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LETTER

Satisfaction, water and fertilizer use in the American residential macrosystem

Peter M Groffman[1,15,16], **J Morgan Grove**[2], **Colin Polsky**[3], **Neil D Bettez**[1], **Jennifer L Morse**[4], **Jeannine Cavender-Bares**[5], **Sharon J Hall**[6], **James B Heffernan**[7], **Sarah E Hobbie**[5], **Kelli L Larson**[8], **Christopher Neill**[9], **Kristen Nelson**[10], **Laura Ogden**[11], **Jarlath O'Neil-Dunne**[12], **Diane Pataki**[13], **Rinku Roy Chowdhury**[14] and **Dexter H Locke**[14]

1 Cary Institute of Ecosystem Studies, 2801 Sharon Turnpike, Millbrook, NY 12545, USA
2 USDA Forest Service, Baltimore Field Station, Suite 350, 5523 Research Park Dr, Baltimore, MD 21228, USA
3 Florida Atlantic University, Center for Environmental Studies, 3200 College Ave., Building DW-312, Davie, FL 33314, USA
4 Portland State University, Department of Environmental Science and Management, PO Box 751-ESM, Portland, OR 97207, USA
5 Department of Ecology, Evolution and Behavior, University of Minnesota, St. Paul, MN 55108, USA
6 School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501, USA
7 Nicholas School of the Environment, Box 90328, Duke University, Durham, NC 27708, USA
8 School of Geographical Sciences and Urban Planning and School of Sustainability, Arizona State University, Tempe, AZ 85287-5302, USA
9 The Ecosystems Center, Marine Biological Laboratory, 7 MBL Street, Woods Hole, MA 02543, USA
10 Department of Forest Resources and Department of Fisheries, Wildlife, & Conservation Biology, 115 Green Hall, 1530 Cleveland Ave. N. St. Paul, MN 55108, USA
11 Dartmouth College, Department of Anthropology, 406A Silsby Hall, Hanover, NH 03755-3529, USA
12 University of Vermont, Spatial Analysis Lab, Rubenstein School of Environment and Natural Resources, 205E Aiken Center, 81 Carrigan Drive, Burlington, VT 05405, USA
13 Department of Biology University of Utah, 257 S 1400 E, Salt Lake City, UT 84112, USA
14 Graduate School of Geography, Clark University, 950 Main St., Worcester, MA 01610, USA
15 Current address: City University of New York, Advanced Science Research Center, 85 St. Nicholas Terrace, New York, NY 10031.
16 Author to whom any correspondence should be addressed.

E-mail: peter.groffman@asrc.cuny.edu

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Supplementary material for this article is available online

Abstract

Residential yards across the US look remarkably similar despite marked variation in climate and soil, yet the drivers of this homogenization are unknown. Telephone surveys of fertilizer and irrigation use and satisfaction with the natural environment, and measurements of inherent water and nitrogen availability in six US cities (Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, Los Angeles) showed that the percentage of people using irrigation at least once in a year was relatively invariant with little difference between the wettest (Miami, 85%) and driest (Phoenix, 89%) cities. The percentage of people using fertilizer at least once in a year also ranged narrowly (52%–71%), while soil nitrogen supply varied by 10x. Residents expressed similar levels of satisfaction with the natural environment in their neighborhoods. The nature and extent of this satisfaction must be understood if environmental managers hope to effect change in the establishment and maintenance of residential ecosystems.

1. Introduction

Urban, suburban and exurban ecosystems are increasing in area across the US (Goetz *et al* 2004, Brown *et al* 2005). There is significant concern—and uncertainty—about the environmental impacts of these ecosystems, especially the extent to which they contribute to water use and pesticide and nutrient pollution, and how these effects are related to human behavior (Kaye *et al* 2006). Management of urban water quality is further handicapped by uncertainties and knowledge gaps in the social science domain associated with the limited success of regulating a heterogeneous collection of non-point pollution sources using traditional command-and-control and water quality trading approaches (Shortle 2013). The socio-economic tradeoffs, normative constraints and behavioral incentives associated with various types of potential management interventions requires more systematic understanding (Ando and Netusil 2013, Wainger *et al* 2013).

