Reconstructing Developer and Homeowner Decisions to Understand the Complex Assembly of New Residential Patches and Plant Communities

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A dissertation

submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

University of Washington

2020

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Program Authorized to Offer Degree:

Program in Urban Design and Planning

University of Washington

Abstract

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Residential developers and homeowners are urban ecosystem engineers, shaping the structure and function of the residential landscapes, which occupy a large proportion of urban areas. Developers set the template by allocating space to different patch types and by establishing the initial plant communities in new yards. New homeowners then modify these spaces to suit their own preferences, life stages, and neighborhood norms. We know little about how the decisions of developers and homeowners interact to create the residential land covers. To document initial conditions of single family residential landscapes, I recruited a stratified random sample of 60 homeowners who had purchased a newly built home in the lower Green-Duwamish watershed of the Seattle Metropolitan Statistical Area in Washington State in 2014 or 2015. Through field sampling, aerial photo interpretation, conversations with the new homeowners, and archival photo research, I reconstructed the decisions of the developers and new homeowners. By taking a

patch mosaic and plant community approach, I showed that urban form and economic considerations shape developer and homeowner decisions. I also found that homeowner yard use and plant preferences influenced the observed plant community patterns. Future investigations of residential landscapes should incorporate preferences of developers and homeowners, site-specific constraints, and broader scale influences. Further research is needed to understand developer incentives and preferences.

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ACKNOWLEDGEMENTS

I thank the 60 participating homeowners who gave me permission to study their yards, told me what they changed, and answered my questions about their yards and themselves. Thank you for your hospitality, time, and hot coffee on cold, rainy days. You gave me lots of good ideas and showed me how you see your new spaces.

My research would not have been possible without my enthusiastic field crew, advice and training from all over the University, and funding from the Bullitt Foundation. Kimberly Trask, Jonnie Narita, Sophia O'Hara, Elena Boyle, and Ryan Boyle helped me measure area and count plants while I was on crutches on three months. Estella Leopold and Sarah Reichard reminded me to think carefully about plant diversity in relation to people. The UW Center for Statistics and the Social Sciences provided statistical consulting services. I thank the Bullitt Foundation for awarding me the Patsy Bullitt Collins Environmental Fellowship.

This dissertation would not exist without my lab mates, fellow students, and other writing buddies who provided motivation, beverages, advice, and commentary on some very terrible first drafts and awkward figures. Thank you Laurel, Sush, Karen, Carol, Raphael, Carey, Tom, Simone, Max, Heather, J.D., Daniele, Lan, Dorian, Jason, Karis, and Julia.

I appreciate the diverse expertise and unique interests of my committee. Marina Alberti taught me to look at the complexity of the urban environment. Richard Olmstead confirmed my identifications of unusual plants, reviewed nomenclature, and reminded me to pay attention to species identity, not just species richness. David Montgomery and Jan Whittington encouraged me to look at broader scales and the interactions of people and the environment.

Finally, I thank my family. My mother, Cindy, always told me that I could do anything and always supported me while I did. She and the rest of my Seattle family, Pat, Ryan, and Elena put up with me while I tried to figure out how urban ecosystems work. My father, G.L., and stepmother, Dolores, gave me a love of the outdoors. I love you all.

Chapter 1. Introduction

1.1 RESEARCH MOTIVATION & STUDY SYSTEM

Residential development drives a large proportion of urban and suburban land use and land cover change (Irwin and Bockstael 2007; Pejchar et al. 2015, Liu and Robinson 2016). Despite the efforts of planners to mitigate negative environmental and social effects of residential development by encouraging density (Gaigné, Riou, and Thisse 2012; Gordon and Richardson 1997; Grant, Manuel, and Joudrey 1996), most new residential development occurs at the urban fringe (Robinson 2005; Theobald 2005; Liu & Robinson 2016). In some desirable locations in central cities and older suburbs, new residential development also consists of teardowns and infill development (Charles 2013; Steinacker 2003; Weber et al. 2006) .

Understanding the creation and management of residential landscapes is critical for urban planners, developers and ecologists, given their spatial extent and large footprint compared to other developed land uses (Brown and Vivas 2005; Irwin and Bockstael 2007). Theobald (2014) estimated that residential lands covered the most area of all built up areas in the United States. Low density exurban/rural residential lands covered 61% of the total built up area (732,797 km^2), and urban residential lands covered 12% (148,502 km^2). Miles et al. (2007:1) encouraged urban researchers to look at all of the involved actors: “principles and process of real estate development should not be studied without looking at both the people who are involved in the process and the people who are the ultimate users of the product.” The diverse decisions and management practices of developers and homeowners interact on land parcels, to produce the patterns typically observed by researchers after a parcel is sold.

In this study, I chose new single-family residential landscapes as my study system. I view these landscapes and the land cover on them as the result of the interactions and decisions of urban residential developers and homeowners (Figure 1.1). Residential developers and homeowners respectively target specific neighborhoods. To build the new house and yard, the residential developer must first purchase land, targeting specific locations and neighborhoods based on existing firm market niche and structure (Coiacetto 2007; Kohlhepp and Kohlhepp 2018). Their purchase decisions are constrained by available land, competition with other firms, the real estate market, and multiple levels of policy and planning (Coiacetto 2007). The new homeowners, in turn, compete for and buy their new home in a specific neighborhood based on for a variety of socioeconomic, demographic, travel, and personal preference reasons (Cao 2015; McFadden 1978; Walker and Li 2007).

1.2 THEORETICAL FRAMEWORK & CONCEPTUALIZATION

To understand emergent urban patterns, urban scholars must understand how people build and inhabit cities (Logan and Molotch 1987; Guy and Henneberry 2002; Brown 2015). Cities are contested spaces, products of unequal power and wealth (Lefebvre 1991; Swyngedouw and Heynen 2003; Purcell 2014). Thus, competition, social inequality and uneven power dynamics underpin where people live, work, and how they interact with each other and with the urban environment (Crowder and Downey 2010; Downey 2003; Tickamyer 2000).

Different individuals, households, groups, and firms have distinct needs and preferences, and so they compete for desirable neighborhoods and locations (Kaiser 1978; Webster and Lai 2003). Thus, real estate markets are social phenomena. The continuing conflict-resolution cycle between use, users, and exchange value of land determines urban form, influencing the distribution of people and the way that people inhabit urban space and interact with each other. These interactions are not neutral; the distribution of people, housing, other buildings, infrastructure, green space, and opportunity are not random.

Given the complexity of the processes creating residential patches, I draw upon complex systems theory (Liu et al. 2007). Urban lands are coupled human natural systems, where human and biophysical components interact to produce the urban landscape pattern (Alberti et al. 2003; Cadenasso, Pickett, and Schwarz 2007; Machlis, Force, and Burch 1997). Thus, I conceptualize residential land cover and vegetation as a product of urban complexity (Figure 1.1).

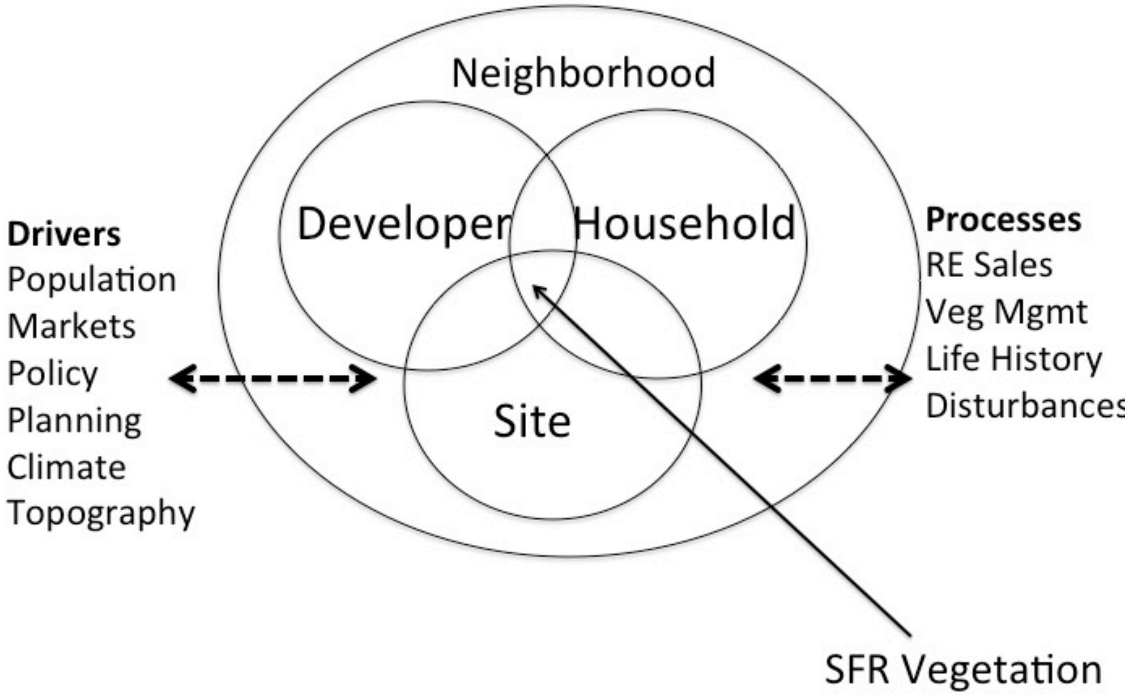


Figure 1.1. Venn diagram conceptualizing single family residential (SFR) land cover and vegetation as a complex, emergent phenomenon, resulting from the fine scale interactions between developers, households, and planning embedded within broader spatial and temporal scales of neighborhoods, urban ecosystems, and beyond. Dashed arrows represent cross-scale interactions.

1.2.1 *Urban Ecosystem Complexity*

Coupled human natural systems exhibit complexity in time, space, and organizational structure (Liu et al. 2007). Feedback loops and thresholds may arise from non-linear interactions between different parts of the system. Legacy effects and time lags from previous cross-scale interactions can affect current conditions and future possibilities and lead to surprising or unpredictable outcomes.

During the last two decades, numerous research teams have developed urban ecosystem frameworks to frame urban complexity (Machlis 1997; Grimm et al. 2000, Pickett et al. 2001, Alberti et al. 2003). These frameworks can be adapted to focus on important interactions and feedbacks, in order to detect the changes to specific parts of the system. To reduce the multi-scalar patterns, processes, and flows into a simplified 2D conceptual framework, tradeoffs about which social and biophysical components of particular systems should be included are made.

Machlis et al. (1997) proposed the human ecosystem model, emphasizing the human parts of the system. They characterize urban ecosystems as interactions and flows of "critical resources" (natural resources, socioeconomic resources, and cultural resources) and the "human social system." They specifically caution urban researchers to consider how people organize themselves hierarchically in their environments to control access to resources: wealth, power, status, knowledge, and territory.

Pickett et al. (2001) added to Machlis (1997) framework by including ecosystem structure and processes, rather than a list of natural resources. In particular, they added patch dynamics as a key component of human ecosystems and specifically described a new category of patches: human ecosystem patches. They define human ecosystem patches as "homogeneous areas for a specified set of sociocultural and biophysical variables within a landscape (Pickett et. al.2001:145-146)." Although the text discusses how people control access to desired resources, their conceptual framework omits it.

Grimm et al. (2000, 2017) challenged the traditional ecological assumption that people interact with ecosystems solely as disturbing agents. Instead, they argue that cities are ecosystems, with definable structures and functions. Their framework (Grimm et al. 2000) integrates human and biophysical systems, placing land use and ecological patterns at the center of the diagram and emphasizing the biophysical portion of urban systems. In 2017, they called out urban ecologists who still tend to view urban ecosystems as inherently disturbed. Under this "naïve ecological habit (Grimm et al. 2017:1), people are disturbance agents, and all human activities can be viewed as disturbances. Using urban ecosystems case studies and Peters et al. (2011) disturbance framework, they revaluated the utility of the disturbance concept to urban systems. They found that viewing disturbance as a specific, sudden event has utility in urban systems, provided that the following are recognized: 1) the disturbance model components, including relevant temporal and spatial scales; 2) more explicit consideration of the human elements of the system, including culture, power, and equity; and 3) recognition that drivers of disturbance interact and may have cascading effects on other parts of the system.

Alberti et al. (2003) proposed an urban ecology framework to conceptualize the urban ecosystem as coupled system of interacting drivers, patterns, processes, and effects. Each of these urban ecosystem components has both human and biophysical subcomponents, which cycle and interact in complex, non-linear ways and feedback from environmental to human systems.

They highlight that these interactions occur across scale within and across the human and the biophysical components.

As I have shown above, the field of urban ecology has developed multiple theoretical and conceptual frameworks apply. However, the continued use of diverse frameworks by different groups of researchers may constitute a major obstacle to the advancement of the field, highlighting the need to develop more unified conceptual frameworks to advance urban ecology theory (McPherson et al 2016). In order for the field to respond to the complex challenges and opportunities of urban systems, urban ecologists must carefully and appropriately people into ecological systems.

1.2.2 *Conceptualizing Residential Land Cover as a Product of Urban Complexity*

Urban land is a coupled human-natural-system (Cadenasso et al. 2007; Alberti 2008) and a finite resource, with different urban sectors competing for its use (Alonso 1964, Ridd 1995, Webster and Lai 2003). When urban land use type or intensification changes occur, multiple aspects of urban land are affected: how the land is used (land use), what is on the land (land cover), its physical layout and design (urban form), who is using the land (land user), and how the land is managed (land management).

In this dissertation, I focus on one land use – single family residential - and the land covers that result from multiple processes: new home and yard creation, change in ownership, and land management. I define urban residential land covers as newly created urban patch mosaics, consisting of three main built patch classes: buildings, other paved surfaces, and pervious yard patches, which fits well with Ridd’s (1995) urban land cover classification: vegetation, impervious surfaces, and soil (V-I-S), as well as water. Buildings and other paved surfaces would be grouped into impervious surfaces. Pervious yards would contain both vegetated and soil patches.

To conceptualize the complex emergence of residential landscapes, I draw on urban complexity theory (Machlis 1997, Picket et al. 2001, Alberti 2003), urban land economics (Harvey and Jowsey 2003, Dong and Sing 2014, Magliocca et al. 2015), landscape ecology (Forman and Godron 1981; Godron and Forman 1983; Wu 2008; Turner 2010), residential real estate processes and developer behavior (Peiser 1990; Healey 1994; Coiacetto 2007; Brown 2015; Kohlhepp and Kohlhepp 2018), household preferences and decision-making (McFadden

1978; Schwanen and Mokhtarian 2005; Walker and Li 2007), urban vegetation ecology theories (Sanders 1984; Hope et al. 2003; Williams et al. 2009; Aronson et al. 2016; Pearse et al. 2018), plant functional traits (Bernhardt-Römermann et al. 2008; Diaz, Cabido, and Casanoves 1998; Kalusová, Čeplová, and Lososová 2017; Pataki et al. 2013; Violle and Jiang 2009), and gardening literature (Brenzel 2007; Kruckeberg and Chalker-Scott 2019; Stoecklein 2011).

Both urban land economics and urban ecologists have relied upon a monocentric view of the city, where human influences are strongest at the urban core, to explain urban patterns they observe. Urban land economic theory links location desirability, preference, and price to explain how land values influence urban form (Webster and Lai 2003; Harvey and Jowsey 2003). In economic terms, urban land can be both rivalrous and excludable, and so urban lands are mostly private goods exchanged on the real estate market (Qadeer 1981, Ostrom 2009). Different land users compete with each other for the most desirable locations (Alonso 1964, Harvey and Jowsey 2003). The most expensive lands are the closest to the city center (a bid rent curve or urban land rent gradient), because transportation and other transaction costs decrease and because they have desirable amenities (Hansen 1959; O'Sullivan 2011). Each urban sector (e.g., commercial, retail, office, residential) has its own unique bid rent curve. Similarly, urban ecologists have applied Whittaker's gradient concept (Whittaker and Niering 1965, Whittaker 1967) to assess the effects of people on the environment. McDonnell, Pickett, and Pouyat (1990) proposed that using an urban to rural gradient approach to allow ecologists to evaluate and quantify the changes in ecosystem patterns and processes as a result of urbanization. In particular, they viewed changes in disturbance regimes, biota, landscape structure, and physiological stress as particularly suited to an urban gradient approach. Ramalho and Hobbs (2012) criticize the urban gradient concept for oversimplifying urban complexity, for poorly defining urban, and for aggregating urban metrics inappropriately. In particular, they fault the approach for failing to incorporate the fact that the many urban areas grow in a non-linear, spatially complex fashion. Arribas-Bel and Sanz-Gracia (2014) noted that urban areas trend toward developing multiple centers once they pass a certain population size threshold.

Although the monocentric model of the city is an oversimplification of complex urban structures and processes, it predicts two things relevant for my study: 1) firms tend to outbid households for more central locations, 2) residential parcels and units exhibit a price and density gradient. As distance from the center increases and land values decrease, residential density decreases, but parcel size and yard size increase. Thus, urban land rent and residential density variables should be accounted to understand the creation of residential land use and land cover patches. Distance to urban centers, land value, and residential density are just three human system variables contributing to the underlying complex urban gradient.

The urban patches we observe are a product of the urban gradient. Urban patches do not just appear spontaneously on the landscape. People site and construct them in non-random patterns. Thus, to adequately understand the processes driving the emergence of residential land cover patterns, we need to consider how and why they are created and for whom. We can characterize the two agents of pattern formation—residential developers and homeowners—as two distinct kinds of urban ecosystem engineers (Jones, Lawton, and Shachak 1994; Wu 2008), creating and maintaining urban patch types based on specific values, preferences, incentives, time and available resources. A third actor also influences the urban form of new single-family residences is the institutional agency governing land use represented by the urban planners. To create subdivisions and obtain building permits, residential developers must also comply with the local planning regulations (Kaiser 1978; Kim and Ellis 2009; Fraser, Bazuin, and Hornberger 2016). Previous decisions, site layout, and planning requirements limit possible development activities.

The resulting land cover patches and plant communities are the outcomes of human decisions interacting with the multi-scalar urban ecosystem (Figure 1.2). The regional, neighborhood, and parcel scale patterns, processes, and drivers interact with each other, across scales, and with broader scales. Newly created residential patch types include both impervious (buildings, sidewalks, walkways, driveways, patios, and other pavement) and pervious types in the yard (vegetation, mulches, rocks of various sizes, and bare soil). Planning regulations and developer design decisions directly influence area of impervious patch types (Brown 2015; Stone 2004; Talen 2012). Less well understood is how decisions influence other residential patch types or vegetation.

