Segmentation*. Available at www.claritas.com/MyBestSegments/Default.jsp. Accessed June 20, 2013.
- Grove JM (2009) *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World*, eds Chapin FS, Kofinas GP, Folke C (Springer, New York), pp 281–294.
- Easterling WE, Polisky C (2004) *Scale and Geographic Inquiry*, eds McMaster R, Sheppard E (Blackwell, Oxford), pp 55–64.
- Polisky C, Easterling WE (2001) Adaptation to climate variability and change in the US Great Plains: A multi-scale analysis of Ricardian climate sensitivities. *Agric Ecosyst Environ* 85:133.
- Meyer WB, Gregory D, Turner BL, McDowell P (1992) *Geography's Inner Worlds: Pervasive Themes in Contemporary American Geography*, eds Abler R, Marcus M, Olson J (Rutgers Univ Press, New Brunswick, NJ).
- Carrico AR, Fraser J, Bazuin JT (2012) Green with envy: Psychological and social predictors of lawn fertilizer application. *Environ Behav*.
- Larson KL, Cook E, Strawhacker C, Hall SJ (2010) The influence of diverse values, ecological structure, and geographic context on residents' multifaceted landscaping decisions. *Hum Ecol* 38(6):747–761.
- Turner VK, Ibes DC (2011) The impact of homeowners associations on residential water demand management in Phoenix, Arizona. *Urban Geogr* 32(8):1167–1188.
- Nassauer JI, Wang Z, Dayrell E (2009) What will the neighbors think? Cultural norms and ecological design. *Landsc Urban Plan* 92(3):282–292.
- Martini NF, Nelson KC, Hobbie SE, Baker LA (2013) Why "feed the lawn"? Exploring the influences on residential turf grass fertilization in the Minneapolis–Saint Paul metropolitan area. *Environ Behav*, 10.1177/0013916513492418.
- O'Neil-Dunne JPM, MacFaden SW, Royar AR, Pelletier KC (2013) An object-based system for LiDAR data fusion and feature extraction. *Geocarto International* 28(3):227–242.
- Polisky C, et al. (2012) *HERO Object-based Lawn Mapping Exploration of Suburbia: Rationale, Methods and Results for the NSF Plum Island Ecosystems Long-Term Ecological Research Site*, George Perkins Marsh Institute Working Papers (Clark Univ, Worcester, MA).
- Haeg F (2008) *Edible Estates: Attack on the Front Lawn* (Metropolis Books, New York).
- Lovett I (August 12, 2013) Arid Southwest cities' plea: Lose the lawn. *NY Times*, Section A, p10.
- Charles JS (October 19, 2008) Healthy lawns vs. clean water? *NY Times*, Section WE, p 1.
- Pincetl S (2010) From the sanitary city to the sustainable city: Challenges to institutionalizing biogenic (nature's services) infrastructure. *Local Environ* 15(1):43–58.
- National Research Council (2010) *Strategic Directions for the Geographical Sciences in the Next Decade* (National Academies Press, Washington).
- National Research Council (1999) *Our Common Journey: A Transition Toward Sustainability* (National Academies Press, Washington).
- National Research Council (1992) *Global Environmental Change: Understanding the Human Dimensions*. (National Academies Press, Washington).
- Troy A (2008) *Encyclopedia of Geographical Information Science*, eds Shenkar S, Xiong H (Springer, New York), pp 347–355.