Grass is a dominant land cover in urban, suburban and exurban ecosystems, representing as much as 20%–30% of typical residential parcels (Blanco-Montero *et al* 1995, Robbins and Birkenholtz 2003, Polsky *et al* 2012). Lawns comprise over 150 000 km^2 of land in the US, an area larger than that of any irrigated crop (Milesi *et al* 2005). There is also significant structural similarity in residential parcels across the US, with a relatively homogeneous mixture of impervious surfaces, grass and ornamental plantings within and among cities (Groffman *et al* 2014). The large area of residential land use represents a 'macrosystem' which Heffernan *et al* (2014) define as a regional to continental-scale system of interacting biological, geophysical, and social components. This perspective treats patterns and processes as dynamic and interactive, both within and across scales of time and space (Roy Chowdhury *et al* 2011).

The apparent structural homogeneity of the American residential macrosystem may mask significant variation in the management intensity and environmental performance of residential landscapes (Law *et al* 2004, Osmond and Hardy 2004, Carrico *et al* 2013, Harris *et al* 2012, 2013, Fraser *et al* 2013, Polsky *et al* 2014). Moreover, despite a significant body of past research seeking to characterize the impact of household-scale drivers on lawncare behavior—often attitudes, information, demographics, or socio-economic status—there is still little integrated understanding of linkages between social drivers and ecological outcomes of lawn management across multiple spatial scales (Roy Chowdhury *et al* 2011, Cook *et al* 2012).

In this study, we compared natural and anthropogenic drivers of water and fertilizer use in residential landscapes across six US Metropolitan Statistical Areas: Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, and Los Angeles. We conducted telephone surveys to assess residents' use of fertilizer and irrigation water (yes or no), and the level of household satisfaction with the natural environment in their neighborhood. Average annual precipitation (mm) and the ratio of precipitation to potential evapotranspiration were used to index natural water availability, and indices of soil nitrogen (a key component of fertilizer) availability were made on a subset (N ~ 100, 12–20 per city) of respondents' properties to estimate natural nitrogen supply. Our objectives were to (1) determine if natural availability of water and nitrogen had any influence on human irrigation and fertilization practices and (2) explore other factors that might influence these practices.

2. Methods

As described elsewhere (Polsky *et al* 2014), 9480 telephone interviews were conducted in the six cities between November 21st and December 29th, 2011. Surveys were stratified by population density and socio-economic status (SES) using the PRIZM marketing classification scheme (Grove *et al* 2006, Troy *et al* 2007, Troy 2008, CLARITAS 2013), which classifies each Census Block Group in the United States into a single group based on an analysis of the areal unit's population density, affluence, and life-stage. The population density classification ranged from Urban (highest population density) to Suburban/ Second City (intermediate), and Exurban (lowest); each neighborhood was classified as either High or Low SES. We first contacted >100 000 households and identified >13 500 where the respondent was over 18 years of age and their home had either a front or back yard. Approximately 70% of these respondents completed a 32 multi-part question telephone survey. The resulting ~9500 completed surveys were equally distributed across our target social groups and cities.

Indices of natural water availability were estimated from long-term mean annual precipitation and the ratio of precipitation to potential evaporation at weather stations in each of the cities. Precipitation data (1980–2010 normals) were obtained from http://usclimatedata.com/ and evapotranspiration was calculated using the formula provided by Thornthwaite (1948).

The natural nitrogen supplying capacity of soils from native ecosystem reference sites (forests, grasslands, deserts) in each city was assayed by measuring potential net nitrogen mineralization, which quantifies the production of inorganic nitrogen (ammonium plus nitrate) from soil organic matter over a 10 day laboratory incubation of field moist soils (Robertson *et al* 1999). Soils (0–10 cm) were sampled in each city during the middle of the growing season in either 2012 or 2013 and shipped to the Cary Institute of Ecosystem Studies in Millbrook, NY for mineralization assays.

