

**A New Look at Residential Ecosystems Management: Heterogeneous Practices and
the Landscape Mullets Concept**

Dexter Henry Locke

AUGUST 2017

A DISSERTATION

**Submitted to the faculty of Clark University,
Worcester, Massachusetts,
in partial fulfillment of
the requirements for
the degree of Doctor of Philosophy
in the Graduate School of Geography**

DISSERTATION COMMITTEE

Rinku Roy Chowdhury, PhD
Chief Instructor

John Rogan, Ph.D.
Committee Member

Deborah Martin, Ph.D.
Committee Member

J. Morgan Grove, Ph.D.
External Committee Member
USDA Forest Service Northern Research Station, MD

ABSTRACT

Residential lands are an omnipresent, complex, and important component of the North American landscape. The spatial extent of lawns, for example, is now four times larger than the area covered with irrigated corn, the United States' next leading crop. This dissertation examines the geographic variation, drivers, and outcomes of yard care practices, at regional, neighborhood, household, and intra-parcel scales. This dissertation contains theoretical, methodological, and empirical contributions to human-environment domain of geographic scholarship.

As a type of ecosystem, evidence suggests that cities are more biophysically similar to each other than the native ecosystem they have replaced. This phenomenon is called the Ecological Homogenization Hypothesis. But are the social processes that lead to that apparent ecological homogeneity also homogenous? Chapter 2 is a systematic, spatially explicit, cross-site, and unambiguously multi-scalar analyses of residential ecologies that reveals the geographic variability of irrigation, fertilization, and pesticide application for ~7,000 households. Irrigation varies by climate, but not along an urban-rural gradient, while the opposite is true for fertilization. This chapter demonstrates the methodological feasibility of explicitly multi-scalar analyses with cross-site data; Geographers should consider multi-level statistical alongside the commonly employed spatially autoregressive statistical models. We also found that knowing more neighbors by name is associated with ~8% greater odds of both irrigation and fertilization.

Prior research consistently identifies social norms as a key driver of yard care practices, which is linked to self-presentation. But self-presentation can only occur where

it can be seen. Are less-visible back yards managed differently because of reduced visibility? Through thirty-six semi-structured interviews conducted across seven neighborhoods in Baltimore, MD, Chapter 3 shows the relevance and salience of what is termed the Landscape Mullet concept, this dissertation's primary theoretical contribution. The two components of this advance are that 1) social norms are an important driver of yard care, and 2) those norms vary spatially across a residential parcel from front (public) to back (private) spaces. Interviews with households in six of the seven neighborhoods provided supporting evidence for both of these premises. The concept is therefore not neighborhood specific, but applicable in a range of contexts.

Because differences were found in how social norms translate into different front and back yard management practices, the environmental outcomes of the front/back division were further investigated. In Chapter 4, plant species richness and evenness in lawns were analyzed for seven cities, soils properties in six cities, and entire-yard vegetation species richness in two cities by front and back yard. Species of vegetation in lawns and key components of the nitrogen cycle found in soils beneath lawns are fairly homogenous at the sub-parcel scale (as predicted by the Homogenization Hypothesis), but the more encompassing yards are 10% - 20% more species rich in back yards than front yards (lending support to the Landscape Mullet concept). This robust empirical finding extends knowledge of urban residential ecosystem diversity via the spatially differentiated nature of social norms theorized in the preceding chapter. This dissertation makes several methodological, theoretical, and empirical advances towards

understanding the geographic variation, drivers, and outcomes of yard care at the regional, neighborhood, household, and intra-parcel scales.

© 2017

Dexter Henry Locke

ALL RIGHTS RESERVED

ACADEMIC HISTORY

Name: Dexter Henry Locke

Date: August 2017

BS Natural Resources, Resource Planning (*summa cum laude*), University of Vermont, Rubenstein School of Environment & Natural Resources, May 2009

MESc. Environmental Science, Yale School of Forestry and Environmental Studies, Yale University, May 2013

MA Geography, Graduate School of Geography, Clark University, May 2016

DEDICATION

I dedicate this dissertation to my mother Karen and brother Taylor, and especially my father Peter who has proof read all of my papers since 2009. All mistakes in this dissertation can be rightfully attributed to him.

Thanks to those who lived with me during my PhD experience, including Catherine Jampel, Victor Miranda, Chelsea Hayman (plus Chubs and Radar), Will Kline, Lizzie Schachterle, Sam Topper, Jane Lebherz, Bridget Amponsah, and especially to Ashley York (and Kitthen). Thanks also to Morgan, Kim, Zeb, Caroline, Daisy, and Dancer Grove for letting me crash at their home during summers and from time to time.

Thank you Colin Polsky for the guidance and mentorship provided.

Eli Goldman provided expert assistance. My most sincere gratitude and appreciation go to him.

My dissertation benefited tremendously from my association with the USDA Forest Service, Northern Research Station. I am thankful for working with New York City Urban Field Station, and especially for working with Erika Svendsen, Lindsay Campbell, and Michelle Johnson. Erika and Lindsay gave me my first real job after college, which helped inspire me to become a researcher. This document is partially your fault. Also from New York, thank you Jackie Lu and Kristy King. From the Philadelphia Field Station, thank you Sarah Low, Lara Roman, Michele Kondo, SeungHoon Han (now at the University of Nebraska Omaha), Vi Nguyen (now at Bureau of Land Management), and Michael Leff (Ecological Connections). Also in Philadelphia, thank you Joan Blaustein (Parks and Recreation), Erica Smith Fichman (TreePhilly) and Lindsey Walker (TreePhilly). From Chicago, thank you Sonya Sachdeva and Lynne Westphal. Finally, most of my work with the Forest Service has been out of, and in collaboration with, the Baltimore Field Station. Big thanks to J. Morgan Grove, Nancy Sonti, Beth Larry, Miranda Mockrin, Ian Yesilonis, Sarah Hines, Quintania Holifield, Katrina Krause, Ken Belt, and Anne Timm. Thank you Erik Dihle and Charles Murphy for being fantastic partners with the Baltimore Field Station and Baltimore Ecosystem Study, and for all of the excellent work they do for the City of Baltimore. It has also been great working with Wen-Juan Yu (Chinese Academy of Sciences) who visited the Baltimore Field Station for the academic year of 2016-2017 and sat next to me during the final weeks of writing this dissertation.

Peter Groffman and the entire MacroSystems Biology group (both current and former) helped me grow as researcher, especially Meghan Avolio (Johns Hopkins University) and Tara Trammell (University of Delaware).

Thanks to Cindy Wei, J. Morgan Grove, Jim Boyd, Margret Palmer, and the entire 2016-2017 Socio-Environmental Immersion Program participants and guests at the National

Socio-Environmental Synthesis Center (SESYNC) for thought-provoking and insightful conversations.

There are many, many more friends and colleagues who have helped me grow over the last four years and therefore aided in the creation of this dissertation. In no particular order they include Jarlath O’Neil-Dunne, Michael F. Galvin, Gillian Baine, Shawn Landry, Tenley Conway, Adam Berland, Mike Mitchell, Claire Turner, John Douglas, Christopher Small, Dana Fisher, Michele Romolini, Laurel Hunt, Eric Strauss, Dakota Solt, Armando and Diego, Colleen Murphy-Dunning and Rachel Holmes. Thanks to my climbing buddies Arielle Conti, Aisha Jordan, Vitaly Bekkerman, and Katie Pazamickas for helping me keep a level head in the last few months. Thanks to #popscoopers Ariel Hicks and Audrey Buckland who have inspired Baltimoreans to stay curious and to keep looking up.

To anyone I may have inadvertently left out, I extend my humble apologies.

ACKNOWLEDGEMENTS

Thank you to my committee: Drs Rinku Roy Chowdhury, John Rogan, Deborah Martin, and J. Morgan Grove. Thanks to my funders, which include the USDA, Northern Research Station’s Baltimore Field Station and the Philadelphia Field Station for the Sustainable Science Fellowship, the Parks and People Foundation. Thanks Clark University for the Marion I. Wright ‘46 Travel Grant, Libby Fund Enhancement, and the Pruser Awards. Thanks Drs. Karen Frey and Anthony Bebbington for support via the Edna Bailey Sussman Foundation. Thank you Temple University, Department of Geography and Urban Studies, and Hamil Pearsall in particular.

This research is supported by the Macro- Systems Biology Program (US NSF) under Grants EF-1065548, -1065737, -1065740, -1065741, -1065772, -1065785, -1065831, and -121238320. The work arose from research funded by grants from the NSF LTER program for Baltimore (DEB-0423476); Phoenix (BCS-1026865, DEB-0423704, and DEB-9714833); Plum Island, Boston (OCE-1058747 and 1238212); Cedar Creek, Minneapolis–St. Paul (DEB-0620652); and Florida Coastal Everglades, Miami (DBI-0620409). This research was also supported by the DC-BC ULTRA-Ex NSF-DEB-0948947. The findings and opinions reported here do not necessarily reflect those of the funders of this research.

TABLE OF CONTENTS

LIST OF TABLES	xi
LIST OF FIGURES	xii
INTRODUCTION	1
Background and the Cross-cutting Attention to Scale	3
Overview of the three papers	5
Chapter 2 “Heterogeneity of practice underlies the homogeneity of ecological outcomes of United States yard care in metropolitan regions, neighborhoods and household”	6
Chapter 3 “Landscape Mullets Part 1: Hearing it from the horse’s mouth”	8
Chapter 4 “Landscape Mullets Part 2: Plots and Parcels”	9
Conclusions	11
Acknowledgements	12
References	12
CHAPTER 2 HETEROGENEITY OF PRACTICE UNDERLIES THE HOMOGENEITY OF ECOLOGICAL OUTCOMES OF UNITED STATES YARD CARE IN METROPOLITAN REGIONS, NEIGHBORHOODS AND HOUSEHOLDS	16
Abstract	17
Introduction	18
Urban ecological homogenization hypothesis	21
<u>Understanding residential land management as a multi-scaled process</u>	<u>24</u>
Household level factors	25
Urban-rural gradients	27
Regional analyses and climate	28
Materials and Methods	29
Methodological rationale and the advances needed	29
Data and study areas	31
Statistical analyses	33
Results	36
Irrigation	38
Fertilization	43
Pesticide Application	44
Discussion	45
Heterogeneous practices and homogeneous ecological outcomes	45
Household drivers of residential landscape behavior	47
Insights from incorporating scale	49
Limitations	49
Conclusion	50
Acknowledgements	52
References	53
CHAPTER 3 LANDSCAPE MULLETS HYPOTHESES PART 1: HEARING IT FROM THE HORSE’S MOUTH	61
Abstract	62
Keywords	63
1 Introduction	64

2 Methods	68
2.1 Study Area	68
2.2 Recruitment	69
2.3 Procedures	69
2.4 Analysis	71
3 Findings	72
3.1 Business in the front, party in the back	72
3.2 Ease of Maintenance and Effort	77
3.3 Neighborhood Norms and Identity	78
4 Conclusions	80
Acknowledgements	83
Literature	83
Appendix 1. Emergent coding scheme	90
CHAPTER 3 LANDSCAPE MULLETS HYPOTHESES PART 2: PLOTS AND PARCELS	91
Abstract	92
Keywords	93
Introduction	94
1.1 Landscape Mullets.....	96
1.1.1 Theoretical underpinnings	96
1.1.2 Empirical foundations	99
2 Methods	103
2.1 Experimental Design	103
2.1.1 Lawns	104
2.1.2 Soils	104
2.1.3 Entire-Yard Vegetation	105
2.2 Statistical Analyses.....	106
3 Results	106
3.1 Lawn vegetation	106
3.2 Soils	109
3.3 Entire-Yard Vegetation	112
4 Discussion	114
5 Conclusions	117
6 Acknowledgements	118
7 References	119
8 Appendix 1. Contributed R packages used for statistical analyses	129
CONCLUSION	130
Summary and Future Research	135
References	138
APPENDIX 1: R CODE	140
Introduction	140
Scripts	140
Chapter 2	140
Chapter 4	149

LIST OF TABLES

Table 2-1.....37

Table 2-2.....39

Table 2-3.....41

Table 3-1.....69

Table 3-2.....77

Table 4-1.....109

Table 4-2.....111

Table 4-3.....114

LIST OF FIGURES

Figure 1-1	5
Figure 2-1	21
Figure 2-2	43

INTRODUCTION

How much do social norms matter, and what are the environmental consequences? These questions are motivated by a desire to develop, refine, and test social theories about human behavior. These questions also necessitate methodological advances and a mixed-methods approach. These questions are motivated by the practical challenges of mounting environmental problems too. Finally, these grand questions are larger than any one person can possibly answer in a lifetime; this dissertation represents one step along a much longer journey.

Residential ecosystems are an omnipresent, complex, and fascinating component of the North American landscape. In the United States alone, turfgrass occupies about four times as much land area as corn, the country's next leading irrigated crop (Milesi et al. 2005). As urban, suburban and exurban developments expand in the US, so do overall areas under residential land use (Brown et al. 2005). For many residents, yards and yard care may be their primary or only spaces of interaction with nature, and thus presents an opportunity to develop and test theories about human-environment interactions. These spaces and interactions have important footprints, moreover. For example, the environmental consequences of mowing on the carbon cycle; irrigation on regional hydrology; chemical inputs on vegetation, animal species and human health, and plant species on continental-scale biodiversity are substantial (Grimm et al. 2008). Despite accumulating research on residential land use and management impacts, significant gaps remain in our knowledge of the geographic variation, drivers, and outcomes of yard care – *and* the scale of these dimensions. The generalizability of single-site studies remains

unclear too. In particular, more work is needed on the scalar relations within which residents and residential parcels are embedded, on how social norms may shape residential ecologies especially at the intra-parcel scale, and on the environmental implications of management.

This dissertation also builds on recent research on the Ecological Homogenization of Urban America Hypothesis (Groffman et al. 2014). The definition of ecological homogenization used here is that the ecological structure and function of urban areas resemble one another, including residential ecosystems, even when the cities are located in biophysically distinct settings (Groffman et al. 2014). As a type of ecosystem, are cities more similar to each other than the native ecosystem they have replaced? Testing the homogenization hypothesis requires cross-site data. One team of researchers has found evidence for ecological homogenization in regional hydrography (Steele et al 2014), microclimates (Hall et al 2016), and species of vegetation (Pearse et al 2016, Wheeler et al *In Press*), across Baltimore, MD; Boston, MA; Los Angeles, CA; Miami, FL; Minneapolis-St. Paul, MN; and Phoenix, AZ. However the social practices that produce those apparently increasingly similar residential ecosystems are decidedly more mixed and complex (Polsky et al 2014, Larson et al 2015, Groffman et al 2016), and warrant further investigation. The complexity also presents an opportunity to better understand social norms and their environmental outcomes.

The widespread and increasing coverage of residential land, resource-intensive landscaping practices with uncertain environmental outcomes, and the interest in homogenizing ecosystems motivate this dissertation. There is a clear need to understand

the geographic variation (ch 2, 4), drivers (ch 2, 3), and environmental outcomes (ch 3, 4) of yard care, and by scale. Correspondingly, this dissertation's three Stand Alone Articles center on these overarching research questions: What are people doing and where (ch 2), Why are they doing it (ch 3), and What are the environmental outcomes (ch 4)? As described next, attention is given to nested and interacting scales throughout. Together these overarching questions contain several supporting research questions embedded in each Stand Alone Article, and collectively build toward understanding the role of social norms and their environmental outcomes – using the dominant human habitat as an example.

It is important to note that this dissertation contributes to and builds from a larger project on ecological homogenization. Peter Groffman is the principal investigator of the “Ecological homogenization of urban America: a research project” funded by the U.S. National Science Foundation program on “MacroSystems Biology: Research on Biological Systems at Regional to Continental Scales.” Chapters 2 and 4 rely on data collected through that larger project; Dexter Locke collected the data supporting Chapter 3.

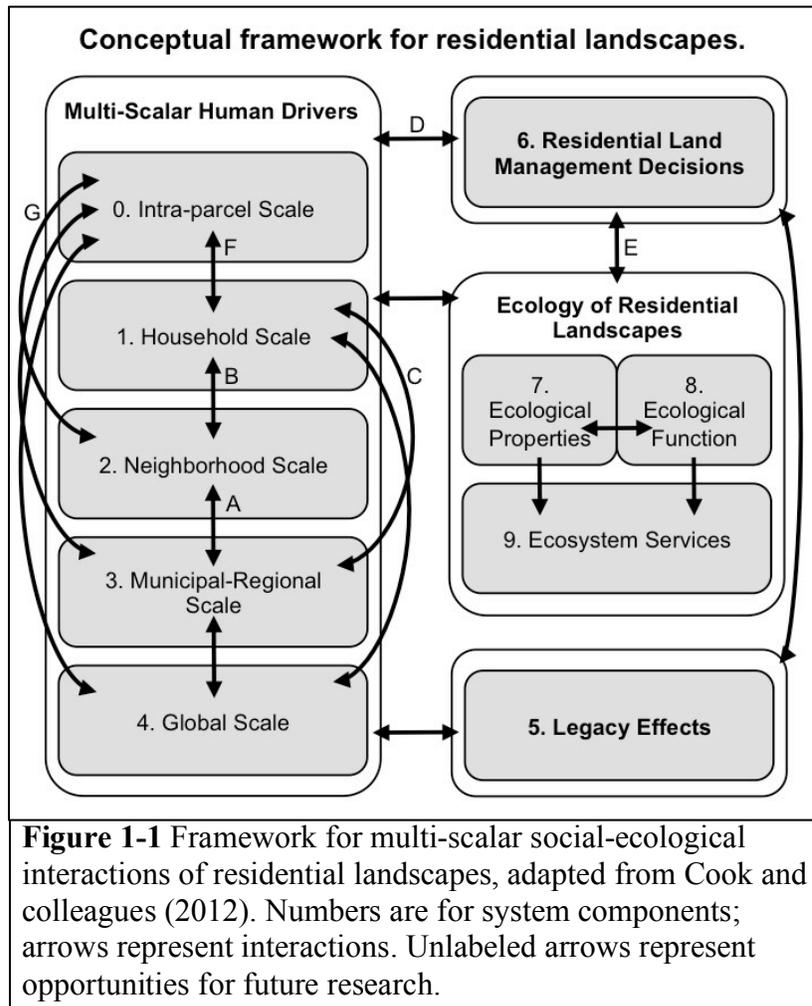
Background and the Cross-cutting Attention to Scale

A review of 256 papers on private residential landscapes conducted by Cook and colleagues (2012) identified that more work is needed to apply methods across geographic contexts and scales, and incorporate multi-scalar interactions. Another research gap identified in their review is that more research is needed to understand the

causes and consequences of private land management activities such as irrigating, fertilizing, and pesticide application, and how management varies across climates, space, and by scale. Moreover, although social norms are often cited as an important driver of yard care behaviors, owing to residents' desires to 'fit in', it remains unclear how those social pressures may influence management in back yards, where visibility is reduced if not completely eliminated. Social norms compel residents to create a yard appearance deemed acceptable in their perceptions of such norms. What about the spaces that are not as easily seen by others? Differences between front and back yards are understudied owing to the difficulty of data collection, especially in backyards. This dissertation is approached using a modified version of their existing framework, derived from their review of existing literature (Cook et al 2012, See Figure 1-1).

This dissertation focuses on the Multi-Scalar Human Drivers, Residential Land Management Decisions, Ecological Properties, and Ecological Function (Figure 1-1). I also argue for and investigate the potential importance for including Cell 0: the Intra-Parcel scale. This dissertation addresses the interactions of these components via three targeted research papers. Chapter 2 examines the geographic variation of irrigation, fertilization, and pesticide application (Cell D) across regional, neighborhood, and household scales (Cells 1 – 3), and their interactions (Arrows A – C) using multi-level statistical models. Chapter 3 examines how neighborhood contexts (Cell 2) shape via social norms (Arrow B) household (Cell 1) and intra-parcel (Cell 0) management decisions (Arrow D) using semi-structured interviews. Chapter 4 examines the intra-parcel scale (Cell 0) variability in ecological properties (Cell 7) and ecological function

(Cell 8) across several regions (Cell 3) in different climates. Scalar interactions are important throughout each of the dissertation's stand alone articles.



Overview of the three papers

To reiterate, the widespread and increasing coverage of residential land, resource-intensive landscaping practices with uncertain environmental outcomes, and the interest in homogenizing ecosystems motivate this dissertation. In studying the geographic variation (ch 2, 4), drivers (ch 2, 3), and environmental outcomes (ch 3, 4) of yard care

deliberate care and attention are given to scales and their interactions throughout (Figure 1-1). Each of the Stand Alone Articles contains theoretical, methodological, and empirical contributions to geographic research, which are highlighted next.

Chapter 2 “Heterogeneity of practice underlies the homogeneity of ecological outcomes of United States yard care in metropolitan regions, neighborhoods and household”

Recent studies suggest that urbanization homogenizes environmental conditions and processes across the United States (Groffman et al. 2014; Steele et al 2014; Hall et al 2016; Pearse et al 2016, Wheeler et al *In Press*). An objective of the first paper in this three-article dissertation is to advance theory on the extent to which—if at all—residential yard care practices associated with homogeneous ecological outcomes are also homogeneous. Despite repeated calls for attention to the scalar dynamics and nesting of residential land use and landscapes (Grove et al 2005; Cook et al 2012; Roy Chowdhury et al 2011), we continue to lack systematic, spatially explicit, cross-site analyses of residential ecologies that are also unambiguously multi-scalar in their approach. The commonly evoked explanations for private residential land management, as demonstrated in chapter two, operate at global, municipal-regional, neighborhood, and household scales (Figure 1-1), with theorized interactions. Yet most the published research on the topic is focused on either the neighborhood or household scale, making claims about the totality of the known drivers impossible – by design. Moreover, the generalizability of single-site studies is also limited.

One of the many contributions of this dissertation is methodological in nature. A telephone survey of 7,021 households collected data to characterize what people are

doing with respect to irrigation, fertilization, and pesticide application. Chapter two responds to calls for assessing multiple drivers jointly, and uses binary logistic multilevel statistical models to unambiguously link the household, neighborhood, and regional scales to management activities via the analysis of telephone surveys of randomly selected households located in six US cities (Baltimore, MD; Boston, MA; Los Angeles, CA; Miami, FL; Minneapolis-St. Paul, MN; and Phoenix, AZ). This chapter demonstrates the methodological feasibility of explicitly multi-scalar analyses with cross-site data. Geographers should use multi-level models instead of, or as a complement to, the commonly employed spatially autoregressive models (i.e. Locke et al 2016). This is because multi-level models control for spatial autocorrelation like spatially autoregressive models, allow for spatial non-stationarity like geographically weighted regression, and allow for the assessment of correlations at multiple nested scales (Locke et al 2016).

Empirically, we found that the odds of irrigating vary widely at the regional scale, but not along an urban-rural gradient. The opposite was true for fertilization. Having more than the average reported household income was associated with ~16% to 23% greater odds of irrigation, fertilization, and pesticide application after adjusting for population density and regional factors. Importantly for the questions about social norms this dissertation addresses, we found that knowing more neighbors by name corresponded to an ~8% increase in the odds of both irrigation and fertilization, but not a significant increase or decrease in the odds of applying pesticides. In addition to answering several

smaller research questions, this paper addresses the overarching, “What are people doing and where?” with respect to yard care question.

Chapter 3 “Landscape Mullets Part 1: Hearing it from the horse’s mouth”

This dissertation extends also the theoretical body of work on the drivers of residential yard management decisions and practices (i.e., addressing why residents manage parcels as they do), by considering how social norms may affect residential ecologies within parcels via self-presentation and performance. The abundant literature on residential landscaping consistently identifies the role of social norms influencing management. The concept of the Moral Economy asserts that anxiety over particular aesthetics compel people to maintain the quintessential American Lawn (Robbins, Polderman & Birkenholtz, 2001; Robbins & Sharp 2003; Robbins 2007). A complementary concept called the Ecology of Prestige asserts that households are motivated by pride and joy and use landscaping as status symbols when seeking acceptance in their social group (Grove et al 2006a,b, 2014; Troy et al 2007; Zhou et al 2009; Locke et al 2016). Both explanations rely on people seeking acceptance via self-presentation.

Self-presentation can only occur where it can be seen. So those explanations do not grapple with how social norms are potentially spatially differentiated (or not) at the intra-parcel scale, specifically from visible to less-visible spaces. While previous research has uncovered different management practices between front and back yard practices (e.g. Harris et al 2012), they have for the most part done so accidentally. We therefore introduce and define the Landscape Mullet concept as a difference in yard care priorities

between front and back driven by the reduced sense of social norms associated with back yards as a theoretical advance. The two key components are 1) social norms are an important driver, and 2) those norms vary spatially across a residential parcel from front (public) to back (private).

Chapter three uses 36 in-depth, semi-structured interviews with residents in a case study city (Baltimore, MD) to learn their motivations, capacities, and interests in residential land management. This paper specifically and intentionally looks at how the visible and less-visible aspects of residential properties connect to social norms influencing residents' decisions. Interviews and tours of residents' yards were used to examine firsthand the Landscape Mullets concept. This chapter therefore addresses the, "Why are they doing it?" overarching question, with specific attention given to front/back, public/private aspects of yards care.

There was empirical support for the two-part premise described above in six of the seven neighborhoods studied. In one neighborhood the evidence was inconclusive due to short interviews and lack of access. Therefore the front/back, public/private distinction as a refinement to the commonly evoked social norms explanation does not appear to be neighborhood specific. The findings suggest further research should examine the potential environmental consequences of unevenly distributed yard care within a residential property parcel.

Chapter 4 "Landscape Mullets Part 2: Plots and Parcels"

If social norms play an important role in yard care behaviors, and those pressures are reduced if not completely eliminated where visibility is reduced if not completely

eliminated, then vegetation species and soil characteristics should be different as well. The intra-parcel scale management is largely ignored in previous studies, an empirical gap this paper begins to fill. Informed by the Landscape Mullets concept, chapter four tests how social norms may lead to sub-parcel scale environmental differentiation, by examining vegetation species and seven indicators of biogeochemical cycling on front and back yards located in seven climatically distinct metropolitan regions: Baltimore, MD; Boston, MA; Los Angeles, CA; Miami, FL; Minneapolis-St. Paul, MN; Phoenix, AZ; and Salt Lake City, UT.

We analyzed plant species in lawns in seven cities, soils properties in six cities, and entire-yard vegetation species in two cities across front and back yards. Specifically we examined vegetation species richness and evenness in lawns; microbial biomass, respiration, potential net mineralization, potential net nitrification, potential denitrification, ammonium, biologically available nitrogen measures in soils; and vegetation species richness for entire yards. We found no significant differences between front and back yards in lawn species richness or evenness, or seven key indicators of the nitrogen cycle found in soils. When examining entire-yard species richness of spontaneous vegetation species (i.e. not planted by a human), we also did not find significant differences between front and back yards. However, cultivated species richness in back yards in Salt Lake City and Los Angeles have a regression-adjusted estimate of approximately 10% more cultivated species and there was no interaction effect for city. The raw, unconditional mean cultivated species richness was 19.53 (median = 17) for front yards, and 24.71 (median 21) for back yards, which is on average

~20% more species. It appears that lawns and the soils beneath them are fairly homogenous at the sub-parcel scale (lending partial support to the homogenization hypothesis), but the entire-yard species richness was 10% - 20% greater in back yards than front yards (lending support to the Landscape Mullets concept).

Conclusions

Residents' management decisions remain understudied despite the substantial environmental impacts – positive or negative – of millions of decisions affecting billions of acres of land. This dissertation investigates 1) the geographic variation of yard care practices in different climatic regions of the U.S., 2) households' motivations for front and backyard yard care practices, and the role of social norms in shaping those land management decisions, and 3) the potential intra-parcel scale variation in vegetation communities and nitrogen cycling.

In order to advance theory development, this dissertation uses a mixed methods approach, integrating both quantitative and qualitative data and approaches. The blending of telephone surveys (chapter 2), residential land manager interviews (chapter 3), and ecological field surveys (chapter 4) offer the potential to advance understanding of the patterns and the processes that drive residential yard care decisions at multiple scales. This dissertation contributes to broader literatures on public and private spaces and places, using residential environmental behaviors and outcomes as an example. The practical motivations for understanding the dominant human habitat in the United States are manifold. Efforts to theorize and explain households' behaviors within larger nested

scales – neighborhoods, municipalities, metropolitan regions, and the global context – make understanding other human-environment interactions possible.

Acknowledgements

This research is supported by the Macro- Systems Biology Program (US NSF) under Grants EF-1065548, -1065737, -1065740, -1065741, -1065772, -1065785, -1065831, and -121238320 and the NIFA McIntire-Stennis 1000343 MIN-42-051. The work arose from research funded by grants from the NSF LTER program for Baltimore (DEB-0423476); Phoenix (BCS-1026865, DEB-0423704, and DEB-9714833); Plum Island, Boston (OCE-1058747 and 1238212); Cedar Creek, Minneapolis–St. Paul (DEB-0620652); and Florida Coastal Everglades, Miami (DBI-0620409). The findings and opinions reported here do not necessarily reflect those of the funders of this research.

References

- Brown, Daniel G., Kenneth M. Johnson, Thomas R. Loveland, and David M. Theobald. 2005. “Rural Land-Use Trends in the Conterminous United States, 1950-2000.” *Ecological Applications* 15 (December): 1851–63. doi:10.1890/03-5220.
- Cook, Elizabeth M., Sharon J. Hall, and Kelli L. Larson. 2012. Residential Landscapes as Social-Ecological Systems: A Synthesis of Multi-Scalar Interactions between People and *Their Home Environment*. *Urban Ecosystems*. Vol. 15. doi:10.1007/s11252-011-0197-0.

- Grimm, Nancy B., Stanley H. Faeth, Nancy E Golubiewski, Charles L Redman, Jianguo Wu, Xuemei Bai, and John M Briggs. 2008. "Global Change and the Ecology of Cities." *Science* 319 (5864): 756–60. doi:10.1126/science.1150195.
- Groffman, Peter M., Jeannine Cavender-Bares, Neil D Bettez, J. Morgan Grove, Sharon J Hall, James B Heffernan, Sarah E. Hobbie, et al. 2014. "Ecological Homogenization of Urban USA." *Frontiers in Ecology and the Environment* 12 (1): 74–81. doi:10.1890/120374.
- Groffman, Peter M., J. Morgan Grove, Colin Polsky, Neil D Bettez, Jennifer L Morse, Jeannine Cavender-Bares, Sharon J Hall, et al. 2016. "Satisfaction, Water and Fertilizer Use in the American Residential Macrosystem." *Environmental Research Letters* 11 (3): 34004. doi:10.1088/1748-9326/11/3/034004.
- Grove, J. Morgan, William R. Jr. Burch, and Steward T. A. Pickett. 2005. "Social Mosaics and Urban Community Forestry in Baltimore , Maryland Introduction: Rationale for Urban Community Forestry Continuities From Rural to Urban Community Forestry." In *Communities and Forests: Where People Meet the Land*, edited by R. G. Lee and Field D. R., 248–73. Corvallis: Oregon State University Press.
- Hall, Sharon J, J. Learned, B. Ruddell, K. L. Larson, J. Cavender-Bares, N. Bettez, Peter M. Groffman, et al. 2016. "Convergence of Microclimate in Residential Landscapes across Diverse Cities in the United States." *Landscape Ecology* 31 (1): 101–17. doi:10.1007/s10980-015-0297-y.