We can view residential patches and floras as emerging from the bottom up, individual decisions of developers, and residents interacting with broader scale urban plans, patterns, and processes (Cook, Hall, and Larson 2012) or filters (Aronson et al. 2016; Pearse et al. 2018). These bottom-up processes are constrained by top-down mechanisms such as policies and regulations. Most of the residential plant community research focuses on homeowners responding to site, neighborhood, and ambiguously defined personal preferences (Cook, Hall, and Larson 2012).

Very little research has focused on how specific decisions or values shape residential plant communities. As Kendal, Williams, and Williams (2012) noted, residential landscapes are the "cumulative result of many individual decisions about plant choice over time that combine to determine the social and biophysical benefits provided." Throughout this dissertation, I argue that patches and plants on new residential landscapes are a direct result of how developers and homeowners view parcel conditions, the surrounding neighborhood, and make decisions about how to change and manage the newly developed space.

Many urban ecologists have found that money buys green, the so-called *luxury effect* (Hope et al. 2003; Leong, Dunn, and Trautwein 2018). Wealthier households and neighborhoods have greater woody species richness and cover (Clarke, Jenerette, and Davila 2013; Schwarz et al. 2015) and more greenness (Luck, Smallbone, and O'Brien 2009; Zhou et al. 2009). I specifically use urban economic metrics to test for this effect, as well other possible urban and agent drivers of urban patch and plant form.

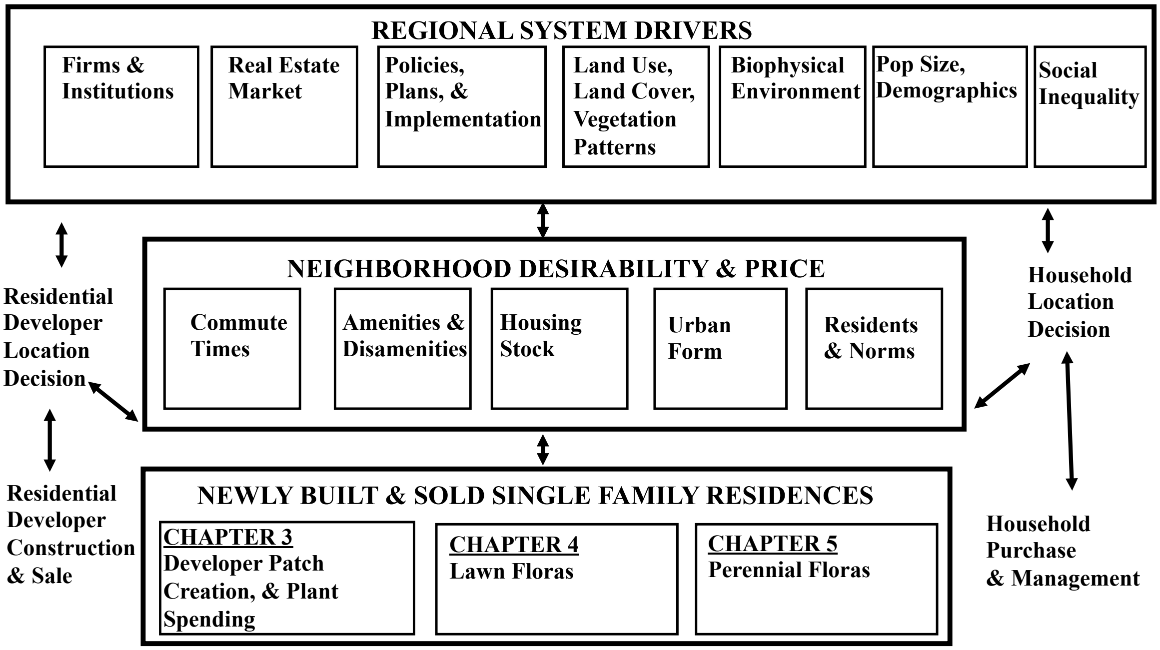


Figure 1.2. Conceptual diagram describing how new residential landscapes emerge from developer and homeowner decisions interacting with broader scale drivers. My research seeks to understand how observed residential land cover is a product of human decisions interacting with drivers at the parcel, neighborhood, and regional scales. In Chapter 3, I explore developers patch allocation and plant material spending decisions interacting with urban metrics at the site and neighborhood extent. In Chapter 4, I examine how new lawn floras rapidly arise from the interaction of household decisions and urban metrics at the site and neighborhood extent. In Chapter 5, I examine perennial planting decisions of developers and homeowners and test whether their decisions are influenced by urban metrics at the site and neighborhood extent. I also examine whether homeowner preferences are reflected in their planting decisions.

1.3 DISSERTATION STRUCTURE & RESEARCH QUESTIONS

My research provides empirical evidence of how residential developers and homeowner preferences and decisions and their interactions drive the emergence of urban residential landscape. Although I do not include explicitly planners as an agent of landscape formation, I do represent planning decisions by including land use and planning regulations that govern the construction of new single-family residences. I focus on the decisions and actions that the residential developers and homeowners make during the construction, landscaping, and management of new single-family residential parcels. In this study, I ask three overarching questions:

1. What are the residential landscape outcomes of decision-making?
2. How do diverse decisions of developers and homeowners shape the resulting residential landscape?
3. How do those decisions emerge from the multi-scalar urban environment (Figure 1.2)?

I have organized the remainder of my dissertation into five chapters to document how I selected sites (Chapter 2) and how I examined possible drivers of developer and homeowner decisions (Chapters 3-5). Finally, in Chapter 6, I summarize the results, explain their contribution to the literature, and discuss possible implications to planning, and describe some potential future research.

In Chapter 3, I examined new residential development as an act of urban patch creation. The study objective was to characterize developer patch creation decisions and to examine whether urban environmental drivers influenced their decisions. I addressed two specific research questions:

1. How do developers allocate space to built (buildings, other paved area, and yard) and yard patch types?
2. How much do developers spend on vegetated patch types given their well-known tendency to control costs to manage risk?

Then, in Chapter 4, I examined new lawns, the largest and most abundant yard patch type. My study objective was to characterize how lawn diversity arises from urban environmental drivers and household preferences and management. I addressed four specific research questions:

1. What are new homeowners yard preferences and lawn care regimes?
2. What is the floristic composition of new residential lawns?
3. Are patterns of lawn diversity driven by urban variables measured at the parcel or neighborhood extent?
4. Which homeowner preferences and management regimes drive lawn diversity?

Finally, in Chapter 5, I examine how developers and homeowners assemble all other perennial vegetation by making decisions to keep or remove perennials and by choosing whether or not to plant new ones. I addressed four specific research questions:

1. Do developers and homeowners select the same types of perennials to plant?
2. How do urban environmental drivers influence perennial planting diversity for developers or homeowners?
3. Which self-reported preferences drive homeowner perennial planting diversity?
4. How do developer and homeowner decisions influence the observed species composition and diversity of perennial floras?

Chapter 2. Sampling Frame & Homeowner Recruitment

2.1 REGIONAL CONTEXT AND STUDY AREA

The Puget Sound Region of Washington State supports diverse terrestrial communities resulting from the abrupt elevation, temperature, and moisture gradients (Kruckeberg 1995). Lowland vegetation (<150m) on the west slope of the Cascades Mountains is mostly temperate coniferous forest. Dominant conifers are *Pseudotsuga menziesii* (Douglas-fir), *Tsuga heterophylla* (western hemlock), and *Thuja plicata* (western red-cedar). Less common are *Quercus garryana (*Garry oak) woodlands and prairies in the southern part of the region, which have been greatly reduced from their historical extent from agriculture and then urbanization.

The Seattle-Tacoma- Bellevue- Metropolitan Statistical Area (Seattle MSA) occurs in the central part of the Puget Sound Region and contains all of King, Pierce, Snohomish, and Kitsap Counties (U.S. Census Bureau 2017). An estimated 3.87 million people live in the Seattle MSA, with the majority (2.2 million) living in King County.

I chose the lower Green-Duwamish Watershed as my study area, which supports both heavy industry and diverse, low-income neighborhoods (Puget Sound Regional Council 2015, Sheppard 2014). In addition, high quality parcel data and real estate transactions are available (King County 2016).

2.2 SAMPLING FRAME CONSTRUCTION & SAMPLE DESIGN

To accurately represent the population of interest (residential parcels supporting new single family homes built by developers and sold to new homeowners), I constructed a sampling frame using publicly available data (Figures 2.1, 2.2). Eligible parcels had to meet all of the following criteria: 1) be located in the lower Green-Duwamish WRIA, 2) contain only one single family home, 3) be built in 2014 or 2015 by a developer, and 4) be sold to a household by July 1, 2016). Final sampling frame had 1,258 single-family residential parcels.

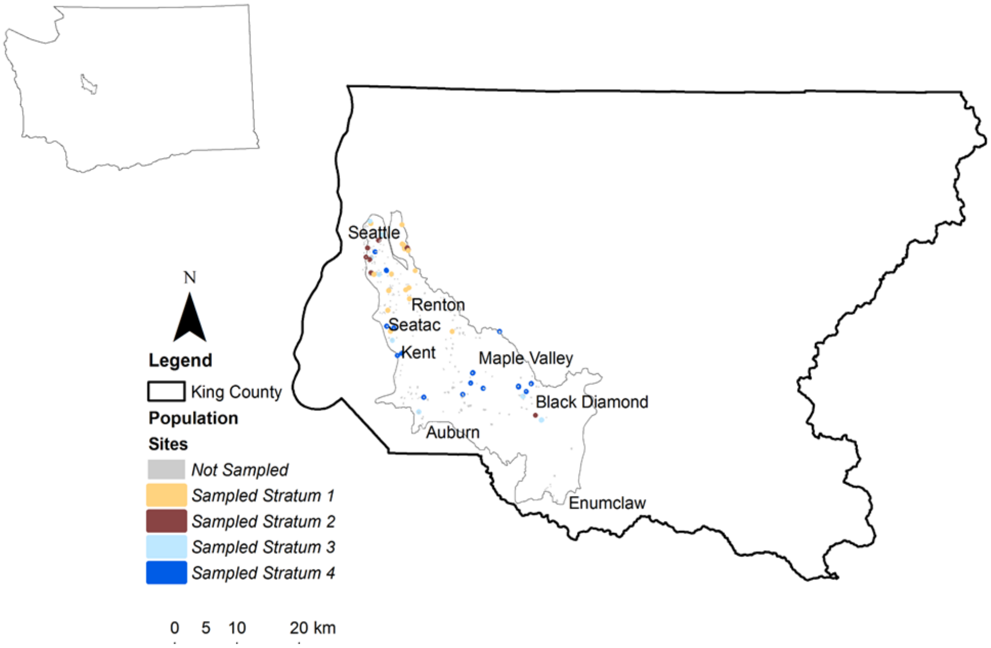


Figure 2.1. Study area (lower Green-Duwamish Watershed Resource Inventory Area in gray) and parcels within Washington State (upper left) and King County (center). Strata: number of parcels each unique developer has in sampling frame: 1= 1 parcel; 2 = 2 parcels; 3= 3-8 parcels; 4 = 9 or more parcels. Unsampled parcels are light grey.

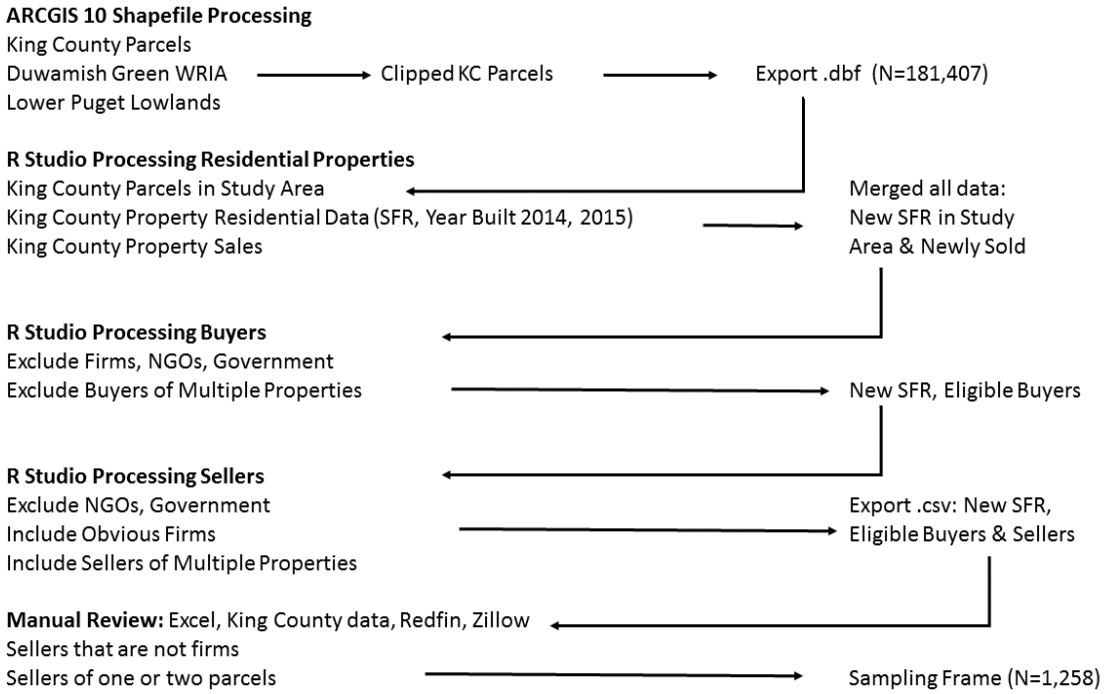


Figure 2.2. Construction of sampling frame from publicly available data.

After constructing the sampling frame, I chose a stratified random sampling approach. I chose a stratified design for two reasons: 1) stratified random designs can give the same precision as a simple random design at a lower cost (Lumley 2010), and 2) I wanted agent and parcel diversity in my sample, which meant limiting parcels in large subdivisions. Because developers are constrained by available land and because they specialize by location, project types (infill vs new subdivision), and building types (Coiacetto 2007), I assigned parcels to one of four strata, depending on how many homes the developer had within the frame (Table 2.1).

Table 2.1. Overview of population sampling frame by strata, number of per stratum, and number of developers per stratum.

Stratum	#Parcels/ Developer	# Developers	# Parcels and Households
1	1	126	126
2	2	28	56
3	3-8	31	131
4	9+	24	945

2.3 HOMEOWNER RECRUITMENT AND SITE OVERVIEW

To obtain homeowner permission to participate in the study, I sent a letter to the registered owner describing my research and a self-addressed stamped postcard (Appendix A). I sent 40 post cards per stratum on my initial mailing. Overall, affirmative mail response rates were low (Table 2.2). I had originally planned to recruit 25 parcel/strata. However, I dropped my number of parcels per stratum to 15, because stratum 2 was the smallest and had the lowest response to my mailing (Table 2.2). To fill the remaining 5-8 slots per stratum, I visited the potential sites to recruit in person, on a Saturday or Sunday between 10am-5pm. I first visited the homes that I mailed previously, and then pulled a new random sample of 20 from each stratum. I stopped recruiting from random sample two when I reached a full set of 15/stratum. Characteristics of sampled sites are in Table 2.3.The University of Washington Human Subjects Division determined that study was qualified for exempt status, based on its interview procedures, lack of risk to participants, and subject matter.

Table 2.2. Response rates by stratum and recruitment method. Mail was original sample of 40 per stratum. In Person #1 is in-person visit to parcels previously mailed. In Person #2 is in-person visit to new draw of 20 parcels per strata. However, I did not visit all 20, because I stopped when I reached 15 affirmative responses per stratum.

			Responses by Recruitment		
Stratum	**#Parcels/ Developer**	**# Parcels**	**Mail** Yes/No/NR	**In Person #1** Yes/No/NR	**In Person #2** Yes/No/NR
1	1	126	9/1/30	4/3/13	2/4/2
2	2	56	7/2/31	5/2/14	3/2/4
3	3-8	131	10/6/24	1/1/22	4/0/11
4	9+	945	10/2/28	2/0/26	3/8/6

Table 2.3. Overview of sampled site environmental data. Error is standard deviation. Parcel variables are for the sampled parcel. Neighborhood variables calculated for the Census Block Group that contains the sampled parcel.

Parcel Variable	**Mean**	**Range**	**Source & Manipulation**
Elevation (m)	104.7 ± 41.0	21.1 – 179.4	Google Maps (Google 2017)
2016 Land Value ($/lot area ($m^2$))	265.3 ± 173.6	40.1-1039.1	Calculated in R from 2016 Assessor Data (King County 2016)
2016 Improvement Value ($1000)	426.2 ± 152.7	172-933	2016 Assessor Data
Developed Area (m)	649.4 ±4 02.6	209.9-2,781.7	Aerial photo interpretation of parcel area developed. Close, but not exactly lot size. See Chapter 3.
Neighborhood Variable	**Mean**	**Range**	**Source & Manipulation**
Residential Density (# residences/km^2)	624.1 ± 381.5	15.5-1760.0	Calculated in R from 2016 Assessor Data
Median Age in Years Median (2016 – year built)	52.8 ± 22.0	8 - 90	Calculated in R from 206 Assessor Data
Median 2016 Assessed Value (1000$)	326.0 ± 98.9	185.0-664.5	Calculated in R from 2016 Assessor Data
Median Yard Size (m^2)	629.9 ± 492.4	99.4-3442.7	Calculated in R from 2016 Assessor Data

Chapter 3. RESIDENTIAL DEVELOPERS ARE URBAN PATCH CREATORS

3.1 INTRODUCTION

Diverse agents build and shape urban ecosystems (Alberti et al. 2003; Pickett et al. 2017; Waddell 2002). Households (Cook, Hall, and Larson 2012; McFadden 1978), businesses (Funk 2014; Laursen, Masciarelli, and Prencipe 2012), and real estate developers (Healey and Barrett 1990; Coiacetto 2007) filter their decisions through their own unique backgrounds, values, location preferences, constraints, and motivations for action. The fine scale decisions of these heterogeneous agents aggregate to create higher-level urban structures, forms, and patterns (Batty 2008; Liu et al. 2007; Machlis, Force, and Burch 1997; Zhou et al. 2009). Thus, urban landscapes are spatially and temporally complex outcomes of bottom up human decisions limited by top down constraints of the human and biophysical systems in which they are embedded (Zhang et al. 2013; McPhearson et al. 2016). Although real estate developers are key agents of urban land use and cover change (Kaiser 1978; Guy and Henneberry 2000), urban researchers have not tended to study specific developer decisions (Beuschel and Rudel 2010; Brown 2015).