All significance tests used an alpha of 0.05. Differences in means were tested using an ANOVA, followed by Tukey's HSD. All tests were repeated using the non-parametric Kruskal–Wallis rank sum test, after examining the univariate distributions and determining their non-normality. Kruskal–Wallis multiple comparison tests were run as a post hoc examination of which populations were different (Giraudoux 2013). The non-parametric test always confirmed what the original parametric equivalents reported. All statistical analyses were conducted using the free R programing language version 3.0.2—'Frisbee Sailing' (R Core Team 2013).

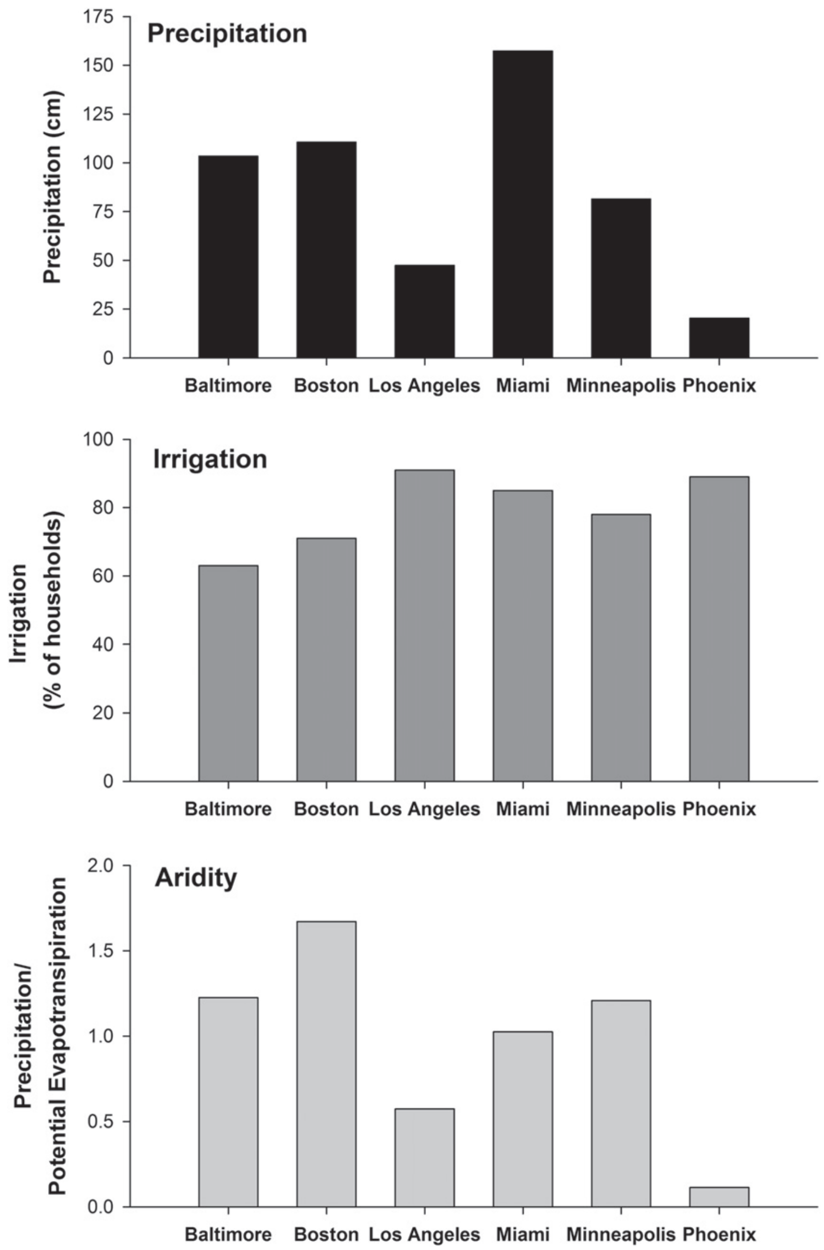

Figure 1. Annual average precipitation (top) and the percent of households that applied water for irrigation over the past year (middle) and the ratio of annual precipitation to potential evaporation in six cities across the US (bottom). Approximately 1600 households provided telephone responses in each city.