- Harris, Edmund M., Colin Polsky, Kelli L. Larson, Rebecca Garvoille, Deborah G. Martin, Jaleila Brumand, and Laura Ogden. 2012. "Heterogeneity in Residential Yard Care: Evidence from Boston, Miami, and Phoenix." *Human Ecology*, August. doi:10.1007/s10745-012-9514-3.
- Larson, K. L., K. C. Nelson, S. R. Samples, S. J. Hall, N. Bettez, J. Cavender-Bares, Peter M. Groffman, et al. 2015. "Ecosystem Services in Managing Residential Landscapes: Priorities, Value Dimensions, and Cross-Regional Patterns." *Urban Ecosystems*. doi:10.1007/s11252-015-0477-1.
- Locke, Dexter H., Shawn M. Landry, J. Morgan Grove, and Rinku Roy Chowdhury. 2016. "What's Scale Got to Do with It? Models for Urban Tree Canopy." *Journal of Urban Ecology* 2 (1): juw006. doi:10.1093/jue/juw006.
- Milesi, Cristina, Steven W Running, Christopher D Elvidge, John B Dietz, Benjamin T Tuttle, and Ramakrishna R Nemani. 2005. "Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States." *Environmental Management* 36 (3): 426–38. doi:10.1007/s00267-004-0316-2.
- Pearse, William D, Jeannine Cavender-Bares, Sarah E Hobbie, Meghan Avolio, Neil Bettez, Rinku Roy Chowdhury, Peter M Groffman, et al. 2016. "Ecological homogenisation in North American urban yards: vegetation diversity, composition, and structure" bioRxiv 061937; doi: <https://doi.org/10.1101/061937>
- Polsky, Colin, J. Morgan Grove, Chris Knudson, Peter M. Groffman, Neil D Bettez, Jeannine Cavender-Bares, Sharon J. Hall, et al. 2014. "Assessing the Homogenization of Urban Land Management with an Application to US

- Residential Lawn Care.” *Proceedings of the National Academy of Sciences* 111 (12): 4432–37. doi:10.1073/pnas.1323995111.
- Robbins, Paul, Annemarie Polderman, and Trevor Birkenholtz. 2001. “Lawns and Toxins: An Ecology of the City.” *Cities* 18 (6): 369–80. doi:10.1016/S0264-2751(01)00029-4.
- Robbins, Paul, and JT Sharp. 2003. “Producing and Consuming Chemicals: The Moral Economy of the American Lawn.” *Economic Geography* 79 (4): 425–51.
- Robbins, Paul. 2007. *Lawn People: How Grasses, Weeds, and Chemicals Make Us Who We Are*. Temple University Press.
- Roy Chowdhury, Rinku, Kelli L. Larson, J. Morgan Grove, Colin Polsky, and Elizabeth M. Cook. 2011. “A Multi-Scalar Approach to Theorizing Socio-Ecological Dynamics of Urban Residential Landscapes.” *Cities and the Environment (CATE)* 4 (1): 1–19. <http://digitalcommons.lmu.edu/cate/vol4/iss1/6/>.
- Steele, M. K., J. B. Heffernan, Neil D Bettez, Jeannine Cavender-Bares, Peter M. Groffman, J. Morgan Grove, S. Hall, et al. 2014. “Convergent Surface Water Distributions in U.S. Cities.” *Ecosystems* 17 (4): 685–97. doi:10.1007/s10021-014-9751-y.
- Wheeler, Megan M., Christopher Neill, Peter M Groffman, Meghan Avolio, Neil D Bettez, Jeannine Cavender-Bares, Rinku Roy Chowdhury, et al. *In Press*. “Homogenization of residential lawn plant species composition across seven US urban regions.” *Landscape and Urban Planning* <http://dx.doi.org/10.1016/j.landurbplan.2017.05.004>

**CHAPTER 2 HETEROGENEITY OF PRACTICE UNDERLIES THE
HOMOGENEITY OF ECOLOGICAL OUTCOMES OF UNITED STATES YARD
CARE IN METROPOLITAN REGIONS, NEIGHBORHOODS AND
HOUSEHOLDS**

Submitted to *PLoS ONE* on December 22, 2016.

Dexter H. Locke¹, Colin Polsky², J Morgan Grove³, Peter M Groffman⁴, Kristen C.

Nelson⁵, Kelli L. Larson⁶, Jeanine Cavender-Bares⁷, James B. Heffernan⁸, Rinku Roy

¹ Graduate School of Geography, Clark University 950 Main Street, Worcester MA 01610-1477, USA

² Florida Atlantic University, Center for Environmental Studies, 3200 College Ave., Building DW, Davie, FL 33314

³ USDA Forest Service, Baltimore Field Station, Suite 350, 5523 Research Park Dr., Baltimore, MD 21228

⁴ CUNY Advanced Science Research Center and Brooklyn College Department of Earth and Environmental Sciences 85 St. Nicholas Terrace, 5th Floor New York, NY 10031

⁵ Department of Forest Resources and Department of Fisheries, Wildlife, & Conservation Biology, University of Minnesota, 115 Green Hall, 1530 Cleveland Ave. N. St. Paul, MN 55108

⁶ Schools of Geographical Sciences and Urban Planning and Sustainability, Arizona State University, Tempe, AZ 85287-5302

⁷ Department of Ecology, Evolution and Behavior, University of Minnesota, St. Paul, MN 55108

⁸ Nicholas School of the Environment, Box 90328, Duke University, Durham, NC 27708

Chowdhury¹, Sarah E. Hobbie⁷, Neil D. Bettez⁹, Sharon J. Hall¹⁰, Christopher Neill¹¹,
Laura Ogden¹², Jarlath O’Neil-Dunne¹³

Abstract

Recent studies of urban ecosystems suggest that cities resemble one another in ecological structure and function. The management of residential landscapes may be an important driver of this similarity because most vegetation in urban areas is located within residential properties. To understand geographic variation in yard care practices (irrigation, fertilization, pesticide application), we analyzed previously studied drivers of urban residential ecologies with multi-level models to systematically address nested spatial scales within and across regions. We examine six U.S. metropolitan areas—Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, and Los Angeles—that are located in diverse climatic conditions. We find significant variation in yard care practices at the household (the relationship with income was positive), urban-rural gradient (the relationship with population density was an inverted U), and regional scales (metropolitan statistical areas-to-metropolitan statistical area variation), and that a multi-level modeling framework is instrumental in discerning these scale-dependent outcomes. Multi-level statistical models control for autocorrelation at multiple spatial scales. The

⁹ Cary Institute of Ecosystem Studies, 2801 Sharon Turnpike, Millbrook, NY 12545

¹⁰ School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501

¹¹ The Ecosystems Center, Marine Biological Laboratory, 7 MBL Street, Woods Hole, MA 02543

¹² Dartmouth College, Department of Anthropology, 406A Silsby Hall, Hanover, NH 03755-3529

¹³ University of Vermont, Spatial Analysis Lab, Rubenstein School of Environment and Natural Resources, 205E Aiken Center, 81 Carrigan Drive, Burlington, VT 05405

results also suggest that heterogeneous yard management practices may be significant in producing homogeneous ecological outcomes on urban residential lands.

Introduction

Recent studies suggest that urbanization homogenizes environmental conditions and processes across the United States (1-3). These findings lend support to the so-called urban ecological homogenization hypothesis: the ecological structure and function of urban areas resemble one another, even when the cities are located in biophysically distinct settings (4, 1). This homogenization raises important questions about large-scale changes in nutrient (e.g., nitrogen and phosphorous) cycling, biodiversity, water availability, and other environmental outcomes important for societies and ecosystems (5). Responding to this homogenizing set of outcomes requires understanding the underlying social behaviors. Interestingly, homogenized ecological outcomes are not necessarily produced by homogeneous social practices or influences (4, 6-8). This distinction is important because homogeneous ecological outcomes may be associated with heterogeneous social practices. For instance, arid areas may require more irrigation than mesic and humid areas to create similar ecological structure. The social practices that lead to urban ecological homogenization may be heterogeneous at different scales such as households, neighborhoods approximated with Census block groups, and regions, and influenced by a variety of socio-cultural processes as well as by biophysical conditions such as climate (9, 8).

Residential areas are a dominant land use in urban regions, and their management

may be a significant driver of the ecological homogenization of cities (10). Here we define yards as outdoor areas around homes inclusive of lawns and other types of groundcover and vegetation. Yard care may produce substantial alterations in nutrient and hydrologic cycles and general ecosystem structure and function. Lawns in the United States occupy nearly four times as much land area as corn, the country's leading irrigated crop (11). Lawn, garden, and yard equipment manufacturing, landscaping services, and lawn and garden stores accounted for \$72.7 billion of sales in 2002 in the US (12). These expenditures raise concern about the use of water, nitrogen, phosphorous, and pesticide inputs, which may have unintended environmental consequences on beneficial insects and downstream water quality (1, 13-15). Because of the widespread adoption and significance of these activities and their potential environmental effects, there is a need to better understand the drivers, outcomes and geographic variation in yard care practices, across the U.S.

Investigating lawn and yard care practices is a growing part of residential ecosystems research (7, 10, 16). However, it is unclear whether or to what degree case study or city-specific findings can be generalized to multiple locations. Differences or similarities in results from site-specific studies of residential ecosystems may be attributable to methodological choices or from actual differences in the social and/or biophysical characteristics of a particular study site. A multi-site approach with standardized methods is needed to evaluate the generalizability of site-specific research on residential ecosystems, and is particularly relevant to theorization of urban ecological homogenization (8-10, 17).

This paper contributes to knowledge of urban residential landscapes. We pursue three specific objectives. The first is to advance theory on the extent to which—if at all—residential yard care practices associated with homogeneous ecological outcomes are also homogeneous. A second objective is to better understand drivers of three yard care behaviors. Specifically, we characterize patterns of irrigation, fertilizer, and pesticide applications among households and across block groups in metropolitan regions using a georeferenced telephone survey of ~7,000 households. A third objective is to employ multi-level modeling (MLM) to examine how household, neighborhood, and regional scale factors relate to yard management. Although scholars have recognized the multi-scalar influences on household landscaping decisions (Figure 2-1, 8-10), few studies have used MLM to empirically examine scaled relationships with various management practices. We therefore demonstrate how data and methods that explicitly incorporate the multi-scaled nature of these relationships are needed to better understand the urban ecological homogenization hypothesis and drivers of yard care. Next we review recent literature on urban ecological homogenization, the multi-scalar drivers of yard care practices, and the empirical foundations for our methodological approach.

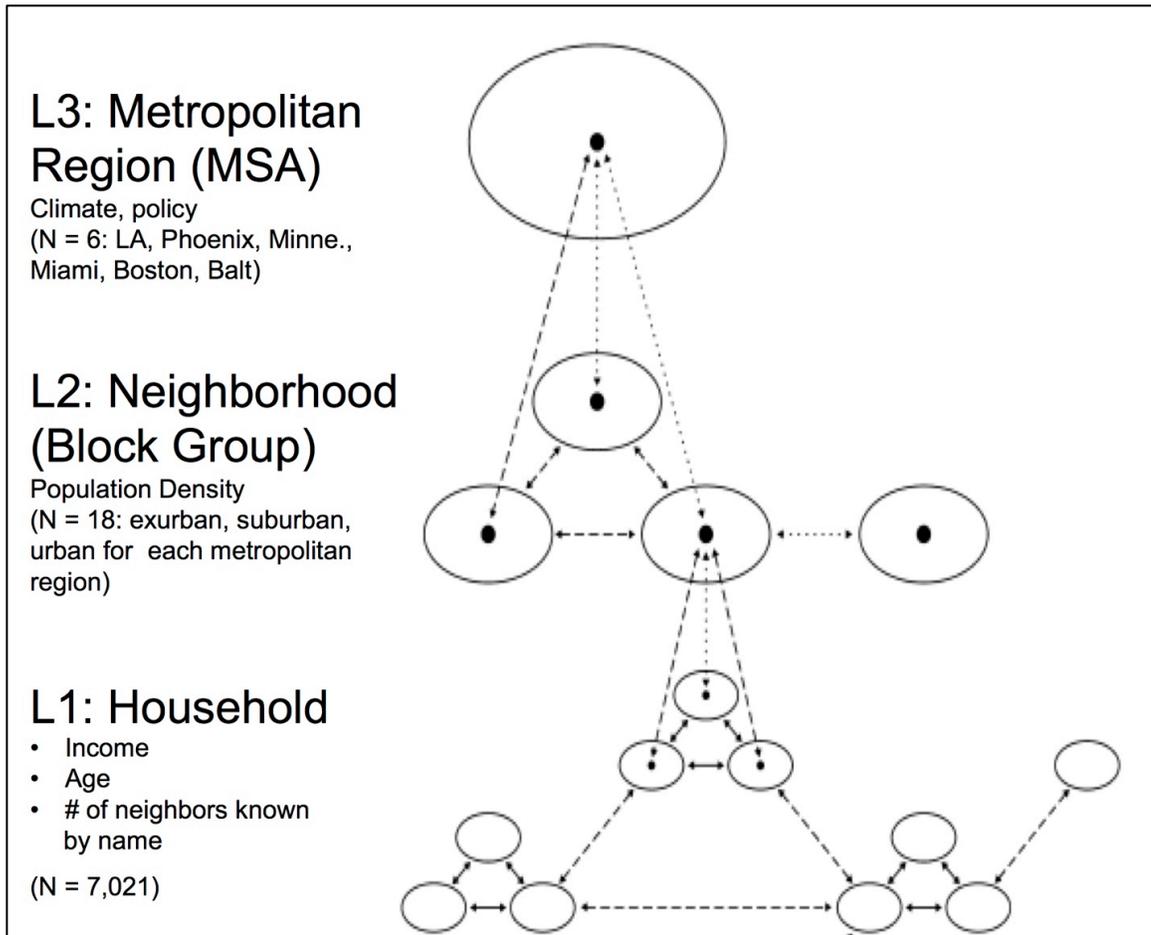


Figure 2-1 Adapted from 9, 18-19. L = Level, MSA= Metropolitan Statistical Area.

Urban ecological homogenization hypothesis.

Recent biophysical research has begun to empirically test the urban ecological homogenization hypothesis (6, 20). While some exotic species are common in many cities, global urban biotas are not yet taxonomically identical (20). Our definition of ecological homogenization is that the ecological structure and function of urban areas resemble one another, including residential ecosystems, even when the cities are located in biophysically distinct settings (1). This homogenization of “outcome” is driven at least partially by a homogenization of “practice” through the use of water and fertilizer (8, 21).

In addition, microclimates at the residential property scale appear increasingly similar across diverse biophysical regions (3). In a study of ~1 million water bodies and 1.4 million km of flow paths in the contiguous United States, the authors found that urbanization reduced the number of surface water bodies in humid cities and increased the number of water bodies in arid cities, leading to similar distributions of water bodies across urban regions regardless of climate (2). This provides evidence for the idea of urban ecological homogeneity for at least some aspects of ecosystem structure.

Urban ecosystem research has examined the social practices related to homogenization. To understand how residents valued a wide range of ecosystem services provided from their own yards, Larson and others (17) conducted in-person interviews with residential homeowners in six metropolitan areas of the U.S. — Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, and Los Angeles. Residents in all metropolitan regions highly valued certain cultural ecosystem services such as aesthetics and personal enjoyment of yards. Green, weed-free yards with a neat appearance were preferred, as were low-maintenance and low-cost management practices. In contrast, residents uniformly placed lower value on the potential educational, spiritual, and heritage benefits of yards. A few ecosystem services varied in importance across broad regions. For example, residents in warmer climates—Phoenix, Los Angeles, and Miami—valued aesthetics and the cooling effects of vegetation, but those in northern cities—Baltimore, Boston, and Minneapolis-St. Paul—valued low-maintenance landscapes. Residents of the humid eastern U.S.—Miami—placed more value on the climate change regulation and native wildlife benefits than did those in the western U.S.; they also said costs were more

important. As a whole, this study found substantial uniformity in which ecosystem services are valued by residents, yet some distinctions were found for select cultural and provisioning services.

Another recent cross-site study suggested that heterogeneous practices may underlie homogenous ecological outcomes for residential yards. Irrigation and fertilization were analyzed based on responses to a telephone survey stratified by population density, socioeconomic status, and lifestage (8). The number of respondents who irrigated or fertilized in the last year were analyzed for within metropolitan region variation (i.e., along population density, socioeconomic status and/or lifestage gradients) and for across-region variation. Of the 36 types of comparisons (2 practices [irrigation and fertilization] x 3 social gradients x 6 regions), the results provided only 2 cases for both within-region and across-region homogeneity. There were 13 examples of within-region homogeneity and across-region differentiation, 9 cases of within-region differentiation and across-region heterogeneity, and 12 cases of within-region and across-region differentiation (8).

The mixed findings of homogenization and differentiation – and at two coarse scales (treated as two statistical groups – within- vs. between-region) – suggests the need to look more closely at other factors. Moreover, pesticide application is a significant yard care management practice with important social and ecological dimensions as well as potential health consequences (15), and needs to be examined for broad cross-site trends. Finally, other research has emphasized the need to examine multiple scales simultaneously (9), not in isolation, yet few studies attempt to do so systematically. In

particular, the drivers of yard care practices are not routinely analyzed using multi-level modeling techniques, despite the recognition that household, neighborhood, municipal, and broader scale factors influence decision making at the local level (9, 10, 22). Thus, while recent studies have demonstrated homogeneity and heterogeneity in one or more yard management practices across cities, we continue to lack integrated research that examines all three common yard management practices (irrigation, fertilization, and pesticide application), identifies the extent to which those practices and outcomes diverge or converge across distinctive geographies and scales, and links those management practices to broader sets of driving processes. This paper addresses these knowledge gaps by investigating pesticide application in addition to irrigation and fertilization; examining a broader set of potential drivers in an explicit, multi-level modeling framework, and assessing whether heterogeneous or homogenous practices underlie homogenization of outcomes in residential yards. We systematically examine the role of scaled underlying drivers by estimating explicitly multi-level models including income, respondent age, and the number of neighbors known by name at the household level, the role of population density across an urban-rural gradient, and the potential role of climate by simultaneously studying people in cities pertaining to very different eco-climatic regions of the US.

Understanding residential land management as a multi-scaled process

Use of water for irrigation, fertilizers, and pesticides across U.S. households may present a mounting environmental problem of national scope (8, 14, 15). However, the prevalence of specific lawn care practices appears to be highly variable and more

research is needed to evaluate the factors that underlie this variation (23-26). While irrigation, fertilization and pesticide applications occur ultimately at the household-scale, the factors influencing these household-scale practices may operate at multiple scales, including the neighborhood, municipal, regional, and climatic scales (Figure 2-1, 9). Given this apparent variability by scale we propose that these scales should be considered explicitly and simultaneously with appropriate data and methods.

Household level factors

Understanding the decision-making process begins at the household scale or “level”. Some have argued that yard care practices are a basic economic cost-benefit question about a specific kind of lawn and yard design and the resources required to produce that outcome. Because irrigation, fertilization, and pesticide practices are not free, a plausible hypothesis is that higher-income households irrigate, fertilize, and apply pesticides more than lower-income households (27-29). Research in Baltimore, MD found positive correlations between household income and total yard care expenditures, expenditures on yard care supplies, and expenditure on yard machinery (30). The underlying rationale for this hypothesis is that although all households may desire the same outcome, not all households have the same economic resources needed to achieve the outcome. If this hypothesis is correct, we would expect higher income households to manage their yards more intensively.

Another household-level hypothesis is that preferences for different yard types vary with homeowner age. Older residents may prefer less management-intensive

strategies, for example. Alternatively, the time available for engaging in yard care may increase with age. The overall empirical evidence is mixed. Some studies have demonstrated the importance of homeowner age on yard care (31-33). In a study of Nashville, TN, Carrico and others (25) found a modest, positive correlation between age and fertilizer use after controlling for property value, individualistic interests, environmental concerns, social pressures among others. In contrast, Martini and colleagues (34) did not find significant associations between age and fertilizer use or frequency of fertilizer application in a study of Minneapolis-St. Paul, MN, when controlling for property size, other sociodemographic variables, and cognitive and affective components. Thus, how homeowner age may affect yard care decision-making remains poorly understood. Household age effect may be significant in explaining specific yard care behaviors, but there is not yet a consensus on which behaviors are linked with older or younger residents, or why. More research with standardized methods across diverse regions is needed to better understand the relationship between yard care and resident age.

Researchers have also argued that household-level analyses should include sociological factors. One theory of residential behavior is called an “ecology of prestige” (35-38). An ecology of prestige proposes that “household patterns of consumption and expenditure on environmentally relevant goods and services are motivated by group identity and perceptions of social status associated with different lifestyles” (30: 746). Lifestyle groups are composed of several key characteristics including income, race, family status, and population density as a proxy for housing type. From this perspective,

housing and yard styles, green grass, and tree and shrub plantings are symbols of prestige. These status symbols also represent participation in a social group, reflecting the social cohesion of the lifestyle group. These status symbols are not just economic luxuries, but are crucial to group identity and social cohesion. For example, a “neat” residential landscape may signal wealth, power, or prestige and membership in a desirable social group (39). By extension, practices often do not reflect a residents’ preferences but instead his or her perceptions of the neighbors’ expectations for what the individual’s yard should look like (40-41). Land management preferences are shaped by peer pressure and the household’s desire to ‘fit in’ with their lifestyle group (22). Thus, different combinations of plantings and care practices reflect the different types of social groups and neighborhoods to which people belong (31, 42-44). An indicator of the social pressures to uphold an established neighborhood aesthetic through yard care behaviors may be associated with whether a household knows their neighbors (44). We hypothesize that knowing more neighbors increases social pressures to uphold the established neighborhood aesthetic for certain yard care behaviors, and is therefore associated with more inputs and management. This more expansive view of sociological benefits (i.e., a sense of belonging and acceptance) of residential land management points to potentially important neighborhood effects.

Urban-rural gradients

As shown above, there are several neighborhood-level theories hypothesized to explain residential landscape features such as lawns, shrubs, and trees. Another factor that has been proposed is population density. The salience of population density as a

variable at the neighborhood scale can be explained based upon a two-part premise (37, 38, 45, 46). First, residential land management will be limited by the amount of land that is available. One cannot water a yard that is not present. Second, the amount of available land may influence the intensity of the management because of differences in social norms associated with population and housing types characteristic of rural, suburban, and urban environments.

Regional analyses and climate

Given the possible influence of urban form and housing types on yard management, it is somewhat surprising that previous research has not investigated if, how, or to what extent different climates across multiple cities are linked to yard care practices such as irrigation and the application of fertilizers and pesticides. We hypothesize that irrigation will be more linked to climate than fertilization and pesticide application. Multi-site analyses are important for understanding how variation in precipitation, soil quality, and potential evapotranspiration may influence yard care behaviors if a certain aesthetic is desired and affordable. Examining regional variations are critical to account for whether different practices in different places are required to achieve similar outcomes (2).

In summary, given recent interest in urban ecological homogenization and in potential drivers of residential land management at different scales, we adopt a multi-management practice, multi-site, and multi-level approach in this paper. This paper adds to the growing body of empirical research on the drivers of yard care in several ways.

First, we use a multi-site comparative approach, while adding to the practices examined, and to the variables that may explain variations in those practices. Second, we advocate for the use and importance of multi-level modeling for multi-scaled socio-ecological processes by empirically demonstrating their utility. Therefore, in support of the three objectives described in the introduction, our three research questions are:

- 1) Is there homogeneity of yard care practices among six urban regions in different climates, and if so, at what scales?
- 2) What are the drivers of variation in practices and on what scale do they operate?
- 3) How does the use of multi-level models improve our understanding of these patterns and drivers at different scales?

Materials and Methods

Methodological rationale and the advances needed

Our literature review suggests that although it is widely recognized that the multiple drivers of yard care may also be multi-scaled, few studies have employed multi-scaled data and analyses. More complex methods may be needed for multi-site, multi-scale research questions. Multi-level modeling is a statistical technique designed to examine clustered, autocorrelated, or hierarchically nested datasets. This technique extends traditional ordinary least squares regressions and is referred to as hierarchical linear modeling or mixed-effects modeling. Multi-level models accommodate observations from multiple scales and/or organizational levels simultaneously.

Most of the existing research on residential yard care practices has examined influences at only one scale at a time. Single-scale research may also confound multiple scales. For example, researchers have confounded household-level research questions on yard care with neighborhood-level analyses frequently operationalized with census block group data (e.g., 30, 35-38, 47-49, among others). While examining block group-level correlates of residential landscape outcomes, such as land cover, this approach averages out household-level heterogeneity of interest, and mixes household-level questions with block group-level analyses. These studies are also prone to the ecological fallacy, which occurs when population-based insights or results are extended or assumed to apply to individual cases (50). Other studies focused on the household scale (e.g., 34, 51 among others), which precludes insights into multi-scaled relationships. Individual- or household-scale analyses may be susceptible to the atomistic fallacy, which occurs when individual samples are considered representative of aggregates of individuals, when they are not (52). The theoretical case and evidence for the presence of multi-scaled influences is overwhelming. We are not suggesting multi-level models are universally applicable; in fact, they may be unnecessary in some cases due to particular scales of variability in specific datasets (e.g. 25). We do contend, however, that the presence and degree of clustering and autocorrelation should be empirically evaluated rather than (implicitly) assumed away or ignored in geographical analyses, and that the scale of analysis should match the scale of the research question. Therefore multi-scaled empirical research questions require multi-scaled statistical techniques.

In addition to the conceptual rationale, there are also statistical reasons for multi-

level analyses. Because household-level management practices may vary across regions, those observations are plausibly clustered or autocorrelated. This violates the independence assumption of ordinary least squares regression and leads to more false positives (Type-I errors) in the significance tests for parameter estimates (53, 54). It is therefore possible that previous research based on aggregates of single-scale or single-level analyses contain spuriously significant results.

Data and study areas

We investigated self-reported irrigation, fertilizer use and pesticide applications in six Metropolitan Statistical Areas (MSAs or simply “regions”) that cover major climatic regions of the US (Boston, MA; Baltimore, MD; Miami, FL; Minneapolis-St. Paul, MN; Phoenix, AZ; and Los Angeles, CA). Telephone interviews were stratified by population density (urban, suburban and rural) because we hypothesized that yard care behaviors vary at the neighborhood scale, along a density gradient. Ordinal population density categories were defined by the PRIZM geodemographic segmentation system using a cluster analysis (55). Also, we operationalize population density within Census block groups, and call MSAs regions. Using these strata, >100,000 households were contacted between November 21 and December 29, 2011, across the six metropolitan regions. Institutional Review Board approval was obtained from the [Institution redacted to preserve anonymity during review] Committee on Human Subjects. Funded by National Science Foundation’s Macro- Systems Biology program, the research team hired the professional survey firm Hollander, Cohen, and McBride (HCM) to carry out the telephone survey. HCM had conducted similar telephone interviews as part of the

Baltimore Ecosystem Study in years 1999, 2000, 2003 and 2006, and thus was known to be a reliable and professional group for this type of telephone interviews.

Telephone interviews with 9,480 people were conducted, of which 7,021 respondents completed the questions that were the focus of this study, and indicated that they made their own decisions about yard management or about contracting yard care. Of the 7,021 complete responses, 98% owned their home. All respondents were at least 18 years of age and had a front yard, a back yard, or both. Our three dependent variables are irrigation, fertilizer use and pesticide application. Respondents were asked “In the past year, which of the following has been applied to any part of your yard:

fertilizers?

pesticides to get rid of weeds or pests?

water for irrigating grass, plants or trees?”

The responses were coded as a binary 0 no, 1 yes. We specified a three-level binary logistic multi-level model for each of the three yard care behaviors. Respondents were also asked about their household income, which was recorded in 8 ordinal categories from 1 to 8 (<\$15K, \$15K - \$25K, \$25K - \$35K, \$35K - \$50K, \$50K - \$75K, \$75K - \$100K, \$100K - \$150K, >\$150K). The self-reported age of the respondent was recorded in five ordinal categories from 1 to 5 (<35 years old, 35 to 44, 45 to 54, 55 to 64, and > 65). Respondents were also asked “*About how many neighbors do you know by name?*” Answer choices included “*None, A few, About half, Most of them, and All of them*”, with

responses also recorded as five ordinal categories from 1 to 5.

Statistical analyses

In order to account for differences in the dependent variables by income, age and number of neighbors known by name, simultaneously by population density and region, three-level generalized linear models were fit for each dependent variable: irrigation, fertilization, and pesticide application. Consistent with best practices in multi-level modeling we first specified a three-level null model for each of the three dependent variables. The null model parses the variation in each household-level dependent variable across the higher-level neighborhood, and metropolitan regional scales. If the null model indicates that the responses appear to cluster by scale, then a more comprehensive multi-level model needed (56). Measures of household-level independent variables were subtracted from their grand means to improve interpretation (56). This approach first tests if a multi-level model is warranted or not. The null model is:

$$\log\left(\frac{\pi_{ijk}}{1-\pi_{ijk}}\right) = \beta_{0jk} + v_{00k} + u_{0jk} + e_{ijk} \quad (\text{eq. 1})$$

where π is the response from household i in Census block group j in metropolitan region k , and β_{0jk} is the household-level intercept in level-two (block group) j in level-three (metropolitan region) k . Because the response variables are binary, the log odds of were modeled instead. In Equation 1, $v_{00k} \sim N(0, \sigma^2)$, $u_{0jk} \sim N(0, \sigma^2)$, $e_{ijk} \sim N(0, \sigma^2)$. No slopes are

specified in equation 1. is decomposed and estimated as a hierarchically nested set of regression equations:

$$\text{at Level 2 (Census block group): } \beta_{0jk} = \delta_{00k} + u_{0jk} \quad (\text{eq. 2})$$

$$\text{at Level 3 (metropolitan region): } \delta_{00k} = \gamma_{000} + v_{00k} \quad (\text{eq. 3})$$

where δ_{00k} represents a neighborhood-scale random effect, γ_{000} is a metropolitan regional-scale random effect, and e_{ijk} is the household-scale residual error term. Here random means allowed to vary, which is in contrast to fixed effects, such as the household-level covariates described below. Level three consists of six units of analysis, whereas level 2 includes 18 units of analysis: six metropolitan regions times three levels of population density—urban, suburban, and rural. As eq 4 below demonstrates, at the household scale there are three variables (income, age, and number of neighbors known by name), at the neighborhood scale there is one variable (population density with three ordinal categories: urban, suburban, and rural), and at the regional scale the region itself acts as a proxy for unmeasured variation from climate.

Next, we fit random intercept, fixed-slope models because the null models demonstrated significant level 2 and 3 variation. This second set of models test the notion that the household lawn care behaviors vary systematically with neighborhood-level population density, and by MSA. After substituting equations 2 and 3 into equation 1, and adding household-level independent variables, the random intercept, fixed-slope models estimated were:

$$\log\left(\frac{\pi_{ijk}}{1 - \pi_{ijk}}\right) = \gamma_{000} + \sum_{s=3} \gamma_{s00}(x_{ijk} - \bar{x}) + v_{00k} + u_{0jk} + e_{ijk} \quad (\text{eq. 4})$$

where γ_{100} is household income, γ_{002} is the respondent's age, and γ_{003} the number of neighbors known by name. For all three practices the random intercept, fixed-slope models had better fit than their null model counterparts. Equation 4 can be extended to accommodate random slopes as well as intercepts, by adding fixed effects into equations 2 and/or 3. Following common best practices in multi-level modeling (56) for each of the three dependent variables (yard care behaviors), a more complex version of eq 4 was also specified. These models add randomly varying slopes of the independent variables to eq 4, at the neighborhood- and city-scales. However, the AIC and deviance criteria did not indicate superior model fits compared to eq 4. Thus the models reported here reflect the specification in eq 4; no added complexity is warranted beyond eq 4., which contains random slopes at levels two and three.

In summary, nine models were fit (three dependent variables, times three specifications: the null model shown in equation 1, a random intercept, fixed-slope model shown in equation 4, and random intercept, random slope model not shown for brevity). All statistical analyses were conducted using the free R programming language version 3.0.2 -- "Frisbee Sailing" (57). Multi-level models were fit using the lme4 package version 1.1-4 (58-59), and significance tests were carried out with the lmerTest package version 2.0-6 (60).

Results

The mean (5.6) and median (6) income score correspond to the \$75K - \$100K group (Table 2-1). The mean (3.34) and median (3) score for age correspond to the 45 to 54 age group. The mean (2.96) of number of neighbors known by name corresponds to the “*About half*” answer, although the median (3) aligns with the “*Most of them*” response.

Table 2-1. Dependent and independent variable definitions, summary statistics, and correlations.

Thematic group	Variable	Mean (%)	s.d.	Min	Max	Spearman's ρ Correlations				
						2	3	4	5	6
Dependent variable (lawn care practice)	1 Irrigation use (Y/N)	(80%)	0.40	0	1	0.25***	0.16***	0.10***	0.00	0.03*
Dependent variable (lawn care practice)	2 Fertilizer use (Y/N)	(64%)	0.48	0	1	1	0.34***	0.15***	0.04***	0.07***
Dependent variable (lawn care practice)	3 Pesticide application (Y/N)	(53%)	0.50	0	1		1	0.10***	-0.01	-0.01
Socio-economic Status	4 Income ^a	5.60	1.74	1	8			1	-0.2***	0.15***
Lifestage	5 Age of respondent ^b	3.34	1.21	1	5				1	0.02
Neighborhood cohesion	6 # of neighbors known by name ^b	2.96	1.01	1	5					1

*** p < 0.001, ** p < 0.01, * p < 0.05

^a eight ordinal categories

^b five ordinal categories

n = 7,021

Irrigation

Irrigation was the most common yard care practice in our study. Across the six US metropolitan areas, 80% of residents reported having irrigated their yard in the last year. The range in irrigation by metropolitan region varied from 64% in Baltimore to 92% in Los Angeles (Table 2-2). When analyzed in terms of the three population density categories (urban, suburban, and rural) per metropolitan region, rural respondents in Baltimore had the lowest proportion of irrigation (60%), and rural communities in Phoenix and suburban areas of Los Angeles had the greatest proportion of irrigators (94%, Table 2-2).