I argue that new residential development is an act of space allocation and urban patch creation, the end point of multiple decisions (Brown 2015; Coiacetto 2007; Kohlhepp and Kohlhepp 2018). Therefore, to understand the patterns of urban landscapes, urban scholars must include the people who directly create those patterns via construction. As Jones, Lawton, and Shachak (1994, 379) noted, "Ecologists in general have paid surprisingly little attention to how environments are created and maintained….without formally considering the role of engineering in habitat modification, creation, and maintenance. Therefore, in this chapter, I view residential developers as urban ecosystem engineers (Jones, Lawton, and Shachak 1994; Wu 2008), who create new habitat for other people and species.

Through this urban ecosystem engineer lens, I treat newly constructed homes and yards as new urban patch mosaics, resulting from specific decisions by heterogeneous residential developers and their agents: which lands to purchase; what previous structures, infrastructure, and landscaping to retain; and what to build, install, and plant (Brown 2015; Coiacetto 2007; Kohlhepp and Kohlhepp 2018; Miles, Netherton, and Schmitz 2015). I draw upon the literature of hierarchical patch dynamics (Wu and Loucks 1995; Zhang et al. 2013; Pickett et al. 2017), complex urban ecosystems (Alberti 2008; McPhearson et al. 2016; Meyfroidt et al. 2018), urban land economics (Dong and Sing 2014; Harvey and Jowsey 2003; Magliocca, McConnell, and Walls 2015), and residential developer behavior (Brown 2015; Coiacetto 2007; Kohlhepp and Kohlhepp 2018; Mohamed 2006) to link bottom up decisions and top down constraints.

3.2 RESEARCH OBJECTIVES

A new, detached house is the main product of single family residential development (Brown 2015; Miles, Netherton, and Schmitz 2015). To construct, market, and sell their product, residential developers respond to underlying urban land rent gradients (Anas 1978; Beuschel and Rudel 2010; Coiacetto 2007), focus on controlling project costs (Mohamed 2006), target specific socioeconomic groups and age classes (Boddy 2007; Coiacetto 2006; Tewari and Beynon 2017), and tend to copy themselves and other developers in project decisions (Peiser 1990; Ro et al. 2018).

Given these behaviors, I have three main research questions:

1. How do developers allocate space to built (buildings, other paved area, and yard) and yard patch types?
2. How much do developers spend on vegetated patch types given their well-known tendency to control costs to manage risk?
3. Are their space and spending decisions influenced by urban variables?

Urban land rent gradient theory links land values to competition for urban land and urban form (Alonso 1964; Harvey and Jowsey 2003). The most expensive lands are closest to the city center, because transportation and transactions costs decrease (Harvey and Jowsey 2003). Although this monocentric view of the city is an oversimplification of complex urban structure (Gordon and Richardson 1996; Hajrasouliha and Hamidi 2017; Zhang, Sun, and Li 2017), it predicts that residential parcels exhibit density gradient in response to the underlying land rent. As land value increases, parcel and yard sizes should decrease. Therefore, I predict proportion of the parcel allocated to yard will decrease as land value and density increase.

Because a new house is the main product of residential development (Brown 2015; Miles, Netherton, and Schmitz 2015), and because lawns are the dominant patch type of residential yards (Giner et al. 2013; Robbins and Birkenholtz 2003; Zhou and Troy 2008) and urban vegetation (Ignatieva and Hedblom 2018; Mennis 2006; Milesi et al. 2005), I predict that buildings and lawn will cover the largest area on the parcel. Further, I predict that land values will drive yard patch allocation decisions.

Given the tendency of residential developers to focus on controlling costs rather than increasing final product value (Goldberg and Ulinder 1976; Mohamed 2006, 2009), how much do developers spend on plant materials for a particular yard size? If it is a cost to control, then only builders of more expensive homes would be willing to spend more on plant materials as a signal to the wealthier households they are targeting (Boddy 2007; Coiacetto 2006; Tewari and Beynon 2017). Thus, plant material spending represents an opportunity to consider revealed preferences (Hands 2014; Houthakker 1950; Samuelson 1938, 1948) as well as the luxury effect (Hope et al. 2003; Leong, Dunn, and Trautwein 2018) in developer landscaping decisions in new yards. Briefly, revealed preference theory posits that a purchaser's preferences can be revealed by what they purchase under different budget constraints; the luxury effect is a phenomenon where wealthier households and neighborhoods have access to more abundant and more diverse vegetation. Therefore, I predict 1) that spending on patch types will be heterogeneous despite controlling for patch and yard area; and 2) that spending will be positively correlated with appraised improvement value and median assessed value.

3.3 METHODS

3.3.1 *Overview*

I surveyed 60 newly built and sold homes, selected by stratified random sample of 1,258 homes in the Lower Duwamish Watershed (Chapter 2). From each parcel, I collected and analyzed three types of data: patch types and area, perennial plant prices, and built environment data at the parcel and neighborhood extent (Table 3.1).

Table 3.1. Summary of independent and dependent variables evaluated.

Site Extent	**Data Source and Description**
Latitude (degrees)	King County Assessor Data (King County 2016)
Longtidue (degrees)	King County Assessor Data
Elevation (m)	Google Maps – elevation above mean sea level
Land Value ($\$/m^2$)	King County Assessor Data – land value/lot area
Assessed Improvement Value ($)	King County Assessor Data – value of house and buildings in 2016 (used in multivariate analysis plant spending)
Yard Area (m^2)	Aerial Photo Interpretation of King County Data (used in multivariate analysis plant spending)
Patch Area (m^2)	Calculated in R from field data and aerial photo interpretation (used in univariate analysis)
Census Block Group (CBG) Extent	**Data Source**
Residential Density (# residences/km^2)	Calculated from King County Assessor Data, # residential units/CBG area
Median Age (years)	Calculated from King County Assessor Data; 2016-median year built all residential properties within CBG
Median Assessed Value (m^2)	Calculated from King County Assessor Data; Median improvements and land value 2016
Median House Footprint (m^2)	Calculated from King County Assessor Data Median (Estimated Building Footprints)
Median Yard Size (m^2)	Calculated from King County Assessor Data Median (Lot Area – Estimated Building Footprints)
Dependent Variables	
Matrix of Patch Area by Type	Calculated in R from field data and aerial photo interpretation
Matrix of Vegetation Patch Spending	Calculated in R from field data of perennial counts, turf area, and median prices of perennial or turf
Vegetated Plant Patch Spending	Calculated in R from field data of perennial counts, turf area, and median prices of perennial or turf

3.3.2 *Data: Yard Patch Types & Area*

After obtaining permission for access from the new homeowner, I surveyed all 60 parcels during the growing season of 2016. I noted all homeowner created patches and noted what the original developer patch type was. For example, several homeowners had converted some of the original backyard lawn into garden beds, planted perennials after removing lawn, installed sheds or greenhouses, or established chicken coops. To obtain additional information about what patch types were present before the house sold, I also reviewed available imagery from before, during, and after construction (Google 2017; Redfin 2017)

Using a 50 m tape, I measured the dimensions of all patch types and noted their shapes. I then used standard geometry equations to calculate area for circles, ovals, rectangles, triangles, and trapezoids. For irregularly shaped planting patches, I used the offset method (Christians and Agnew 2008) to estimate area. I placed the length line along the longest axis of the patch, and measured shape length along lines placed perpendicularly to the length line. To maximize accuracy of estimations for irregular patches, I divided the length line into 1 m segments. For each yard patch, I assigned one of nine patch categories, based on the dominant vegetation (Table 3.2, Figure 3.1) or surface type (Table 3.1; Figure 3.2).

3.3.3 *Data: Perennial Plant Prices*

In each patch, I counted and identified all plants. Then, I assigned each plant to one of four origin categories: developer retained (present on site before development and retained by developer), developer planted, household planted, or spontaneously establishing after developer landscaping. Nomenclature follows Hitchcock and Cronquist (2018) or Missouri Botanical Garden (2017). In Chapter 4, I analyzed lawn floras. In chapter 5, I analyzed perennial floras.

For all perennials planted by developers, I calculated the median retail price for that taxon. After creating the list of all developer planted taxa, I obtained at least four different prices for each taxon. Prices are from visits to plant retailers, reviews of online catalogs, and from values printed on tags that were still on many of the plants in my sample. All stores and nurseries that I visited were within the Seattle Metropolitan Statistical Area; some, but not all, were inside the study area boundaries. Turf price, the median price per m^2, does not include transport costs, which some sod companies included in their quotes.

I originally planned to include mulch, gravel, cobble, or rock in my estimates of patch prices. Quoted prices from landscaping firms and rock sources were too variable to reliably estimate price. Factors influencing quoted prices included parent material for rock walls and

Figure 3.1. Examples of the four vegetated patch types found in sampled yards: A) *Lawn*; B) *Tree* – back yard patch of retained *Pseudotusga menziesii* (Douglas-fir); C) *Mix* – front yard patch with shrubs, herbs, and single accent *Acer palmatum* (Japanese maple); D) *Mono* – row of *Juniperus squamata* 'Blue Star' (blue star juniper); E) *Tree* – newly planted *Thuja occidentalis* (arborvitae); F) *Mix* –developer installed rain garden with several graminoids and shrubs.

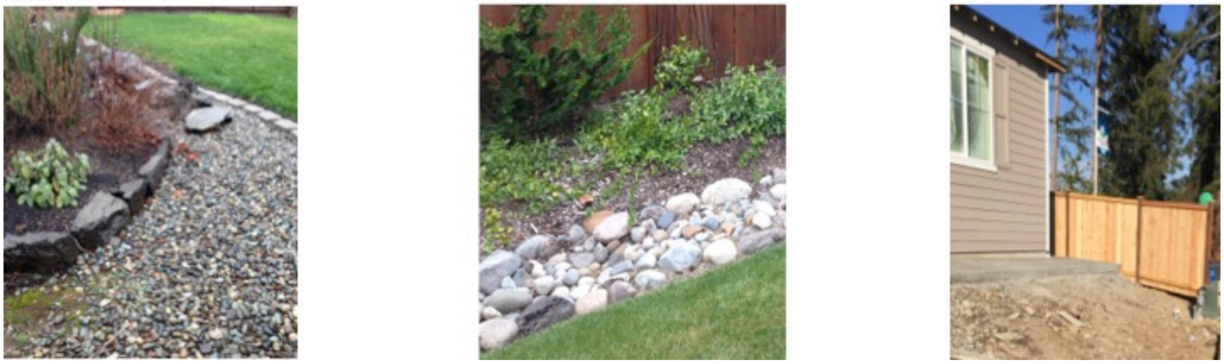
Table 3.2. The four vegetated yard patch types and descriptions.

Patch Name	**Description**
Lawn	Traditional turfgrass lawn. Isolated trees in lawn patches not assigned to *Tree*. Kept within *Lawn*
Tree	Dominant cover woody perennials with mature height >2m. Includes patches of large, native trees as well as tall hedge species
Mix	Mostly mix of shrubs and herbs, but may have a few accent trees. Mixed, short stature borders and rain gardens classified here.
Mono	Single species planting of short stature perennial.

A) *Mulch*

B) *Gravel/Mulch*

C) *Rock*



D) *Gravel/Cobble*

E) *Gravel/Cobble*

F) *Bare*

Figure 3.2. Examples of the five non-vegetated patch types found in sampled yards: A) *Mulch*; B) *Gravel/Mulch*; C) *Rock*; D) *Gravel/Cobble*; E) *Gravel/Cobble*; F) *Bare*.

Table 3.3. The five non-vegetated yard patch types and descriptions.

Patch Name	**Description**
Mulch	Wood chips, bark, or sawdust
Gravel/Mulch	Linear strip of mulch and gravel, often used as borders around lawns or in side yards.
Rock	Accent boulders and rock walls
Gravel/Cobble	Small particle size rocks, usually linear or curvilinear. Gravel often used for paths. Cobble is often used for drainage, alone or in combination with gravel.
Bare	Unplanted, bare mineral soil

boulders, finer size and shape criteria than I had recorded for gravel and cobble, minimum quantity purchase requirements, and transport costs.

The median retail plant price may be an over estimate. Developers may be able to get wholesale prices or discounts buying in bulk for certain plants. In addition, estimated prices may be higher than when the landscapes were installed in 2014 or 2015.

3.3.4 *Data: Built Patch Areas & Yard Patch Area Corrections*

After I visited all the parcels, I measured the developed area and the area of built patches (buildings, other impervious area, yard), using the county parcel viewer tool (King County 2017). The viewer allowed me to overlay high-resolution aerial photos of the new construction with property boundaries. Developed area is the sum of all sampled yard patches plus all parcel-associated impervious surfaces (building footprint plus driveways, sidewalks, other walkways, and patios). Buildings are the footprint areas of all houses, garages, and developer constructed buildings. Other impervious surfaces are sidewalks, walkways, and uncovered patios. Yard area is the difference of developed area and the area of all impervious surfaces.

For some parcels, developed area was not the same as lot size as in the assessor dataset. Two parcels had non-buildable areas. One had a steep slope covered with mature trees that the developer was required to avoid per the issued building permit. The other had a large riverine wetland that covered more than 40% of the parcel area. Second, curb strips are sometimes within property boundaries and sometimes not. Third, I included sidewalks, because developers are required to build them in certain jurisdictions and because I wanted to include all parcel-associated impervious surfaces except streets. Fourth, developers did not always place fence lines precisely along property boundaries. Finally, two homeowners told me that that they managed specific patches shared between themselves and their adjacent neighbor. Instead of dividing the patch by where I estimated the property boundary to be, I included this shared area as part of the developed area.

Because I did not use survey grade approaches to measure patch area, I corrected patch area to account for measurement error. I summed the area of all yard patches to calculate field yard area. Then, I calculated the proportion of field yard area occupied by each patch. I multiplied this proportion by aerial photo estimate of yard area to obtain corrected patch area for each unique patch type. Correlations between patch areas are in Appendix B (Figures A1-A3).

3.3.5 *Data: Geospatial*

All variables except elevation are calculated from 2016 data (King County 2016). Land value ($/m^2) represents a measure of the urban land rent gradient and household income; improvement value ($) is also a household income surrogate. Neighborhood variables were calculated at the Census Block Group extent, which is commonly used in urban vegetation studies (e.g., Avolio et al. 2015; Endsley, Brown, and Bruch 2018). Median assessed value has been found to be a strong metric of neighborhood wealth in other urban studies (Leonard et al. 2016; Moudon et al. 2011) and a more accurate measure of neighborhood wealth than median household income from the American Community Survey (ACS). Because these are all newly built and sold homes, median household income may be very different in new subdivisions.

3.3.6 *Data Management & Analysis*

All further data manipulation and analysis occurred in R, via *tidyverse* (Wickham 2017) and other packages specified below. I calculated mean area, total area, mean plant spending, and total plant spending for all patch types. Then, I used the *survey* package (Lumley 2019) to estimate the same metrics for the entire population, specifying a stratified random design.

To test the relationships between predictor variables and developers' patch decisions, I ran redundancy analyses (RDA) in the *vegan* package (Oksanen 2018). A constrained ordination similar to multivariate linear regression, RDA maximizes the predictability of multivariate response variables, given a suite of multivariate predictor variables (Legendre and Legendre 2012). Built patch matrix (60 x 11) consisted of the proportion of the developed area occupied by buildings (*Buildings*), other impervious surfaces (*Paved*) and nine yard patch types (*Lawn*, *Mix*, *Mono*, *Tree*, *Gravel/Cobble, Mulch*, *Gravel/Mulch*, *Rock*, and *Bare)*. Plant patch spending matrix (58 x 4) consisted of the total spending per patch type on the four vegetated yard types (*Lawn, Mix, Mono, Tree*). I evaluated final model fit using analysis of variance.

To further investigate per site plant spending, I ran a mixed level model regression in the *lme4* package. Dependent variable was plant material patch price (rounded to the nearest dollar). For the mixed level model, fixed effects were patch type (*Lawn*, *Mix, Mono,* or *Tree*) and patch area (converted to log10 and standardized). Random effect is the site, used as a grouping variable. I used a negative binomial distribution for both approaches, because the data are right skewed. I evaluated model fit with corrected Akaike Information Criterion (AIC) values, as calculated in *AICcmodavg* (Mazerolle 2019) and likelihood tests.

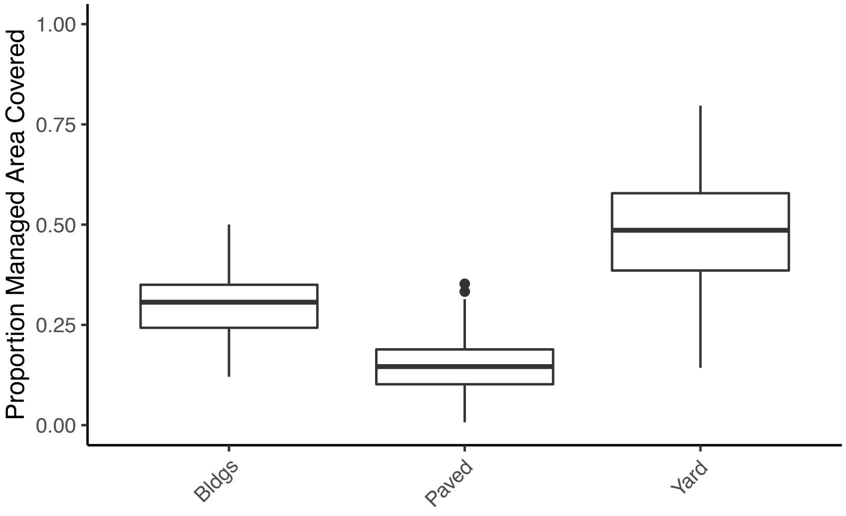
3.4 RESULTS

3.4.1 *Comparing Sample to Sample Frame*

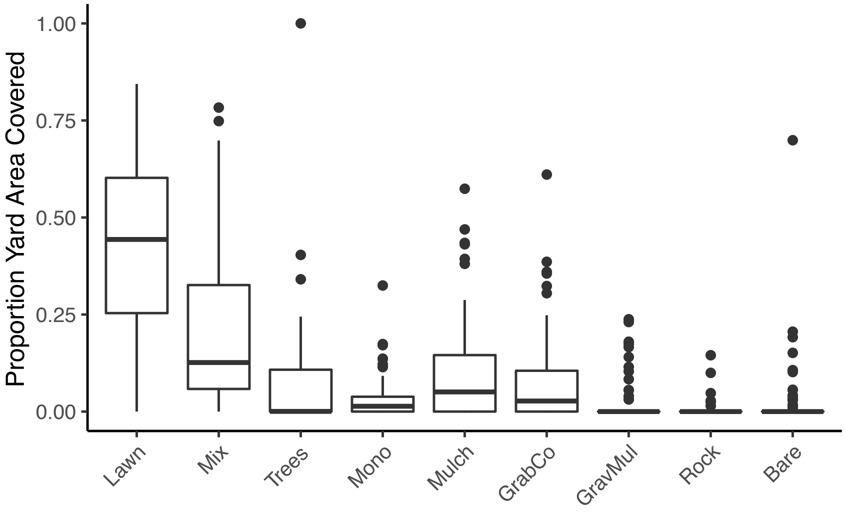
Buildings, *Lawn*, and *Paved* cover the most area (Table 3.4, Figure 3.3). *Lawn, Mix, and Tree* area means are larger for the sample; all other means are similar to the frame. Impervious surfaces cover about 44% of the developed area in the sample and about 51% in the sampling frame. Of the yard patches, *Lawn*, *Mix*, *Tree*, *Mulch*, and *Gravel/Cobble* cover the largest proportion of the yard. *Mono*, *Gravel/Mulch*, *Rock*, and *Bare* are minor patch types.