3. Results and discussion

Resident responses to the question, 'In the past year, was water for irrigating grass, plants or trees applied to any part of your yard' varied much less than mean annual precipitation or the ratio of annual precipitation to potential evaporation among our cities (figure 1). Precipitation ranged from a low of 20 cm yr^{-1} in Phoenix to 157 cm yr^{-1} in Miami (varying by 7.9 times), while use of water for irrigating varied much less, ranging from 63% to 89% of households (1.4 times). Most notably, water for irrigating was used in 85% of homes in Miami (the wettest site) and 89% of homes in Phoenix (the driest site). The ratio of annual precipitation to evaporation ranged from a low of 0.11 in Phoenix to 1.67 in Boston (varying by 15.2 times). Using this ratio as an index of water availability more accurately expresses the inherent need for irrigation water in a city like Miami that has high rainfall but also high temperature, and there was a significant negative correlation between use of water for irrigating and this ratio ($r = 0.79, p < 0.06$). Still, the difference in the percent of residents using water for irrigating varied much less between Boston (71%) (the wettest city by this index) and Phoenix (89%) than this index of water availability. The year of our study (2011) was wet in Baltimore (139% of normal) and Boston (123%), close to average in Miami (108%) and Minneapolis (102%), and below normal in Los Angeles (82%) and Phoenix (65%).

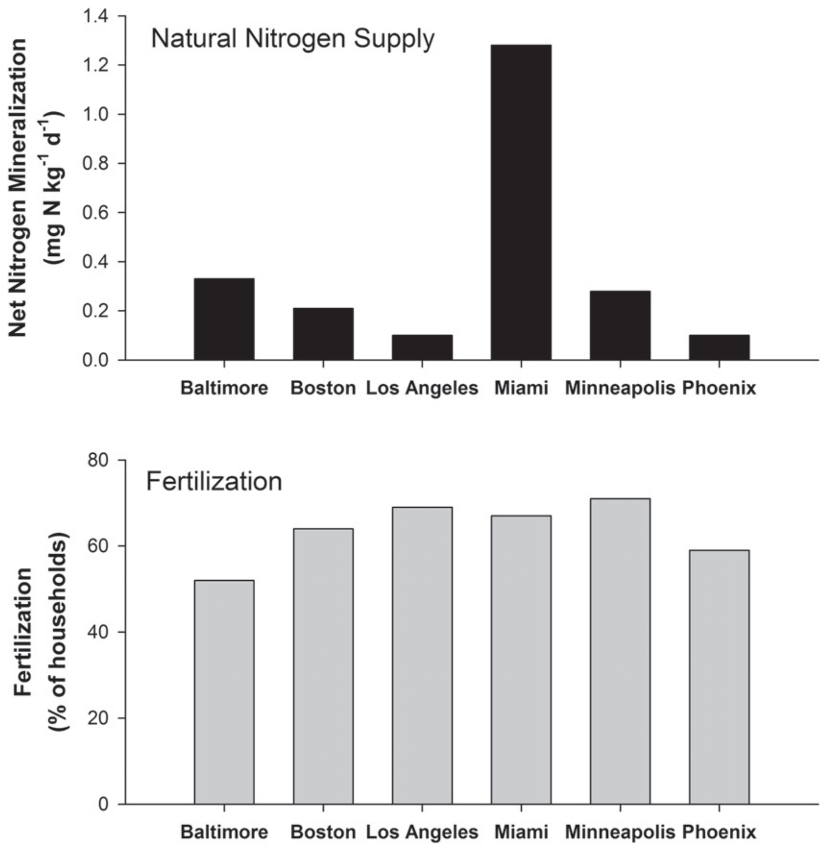

Figure 2. Rates of potential net nitrogen mineralization in native ecosystem reference sites (top) and the percent of households that applied fertilizer over the past year (bottom) in six cities across the US. Potential net nitrogen mineralization was measured in a 10 day laboratory incubation. Approximately 1600 households were contacted by telephone in each city.