Table 2-2. Self-reported irrigation, fertilization, and pesticide application proportions by population density and metropolitan region.

n	n	Irrigation	(80%)	Fertilization	(64%)	Pesticide Application	(53%)
Phoenix (1,246)	Urban (294)		84%		57%		53%
	Suburban (572)	90%	90%	61%	64%	67%	69%
	Exurban (380)		94%		57%		74%
Minneapolis (1,285)	Urban (304)		84%		45%		33%
	Suburban (568)	85%	87%	70%	80%	53%	58%
	Exurban (413)		83%		74%		61%
Miami (1,011)	Urban (281)		70%		57%		52%
	Suburban (478)	78%	85%	67%	74%	63%	66%
	Exurban (252)		72%		67%		71%
Los Angeles (1,073)	Urban (228)		87%		56%		39%
	Suburban (601)	92%	94%	70%	73%	45%	46%
	Exurban (244)		92%		75%		47%
Boston (1,195)	Urban (225)		74%		51%		30%
	Suburban (595)	72%	71%	64%	65%	43%	44%
	Exurban (375)		72%		71%		48%
Baltimore (1,211)	Urban (263)		66%		43%		39%
	Suburban (553)	64%	66%	54%	62%	47%	51%
	Exurban (395)		60%		49%		48%

Household income and the number of neighbors known by name, reflecting

cohesion, were positively and significantly associated with irrigation when controlling for metropolitan region and block group-level population density (Table 2-3). On the other hand, respondent age did not exhibit a significant relationship with irrigation. Households with higher incomes were on average 1.23 times more likely (95% CI [1.18, 1.27]) to report that they irrigated their yards in the last year, while the odds of irrigating were 8% larger (95% CI [1.01, 1.15]) when homeowners knew more neighbors by name. Note that in the preceding sentence, 1.23 is an odds ratio (OR), which is simply the probability of an event divided by one minus that same probability. Therefore probabilities and ORs measure the same phenomenon on different scales. Odds ratios are easy to interpret; an OR of 1.23 corresponds to an increase of 23% in the odds of irrigating with a one-unit increase in income above the average.

Table 2-3. Three-level binary logistic regression outputs for irrigation, fertilization, and pesticide application.

Level and Parameter	Model					
	Irrigation		Fertilization		Pesticide Application	
	Odds	(95% CI)	Odds Ratio	(95% CI)	Odds Ratio	(95% CI)
Level 1 – Households						
Intercept (γ_{000})	4.72 ^{***}	(2.68, 8.31)	1.75 ^{***}	(1.38, 2.22)	1.08	(0.76, 1.54)
Income (γ_{100})	1.23 ^{***}	(1.18, 1.27)	1.22 ^{***}	(1.18, 1.26)	1.16 ^{***}	(1.13, 1.20)
Age (γ_{200})	1.03	(0.97, 1.08)	1.09 ^{***}	(1.04, 1.13)	1	(0.96, 1.05)
# neighbors' names known (γ_{300})	1.08 [*]	(1.01, 1.15)	1.08 ^{**}	(1.03, 1.14)	0.99	(0.94, 1.04)
Variance components						
Level 2 – Neighborhoods (n = 18) Intercept variance (σ_u^2)	1.071		0.178		0.119	
Level 3 – Metropolitan regions (n = 6) Intercept variance (σ_e^2)	0.468		0.025		0.148	
Diagnostics						
AIC	6,459		8,731		9305	
-2 log likelihood (FIML)	6,447		8,719		9293	
# of estimated parameters	6		6		6	
R ² _{GLMM(M)}	0.035		0.037		0.019	
R ² _{GLMM(C)}	0.171		0.093		0.092	

*** p < 0.001; ** p < 0.01; * p < 0.05

FIML = full information maximum likelihood estimation

R²_{GLMM(M)}, marginal R² for generalized linear mixed model, which is concerned with variance explained by fixed factors

The odds of having irrigated in the last year vary across the examined metropolitan regions in distinct climate zones (Figure 2-2A). As expected, households in the hot, dry climates (Los Angeles and Phoenix) were significantly more likely to water their yards than their counterparts in the cooler, wetter metropolitan areas of Boston and Baltimore. The odds of irrigating in Minneapolis-St. Paul and Miami reflect the sample average, after controlling for population density and the household-level predictors. In contrast, household-level relationships were fairly homogenous at the block group-scale, after the effects of the metropolitan regions were incorporated (Figure 2-2B). Of the 18 metropolitan region-population density combinations, just two had intercepts that varied from the average joint effect for the full sample. Specifically, households in suburban Miami were more likely to irrigate their yards than the other population density categories, and households in rural Miami, were significantly less likely to water (Figure 2-2B). The remaining 16 combinations showed no variation at that scale.

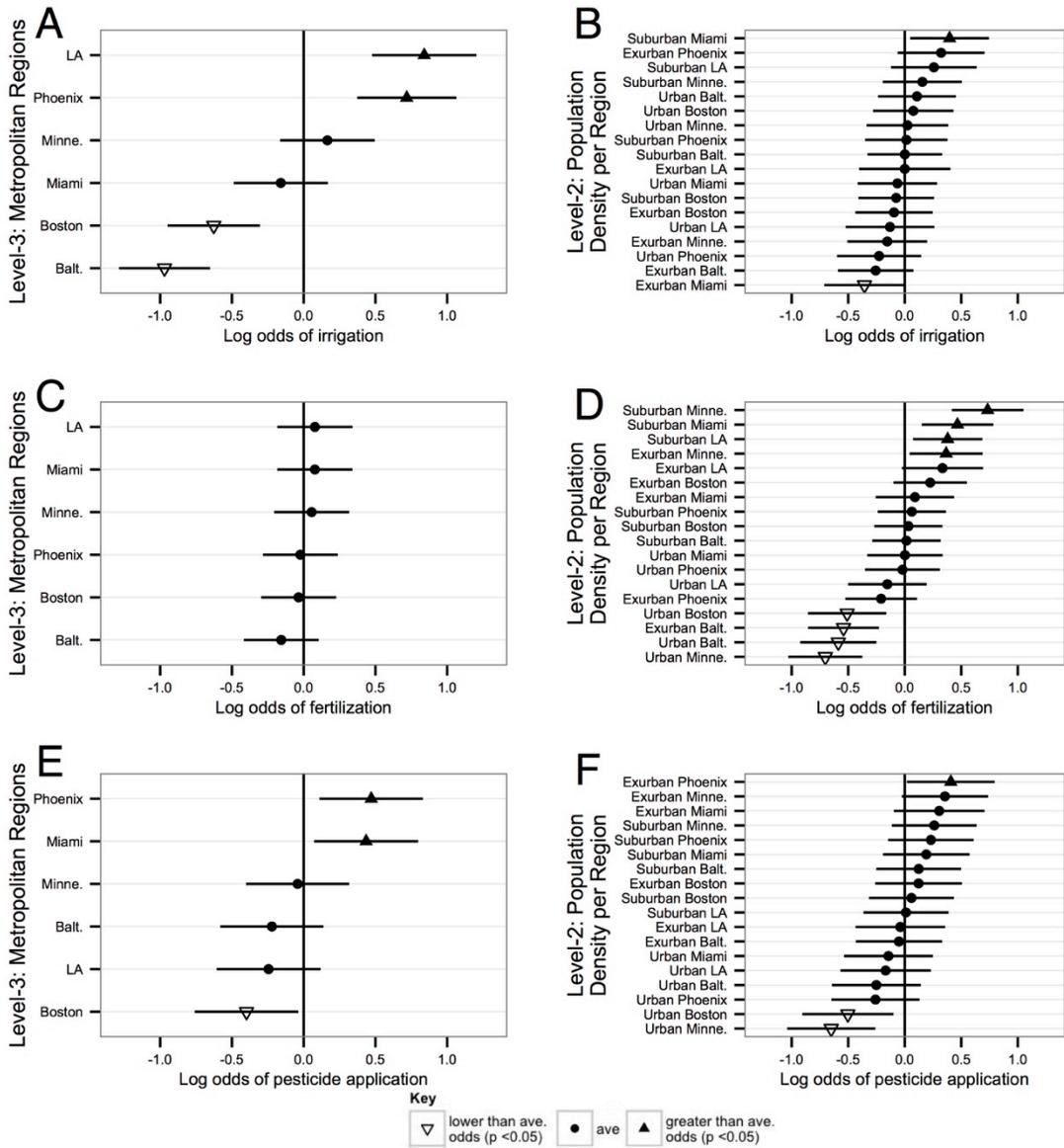


Figure 2-2. Dots and triangles represent the point estimates for the random effects for block group and metropolitan regions, v_{00k} and u_{0jk} , respectively. Horizontal lines are the 95% confidence intervals. When the interval crosses the mean (zero) the estimate is not significantly different from the mean, which is shown with dots. When there are significant differences below the mean, they are shown with downward-oriented triangles, while positive differences above the mean are shown with upward-facing

triangles.

Fertilization

Fertilization was less common than irrigation in our sample, with 64% of all respondents having applied fertilizer in the past year (Table 2-2). The proportion varied by metropolitan region, with Baltimoreans exhibiting the lowest proportion of households applying fertilizers (54%) and Minneapolitans and Angelinos the greatest (70%, Table 2-2). The application of fertilizers was least prevalent among households in urban Baltimore (43%), and most prevalent in suburban Minneapolis-St. Paul (80%, Table 2-2).

All three household-level independent variables exhibited statistically significant, positive relationships with fertilization. The OR for income and fertilization (1.22, 95% CI [1.18, 1.26]) is very similar to the previously noted positive relationship between income and irrigation. Age and number of known neighbors increased the odds of fertilization, with odds ratios of 1.09 and 1.08, 95% CIs [1.04, 1.13] and [1.03, 1.14], respectively.

The odds of fertilization in suburban Minneapolis-St. Paul, Miami, Los Angeles and in rural Minneapolis-St. Paul are significantly higher than in urban Boston, Minneapolis, Baltimore, and rural Baltimore. The remaining ten metropolitan regional-population density combinations exhibit similar, and average, probabilities of applying fertilizers (Figure 2-2D). Greater, and statistically significant, variation is observed across an urban-rural gradient at the block group-scale, than at the regional-scale. There was no variation among metropolitan regions, indicating relative homogeneity at that scale for

applying fertilizers after accounting for population density and household-level predictors (Figure 2-2C).

Pesticide Application

Pesticide application, a management practice that can have important ecological and health impacts, was the least prevalent yard care activity reported in our responses: 53% of all respondents indicated that they applied pesticides to eliminate weeds or pests in the last year. Income was an important correlate of this practice, but it was also the only household-level variable that was statistically significantly related to pesticide use, with wealthier respondents more likely to apply pesticides (OR = 1.16, 95% CI [1.13, 1.20]). Relatively little variation was observed across block group-scale population density classes.

Similar to irrigation and fertilization yard care practices, the prevalence of household pesticide applications by block group-scale population density classes revealed geographic differences. However, those differences were evident in only 3 of the 18 cases: urban Minneapolis-St. Paul and Boston exhibited a significantly lower proportion of households that applied pesticides, while households in the rural Phoenix region were more likely to apply pesticides (Figure 2-2F). Regional-scale results show that more residents in Phoenix and Miami, and fewer residents in Boston, applied pesticides, compared to the other regions, when controlling for the household-level predictors (Figure 2-2E, F).

Discussion

Heterogeneous practices and homogeneous ecological outcomes

The research presented here supports the recent findings that yard care behaviors are relatively heterogeneous both within and across metropolitan areas (8, 40-41). We expected and found the greatest heterogeneity among yard care practices to be for irrigation at the regional scale. For example, the odds of irrigation vary significantly from metropolitan region to region, with households in warmer, drier regions (LA and Phoenix) more likely to irrigate than households in cooler, wetter areas (Baltimore and Boston) (Figure 2-2A). The average annual precipitation in LA and Phoenix is 33 and 20 cm per year, respectively, while the average annual precipitation in Baltimore and Boston is 106 and 111 cm per year, respectively (Wheeler et al *In Press*)¹⁴. The regression-adjusted estimates for the proportion of households that irrigated any part of their yard in the last year were relatively similar across block group-level population density categories within the six metropolitan areas studied, only 2 of 18 cases differed significantly from their mean (Figure 2-2B). In other words, across the wide-ranging climatic conditions found in the six studied regions, respondents addressed natural water limitations through irrigation. These findings suggest that the heterogeneity in household irrigation practices may be understood as a difference in behavior in response to regional climate limitations in order to produce similar ecological outcomes deemed desirable (17, 21).

¹⁴ See Wheeler et al *In Press* for a more in-depth discussion of precipitation, evaporative demand, and vegetation species.

Irrigation as a practice is more easily linked through yard vegetation's hydrological demands to rainfall and climate regimes. In contrast, we expected fertilization to vary independently of climate. After controlling for the household-level predictors of fertilization, we confirmed that the presence/absence of fertilizer use was not related to climate among our six metropolitan regions (Figure 2-2C), but did find evidence of strong variation along urban-rural gradients. We found relatively high variation in the odds of fertilizing across the degree of population density, with 8 of 18 cases differing significantly from the mean (Figure 2-2D). All of the MSAs showed the same pattern of suburban households more likely to fertilize than urban households, controlling for differences in metropolitan area. It is notable that respondents' fertilization practices in the Minneapolis-St. Paul region nearly encompasses the entire range in variation within the overall sample for the entire study. Specifically, in the Minneapolis-St. Paul MSA, only 45% of households in urban areas applied fertilizers, while 80% in suburban block groups applied fertilizers (Table 2-2), a difference that was significant between these two Minneapolis groups, and also from the sampled average (Figure 2-2D). Variation in practices may be linked to differences in preferences, norms, and social expectations associated with urban, suburban, and rural lifestyles.

Compared to households' irrigation and fertilization, application of pesticides exhibited an intermediate level of heterogeneity. At the household-level, pesticide application was more variable than fertilizer application but less variable than irrigation. At the metropolitan-level, pesticide use was more heterogeneous than irrigation but less than fertilizer application (Table 2-2 and Figure 2-2). Fewer households applying

pesticides may be due in part to concerns regarding the harmful effects of those agrochemicals on human health and the environment, and/or different regulatory environments. Some municipalities within the studied regions may ban certain chemicals for household use¹⁵. Household concerns over pesticide use may also help explain the ambiguous patterns of pesticide application across regions, an urban-rural population density gradient, and households.

Household drivers of residential landscape behavior

Because yard care practices examined here have financial costs, we expected that higher income-earning households would be more likely to irrigate and apply fertilizers and pesticides than lower-income households. We found that higher-income households were more likely to report irrigation, fertilization and pesticide application than lower-income households (~16% to 23% greater odds, Table 2-3), after adjusting for population density and regional influences. Income was the only household-level variable that was statistically significant across all models for yard care practices, so yard care practices may be cost-prohibitive for some households who wish to obtain a well-manicured aesthetic.

Yard care behaviors have also been hypothesized to vary with the resident's age. Previous research on the relationship between age and yard care practices revealed mixed findings. Some researchers have suggested the capacity for yard care decreases with

¹⁵For example, the City of Minneapolis has an ordinance prohibiting the use of fertilizers containing phosphorous <http://www.ci.minneapolis.mn.us/www/groups/public/@regservices/documents/webcontent/wcms1q-066035.pdf> This important dimension of yard care was beyond the scope of this study, but should be investigated in future research.

increasing age (31-33), while other studies employing multivariate analyses have revealed no significant relationships (i.e. 25, 34). In this systematic, multi-site comparative sample, we found a ~9% increase in the odds of fertilizing with increased age, but no significant associations between age and irrigation or pesticide application.

The relationship between age and yard care could be positive for some age classes or lifestages and negative for others, which would explain a null finding. Time and money might be limiting factors for younger households. As a household ages there could be more available time and potentially more money, while retirement may lead to even more available time but fewer financial resources to invest in yard care. It is also possible that older and higher-income households are more likely to hire yard care service companies to perform these tasks, which would diminish the argument that ability declines with age. Specifically, it cannot be assumed that the homeowner does the yard work. Thus, age may not be a predictor of capacity. Since our survey did not specifically identify who does the work of yard maintenance, we are unable to further disentangle this relationship. The influence of age needs to be better understood in research theorizing and empirically documenting urban residential ecologies.

In addition to income and age, peer pressure may also influence yard care practices. Given the abundant literature on social norms and landscaping, we hypothesized a significant and positive relationship between the number of neighbors known by name and the use of water, fertilizer, and pesticides. We found that knowing more neighbors by name corresponded to an 8% increase in the odds of both irrigation and fertilization, but no significant difference in the odds of applying pesticides. This

result may suggest that the desire to fit in and conform to neighborhood norms may increase when a household knows its neighbors by maintaining a neighborhood aesthetic through certain, but not all, yard care behaviors.

Insights from incorporating scale

By using a multi-site approach, we were able to improve the generalizability of our household-level findings and test whether heterogeneous practices underlie urban ecological homogenization, indicating distinct processes may result in the same outcome. Furthermore, our multi-level modeling framework enabled us to examine which practices varied and at which scales. For example, our multi-scale analyses indicated that the odds of irrigation were homogenous across population density categories, but heterogeneous across regions. Similarly, our multi-level analyses were important for uncovering the heterogeneity in odds of fertilizing at the block group scale, across an urban-rural gradient. Our multi-level, multivariate analyses indicate which specific management practices are associated with which scales, and how they are linked to particular sets of behavioral drivers.

Limitations

This research was limited by the coarse yes/no telephone survey questions for yard care practices. In-depth surveys and interviews are likely better for obtaining information about intensity and context yard care practices (e.g. 34, 40, 41, 51). Subsequent research could examine the age of who actually carries out these practices,

possible interaction effects with income, as well as the frequency, amount, location (i.e., part or whole yard), and timing (i.e., seasonality) and of yard care practices. Collecting this type of information would also enable a more explicit connection to household-level environmental outcomes rather than only household-level behaviors. Yard care behaviors studied here are well correlated with each other (Table 2-1). A next step could be to examine a multi-variate, multi-level, multi-site model akin to a multiple analysis of variance with household-level fixed effects. We specified simpler models for ease of interpretation, to build on the bivariate approach adopted elsewhere (8), and to establish the utility of the multi-level analytical strategy.

Conclusion

The results and methods presented in this paper suggest several avenues for future research. First, given the need for multi-scale, multi-site research to understand the dynamics of residential landscapes, this research may be useful for future investigations to test the urban ecological homogenization hypothesis as a function of multiple and explicitly-defined scales, because methods are provided that simultaneously address statistical problems of autocorrelation and aggregation effects. Additional scales of analyses (such as municipality) could be added between block group and MSA/region, to more effectively link to policies that may affect yard care practices. For instance, the current extreme drought conditions in California have created quasi-experimental conditions since each municipality adopts its own water use restrictions. Future research can systematically evaluate how governance at neighborhood and regional scales

influence yard care behavior – if at all. Additionally, research should examine regulations at different levels of jurisdiction such as federal, state, and local. Second, the approaches presented here can be used to advance multi-scale understandings of residential landscapes. Such efforts would benefit from survey instruments that examine diverse aspects of management in greater detail, collecting information on frequency, amount, location (i.e., part or whole yard), and timing (i.e., seasonality) of yard care practices). Finally, further development of this approach and its replication over time could be used to examine whether homogenous ecological outcomes and/or heterogeneous management practices are increasing or decreasing over time, and at what scales. This outcome may be particularly relevant as cities and urban regions enact sustainability and resilience plans that affect the structure and management of residential landscapes to more consistently reflect regional resource availability and concerns.

We examined patterns in yard care practices across scales and among six regions that span a range of climates in order to advance understanding of residential ecosystems, and determine if heterogeneity in management practices underlies homogeneous ecological outcomes across the continental United States. We employed a multi-level statistical modeling approach, given the multi-scalar nature of the drivers of yard care and the nested structure of the data collected. Previous studies have examined both urban homogenization and heterogeneity in residential land management, even if most have not tested multi-level models. Notably, Larson and colleagues (17) found that an underlying desire for a green lawn—highly valued by homeowners across distinct regions—engenders heterogeneous yard management practices in order to achieve that desired

homogeneous outcome. For example, irrigation is more likely in dry regions and pesticide applications more likely in warm areas. All the cities showed the same pattern of suburban households more likely to fertilize than urban households, controlling for differences in metropolitan area. We found significant heterogeneity in the prevalence of yard care practices, while also documenting empirical evidence that this heterogeneity is scale-dependent. In particular, we found significant variation in yard care practices at the household (the relationship with income was positive), urban-rural gradient (the relationship with population density was an inverted U), and regional scales (metropolitan statistical areas-to-metropolitan statistical area variation), and that a multi-level modeling framework is instrumental in discerning these scale-dependent outcomes.

Acknowledgements

This research is supported by the Macro- Systems Biology Program (US NSF) under Grants EF-1065548, -1065737, -1065740, -1065741, -1065772, -1065785, -1065831, and -121238320 and the NIFA McIntire-Stennis 1000343 MIN-42-051. The work arose from research funded by grants from the NSF LTER program for Baltimore (DEB-0423476); Phoenix (BCS-1026865, DEB-0423704, and DEB-9714833); Plum Island, Boston (OCE-1058747 and 1238212); Cedar Creek, Minneapolis–St. Paul (DEB-0620652); and Florida Coastal Everglades, Miami (DBI-0620409). Edna Bailey Sussman Foundation, Libby Fund Enhancement Award and the Marion I. Wright '46 Travel Grant at Clark University, The Warnock Foundation, the USDA Forest Service Northern Research Station, Baltimore and Philadelphia Field Stations, and the DC-BC ULTRA-Ex NSF-

DEB-0948947 also provided support. Anonymous reviewers supplied constructive feedback that helped to improve this paper. The findings and opinions reported here do not necessarily reflect those of the funders of this research.

References

1. Groffman PM, Cavender-Bares J, Bettez ND, Grove JM, Hall SJ, Heffernan JB, et al. Ecological homogenization of urban USA. *Front Ecol Environ*. 2014 Feb;12(1):74–81. Available from: <http://www.esajournals.org/doi/abs/10.1890/120374>
2. Steele MK, Heffernan JB, Bettez ND, Cavender-Bares J, Groffman PM, Grove JM, et al. Convergent Surface Water Distributions in U.S. Cities. *Ecosystems*. 2014 Feb 19;17(4):685–97. Available from: <http://link.springer.com/10.1007/s10021-014-9751-y>
3. Hall SJ, Learned J, Ruddell B, Larson KL, Cavender-Bares J, Bettez N, et al. Convergence of microclimate in residential landscapes across diverse cities in the United States. *Landsc Ecol*. 2016;31(1):101–17.
4. Pouyat RV, Pataki DE, Belt KT, Groffman PM, Hom J, Band LE. Effects of urban land-use change on biogeochemical cycles. In *Terrestrial ecosystems in a changing world 2007* (pp. 45-58). Springer Berlin Heidelberg.
5. Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, et al. Global change and the ecology of cities. *Science* (80-). 2008 Feb 8;319(5864):756–60.
6. McKinney ML. Urbanization as a major cause of biotic homogenization. *Biol Conserv*. 2006 Jan;127(3):247–60.

7. Pickett S, Cadenasso ML, Grove JM, Boone CG, Groffman PM, Irwin E, et al. Urban ecological systems: scientific foundations and a decade of progress. *J Environ Manage*. Elsevier Ltd; 2011 Mar;92(3):331–62.
8. Polsky C, Grove JM, Knudson C, Groffman PM, Bettez ND, Cavender-Bares J, et al. Assessing the homogenization of urban land management with an application to US residential lawn care. *Proc Natl Acad Sci*. 2014 Mar 10;111(12):4432–7.
9. Roy Chowdhury R, Larson KL, Grove JM, Polsky C, Cook EM. A multi-scalar approach to theorizing socio-ecological dynamics of urban residential landscapes. *Cities Environ*. 2011;4(1):1–19.
10. Cook EM, Hall SJ, Larson KL. Residential landscapes as social-ecological systems: A synthesis of multi-scalar interactions between people and their home environment. Vol. 15, *Urban Ecosystems*. 2012. 19-52 p.
11. Milesi C, Running SW, Elvidge CD, Dietz JB, Tuttle BT, Nemani RR. Mapping and modeling the biogeochemical cycling of turf grasses in the United States. *Environ Manage*. 2005 Sep;36(3):426–38.
12. Hall CR, Hodges AW, Haydu JJ. The Economic Impact of the Green Industry in the United States. *Horttechnology*. 2006;16(2):345–53.
13. Bormann FH, Balmori D, Geballe GT. Redesigning the American lawn: a search for environmental harmony. New Haven, CT: Yale University Press; 2001.
14. Robbins P. Lawn people: How grasses, weeds, and chemicals make us who we are. Temple University Press; 2007.

15. Hernke MT, Podein RJ. Sustainability, health and precautionary perspectives on lawn pesticides, and alternatives. *Ecohealth*. 2011;8(2):223–32.
16. Pickett S, Cadenasso ML, Grove JM, Nilon CH, Pouyat R V, Zipperer WC, et al. Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. *Annu Rev Ecol Syst*. 2001 Nov;32(1):127–57.
17. Larson KL, Nelson KC, Samples SR, Hall SJ, Bettez N, Cavender-Bares J, et al. Ecosystem services in managing residential landscapes: priorities, value dimensions, and cross-regional patterns. *Urban Ecosystems*. 2015
18. Urban D, O’Neill R, Shugart HJ. A hierarchical perspective can help scientists understand spatial patterns. *Bioscience*. 1987
19. Grove JM, Burch WRJ, Pickett S. Social Mosaics and Urban Community Forestry in Baltimore, Maryland Introduction: Rationale for Urban Community Forestry Continuities From Rural to Urban Community Forestry. In: Lee RG, Field D. R., editors. *Communities and Forests: Where People Meet the Land*. Corvallis: Oregon State University Press; 2005. p. 248–73.
20. Aronson MFJ, Sorte FA La, Nilon CH, Katti M, Goddard M a, Lepczyk CA, et al. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceeding R Soc B*. 2014;281(1780):20133330.
21. Groffman PM, Grove JM, Polsky C, Bettez ND, Morse JL, Cavender-Bares J, et al. Satisfaction, water and fertilizer use in the American residential macrosystem. *Environ Res Lett*. 2016;11(3):34004.

22. Larson KL, Brumand J. Paradoxes in Landscape Management and Water Conservation: Examining Neighborhood Norms and Institutional Forces. *Cities Environ.* 2014;7(1):1–24.
23. Law NL, Band LE, Grove JM. Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore county, MD. *J Environ Plan Manag.* 2004 Sep;47(5):737–55.
24. Osmond DL, Hardy DH. Characterization of turf practices in five North Carolina communities. *Journal of Environmental Quality.* 2004 Mar 1;33(2):565-75.
25. Carrico AR, Fraser J, Bazuin JT. Green With Envy: Psychological and Social Predictors of Lawn Fertilizer Application. *Environ Behav.* 2012 May 23;45(4):427–54.
26. Fissore C, Hobbie SE, King JY, McFadden JP, Nelson KC, Baker LA. The residential landscape: fluxes of elements and the role of household decisions. *Urban Ecosyst.* 2012 Jul 6;15(1):1–18.
27. Hope D, Gries C, Zhu W, Fagan WF, Redman CL, Grimm NB, et al. Socioeconomics drive urban plant diversity. *Proc Natl Acad Sci.* 2003 Jul 22;100(15):8788–92.
28. Hope D, Gries C, Casagrande D, Redman CL, Grimm NB, Martin C. Drivers of Spatial Variation in Plant Diversity Across the Central Arizona-Phoenix Ecosystem. *Soc Nat Resour.* 2006;19(2):101–16.
29. Martin CA, Warren PS, Kinzig AP. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landsc Urban Plan.* 2004 Oct;69(4):355–68.

30. Zhou W, Troy AR, Grove JM, Jenkins JC. Can Money Buy Green? Demographic and Socioeconomic Predictors of Lawn-Care Expenditures and Lawn Greenness in Urban Residential Areas. *Soc Nat Resour*. 2009 Aug 11;22(8):744–60.
31. Robbins P, Polderman A, Birkenholtz T. Lawns and toxins: An ecology of the city. *Cities*. 2001;18(6):369–80.
32. Yabiku ST, Casagrande DG, Farley-Metzger E. Preferences for Landscape Choice in a Southwestern Desert City. *Environ Behav*. 2007 Aug 2;40(3):382–400.
33. Larson KL, Casagrande DG, Harlan SL, Yabiku S. Residents' yard choices and rationales in a desert city: social priorities, ecological impacts, and decision tradeoffs. *Environ Manage*. 2009;44:921–37.
34. Martini NF, Nelson KC, Hobbie SE, Baker LA. Why “Feed the Lawn”? Exploring the Influences on Residential Turf Grass Fertilization in the Minneapolis-Saint Paul Metropolitan Area. *Environ Behav*. 2015 Jun 29;47(2):158–83
35. Grove JM, Cadenasso ML, Burch WRJ, Pickett S, Schwarz K, Neil-Dunne JPM, et al. Data and Methods Comparing Social Structure and Vegetation Structure of Urban Neighborhoods in Baltimore , Maryland. *Soc Nat Resour*. 2006;30(19):117–36.
36. Grove JM, Troy AR, O'Neil-Dunne JPM, Burch WRJ, Cadenasso ML, Pickett S. Characterization of Households and its Implications for the Vegetation of Urban Ecosystems. *Ecosystems*. Springer; 2006;9(4):578–97.
37. Grove JM, Locke DH, O'Neil-Dunne JPM. An Ecology of Prestige in New York City: Examining the Relationships Among Population Density, Socio-economic

- Status, Group Identity, and Residential Canopy Cover. *Environ Manage*. 2014 Jul 18;54(3):402–419.
38. Troy AR, Grove JM, O’Neil-Dunne JPM, Pickett S, Cadenasso ML. Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environ Manage*. 2007 Sep;40(3):394–412.
39. Nassauer JI. Messy ecosystems, orderly frames. *Landsc J*. 1995;14(2):161–70.
40. Harris EM, Polsky C, Larson KL, Garvoille R, Martin DG, Brumand J, et al. Heterogeneity in Residential Yard Care: Evidence from Boston, Miami, and Phoenix. *Hum Ecol*. 2012 Aug 29
41. Harris EM, Martin DG, Polsky C, Denhardt L, Nehring A. Beyond “Lawn People”: The Role of Emotions in Suburban Yard Management Practices. *Prof Geogr*. 2013;(May 2012):37–41.
42. Jenkins VS. *The Lawn: A history of an American obsession*. Washington and London: Smithsonian Institute Press.
43. Scotts 1998. *Scotts lawncare special annual program edition: lawn successes made easy*. Scotts Company, Marysville, p 11
44. Robbins P, Sharp J. Producing and consuming chemicals: the moral economy of the American lawn. *Econ Geogr*. 2003 [cited 2014 Apr 30];79(4):425–51.
45. Smith RM, Gaston KJ, Warren PH, Thompson K. Urban domestic gardens (V): relationships between landcover composition, housing and landscape. *Landsc Ecol*. 2005;20(2):235–53.

46. Marco A, Dutoit T, Deschamps-Cottin M, Mauffrey JF, Vennetier M, Bertaudière-Montes V. Gardens in urbanizing rural areas reveal an unexpected floral diversity related to housing density. *C R Biol.* 2008;331(6):452–65.
47. Pham T-T-H, Apparicio P, Landry S, Séguin A-M, Gagnon M. Predictors of the distribution of street and backyard vegetation in Montreal, Canada. *Urban For Urban Green*; 2012 Oct
48. Pham T-T-H, Apparicio P, Séguin A-M, Landry S, Gagnon M. Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity? *Landsc Urban Plan*; 2012 Jul 107(3):214–24.
49. Giner NM, Polsky C, Pontius RG, Runfola DM. Understanding the social determinants of lawn landscapes: A fine-resolution spatial statistical analysis in suburban Boston, Massachusetts, USA. *Landsc Urban Plan.* Elsevier B.V.; 2013 Mar;111:25–33.
50. Robinson WS. Ecological Correlations and the Behavior of Individuals. *American Sociological Review.* 1950 Jun;15(3).
51. Fraser J, Bazuin JT, Band LE, Morgan Grove J. Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization. *Landsc Urban Plan.* Elsevier B.V.; 2013;115:30–8.
52. Subramanian SV, Jones K, Kaddour A, Krieger N. Revisiting Robinson: the perils of individualistic and ecologic fallacy. *Int J Epidemiol.* 2009 Apr;38(2):342-60-3.
53. Hox J. Multilevel Modeling: When and Why. In: *Classification, Data Analysis, and Data Highways.* Springer Berlin Heidelberg; 1998. p. 147–54.

54. Snijders T, Bosker R. Multilevel modeling: An introduction to basic and advanced multilevel modeling.
55. Claritas Inc. PRIZM Segment Narratives. The Nielsen Company (US), Inc.; 2008. Retrieved December 11, 2013
http://www.geographicresearch.com/PDF/PRIZM_Methodology.pdf
56. Aguinis H, Gottfredson RK, Culpepper SA. Best-Practice Recommendations for Estimating Cross-Level Interaction Effects Using Multilevel Modeling. *J Manage.* 2013 Apr 2;39(6):1490–528.
57. R Core Team. R: A language and environment for statistical computing. 2013. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org/>.
58. Bates D, Maechler M, Bolker B, Walker S. lme4: Linear mixed-effects models using Eigen and S4. R package version. 2014 Jun 23;1(7). <http://CRAN.R-project.org/package=lme4>.
59. Bates D, Maechler M, Bolker B Walker S. “lme4: Linear mixed-effects models using Eigen and S4.” 2014b. *J Stat Sof* <http://arxiv.org/abs/1406.5823>.
60. Kuznetsova A, Brockhoff PB, Christensen RH. Package ‘lmerTest’. R package version. 2015:2-0.