Table 3.4. Mean area and total area, by sample and sampling frame. Areas are estimates of area covered by that patch type. Error is standard error. Types: Building = houses and other buildings. Other Paved = sidewalks, walkways, driveways, steps, and patios. Yard = Area not covered by buildings or other pavement. Italicized words are yard patch names used in the text.

Patch Type	**Sample (n=60)**		**Sample Frame (n=1,258)**	
	Mean Total Area/Parcel (m^2)	**Total Area** (m^2)	**Mean Total Area/Parcel (m^2)**	**Total Area** (m^2)
Built Patches				
Buildings	185.8 ± 7.5	11,147.4	183.4 ± 8.8	230,759 ± 11,016
Paved	100.7 ± 9.5	6,038.9	92.9 ± 10.2	116,911 ± 12,768
Yard	363.0 ± 41.2	21,779.8	268.8 ± 25.8	338,191 ± 32,508
Impervious (%)	44.1	44.1	50.7	50.7
Yard Patches				
Lawn	189.3 ± 37.7	9,720.0	115.0 ± 17.9	144,603 ± 22,507
Mixed Perennials (*Mix*)	60.8 ± 8.8	3,645.4	38.9 ± 5.3	48,958 ± 6,624
Tree	51.7 ± 23.5	3,101.5	28.4 ± 8.5	35,658 ± 10,730
Single Species (*Mono*)	12.1 ± 4.1	724.3	10.2 ± 3.9	12,771 ± 4,889
Mulch	33.5 ± 7.5	2,007.5	29.8 ± 8.8	37,468 ± 11,104
Gravel/Cobble	23.6 ± 4.1	1,415.7	32.7 ± 6.9	41,164 ± 8,658
Gravel/Mulch	5.9 ± 1.6	354.2	4.8 ± 2.0	5,979 ± 2,463
Rock	1.7 ± 0.8	102.1	0.6 ± 0.3	709 ± 351
Bare	9.6 ± 4.7	574.6	7.5 ± 3.9	9,445 ± 4,929



a) Built Patches



b) Yard Patches

Figure 3.3. Proportion of area covered by patch type for a) built types and b) yard types in the sample. Patch: Bldgs = footprint of buildings. Paved = sidewalks, walkways, driveways, steps, and patios. Yard = Area of Managed Parcel Area not covered by buildings or pavement. Managed parcel area may differ from parcel area. Lawn = dominated by turfgrasses; Trees = dominated by woody vegetation >2m tall; Mix = mix of perennial species and types; Mono = single species planting; GraCob = gravel and/or cobble; Mulch = wood chips, bark, mulch, or sawdust; GravMul = narrow gravel/mulch strip; Rock = rock walls or boulders; and Bare = bare mineral soil.

All mean spending estimates for the sample are larger than for the sampling frame (Table 3.5). A typical planting for a new yard cost \$1,170 for the sample and \$1,027 for the population. Developers spent nearly \$70,000 for the vegetated patches in the sample and nearly \$1.3 M in the population. Of this, developers spent the most money on *Mix* and then *Lawn* patches.

Table 3.5. Estimated spending on plant patch types for the sample (n=58) and sampling frame (1,258 parcels).

Plant Patch Type	**Sample Spending (\$)**			**Sample Frame Estimate (\$)**			
	Mean	**SE**	**Total**	**Mean**	**SE**	**Total**	**SE**
Lawn	439	63	25,450	316	47	397,690	58,837
Mix	588	76	34,077	571	98	717,714	123,268
Tree	110	26	6,431	83	19	104,754	23,702
Mono	62	13	6,431	57	21	71,967	25,661
Total	1,170	103	69,559	1,027	116	1,292,124	146,414

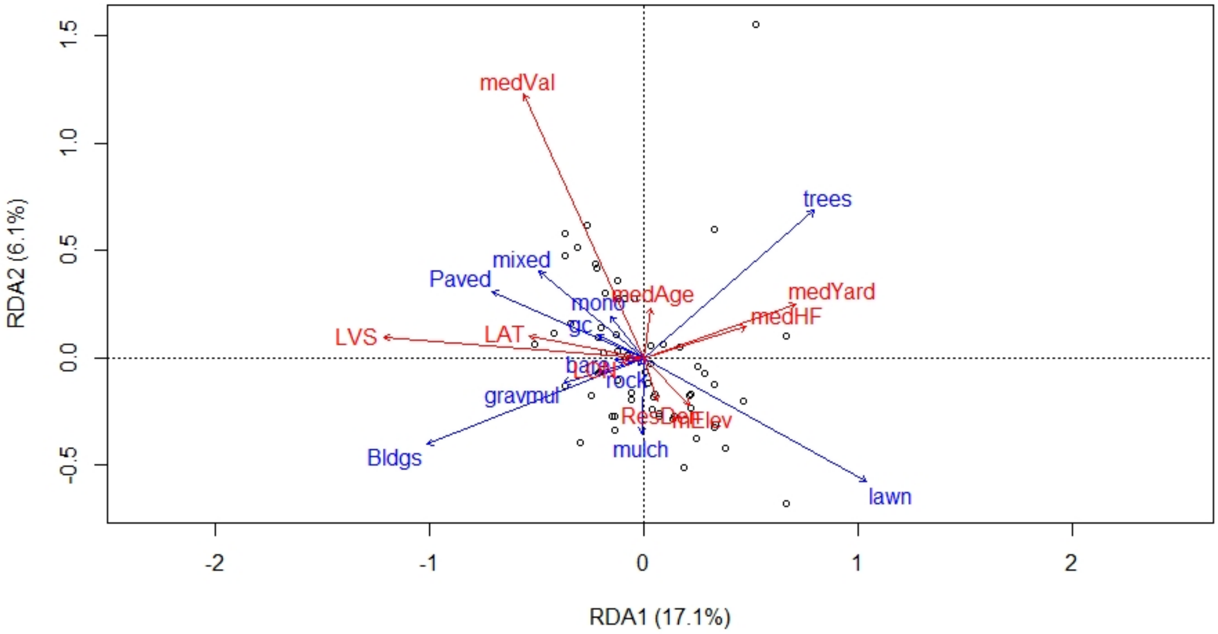
3.4.2 *Multivariate Approaches to Understanding Drivers of Developer Decisions*

Both RDAs explained a significant amount of variance (p≤0.003). Constraining site and neighborhood variables explained 29% of the variance in the patch area RDA and 24% of the variance in the patch spending RDA. Value and density variables influenced space allocation and plant patch spending decisions (Figure 3.4). In both RDAs, land value, latitude, and median assessed value were negatively loaded on axis 1, and median house foot print and median yard size were positively loaded.

Greater building and pavement area are positively associated with each other, higher land and higher latitudes (closer to Seattle to the north) and negatively with tree and lawn area (Figure 3.4). Greater paved area (*Paved*) and mixed perennial area (*Mix*) were positively associated with each other, slightly with *Mono* and *gravel/cobble* and negatively with *Lawn* area.

In terms of plant spending, greater lawn and tree spending was positively associated with larger yard sizes and negatively with land values and latitude. *Mix* and *Mono* spending, median assessed value, appraised improvement value, and residential density were positively associated with each other and negatively with longitude, elevation, and median yard area. Less was spent on plant patches further from Seattle (negative loadings of latitude, longitude, and elevation).

A) Parcel Area RDA – 29% of inertia explained; ANOVA RDA: F=2.23, p=0.003



B) Plant Patch Spending RDA - 24% of inertia, ANOVA RDA: F=2.26, p=0.001

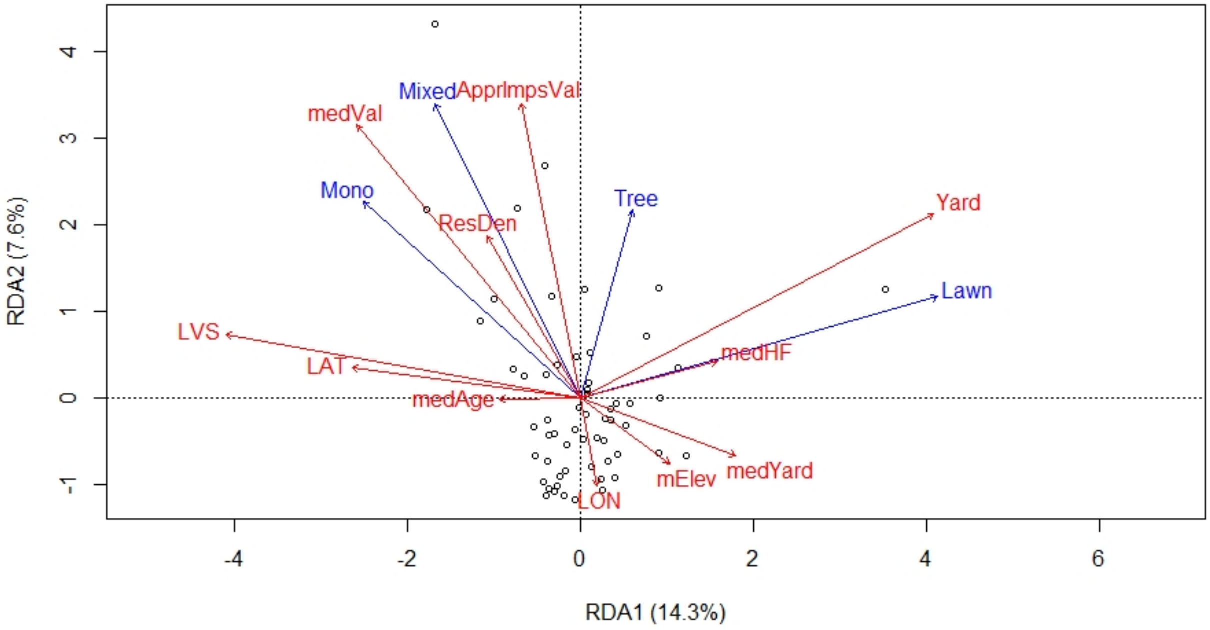


Figure 3.4. Redundancy analysis (RDA) triplots for A) patch area and B) plant patch spending. Sites are black circles, patch types are blue vectors, and predictor variables are red vectors. Variables: LVS=land value/m^2; LAT = latitude; LON= longitude; mElev = elevation (m); medVal = median assessed value; medAge = median Age; medYard = median yard area; medHF= median house footprint; ResDen = residential density. Two additional variables included in spending RDA: Yard = yard area and ApprImpsVal = appraised improvement value.

3.4.3 *Univariate Approaches to Understanding Drivers of Developer Spending*

Patch area, patch type and random effect of developer on the parcel influenced per plant patch spending (Figure 3.5). *Lawn* patches are less expensive than *Mix*, *Mono*, or *Tree* patches per unit area. For a typical patch (mean patch area of all vegetated patches; 33 m^2), a typical developer would spend about \$60 on a *Lawn* patch, \$218 on a Mix patch, \$120 on a *Mono* patch, or \$243 on a *Tree* patch. Increasing patch area by one standard deviation to 94 m^2 increases patch spending much more for all patch types except *Lawn*.

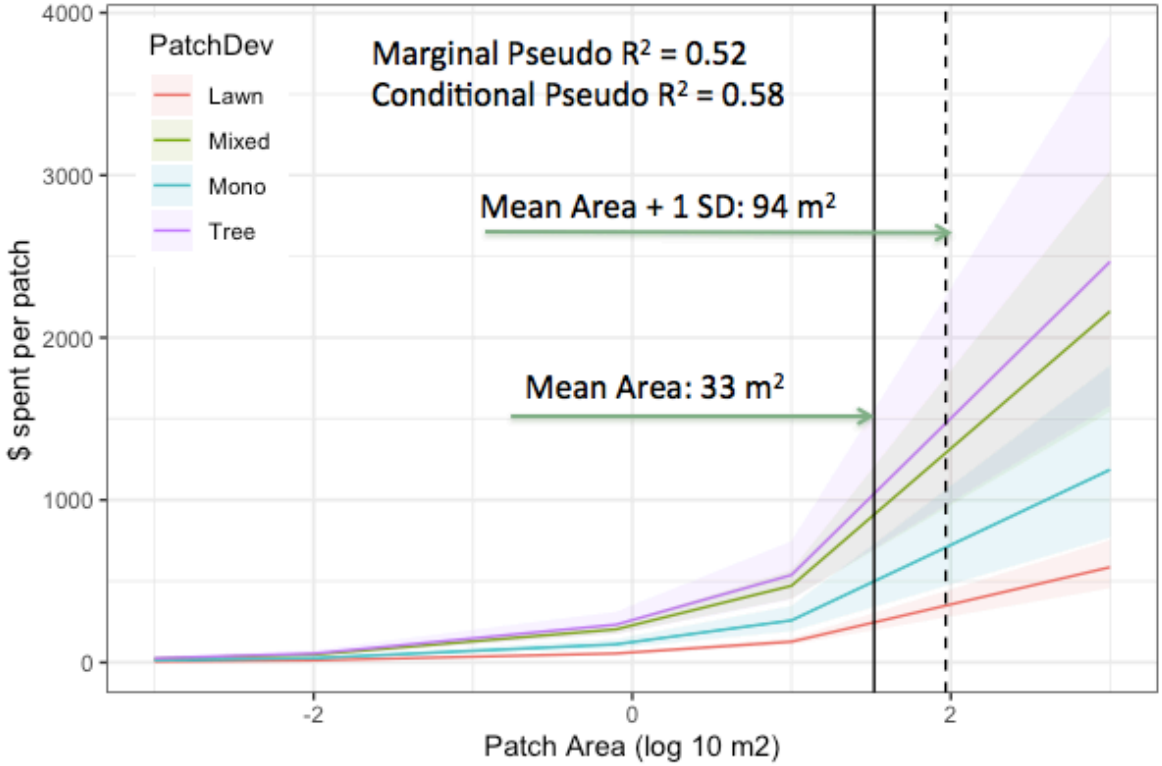


Figure 3.5. Plotted fixed effects from mixed effects model of vegetation patch spending by patch type. Shaded areas represent 95% confidence interval for that patch type.

I examined patch spending for each of the four minima and maxima from the mixed level model (Figure 3.6). Minimum developers spent less per vegetation patch than did maximum developers for *Mix*, *Mono*, and *Tree* patches. No minimum developer planted tree patches. One minimum developer kept three tree patches and planted a few understory shrubs; these retained tree patches are larger in area than the newly established tree patches of the maximum developers.

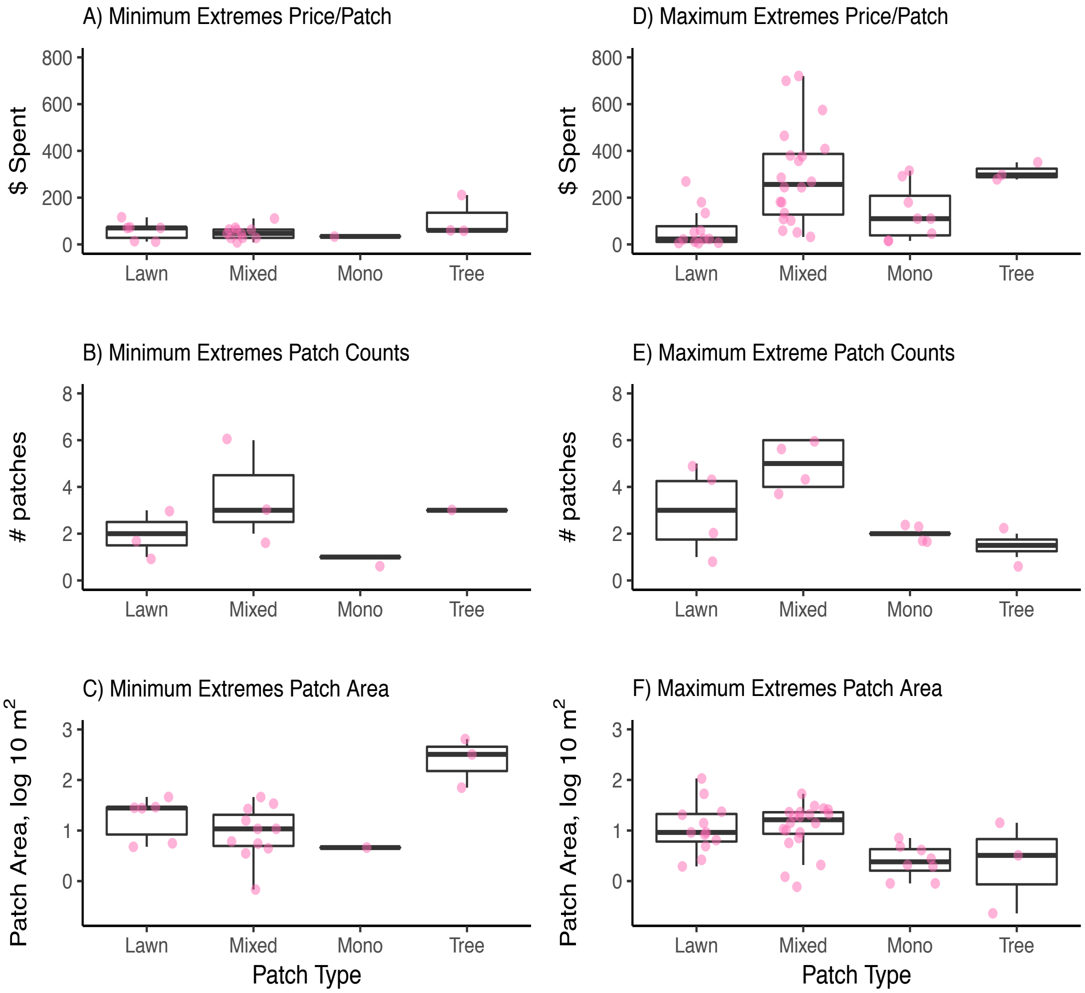


Figure 3.6. Boxplots comparing vegetation patch decisions of minimum (A-C) and maximum (D-F) developers, as identified by mixed level negative binomial regression model of patch spending at each parcel ($/patch/parcel). Dark horizontal lines are medians for that patch type. Lighter horizontal lines are first and third quartiles. Jittered pink circles represent actual values. Minimum developers are the four developers who spent the least per patch compared to others in the sample. Maximum developers are the four who spent the most.