Resident responses to the question, 'In the past year, were fertilizers applied to any part of your yard' varied much less than natural soil nitrogen availability among our cities (figure 2). Use of fertilizer ranged relatively narrowly, from 52% to 71% of households (1.4 times), while natural nitrogen supply ranged from 0.1 to 1.28 mg N kg^{-1} d^{-1} (12.8 times).

While these data suggest that natural availability of water and nitrogen have little influence on whether or not humans apply water and fertilizer in residential ecosystems, there are several important caveats to note. Most important is that we do not have information on the amount of water and fertilizer applied. While the percent of households applying water in Phoenix and Miami was very similar, it is likely that the amount of water applied was higher in Phoenix than in Miami. Interestingly, water use in Phoenix has been found to be insensitive to climate variability and has been declining in recent years (Balling and Gober 2007). For fertilizer use, it is possible that households with inherently nitrogen-rich soils applied less fertilizer than households with naturally nitrogen-poor soils, although it is difficult to assess soil nitrogen supply without detailed testing. While these questions deserve further analysis, our results provide important preliminary insight into how human behavior is grounded, or not, in biophysical conditions.

The proportion of households applying water for irrigating and fertilizer was strikingly similar across the American residential macrosystem. The uniformly high percentage of households that added irrigation water to their yards is surprising even if we consider that there is a need to add water to new plantings or vegetable gardens or during dry periods, even in relatively wet areas such as Miami. Several studies have analyzed the multiple factors that influence fertilization practices, from individual aesthetic preferences, to the desire to maintain social cohesion, to societal and commercial pressures to conform to neighborhood norms (Robbins 2007, Larson *et al* 2009, 2010, Zhou *et al* 2009, Harris *et al* 2012, 2013, Martini *et al* 2013). It is notable that a significant percentage (29%–48%) of households did not apply fertilizer at all.

The relatively uniform use of water and fertilizer across these US cities, which appears decoupled from natural availability of precipitation and soil nitrogen, may be related to the emotional dimension of residential yard management: people appear to derive significant positive value from both yard management activities and their outcomes (Harris *et al* 2012, 2013). Responses to the question, 'How satisfied are you with the quality of the natural environment in your neighborhood (using a scale of zero through 10)' were high and uniform across the six cities, ranging from a