**CHAPTER 3 LANDSCAPE MULLETS HYPOTHESES PART 1: HEARING IT
FROM THE HORSE'S MOUTH**

To be submitted to Society and Natural Resources

Dexter H Locke¹, Rinku Roy Chowdhury¹, J Morgan Grove², Deborah Martin¹, Eli
Goldman¹, John Rogan¹, Peter Groffman³

¹School of Geography, Clark University, 950 Main Street, Worcester MA 01610-1477

USA

PHONE 310 463 6202

EMAIL dexter.locke@gmail.com

²USDA Forest Service, Baltimore Field Station, Suite 350, 5523 Research Park Dr.,
Baltimore, MD 21228

³CUNY Advanced Science Research Center and Brooklyn College Department of Earth
and Environmental Sciences 85 St. Nicholas Terrace, 5th Floor New York, NY 10031

Abstract

The abundant literature on private residential land management in urban and suburban areas identifies many influencing factors of yard care behaviors, but the explicit examination of front versus back yards remains understudied. This paper introduces the Landscape Mullet concept, which is the difference in yard care priorities between front and back driven by the reduced sense of social norms associated with back yards, as a theoretical advance. The two key components are: 1) social norms are an important driver; and 2) those norms vary spatially across a residential parcel from front (public) to back (private). In order to test the mullet concept thirty six semi-structured interviews and walking tours of yards were conducted in Baltimore, MD. Corroborating previous research, we found that neatness and aesthetics, ease of maintenance and effort, and neighborhood norms and identity are important facets of residents' yard care behaviors. Extending prior work, support for the notion that social pressures are an important driver of yard care practices, and that those pressures are not evenly expressed with in residential property parcel was found in six of seven neighborhoods studied. Therefore the front/back, public/private distinction as a refinement to the commonly evoked social norms explanation does not appear to be neighborhood specific. Future research should not ignore or assume away this spatial scale of heterogeneity for both social and environmental reasons. In particular, more work is needed on the scalar relations within which residents and residential parcels are embedded, on how social norms may shape residential ecologies, especially at the intra-parcel scale, and on the environmental implications of management.

Keywords

Ecological Homogenization of Urban America Hypothesis, Landscape Mullets concept, lawncare practices, residential ecosystems, residential landscapes, sustainability science, urban ecology, Yard care practices

1 Introduction

Given the preponderance of residential land use in United States, and its growing spatial footprint (Brown et al 2005), it is imperative to understand the motivations, capacities, and interests of private residential land management. Drawing on 36 semi-structured interviews and yard tours in Baltimore City, MD we investigate if the management, care, and stewardship of visible (front yard) and relatively invisible (back yard) spaces on residential properties are guided by different values. For example, does fitting into a particular neighborhood aesthetic, or establishing an outward display in the front yard perceived as desirable influence decisions pertaining to the back yard too? The lack of visibility associated with more secluded back yards may influence management decisions. We therefore introduce and define the Landscape Mullet concept as a difference in yard care priorities between front and back driven by the reduced sense of social norms associated with back yards as a theoretical advance. The two key components are: 1) social norms are an important driver; and 2) those norms vary spatially across a residential parcel from front (public) to back (private). This paper explores the potential differences in front and back yard management preferences as a way of understanding social norms in an urban natural resources management context, and to develop and refine theory.

The abundant literature on private residential land management identifies many influencing factors of yard care behaviors (Roy Chowdhury et al 2011), but the explicit examination of front versus back yards remains understudied (Cook et al 2012). One commonly identified influence of yard care choices is norms. Norms and rules of all type

may influence yard care behaviors differently, and in different parts of a city too. Home Owners Associations (HOAs) are frequently identified in previous research as a driver of yard care behaviors, via their specific covenants, codes and restrictions (CCRs; Turner & Ibes 2011; Fraser et al 2013; Larson & Brumand 2014). Because HOAs impose legal constraints, “homogeneity in residential landscapes reflects households ‘fitting in’ with existing neighborhood practices or maintaining a landscape established by developers” (Harris et al 2012: 47). However, HOAs do not always coerce residents into decreasing biodiversity via reinforcing homogeneity among yards. In fact, a study across neighborhoods in Phoenix showed *greater* biodiversity for native bird and plant communities in neighborhoods belonging to an HOA, when compared to those without an HOA because of the predictable management regimes that introduce regular disturbances (Lerman, Turner and Bang 2012). This evidence suggests that HOAs’ CCRs may act as a vehicle for increasing biodiversity, and thus may counter the notion that HOAs increase homogeneity via rules.

Formal rules such as CCRs may not need enforcement to be effective in reaching their goals. In Nashville, TN, the simple existence of the rules appears to change behavior, even when enforcement is absent because of perceptions and/or fears of enforcement (Fraser, Bazuin, & Hornberger 2015). A study in Baltimore examined households in HOAs, households with neighborhood associations (NAs), which did not have legally binding rules, and households in neither an HOA or an NA. Households within HOAs were found to apply more fertilizer than households that were not members of a HOA; however, households within NAs did not fertilize more than their non-HOA

counterparts (Fraser et al 2013). Importantly for the questions this paper aims to address, CCRs commonly only apply to the visible front yard (Larsen & Harlan 2006); which may further explain the difference between stated preferences and behavior (Harris et al 2012, 2013; Larson et al 2009). The degree to which HOAs and NAs influence household decisions, across a city and may influence front yard appearances warrants further empirical research.

Written or not, a given household's land management preferences may be affected by informal factors such as peer pressure or the household's desire to 'fit in' with their perceived neighborhood expectations (Jenkins 1994; Robbins, Polderman & Birkenholtz, 2001; Robbins & Sharp 2003; Scotts 1998; Nassauer, Wang & Dayrell 2009; Harris et al 2012; 2013; Larson & Brumand 2014; Stehouwer, Nassauer & Lesch 2016, among others). Yard care practices often do not reflect homeowners' preferences but instead his or her perceptions of the neighbors' expectations for what the individual's lawn should *look like* (Harris et al 2012, 2013; Larson et al 2009). Germane to the questions posed here is *look*.

Landscapes that visually indicate or communicate human intention, and provide the so-called 'cues to care' are often perceived as desirable (Nassauer 1988; 1995). But are the indicators of neatness and care only occurring in the visible spheres of neighborhood life? Are residents' rationales for front and back yard care practices different, and if so, how? Do residents prioritize neighborhood norms for front yards, and do perceptions of neighborhood norms play a role? Are back yard practices an extension

of personal preferences, and do residents rationalize visible and less-visible spaces in their yards?

In one of the few explicitly front yard vs. back yard comparisons that examines social pressures, Larsen and Harlan (2006: 14), “..propose that in the front yard, form follows fashion while in the backyard, form follows fantasy. In the backyard, many of the stated reasons for preference relate to using this space for recreational purposes.” This fashion in front and function in the back parallels one of the descriptions of the mullet: *business in the front, party in the back*. According to the Oxford English Dictionary, the mullet is a “a hairstyle, worn esp. by men, in which the hair is cut short at the front and sides, and left long at the back. (“mullet,” 1989). Drawing on the mullet, we define the Landscape Mullet concept as a difference in yard care priorities between front and back driven by the reduced sense of social norms associated with back yards. The two key components of this theoretical advance are: 1) social norms are an important driver; and 2) those norms vary spatially across a residential parcel from front (public) to back (private).

The purpose of this paper is not to determine with certainty which factors are correlated or associated with supporting the Landscape Mullet concept, and/or having a landscape mullet-like effect, yard type, or management practice. The goal is expose and refine the potential and limit of the concept. Where are the edges of its applicability, and what else is going on in those cases that might help us build a stronger and more robust explanation?

2 Methods

2.1 Study Area

This research is part of the Baltimore Ecosystem Study (BES, <http://www.beslter.org/>). The neighborhood called Guilford was selected first because it is a high-income area with abundant tree canopy, built in the 1920s with an active Homeowner’s Association, and is an Historic District. Guilford therefore serves as a point of reference, or anchor, for comparing to the other neighborhoods. Interviews (described below) were conducted until saturation was approached, and then other five neighborhoods were purposively sampled that were different than Guilford along one or more of these dimensions to serve as the basis for comparisons (Table 3-1).

Table 3-1. Description of study neighborhoods

Neighborhood	Income ^a	Income ^b	Tree canopy	Race/ethnicity ^a	Groups (HOA, NA, CA, historic) ^c
Guilford	High	\$538,225	High	Predominantly White	HOA, Historic District ^d
Winston-Govans	Low	\$42,375	Medium	African American	NA, optional
Cedarcroft	High	\$84,107	High	White	HOA, Historic District
Walker-Lake	Medium / mixed	\$40,303	High	White	CA
Parkville	Unsure	\$56,377	Low	Predominantly White	None
Hamilton	Unsure	\$43,768	Low		NA

^aFrom questionnaire
^bAverage Median Household Income of intersecting Census block groups, American Community Survey 2007 – 2011.
^cFrom interviews, HOA = Home Owner’s Association; NA = Neighborhood Association; CA = Community Association
^dOptional extra private security available

2.2 Recruitment

In the summer of 2016 two researchers conducted door-to-door canvassing in Baltimore across seven neighborhoods. If the resident answered the door, the researchers briefly described the Baltimore Ecosystem Study, and explained that they were conducting research on landscaping in that particular neighborhood. Then they asked if they were willing to participate. If they agreed the semi-structured interview began, or a day and time to return was scheduled. If no one answered the door, a post card was left in an easy to reach place that would not blow away. The researchers returned up to three times. Canvassing occurred on weekday afternoons, but some interviews occurred on nights and weekends.

2.3 Procedures

The protocol also consisted of five parts:

1) Semi-structured interview: The interviews used a previously established, and tested script (Harris et al 2012; 2013; Larson et al 2015), which was designed to investigate residents' motivations, capacities, and interests in various yard care practices. Questions were also asked to learn more about social pressures, neighborhood norms, governance, and attitudes and perceptions about neighbor's yard care practices. Questions were added to probe for possible front/back differences.

2) Tour of the property: Walking is increasingly recognized among urban geographers as an important method for grounding and improving empirical research (Pierce and

Lawhon 2015). The tour included walking around the front and back yards, when access was granted. Walking interviews help ensure data quality by reminding residents about different aspects of their yards, and better place the interviews in their context (Elwood and Martin 2000).

3) Photographing the landscape: Pictures were taken, when permitted, of the residents' front and back yards. The pictures serve to visually contextualize and ground residents' answers.

4) Hand-drawn map: The resident drew a map of the property, which was inspired by the researcher-drawn maps in Harris et al (2013). Features that the resident cared more about were often highlighted and otherwise received more attention because the resident performed the diagramming.

5) Questionnaire: To prevent priming other responses, a short questionnaire that partially overlapped with the semi-structured interview was provided at the end. The first of two large-typed pages contained multiple-choice questions to categorize and quantify some of the interview questions. The second page asked some of the same demographic questions as the US Census.

2.4 Analysis

After the protocol was complete the researchers would leave and recapitulate the residents' main points to each other; discuss themes, decide if they were new, how they might support or refute previous interviewees' responses and topics in previously published material; and talk about what was learned with respect to front/back differences, social norms, and the neighborhoods they visited. When residents did not want to be audio recorded, the debriefing sessions were audio recorded. During these debriefing sessions deductive codes and emerging themes were discussed and iteratively refined.

The recorded interviews were transcribed then coded, and the audio debriefing sessions coded using NVivo 10.2.1 with a mix of deductive and inductive coding strategies (Saldaña 2013). The principal deductive code of interest was for ideas about front and back yards and social pressures, while inductive themes included neatness and aesthetics, ease of maintenance and effort, and neighborhood norms and identity. Each of these three overarching themes is composed of other emergent themes, as shown in Appendix 1. Although not necessarily numerically the most popular, we focus on a select subset of the sub codes that help situate and reveal the edges of the Landscape Mullets concept and that provide context for the two-part premise of 1) the importance of social norms, and 2) how those social norms influence behaviors at the sub-parcel scale. Some sub-codes are cross-cutting, and all themes are related. For example the two-part premise of the Landscape Mullets is part neatness and aesthetics and part neighborhood norms and identity.

3 Findings

3.1 Business in the front, party in the back

For many residents the front yard was clearly identified as being visible to the neighbors. For example, one resident said:

DL: And what features of your yard do you think matter most to your neighbors?

R: I think the front, appearance of the front.

DL: The front?

R: Because a lot everybody's doors is to the front so when you first open the door

The publically visible nature of the front yard was frequently linked to the resident's landscaping priorities via aesthetics and concerns about neighbor's views. For example, a woman familiar with several of the local environmental non-profit organizations declared,

R: I want more flowering things in the front

DL: Uh huh

R: Than in the back

DL: Why is that?

R: Then everybody can see it not many people see the back.

Visibility connects to certain plants, here flowers, and to sharing that appearance with others. In the same interview the resident further articulated the public/private divide when describing both her actual gardening practices as well as preferences for different features. When asked if they had different ideas about what they want in front versus the backyard, another two residents in different neighborhoods shared a similar *fashion in the front, function in the back* sentiment. Another respondent said,

R: Front because people see it it's a front of the house probably focused a little bit more on aesthetic.

DL: Ok.

R: And backyard a little bit less aesthetic and also a play area in back

While another interviewee described her preferences:

R: Yeah, definitely. I prefer a more, this is a little wild for me actually [points to front-yard plantings] so I'm still thinking through the design.

DL: In the front?

R: Yeah, I like the front to be slightly more formal and the back a little more informal.

DL: Interesting.

R: And to have more trees. In the back I'm mostly concerned with creating privacy and sort of restful areas. The front is more presentation or public.

Their responses suggest a keen awareness of the publicly visible nature of these front yard spaces, in contrast to more private and utilitarian areas in back yards. Moreover trees are valued in part for creating privacy. These quotes also suggest a need to create an aesthetic they feel their neighbors will appreciate or at least deem acceptable. Again the front/back maps onto the public/private, and further onto a fashion/function dichotomy. A resident in home built just three months prior also expressed concern about fitting into the neighborhood and not wanting to upset the neighbors. He said,

“I want to do as little work possible while not looking like the trash in the neighborhood [...] Minimal maintenance in the front as much as possible and then food, productive stuff in the back [...] Yeah, front will be to have the neighbors not not get mad and the back will be more hopefully for herbs and vegetables.”

So while the desired function may be different, food production in contrast to a place for children to play or a private place for rest, the fashion-function divide is still present. Further the peer pressure to adhere to a perceived valuable aesthetic is also present and connected to landscaping decisions. Fear over acceptance matters for him. This resident repeated several times that he thought grass was “idiotic” and he did not like ornamentals plants or what he termed “the sort of plants for plants sake”. Despite these seemingly strong feelings, he still felt compelled to maintain a large sweeping lawn, which was commonplace in the neighborhood.

What these exemplary quotes demonstrate is how social pressures and neighborhood norms manifest themselves in an unbalanced way across a property parcel. The quotes also show that the Landscape Mullet concept resonates with people across different neighborhoods where social norms vary. For example, pride, joy, and a desire to fit into a neighborhood aesthetic to gain acceptance (the Ecology of Prestige; cf Grove et al 2006, 2014; Troy et al 2007; Zhou et al 2009; Locke et al 2016) motivates some yard care behaviors in the front, but not in the back. Peer pressures do not extend to the back yard, or at least not as much in these cases. For other residents anxiety or even fear (the Moral Economy; cf Robins, Polderman, Birkenholtz 2001; Robins and Sharp 2003; Robbins 2007) prompts the creation of a monoculture lawn, when the desires for food production are preferred. These quotes also show that either encouraged by neighborhood norms or begrudgingly complying with front yard design and maintenance, the function part of the fashion in the front / function in the back varies too. Some want safe places, others want play spaces, and others still want to grow food. The Landscape Mullet concept is flexible enough to accommodate this variety while maintaining explanatory power. This is a primary theoretical refinement and extension of Moral Economy and Ecology Prestige explanations that the Landscape Mullet concept provides.

Residents we spoke with showed some evidence of the public/private divide, with peer pressures influencing front yard decisions, but less so for back yard in every neighborhood except for Hamilton. Only three interviews were conducted Hamilton, which were short and did not include a tour; all three were deemed inconclusive. Not every resident interviewed fit the Landscape Mullet concept (Table 3-2), but examples of

split management concerns and corresponding action (e.g. supporting the concept) could be found at homes in each neighborhood.

Table 3-2. Interviewees were categorized as providing evidence for one, the other, or both parts of the Landscape Mullets concept, or inconclusive.

		Different front vs back uses, care, and/or management?		
		Yes	No	Inconclusive
Consideration of neighbors and peer pressures relevant?	Yes	13	3	14
	No	2	4	
	Inconclusive			

Three residents showed little front/back differentiation and identified peer pressures as relevant to their yard care practices. But in these instances it was clear that they were avid gardeners who maintained their yards as a hobby, for themselves, and personal preferences were expressed in both the front and back yards. During these interviews residents made reference to wanting to keep up the front yard and ‘do right by the neighborhood’, but they also dedicated considerable effort in their back yards. Hence these three cases are one type of mixed support for the Landscape Mullet concept (red).

These mixed cases are in contrast to two other mixed cases (blue). In these instances residents showed little deference to their neighbors. They wanted to please themselves. Nevertheless these residents used their yards differently in front and back – but this did not appear to be driven by peer pressures at all, but instead by their own interests gardening. As a practical matter, site conditions such as steep slopes or abundant shade were different in front and back and were correspondingly used differently. These mixed cases are therefore distinct from the three mixed cases described above. Finally,

there were four residents that showed no indication of peer pressures, or no indication of different front vs. versus back yard care. For these residents the Landscape Mullets concept did not appear to have salience at all (grey).

3.2 Ease of Maintenance and Effort

Another dominant theme pertains to labor. One respondent described his ideal yard as “one that never has to be mowed. No mowing, just stays green”. This sentiment was commonplace, and as noted above also ties to the theme of aesthetics. For many residents, mowing and other yard care practices are not enjoyable, so priority is given to low maintenance options. These residents are what Harris et al 2013 have termed “Reluctant Maintainers” because they are moved by the moral economy explanation and unwillingly invest resources in keeping up with the proverbial Joneses. Among those enthusiastic gardeners and hobbyists, many deliberately grew food. Even growing food fits into the lens of front/back and aesthetics. When describing her back yard, one resident said, “The aesthetics are a little bit less of a concern, so I have a dedicated vegetable bed back there.”

While some residents do all of their own yard care, there is a plethora of maintenance arrangements. First, some hire different services such as mowing, general landscaping, tree trimming, and/or pest control and complement those contractors’s labor themselves with some form of yard care. For example, some would pay for bi-weekly mowing, but would enjoy vegetable or ornamental gardening as a hobby. Alternatively some only hire out for big or infrequent jobs such as large tree removal or bi/annual

mulching. Secondly, there were often divisions of labor within the household. Interviews with couples were illuminating. Commonly one member of the household irrespective of age or sex has strong opinions (usually avid gardeners) on what types of practices should or should not be done and the other members simply comply.

3.3 Neighborhood Norms and Identity

Fear of judgement and anxiety over the lawn and attempting to avoid ostracization among neighbors were common themes among interviewed respondents, corroborating similar prior research (i.e. Fraser, Bazuin, & Hornberger 2015, Robbins, Polderman & Birkenholtz, 2001; Robbins & Sharp 2003). As one resident explained, “They see how you keep your front of your lawn and they [...] judge you actually judge you about your character.” Other residents explicitly mentioned not wanting to get reported for code violations by their neighbors if the lawn was too long. When asked about being reported, usually the respondent said they had never been reported, reported someone else, or known someone who was reported, although reporting neighbors for violations was very common in the Winston-Govans neighborhood. Even without enforcement, rules compel compliance through the fear of surveillance and enforcement (Fraser, Bazuin, & Hornberger 2015).

Related to the fear over judgement and anxiety theme was an emergent theme about ‘getting along’. To avoid conflict, neighbors adopt the behaviors they feel are perceived as desirable, corroborating reference group behavior theory. Others took on ‘a good fences make good neighbors’ mentality, and one respondent said about his long-

time neighbor who he did not know, “I prefer to preserve the domestic tranquility”.

Others boasted how great their neighbors are, and that their community association was extremely active. Many had grown close ties with their neighbors and regarded them as close friends. There are clearly different strategies for fitting in, and as shown above the lawn and yard is part of that attempt to gain acceptance through conflict avoidance, or via friendship formation.

One way to fit in or get a long is to copy each other, including landscaping styles and practices. Sentiments like “I have as much fun looking at her yard as I do looking at mine” were not uncommon. In one Montréal, QC, neighborhood front yard vegetation and architectural similarity was high spatial autocorrelated, which declined with distance (Zmyslony & Gagnon, 1998). A follow-up study showed that lots with similar features such as size, building material, and color shared more vegetation characteristics in common than homes with differing built features, independent of location on street section (Zmyslony & Gagnon, 2000). Attributed to mimicry (Zmyslony & Gagnon, 1998; 2000), this type of ‘spatial contagion’ has been found in roadside gardens in Michigan (Hunter & Brown, 2012), green infrastructure uptake in suburban neighborhoods around Cleveland, OH (Turner, Jarden, Jefferson 2016), and to a lesser degree among households in suburban Australia (Kirkpatrick, Daniels & Davidson, 2009). In Baltimore, residents mentioned observing neighbors’ yards in their daily rounds or while walking a dog, taking note of different plantings, and wanting to copy or emulate them. Planting styles and mimicry is related to neatness and aesthetics. One interviewee said, “..they expect for you to keep your yard up like everybody else’s”. In summary, neatness and aesthetics,

ease of maintenance and effort, and neighborhood norms and identity were the dominant themes found among the 36 Baltimore residents we spoke with in seven neighborhoods.

A limitation of this study is that we looked predominantly at single-family detached housing with yards. This approach ensured that residents had legal control over their properties. This household structure-housing unit type combination is not dominant in Baltimore, nor is it exemplary of the region. However this arrangement is of course commonplace throughout North America; it is important to keep in mind who the study participants represent and whom they do not. Homes without yards were not included.

4 Conclusions

Residential land – including lawn – increasingly covers the United States and replaces native ecosystems (Brown et al 2005). Lawn is the country’s leading irrigated crop by area, and covers four times more land area than irrigated corn (Milesi et al 2005). The apparently widespread use of water, fertilizer, (Polsky et al 2014; Groffman et al 2016), and pesticide inputs (Locke et al *In Review*), which may have unintended environmental consequences on beneficial insects and downstream water quality (Bormann et al. 2001, Robbins 2007, Hernke and Podein 2011, Groffman et al 2014), raises concerns over environmental quality. Previous research in a variety of contexts consistently identifies the importance of peer pressures and social norms as a key driver of yard care (Jenkins 1994; Robbins, Polderman & Birkenholtz, 2001; Robbins & Sharp 2003; Scotts 1998; Nassauer, Wang & Dayrell 2009; Harris et al 2012; 2013; Larson & Brumand 2014; Stehouwer, Nassauer & Lesch 2016, among others). But what about back

yards, where visibility is reduced if not completely eliminated? Shouldn't the same desire to fit in also be reduced if not completely eliminated, with different management practices, and therefore altered environmental consequences (i.e. water use, chemical inputs, modification of habitat)?

Through 36 semi-structured interviews in seven neighborhoods in Baltimore, MD, we found support for the notion that social pressures are an important driver of yard care practices, and that those pressures are not evenly expressed within residential property parcels. Support was found in six of the seven neighborhoods; in one neighborhood (Hamilton) the evidence was inconclusive due to short interviews and lack of access. This front/back, public/private dichotomy therefore does not seem neighborhood specific. The concept is salient and relevant in different neighborhoods, and across a variety of residents. Although we also spoke with several residents where either social pressures did not seem relevant enough to evoke different behaviors, or care and management was spread throughout the property. The front/back divide should be researched in more depth in the future to better understand social norms and the environmental outcomes of varied yard care practices.

Corroborating previous research, we found that neatness and aesthetics, ease of maintenance and effort, and neighborhood norms and identity are important facets of residents' yard care behaviors. Nested within and supporting the theme of maintenance and effort are notions about the division of labor within a household, food production, and physical site characteristics. For example, typically one member of the household had greater interest in yard care and the less interested members attempted to avoid conflict.

Among residents with the means, some chose to hire landscaping services. More often there was a blend of labor from within the household and these hired companies.

The way residents spoke about their neighborhoods revealed a commonly held value about the need to get along. Yet neighbors also described anxiety about letting each other down, and there was some degree of fear about Home Owners Associations and/or fines from the city. Several residents mentioned copying their neighbors, providing support for mimicry (Zmyslony & Gagnon, 1998; 2000) or ‘spatial contagion’ (Hunter & Brown 2012; Turner, Jarden, Jefferson 2016). In two neighborhoods there were annual plant exchanges where residents dug up perennials, divided them, and came together to share or swap. These neighborhood gatherings are community events that build a collective identity in their respective neighborhoods. The plant exchanges also reinforce mimicry and the within-neighborhood similarity among some yards.

Abundant prior research asserts the importance of yard care, and the role of social norms (Jenkins 1994; Robbins, Polderman & Birkenholtz, 2001; Robbins & Sharp 2003; Scotts 1998; Nassauer, Wang & Dayrell 2009; Harris et al 2012; 2013; Larson & Brumand 2014; Stehouwer, Nassauer & Lesch 2016, among others). But the social norms explanations do not meaningfully grapple with the less-visible spaces - namely back yards. This paper makes a theoretical advance and empirical contribution to the study of residential land management by examining the whole residential parcel with respect to public and private motivations. Future research should not ignore or assume away this spatial scale of heterogeneity for both social and environmental reasons.

Acknowledgements

This research is supported by the Macro- Systems Biology Program (US NSF) under Grants EF-1065548, -1065737, -1065740, -1065741, -1065772, -1065785, -1065831, and -121238320. The work arose from research funded by grants from the NSF LTER program for Baltimore (DEB-0423476); Phoenix (BCS-1026865, DEB-0423704, and DEB-9714833); Plum Island, Boston (OCE-1058747 and 1238212); Cedar Creek, Minneapolis–St. Paul (DEB-0620652); and Florida Coastal Everglades, Miami (DBI-0620409). Edna Bailey Sussman Foundation, Libby Fund Enhancement Award and the Marion I. Wright '46 Travel Grant at Clark University, The Warnock Foundation, the USDA Forest Service Northern Research Station, Baltimore and Philadelphia Field Stations, and the DC-BC ULTRA-Ex NSF-DEB-0948947 also provided support. The findings and opinions reported here do not necessarily reflect those of the funders of this research.

Literature

Brown, Daniel G., Kenneth M. Johnson, Thomas R. Loveland, and David M. Theobald.

2005. "Rural Land-Use Trends in the Conterminous United States, 1950-2000."

Ecological Applications 15 (December): 1851–63. doi:10.1890/03-5220.

Cook, Elizabeth M., Sharon J. Hall, and Kelli L. Larson. 2012. *Residential Landscapes as*

Social-Ecological Systems: A Synthesis of Multi-Scalar Interactions between

People and Their Home Environment. Urban Ecosystems. Vol. 15.

doi:10.1007/s11252-011-0197-0.

- Elwood, Sarah, and Deborah G. Martin. 2000. “‘Placing’ Interviews: Location and Scales of Power in Qualitative Research.” *The Professional Geographer* 52 (July 1999): 649–57. <http://www.tandfonline.com/doi/abs/10.1111/0033-0124.00253>.
- Fraser, JC, J. T. Bazuin, Lawrence E. Band, and J. Morgan Grove. 2013. “Covenants, Cohesion, and Community: The Effects of Neighborhood Governance on Lawn Fertilization.” *Landscape and Urban Planning* 115. Elsevier B.V.: 30–38. doi:10.1016/j.landurbplan.2013.02.013.
- Fraser, J., J. T. Bazuin, and G. Hornberger. 2015. “The Privatization of Neighborhood Governance and the Production of Urban Space.” *Environment and Planning A*. doi:10.1177/0308518X15621656.
- Groffman, Peter M., J. Morgan Grove, Colin Polsky, Neil D Bettez, Jennifer L Morse, Jeannine Cavender-Bares, Sharon J Hall, et al. 2016. “Satisfaction, Water and Fertilizer Use in the American Residential Macrosystem.” *Environmental Research Letters* 11 (3): 34004. doi:10.1088/1748-9326/11/3/034004.
- Grove, J. Morgan, Austin R Troy, J P M O’Neil-Dunne, William R. Jr. Burch, Mary L. Cadenasso, and Steward T. A. Pickett. 2006. “Characterization of Households and Its Implications for the Vegetation of Urban Ecosystems.” *Ecosystems* 9 (4). Springer: 578–97. doi:10.1007/s10021-006-0116-z.
- Grove, J. Morgan, Dexter H. Locke, and Jarlath P. M. O’Neil-Dunne. 2014. “An Ecology of Prestige in New York City: Examining the Relationships Among Population Density, Socio-Economic Status, Group Identity, and Residential Canopy Cover.” *Environmental Management* 54 (3): 402–419. doi:10.1007/s00267-014-0310-2.

- Harris, Edmund M., Colin Polsky, Kelli L. Larson, Rebecca Garvoille, Deborah G. Martin, Jaleila Brumand, and Laura Ogden. 2012. "Heterogeneity in Residential Yard Care: Evidence from Boston, Miami, and Phoenix." *Human Ecology*, August. doi:10.1007/s10745-012-9514-3.
- Harris, Edmund M., Deborah G. Martin, Colin Polsky, Lillian Denhardt, and Abigail Nehring. 2013. "Beyond 'Lawn People': The Role of Emotions in Suburban Yard Management Practices." *The Professional Geographer*, no. May 2012: 37–41. doi:10.1080/00330124.2012.681586.
- Hernke, Michael T., and Rian J. Podein. 2011. "Sustainability, Health and Precautionary Perspectives on Lawn Pesticides, and Alternatives." *EcoHealth* 8 (2): 223–32. doi:10.1007/s10393-011-0697-7.
- Hunter, Mary Carol R., and Daniel G. Brown. 2012. "Spatial Contagion: Gardening along the Street in Residential Neighborhoods." *Landscape and Urban Planning* 105 (4): 407–16. doi:10.1016/j.landurbplan.2012.01.013.
- Jenkins, Virginia Scott. "The Lawn: A History of an American Obsession" Washington, DC. (1994).
- Kirkpatrick, James B., Grant D. Daniels, and Aidan Davison. 2009. "An Antipodean Test of Spatial Contagion in Front Garden Character." *Landscape and Urban Planning* 93 (2): 103–10. doi:10.1016/j.landurbplan.2009.06.009.
- Larsen, Larissa, and Sharon L. Harlan. 2006. "Desert Dreamscapes: Residential Landscape Preference and Behavior." *Landscape and Urban Planning* 78 (1–2): 85–100. doi:10.1016/j.landurbplan.2005.06.002.

- Larson, Kelli L., D. G. Casagrande, Sharon L. Harlan, and ST Yabiku. 2009. "Residents' Yard Choices and Rationales in a Desert City: Social Priorities, Ecological Impacts, and Decision Tradeoffs." *Environmental Management* 44: 921–37. doi:10.1007/s00267-009-9353-1.
- Larson, Kelli L., and J Brumand. 2014. "Paradoxes in Landscape Management and Water Conservation: Examining Neighborhood Norms and Institutional Forces." *Cities and the Environment (CATE)* 7 (1): 1–24. <http://digitalcommons.lmu.edu/cate/vol7/iss1/6/>.
- Larson, K. L., K. C. Nelson, S. R. Samples, S. J. Hall, N. Bettez, J. Cavender-Bares, Peter M. Groffman, et al. 2015. "Ecosystem Services in Managing Residential Landscapes: Priorities, Value Dimensions, and Cross-Regional Patterns." *Urban Ecosystems*. doi:10.1007/s11252-015-0477-1.
- Lerman, Susannah B., Victoria Kelly Turner, and Christofer Bang. 2012. "Homeowner Associations as a Vehicle for Promoting Native Urban Biodiversity." *Ecology and Society* 17 (4). doi:10.5751/ES-05175-170445.
- Locke, Dexter H., Shawn M. Landry, J. Morgan Grove, and Rinku Roy Chowdhury. 2016. "What's Scale Got to Do with It? Models for Urban Tree Canopy." *Journal of Urban Ecology* 2 (1): juw006. doi:10.1093/jue/juw006.
- Locke, Dexter H., Colin Polsky, J Morgan Grove, Peter M. Groffman, Kristen C. Nelson, Kelli K. Larson, Jeannine Cavender-Bares, Jim B Heffernan, Rinku Roy Chowdhury, Sarah E. Hobbie, Neil Bettez, Christopher Neill, Laura A Ogden, Jarlath P. M. O'Neil-Dunne. *In Review*. Heterogeneity of practice underlies the

homogeneity of ecological outcomes of United States yard care in metropolitan regions, neighborhoods and households. Submitted to *PLoS ONE* on December 22, 2016.

Milesi, Cristina, Steven W Running, Christopher D Elvidge, John B Dietz, Benjamin T Tuttle, and Ramakrishna R Nemani. 2005. "Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States." *Environmental Management* 36 (3): 426–38. doi:10.1007/s00267-004-0316-2.

"mullet, n.9." *OED Online*. Oxford University Press, June 2015. Web. 17 June 2015.
<http://www.oed.com/view/Entry/253382>

Nassauer, Joan Iverson. 1988. "The Aesthetics of Horticulture: Neatness as a Form of Care." *HortScience* 23 (6): 973–77.

Nassauer, Joan Iverson. 1995. "Messy Ecosystems, Orderly Frames." *Landscape Journal* 14 (2): 161–70. doi:doi: 10.3368/lj.14.2.16.

Nassauer, Joan Iverson, Zhifang Wang, and Erik Dayrell. 2009. "What Will the Neighbors Think? Cultural Norms and Ecological Design." *Landscape and Urban Planning* 92 (3–4): 282–92. doi:10.1016/j.landurbplan.2009.05.010.