3.5 DISCUSSION

I focused on a single cohort of new residential landscapes, viewing construction of new residential landscapes as an act of urban patch creation. With the goal of documenting typical real estate developer patch creation activities and possible drivers, I examined two different decisions: 1) how developers allocated the developable area to different patch types, and 2) how much they spent on plant materials by yard and by patch type. I found broad support for my hypotheses that many of their decisions are linked to urban economic variables.

3.5.1 *Patch Area*

Most studies of urban landscapes map land covers via remote sensing techniques. These studies have shown that residential landscapes contain a higher proportion of vegetation compared to other land uses (e.g. Pozzi and Small 2002, Gill et al. 2008). However, most of these studies were unable to distinguish many pervious patch types due to sensor limitations, overlapping cover types, and minimum mapping sizes. As a result, the most commonly used pervious patch types are tree/shrub, grass, and soil/rock/bare (e.g. Akbari et al. 2003, Li et al. 2014). Nielsen and Jensen (2015) noted that field mapping allows for finer resolution of more diverse cover types, but is time consuming, requires land owner permission for access, and is thus impractical for broader spatial scale studies of neighborhoods and cities.

In my reconstruction of developer patch creation decisions, I included both impervious and pervious patch types. Exclusive of roads, each newly developed parcel in the sampling frame generates about 276 m^2 of impervious surfaces (buildings and other paved surfaces; 44% of sample) and 115 m^2 of lawn. These land cover types prioritize human uses, providing little habitat for other species.

For yard patch types, *Lawn*, *Mix*, *Tree*, *Mulch*, and *Gravel/Cobble* are the predominant yard patch types, with *Lawn* covering the most area. My patch type areas correspond well with those of Nielsen and Jensen (2015), who that found that grass was the most abundant vegetation type in Danish neighborhoods (170-243 m^2/parcel), followed by tree cover (23-121 m^2), bushes, and planting beds. Loose surface (2.2-6.1 m2) and loose ground cover (0.3-1.6 m^2) correspond roughly to mulch and gravel types of my study. Loram et al. (2008) found that cultivated borders, mown grass, path, trees, and uncultivated were some of the most frequently occurring types (more than 100 of 267 sites) in five UK cities.

At the neighborhood and parcel extents, land rent gradients are well known to influence urban form (Anas 1978, Thrall 1991. As land values increase, building footprints tend to decrease and heights tend to increase, allocating building floor area upwards rather than outwards (O'Sullivan 2011, Barr and Cohen 2014).

I found building footprint and paved area to be positively associated with greater land values, consistent with land rent gradient theories. The positive association of non-*Lawn* plant patch types with land value metrics probably represents both a land rent gradient effect as well as a luxury effect, where wealthier homeowners and neighborhoods have more abundant vegetation (Wang et al. 2015, Endsley, Brown, and Bruch 2018). *Gravel/Cobble* could also be a reflection of the underlying land rent gradient and a luxury effect. Because it was positively associated *Mix*, *Mono*, and economic variables, developers may substitute *Gravel/Cobble* for *Mulch* or for *Gravel/Mulch* as land values increase.

3.5.2 *Developer Plant Spending Behavior*

I evaluated the overall perennial yard spending and vegetation patch spending to explore how residential developers control costs when establishing the new yards and yard patches. In my review of the residential vegetation literature, I found no other studies that examined how developers value landscapes. Instead, most of the landscape valuation literature asks consumers how much more they are willing to pay for more different landscape designs (e.g., Behe et al. 2005; Hardy et al. 2000) or relies on hedonic modeling to estimate how much vegetation quality and quantity influenced sale price (e.g. Kadish and Netusil 2012). In fact, no other residential study has determined how much developers spend on plant materials when creating new yards.

To explore how people value different landscapes, researchers have used conjoint analysis, a technique to evaluate consumer's willingness to pay for different components of an individual product (Behe et al. 2005; Hardy et al. 2000). By presenting different landscapes designs for a base model home, the conjoint analyses estimated how much more informed consumers (attendees of home and garden shows) were willing to pay for better front yard landscaping. Compared to the base design of home, lawn, and straight driveway and walkway, consumers in both studies preferred larger plant materials and more sophisticated designs (curved planting beds and hardscapes, mixes of deciduous and evergreen species, multiple beds and islands, and colored annual plants). Both studies found that the informed consumers were willing to pay 10-15% more for the most desirable landscapes.

Many researchers have used hedonic models to disentangle the estimated effects of vegetation from the other structural, site, and neighborhood factors contributing to sale price of single-family residential homes. Most studies find a positive effect on sale price from trees presence or higher quality landscaping, which increase price by about 3-10% (Anderson and Cordell 1988; Kadish and Netusil 2012; Stigarll and Elam 2009).

My work differs from both of these approaches. I reconstructed how much the different developers actually spent on plant materials per yard. For a typical patch area to vegetate, I found *Lawn* to be the least expensive patch type to install. The other three types cost at least twice as much per unit area. I also found extreme differences in how much each developer spent per plant patch type. The maximum developers spent at least twice as much per patch as much on *Mix*, *Mono*, and *Tree* patches compared to the minimum developers. Given the amount of yard area to vegetate, different developers appear to have made very different plant spending decisions, possibly because of their target buyer (Boddy 2007; Tewari and Beynon 2017). Builders of more expensive homes spent more on non-*Lawn* plant patches. In contrast, developers spent more on lawn patches when yards were larger and land values lower.

3.5.3 *Strengths & Limitations*

I linked developer space and patch allocation decisions to underlying gradients that characterize the site and neighborhood: land values and median assessed value, neighborhood age, and yard area.

By obtaining plant prices from nurseries, I was able to estimate plant costs per yard and per patch type, a form of revealed preference for how developers value yard patches. Previous landscape valuation work has mainly focused on preferences of informed and interested consumers, who were surveyed at home and garden shows. My landscape valuation focused on developers, who may or may not be as interested as in plants as home and garden show attendees. The calculated costs of the new landscapes may be overestimates, because developers are more likely to get bulk discounts and because I may not have been able to detect some of the plants that homeowners removed.

For space allocation description and analysis, I included all 60 parcels; for the price evaluations I excluded two possible outliers: Site 2, where the developer installed no vegetated patches in the yard, and Site 41, where the homeowner turned out to be related to the developer. These factors may be common in the development process and should be incorporated in space allocation decisions. However, I felt they could be too influential in the spending analysis. Moreover, for Site 41, I was not confident that I could accurately separate patch-spending decisions of the developer and homeowner.

3.6 CONCLUSIONS

Newly constructed homes and yards are new urban patch mosaics, resulting from specific decisions by heterogeneous residential developers and their agents: which lands to purchase; which previous structures, infrastructure, and landscaping to retain; and what to build, install, and plant. Profit targets, planning regulations, site morphology, and buyer preferences constrain their decisions. In this study, I described the space and spending decisions of new residential developers, which are undescribed in the urban ecology literature. Then, I tested whether those decisions were influenced by urban metrics at the parcel or neighborhood extent.

Developers allocated the most space to buildings and lawn patch types. Such a pattern is a typical US residential urban form (Akbari et al. 2003, Brown 2015, Giner et al. 2013).

Developer behavior regarding yard patch creation and spending is consistent with what has been defined in the literature the *luxury effect,* where wealthier neighborhoods have more abundant and species rich vegetation (Hope et al. 2003; Leong, Dunn, and Trautwein 2018). As land value and median assessed value increased, I found that developers allocate a greater proportion of the yard to vegetation patches other than *Lawn* and also to *GravelCobble*, which I presume is more expensive than other non-vegetated types. Similarly, I found increasing land or neighborhood values increased developer spending on non-*Lawn* plant materials.

Chapter 4. NEW LAWN FLORAS AND SPECIES DIVERSITY

4.1 INTRODUCTION

Lawns are the dominant land cover of urban ecosystems, particularly in residential landscapes (Ignatieva and Hedblom 2018; Robbins and Birkenholtz 2003). Homeowners typically prefer green lawns with turfgrasses only, allowing few or no broadleaf herbaceous species (Sisser et al. 2016; Varlamoff et al. 2001). To maintain this desirable, nearly uniformly green surface, most homeowners implement an intensive regime of frequent watering and mowing, managing weeds and pests, and applying fertilizer (Behe 2006; Blaine et al. 2012; Carpenter and Meyer 1999; Martini and Nelson 2015; Robbins 2007).

Despite the ubiquity of intensively managed lawns, few researchers have explored how human and biophysical drivers interact to produce their unique ecology, composition, and appearance. Thompson et al. (2004) sampled United Kingdom residential lawns and investigated whether local (lawn area and management) or broader biophysical scale factors influenced species composition. Nielson and Smith (2005) explored how neighborhood norms for lawn maintenance and appearance influenced actual lawn appearance and management. Bertoncini et al. (2012) conducted lawn species inventories, linking composition to ownership (private or public) and management regimes. Ignatieva et al. (2017) investigated the social and cultural perceptions of lawn establishment and management in three Swedish cities.

A number of researchers have found that neighborhood rules and norms set expectations for yard appearance and management. A particularly common neighborhood norm is that desirable landscapes are neat and orderly, providing distinct evidence of human management and cues to care (Nassauer 1995). Clean, neat lawns that are mown and weed free are attractive, and show neighbor pride and hard work (Mustafa et al. 2010; Nassauer, Wang, and Dayrell 2009; Sisser et al. 2016). Robbins and Sharp (Robbins 2007; Robbins and Sharp 2008) argued that lawn care decisions are both individual and communal, reflecting the social context in which those decisions are made. Keeping a neat, green, monoculture lawn is an act of stewardship to protect the community and property values. Thus, residents, neighborhoods, and expectations are each shaped by the practice of lawn management.

More recently, researchers have investigated homogeneity of lawn care practices and plant communities. Polsky et al. (2014) found that lawn irrigation and fertilization varied within and among U.S. cities. Wheeler et al. (2017) explored whether residential lawn communities were compositionally similar across U.S. cities and to more natural vegetation types within the same cities. They found that lawn floras were more similar to each other than to the reference communities. They also found fewer species in lawns that were fertilized or that were in wealthier neighborhoods.

4.2 RESEARCH OBJECTIVES

I focus on the interactions of new homeowners and their newly installed lawns to see how lawn care regimes and lawn floras develop. I frame my research by viewing lawns and lawn care as products of household decision-making and emotions (Carmi, Arnon, and Orion 2015; Grob 1995; Harris et al. 2013; Robbins 2007). The household acts within a multi-scalar framework of people, place, and plants, where complex human and natural system drivers interact at regional, municipal, local, and finer scales to produce the individual decisions and urban landscape patterns (Chowdhury et al. 2011; Cook, Hall, and Larson 2012).

First, I describe new homeowners' yard preferences and lawn care practices. How variable are the preferences and lawn care practices of new homeowners? I predicted that yard goals based on normative ideas of lawn appearance should be homogeneous, while ideas about ease of maintenance should be more variable to reflect homeowner ambivalence about lawn care labor (Harris et al. 2013; Robbins 2007). Yard goals based on use of space should be more variable, reflecting differences in personal preferences (van den Berg and van Winsum-Wesdtra 2010, Locke et al. 2018), socioeconomics (Larsen and Harlan 2006; Zhou et al. 2009), and life stage (Behe and Dennis 2009; Carrico, Fraser, and Bazuin 2012; Yabiku, Casagrande, and Farley-Metzger 2007). I made no predictions about variability of homeowner practices, because actual lawn practices of homeowners not well documented in the urban ecology literature.

Second, I document the composition and species diversity of new residential lawns. How diverse are they? How similar are they to other lawn floras? Given their young age, I predicted non-turfgrass species diversity to be low. However, despite the low diversity, I expect the species that did establish to be present in other lawn floras.

Third, I explore whether parcel or neighborhood variables lead to differences in lawn diversity. I predicted that lawn species richness will be lower in wealthier neighborhoods and when the appraised value of the house is greater. Wealthier homeowners tend to have more intense lawn care regimes (Fraser et al. 2013; Robbins 2007). It is not clear how household preferences, area (lawn or neighborhood yard size), and other built environment variables interact to permit or restrict species establishment in new lawns, so I made no further predictions.

Fourth, I explored whether homeowner preferences or lawn care practices lead to differences in diversity. I predicted that the probability that the lawn will be a turfgrass monoculture will be less for those who select *Easy* as a higher priority goal and greater for those who select *Neat*. Conversely, lawn species richness will be greater for households who select Easy as a higher priority yard goal and lower for those who select *Neat*. I made no predictions for other yard goals. I also predicted that higher frequencies of watering fertilizer application will be positively correlated with the probability that lawn is a monoculture (Nielson and Smith 2005; Wheeler et al. 2017). I made no predictions for other lawn care variables.

Finally, I tested to see whether significant drivers of lawn diversity from parcel, neighborhood, or households were correlated with each other.

4.3 METHODS

4.3.1 *Documenting Lawn Floras & Measuring Area*

In 2016, I sampled 60 new yards selected by stratified random sample from a potential pool of 1,258 homes (Chapter 2). All but two yards had lawns. At each site, I conducted a complete vegetation survey of all lawn patches. Assuming that most homeowners would not differentiate among different grasses, but would consider the presence of other plants as lawn weeds, I lumped all turfgrasses as “turf” and identified all other vascular taxa to species. Nomenclature follows Hitchcock and Cronquist (2018). The new lawns were mostly combinations of *Lolium perenne*, *Poa pratensis*, and *Festuca* spp.

Vegetation sampling is often recommended over a complete survey of a single community, because it is more reliable, efficient, and cost effective in detecting local variation over large area (Mueller-Dombois and Ellenberg 1974; Stohlgren 2007). Because I was not interested in detecting within parcel variation and because the lawns were relatively small, a complete survey was appropriate. To account for area, I measured all yard patches (not just lawn patches) using a 50m tape and converted dimensions to area, using standard geometry equations or offset method for irregular patches(Christians and Agnew 2008).

4.3.2 *Yard management*

I sent all homeowners a questionnaire (Appendix A); only 35/60 responded. Two of these responses were from homeowners who did not have lawns. From the responses, I created two datasets: 1) a ranking of yard goals, and 2) estimated counts of specific lawn care activities by season (Table 4.1). I excluded herbicide use from further evaluation. Several households stated that they did not use herbicides, but also reported lawn care products that do contain herbicide.

4.3.3 *Geospatial Parcel Data*

To investigate the effects of site and neighborhood variables on yard floras, I compiled and calculated variables at the site and neighborhood extent (Table 4.2). For a neighborhood surrogate, I used Census Block Group extent, which is commonly used residential lawn studies (e.g. Giner et al. 2013; Carrico et al. 2018). Because these new residential properties in this sample are a mix of infill development, redevelopment, and newly built subdivisions, census derived estimates may not accurately capture changes in the built environment or household demographics. Other studies of residential lawns, urban vegetation, and management have found a strong link with neighborhood wealth expressed as household income (e.g., (Fraser et al. 2013; Robbins and Birkenholtz 2003; Wheeler et al. 2017). Here, I use appraised improvement value and median assessed value as surrogates for household income. Other researchers have found median assessed value be a strong metric of neighborhood wealth (Endsley, Brown, and Bruch 2018; Leonard et al. 2016; Moudon et al. 2011).

Table 4.1. Lawn data, from households who returned questionnaire and had lawns.

Homeowner Variables	**Variable Description**
Yard Management Goals (n=33)	
Yard is Beautiful (*Beautiful*)	Rank: 1: very unimportant; 5: very important
Yard is Neat (*Neat*)	Rank: 1: very unimportant; 5: very important
Yard is Easy to Manage (*Easy*)	Rank: 1: very unimportant; 5: very important
Yard Provides Wildlife Habitat (*Habitat*)	Rank: 1: very unimportant; 5: very important
Yard Provides Food (*Food Space*)	Rank: 1: very unimportant; 5: very important
Yard Provides Space for Kids (*Kid Space*)	Rank: 1: very unimportant; 5: very important
Yard Provides Space for Pets (*Pet Space*)	Rank: 1: very unimportant; 5: very important
Lawn Care Regime Variables (n=33)	
Spring Water	Count Estimate – # times watered in spring
Summer Water	Count Estimate - # times watered in summer
Fall Water	Count Estimate - # times watered in fall
Annual Mow	Count Estimate – # times mowed per year
Annual Edge	Count Estimate – # times edged per year
Annual Fertilizer	Count Estimate – # times fertilized per year

Table 4.2. Summary of built environment variables evaluated in diversity analysis.

Site Extent	**Data Source and Description**
Elevation (m)	Google Maps – elevation above mean sea level
Assessed Improvement Value ($)	King County Assessor Data – value of house and buildings in 2016
Lawn Area (m^2)	Field Measurements adjusted by Aerial Photo Corrections for Yard Area
Census Block Group (CBG) Extent	**Data Source**
Residential Density (# residences/km^2)	Calculated from King County Assessor Data, # residential units/CBG area
Median Age (years)	Calculated from King County Assessor Data; 2016-median year built all residential properties within CBG
Median Assessed Value (m^2)	Calculated from King County Assessor Data; Median improvements and land value 2016
Median Yard Size (m^2)	Calculated from King County Assessor Data Median (Lot Area – Estimated Building Footprints)

4.3.4 *Data Management & Analysis*

I used R version 3.5.1 (R Core Team 2019) for all further data manipulation and calculations. I corrected yard area and patch type area to account for measurement error (Chapter 3). Briefly, I used 2017 aerial photos from King County to accurately measure building footprint, other paved surfaces, and sampled yard area within the parcel. Then, I adjusted field patch measurements so that sum of all yard patch types was the same as the corrected yard area. Note that I define yard area to be the part of the parcel actively managed by the homeowner, after subtracting house footprint and other paved area. It includes curb strip vegetation, but not irregular areas outside of fences or undeveloped parts of the parcel (steep slopes and wetlands).

For analyses, I used *vegan* (Oksanen 2018) to calculate diversity indices, *spdep* (Bivand et al. 2019) for spatial analysis, and stepAIC in *MASS* (Ripley et al. 2018) to select a possible best fitting model from stepwise regressions (both directions). I fit separate regressions for parcel, neighborhood, and household variables. To control for magnitude and range differences, I standardized all independent variables (mean centered and divided by standard deviation).