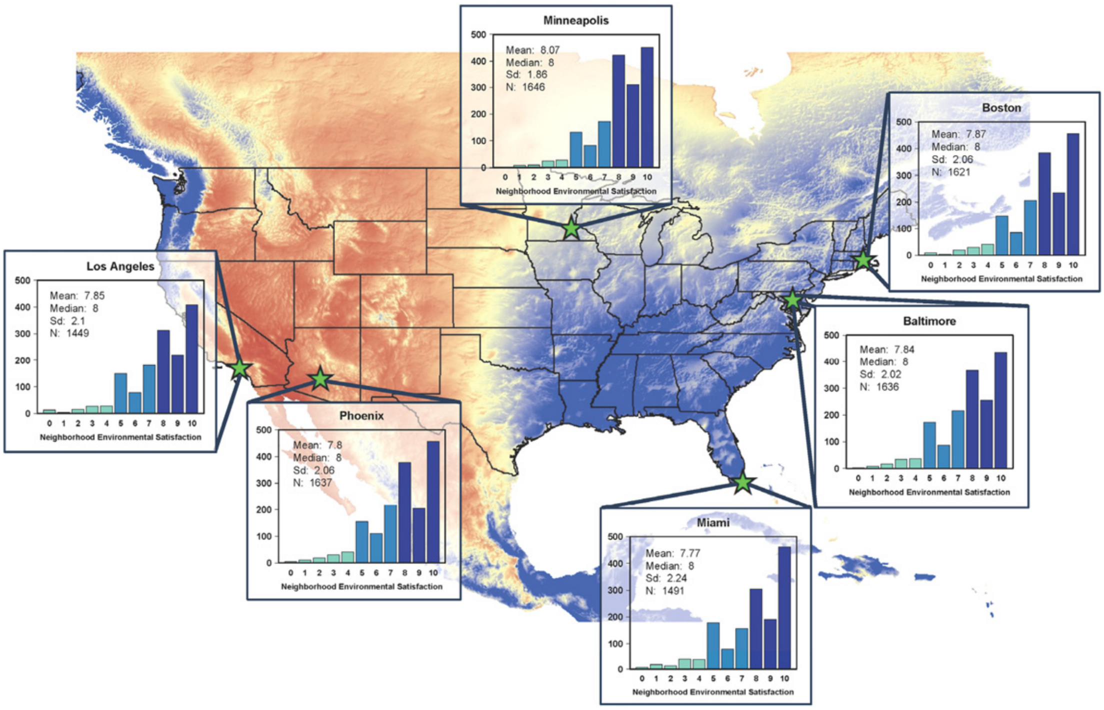

Figure 3. Response to household survey question; ' How satisfied are you with the quality of the natural environment in your neighborhood' in six cities across the US. Values are means across density and socio-economic gradients in each city imposed on a map of the US showing variation in mean annual precipitation from high (blue) to low (brown). Color codes in the graphs break the respondents into groups of low, medium and high satisfaction.

ranking of 7.77 out of 10 in Miami to 8.07 out of 10 in Minneapolis-St. Paul (figure 3). Satisfaction varied significantly with population density and socioeconomic status (SES); exurban residents had higher satisfaction than suburban residents who in turn were more satisfied than urban residents (figure 4). Within each density class, residents of high SES neighborhoods were more satisfied than residents of lower SES neighborhoods (figure 4). These results are consistent with the idea that people move to suburban and exurban areas at least partially for environmental amenities and that expenditures in wealthier neighborhoods (at yard scale or larger) influence people's perception of natural value and condition (Blaine *et al* 2012). However, mean satisfaction scores remained relatively high across these classes ranging from 6.90 out of 10 in low SES urban neighborhoods to 8.30 out of 10 in high SES exurban neighborhoods. There were small but significant ($p < 0.001$) differences in satisfaction between households that applied fertilizer (7.93) and those that did not (7.75), and no statistically significant differences in satisfaction between households that applied irrigation water (7.89) and those that did not (7.79). These results suggest that it is possible for residents to obtain the environmental benefits of residential land use without using water and fertilizer inputs.

Our survey question about neighborhood satisfaction (intentionally) leaves key terms—neighborhood and satisfaction—undefined. There was likely variation in respondents' perceptions and definitions of these terms. The 'natural environment' was defined as 'trees, animals, grassy areas, streams, and open spaces' and additional research is needed to determine the relationship between 'neighborhood' environmental satisfaction and 'yard' environmental satisfaction. Nonetheless, the fact that satisfaction varied significantly along population and SES gradients suggests that the question was able to elicit functional differences among respondents. More importantly, our results suggest that there is widespread satisfaction with the quality of the natural environment in the American residential macrosystem.