Pierce, Joseph, and Mary Lawhon. 2015. "Walking as Method: Toward Methodological Forthrightness and Comparability in Urban Geographical Research." *The Professional Geographer* 124 (July 2015): 1–8.
doi:10.1080/00330124.2015.1059401.

- Polsky, Colin, J. Morgan Grove, Chris Knudson, Peter M. Groffman, Neil D Bettez, Jeannine Cavender-Bares, Sharon J. Hall, et al. 2014. "Assessing the Homogenization of Urban Land Management with an Application to US Residential Lawn Care." *Proceedings of the National Academy of Sciences* 111 (12): 4432–37. doi:10.1073/pnas.1323995111.
- Robbins, Paul, Annemarie Polderman, and Trevor Birkenholtz. 2001. "Lawns and Toxins: An Ecology of the City." *Cities* 18 (6): 369–80. doi:10.1016/S0264-2751(01)00029-4.
- Robbins, Paul, and JT Sharp. 2003. "Producing and Consuming Chemicals: The Moral Economy of the American Lawn." *Economic Geography* 79 (4): 425–51. <http://onlinelibrary.wiley.com/doi/10.1111/j.1944-8287.2003.tb00222.x/abstract>.
- Roy Chowdhury, Rinku, Kelli L. Larson, J. Morgan Grove, Colin Polsky, and Elizabeth M. Cook. 2011. "A Multi-Scalar Approach to Theorizing Socio-Ecological Dynamics of Urban Residential Landscapes." *Cities and the Environment (CATE)* 4 (1): 1–19. <http://digitalcommons.lmu.edu/cate/vol4/iss1/6/>.
- Saldaña, Johnny. *The coding manual for qualitative researchers*. Sage, 2015.
- Scotts. 1998. "Scotts Lawncare Special Annual Program Edition: Lawn Successes Made Easy." Marysville.
- Stehouwer, Rachel, Joan Iverson Nassauer, and Lauren Lesch. 2016. "Landscape and Urban Planning Homeowner Preferences for Wooded Front Yards and Backyards: Implications for Carbon Storage." *Landscape and Urban Planning* 146. Elsevier B.V.: 1–10. doi:10.1016/j.landurbplan.2015.09.001.

- Troy, Austin R, J. Morgan Grove, Jarlath P M O'Neil-Dunne, Steward T. A. Pickett, and Mary L. Cadenasso. 2007. "Predicting Opportunities for Greening and Patterns of Vegetation on Private Urban Lands." *Environmental Management* 40 (3): 394–412. doi:10.1007/s00267-006-0112-2.
- Turner, Victoria Kelly, and Dorothy C Ibes. 2011. "The Impact of Homeowners Associations on Residential Water Demand Management in Phoenix, Arizona." *Urban Geography* 32 (8): 1167–88. doi:http://dx.doi.org/10.2747/0272-3638.32.8.1167.
- Turner, V. Kelly, Kimberly Jarden, and Anne Jefferson. "Resident perspectives on green infrastructure in an experimental suburban stormwater management program." *Cities and the Environment (CATE)* 9, no. 1 (2016): 4.
- Zhou, Weiqi, Austin R Troy, J. Morgan Grove, and Jennifer C. Jenkins. 2009. "Can Money Buy Green? Demographic and Socioeconomic Predictors of Lawn-Care Expenditures and Lawn Greenness in Urban Residential Areas." *Society & Natural Resources* 22 (8): 744–60. doi:10.1080/08941920802074330.
- Zmyslony, Jean, and Daniel Gagnon. 1998. "Residential Management of Urban Front-Yard Landscape: A Random Process?" *Landscape and Urban Planning* 40 (4): 295–307. doi:10.1016/S0169-2046(97)00090-X.
- Zmyslony, Jean, and Daniel Gagnon. 2000. "Path Analysis of Spatial Predictors of Front-Yard Landscape in an Anthropogenic Environment." *Landscape Ecology* 15 (4): 357–71. doi:10.1023/A:1008160131014.

Appendix 1. Emergent coding scheme

- 1. Neatness and Aesthetics (overarching theme)
 - A. Neatness (code)
 - B. Landscape Mullets (code)
 - i. Support (sub code)
 - ii. Refute (sub code)
 - iii. Inconclusive (sub code)
- 2. Ease of Maintenance and Effort (overarching theme)
 - A. Division of labor (code)
 - i. Do it yourself versus hiring out (sub code)
 - ii. Learning from elders, family, and others (sub code)
 - B. Food production (code)
 - C. Physical imitations and site characteristics (code)
 - D. Environmental agency and control (code)
- 3. Neighborhood Norms and Identity (overarching theme)
 - A. Getting along, being neighborly (code)
 - B. Groups and governance (code)
 - C. Identity (code)
 - D. Mimicry or ‘spatial contagion’ (code)
 - E. Segregation (code)

CHAPTER 3 LANDSCAPE MULLETS HYPOTHESES PART 2: PLOTS AND PARCELS

To be submitted to Landscape and Urban Planning

Dexter H Locke¹, Rinku Roy Chowdhury¹, J Morgan Grove², John Rogan¹, Deborah Martin¹, Meghan Avolio³, Tara Trammel⁴, Peter Groffman⁵, and possibly others in consultation with Peter Groffman

¹School of Geography, Clark University, 950 Main Street, Worcester MA 01610-1477

USA

PHONE 310 463 6202

EMAIL dexter.locke@gmail.com

²USDA Forest Service, Baltimore Field Station, Suite 350, 5523 Research Park Dr.,

Baltimore, MD 21228

³National Socio-Environmental Synthesis Center, 1 Park Pl Suite 300, Annapolis, MD

21401

⁴Department of Plant and Soil Sciences, University of Delaware, Newark, DE 19716

⁵CUNY Advanced Science Research Center and Brooklyn College Department of Earth and Environmental Sciences 85 St. Nicholas Terrace, 5th Floor New York, NY 10031

Abstract

Prior research consistently suggests that social norms are a key driver residential yard care. The reduced public visibility associated with back yards may influence management decisions, and therefore the resultant ecological structure and function of residential properties. We examined vegetation species richness and evenness found in lawns in Boston, MA; Baltimore, MD; Miami, FL; Minneapolis-St. Paul, MN; Phoenix, AZ; Los Angeles, CA; and Salt Lake City, UT for evidence of varied ecological structure. Seven key measures of the Nitrogen cycle were also measured and compared for potential differences in ecosystem function. Entire-yard vegetation species richness was analyzed for Los Angeles and Salt Lake City, parsed by whether or not the species were intentionally cultivated versus spontaneous. Lawn, soil, and spontaneous entire-yard measures are not different between front and back yards. However, backyards have a regression-adjusted estimate of approximately 10% more cultivated species and there was no interaction effect for city. The raw, unconditional mean cultivated species richness was 19.53 (median = 17) for front yards, and 24.71 (median 21) for back yards, which is on average ~20% more species. It is possible that priorities for less-visible back yards are guided by different priorities and/or motivations that do not include fitting into a particular neighborhood aesthetic, or establishing an outward display perceived as desirable. These social norms should in turn manifest as different ecological outcomes, but it largely did not. It appears that lawns are relatively homogenous at the sub-parcel scale, but entire yards are 10% - 20% more species rich in back yards than front yards.

Keywords

Landscape Mullets, Ecological Homogenization of Urban America Hypothesis, lawncare practices, sustainability science, urban ecology, residential ecosystems, residential landscapes

Introduction

In the United States, often a majority of a given municipality's land is private and residential. It is important to understand the differences – or lack thereof – in ecological structure and function between front and back yards because of the omnipresent and growing spatial extent of residential landscapes (Brown et al 2005). Moreover, according to ESRI's Consumer Expenditure Data (ESRI 2016), which combines Bureau of Labor Statistics, Americans spent nearly \$50 billion on lawn care, supplies, and equipment in 2013 and 2014. These expenditures suggest that residential ecosystems are resource-intensive, with possible deleterious environmental consequences. However, the spatial variation of some practices remains uncertain, within and across metropolitan regions (Groffman et al 2014; Polsky et al 2014; Locke et al In Review).

Social science theories suggest that how residents maintain their front yard – which is publically visible – depends in part on self-presentation and social norms (Robbins 2007). It is therefore possible that priorities for less-visible back yards are guided by different principles that do not include fitting into a particular neighborhood aesthetic, or establishing an outward display perceived as desirable. The reduced visibility associated with back yards may influence management decisions and the resultant ecological structure and function of residential properties. In this paper, we ask: does the ecological structure and function of private residential front yards differ from back yards across the climatically diverse regions of Boston, Baltimore, Miami, Minneapolis-St. Paul, Phoenix, Los Angeles, and Salt Lake City?

Despite a growing literature examining the social drivers for particular land management activities of urban and suburban residents (Cook et al 2012; Robbins 2007), surprisingly little attention has been paid to sub-residential parcel scale, and the variation within a single residential parcel. However, notable counter examples are discussed below (e.g. Dorney et al 1984; Daniels and Kirkpatrick 2006; Belaire et al 2015). The lack of studies that examine sub-parcel variation is possibly an artifact of the methodological and logistical difficulties associated with accessing back yards and collecting the requisite data. However, sub-parcel scale analyses are needed to more fully elucidate the geographic variation, drivers, and outcomes of residential ecosystems yard care practices (Cook et al 2012).

In this paper we examine the Landscape Mullets concept: that front yards are simpler and more clean-cut reflecting an aesthetic perceived as desirable plain yard, while back yards are wilder, and more diverse, reflecting an array of personally-held values and/or priorities. We evaluate the variation in front and back yards with multiple complementary yet distinct measures of ecosystem structure (components or parts) and function (processes and flows). We analyzed plant species in lawns in seven cities, soils properties in six cities, and entire-yard vegetation species in two cities across front and back yards. This paper aims to understand the possible environmental variation between front versus back yards in residences across climatically diverse regions, and to test a theory of residential land management based on the visible (public) and less-visible (private) to better understand the role of social norms and yard care.

1.1 Landscape Mullets

A “Mullet” is a humorous slang term for a hairstyle in which the hair is cut short in the front and along the sides, while the back is left long (“mullet,” 1989). The mullet is colloquially referred with several nicknames and descriptions including “business in the front, and party in the back”. Due to the short, often clean-cut, appearance in the front coupled with the long, and occasionally disorderly and wilder hair in the back, we propose that mullets may serve as a useful metaphor for understanding residential ecosystems. The Landscape Mullets concept has a two-part premise: 1) social norms are a driver of yard care, and 2) these social norms express themselves differently from front to back yards. These ideas stems from advances in reference group behavior theory, derived from sociology and applied to residential ecosystems, and recent empirical findings in the broader urban ecology literature, described next.

1.1.1 Theoretical underpinnings

Reference group behavior theory is the idea that individuals seek membership in social groups they perceive as desirable, and therefore adopt the values, judgments, standards, and/or norms of those social groups (Hyman 1942; Merton and Kit 1950). Pioneering work on the production of the American lawn asserts that multi-national petrochemical companies helped craft an idealized image of lawns (Robbins 2007). The apparently well-maintained lush front lawn required many resource inputs such as water, fertilizers, and pesticides that “lawn people” would need to purchase in order to reproduce the “industrial” lawn (Bormann et al 2001; Robbins 2007; Groffman et al

2014). Other factors were important too. Declining maintenance costs, changes in the global non-lawn-related chemical market, and the growing popularity of larger suburban housing lots also played a role in the widespread adoption and proliferation of the quintessential and iconic front lawn (Robbins and Sharp 2003; Robbins 2007).

Nevertheless, a collective culture of obligation among a community is often created, and termed a “moral economy”. The moral economy explanation of the lawn care suggests that members of households will feel ashamed and as though they have let down their neighbors if they do not properly maintain a particular lawn appearance. Recent evidence from the cognitive sciences support the theory that shame is an evolutionarily advantageous emotion - while unpleasant, like pain - that is designed to defend against devaluation in one’s social ecology (Sznycer et al 2016). Fear, anxiety, shame, and/or guilt motivate people into adopting practices that allow them to mimic their neighbors’ visible lawn care practices (Robbins 2007).

Other extensions of reference group behavior theory and the moral economy are used to help explain why residents choose particular yard care strategies. Because neat, picturesque, safe and inviting landscapes may require substantial financial inputs, they indicate to casual observers that residents belong to a certain socioeconomic class (Nassauer 1988; 1995). The theory of an ecology of prestige also applies reference group behavior theory to visible landscaping practices. The ecology of prestige explains expenditures on environmentally relevant goods and services as motivated in part by group identity and perceptions of inclusion in lifestyle groups (Grove et al 2006; Zhou et al. 2009). Although research in Raleigh, NC found that tree canopy is better correlated

with social status than with indicators of lifestyle (Bigsby 2014), comparable research in Baltimore, MD (Troy et al 2007), New York City (Grove et al 2014), and Philadelphia (Locke et al 2016) show existing vegetative cover, as well as the space potentially available for expanding vegetation on private residential lands, are better correlated with measures associated with different lifestyle groups (e.g. family size, marital status, housing styles) than with measures of socioeconomic status alone.

Whether motivated by fear, anxiety, shame and/or guilt (i.e. the moral economy) or by pride, joy, and/or a desire to uphold the image of the neighborhood (i.e. ecological prestige), abundant empirical evidence shows neighborhood norms influence households behaviors, including land management practices (Nassauer et al. 2009; Carrico et al 2012; Fraser et al. 2013; Larson and Brumand 2014). Neighbors are an important reference group for landscaping practices. In a cross-site study of yard care behaviors among ~7000 households, Locke et al. (*In Review*) found that when residents know more neighbors by name, the odds of their irrigating and fertilizing their parcels increases by ~8%. It is clear that desires to conform, or even perform, within a reference group (i.e. among neighbors) shape yard care decisions.

But what about the less-visible back yard? We hypothesize based on reference group behavior theory, the moral economy, the theory of an ecology of prestige, and recent empirical evidence described next that how one manages one's front yard is related to self-presentation. Self-presentation can only occur where it can be seen. The visibility of backyards is reduced if not completely eliminated, it therefore stands to

reason that the social pressures to maintain a particular aesthetic are also reduced if not completely eliminated in back yards.

1.1.2 Empirical foundations

A review of more than 250 research papers on residential lands in urban areas, identified that “most residential vegetation studies focus on front yards because they are readily surveyed through field observations” Cook et al (2012: 24). Among the few explicitly front versus back yard comparisons on urban residential lands are studies that suggest substantial differences in vegetation structure. For example, across neighborhoods in Syracuse NY there was 1.5 to 2.4 times more vegetated area in back yards compared to front yards, and 0.9 to 1.8 times more tree canopy (Richards et al 1984). Care for shrubs in front yards 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 back yards. A similar study of Shorewood, WI found high species richness in front yards (30 of 38 tree species taxa) across all size classes, and back yards that were less diverse (21 taxa), but with more abundant trees, attributed to greater seedling survival near fences, garages, and other structures in these more private spaces (Dorney et al 1984). In contrast, Belaire et al. (2015) found that neighbors’ yards and socioeconomic characteristics best explained residents’ front yard vegetation in a suburb of Chicago, while perceptions of and habitat resources for birds were most important for back yard vegetation structure and wildlife-friendly attributes. The ecological structure and other bird-supporting resources were more favorable in back yards than front yards.

Further evidence shows differences in the species of vegetation found in front yards when compared to back yards. A study of an Australian suburb showed similar species richness across front and back yards, when controlling for yard size, but the *types* and *purpose* of the vegetation was significantly different. For example, there was more small shrub cover in front than in back yards, and “Simple native gardens, woodland gardens and exotic shrub gardens are concentrated in front yards. Productive gardens, flower and vegetable gardens, no input exotic gardens and shrubs and bush trees gardens are concentrated in back yards” (Daniels and Kirkpatrick 2006: 346). The proportion of showy front gardens to non-showy back yards is negatively correlated with suburb age; in newer developments the difference between the front and back vegetation species is more pronounced (Daniels and Kirkpatrick 2006). Aesthetic and functional differences in plant species have also been examined in the tropical city of San Juan, Puerto Rico. There were significantly more ornamental plants in front yards than back yards by both species richness and by number of stems, across six neighborhoods representing different architectural styles. Moreover, there were more cultivated edible food species in back yards than front yards (Vila-Ruiz et al 2014). These examples indicate that for some households, aesthetics may influence front yard care decisions, while back yard spaces are tended for more functional and utilitarian purposes. The fashion in front, function in back findings distinction inspired and supports the Landscape Mullets concept.

In addition to vegetation, some have examined soils across front and back yards. Martinez et al. (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 back yards. A different study in Baltimore County found significantly higher concentrations of calcium (26%), magnesium (10%) and a higher pH (6.2 vs 5.7) in front yards compared to back yards (Yesilonis et al 2015). Organic matter was slightly higher in front yards, and there were no observed differences for phosphorus and potassium (Yesilonis et al 2015). The observed differences, however, are plausibly attributable to the practice of liming. This suggests different front and back yard management practices with environmental markers or outcomes.

There are a few front/back research papers that focus on the social drivers of yard care, which helped inspire and support the Landscape Mullets concept. In Phoenix, AZ research suggests that front yard styles signal social status and/or adherence to perceptions of social norms and rules, while residents' preferences and values are expressed in backyards (Larsen and Harlan 2006). Moreover, this work points to sub-parcel differences in yard care as influenced by neighborhood-level social processes. This is congruent with reference group behavior theory, the moral economy, and the ecology of prestige. Another study of Phoenix found that residents had distinctly different rationales for yard management across front and back yards, even when residents had different yard types (i.e. mesic, oasis, xeric, patio courtyard; Larson et al 2009). Importantly, there was gap between preferences and actual yard care, attributable to social norms (Larson et al 2009). Significant differences in the preferences for large trees in front and neatness, and privacy and wildlife in back yards were found suburban

Michigan (Stehouwer, Nassauer and Lesch, 2016). The difference between preferences and behaviors seem to vary from the publicly visible front yards and more private back yard spaces, giving rise to the Landscape Mullets concept, and plausibly contributed to varied environmental outcomes such as ecosystem structure and function. Given the prior theoretical and empirical work described above, we hypothesize:

Hyp 1 Lawn vegetation species richness will be lower in front yards than in back yards.

Hyp 2 Lawn vegetation species evenness will be lower in front yards than in back yards.

Hyp 3 The biogeochemical cycling indicators found soils will be greater in front yards than in back yards.

Hyp 4 Entire-yard cultivated vegetation (intentionally grown plants) species richness will be lower in front yards than in back yards.

Hyp 5 Entire-yard spontaneous vegetation (which seeds itself) species richness will be lower in front yards than in back yards.

2 Methods

In order to test if front yards are ecologically different from back yards, we examine several elements of ecological structure (vegetation) and function (indicators of biogeochemical cycling found in soils) partitioned into those spaces. We analyzed vegetation species in lawns in seven cities, soils properties in six cities, and entire-yard (i.e., not just the lawn) vegetation species in two cities across front and back yards

2.1 Experimental Design

The Potential Rating Index of Zip Code Markets (PRIZM) was used to inform a stratified random sample of Census block groups. Specifically, block groups were selected in the climatically diverse metropolitan statistical areas of Boston, MA (BOS), Baltimore, MD (BAL), Miami, FL (MIA), Minneapolis-St. Paul, MN (MSP), Phoenix, AZ (PHX), and Los Angeles, CA (LA), that were high or low socioeconomic status block groups, and across an urban-rural gradient (urban, suburban, or exurban). Then 9,480 telephone interviews were completed to understand residents' characteristics and their yard management practices (see Polsky et al 2014 and Groffman et al 2016), and among those respondents 21 to 31 single-family homes with lawns per metropolitan region were chosen for field sampling of vegetation and soils (see Wheeler et al *In Press*). Data from Salt Lake City were added later. Fifty letters were sent to homeowners in select comparable PRIZM categories as the other six regions, and thirty yards were ultimately visited where five homes were in each category. We analyzed: 1) vegetation species in

lawns; 2) soils in lawns; and 3) entire-yard vegetation species, inclusive of non-lawn areas.

2.1.1 Lawns

Following the methods described by Wheeler et al. (*In Press*) three 1×1 m 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 each front vs. back yards, 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 to the front and back yards for each home visited. Richness is the number of unique species, where as 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 species, p is the proportion of individuals of one particular species divided by the total number of individuals.

2.1.2 Soils

At the same residential sites, the front and back yards were divided into three sections each for a total of six subplots, and two subplots randomly selected. Only residential sites with matched front vs. back pairs are analyzed here, hence the lower

number of observations for soils relative to vegetation. A soil corer was used to extract 1-m cores from undisturbed portions of the lawn. Cores were placed in plastic sleeves with cap and transported to the laboratory in coolers and stored at 4°C until they could be processed. Laboratory methods followed those used by Raciti and colleagues (2011a, b) to create measures of microbial biomass, respiration, potential net mineralization, potential net nitrification, potential denitrification, ammonium, biologically available nitrogen. Because the focus is on human activities that may influence biogeochemical cycling, analyses were restricted to the top 10 cm of the cores. Two cores were shorter because of practical limitations, they were 8 and 9 cm long. These measures were chosen because microbial biomass drives respiration, mineralization, nitrification, and denitrification, which in turn drive NH_4 , NO_2/NO_3 , and biologically available N (Brady and Weil 1996).

2.1.3 Entire-Yard Vegetation

In Los Angeles and Salt Lake City an inventory of all plants – not restricted to the lawn – at each yard was also conducted. Species were identified to the lowest possible taxon, which occasionally included the cultivar level. Species were marked as cultivated or spontaneous. Spontaneous plants are those that were not planted by a human, in contrast with cultivated species which were intentionally planted by people. When there was uncertainty as to whether the plant was intentionally cultivated or not, the species was labeled as uncertain. Analyses were conducted with the unknown species classified as spontaneous, and again where unknown species were grouped with cultivated. The

results were not sensitive to this choice, and we report the analyses were uncertain were classified as spontaneous.

2.2 Statistical Analyses

In order to meet normality, all dependent variables were log-transformed after adding one. Linear mixed effects models were fit where the front/back variable interacted with city of origin. Random intercepts for site were also included to explicitly take into account the paired nature of the non-independent samples, and site was nested within city. As Wickham (2014) explains this random intercept for site is equivalent to a paired t test. The statistical analyses were carried out with R version 3.2.2 (14 August 2015) -- "Fire Safety" (R Core Team (2015)). Several contributed packages were used, as shown in Appendix 1.

3 Results

3.1 Lawn vegetation

There were no statistically significant differences in lawn vegetation species richness or evenness by front and back yard (Table 4-1). The city-to-city variation accounted for 32 and 24 percent of variance in richness and evenness, respectively. The R^2 value richness was 0.89 and 0.80 for evenness. Relative to the base case of Baltimore, front and back yards in other cities differed in their richness (Los Angeles, Minneapolis-St. Paul, Phoenix, and Salt Lake City all had fewer) and species evenness (Boston, Los

Angeles, Miami, and Salt Lake City). The relationship between front and back vegetation species evenness and richness was significantly different in Los Angeles. Therefore, hypotheses 1 and 2 are unsupported.

Table 4-1 Mixed model output for vegetation species richness and evenness found in lawns by front and back yard and region.

	Species Richness in Lawns			Species Evenness in Lawns		
	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>
Fixed Parts						
(Intercept)	2.12	1.95 to 2.29	<.001	0.39	0.35 to 0.44	<.001
Front / Back (Back as Reference)	-0.08	-0.23 to 0.06	.263	0.02	-0.03 to 0.06	.523
Boston (Baltimore as Reference)	-0.13	-0.34 to 0.09	.241	-0.08	-0.14 to -0.02	.008
Los Angeles	-0.93	-1.17 to -0.68	<.001	0.10	0.03 to 0.17	.007
Miami	-0.13	-0.37 to 0.11	.284	-0.09	-0.16 to -0.02	.008
Minneapolis-St. Paul	-0.35	-0.58 to -0.11	.004	-0.03	-0.09 to 0.04	.408
Phoenix	-0.78	-1.01 to -0.55	<.001	0.06	-0.00 to 0.13	.056
Salt Lake City	-0.82	-1.04 to -0.61	<.001	0.09	0.02 to 0.15	.006
Front / Back x Boston	-0.00	-0.19 to 0.18	.967	0.00	-0.06 to 0.07	.900
Front / Back x Los Angeles	0.47	0.25 to 0.69	<.001	-0.10	-0.18 to -0.03	.006
Front / Back x Miami	-0.03	-0.23 to 0.18	.800	-0.01	-0.08 to 0.05	.694
Front / Back x Minneapolis-St. Paul	0.09	-0.11 to 0.29	.393	-0.01	-0.07 to 0.06	.850
Front / Back x Phoenix	0.06	-0.16 to 0.28	.575	-0.01	-0.08 to 0.07	.843
Front / Back x Salt Lake City	0.17	-0.02 to 0.35	.074	-0.04	-0.10 to 0.02	.215
Random Parts						
σ^2		0.051			0.006	
$\tau_{00, \text{City:Lot_ID}}$		0.049			0.003	
$\tau_{00, \text{Lot_ID}}$		0.047			0.003	
$N_{\text{City:Lot_ID}}$		167			167	
$N_{\text{Lot_ID}}$		167			167	
$\text{ICC}_{\text{City:Lot_ID}}$		0.332			0.273	
$\text{ICC}_{\text{Lot_ID}}$		0.322			0.242	
Observations		312			312	
R^2 / Ω_0^2		.887 / .876			.799 / .769	

Notes: Confidence intervals and p-values are calculated based on normal-distribution assumption, treating the t-statistics as Wald z-statistics. σ^2 is the within-group (residual) variance, τ_{00} is the between-group-variance, variation between individual intercepts and average intercept, and 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 Ω_0^2 value is calculated as $(1 - (\text{residual variance} / \text{response variance}))$, as suggested by Xu (2003) and Nakagawa and Schielzeth (2013). Ω_0^2 statistic is therefore the proportion of the residual variation explained by the covariates.

3.2 Soils

Congruent with the findings regarding vegetative diversity in lawns, there are no significant differences between front and back yards in any of the seven biogeochemical cycling variables recorded (Table 4-2). There was less microbial biomass in Minneapolis-St. Paul and Phoenix than in Baltimore. Respiration was higher in Los Angeles and lower in Phoenix compared to Baltimore. Nitrification was lower in Los Angeles than Baltimore. For microbial biomass and respiration 21% and 15% of the variation was from site to site, respectively ($ICC_{\text{Lot_ID}}$), whereas for the other indicators relatively little variation occurred at that scale when controlling of the city, front/back and their interactions.

Table 4-2 Mixed model output for indicators of the Nitrogen Cycle by front and back yards by region

	Microbial biomass (ugC/g soil)			Respiration (ug C/g soil/day)			Mineralization (ug N/g dry soil/day)			Nitrification (ug N/g dry soil/day)		
	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>
Fixed Parts												
(Intercept)	6.30	5.84 to 6.75	<.001	2.33	2.04 to 2.63	<.001	0.04	-0.20 to 0.28	.742	0.23	-0.04 to 0.49	.097
Front / Back (Back as Reference)	-0.05	-0.55 to 0.44	.829	0.06	-0.27 to 0.39	.735	0.01	-0.30 to 0.32	.962	-0.02	-0.36 to 0.32	.918
Boston (Baltimore as Reference)	-0.25	-0.79 to 0.28	.352	-0.12	-0.47 to 0.22	.491	0.28	-0.01 to 0.57	.054	0.14	-0.17 to 0.45	.380
Los Angeles	-0.42	-1.10 to 0.26	.228	0.48	0.04 to 0.93	.032	-0.25	-0.61 to 0.12	.187	-0.59	-0.99 to -0.19	.004
Miami	-0.23	-0.86 to 0.40	.467	0.06	-0.35 to 0.47	.779	0.25	-0.08 to 0.59	.139	0.04	-0.33 to 0.41	.831
Minneapolis-St. Paul	-0.91	-1.51 to -0.30	.003	-0.30	-0.69 to 0.09	.133	0.14	-0.18 to 0.47	.392	-0.01	-0.36 to 0.35	.972
Phoenix	-1.32	-1.98 to -0.66	<.001	-0.54	-0.96 to -0.11	.014	-0.02	-0.38 to 0.33	.900	-0.05	-0.43 to 0.34	.810
Front / Back x Boston	0.09	-0.49 to 0.68	.759	0.09	-0.30 to 0.48	.643	-0.02	-0.39 to 0.34	.904	-0.06	-0.46 to 0.34	.763
Front / Back x Los Angeles	-0.03	-0.77 to 0.72	.945	-0.47	-0.96 to 0.03	.065	0.33	-0.14 to 0.79	.167	0.48	-0.03 to 1.00	.066
Front / Back x Miami	0.22	-0.46 to 0.91	.522	0.05	-0.40 to 0.51	.815	0.15	-0.28 to 0.58	.502	0.27	-0.20 to 0.75	.257
Front / Back x Minneapolis-St. Paul	-0.10	-0.76 to 0.57	.772	-0.03	-0.47 to 0.41	.892	-0.13	-0.54 to 0.29	.548	-0.12	-0.57 to 0.34	.616
Front / Back x Phoenix	0.28	-0.44 to 1.01	.445	0.09	-0.39 to 0.57	.708	0.02	-0.43 to 0.47	.937	-0.25	-0.75 to 0.25	.322
Random Parts												
σ^2		0.324			0.142			0.125			0.153	
$\tau_{00, \text{City:Lot_ID}}$		0.100			0.051			0.028			0.030	
$\tau_{00, \text{case_id}}$		0.115			0.034			0.001			0.002	
$N_{\text{City:Lot_ID}}$		78			78			78			78	
$N_{\text{Lot_ID}}$		78			78			78			78	
$\text{ICC}_{\text{City:Lot_ID}}$		0.186			0.225			0.182			0.162	
$\text{ICC}_{\text{Lot_ID}}$		0.213			0.149			0.007			0.008	
Observations		156			156			156			156	
R^2 / Ω_0^2		.718 / .680			.686 / .634			.481 / .423			.462 / .416	

Table 4-2 (cont.) Mixed model output for indicators of the Nitrogen Cycle by front and back yards by region

	Denitrification (ng N/g soil/hour)			Ammonium (ug N/g dry soil)			Biologically available N (ug N/g dry soil)		
	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>
Fixed Parts									
(Intercept)	5.10	3.98 to 6.21	<.001	1.24	0.85 to 1.63	<.001	3.80	3.32 to 4.28	<.001
Front / Back (Back as Reference)	-0.06	-1.53 to 1.42	.940	-0.14	-0.62 to 0.35	.580	-0.04	-0.70 to 0.62	.916
Boston (Baltimore as Reference)	-0.56	-1.85 to 0.73	.398	-0.35	-0.80 to 0.11	.139	-0.08	-0.65 to 0.48	.772
Los Angeles	-0.55	-2.35 to 1.25	.548	-0.18	-0.77 to 0.41	.549	0.01	-0.71 to 0.74	.973
Miami	-0.49	-1.99 to 1.01	.525	-0.59	-1.13 to -0.05	.032	0.11	-0.56 to 0.78	.747
Minneapolis-St. Paul	-0.12	-1.54 to 1.31	.873	-0.50	-1.02 to 0.02	.060	-0.04	-0.69 to 0.60	.895
Phoenix	-3.13	-4.77 to -1.50	<.001	-0.43	-1.00 to 0.14	.135	-1.22	-1.92 to -0.52	<.001
Front / Back x Boston	-0.14	-1.86 to 1.57	.871	0.21	-0.35 to 0.78	.459	0.19	-0.59 to 0.96	.638
Front / Back x Los Angeles	0.39	-1.89 to 2.67	.739	-0.15	-0.87 to 0.58	.692	0.38	-0.61 to 1.37	.455
Front / Back x Miami	-0.26	-2.27 to 1.74	.798	0.57	-0.10 to 1.24	.094	0.32	-0.60 to 1.23	.497
Front / Back x Minneapolis-St. Paul	0.31	-1.58 to 2.21	.745	-0.01	-0.65 to 0.63	.975	-0.13	-1.01 to 0.75	.776
Front / Back x Phoenix	1.07	-1.12 to 3.27	.337	-0.24	-0.95 to 0.46	.498	0.58	-0.38 to 1.53	.239
Random Parts									
σ^2		2.368			0.304			0.566	
$\tau_{00, \text{City:Lot_ID}}$		0.196			0.093			0.001	
$\tau_{00, \text{case_id}}$		0.044			0.001			0.041	
$N_{\text{City:Lot_ID}}$		76			78			78	
$N_{\text{Lot_ID}}$		76			78			78	
$\text{ICC}_{\text{City:Lot_ID}}$		0.075			0.233			0.001	
$\text{ICC}_{\text{Lot_ID}}$		0.017			0.001			0.067	
Observations		138			156			156	
R^2 / Ω_0^2		.345 / .325			.537 / .444			.303 / .291	

Notes: Confidence intervals and p-values are calculated based on normal-distribution assumption, treating the t-statistics as Wald z-statistics. σ^2 is the within-group (residual) variance, τ_{00} is the between-group-variance, variation between individual intercepts and average intercept, and 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 Ω_0^2 value is calculated as $(1 - (\text{residual variance} / \text{response variance}))$, as suggested by Xu (2003) and Nakagawa and Schielzeth (2013). Ω_0^2 statistic is therefore the proportion of the residual variation explained by the covariates.