I fit logistic regressions to explore drivers of turfgrass monoculture and negative binomial regressions to explore drivers of non-turfgrass species richness. To be counted as monoculture, all lawn patches in the parcel had to be free of non-turfgrass species. If Monte Carlo simulation of Moran's I detected spatial autocorrelation for some response variables ($p<0.10$), I fit a spatial filtering model to add spatial lags. Because of the small number of observations, final models had the smallest corrected Akaike Information Criterion (AIC) values, as calculated in *AICcmodavg* (Mazerolle 2019). Because land value ($\$/m^2$) drove initial builder allocation of space to yard and lawn (Chapter 3), I could not include lawn area and land value together in the site model. Therefore, I used appraised improvement value, and not land value, as a household income surrogate in order to include lawn area. I converted lawn area and median yard area to base 10 logarithm and then standardized them. Thompson et al. (2004) found that lawn species richness and log lawn area to be positively linearly associated ($R^2=0.383$, $p<0.001$).

Finally, I tested for correlations between significant household yard goals, lawn and median yard area, and household reported lawn care practices. I ran Spearman rank correlations in *Hmisc* (Harrell 2019) and plotted them in *corrplot* (Wei and Simko 2017).

4.4 RESULTS

4.4.1 *Yard Goals & Lawn Care Regimes*

Homeowners consistently ranked a few yard goals as important: *Beautiful, Neat*, *Easy*, and *Pet Space* (Figure 4.1). Conversely, the rankings for the other yard goals were more variable. *Habitat* (Provide wildlife habitat) and *Kid Space* (Space for Kids) had the widest ranges. Several of the yard goals are correlated (Appendix 3). *Neat* and *Beautiful* are positively correlated (Spearman rho = 0.66, p<0.001), as are *Habitat* and *Entertain* (Spearman rho = 0.42, p=0.009). *Easy* and *Entertain* are negatively correlated (Spearman rho = -0.36, p=0.028).

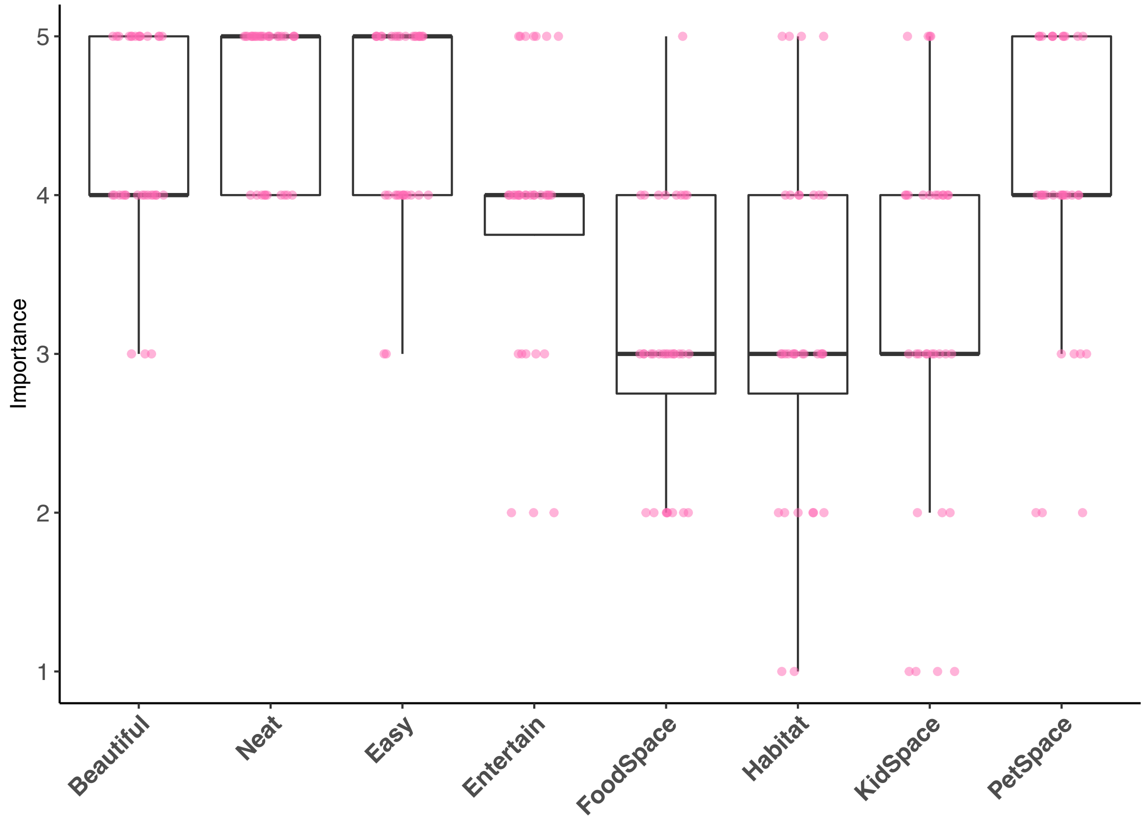


Figure 4.1. Homeowner rankings of the importance of eight different yard management goals, from questionnaire responses (33/58 responses from homeowners). Importance: 1= Very unimportant; 5= Very Important. Darkest horizontal lines represent the median ranking for that yard goal. Points are actual responses, jittered horizontally to spread similar responses.

Of all lawn care activities, summer watering, mowing, and edging occurred the most frequently (Figure 4.2). A typical homeowner irrigation routine (based on medians) consisted of watering three times in the spring, 24 times in the summer, and not at all in the fall. The typical routine for other lawn care activities are fertilizing twice, mowing 21 times, and edging 15 times. Extreme watering counts (>45) are from reported daily watering during the season. Extreme fertilizer counts (6x/year) are from reported monthly applications.

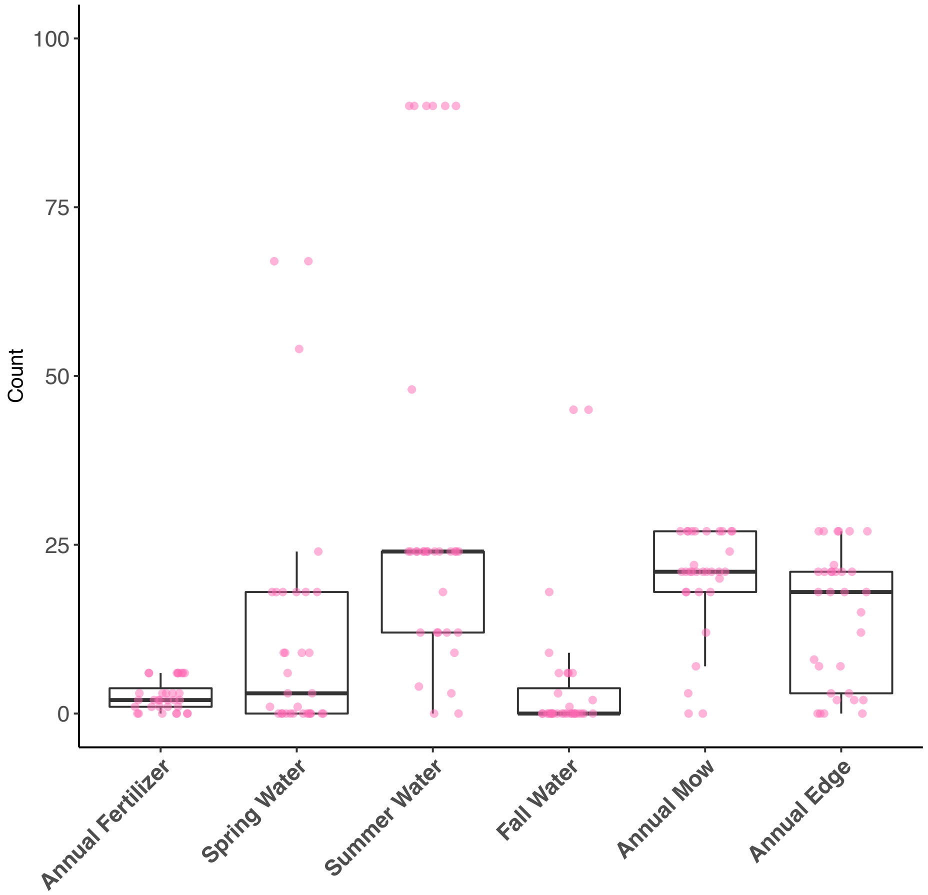


Figure 4.2. Estimated counts of homeowner reported lawn care by activity, derived from questionnaire responses (32/58 responses from homeowners). Darkest horizontal lines represent the median ranking for that lawn management activity.

4.4.2 *Lawn Species Diversity & Composition*

Eleven sites were monoculture. Homeowners manage about 33,418 ±16,489 m^2 as monoculture lawn and about 128,967 ±24,317 m^2 as polyculture lawn. Including turfgrass as a single taxon, a typical yard had about 6 lawn species (Table 4.3; Figure 4.3). The steep decline (49%) in mean effective species richness as order increases from richness to inverse Simpson represents a very uneven community dominated by only a few species.

Table 4.3. Mean effective species richness (ESR; Jost 2006a) by diversity index.

Diversity Index	**Mean ESR and Standard Deviation**
Richness (order 0 diversity index)	6.5 ± 5.3
Shannon (exp (H')) (order 1 diversity index)	4.0 ± 2.8
Inverse Simpson (order 2 diversity index)	3.2 ± 2.1

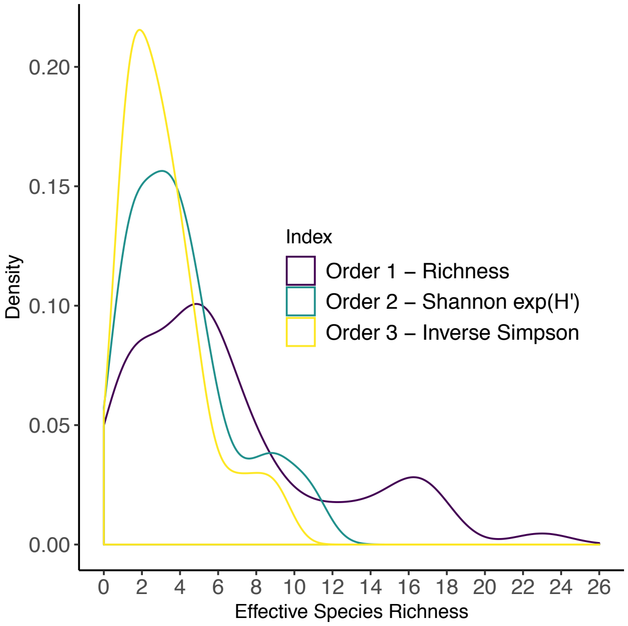


Figure 4.3. Density plots of lawn herbaceous diversity (n=58), by diversity index in effective species richness form and order (Jost 2006). Richness is number of species by site. Shannon is exponent (H') with count of individuals by taxon as abundance. Inverse Simpson is 1/Simpson, with count of individuals by taxon as abundance. Turfgrass is included as single species, with count as total number of lawn patches by site.

Only 28 of the 55 taxa occurred at more than 3 sites (Figure 4.4); these frequent taxa are also represented in other lawn floras (Appendix C). Turfgrasses, *Hypochaeris radicata* (spotted cat's ear), *Taraxacum officinale* (dandelion), and *Trifolium repens* (white clover) were the only species to occur at about half the sites. *Rubus bifrons* (Himalayan blackberry) was the only frequent woody species. Of the taxa native to the Pacific Northwest, only *Epilobium ciliatum (*common willowherb) occurred frequently. Other native taxa occurred at two or fewer sites.

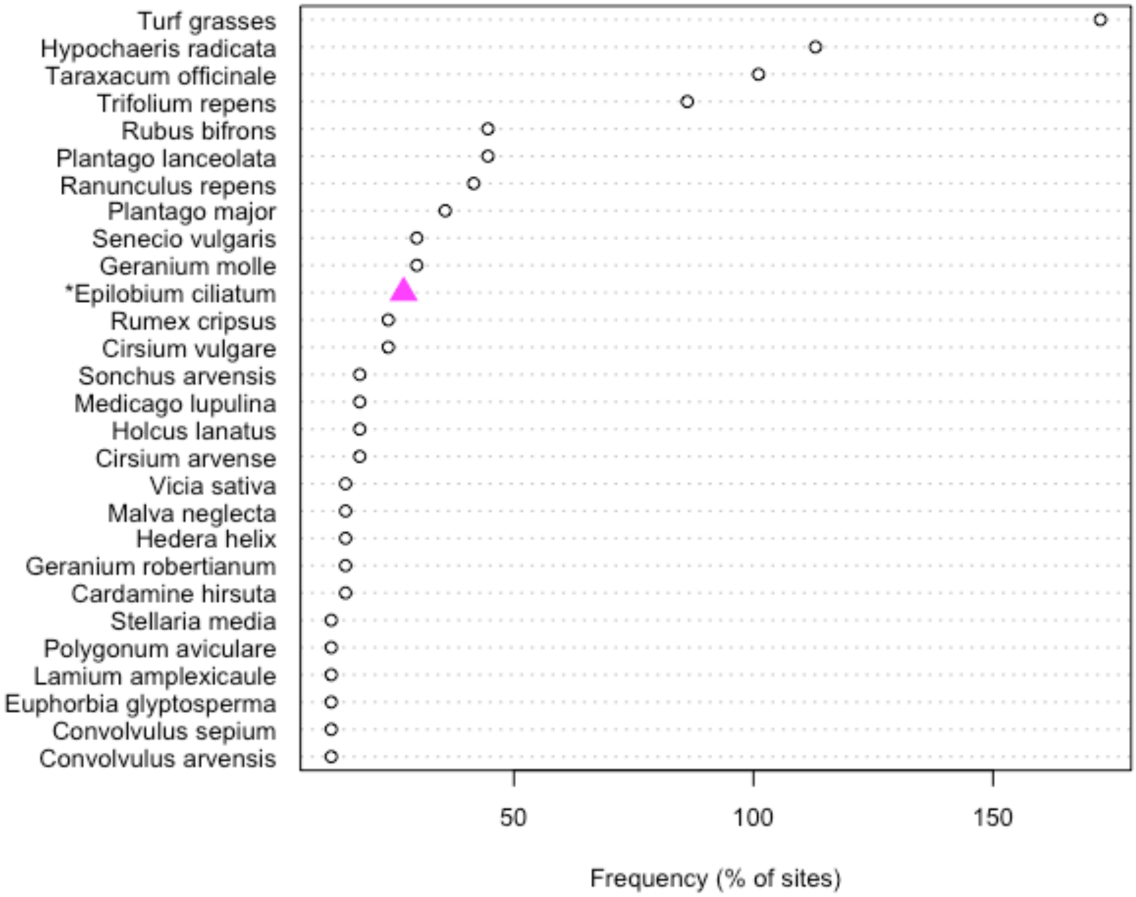


Figure 4.4. Frequency of occurrence for the 28 species occurring at 3 or more sites. Species marked with asterisk and a magenta triangle are native to Washington State.

The new lawn flora has the substantial overlap with other lawn floras (Table 4.4; Appendix 3). Temperate sites had the most species in common.

Table 4.4.Comparison of study with other lawn floras. See Appendix C for species list comparison.

Study Location	**% of Study Species in Flora**	**# lawns sampled**
Seattle, WA, USA (this study)	100	58
Wooster, OH, USA[1]	36	38
Baltimore, MD, USA[2]	35	23
Boston, MA, USA[2]	31	31
Los Angeles, CA, USA[2]	15	20
Miami, FL, USA[2]	6	21
Minneapolis-St. Paul, MN[2]	26	21
Phoenix, AZ, USA[2]	16	28
Salt Lake City, UT, USA[2]	18	30
Sheffield, United Kingdom[3]	55	52
Paris, France[4]	42	100
Christchurch, New Zealand[5]	20 (complete species list not found)	327

Studies: [1]Whitney (1985); [2]Wheeler et al. (2017); [3]Thompson et al. (2004); [4]Bertoncini et al. (2012); [5]Stewart et al. (2009)

4.4.3 *Drivers of Species Diversity*

Although turfgrass monoculture lawns were not spatially autocorrelated (Monte-Carlo simulation of Moran's I = -0.06; p =0.717), richness of non-turfgrass species was (Monte-Carlo simulation of Moran's I = 0.146; p =0.031). Including a spatial lag term improved the fit of the Census Block Group and yard goal models of non-turfgrass species richness. Yard goal models estimating monoculture lawn probability and richness of non-turf species explained more deviation than the parcel or Census Block Group models (Tables 4.6, 4.7; Appendix C).

Increasing median neighborhood yard area, wanting to provide wildlife habitat (*Habitat*), and wanting to have space for kids (*KidSpace*) increased the probability that a homeowner will manage all lawn patches as turfgrass monoculture (Table 4.6), as does watering more in the summer and applying fertilizer more frequently. However, having easy to manage (*Easy*) as a yard goal decreases the probability that all lawn patches are turfgrass monocultures.

Table 4.5. Logistic regression models predicting whether homeowners manage their lawns as turfgrass monocultures (Appendix C). Parcel model (n=58) was intercept only, so is not depicted.

Model	**Variable**	**Estimate**	**Std. Error**	**P**
Census Block Group Pseudo $R^2 = 0.16$ p=0.008 n=58	Intercept	-1.66	0.39	<0.0001
	Log 10 Yard Area	0.94	0.40	0.019
Yard Goal Model Pseudo $R^2 = 0.57$ p=0.02 n=33	Intercept	-6.29	7.41	0.396
	Easy	-2.63	1.45	0.069
	Habitat	2.77	1.15	0.016
	Kid Space	2.02	1.06	0.058
Lawn Management Model Pseudo $R^2 = 0.33$ p=0.01 n=33	Intercept	-1.79	0.66	0.007
	Summer Water	2.45	0.53	0.018
	Fertilizer	1.29	0.60	0.032

For those homeowners who do not manage their lawns as monocultures, a mix of parcel, neighborhood, and yard goal variables influenced the resulting richness of non-turfgrass species (7). Having a larger lawn and increased species richness were positively correlated. In contrast, lawn species richness was negatively correlated with elevation, improvement value, median assessed value, and higher rankings of *Habitat*.

Table 4.6. Negative binomial regressions of lawn species richness for those lawns not managed as turgrass monocultures (Appendix C). Parcel model without a spatial lag fit better than the model with a spatial lag. The reverse was true for the census block group and yard goal models.