Our results suggest that there is significant homogenization of practices across the American residential macrosystem, with the percentage of households applying water and fertilizer varying much less than natural supply of water and nitrogen across vastly different climatic zones. It is important to note that there is evidence for significant within-city variations in these measures of practices and outcomes (cf 20). However, these variations are small relative to natural supply of water and nitrogen. We also observed widespread satisfaction with the relatively homogeneous mixture of impervious surfaces, grass and ornamental plantings that characterizes the American residential macrosystem that spans dramatically different natural environments across the continent. The nature and extent of this satisfaction must be understood better if environmental decision makers and managers hope to effect change in the establishment and maintenance of

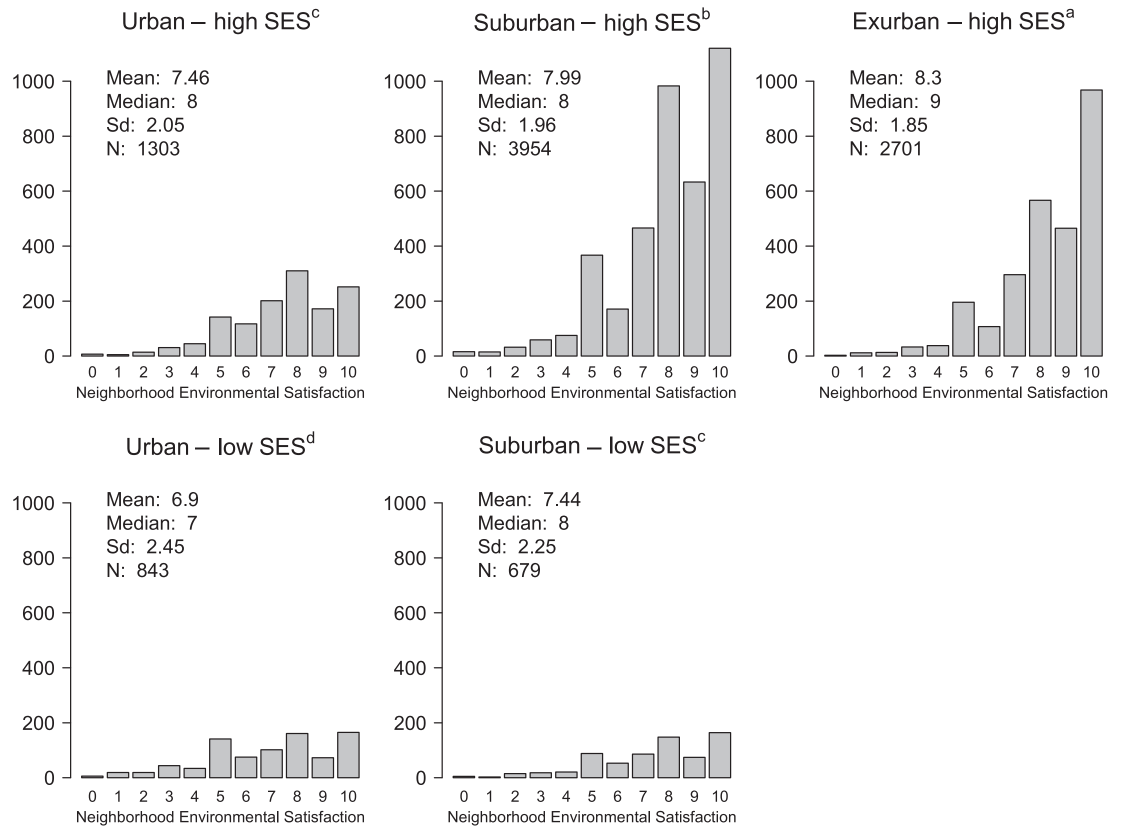

Figure 4. Response to household survey question; ' How satisfied are you with the quality of the natural environment in your neighborhood' in six different geodemographic segments varying in population density and socioeconomic status (SES) in six cities across the US. Segments followed by different superscripts are significantly different at $p < 0.05$.

this widespread ecosystem. There is a particular need to understand the motivations, levels of satisfaction, and the environmental performance of households that do not apply fertilizer and water for irrigating as a possible model for less intensive residential landscape management that potentially minimizes environmental impacts while still fulfilling the desires of households.

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