3.3 Entire-Yard Vegetation

There are significantly more cultivated garden species in back yards than front yards, but there are no differences for spontaneous species (Table 4-3). Hypothesis 4 was supported but Hypothesis 5 was not. The back-transformed (i.e. exponentiated) intercept was 15.92, while the back/front coefficient was 1.52. Backyards have a regression-adjusted estimate of approximately 10% more species. There was no statistically significant interaction effect for city. The raw, unconditional mean richness for cultivated species was 19.53 (median = 17) in front yards, and 24.71 (median 21) in back yards. Back yards on average contained ~20% more species than front yards.

Table 4-3 Mixed model output for entire-yard vegetation species by front and back yard by region.

	Cultivated Garden Species Richness			Spontaneous Garden Species		
	<i>B</i>	<i>CI</i>	<i>p</i>	<i>B</i>	<i>CI</i>	<i>p</i>
Fixed Parts						
(Intercept)	2.77	2.44 to 3.09	<.001	2.35	2.00 to 2.69	<.001
Front / Back (Back as Reference)	0.42	0.08 to 0.76	.015	0.24	-0.14 to 0.61	.212
Salt Lake City (Los Angeles as Reference)	0.02	-0.40 to 0.45	.912	-0.34	-0.80 to 0.11	.137
Front / Back x Salt Lake City	-0.43	-0.87 to 0.01	.055	0.14	-0.35 to 0.63	.570
Random Parts						
σ^2		0.309			0.384	
$\tau_{00, \text{City:Lot_ID}}$		0.131			0.128	
$\tau_{00, \text{Lot_ID}}$		0.133			0.150	
$N_{\text{City:Lot_ID}}$		51			51	
$N_{\text{Lot_ID}}$		51			51	
$ICC_{\text{City:Lot_ID}}$		0.229			0.194	
$ICC_{\text{Lot_ID}}$		0.231			0.226	
Observations		102			102	
R^2 / Ω_0^2		.729 / .647			.705 / .618	

Notes: Confidence intervals and p-values are calculated based on normal-distribution assumption, treating the t-statistics as Wald z-statistics. σ^2 is the within-group (residual) variance, τ_{00} is the between-group-variance, variation between individual intercepts and average intercept, and 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 Ω_0^2 value is calculated as $(1 - (\text{residual variance} / \text{response variance}))$, as suggested by Xu (2003) and Nakagawa and Schielzeth (2013). Ω_0^2 statistic is therefore the proportion of the residual variation explained by the covariates.

4 Discussion

Prior research consistently suggests that peer pressures and social norms are a key driver of yard care behaviors (Bormann et al 2001; Robbins 2007; Nassauer et al. 2009; Carrico et al 2012; Fraser et al. 2013; Larson and Brumand 2014). ‘Fitting in’ is accomplished by altering visible aspects of residential yards to conform to neighborhood aesthetics and social expectations. However, the leverage of such social norms may not extend to back yards, where visibility is reduced if not completely eliminated. Peer pressures should therefore be reduced if not completely eliminated in back yards. Correspondingly back yards should have a distinct ecological structure and function. This is the Landscape Mullet concept, which is a theoretical advance and extension of reference group behavior theory, the moral economy, and the theory of an ecology of prestige. We analyzed plant species in lawns in seven cities, soils properties in six cities, and entire-yard vegetation species in two cities across front and back yards.

We expected to find lower species richness and species evenness in lawns in front yards when compared to back yards (Hyps 1 and 2). The rationale was that driven to maintain the quintessential “industrial” lawn, Robbins’ “lawn people” would devote more resources (i.e. time and money) into creating a monoculture where it can be more readily seen – in the front yard – and allow for more species in back yards. But our data do not support those expectations. We did observe some variation in lawn species richness and evenness by city, plausibly owing to different climates. But we did not

observe the sharp differences between front and back yards that is suggested by prior theoretical and empirical work.

We expected to find more evidence of biogeochemical cycling in the front yard soils than in back yards (Hyp 3). This expectation was based on the rationale that increased inputs of water and fertilizers in front yards would significantly drive the nitrogen cycle in those spaces. Yet we failed to find statistically significant differences the front compared to the back. Either residents are managing their lawns the same in the front and the back, or management inputs do not alter the measured indicators. More research is needed to link management inputs and soils outcomes. While there were some differences by city, those were the exception rather than the rule.

We expected to find fewer cultivated species of vegetation in front yard gardens than in back yard gardens (Hyp 4), and did. This is driven by the idea that residents are seeking a monoculture in front, and more utilitarian and/or functional landscapes in the more private back yard spaces. Unconditional differences in means among the surveyed sites show that back yards tend to have ~20% more cultivated species than front yards. The regression-adjusted estimates provide a more modest, but still meaningful difference of ~10%. We also expected to find fewer spontaneous species in front (Hyp 5), but did not. We reasoned that residents would strive to reduce weeds more in the visible spaces than the relatively invisible spaces. Our two-city evidence did not support that notion.

When taken together, lacking support for Hyps 1-3, 5 is counter intuitively consistent with the initial premise of “business in the front and party in the back”. What was found is that the intentionally managed, non-lawn areas show substantial differences in vegetation species richness. It appears that lawns are fairly homogenous at the sub-parcel scale, but gardens are 10% - 20% more species-rich in back yards than front yards. Lawns and the soils beneath them vary regionally but not significantly within the same parcel. The variability of soils appears at a coarser scale than the individual residential parcel.

The abundant literature on yard care practices and outcomes highlights myriad factors related to management activities (Roy Chowdhury et al 2011; Cook et al 2012). In this paper we focused on an often-neglected (or ignored), yet seemingly important dimension: how differences may emerge between the seen and unseen spaces. This explicit focus on the spatial partitioning was based in yard care practices and ensuing environmental outcomes, and was motivated by an apparent gap in prior research. The influence of peer pressure commonly evoked do not take into account the public nature of front yards, and the relatively more private nature of back yards. A contribution of this paper is to refine the moral economy and ecology of prestige explanations. When front/back differences were uncovered in previous research (Dorney et al 1984; Richards et al 1984; Daniels and Kirkpatrick 2006; Vila-Ruiz et al 2014; Belaire et al 2015; Yesilonis et al 2015) these differences were often emergent; the researchers did not set out to intentionally examine sub-parcel, front-to-back variation with respect to

social pressures (save for Larsen and Harlan 2006 and Larson et al 2009). The few studies that did focus on front-to-back variation were unfortunately limited in their single-site design, and therefore larger generalizations were not feasible. In this paper we found that the intentionally managed parts of the garden were more species rich, which is empirical contribution to the growing residential ecologies literature.

5 Conclusions

The reduced visibility associated with back yards may influence management decisions and the resultant ecological structure and function of residential properties. But this seemingly reasonable premise is under-tested. Using the mullet as a metaphor, this paper strove to understand some of the environmental impacts diverged in front versus back yards, plausibly linked to peer pressures and the process of self-appraisal and self-presentation. The evidence was mixed: the lawn, soil, and spontaneous garden data did not reveal differences beyond the realm of chance. Alternatively, we found that cultivated species richness was greater in back yards than front yards. Future research should examine other drivers and covariates in concert with more systematically collected front and back yard environmental data. Moreover, in-depth, qualitative research should explicitly examine peer pressures, social norms, perceptions of social norms through the lens of front and back yards. Rather than assume away variation at the sub-parcel level, or ignore this source of social and environmental variation, more work should investigate this spatial scale.

6 Acknowledgements

This research is supported by the Macro- Systems Biology Program (US NSF) under Grants EF-1065548, -1065737, -1065740, -1065741, -1065772, -1065785, -1065831, and -121238320. The work arose from research funded by grants from the NSF LTER program for Baltimore (DEB-0423476); Phoenix (BCS-1026865, DEB-0423704, and DEB-9714833); Plum Island, Boston (OCE-1058747 and 1238212); Cedar Creek, Minneapolis–St. Paul (DEB-0620652); and Florida Coastal Everglades, Miami (DBI-0620409). Edna Bailey Sussman Foundation, Libby Fund Enhancement Award and the Marion I. Wright '46 Travel Grant at Clark University, The Warnock Foundation, the USDA Forest Service Northern Research Station, Baltimore and Philadelphia Field Stations, and the DC-BC ULTRA-Ex NSF-DEB-0948947. The findings and opinions reported here do not necessarily reflect those of the funders of this research.

7 References

- Bates, D., Maechler, M., Bolker, B., Walker, S.. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1-48.
doi:10.18637/jss.v067.i01.
- Bigsby, K., McHale, M., & Hess, G. (2014). Urban Morphology Drives the Homogenization of Tree Cover in Baltimore, MD, and Raleigh, NC. *Ecosystems*, 17, 212–227. <http://doi.org/DOI:10.1007/s10021-013-9718-4>
- Brady, N. C., Weil, R. R.. (1996). *The nature and properties of soils* (No. Ed. 12). Macmillan publishing company.
- Brown, D. G., Johnson, K. M., Loveland, T. R., & Theobald, D. M. (2005). Rural land-use trends in the conterminous United States, 1950-2000. *Ecological Applications*, 15(December), 1851–1863. <http://doi.org/10.1890/03-5220>
- Boone, C. G., Cadenasso, M. L., Grove, J. M., Schwarz, K., & Buckley, G. L. (2010). Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. *Urban Ecosystems*, 13(3), 255–271.
<http://doi.org/10.1007/s11252-009-0118-7>
- Bormann, F. H., Balmori, D., & Geballe, G. T. (2001). *Redesigning the American lawn: a search for environmental harmony*. New Haven, CT: Yale University Press.
- Byrnes, J. 2008. Re: Coefficient of determination (R^2) when using lme()
(<https://stat.ethz.ch/pipermail/r-sig-mixed-models/2008q2/000713.html>)

- Carrico, A. R., Fraser, J., & Bazuin, J. T. (2012). Green With Envy: Psychological and Social Predictors of Lawn Fertilizer Application. *Environment and Behavior*, 45(4), 427–454. <http://doi.org/10.1177/0013916511434637>
- Cook, E. M., Hall, S. J., & Larson, K. L. (2012). Residential landscapes as social-ecological systems: a synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosystems*, 15(1), 19–52. doi:10.1007/s11252-011-0197-0
- Clarke, L. W., Jenerette, G. D., & Davila, A. (2013). The luxury of vegetation and the legacy of tree biodiversity in Los Angeles, CA. *Landscape and Urban Planning*, 116, 48–59. <http://doi.org/10.1016/j.landurbplan.2013.04.006>
- Daniels, G. D., & Kirkpatrick, J. B. (2006). Comparing the characteristics of front and back domestic gardens in Hobart, Tasmania, Australia. *Landscape and Urban Planning*, 78(4), 344–352. doi:10.1016/j.landurbplan.2005.11.004
- Dorney, J., Guntenspergen, G. R., Keough, J. R., & Stearns, F. (1984). Composition and Structure of an Urban Woody Plant Community. *Urban Ecology*, 8, 69–90.
- ESRI (2016). *ESRI Consumer Spending Methodology 2016*. (An ESRI White Paper, June 2016). Redlands, CA: ESRI
http://downloads.esri.com/esri_content_doc/dbl/us/J9945_2016_US_Consumer_Spending_Data.pdf
- Fraser, J., Bazuin, J. T., Band, L. E., & Morgan Grove, J. (2013). Covenants, cohesion, and community: The effects of neighborhood governance on lawn fertilization.

Landscape and Urban Planning, 115, 30–38.

<http://doi.org/10.1016/j.landurbplan.2013.02.013>

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., &

Briggs, J. M. (2008). Global change and the ecology of cities. *Science*,

319(5864), 756–60. doi:10.1126/science.1150195

Groffman, P. M., Cavender-Bares, J., Bettez, N. D., Grove, J. M., Hall, S. J., Heffernan,

J. B., ... Steele, M. K. (2014). Ecological homogenization of urban USA.

Frontiers in Ecology and the Environment, 12(1), 74–81.

<http://doi.org/10.1890/120374>

Groffman, P. M., Grove, J. M., Polsky, C., Bettez, N. D., Morse, J. L., Cavender-Bares,

J., ... Locke, D. H. (2016). Satisfaction, water and fertilizer use in the American

residential macrosystem. *Environmental Research Letters*, 11(3), 34004.

<http://doi.org/10.1088/1748-9326/11/3/034004>

Grove, J. M., Troy, A. R., O’Neil-Dunne, J. P. M., Burch, W. R. J., Cadenasso, M. L.,

& Pickett, S. (2006). Characterization of Households and its Implications for the

Vegetation of Urban Ecosystems. *Ecosystems*, 9(4), 578–597.

doi:10.1007/s10021-006-0116-z

Grove, J. M., Locke, D. H., & O’Neil-Dunne, J. P. M. (2014). An Ecology of Prestige

in New York City: Examining the Relationships Among Population Density,

Socio-economic Status, Group Identity, and Residential Canopy Cover.

Environmental Management, 54(3), 402–419. doi:10.1007/s00267-014-0310-2

- Harris, E. M., Martin, D., Polsky, C., Denhardt, L., & Nehring, A. (2012). Beyond “Lawn People”: The Role of Emotions in Suburban Yard Management Practices. *The Professional Geographer*, (May 2012), 37–41.
doi:10.1080/00330124.2012.681586
- Harris, E. M., Polsky, C., Larson, K. L., Garvoille, R., Martin, D. G., Brumand, J., & Ogden, L. (2012). Heterogeneity in Residential Yard Care: Evidence from Boston, Miami, and Phoenix. *Human Ecology*. doi:10.1007/s10745-012-9514-3
- Hox J. 2002. Multilevel analysis: techniques and applications. Mahwah, NJ: Erlbaum
- Hyman, H. H. (1942). The psychology of status. *Archives of Psychology (Columbia University)*.
- Johnson, A. L., Tauzer, E. C., & Swan, C. M. (2014). Human legacies differentially organize functional and phylogenetic diversity of urban herbaceous plant communities at multiple spatial scales. *Applied Vegetation Science*, 18, n/a--n/a.
<http://doi.org/10.1111/avsc.12155>
- Kirkpatrick, J. B., Daniels, G. D., & Zagorski, T. (2007). Explaining variation in front gardens between suburbs of Hobart, Tasmania, Australia. *Landscape and Urban Planning*, 79(3-4), 314–322. doi:10.1016/j.landurbplan.2006.03.006
- Larsen, L., & Harlan, S. L. (2006). Desert dreamscapes: Residential landscape preference and behavior. *Landscape and Urban Planning*, 78(1-2), 85–100.
doi:10.1016/j.landurbplan.2005.06.002

- Larson, K. L., Casagrande, D. G., Harlan, S. L., & Yabiku, S. (2009). Residents' yard choices and rationales in a desert city: social priorities, ecological impacts, and decision tradeoffs. *Environmental Management*, *44*, 921–937.
<http://doi.org/10.1007/s00267-009-9353-1>
- Larson, K. L., & Brumand, J. (2014). Paradoxes in Landscape Management and Water Conservation: Examining Neighborhood Norms and Institutional Forces. *Cities and the Environment (CATE)*, *7*(1), 1–24.
- Locke, D. H., & Baine, G. (2015). The good, the bad, and the interested: how historical demographics explain present-day tree canopy, vacant lot and tree request spatial variability in New Haven, CT. *Urban Ecosystems*, *18*(2), 391–409.
<http://doi.org/10.1007/s11252-014-0409-5>
- Locke, D. H., Landry, S., Grove, J. M., Roy Chowdhury, R.. (2016). What's scale got to do with it? Models for urban tree canopy. *Journal of Urban Ecology*. *2*(1): 1-16.
doi:10.1093/jue/juw006
- Locke, D.H., Polsky, C., Grove, J. M., Groffman, P. M., Nelson, K.C., Larson, K. L., Cavender-Bares, J., Heffernan, J. B., Roy Chowdhury, R., Hobbie, S. E., Bettez, N., Neill, C., Ogden, L.A., O'Neil-Dunne, J. P. M.. [In Review]. Heterogeneity of practice underlies the homogeneity of ecological outcomes of United States yard care in metropolitan regions, neighborhoods and households. Submitted to *PLoS ONE* on December 22, 2016.

- Luck, G. W., Smallbone, L. T., & O'Brien, R. (2009). Socio-Economics and Vegetation Change in Urban Ecosystems: Patterns in Space and Time. *Ecosystems*, 12(4), 604–620. <http://doi.org/10.1007/s10021-009-9244-6>
- Lüdecke D (2016). *_sjPlot: Data Visualization for Statistics in Social Science_*. R package version 2.1.2. <https://CRAN.R-project.org/package=sjPlot>
- Macie, E. A. (1984). Residential Greenspace and Vegetation in a Mature City: Syracuse, New York. *Urban Ecology*, 8, 99–125.
- Martinez, N. G., Bettez, N. D., & Groffman, P. M. (2014). Sources of Variation in Home Lawn Soil Nitrogen Dynamics. *Journal of Environment Quality*, 43(6), 2146. <http://doi.org/10.2134/jeq2014.03.0103>
- Merton RK, Kitt A (1950) Contributions to the theory of reference group behavior. In: Merton RK, Lazarsfeld P (eds) Reprinted in part from studies in the scope and method of “The American soldier”. Free Press, Glencoe, IL
- "mullet, n.9." *OED Online*. Oxford University Press, June 2015. Web. 17 June 2015. <http://www.oed.com/view/Entry/253382>
- Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R² from generalized linear mixed-effects models. *Methods in Ecology and Evolution*, 4(2), 133-142.
- Nassauer, J. I. (1988). The aesthetics of horticulture: neatness as a form of care. *HortScience*, 23(6), 973–977.

- Nassauer, J. (1995). Messy ecosystems, orderly frames. *Landscape Journal*, 14(2), 161–170.
- Nassauer, J. I., Wang, Z., & Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landscape and Urban Planning*, 92(3–4), 282–292. <http://doi.org/10.1016/j.landurbplan.2009.05.010>
- Neuwirth, E.. (2014). RColorBrewer: ColorBrewer Palettes. R package version 1.1-2. <http://CRAN.R-project.org/package=RColorBrewer>
- Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Henry, M., Stevens, H., Wagner, H.. (2015). vegan: Community Ecology Package. R package version 2.3-2. <http://CRAN.R-project.org/package=vegan>
- Polsky, C., Grove, J. M., Knudson, C., Groffman, P. M., Bettez, N. D., Cavender-Bares, J., ... Steele, M. K. (2014). Assessing the homogenization of urban land management with an application to US residential lawn care. *Proceedings of the National Academy of Sciences*, 111(12), 4432–4437. <http://doi.org/10.1073/pnas.1323995111>
- Raciti, S. M., Groffman, P. M., Jenkins, J. C., Pouyat, R. V., Fahey, T. J., Pickett, S. T. A., & Cadenasso, M. L. (2011). Nitrate production and availability in residential soils. *Ecological Applications*, 21(7), 2357–2366. <http://doi.org/10.1890/10-2009.1>

- Raciti, S. M., Groffman, P. M., Jenkins, J. C., Pouyat, R. V., Fahey, T. J., Pickett, S. T. A., & Cadenasso, M. L. (2011). Accumulation of Carbon and Nitrogen in Residential Soils with Different Land-Use Histories. *Ecosystems*, *14*(2), 287–297. <http://doi.org/10.1007/s10021-010-9409-3>
- R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>
- Richards, N. A., Mallette, J. R., Simpson, R. J., & Macie, E. A. (1984). Residential Greenspace and Vegetation in a Mature City: Syracuse, New York. *Urban Ecology*, *8*, 99–125.
- Robbins, P. (2007). *Lawn people: How grasses, weeds, and chemicals make us who we are*. Temple University Press.
- Robbins, P., & Sharp, J. (2003). Producing and consuming chemicals: the moral economy of the American lawn. *Economic Geography*, *79*(4), 425–451.
- Robinson, D. (2016). broom: Convert Statistical Analysis Objects into Tidy Data Frames. R package version 0.4.1. <http://CRAN.R-project.org/package=broom>
- Stehouwer, R., Nassauer, J. I., & Lesch, L. (2016). Landscape and Urban Planning Homeowner preferences for wooded front yards and backyards: Implications for carbon storage. *Landscape and Urban Planning*, *146*, 1–10. <http://doi.org/10.1016/j.landurbplan.2015.09.001>

- Sznycer, Daniel, John Tooby, Leda Cosmides, Roni Porat, Shaul Shalvi, and Eran Halperin. 2016. "Shame Closely Tracks the Threat of Devaluation by Others, Even across Cultures." *Proceedings of the National Academy of Sciences*, 201514699. doi:10.1073/pnas.1514699113.
- Troy, A. R., Grove, J. M., O'Neil-Dunne, J. P. M., Pickett, S., & Cadenasso, M. L. (2007). Predicting opportunities for greening and patterns of vegetation on private urban lands. *Environmental Management*, 40(3), 394–412. doi:10.1007/s00267-006-0112-2
- Vila-Ruiz, C. P., Meléndez-Ackerman, E., Santiago, R., García-Montiel, D., Lastra, L., Fuguerola, C., & Fumero, J. (2014). Plant species diversity of residential yards across a tropical watershed: implications for urban sustainability. *Ecology and Society*, 19(3), 22. <http://doi.org/10.5751/ES-06164-190322>
- Warnes, G.R., Bolker, B., Bonebakker, L., Gentleman, R., Huber, W., Liaw, A., Lumley, T., Maechler, M., Magnusson., Moeller, S., Schwartz, M., Venables, B.. (2015). gplots: Various R Programming Tools for Plotting Data. R package version 2.17.0. <http://CRAN.R-project.org/package=gplots>
- Wheeler, M. M., C. Neill, P. M. Groffman, M. Avolio, N. D. Bettez, J. Cavender-Bares, R. Roy Chowdhury, L. Darling, J. M. Grove, S. J. Hall, J. B. Heffernan, S. E. Hobbie, K. L. Larson, J. L. Morse, K. Nelson, L. A. Ogden, and J. O'Neil-Dunne. *In Press*. Homogenization of residential lawn plant species composition

- across seven US urban regions. *Landscape and Urban Planning*,
<http://dx.doi.org/10.1016/j.landurbplan.2017.05.004>.
- Wickham, H.. (2016). tidyr: Easily Tidy Data with `spread()` and `gather()` Functions. R package version 0.6.0. <http://CRAN.R-project.org/package=tidyr>
- Wickham, H., and Francois, R. (2016). dplyr: A Grammar of Data Manipulation. R package version 0.5.0. <http://CRAN.R-project.org/package=dplyr>
- Xu, R. (2003). Measuring explained variation in linear mixed effects models. *Statistics in medicine*, 22(22), 3527-3541.
- Yesilonis, I. D., Pouyat, R. V., Russell-Anelli, J., & Powell, E. (2015). The effects of landscape cover on surface soils in a low density residential neighborhood in Baltimore, Maryland. *Urban Ecosystems*. <http://doi.org/10.1007/s11252-015-0502-4>
- Zhou, W., Troy, A. R., Grove, J. M., & Jenkins, J. C. (2009). Can Money Buy Green? Demographic and Socioeconomic Predictors of Lawn-Care Expenditures and Lawn Greenness in Urban Residential Areas. *Society & Natural Resources*, 22(8), 744–760. doi:10.1080/08941920802074330

8 Appendix 1. Contributed R packages used for statistical analyses.

Package name	Citation	Purpose
dplyr	(Wickham and Francois 2016)	data manipulation
lme4	(Bates et al 2015)	fitting mixed models
sjPlot	(Lüdecke 2016)	calculating fixed effects significance values and model diagnostics, and formatting outputs
tidyr	(Wickham 2016)	data manipulation
vegan	(Oksanen et al 2015)	vegetation analyses

CONCLUSION

Given the enormity of the American lawn, and the potentially deleterious environmental consequences of industrial lawn care, there is a clear need to understand the geographic variation, drivers, and outcomes of yard care practices, and by scale. The structure of this dissertation and its sampling regime may be likened to the shape of an hourglass, alternating between extensive (large-n) and intensive (smaller-n) research designs. Chapter 2 is spatially and geographically extensive, examining patterns and variations across thousands of observations drawn from cities spanning a large geographic and ecoclimatic range, and across the household, neighborhood and regional scales. Chapter 3's sample size is far more modest, with attention is deliberately placed on social processes and drivers of yard management decisions, relying on intensively collected data. Chapter 4 scales back up again to larger and more extensive datasets across space to test for differences in ecosystem structure and function between front and back yards. Together these papers build a narrative arc connecting three important facets of yard care practices: geographic variation, social drivers, and environmental outcomes – and by scale. Some of the dissertation's theoretical, methodological, and empirical contributions are highlighted below.

In chapter 2, "*Heterogeneity of practice underlies the homogeneity of ecological outcomes of United States yard care in metropolitan regions, neighborhoods and household*" a telephone survey of 7,021 households was used to characterize irrigation, fertilization, and pesticide application with respect to household income, age, and

number of neighbors known by name. The use of binary logistic hierarchical (aka “multi-level” or “mixed effects”) models allowed for the simultaneous estimation of geographic variation at the household, neighborhood, and regional scales. Geographers should consider using multi-level models along side spatially autoregressive models (e.g. Locke et al 2016). This is because multi-level models control for spatial autocorrelation like spatially autoregressive models, allow for spatial non-stationarity like geographically weighted regression, and allow for the assessment of correlations at multiple nested scales (Locke et al 2016). We found that irrigation was more common in dry regions (Phoenix and Los Angeles) and less common in wet regions (Boston and Baltimore). This evidence suggests that different social practices are used to overcome natural limitations to support the Ecological Homogenization Hypothesis (Groffman et al 2014; 2016), thus supporting the idea that there is a nation ideology of what a lawn should look like (Robbins et al 2007). Moreover, we found that the odds of irrigating and fertilizing are ~8% higher when respondents know more neighbors by name than the average respondent. This finding, in part, motivated chapter 3, which investigated how social norms may shape yard care. This finding may also suggest that policy interventions relying on lawn-induced fear and anxiety are to neighbors could inspire more environmentally friendly alternatives.

Social norms are important for understanding yard care practices. Paul Robbins’ idea of a Moral Economy suggests that anxiety and even fear around norms of particular aesthetics motivate yard care practices (Robbins, Polderman & Birkenholtz, 2001;

Robbins & Sharp 2003; Robbins 2012). People want to fit in. To avoid judgment or perceived judgment from their neighbors, households comply by begrudgingly conforming. A complementary and parallel explanation championed by J. Morgan Grove is called the Ecology of Prestige (Grove et al 2006a,b, 2014; Troy et al 2007; Zhou et al 2009; Locke et al 2016). In this view, households are motivated by pride and joy, seeking acceptance in their social group, and use landscaping as status symbols. Households want to perform for their neighbors. These two mutually reinforcing and empirically supported explanations hinge upon the idea of visible landscaping practices because the yard has to be seen to allow for appraisal of conformity and/or performance. This dissertation advanced new evidence supporting these parallel explanations. But what about back yards where visibility is reduced if not completely eliminated? Based on social theories we would expect front yards to be managed with peer pressures in mind, and back yards to reflect more personal, private priorities. This hypothesis is the Landscape Mullets concept, refinding the dominant existing theories in the urban ecology domain. The concept also reinforces the need to examine sub-parcel scale as nested within households, which are in turn nested in their neighborhoods, and climates.

In chapter 3, “*Landscape Mullets Part 1: Hearing it from the horse’s mouth*” the conceptual underpinnings of the Landscape Mullets are established and tested with 36 semi-structured interviews at residents’ homes across seven neighborhoods in Baltimore. The Landscape Mullets concept has a two-part premise: 1) social norms are

a driver of yard care, and 2) these social norms express themselves differently from front to back yards. There was evidence supporting the salience of the front/public vs. back/private dichotomy as a driver of yard care in six of the seven neighborhoods studied. The exception was a neighborhood called Hamilton, where only three short interviews without tours were conducted; it was inconclusive. There were also interviewees that showed support for one, but not the other of these premises, serving to expose the limits and edges of the concept. For example, some respondents plainly did not provide evidence for either considering social pressures, or did not differentiate the use and care of their yards by front and back. In other cases still the support was inconclusive; there was not enough information because the interview was too short and/or a tour of the property was not permitted. Nevertheless, the public/private divide has some relevance as an outcome of social norms and peer pressures.

In this chapter we also found that social norms and peer pressures are different in different neighborhoods. For example, residents in the Winston-Govans neighborhood boasted that they routinely reported each other for code violations and lodged complaints through the city's anonymous tracking system. In contrast in Lake Walker, residents reported feeling comfortable about talking to neighbors about their yards. If lawns had grown too tall, some would simply ask their neighbors to mow. These examples elucidate how either fear and anxiety (linked to moral economies and conformance) or pride and joy (linked to ecology of prestige and performance) can drive yard care, and in turn, that those pressures are sometimes more muted or even

absent in back yards. Even though for some residents the Landscape Mullets concept did not resonate, this chapter advances a conceptual frontier for the theories of yard care. The empirical evidence that social pressures vary – for some – within their property boundaries then motivated a rigorous analysis of whether environmental outcomes also vary by front and back yard.

In chapter 4, “*Landscape Mullets Part 2: Plots and Parcels*” we analyzed vegetation species in lawns in seven cities, soils properties in six cities, and entire-yard vegetation species in two cities across front and back yards. In lawns, we examined vegetation species richness and evenness, two important measures of ecosystem structure in Boston, MA; Baltimore, MD; Miami, FL; Minneapolis-St. Paul, MN; Phoenix, AZ; Los Angeles, CA; and Salt Lake City, UT, but did not find any significant differences. Seven key indicators of the nitrogen cycle derived from soil samples were therefore measured for front/back differences in the first six cities listed above. Again, we did not find any statistically significant differences in these measures of ecosystem function. Finally, entire-yard vegetation species richness was analyzed for Los Angeles and Salt Lake City, parsed by cultivated (those intentionally planted by people) versus spontaneous plant species (not planted). We found that backyards had approximately a regression-adjusted difference of 10% more cultivated species and there was no interaction effect for city. Unconditional differences in means among the surveyed sites show that back yards tend to have ~20% more cultivated species than front yards. The theory developed in chapter 3 suggests that peer pressure should manifest itself in

different environmental outcomes for some residents. Surprisingly, not finding differences among lawn vegetation species, biogeochemical cycling indicators, and spontaneous vegetation species by front and back yard is counter intuitively consistent with the Landscape Mullets concept. This is because the intentionally managed, non-lawn spaces do show significant and meaningful differences in the number of vegetation species grown.

Summary and Future Research

In conclusion, this dissertation contributes to the discipline of Geography in several ways. In the second chapter, cross-site research design, and multi-level modeling methods overcame the lack of comparability in the previous literature, while responding to calls for explicitly multi-scalar analyses. Geographers should welcome these statistical techniques into their proverbial toolboxes. Different explanations operate at different scales. Therefore analyses need to encompass unambiguously multiple units of analysis at different scales simultaneously. In order to target an effective intervention, one has to know which scales are relevant and appropriate. The multi-level statistical models accomplish that goal.

In chapter three conceptual advances about visible and less-visible spaces and the role of social norms were empirically tested with semi-structured interviews across 36 neighborhoods. Support for the front/public vs back/private nature of yards as a driver of behavior is not neighborhood-specific. The theoretical advanced termed the

Landscape Mullets concept appears relevant across a range of contexts and conditions. Future research should continue to test and refine how social norms are differentiated across space and by scale.

The fourth chapter assessed the environmental outcomes associated with front and back yard management. We found a 10% - 20% difference in cultivated species diversity. Rather than ignore or assume away the potential within parcel heterogeneity by front and back yards, future research should further examine this scale for social and environmental reasons.

This dissertation sought to make an incremental step toward understanding how much social norms matter and their environmental consequences. Theoretical, methodological, and empirical gains were made. This dissertation could have been about solar panel adoption, or driving low-emission vehicles because these environmentally relevant behaviors are visible. Use of these technologies is inherently part of the social realm, and consequently available for judgment by others. While low-flush toilets and double pane windows are important for water and energy conservation, respectively, they are largely unseen. Instead I focused on yards. These seemingly innocuous spaces hide in plain sight, but enable insights into larger human-environment relationships.

Lessons from other visible pro-environmental programs such as recycling could be used to inform lawn-alternative programs that help residents choose more

environmentally friendly alternatives to highly-resource intensive lawns. If alternatives are adopted, it is possible that new norms could become entrenched.