Model	**Variable**	**Estimate**	**Std. Error**	**P**
Parcel Model Pseudo $R^2 = 0.34$ p=0.06 n=58	Intercept	1.83	0.09	<0.0001
	Elevation	-0.36	0.01	<0.0001
	Appraised Improvement Value	-0.20	0.10	0.054
	Log10 Lawn Area	0.39	0.01	<0.0001
Census Block Group Model Pseudo $R^2 = 0.20$ p=0.01 n=58	Intercept	1.87	0.01	<0.0001
	Median Assessed Value	0.23	0.11	0.027
	Spatial Lag	1.70	0.63	0.007
Yard Goal Model Pseudo $R^2 = 0.57$ p=0.02 n=33	Intercept	1.67	0.12	<0.0001
	Habitat	-0.23	0.13	0.067
	Spatial Lag	-1.93	0.63	0.002

4.4.4 *Exploring Links Between Diversity Drivers & Lawn Care Practices*

The correlation matrix (Figure 4.5) of significant predictors of diversity shows the complex interactions that produce new lawns and lawn floras. *Easy* is positively correlated with elevation and negatively with improvement value. *Habitat* is negatively correlated with both lawn area and improvement value, and *Kid Space* is positively correlated with lawn and median yard area. Both summer water and fertilizer are positively correlated with bigger lawns and neighborhoods with larger yards. Fertilizer frequency is also positively correlated with elevation and median assessed value.

Figure 4.5. Spearman rank correlations of diversity predictors from regression models (Tables 4.6, 4.7). Size of circles represents strength of correlation. Red circles represent negative correlations, and blue circles represent positive correlations. Dataset reduced to 33 homeowners who responded to survey.

Homeowners who ranked the three goals differently appear to have different lawn care regimes (Figure 4.6). Homeowners who prioritize *Kid Space* appear to have a much more intensive lawn care regime those who ranked *Easy* or *Habitat* highly. Spring watering, mowing, edging, and fertilizing are all positively correlated with *Kid Space*. Homeowners who ranked *Easy* and *Habitat* highly appear to water, mow, and fertilize fewer times.

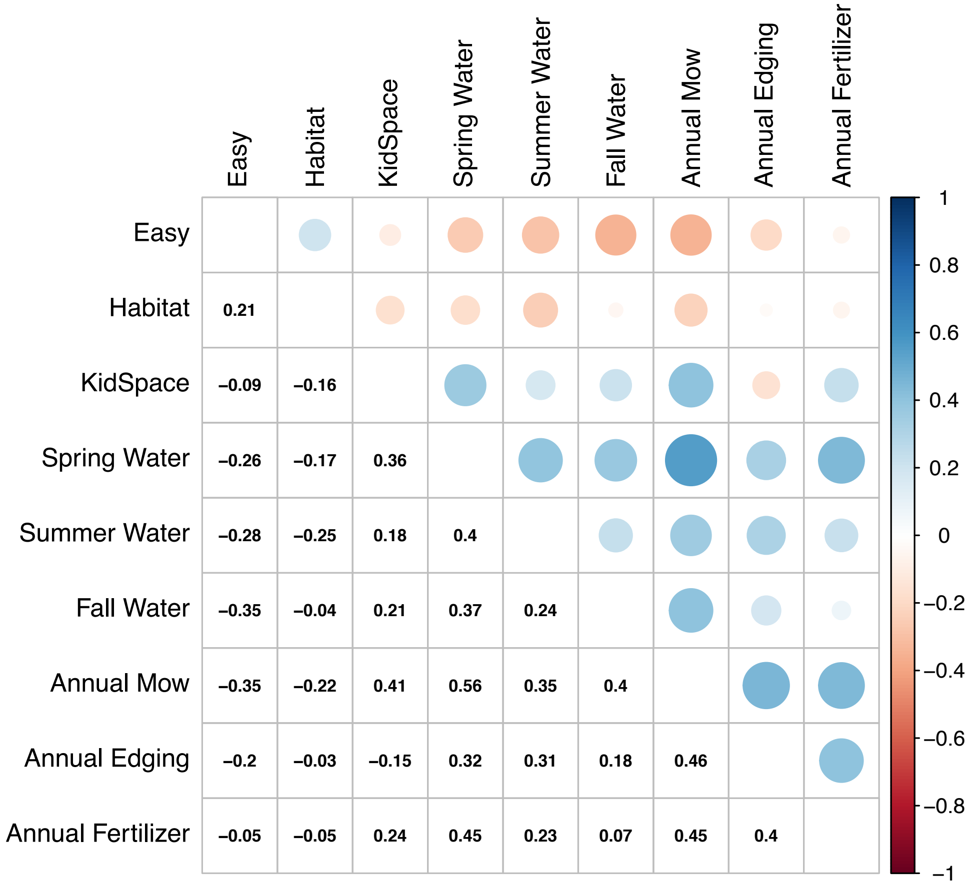


Figure 4.6. Spearman rank correlations of significant yard goals (Figures 4.5, 4.6) with lawn care practices (n=33). *Easy*, *Habitat*, and *KidSpace* are rankings of the importance having a yard that is easy to manage (*Easy*), provides wildlife habitat (*Habitat*), or provides space for kids (*KidSpace*). *Spring Water, Summer Water, and Fall Water* are estimates of season watering frequency. *Annual Mow, Annual Edging, and Annual Fertilizer* are annual estimated frequency of lawn care practice.

4.5 DISCUSSION

4.5.1 *Variability in Yard Goals & Lawn Care Practices*

Lawns can be spaces for conflict and negative emotions, when homeowner personal preferences are at odds with neighborhood standards for lawn appearance and management (Robbins 2007; Harris et al. 2013). Robbins (2007) argued that having a lawn converts homeowners into “lawn people” who adopt resource intensive lawn care regimes to comply with neighborhood norms for aesthetics and protecting property values. These norms are then reinforced by widespread messages from the lawn care industry.

For the yard goals, I hypothesized that aesthetic concerns would be less variable than ease of maintenance or space-related yard goals. While I did find less variability in *Beautiful* and *Neat*, I also found *Easy* and *Pet Space* to have smaller ranges as well. In contrast, the ranges for other uses of yard space are larger. Thus, homeowners appeared to agree that aesthetics and labor concerns are important, but have divergent views about how their yards could be used.

Other researchers have found substantial differences in lawn irrigation and fertilization within and across cities (Fraser et al. 2013; Gu et al. 2015; Polsky et al. 2014), but I was unsure whether the new homeowners would have differentiated practices, given the newness of the lawns, desire to protect their investment, and norms of their new neighborhoods. I found only one other study (Gu et al. 2015) that described a typical lawn care regime as practiced by homeowners, providing frequency estimates of watering, fertilizing, and mowing. Most studies exclude frequency of mowing and use of other power tools.

The lawn care regimes of new homeowners are similar. Homeowners reported high frequencies of summer watering, mowing, edging, and fertilizer application. Spring and fall watering have more divergence, with some homeowners watering heavily, while others report little to no watering during those seasons.

The typical new homeowner lawn regime was similar to that for Tennessee lawns (Gu et al. 2015). Mean frequencies of fertilization (2.6 vs. 2.5/year) and mowing (20 vs. 18 times/year) were similar as were irrigation seasons (nearly everyone in summer, about 75% of households in spring, and less than 10% in fall). However, total irrigation frequency was greater for this study (48.0 vs. 38.7 times/year), which could be from promoting new lawn establishment.

4.5.2 *Lawn Herbaceous Composition*

Comparing the lawn flora to other studies, I found substantial overlap in composition. The most frequent species in sampled lawns (Figure 4.4) are often some of the most frequent in studies of lawn communities in 10 cities (Bertoncini et al. 2012; Stewart et al. 2009; Thompson et al. 2004; Wheeler et al. 2017; Whitney 1985), suggesting a widespread lawn forb flora able to quickly establish and tolerate typical lawn management. Of these frequent species, *Medicago lupulina* (black medic), *Plantago lanceolata* (English plantain), *Plantago major* (common plantain), *Polygonum aviculare* (common knotgrass), *Stellaria media* (chickweed), T. *officinale*, and *T. repens* occur in lawns in 6 or more of these cities. Many of the other, less frequent lawn species in the study area are also present in these other lawn studies and/or able to tolerate a wide range of habitats in the Pacific Northwest (Hitchcock and Cronquist 2018).

Oddly, *H. radicata*, the most frequent forb in my sample, is not particularly frequent or abundant in other lawn floras, although it is present in lawns in the United Kingdom (Thompson et al. 2004), New Zealand (Stewart et al. 2009), France (Bertoncini et al. 2012), and the United States (Wheeler et al. 2017). In roadside verges in the Netherlands, de Kroon, Plaisier, and van Groenendael (1987) described *H. radicata* populations as undergoing density dependent boom and bust cycles. It may be that *H. radicata* undergoes similar processes in lawns or that plot-based methods of sampling in lawns fail to capture its true frequency in residential landscapes, given its scattered patchy distribution, yet worldwide distribution. As a highly plastic, cosmopolitan weed (Mitchell and Bakker 2014; Ortiz et al. 2008), *H. radicata* occurs in multiple habitats, with varying amounts of biophysical and human disturbance, so it seems that it should be a frequent member of residential lawns that are not managed as monocultures. Alternatively, *H. radicata* may be booming within the study area, and/or homeowners who manage their lawns less intensively do not remove *T. officinale*, which looks superficially similar.

4.5.3 *Lawn Diversity & Management*

The J-shaped density and frequency curves (Figure 4.3, 4.4) are similar to what has been found in other studies of lawn communities, where a few taxa are quite frequent and the rest occur only at a few sites. Overall, the species richness of lawns in sampled parcels (6.5±5.3) is on the lower range of reported mean species richness in other studies (15 in UK; Thompson et al.

2004), 9.2 in Paris (Bertoncini et al. 2012), and about 5-15 in 7 US metropolitan areas (Wheeler et al. 2017). Lower richness in this study is likely from lumping turfgrass species and from including only new lawns. Other species may not have had enough time to establish, compared to the older lawns in other studies.

Lawn diversity patterns appear to result from complex interactions of households and their new spaces. However, I found household drivers to be stronger predictors of lawn monoculture status than those of parcels or neighborhoods. In fact, the significant yard goals (*Kid Space*, *Habitat*, and *Easy*) appear to be linked to different yard preferences and management systems. Valuing *Kid Space* is linked to being in neighborhoods with larger yards, selecting parcels with bigger lawns, and having more intensive lawn care regimes. This *Kid Space* pattern appears to be a typical intensive lawn care regime, resulting from individual and communal norms and social contexts (Robbins 2007; Robbins and Sharp 2008; Sisser et al. 2016). In contrast, the other goals appear to have less intensive lawn care regimes. However, I speculate that those who value *Habitat* are more actively removing weeds than those who value *Easy*. In Chapter 5, I found that those who valued *Habitat* planted more tree, shrub, and herb species. Thus, *Habitat* may represent active gardeners; those who favor *Easy* have other interests.

I found that higher frequencies of fertilizer use and summer irrigation were associated with larger lawns and monoculture lawns. Fertilizer frequencies appeared greater in wealthier neighborhoods. Nielson and Smith (2005) found lawn homogeneity and greenness to be associated with more frequent watering and fertilizing of Oregon lawns. They, too, found that more frequent fertilization was associated with higher household income. Wheeler et al. (2017) also found lawn species richness to be lower in higher income neighborhoods and in lawns that were fertilized. In studies that only examined lawn fertilizer use (and not lawn communities), higher household or neighborhood income is associated with greater fertilizer frequency and application amounts (Blaine et al. 2012; Carrico et al. 2018; Carrico, Fraser, and Bazuin 2012; Law, Band, and Grove 2004; Robbins and Sharp 2008; Zhou et al. 2009)

4.5.4 *Strengths & Limitations*

Drawing on a framework of lawns as product of household emotions and decision making processes (Carmi, Arnon, and Orion 2015; Grob 1995; Harris et al. 2013; Robbins 2007) interacting within multi-scalar urban environments (Chowdhury et al. 2011; Cook, Hall, and

Larson 2012), I showed how rapidly new lawn floras and lawn care regimes develop. Because not all of the households returned the yard management questionnaire, some of the household patterns and drivers may not be as robust as the urban variables. Despite this, the household reported yard goals and lawn care regimes explained a large proportion of deviation in analyses. Thus, self-reported household data can be used to construct ecologically meaningful household drivers of diversity.

Because wealthier households are more likely to agree to participate in urban studies (Chaix et al. 2011), be homeowners (Di, Belsky, and Liu 2007), and garden (Behe 2006), my sample could be skewed to wealthier homeowners who intensively manage their lawns.

Green, weed-free lawns are highly desirable (Carpenter and Meyer 1999; Nielson and Smith 2005; Varlamoff et al. 2001) and provide evidence of care (Nassauer 1995; Sisser et al. 2016). Counts of non-turf species may represent a direct reflection of the homeowner's adherence to the traditional lawn aesthetic of having no weeds. Therefore, I chose to treat turfgrasses as a single entity, assuming that households have more concerns about lawn forbs than turfgrass identity. However, removal of lawn weeds, particularly for herbicide use, needs more refinement. Given the intensive management of households favoring *Kid Space,* it seems likely that they are promoting monoculture turfgrass communities through the use of application of lawn chemicals that include fertilizers and herbicides. In contrast, it is unclear how households who favor *Habitat* manage lawn weeds.

Unlike other studies of lawn plant communities, I used lawn patches as the vegetation sampling unit, and controlled for area, rather than traditional smaller 0.25-1 m^2 plots for herbaceous communities (e.g., (Bertoncini et al. 2012; Wheeler et al. 2017), Because residential landscapes are a system of interconnected patches (Chowdhury et al. 2011), the lawn patches themselves represent appropriate sampling units to link human decisions to lawn communities.

4.6 CONCLUSIONS

Lawns are not just the most ubiquitous urban vegetation type. They are a space of leisure and tension between personal preferences and community expectations for upkeep and appearance. Through a detailed case study of new residential lawns, I showed how new lawn herbaceous floras rapidly arise from the interaction of built environment and household preferences and management. I used multiple lines of evidence to link observed floral patterns to parcel, neighborhood, and household drivers. Homeowner preferences and lawn care regimes promote the dominance of turfgrasses, allowing few, if any, broad leaf species to persist. Residential lawns represent a very homogeneous, cosmopolitan plant community arising from intensive lawn care regimes. Few species were Pacific Northwest natives.

Because *Kid Space*, *Habitat*, and *Easy* link household preferences, lawn behaviors, and outcomes, they represent targets for urban planners and conservations to craft different strategies for reducing lawn inputs and promoting lawn alternatives. *Kid Space* seems to represent households who chose neighborhoods with large yards and have high input, large lawns. Working with homeowners in these larger lots neighborhoods to reduce water and fertilizer frequency could provide a substantial environmental benefit. In contrast, households who favor *Habitat* or *Easy* already have a less intensive lawn care regime. If interested in having some green surface, both homeowner types could be interested in more polyculture lawns that require less care and provide more wildlife habitat (Ignatieva and Hedblom 2018), but the messaging would have to be different. Homeowners who value *Habitat* are probably active gardeners and could become intrigued by evaluating and selecting appropriate non-traditional plants that are trample resistant. *Easy* valuing homeowners may be more interested in the most attractive, least labor versions. Alternatively, promoting easy to manage perennial beds and perennials may also be appropriate for both types of homeowners.

Although other researchers have examined lawn management, few have explored the links between actual household preferences, lawn care practices, and lawn diversity patterns. More work is needed to validate linkages between preferences, management, and resulting lawn floristics. Moreover, I recommend separating diversity analyses of turfgrasses from lawn forbs, because homeowners view and manage them differently.

Chapter 5. NEW PERENNIAL FLORAS REFLECT DECISIONS OF DEVELOPERS & NEW HOMEOWNERS

5.1 INTRODUCTION

Most urban vegetation consists of privately managed residential yards and gardens (Aronson et al. 2017; Goddard, Dougill, and Benton 2010; Irwin and Bockstael 2007). Given the large land area occupied by single-family residences, understanding residential vegetation dynamics in general requires a careful assessment of how yards and gardens are built and maintained. As Li et al. (2010) noted, residential landscapes "say something about the people who construct and use them." Therefore, examining their structure and composition requires consideration of the human and the biophysical drivers (Alberti 2008; Dobbs, Nitschke, and Kendal 2017) operating and interacting at multiple scales (Chowdhury et al. 2011; Cook, Hall, and Larson 2012; Pearse et al. 2018).

Urban variables linked to urban plant diversity and abundance patterns include neighborhood wealth (Clarke, Jenerette, and Davila 2013; Hope et al. 2003; Schwarz et al. 2015), housing age (Hope et al. 2003; Wang et al. 2015), and density (Bigsby, McHale, and Hess 2013; Iverson and Cook 2000; Jenerette et al. 2007; Mennis 2006; Ossola and Hopton 2018). Wealth-related metrics, in particular, have been linked with increased plant richness and abundance, while housing characteristics and density-related metrics seem to be more varied, depending on the urban system context. The "luxury effect" (Hope et al. 2003) or "ecology of prestige" (Grove et al. 2006), where wealthier people have access to more diverse and more abundant vegetation appears to result from complex interactions of individuals, land developers, land owners, institutions, and feedbacks between them (Martin, Warren, and Kinzig 2004; Lowry, Baker, and Ramsey 2011; Leong, Dunn, and Trautwein 2018). Neighborhood wealth has been linked to increased plant species richness (Martin, Warren, and Kinzig 2004; Yang et al. 2017), tree species richness (Clarke, Jenerette, and Davila 2013), cover and remotely sensed greenness (Jenerette et al. 2013; Schwarz et al. 2015).

In addition to wealth variables, other household demographic factors are associated with landscape preferences and yard management. Cultural background (Fraser and Kenney 2000), life stage and gender (Yabiku, Casagrande, and Farley-Metzger 2007; Behe and Dennis 2009), and length and type of land tenure (Summit and McPherson 1998; Behe 2006) have all been shown to influence yard preferences and gardening activities. Larson et al. (2009) related these household preferences to the desire for managing these semi-private spaces as “landscapes of leisure”. Thus, yards are designed and managed to meet household needs and preferences: spaces in which to garden, play, entertain family and friends, or relax.