References

- Groffman, Peter M., Jeannine Cavender-Bares, Neil D Bettez, J. Morgan Grove, Sharon J Hall, James B Heffernan, Sarah E. Hobbie, et al. 2014. "Ecological Homogenization of Urban USA." *Frontiers in Ecology and the Environment* 12 (1): 74–81. doi:10.1890/120374.
- Groffman, Peter M., J. Morgan Grove, Colin Polsky, Neil D Bettez, Jennifer L Morse, Jeannine Cavender-Bares, Sharon J Hall, et al. 2016. "Satisfaction, Water and Fertilizer Use in the American Residential Macrosystem." *Environmental Research Letters* 11 (3): 34004. doi:10.1088/1748-9326/11/3/034004.
- Grove, J. Morgan, Austin R Troy, J P M O'Neil-Dunne, William R. Jr. Burch, Mary L. Cadenasso, and Steward T. A. Pickett. 2006. "Characterization of Households and Its Implications for the Vegetation of Urban Ecosystems." *Ecosystems* 9 (4). Springer: 578–97. doi:10.1007/s10021-006-0116-z.
- Grove, J. Morgan, Mary L. Cadenasso, William R. Jr. Burch, Steward T. A. Pickett, Kirsten Schwarz, Jarlath P. M. O'Neil-Dunne, and Matthew Wilson. 2006. "Data and Methods Comparing Social Structure and Vegetation Structure of Urban Neighborhoods in Baltimore , Maryland." *Society & Natural Resources* 30 (19): 117–36.
- Grove, J. Morgan, Dexter H. Locke, and Jarlath P. M. O'Neil-Dunne. 2014. "An Ecology of Prestige in New York City: Examining the Relationships Among Population Density, Socio-Economic Status, Group Identity, and Residential

- Canopy Cover.” *Environmental Management* 54 (3): 402–419.
doi:10.1007/s00267-014-0310-2.
- Locke, Dexter H., Shawn M. Landry, J. Morgan Grove, and Rinku Roy Chowdhury. 2016. “What’s Scale Got to Do with It? Models for Urban Tree Canopy.” *Journal of Urban Ecology* 2 (1): juw006. doi:10.1093/jue/juw006
- Robbins, Paul, Annemarie Polderman, and Trevor Birkenholtz. 2001. “Lawns and Toxins: An Ecology of the City.” *Cities* 18 (6): 369–80. doi:10.1016/S0264-2751(01)00029-4.
- Robbins, Paul, and JT Sharp. 2003. “Producing and Consuming Chemicals: The Moral Economy of the American Lawn.” *Economic Geography* 79 (4): 425–51.
- Robbins, Paul. 2007. *Lawn People: How Grasses, Weeds, and Chemicals Make Us Who We Are*. Temple University Press.
- Troy, Austin R, J. Morgan Grove, Jarlath P M O’Neil-Dunne, Steward T. A. Pickett, and Mary L. Cadenasso. 2007. “Predicting Opportunities for Greening and Patterns of Vegetation on Private Urban Lands.” *Environmental Management* 40 (3): 394–412. doi:10.1007/s00267-006-0112-2.
- Zhou, Weiqi, Austin R Troy, J. Morgan Grove, and Jennifer C. Jenkins. 2009. “Can Money Buy Green? Demographic and Socioeconomic Predictors of Lawn-Care Expenditures and Lawn Greenness in Urban Residential Areas.” *Society & Natural Resources* 22 (8): 744–60. doi:10.1080/08941920802074330.

APPENDIX 1: R CODE

Introduction

This appendix contains the R code written in support of chapters two and four using R version 3.2.2 (2015-08-14) -- "Fire Safety" on Platform: x86_64-apple-darwin13.4.0 (64-bit), Running under: OS X 10.10.5 (Yosemite). As described below, these scripts import the needed data, perform requisite cleaning and reclassifying, and perform the analyses pertinent to the dissertation chapters. Exploratory data analyses are largely omitted. The self-contained R vignettes for the packages employed should be referenced. These scripts should be considered experiential; use at your own risk and contact me with any questions you may have.

Scripts

Chapter 2

```
#### script by
#### Dexter H. Locke, MEdSc., MA
####
#### dexter.locke@gmail.com
#### 310 463 6202
#### http://dexterlocke.com/
#### @DextraordinaryH

#### created on October 13, 2013
#### for preliminary (multi-level) model building on fertilization

#### updated on October 14, 2013
#### to clean up/combine income fields and test out prelim models

#### updated on January 16, 2014
#### improved documentation and to make the data more analysis-ready

#### updated on April 8, 2016
#### streamlined coding for replicating dissertation chapter 2 only,
#### exploratory analyses are omitted. Formatted for inclusion in dissertation
#### achieved more parsimony/faster processing time
#### note that further refinements are possible using the tidyverse
```

```

#### all of the plotting at the end could be replaced with sjPlot::sjp.lmer
#### but that package did not exist at the time, or I was unaware of it

#### Use this script at your own risk, there are no warranties provided
#### Please contact me if you have any questions

# clean up the workspace, delete all objects in memory
rm(list = ls())

# load libraries
library(lme4)                # fits mixed models
library(MuMIn)              # calculates R^2 for GLMMs
library(ggplot2)             # graphing. Load later, conflicts with Hmisc
library(gridExtra)           # multiple graphs on a single image
library(Hmisc)               # correlations with pvalues

> sessionInfo()
R version 3.2.2 (2015-08-14)
Platform: x86_64-apple-darwin13.4.0 (64-bit)
Running under: OS X 10.10.5 (Yosemite)

locale:
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] grid      stats      graphics  grDevices  utils      datasets  methods   base

other attached packages:
[1] Hmisc_3.16-0  ggplot2_2.2.0  Formula_1.2-1  survival_2.38-3  lattice_0.20-33
[6] gridExtra_2.0.0  MuMIn_1.15.1  lme4_1.1-12    Matrix_1.2-2

loaded via a namespace (and not attached):
 [1] Rcpp_0.12.8      cluster_2.0.3    splines_3.2.2    MASS_7.3-43
 [5] munsell_0.4.2    colorspace_1.2-6  minqa_1.2.4      plyr_1.8.3
 [9] tools_3.2.2     nnet_7.3-10      gtable_0.1.2     nlme_3.1-128
[13] latticeExtra_0.6-26 lazyeval_0.2.0    assertthat_0.1   tibble_1.2
[17] RColorBrewer_1.1-2 nloptr_1.0.4     acepack_1.3-3.3  rpart_4.1-10
[21] scales_0.4.1     stats4_3.2.2     foreign_0.8-65   proto_0.3-10

# read in the data, time it, weigh it. Your directory may be different
system.time(tbl <- read.csv("~/projects/MacroBio/MacroData/Eco-System2011NeighborhoodStudyDataFile_dhlCSV.csv", head=T, sep=","))
a <- object.size(tbl); print(a, units="Mb"); rm(a)

# trim down: we won't need all of the data for this project, speed it up
# examine select field names
names(tbl[,c(34, 32, 33, 89, 88, 81, 70, 131, 127)])

# should be
# q6_3 Irrigation
# q6_1 Fertilization
# q6_2 Pesticide Application
# q30c_1 Income <$50K
# q30b_1 Income >$50K
# q26_1 Age
# q16_1 # of Neighs Known by

Name

# URB          Urbanicity
# CityLab      Region

# make the change

```

```

tbl <- tbl[,c(34, 32, 33, 89, 88, 81, 70, 131, 127)]

# double checks / EDA for trimmed table
dim(tbl)
names(tbl)
head(tbl); tail(tbl)
summary(tbl)
str(tbl)

#### reclassify for analysis:           Fertilizer, Pesticide and Irrigation
tbl$q6_1[tbl$q6_1 == 3] <- 0           # NO, did not fertilize
tbl$q6_1[tbl$q6_1 == 2] <- 1           # YES, did fertilize

tbl$q6_2[tbl$q6_2 == 3] <- 0           # NO, did not use pesticides
tbl$q6_2[tbl$q6_2 == 2] <- 1           # YES, did pesticides

tbl$q6_3[tbl$q6_3 == 3] <- 0           # NO, did not irrigate
tbl$q6_3[tbl$q6_3 == 2] <- 1           # YES, did irrigate

# double check the reclassification was successful
par(mfrow=c(1,3))
hist(tbl$q6_1, ylim=c(0, 8000))        # Fert is more common than pest
hist(tbl$q6_2, ylim=c(0, 8000))        # Pest is lest popular
hist(tbl$q6_3, ylim=c(0, 8000))        # Irrigation is most popular
dim(tbl)
head(tbl); tail(tbl)
str(tbl)
summary(tbl)
par(mfrow=c(1,1))                      # restore the graphics window

#### make a new field for combined income
temp.1 <- tbl$q30c_1                    # copy the lower income bins
temp.1[is.na(temp.1)] <- 0              # set NA's to zeros

temp.2 <- tbl$q30b_1 + 4                 # copy the upper income bins and add 4
temp.2[is.na(temp.2)] <- 0              # set NA's to zeros

tbl$INCOME <- temp.1 + temp.2           # add a new field, combining temps
tbl$INCOME[tbl$INCOME == 0] <- NA      # set zeros to NA's

# double check it
summary(tbl$INCOME)                    # note the number of NA's
unique(tbl$INCOME)
hist(tbl$INCOME, breaks=9)

# clean up and verify
rm(temp.1, temp.2); ls()

#### Remove Don't Know (aka DK) and NA from question 16
## recall the Q: About how many neighbors do you know by name?
#           2 = none,           3 = a few, 4 = about half, 5 = most of them,
#           6 all of them, 7 = DK/RF

# check it out first
par(mfrow=c(1,2))
hist(tbl$q16_1, col="light gray")
summary(tbl$q16_1)

# recode and double check it out: graphically and numerically

```

```

tbl$q16_1[tbl$q16_1 == 7] <- NA
hist(tbl$q16_1, col="light gray")
summary(tbl$q16_1)

#### Remove the refusals from the AGE question (coded as 6)
# check it out first
hist(tbl$q26_1, col="light gray"); summary(tbl$q26_1)

# recode and double check it out: graphically and numerically
tbl$q26_1[tbl$q26_1 == 6] <- NA
hist(tbl$q26_1, col="light gray"); summary(tbl$q26_1)

#### add a field that concatenates City and PD to prevent crossed-effects
tbl$CityPD <- paste(tbl$CityLab, tbl$URB); names(tbl)
head(tbl) # looks good!

# cut out the NA's
summary(tbl); names(tbl); dim(tbl)
tbl <- na.omit(tbl[,c(1:3, 6, 7, 10, 9, 11)])
dim(tbl)

#### descriptive statistics
# blank matrix as container
myMat <- matrix(rep(NA, 24), nrow=6, ncol=4)

# loop through each column to get mean, st dev, min, and max, round and print it
for(i in 1:6){
myMat[i, 1] <- round(mean(tbl[,i]), 3)
myMat[i, 2] <- round(sd(tbl[,i]), 3)
myMat[i, 3] <- round(min(tbl[,i]), 3)
myMat[i, 4] <- round(max(tbl[,i]), 3)
}

myMat

# correlation coefficients w pvals
z <- rcorr(as.matrix(tbl[,c(1:6)]), type="spearman"); z

### FIT MODELS
### Irrigation

# Step #1: Unconditional model
system.time(
Null.Model <- glmer(q6_3 ~ 1 + (1| CityPD) + (1 | CityLab),
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

# Step #2: Random Intercept, fixed slope
system.time(
Model.1 <- glmer(q6_3 ~
scale(INCOME, center=T, scale=F) + # income
scale(q26_1, center=T, scale=F) + # Age
scale(q16_1, center=T, scale=F) + # known neighs
(1 | CityPD) + (1 | CityLab), # two levels
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

```

```

# Step #3: Random Intercept, random slope
system.time(
Model.2 <- glmer(q6_3 ~ 1 +
(scale(INCOME, center=T, scale=F) +           # income
scale(q26_1, center=T, scale=F) +           # Age
scale(q16_1, center=T, scale=F) +           # known neighs
  | CityPD) + (1 | CityLab),                 # two levels
  data = tbl, family=binomial(link = "logit"), verbose=2,
  control=glmerControl(optimizer="bobyqa"))))

# Step #3: Random Intercept, random slope
system.time(
Model.3 <- glmer(q6_3 ~
scale(INCOME, center=T, scale=F) +           # income
scale(q26_1, center=T, scale=F) +           # Age
scale(q16_1, center=T, scale=F) +           # known neighs
(scale(INCOME, center=T, scale=F) +         # income
scale(q26_1, center=T, scale=F) +         # Age
scale(q16_1, center=T, scale=F) +         # known neighs
  | CityPD) + (1 | CityLab),                 # two levels
  data = tbl, family=binomial(link = "logit"), verbose=2,
  control=glmerControl(optimizer="bobyqa"))))

# convergence warnings
# http://stats.stackexchange.com/questions/110004/how-scared-should-we-be-about-convergence-warnings-in-lme4
relgrad <- with(Model.3@optinfo$derivs, solve(Hessian, gradient))
max(abs(relgrad))
# its less than 0.001 or 0.002, so its ok to ignore the message

# model selection
IrrSel <- model.sel(NULL.Model, Model.1, Model.2, Model.3); IrrSel
anova(NULL.Model, Model.1, Model.2, Model.3)

# save the model
IRR.Mod <- Model.1
r.squaredGLMM(IRR.Mod) # pseudo-R^2

anova(IRR.Mod, NULL.Model)

# get confidence intervals
se <- sqrt(diag(vcov(IRR.Mod)))
system.time(tab <- cbind(Est = fixef(IRR.Mod),
  LL = fixef(IRR.Mod) - 1.96 * se,
  UL = fixef(IRR.Mod) + 1.96 * se))

# odd ratios are easier to interpret because of the logistic function
Irr_exp_tab <- exp(tab); Irr_exp_tab

### Fertilization

# Step #1: Unconditional model
system.time(
NULL.Model <- glmer(q6_1 ~ 1 + (1| CityPD) + (1 | CityLab),
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))))

# Step #2: Random Intercept, fixed slope
system.time(

```

```

Model.1 <- glmer(q6_1 ~
scale(INCOME, center=T, scale=F) +      # income
scale(q26_1, center=T, scale=F) +      # Age
scale(q16_1, center=T, scale=F) +      # known neighs
(1 | CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"), verbose=2,
  control=glmerControl(optimizer="bobyqa"))

# Step #3: Random Intercept, random slope
system.time(
Model.2 <- glmer(q6_1 ~ 1 +
(scale(INCOME, center=T, scale=F) +      # income
scale(q26_1, center=T, scale=F) +      # Age
scale(q16_1, center=T, scale=F) +      # known neighs
  | CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"), verbose=2,
  control=glmerControl(optimizer="bobyqa"))

# Step #3: Random Intercept, random slope
system.time(
Model.3 <- glmer(q6_1 ~
scale(INCOME, center=T, scale=F) +      # income
scale(q26_1, center=T, scale=F) +      # Age
scale(q16_1, center=T, scale=F) +      # known neighs
(scale(INCOME, center=T, scale=F) +      # income
scale(q26_1, center=T, scale=F) +      # Age
scale(q16_1, center=T, scale=F) +      # known neighs
  | CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"), verbose=2,
  control=glmerControl(optimizer="bobyqa"))

# model selection
FertSel <- model.sel(NULL.Model, Model.1, Model.2, Model.3); FertSel
anova(NULL.Model, Model.1, Model.2, Model.3)

# save the model
Fert.Mod <- Model.1
r.squaredGLMM(Fert.Mod) # pseudo-R^2

anova(Fert.Mod, NULL.Model)

se <- sqrt(diag(vcov(Fert.Mod)))
system.time(tab <- cbind(Est = fixef(Fert.Mod),
  LL = fixef(Fert.Mod) - 1.96 * se,
  UL = fixef(Fert.Mod) + 1.96 * se))

# odd ratios are easier to interpret because of the logistic function
exp(tab)

Fert_exp_tab <- exp(tab); Fert_exp_tab

### Pesticide Application

# Step #1: Unconditional model
system.time(
NULL.Model <- glmer(q6_2 ~ 1 + (1| CityPD) + (1 | CityLab),
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

# Step #2: Random Intercept, fixed slope

```

```

system.time(
Model.1 <- glmer(q6_2 ~
scale(INCOME, center=T, scale=F) +      # income
scale(q26_1, center=T, scale=F) +      # Age
scale(q16_1, center=T, scale=F) +      # known neighs
(1 | CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

# Step #3: Random Intercept, random slope
system.time(
Model.2 <- glmer(q6_2 ~ 1 +
(scale(INCOME, center=T, scale=F) +    # income
scale(q26_1, center=T, scale=F) +    # Age
scale(q16_1, center=T, scale=F)      # known neighs
| CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

# Step #3: Random Intercept, random slope
system.time(
Model.3 <- glmer(q6_2 ~
scale(INCOME, center=T, scale=F) +    # income
scale(q26_1, center=T, scale=F) +    # Age
scale(q16_1, center=T, scale=F) +    # known neighs
(scale(INCOME, center=T, scale=F) +  # income
scale(q26_1, center=T, scale=F) +    # Age
scale(q16_1, center=T, scale=F)      # known neighs
| CityPD) + (1 | CityLab),           # two levels
  data = tbl, family=binomial(link = "logit"),
  control=glmerControl(optimizer="bobyqa"))

# model selection
PestSel <- model.sel(NULL.Model, Model.1, Model.2, Model.3); PestSel

# save the model
Pest.Mod <- Model.1
r.squaredGLMM(Pest.Mod) # pseudo-R^2

se <- sqrt(diag(vcov(Pest.Mod)))
system.time(tab <- cbind(Est = fixef(Pest.Mod),
  LL = fixef(Pest.Mod) - 1.96 * se,
  UL = fixef(Pest.Mod) + 1.96 * se))

# odd ratios are easier to interpret because of the logistic function
exp(tab)
Pest_exp_tab <- exp(tab); Pest_exp_tab

# recall that the simplest model always fits best
IrrSel; FertSel; PestSel

# model summaries
summary(IRR.Mod); summary(Fert.Mod); summary(Pest.Mod)

# graph the level 2 and level 3 variation

# based on: http://stackoverflow.com/questions/13847936/in-r-plotting-random-effects-from-lmer-lme4-package-using-qqmath-or-dotplot

# get the random effects for IRRIGATION, then FERT, then PESTICIDES
randoms.irr <- ranef(IRR.Mod, condVar = TRUE)

```

```

randoms.fert <- ranef(Fert.Mod, condVar = TRUE)
randoms.pest <- ranef(Pest.Mod, condVar = TRUE)

### get the variances of intercepts
# irrigation
L3.i <- attr(ranef(IRR.Mod, condVar = TRUE)[[2]], "postVar") # Level 3
L2.i <- attr(ranef(IRR.Mod, condVar = TRUE)[[1]], "postVar") # Level 2
# fertilization
L3.f <- attr(ranef(Fert.Mod, condVar = TRUE)[[2]], "postVar") # Level 3
L2.f <- attr(ranef(Fert.Mod, condVar = TRUE)[[1]], "postVar") # Level 2
# pesticides application
L3.p <- attr(ranef(Pest.Mod, condVar = TRUE)[[2]], "postVar") # Level 3
L2.p <- attr(ranef(Pest.Mod, condVar = TRUE)[[1]], "postVar") # Level 2

### random intercepts and labels
# irrigation
rand3I.int <- randoms.irr$CityLab
rand2I.int <- randoms.irr$CityPD
# fertilization
rand3F.int <- randoms.fert$CityLab
rand2F.int <- randoms.fert$CityPD
# pesticide application
rand3P.int <- randoms.pest$CityLab
rand2P.int <- randoms.pest$CityPD

### push those new objects into a data frame, create confidence intervals
# irrigation
df3.i <- data.frame(Intercepts=randoms.irr$CityLab[,1], # Level 3
  sd.int3=1.96*sqrt(L3.i[,1:length(L3.i)]),
  lev.names=rownames(rand3I.int))
df2.i <- data.frame(Intercepts=randoms.irr$CityPD[,1], # Level 2
  sd.int2=1.96*sqrt(L2.i[,1:length(L2.i)]),
  lev.names=rownames(rand2I.int))
# fertilization
df3.f <- data.frame(Intercepts=randoms.fert$CityLab[,1], # Level 3
  sd.int3=1.96*sqrt(L3.f[,1:length(L3.f)]),
  lev.names=rownames(rand3F.int))
df2.f <- data.frame(Intercepts=randoms.fert$CityPD[,1], # Level 2
  sd.int2=1.96*sqrt(L2.f[,1:length(L2.f)]),
  lev.names=rownames(rand2F.int))
# pesticide application
df3.p <- data.frame(Intercepts=randoms.pest$CityLab[,1], # Level 3
  sd.int3=1.96*sqrt(L3.p[,1:length(L3.p)]),
  lev.names=rownames(rand3P.int))
df2.p <- data.frame(Intercepts=randoms.pest$CityPD[,1], # Level 2
  sd.int2=1.96*sqrt(L2.p[,1:length(L2.p)]),
  lev.names=rownames(rand2P.int))

### for ordering by intercept values (instead of name)
# irrigation
df3.i$lev.names <- factor(df3.i$lev.names, # Level 3
  levels = df3.i$lev.names[order(df3.i$Intercepts)])
df2.i$lev.names <- factor(df2.i$lev.names, # Level 2
  levels = df2.i$lev.names[order(df2.i$Intercepts)])
# fertilization
df3.f$lev.names <- factor(df3.f$lev.names, # Level 3
  levels = df3.f$lev.names[order(df3.f$Intercepts)])
df2.f$lev.names <- factor(df2.f$lev.names, # Level 2
  levels = df2.f$lev.names[order(df2.f$Intercepts)])
# pesticide application
df3.p$lev.names <- factor(df3.p$lev.names, # Level 3

```

```

      levels = df3.p$lev.names[order(df3.p$Intercepts]])
df2.p$lev.names <- factor(df2.p$lev.names,                                # Level 2
      levels = df2.p$lev.names[order(df2.p$Intercepts]])

library(ggplot2)
p1 <- ggplot(df3.i, aes(lev.names, Intercepts, shape=lev.names))
p2 <- ggplot(df2.i, aes(lev.names, Intercepts, shape=lev.names))
p3 <- ggplot(df3.f, aes(lev.names, Intercepts, shape=lev.names))
p4 <- ggplot(df2.f, aes(lev.names, Intercepts, shape=lev.names))
p5 <- ggplot(df3.p, aes(lev.names, Intercepts, shape=lev.names))
p6 <- ggplot(df2.p, aes(lev.names, Intercepts, shape=lev.names))

# Added horizontal line at y=0, error bars to points & points w size two
p1 <- p1 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df3.i$sd.int3,
    ymax=Intercepts + df3.i$sd.int3), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))
p2 <- p2 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df2.i$sd.int2,
    ymax=Intercepts + df2.i$sd.int2), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))
p3 <- p3 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df3.f$sd.int3,
    ymax=Intercepts + df3.f$sd.int3), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))
p4 <- p4 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df2.f$sd.int2,
    ymax=Intercepts + df2.f$sd.int2), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))
p5 <- p5 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df3.p$sd.int3,
    ymax=Intercepts + df3.p$sd.int3), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))
p6 <- p6 + geom_hline(yintercept = 0) +
  geom_errorbar(aes(ymin = Intercepts - df2.p$sd.int2,
    ymax=Intercepts + df2.p$sd.int2), width = 0, color="black") +
  geom_point() + scale_y_continuous(limits=c(-1.29, 1.29))

# Removed legends and with scale_shape_manual point shapes set to 1 and 16
p1 <- p1 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(25, 25, 16, 16, 17, 17))           #PAY ATTENTION
p2 <- p2 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(25, rep(16,16), 17))             #PAY ATTENTION
p3 <- p3 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(rep(16,6)))                       #PAY ATTENTION
p4 <- p4 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(rep(25,4), rep(16,10), rep(17,4))) #PAY ATTENTION
p5 <- p5 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(25, 16, 16, 16, 17, 17))       #PAY ATTENTION
p6 <- p6 + guides(size=FALSE, shape=FALSE) +
  scale_shape_manual(values=c(25, 25, rep(16, 15), 17))       #PAY ATTENTION

# Changed appearance of plot (black and white theme) and x & y axis labels
p1 <- p1 + theme_bw(base_size = 9) + xlab("Level-3: Metropolitan Regions") + ylab("Log odds of
irrigation")
p2 <- p2 + theme_bw(base_size = 9) + xlab("Level-2: Population
Density per Region") + ylab("Log odds of irrigation")

p3 <- p3 + theme_bw(base_size = 9) + xlab("Level-3: Metropolitan Regions") + ylab("Log odds of
fertilization")
p4 <- p4 + theme_bw(base_size = 9) + xlab("Level-2: Population

```

```

Density per Region") + ylab("Log odds of fertilization")

p5 <- p5 + theme_bw(base_size = 9) + xlab("Level-3: Metropolitan Regions") + ylab("Log odds of
pesticide application")
p6 <- p6 + theme_bw(base_size = 9) + xlab("Level-2: Population
Density per Region") + ylab("Log odds of pesticide application")

#Final adjustments of plot
p1 <- p1 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())
p2 <- p2 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())
p3 <- p3 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())
p4 <- p4 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())
p5 <- p5 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())
p6 <- p6 + theme(axis.text.x=element_text(size=rel(.8)),
  axis.title.x=element_text(size=rel(0.8)),
  axis.text.y=element_text(size=rel(.8)),
  panel.grid.minor=element_blank(),
  panel.grid.major.x=element_blank())

# To put levels on y axis you just need to use coord_flip()
p1 <- p1 + coord_flip()
p2 <- p2 + coord_flip()
p3 <- p3 + coord_flip()
p4 <- p4 + coord_flip()
p5 <- p5 + coord_flip()
p6 <- p6 + coord_flip()

#quartz(h=5.5, w=6.5);grid.arrange(p1, p2, p3, p4, p5, p6, ncol=2)
quartz(h=6.5, w=6.5);grid.arrange(p1, p2, p3, p4, p5, p6, ncol=2)

# end

```

Chapter 4

```

### Plot-based Landscape Mulletts Analyses
### ScRipt by Dexter H. Locke
### with substantial contributions from Meghan Avolio, PhD

### Fall 2016 / Spring 2017

```

```

### contains many extraneous analyses not reported on in chapter 4
### there are substantial opportunities to shorten and improve this script, but it works

# clear the workspace
rm(list=ls())

# set the working directory
setwd("~/projects/MacroBio/MacroData/dumps_for_dexter/WorkingFiles/")

# load libraries
library(tidyr)
library(dplyr)
library(ggplot2)
library(vegan)
library(RColorBrewer)
library(broom)
library(lme4)
library(ggplots)
library(sjPlot)

> sessionInfo()
R version 3.2.2 (2015-08-14)
Platform: x86_64-apple-darwin13.4.0 (64-bit)
Running under: OS X 10.10.5 (Yosemite)

locale:
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] stats      graphics  grDevices  utils      datasets  methods   base

other attached packages:
[1] sjPlot_2.1.2      ggplots_2.17.0    lme4_1.1-12       Matrix_1.2-2
[5] broom_0.4.1       RColorBrewer_1.1-2  vegan_2.3-2       lattice_0.20-33
[9] permute_0.8-4     ggplot2_2.2.0     dplyr_0.5.0       tidyr_0.6.0

loaded via a namespace (and not attached):
[1] stringdist_0.9.4.2  gtools_3.5.0      zoo_1.7-12        modeltools_0.2-21
[5] coin_1.1-0          reshape2_1.4.1    purrr_0.2.2       splines_3.2.2
[9] haven_1.0.0         colorspace_1.2-6  stats4_3.2.2      mgcv_1.8-7
[13] survival_2.38-3     nloptr_1.0.4      DBI_0.5-1         multcomp_1.4-1
[17] plyr_1.8.3          stringr_1.1.0     effects_3.1-2     sjmisc_2.1.0
[21] munsell_0.4.2       gtable_0.1.2      caTools_1.17.1    mvtnorm_1.0-3
[25] codetools_0.2-14    psych_1.5.8       parallel_3.2.2    TH.data_1.0-6
[29] Rcpp_0.12.8         KernSmooth_2.23-15 scales_0.4.1      gdata_2.17.0
[33] mnormt_1.5-3        stringi_0.5-5     grid_3.2.2        tools_3.2.2
[37] bitops_1.0-6        sjstats_0.6.0     sandwich_2.3-3    magrittr_1.5
[41] lazyeval_0.2.0      tibble_1.2        cluster_2.0.3     MASS_7.3-43
[45] assertthat_0.1     minqa_1.2.4       R6_2.1.1          nnet_7.3-10
[49] nlme_3.1-128
>

# read in the data
# lawn quadrants first - the main data set
# the site list - contains PRIZM Codes
# PRIZM table - contains other PRIZM categories
lawn      <- read.csv("LawnDataMN2015-csv.csv")
SiteList <- read.csv("SiteList.csv"); dim(SiteList); head(SiteList)
PRIZM     <- read.csv("PRIZMcodes.csv"); PRIZM

# double checks

```

```

head(lawn); summary(lawn); names(lawn); dim(lawn)

# trim down the data frame to leave only the relevant columns
lawn <- lawn[,c(2, 4, 5, 7, 8, 18, 23, 25)]; dim(lawn)

# double checks
head(lawn); summary(lawn); names(lawn)

# observations per city
table(lawn$City)
# table(lawn$City, lawn$Lot_ID)

# cut out the reference and xeric sites, the NA and NO DATA
table(lawn$Area_Type); dim(lawn)
lawn <- lawn %>%
  filter(Species_Name!="NA", Species_Name!="NO DATA", Area_Type=="B"| Area_Type=="F");
dim(lawn); summary(lawn)

# verify the changes
lawn <- droplevels(lawn); dim(lawn); summary(lawn)
table(lawn$Area_Type); dim(lawn)

# are there any non-species in the species column (i.e. feces, bare ground, etc.)
sort(unique(lawn$Species_Name)) # or just "levels(lawn$Species_Name)"..

# cut the shwag out
lawn <- lawn %>%
  filter(Species_Name != "Bare ground",
         Species_Name != "Dog feces",
         Species_Name != "Litter",
         Species_Name != "Moss", # keep or not?
         Species_Name != "Red 1") # keep or not?

levels(lawn$Species_Name)

# verify the changes
lawn <- droplevels(lawn); dim(lawn); summary(lawn)
levels(lawn$Species_Name); dim(lawn) # looks good

# double check the case_ids per city
# not really needed by potentially handy for other future analyses
sort(unique(lawn$Lot_ID[lawn$City == "Baltimore"]))
sort(unique(lawn$Lot_ID[lawn$City == "Boston"]))
sort(unique(lawn$Lot_ID[lawn$City == "Los Angeles"]))
sort(unique(lawn$Lot_ID[lawn$City == "Miami"]))
sort(unique(lawn$Lot_ID[lawn$City == "Minneapolis St. Paul"]))
sort(unique(lawn$Lot_ID[lawn$City == "Phoenix"]))
sort(unique(lawn$Lot_ID[lawn$City == "Salt Lake City"]))

# merge the SiteList variables into the main data frame
# and then merge the PRIZM codes into the resultant table
# but we don't need all of the SiteList variables, trim it down first
dim(SiteList)
SiteList <- SiteList[,c(2, 4:6)]; dim(SiteList)
head(SiteList); head(lawn); dim(lawn)

lawn <- merge(lawn, SiteList, by="Lot_ID"); head(lawn); dim(lawn)
summary(lawn)
lawn <- droplevels(lawn); summary(lawn)

PRIZM

```

```

lawn <- merge(lawn, PRIZM, by="PRIZM.code")
lawn <- dropLevels(lawn); dim(lawn); head(lawn); summary(lawn)

# this is really silly but I just don't like the order of the columns
lawn <- lawn[,c(3, 2, 4, 5, 8, 7, 6, 9, 1, 12:14, 10, 11)]; dim(lawn); names(lawn)

# should be
# City
# Lot_ID
# Area_Type
# Plot
# Common_Turfgrass_Species
# Native_Where_Recorded
# Species_Name
# Cover_Value
# PRIZM.code
# Urban.density
# Income
# Lifestage
# Type2
# Previous.Type

# URBAN DENSITY, INCOME AND LIFESTAGE SHOULD REALLY BE ORDERED FACTORS
table(lawn$Urban.density); levels(lawn$Urban.density)
lawn$Urban.density <- ordered(lawn$Urban.density,
                             c("urban", "suburban", "second city", "town and rural"))
table(lawn$Urban.density); levels(lawn$Urban.density)

### WE MIGHT ALSO WANT URBANIZATION AS EXURBAN, SUBURBAN, URBAN (3 not 5 classes)
table(lawn$PRIZM.code, lawn$Urban.density)
PRIZM

lawn$URB[lawn$PRIZM.code == "C2F3"] <- "Suburban"
lawn$URB[lawn$PRIZM.code == "S1F1"] <- "Suburban"
lawn$URB[lawn$PRIZM.code == "S2M2"] <- "Suburban"
lawn$URB[lawn$PRIZM.code == "T1Y1"] <- "Exurban"
lawn$URB[lawn$PRIZM.code == "U1F2"] <- "Urban"
lawn$URB[lawn$PRIZM.code == "U1M1"] <- "Urban"
lawn$URB[lawn$PRIZM.code == "U2F3"] <- "Urban"
lawn$URB[lawn$PRIZM.code == "U3M4"] <- "Urban"

# check out new classes
table(lawn$PRIZM.code, lawn$Urban.density, lawn$URB)

# make it ordered too
lawn$URB <- ordered(lawn$URB, c("Urban", "Suburban", "Exurban"))
table(lawn$URB); levels(lawn$URB)

table
(lawn$Income); levels(lawn$Income)
lawn$Income <- ordered(lawn$Income,
                      c("wealthy", "upscale", "upper mid", "lower mid", "downscale"))
table(lawn$Income); levels(lawn$Income)

### RECLASSIFY INCOME INTO HIGH/LOW to match ERL paper
### RECLASSIFY INCOME INTO HIGH/LOW
table(lawn$PRIZM.code, lawn$Income)
PRIZM

```

```

lawn$SES[lawn$PRIZM.code == "C2F3"] <- "Low"
lawn$SES[lawn$PRIZM.code == "S1F1"] <- "High"
lawn$SES[lawn$PRIZM.code == "S2M2"] <- "High"
lawn$SES[lawn$PRIZM.code == "T1Y1"] <- "High"
lawn$SES[lawn$PRIZM.code == "U1F2"] <- "High"
lawn$SES[lawn$PRIZM.code == "U1M1"] <- "High"
lawn$SES[lawn$PRIZM.code == "U2F3"] <- "Low"
lawn$SES[lawn$PRIZM.code == "U3M4"] <- "Low"

# check out new classes
table(lawn$PRIZM.code, lawn$Income, lawn$SES)

# make it ordered too
lawn$SES <- ordered(lawn$SES, c("High", "Low"))
table(lawn$SES); levels(lawn$SES)

# Lifestage is all good
table(lawn$Lifestage); levels(lawn$Lifestage)
lawn$Lifestage <- ordered(lawn$Lifestage,
  c("younger", "family life", "mature"))
table(lawn$Lifestage); levels(lawn$Lifestage)

# Add in variable for humid / arid, matching Larson et al 2015, with SLC as Arid
lawn$precip[lawn$City == "Baltimore" |
  lawn$City == "Boston" |
  lawn$City == "Miami" |
  lawn$City == "Minneapolis St. Paul"] <- "Humid"

lawn$precip[is.na(lawn$precip)] <- "Arid"
lawn$precip <- as.factor(lawn$precip)
table(lawn$City, lawn$precip)

wide <- lawn %>%
  select(City, Lot_ID, Area_Type, Plot, Species_Name, Cover_Value) %>%
  spread(Species_Name, Cover_Value, fill=0); dim(wide)

# double check
wide[c(1:10),c(1:10)]; head(wide)

dat.key <- as.data.frame(wide %>%
  select(City, Lot_ID, Area_Type, Plot))

dim(dat.key); summary(dat.key)

names(wide) # WHERE DO THE SPECIES NAMES START?

startVal <- 5 # depending on which other variables are associated
# with the wide table (PRIZM, other covariates...)
# the species matrix will start at different spot
# PAY ATTENTION TO "startVal" and set it accordingly

names(wide)[c(startVal - 1, startVal, startVal + 1)]
#H <- diversity(wide[, startVal:dim(wide)[2]])
S <- specnumber(wide[, startVal:dim(wide)[2]])
InvD <- diversity(wide[, startVal:dim(wide)[2]], "inv")
SimpEven <- InvD/S

```

```

# double checks
summary(S); summary(SimpEven)

output <- as.data.frame(cbind(S, SimpEven)); head(output)
quadrat <- cbind(dat.key, output); rm(output)

dim(quadrat); head(quadrat)
summary(quadrat)

### Quadrat
lawnHS <- data.frame(quadrat
                    group_by(City, Lot_ID, Area_Type)
                    summarize(meanS=mean(S), meanSimpEven=mean(SimpEven)))

# double checks
plot(table(lawnHS$Lot_ID)); table(lawnHS$Lot_ID)
dev.new(height=7.5, width=10); par(mfrow=c(2,2))
hist(lawnHS$meanS); hist(log(lawnHS$meanS + 1))
hist(lawnHS$meanSimpEven); hist(log(lawnHS$meanSimpEven + 1))
head(lawnHS); dim(lawnHS)

# QUADRAT EVENNESS: visualize distributions, analyze the differences
dev.new(); par(mar = c(12, 4, 4, 2))
boxplot(log(meanSimpEven + 1) ~ Area_Type*City,
        main="Quadrats: Log of Inverse Simpson's Evenness",
        data= lawnHS,
        las=2)

# visualize the paired data - three plots per site hence vertical lines
ggplot(lawnHS, aes(x=interaction(Area_Type, City), y=meanSimpEven, group=Lot_ID)) +
  theme(plot.margin=unit(c(.25, .5, 1.5, .5), "cm")) +
  theme(axis.text.x = element_text(angle=90, vjust=0.5)) +
  geom_point(aes(colour=Area_Type),
            size=4.5,
            position = position_dodge(width=0.1)) +
  geom_line(size=1, alpha=0.5, position=position_dodge(width=0.1)) +
  ggtitle("Quadrats: Species Diversity")

A <- lmer(log(meanSimpEven + 1) ~ Area_Type*City + (1 | Lot_ID / City),
         data=lawnHS)
#sjt.lmer(A, p.kr=F)

# QUADRAT RICHNESS: visualize distributions, analyze the differences
dev.new(); par(mar = c(12, 4, 4, 2))
boxplot(log(meanS + 1) ~ Area_Type*City,
        main="Quadrats: Log of Species Richness (S)",
        data= lawnHS,
        las=2)

# visualize the paired data - three plots per site hence vertical lines
ggplot(lawnHS, aes(x=interaction(Area_Type, City), y=meanS, group=Lot_ID)) +
  theme(plot.margin=unit(c(.25, .5, 1.5, .5), "cm")) +
  theme(axis.text.x = element_text(angle=90, vjust=0.5)) +
  geom_point(aes(colour=Area_Type),
            size=4.5,
            position = position_dodge(width=0.1)) +
  geom_line(size=1, alpha=0.5, position=position_dodge(width=0.1)) +
  ggtitle("Quadrats: Species Richness (S)")

```

```

# summary(aov(meanS ~ Area_Type*City + Error(Lot_ID), data = lawnHS))
B <- lmer(log(meanS + 1) ~ Area_Type*City + (1 | Lot_ID / City), data=lawnHS)
#sjt.lmer(B, p.kr=F)

sjt.lmer(B, A,
  p.kr=F,
  ci.hyphen = " to ",
  cell.spacing = 0.05, # 0.05 give a little more space
  sep.column = F,
  pred.labels = c("Front / Back (Back as Reference)",
                  "Boston (Baltimore as Reference)",
                  "Los Angeles",
                  "Miami",
                  "Minneapolis-St. Paul",
                  "Phoenix",
                  "Salt Lake City",
                  "Front / Back x Boston",
                  "Front / Back x Los Angeles",
                  "Front / Back x Miami",
                  "Front / Back x Minneapolis-St. Paul",
                  "Front / Back x Phoenix",
                  "Front / Back x Salt Lake City"),
  depvar.labels = c("Species Richness in Lawns",
                    "Species Evenness in Lawns"))

# descriptive statistics
lawnHS %>%
  group_by(City) %>%
  summarise(min = min(meanS),
            mean = mean(meanS),
            max = max(meanS),
            sd = sd(meanS),

            min2 = min(meanSimpEven),
            mean2 = mean(meanSimpEven),
            max2 = max(meanSimpEven),
            sd2 = sd(meanSimpEven),
            n = n()) %>%
  write.csv("LawnDescriptives.csv")

#### START OF SOILS exploration
# http://beslter.org/metacat_harvest_attribute_level_eml/html_metadata/bes_584.asp

# did a lot of data clean up in Google/Open Refine
# permalink:
# http://127.0.0.1:3333/project?project=1488712220730&ui=%7B%22facets%22%3A%5B%5D%7D

# read in data
system.time(soil <- read.csv("soils/soils-csv.csv")); head(soil)
summary(soil); dim(soil)

# observations per city
table(soil$MSA); dim(soil)

# showing how the former values were re-coded for meaningful comparisons

```

```

# rows are from categories, columns are to categories
table(soil$categoryRough, soil$category)
#table(soil$categoryRough, soil$category, soil$MSA)          # and by city

# lets make category an ordered factor so that graphing is easier
levels(soil$category); barplot(summary(soil$category))      # plot # obs per type
soil$category <- ordered(soil$category,
  c("Native", "Agriculture", "Exurban", "Suburban", "Urban", "Vacant"))

# confirm the changes
levels(soil$category); barplot(summary(soil$category));
table(soil$category); str(soil$category)

# lots of extra categories / land use types.. we only need the residential areas
dim(soil)
soil <-      soil      %>%
  filter(category == "Exurban"      |
         category == "Suburban"    |
         category == "Urban")
dim(soil); table(soil$category)

soil <- droplevels(soil); dim(soil); table(soil$category)
soil$category <- ordered(soil$category, c("Urban", "Suburban", "Exurban"))
table(soil$category); levels(soil$category)

# check out category (land use) compared to former prev_lu (previous land use)
table(soil$category, soil$prev_lu)

# number of plots per MSA
table(soil$Plot, soil$MSA)          # even though Reference (ag and native) sites
                                   # were removed there are still some 99s
                                   # for Plot values in BAL, BOS, and PHX
                                   # it is assumed these are errors and
                                   # are therefore dropped

dim(soil)
soil <-      soil      %>%
  filter(Plot != 99)

# verification
dim(soil); table(soil$Plot)          ; table(soil$Plot, soil$MSA)
plot(table(soil$Plot, soil$MSA))

# make a new front / back column based on the Plot number
# The Boston data did not have the Plot numbers
# instead front/back was recorded in a notes field
# in Open refine Plot was set to 1 if the core was taken in back
# and Plot was set to 6 if the core was taken in front
soil$front_back <-      ifelse(soil$Plot == 1, "back",
                              ifelse(soil$Plot == 2, "back",
                              ifelse(soil$Plot == 3, "back",
                              ifelse(soil$Plot == 4, "front",
                              ifelse(soil$Plot == 5, "front",
                              ifelse(soil$Plot == 6, "front", soil$Plot))))))

table(soil$front_back)
table(soil$front_back, soil$MSA); plot(table(soil$front_back, soil$MSA))

# Peter Groffman said on Wed, Nov 2, 2016 at 3:04 PM to restrict the analyses
# to the top 10 cm. to focus on human inputs.
# (Raciti et al 2011a,b suggest different activities occur at dif depths)
# cut to top sections only, three sections end at less than 10 cm
table(soil$CoreSecTo)

```

```

# we'll leave those in for now, may need to discard or normalize other measures
# later
dim(soil)
soil <- soil %>%
  filter(CoreSecTo <= 10)
dim(soil); table(soil$CoreSecTo) # looks good
table(soil$front_back, soil$CoreSecTo)
plot(table(soil$CoreSecTo, soil$front_back))
table(soil$front_back, soil$MSA) # worth dropping levels?
table(soil$CoreSections)

# BUT how many of the back fronts are from the SAME site?
table(soil$front_back, soil$case_id) # NOT good

#1140 - Minne (3)
#14535 - Boston (1)
#5377 - LA (2) 5377

# WHISKEY TANGO FOXTROT?!?!
# not a problem when cutting out the non-paired sites

# dropping all of the non-paired sites
dim(soil)
soil <- soil %>%
  filter(case_id == "6284" |
         case_id == "10042" |
         case_id == "10322" |
         case_id == "10579" |
         case_id == "10598" |
         case_id == "11129" |
         case_id == "11668" |
         case_id == "11801" |
         case_id == "12569" |
         case_id == "1294" |
         case_id == "13050" |
         case_id == "13967" |
         case_id == "1404" |
         case_id == "14246" |
         case_id == "14394" |
         case_id == "14405" |
         case_id == "1493" |
         case_id == "15250" |
         case_id == "15263" |
         case_id == "15273" |
         case_id == "15414" |
         case_id == "15440" |
         case_id == "1545" |
         case_id == "159" |
         case_id == "1663" |
         case_id == "17089" |
         case_id == "17255" |
         case_id == "1757" |
         case_id == "178" |
         case_id == "2418" |
         case_id == "2537" |
         case_id == "2589" |
         case_id == "2714" |
         case_id == "3057" |
         case_id == "3109" |
         case_id == "314" |

```

```

case_id == "3187" |
case_id == "3303" |
case_id == "331" |
case_id == "3395" |
case_id == "3737" |
case_id == "3782" |
case_id == "3799" |
case_id == "419" |
case_id == "4217" |
case_id == "4666" |
case_id == "4916" |
case_id == "5058" |
case_id == "526" |
case_id == "5296" |
# case_id == "5377" |
case_id == "5433" |
case_id == "5462" |
case_id == "5506" |
case_id == "5669" |
case_id == "5740" |
case_id == "5844" |
case_id == "6284" |
case_id == "6314" |
case_id == "6503" |
case_id == "664" |
case_id == "6744" |
case_id == "6746" |
case_id == "6809" |
case_id == "6839" |
case_id == "7311" |
case_id == "7477" |
case_id == "7786" |
case_id == "7882" |
case_id == "7946" |
case_id == "827" |
case_id == "8339" |
case_id == "84" |
case_id == "846" |
case_id == "8486" |
case_id == "8735" |
case_id == "8830" |
case_id == "8963" |
case_id == "8994" |
case_id == "8996" |
case_id == "9013")

table(soil$front_back, soil$case_id)
dim(soil)

#### MERGE IN TELEPHONE DATA
# read in the tele data, sanity checks
system.time(tbl <- read.csv("~/projects/MacroBio/MacroData/Eco-
System2011NeighborhoodStudyDataFile_dhlCSV.csv", head=T, sep=","))
a <- object.size(tbl); print(a, units="Mb"); rm(a)

dim(tbl) # dimensions (rows, columns)
names(tbl) # column names
head(tbl); tail(tbl) # first six rows; last six rows

```

```

summary(tbl)                # summary stats
str(tbl)                    # a view of the STRucture, summary stats..

# YARD MANAGEMENT
#### reclassify for analysis:      Fertilizer, Pesticide and Irrigation
tbl$q6_1[tbl$q6_1 == 3] <- 0      # NO, does not fertilize
tbl$q6_1[tbl$q6_1 == 2] <- 1      # YES, does fertilize

tbl$q6_2[tbl$q6_2 == 3] <- 0      # NO, does not use pesticides
tbl$q6_2[tbl$q6_2 == 2] <- 1      # YES, does pesticides

tbl$q6_3[tbl$q6_3 == 3] <- 0      # NO, does not irrigate
tbl$q6_3[tbl$q6_3 == 2] <- 1      # YES, does irrigate

# double checks
par(mfrow=c(1,3))
hist(tbl$q6_1, ylim=c(0, 8000))    # Fert is more common than pest
hist(tbl$q6_2, ylim=c(0, 8000))    # Pest is lest popular
hist(tbl$q6_3, ylim=c(0, 8000))    # Irrigation is most popular

par(mfrow=c(1,1))                # restore the graphics window
summary(tbl$q6_1); summary(tbl$q6_2); summary(tbl$q6_3)

# SATISFACTION
# visualize distribution
par(mfrow=c(3,2))
plot(tbl$q17_1); plot(table(tbl$q17_1)) # Life Satisfaction
plot(tbl$q18_1); plot(table(tbl$q18_1)) # Neigh Satisfaction
plot(tbl$q19_1); plot(table(tbl$q19_1)) # Neigh Env. Satisfaction

# cut out the 99's
tbl$q17_1[tbl$q17_1 == 99] <- NA
tbl$q18_1[tbl$q18_1 == 99] <- NA
tbl$q19_1[tbl$q19_1 == 99] <- NA

# double check numerically and graphically
plot(tbl$q17_1); plot(table(tbl$q17_1)) # Life Satisfaction
plot(tbl$q18_1); plot(table(tbl$q18_1)) # Neigh Satisfaction
plot(tbl$q19_1); plot(table(tbl$q19_1)) # Neigh Env. Satisfaction

par(mfrow=c(1,1))                # restore the graphics window

# PRIZM
#### to match Chris Knudson's "PRIZM combinations.docx"
#### used for verification purposes of the PRIZM codes
table(tbl$prizmhh, tbl$LS, tbl$SES, tbl$URB)
table(tbl$CityLab, tbl$SES, tbl$URB)
table(tbl$q19_1, tbl$CityLab, tbl$SES, tbl$URB)

# some simpler counts
table(tbl$CityLab, tbl$URB)
table(tbl$CityLab, tbl$SES)        # looks good
table(tbl$CityLab, tbl$LS)        # lets make LS ordered

tbl$LS <- ordered(tbl$LS, c("YY", "FL", "MY"))
table(tbl$LS); levels(tbl$LS); str(tbl$LS)    # verify

# INCOME
#### make a new field for combined income
hist(tbl$q30c_1); summary(tbl$q30c_1)
temp.1 <- tbl$q30c_1                # copy the lower income bins

```

```

temp.1[is.na(temp.1)] <- 0 # set NA's to zeros
hist(temp.1); summary(temp.1) # verification

hist(tbl$q30b_1); summary(tbl$q30b_1)
temp.2 <- tbl$q30b_1 + 4 # copy the upper income bins and add 4
temp.2[is.na(temp.2)] <- 0 # set NA's to zeros
hist(temp.2); summary(temp.2) # verification

tbl$INCOME <- temp.1 + temp.2 # add a new field, combining temps
tbl$INCOME[tbl$INCOME == 0] <- NA # set zeros to NA's
hist(tbl$INCOME); summary(tbl$INCOME) # verification
table(tbl$INCOME) # all good.

rm(temp.1); rm(temp.2); ls() # clean up

# trim town tbl to just the variables of interest
tbl <- tbl[,c(1, # case id - will join to soils
              127, # MSA for a double check
              130, # population density
              128, # socioeconomic status (high, low)
              129, # lifestage
              138, # household-reported Income (not Census)
              34, # irrigation
              32, # fertilization
              33, # pesticide application
              71, # Life Satisfaction
              72, # Neigh Satisfaction
              73)] # Neigh Env. Satisfaction
names(tbl) # looks kosher, rename fields

names(tbl) <- c("case_id", # so that it matches exactly with soil
               "CityLab",
               "PD",
               "SES",
               "LS",
               "Income", # household-reported Income (not Census)
               # 1 = <$15K
               # 2 = $15K - $25K
               # 3 = $25K - $35K
               # 4 = $35K - $50K
               # 5 = $50K - $75K
               # 6 = $75K - $100K
               # 7 = $100K - $150K
               # 8 = >$150K
               "Irr", # irrigation
               "Fert", # fertilization
               "Pest", # pesticide application
               "lifeSat", # Life Satisfaction
               "neighSat", # Neigh Satisfaction
               "neighEnvSat") # Neigh Env. Satisfaction
names(tbl); dim(tbl)

### MERGE (aka join) Telephone data INTO SOILS
dim(soil); str(soil)
soil$case_id <- droplevels(soil$case_id); str(soil)
soil <- merge(soil, tbl, by="case_id"); dim(soil)

```

```

# how do we know if it was successful?
table(soil$MSA, soil$CityLab)
ftable(soil$case_id, soil$CityLab, soil$MSA)

# Microbial biomass, respiration, mineralization, nitrification, denitrification,
# ammonium, biologically available nitrogen
# gather relevant fields and make a human-readable label in a new smaller table
varsOfInt      <- c(33:34, 38:39, 41, 36, 37)

AA      <-      lmer(log(MicrobialBiomassC + 1) ~front_back*MSA + (1 | case_id / MSA),
data = soil)

BB      <-      lmer(log(Respiration + 1) ~ front_back*MSA + (1 | case_id / MSA),
data = soil)

CC      <-      lmer(log(MIN + 1) ~ front_back*MSA + (1 | case_id / MSA), data = soil)
DD      <-      lmer(log(NIT + 1) ~ front_back*MSA + (1 | case_id / MSA), data = soil)
EE      <-      lmer(log(DEA + 1) ~ front_back*MSA + (1 | case_id / MSA), data = soil)
FF      <-      lmer(log(NH4 + 1) ~ front_back*MSA + (1 | case_id / MSA), data = soil)
GG      <-      lmer(log(BION + 1) ~ front_back*MSA + (1 | case_id / MSA), data= soil)

#sjt.lmer(AA, BB, CC, DD, EE, FF, GG,
p.kr=F,
ci.hyphen = " to ",
cell.spacing = 0.05,          # 0.05 give a little more space
sep.column = F,
pred.labels = c( "Front / Back (Back as Reference)",
                 "Boston (Baltimore as Reference)",
                 "Los Angeles",
                 "Miami",
                 "Minneapolis-St. Paul",
                 "Phoenix",
                 "Front / Back x Boston",
                 "Front / Back x Los Angeles",
                 "Front / Back x Miami",
                 "Front / Back x Minneapolis-St. Paul",
                 "Front / Back x Phoenix"),
depvar.labels = c("Microbial biomass (ugC/g soil)",
                  "Respiration (ug C/g soil/day)",
                  "Mineralization (ug N/g dry soil/day)",
                  "Nitrification (ug N/g dry soil/day)",
                  "Denitrification (ng N/g soil/hour)",
                  "Ammonium (ug N/g dry soil)",
                  "Biologically available N (ug N/g dry soil)"))

sjt.lmer(AA, BB, CC, DD,
p.kr=F,
ci.hyphen = " to ",

```

```

cell.spacing = 0.00,          # 0.05 give a little more space
sep.column = F,
pred.labels = c( "Front / Back (Back as Reference)",
                 "Boston (Baltimore as Reference)",
                 "Los Angeles",
                 "Miami",
                 "Minneapolis-St. Paul",
                 "Phoenix",
                 "Front / Back x Boston",
                 "Front / Back x Los Angeles",
                 "Front / Back x Miami",
                 "Front / Back x Minneapolis-St. Paul",
                 "Front / Back x Phoenix"),
depvvar.labels = c("Microbial biomass (ugC/g soil)",
                  "Respiration (ug C/g soil/day)",
                  "Mineralization (ug N/g dry soil/day)",
                  "Nitrification (ug N/g dry soil/day)")

sjt.lmer(EF, FF, GG,
         p.kr=F,
         ci.hyphen = " to ",
         cell.spacing = 0.00,          # 0.05 give a little more space
         sep.column = F,
         pred.labels = c( "Front / Back (Back as Reference)",
                          "Boston (Baltimore as Reference)",
                          "Los Angeles",
                          "Miami",
                          "Minneapolis-St. Paul",
                          "Phoenix",
                          "Front / Back x Boston",
                          "Front / Back x Los Angeles",
                          "Front / Back x Miami",
                          "Front / Back x Minneapolis-St. Paul",
                          "Front / Back x Phoenix"),
         depvar.labels = c("Denitrification (ng N/g soil/hour)",
                          "Ammonium (ug N/g dry soil)",
                          "Biologically available N (ug N/g dry soil)")

# descriptive statistics
soil %>%
  group_by(MSA) %>%
  summarise(minMicrobialBiomassC = min(MicrobialBiomassC),
            meanMicrobialBiomassC = mean(MicrobialBiomassC),
            maxMicrobialBiomassC = max(MicrobialBiomassC),
            sdMicrobialBiomassC = sd(MicrobialBiomassC),

            minRespiration = min(Respiration),
            meanRespiration = mean(Respiration),
            maxRespiration = max(Respiration),
            sdRespiration = sd(Respiration),

            minMIN = min(MIN),
            meanMIN = mean(MIN),
            maxMIN = max(MIN),
            sdMIN = sd(MIN),

```

```

minNIT = min(NIT),
meanNIT = mean(NIT),
maxNIT = max(NIT),
sdNIT = sd(NIT),

minDEA = min(DEA, na.rm=T),
meanDEA = mean(DEA, na.rm=T),
maxDEA = max(DEA, na.rm=T),
sdDEA = sd(DEA, na.rm=T),

minNH4 = min(NH4),
meanNH4 = mean(NH4),
maxNH4 = max(NH4),
sdNH4 = sd(NH4),

minBION = min(BION),
meanBION = mean(BION),
maxBION = max(BION),
sdBION = sd(BION),

n = n()) %>%

write.csv("SoilDescriptives.csv")

```

```

# read in the data
wy <- read.csv("SLC_LA_DexterRefined.csv")
wy_sites <- read.csv("SLC_LA_Sites.csv"); wy_sites

# double checks / basic x-tabs
dim(wy); head(wy); str(wy); summary(wy)

table(wy$City)
table(wy$City, wy$Site)
ftable(wy$City, wy$Site, wy$Front)

length(unique(wy$Site))
length(unique(wy$City))

plot(table(wy$Front, wy$Site))

# drop the C dom fields, rename
names(wy)
wy <- wy[,c(1:4, 8, 11:14)]; head(wy)
names(wy)[5] <- "Lawn"
names(wy)[6] <- "Garden"; head(wy)

```

```

# pretty up the site list, reclassify raw PRIZM codes into urban density + income

wy_sites$urb[wy_sites$PRIZM == "S1"]      <- "Suburban"
wy_sites$urb[wy_sites$PRIZM == "S1F1"]   <- "Suburban"
wy_sites$urb[wy_sites$PRIZM == "S2"]     <- "Suburban"
wy_sites$urb[wy_sites$PRIZM == "S2M2"]   <- "Suburban"
wy_sites$urb[wy_sites$PRIZM == "T1Y1"]   <- "Exurban"
wy_sites$urb[wy_sites$PRIZM == "U1M1"]   <- "Urban"
wy_sites$urb[wy_sites$PRIZM == "U2F3"]   <- "Urban"

# order urban density
wy_sites$urb <- ordered(wy_sites$urb,
                       c("Urban", "Suburban", "Exurban"))
table(wy_sites$urb); table(wy_sites$urb, wy_sites$PRIZM)

wy_sites$inc[wy_sites$PRIZM == "S1"]     <- "High"
wy_sites$inc[wy_sites$PRIZM == "S1F1"]   <- "High"
wy_sites$inc[wy_sites$PRIZM == "S2"]     <- "High"
wy_sites$inc[wy_sites$PRIZM == "S2M2"]   <- "High"
wy_sites$inc[wy_sites$PRIZM == "T1Y1"]   <- "High"
wy_sites$inc[wy_sites$PRIZM == "U1M1"]   <- "High"
wy_sites$inc[wy_sites$PRIZM == "U2F3"]   <- "Low"

# ALTERNATIVE (why not use income from telephone?)
#wy_sites$inc[wy_sites$PRIZM == "S1"]     <- "High"
#wy_sites$inc[wy_sites$PRIZM == "S1F1"]   <- "High"
#wy_sites$inc[wy_sites$PRIZM == "S2"]     <- "Low" # the difference
#wy_sites$inc[wy_sites$PRIZM == "S2M2"]   <- "Low" # the difference
#wy_sites$inc[wy_sites$PRIZM == "T1Y1"]   <- "High"
#wy_sites$inc[wy_sites$PRIZM == "U1M1"]   <- "High"
#wy_sites$inc[wy_sites$PRIZM == "U2F3"]   <- "Low"

# order income
wy_sites$inc <- ordered(wy_sites$inc,
                       c("High", "Low"))
table(wy_sites$inc); table(wy_sites$inc, wy_sites$PRIZM)

# Richness by cultivated GARDEN
# Richness by cultivated GARDEN
# Richness by cultivated GARDEN
# front richness
wy_gardenF <- data.frame(wy %>%
  filter(Front == 1, Garden == "Cultivated") %>%
  group_by(Site, Garden) %>%
  summarize(richness=sum(Front))); wy_gardenF

# back richness
wy_gardenB <- data.frame(wy %>%
  filter(Back == 1, Garden == "Cultivated") %>%
  group_by(Site, Garden) %>%
  summarize(richness=sum(Back))); wy_gardenB

# messy! - notes so I can remember next week what I was thinking
# 1 a copy of the site unique IDs are 'cbinded' to "Front"
# 2 that list of sites is then merged to the front yard richness

```

```

# 3 failed matches are kept using "all.x = TRUE", which makes NAs
# where richness was zero
# 4 steps 1 - 3 were done for back yards in parallel
# 5 the front and back yard data frames are 'rbinded' together
# 6 the data frame is printed for inspection
wy_gardenC <- rbind(merge(cbind(wy_sites, fb = "Front"),
                             wy_gardenF, by = "Site", all.x = TRUE),
                  merge(cbind(wy_sites, fb = "Back"),
                             wy_gardenB, by = "Site", all.x = TRUE)); wy_gardenC

# replace NAs with zeros
#wy_gardenC$richness[is.na(wy_gardenC$richness)] <- 0; wy_gardenC

# sort by site ID - aesthetics
wy_gardenC <- wy_gardenC[order(wy_gardenC$Site),]; wy_gardenC

# needed? going to write over three in a second
# rm(wy_garden_F); rm(wy_garden_B)

# Is richness normally distributed?
par(mfrow=c(1,2)); hist(wy_gardenC$richness); hist(log(wy_gardenC$richness))

# visualize the new data
dev.new(height=7.5, width=10); par(mar=c(10, 4, 4, 2))
boxplot(richness ~ fb*City,data=wy_gardenC, las=2,
        main="Species Richness of Cultivated Species found in Gardens by City")

ggplot(wy_gardenC, aes(x=interaction(fb,City), y=richness, group=Site)) +
  geom_point(aes(colour=fb), size=4.5, position=position_dodge(width=0.1)) +
  geom_line(size=1, alpha=0.5, position=position_dodge(width=0.1)) +
  ggtitle("Cultivated Garden Species")

# statistically model these relationships
AAA <- lmer(log(richness + 1) ~ fb*City + (1 | Site / City), _LOG_RICHNESSS
            data = wy_gardenC, REML = FALSE)

# visualize the model outputs
#sjt.lmer(AAA, p.kr=F, ci.hyphen = " to ")
dev.new(height=7.5, width=10); sjp.lmer(AAA, type="fe", p.kr=F)

model.tables(aov(log(richness + 1) ~ fb*City, data = wy_gardenC), type="means")
model.tables(aov(richness ~ fb*City, data = wy_gardenC), type="means")

(24.71 - 19.53) /24.71

round(exp(fixef(AAA)), 2)

exp(2.77)           # intercept
exp(0.42)          # back yard as ref, front yard coef
exp(0.08)          # lower CI
exp(0.76)          # upper CI

wy_gardenC %>% group_by(fb) %>% summarise(median = median(richness))
wy_gardenC %>% group_by(fb, City) %>% summarise(median = median(richness))

# Richness by spontaneous GARDEN
# Richness by spontaneous GARDEN
# Richness by spontaneous GARDEN
# front richness
wy_gardenF <- data.frame(wy %>%

```

```

        filter(Front == 1, Garden == "Spontaneous")           %>%
        group_by(Site, Garden)                               %>%
        summarize(richness=sum(Front))); wy_gardenF

# back richness
wy_gardenB <-      data.frame(wy                               %>%
        filter(Back == 1, Garden == "Spontaneous")         %>%
        group_by(Site, Garden)                             %>%
        summarize(richness=sum(Back))); wy_gardenB

# messy!           - notes so I can remember next week what I was thinking
# 1 a copy of the site unique IDs are 'cbinded' to "Front"
# 2 that list of sites is then merged to the front yard richness
# 3 failed matches are kept using "all.x = TRUE", which makes NAs
# where richness was zero
# 4 steps 1 - 3 were done for back yards in parallel
# 5 the front and back yard data frames are 'rbinded' together
# 6 the data frame is printed for inspection
wy_gardenS <-      rbind(merge(cbind(wy_sites, fb = "Front"),
        wy_gardenF, by = "Site", all.x = TRUE),
        merge(cbind(wy_sites, fb = "Back"),
        wy_gardenB, by = "Site", all.x = TRUE)); wy_gardenS

# replace NAs with zeros
wy_gardenS$richness[is.na(wy_gardenS$richness)] <- 0; wy_gardenS

# sort by site ID - aesthetics
wy_gardenS <- wy_gardenS[order(wy_gardenS$Site),]; wy_gardenS

# needed? keep the workspace clean
rm(wy_gardenF); rm(wy_gardenB)

# Is richness normally distributed?
par(mfrow=c(1,2)); hist(wy_gardenS$richness); hist(log(wy_gardenS$richness))

# visualize the new data
dev.new(height=7.5, width=10); par(mar=c(10, 4, 4, 2))
boxplot(richness ~ fb*City,data=wy_gardenS, las=2,
        main="Species Richness of Spontaneous Species\n(aka weeds) found in Gardens by City")

ggplot(wy_gardenS, aes(x=interaction(fb,City), y=richness, group=Site)) +
        geom_point(aes(colour=fb), size=4.5, position=position_dodge(width=0.1)) +
        geom_line(size=1, alpha=0.5, position=position_dodge(width=0.1)) +
        ggtitle("Spontaneous Garden Species")

# statistically model these relationships           _LOG_ RICHNESS
BBB <- lmer(log(richness + 1) ~ fb*City + (1 | Site / City),
        data=wy_gardenS, REML=FALSE)

# visualize the model outputs
#sjt.lmer(BBB, p.kr=F, ci.hyphen = " to ")
dev.new(height=7.5, width=10); sjt.lmer(BBB, type="fe", p.kr=F)

sjt.lmer(AAA, BBB,
        p.kr=F,
        ci.hyphen = " to ",
        cell.spacing = 0.05,           # 0.05 give a little more space
        sep.column = F,
        pred.labels = c("Front / Back (Back as Reference)",

```

```

                                "Salt Lake City (Los Angeles as Reference)",
                                "Front / Back x Salt Lake City"),
depvvar.labels = c("Cultivated Garden Species Richness",
                   "Spontaneous Garden Species")

wy_gardenC %>%
  group_by(City) %>%
  summarise(min = min(richness),
            mean = mean(richness),
            max = max(richness),
            sd = sd(richness),

            n = n()) %>%
  write.csv("WYDescriptives_C.csv")

wy_gardenS %>%
  group_by(City) %>%
  summarise(min = min(richness),
            mean = mean(richness),
            max = max(richness),
            sd = sd(richness),

            n = n()) %>%
  write.csv("WYDescriptives_S.csv")

# end

```