To link these diverse and somewhat ambiguously defined resident preferences to specific plant outcomes, researchers have incorporated plant traits into their studies. The use of plant traits in urban residential landscape studies draws on community ecology, where specific traits are analyzed to see how plant taxa identity and abundance vary in response to biophysical patterns and processes (Suding et al. 2008; Violle and Jiang 2009). Noting the difficulty in linking common plant ecological traits to how people actually choose plants, Pataki et al. (2013) proposed to use “ecosystem traits” to link plant traits to specific benefits from plants. Some of the ecosystem service traits linked to human preferences are plant size (Hardy et al. 2000), showy flowers (Avolio et al. 2018; Hardy et al. 2000; Kendal, Williams, and Williams 2012), edible fruit (Pataki et al. 2013), leaf width (Kendal, Williams, and Williams 2012), and shade (Avolio et al. 2015; Summit and McPherson 1998). However, Conway (2016) found that people selected trees for aesthetics or low maintenance reasons, not for provisioning ecosystem services.

I build on this body of work by explicitly evaluating the different plant choices by developers and homeowners in newly built and sold residential landscapes. From an urban ecology perspective, residential vegetation can be seen as the outcome of human decisions interacting with multi-scalar processes(Aronson et al. 2016; Chowdhury et al. 2011; Pearse et al. 2018; Waddell 2002). Specifically, two diverse human agents, development firms and homebuyers, interact in the regional real estate market to meet their specific needs and goals.

The initial plant structure and composition of the new landscape reflect this process. Developers compete for and buy land, complete neighborhood and site planning processes, and obtain subdivision and building permits from the local planning authority (Kaiser 1978). The developers then install or upgrade infrastructure, build homes, and add other paved surfaces in and adjacent to the parcel. The landscaping is typically one of the last steps, along with other presale work (Rebele 1994). Depending on the location, municipalities and/or homeowners associations may specifically regulate aesthetics, planting plans, tree removal, and maintenance for subdivisions and for yards (Kim and Ellis 2009; Hirokawa 2011; Lerman, Turner, and Bang

2012; Fraser, Bazuin, and Hornberger 2015). After the new homeowners move in, they may or not update or change the initial yard configuration, remove plants, and plant more or different species.

Urban ecologists have devoted little attention to the real estate developer industry, despite the fact that "it is a highly regulated, high value industry that shapes the built environment" (Coiacetto 2006). Thus, most of the literature about residential plant communities focuses on households or neighborhoods (Cook, Hall, and Larson 2012), despite the fact that developers set the amount and configuration of growing space (Larsen and Harlan 2006; Rebele 1994; Sanders 1984) and establish the vegetation patches. These initial plant communities limit which species and life forms can establish (Egler 1954).

5.2 RESEARCH OBJECTIVES

To understand how the complex interactions of developer and homeowner decisions shape new residential floras, I focus specifically on new residential landscapes in south King County, WA. Through site visits, information from homeowners, and archival photo research, I document specific landscaping decisions in the new yards. How do developer and homeowner landscaping decisions shape the new yards? Do they plant the same types of perennials? Do they select the same or different taxa? How diverse are their selections? Are some plant species or families planted more frequently than others? Which urban variables or household preferences influence planted species diversity?

Although many researchers have attempted to link plant traits to resident choices, none of these specifically consider plant traits that are commonly recommended for choosing plants. Therefore, I reviewed a number of ways that landscape design and gardening books classify all perennials when recommending perennials. I chose Stoecklein's (2011) approach: evergreen and deciduous trees, evergreen and deciduous shrubs, groundcovers, vines, ferns, graminoids, and other herbaceous perennials. Not only does this classification align with urban ecology, plant trait, and landscape design literature, it also is consistent with how plants are displayed and marked in stores and nurseries. For example, mature height and leaf habit (deciduous or evergreen) have been found to affect tree community structure and composition in residential landscapes and are mentioned as considerations in tree preferences (Avolio et al. 2015, 2018; Summit and McPherson 1998; Tenneson 2013; Williams and Cary 2002), landscape design

(Hannebaum 2001; Stoecklein 2011) and gardening books (Brenzel 2007; Kruckeberg and Chalker-Scott 2019).

In this study, I aim to describe the patterns in perennials by source, evaluate possible urban drivers of those patterns, and then evaluate whether self-reported homeowner reported preferences influence planting decisions. I take this approach to disentangle the different decisions of two urban ecosystem engineers (Jones, Lawton, and Shachak 1994; Wu 2008) that have occurred over a short time period on the same parcel of land.

First, I describe and compare the developer retained, developer selected, and homeowner selected perennials. How large and how diverse are these species pools? What proportion is native to the Pacific Northwest? I predict that there will be structural and compositional differences in these pools. The two agents will select different types and taxa, but both will favor certain structural groups or taxa more than others.

Second, for both developers and homeowners, I test to see if there are specific urban variables linked to the diversity patterns grouped by plant buying structural groups. I predict that urban economic variables at the site and neighborhood scale will be associated with plant structural group richness. In particular, wealth-related metrics should be positively associated with increased diversity. At the site scale, these are appraised improvement value and land value. At the neighborhood scale, this is median assessed value, which includes both land and building values.

Third, I test whether expressed homeowner plant selection criteria or yard management goals are reflected in specific patterns in the homeowner planted perennials. I hypothesize that yard management goals and plant selection favoring easier to manage landscapes and species should be negatively associated with woody perennials, while those relating to providing food and wildlife habitat should be positively associated with richness. Other yard management and selection criteria may also be influential but may vary by group.

Fourth, I compare the composition and diversity of the presale and postsale plant communities. I define the presale community as resulting from developer decisions to keep specific plants on the parcel and to plant new after the house and other infrastructure is completed. The postsale community consists of plants from the presale flora that the homeowner kept, as well as new perennials that they plant. I predict that taxa diversity will increase in the postsale flora, but not for all groups.

By focusing solely on perennial plants in new yards of new homes, I identified the specific decisions of each agent and described the initial floristic conditions of these new floras. I found broad support for my hypotheses that developers and homeowners select different plant structural groups and species and that their choices reveal different preferences. Developers plant more woody perennials and graminoids, and homeowners plant more herbaceous perennials. Thus, the majority of woody and graminoids perennial abundance and richness in new yards in this sample results from decisions of developers, while the rest of the herbaceous flora more strongly reflects homeowner decisions.

5.3 METHODS

5.3.1 *Documenting Perennials*

During the growing season of 2016, I conducted a complete vegetation survey of all perennial plants within the actively managed area of the sample parcels. I defined this area as the buildable portion of the parcel, from the street to identifiable property boundaries, such as fences or sidewalks and driveways of adjacent parcels. To conduct the survey, I assigned each planting bed a unique patch number, then identified and counted all perennials within that patch.

I assigned each individual or clump of individual plants as belonging to one of three origin categories: developer retained, developer planted, or household planted. Retained perennials are those that were on site predevelopment and were retained by the developer. They typically include large trees, shrubs, and some rock wall species. Developer planted individuals are 1) planted perennials that the homeowners said were present when they bought the house, 2) planted individuals that the homeowners told me they removed, 3) planted individuals that were present in images prior to sale date and that were absent during the site visit. Household planted individuals are those that the household informed me they planted. Large native trees would be classified as retained, but their seedlings would be classified as spontaneously establishing on site and were excluded.

Because my research questions focus on developer and homeowner landscaping decisions at the parcel level, I used patches, not plots, as the sampling unit. For standard geometric shapes, my field crew and I measured patch dimensions necessary for area calculations. For irregular patches, we used the offset method (Christians and Agnew 2008). To correct for any measurement error and differences in parcel area versus sampled area, I corrected yard area and total area of each patch type via aerial photos analysis of the sampled parcels. Using measuring tools and aerial photos (King County 2017) I measured areas of the building footprint, impervious surfaces, and the remainder of the parcel that was developed. This excludes steep slopes and wetlands and irregular areas outside of fences but includes curb strips. Corrected yard area is total developed area minus building footprint and area of all other impervious surfaces.

At the time of the field survey and afterwards, I asked the new homeowners if they had added or removed plants. To obtain additional information about what plants may have been present earlier, I compiled images of the parcel before the sale (King County 2017; Google 2017; Redfin 2017).

After final plant identifications, I placed each taxon within one of nine perennial groups, following Stoecklein (2011): evergreen or deciduous trees, evergreen or deciduous shrubs, graminoids, groundcovers, ferns, vines, and all other herbaceous perennials (Appendix D). Nomenclature follows Hitchcock and Cronquist (2018) or Missouri Botanical Garden (2017). Trees are tall woody perennials that are >2m at mature height. I included *Trachycarpus fortunei* (windmill palm) as a tree, rather than other perennial monocot, because that is how it is recommended to landscapers and gardeners in the Pacific Northwest. Shrubs include woody taxa <2m in height. Graminoids are true Poaceae, as well as Cyperaceae, Juncaceae, Typhaceae, Asphodelaceae, and a subset of Asparagaceae that are recommended as grasses. Groundcovers are low growing perennials recommended for covering soil and preventing weed establishment. Ferns are members of the Dryopteridaceae. Vines have flexible stems that can be trained around supports. The other perennial group includes all remaining dicot and monocot taxa. These include perennial flowers, small herbs, and unusual genera that don't easily fit into the other categories (e.g. *Cynara*, *Sedum, Musa, and Cycas*).

5.3.2 *Household Preferences*

People select plants based on they how they want to use the yard space and specific characteristics of the plants themselves (Behe 2006; Pataki et al. 2013; Conway 2016; Tenneson 2013; Brenzel 2007; Kruckeberg and Chalker-Scott 2019). Therefore, I mailed participating households a yard management questionnaire after the site visit. In the questionnaire (Appendix A), I asked each household to rate the importance of 10 plant selection criteria and eight different yard management goals. Rated yard management goals included variables to incorporate aesthetics, ease of maintenance, and use of space. Rated plant selection criteria variables included price, ease of maintenance, and provision of food for people and wildlife, as well as more subjective criteria. Of the 60 homes in the original sample, 35 responded to my yard management questionnaire. I discarded one from further analysis in this paper, because the homeowner is related to the builder. Final sample size for household preference analyses is 34.

5.3.3 *Data Management & Analysis*

After field data entry and validation, I used R version 3.5.1 (R Core Team 2019) and specified packages for all further data manipulation and analysis.

To calculate diversity indices, I used *vegan* (Oksanen 2018). All diversity indices are in effective species number equivalents (Hill 1973; Jost 2006): richness, exponent Shannon entropy (H') and 1/Simpson. By converting them to taxa equivalents, the indices exhibit common behaviors allowing for comparing indices in an ecologically meaningful manner. To properly partition taxonomic diversity, I used the multiplicative versions of gamma, alpha, and beta diversities (Jost 2007; Whittaker 1972). Gamma diversity is the total count of unique species, genera, or families. Alpha and beta diversity are calculated twice: by mean taxa richness and mean exponent (H'). Beta is gamma divided by alpha.

I compiled and calculated variables representing urban form, gradients, land economics, and homeowner preferences (Table 5.1). Parcel variables are from on-site measurements or from King County (2016). Neighborhood variables are at the enclosing Census Block Group extent, which is commonly used in urban vegetation studies (Avolio et al. 2015; Endsley, Brown, and Bruch 2018; Schwarz et al. 2015). I calculated all estimates directly for each Census Block Group that contained a sampled yard. Homeowner preferences are a subset of responses from the the yard care questionnaire, screened to exclude correlated preferences.

To assess which urban metrics and household preferences may have influenced planted species richness, I fit negative binomial regressions. For both developers and homeowners, I fit separate site and neighborhood models for trees, shrubs, and herbs. Then, I fit full household yard and plant selection criteria models. Because of the small sample size and correlations in

Table 5.1. Independent variables by model group in negative binomial regressions of planted species richness, by category, name and characteristics.

Site Model	**Data Source and Description**
Elevation (m)	Google Maps – elevation above mean sea level
Assessed Improvement Value ($)	King County Assessor Data – value of house and buildings in 2016
Perennial Bed Area (m^2)	Corrected yard area – lawn area. Area based on field measurements adjusted by aerial photo corrections for yard area
Census Block Group Model	
Residential Density (# residences/km^2)	Calculated from King County Assessor Data, # residential units/CBG area
Median Age (years)	Calculated from King County Assessor Data; 2016-median year built all residential properties within CBG
Median Assessed Value (m^2)	Calculated from King County Assessor Data; Median improvements and land value 2016
Homeowner Yard Goals Model (All Variables From Homeowner Questionnaire) 1=Very unimportant; 5 = Very important	
Neat	Looks Neat/Tidy
Easy	Easy to Maintain
Habitat	Provides Wildlife Habitat
Food Space	Place to grow food
Kid Space	Place for children
Plant Selection Criteria Model (All Variables From Homeowner Questionnaire) 1=Very unimportant; 5 = Very important	
Unique	Is interesting or unique
Privacy	Provides privacy
Inexpensive	Is inexpensive
Low Maintenance	Low maintenance
Household Food	Provides food for household

preference variables, I used a reduced set of preferences as independent variables (Table 5.1). I used the stepAIC function (both directions) in *MASS* (Riley et al. 2018) to select possible best fitting models in multivariate regressions. I tested for spatial autocorrelation via Monte Carlo simulation of Moran's I in *spdep* (Bivand et al. 2019) and fit models with spatial lags when $p<0.1$. Numeric independent variables in the parcel, neighborhood, and household models are mean centered and divided by the standard deviation. To correct for potential model overfitting and bias resulting from small sample sizes (Hurvich and Tsai 1991; Burnham, Anderson, and

Huyvaert 2011), I calculated the corrected Akiaike Information Criterion (AICc). Final models are those with the smallest AIC_c values, which were calculated in *AICcmodavg* (Mazerolle 2019). To calculate model p values, I conducted likelihood tests of potential final models by comparing them to next simpler models.

To assess how composition and diversity changes by ownership, I created two floras. Presale flora consists of perennials present at the time of sale. Postsale flora consists of plants present at the time of site visit, excluding removed or dead perennials.

5.4 RESULTS

5.4.1 *Retained Taxa*

Total number of developer-retained taxa is 38 species, 33 genera, and 20 families (Table 5.2, Appendix D). Most of these are trees and shrubs (Figure 5.1). About 39% (15) of the species were native to the Pacific Northwest, and 61% were not. The six most frequent families are Pinaceae, Rosaceae, Ericaceae, Cupressaceae, Dryopteridaceae, and Sapindaceae (pine, rose, heather, cedar, wood fern, and soapberry families, respectively. Three of the most frequent retained species were large trees (*Pseudotsuga menziesii* (Douglas-fir), *Arbutus menziesii* (Pacific madrone), and *Prunus serrulata* (Japanese flowering cherry). The native *Polysthichum munitum* (sword fern) was the other frequent retained species. All other retained taxa occurred at two or fewer sites.

Table 5.2. Comparison of perennial sources in new residential landscapes by number of individuals, species, genera, and plant families. Six most frequent families are arranged from most to least frequent.

Source	**Individuals**	**Species (# native)**	**Genera**	**Families**	**Six Most Frequent Families**
Developer Retained	174	38 (15)	33	20	Pinaceae, Rosaceae, Ericaceae, Cupressaceae, Dryopteridaceae, Sapindaceae
Developer Planted	2483	108 (23)	78	41	Cupressaceae, Ericaceae, Cyperaceae, Sapindaceae, Poaceae, Berberidaceae
Homeowner Planted	905	134 (14)	106	60	Rosaceae, Asparagaceae, Ericaceae, Iridaceae, Lamiaceae, Cupressaceae

5.4.2 *Planting Behaviors*

Developers planted most of the perennials on each parcel (Table 5.2). About 21% of the developer pool (108 species) is native to the Pacific Northwest, compared to 10% of the homeowner pool (134 species). Of the 58 homeowners, 12 planted no perennials.

Developers and homeowners selected different types of perennials (Figure 5.1). Developers tended to plant trees, shrubs, and graminoids (Figure 5.1). Of the woody plants, developers favor evergreen species over deciduous. Homeowners selected "other herbaceous" more than any other category and showed no difference in preference for evergreen habit or for trees or shrubs when choosing to plant a woody species.

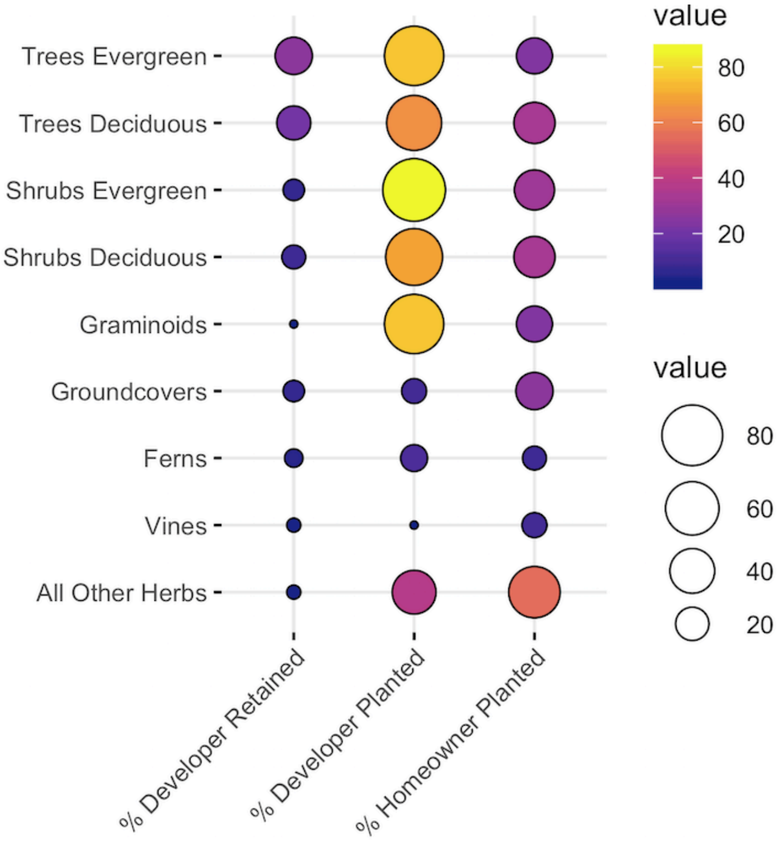


Figure 5.1. Frequency of occurrence (#/58 sites) of the nine different plant groups by source. Developer retained are those perennials that were present before development that the developer did not remove as part of the development process. Developer planted are those perennials planted by developers. Homeowner planted are those perennials planted by the new homeowners. Larger circles and more yellow colors represent higher frequencies.

5.5 URBAN DRIVERS OF PLANTED SPECIES RICHNESS

Parcel models explained the most deviation (Appendix D) for developer shrubs (10%), and all homeowner plantings (11-22%). In contrast, the neighborhood models explained more deviation for developer planted trees (9%) and herbs (19%).

For parcel models, perennial bed area and planted species richness were positively correlated for all but developer planted herbs (Figure 5.3). I detected a luxury effect for developers. Developer planted tree richness and appraised improvement value were positively correlated, as were developer planted perennial herb richness and land value.

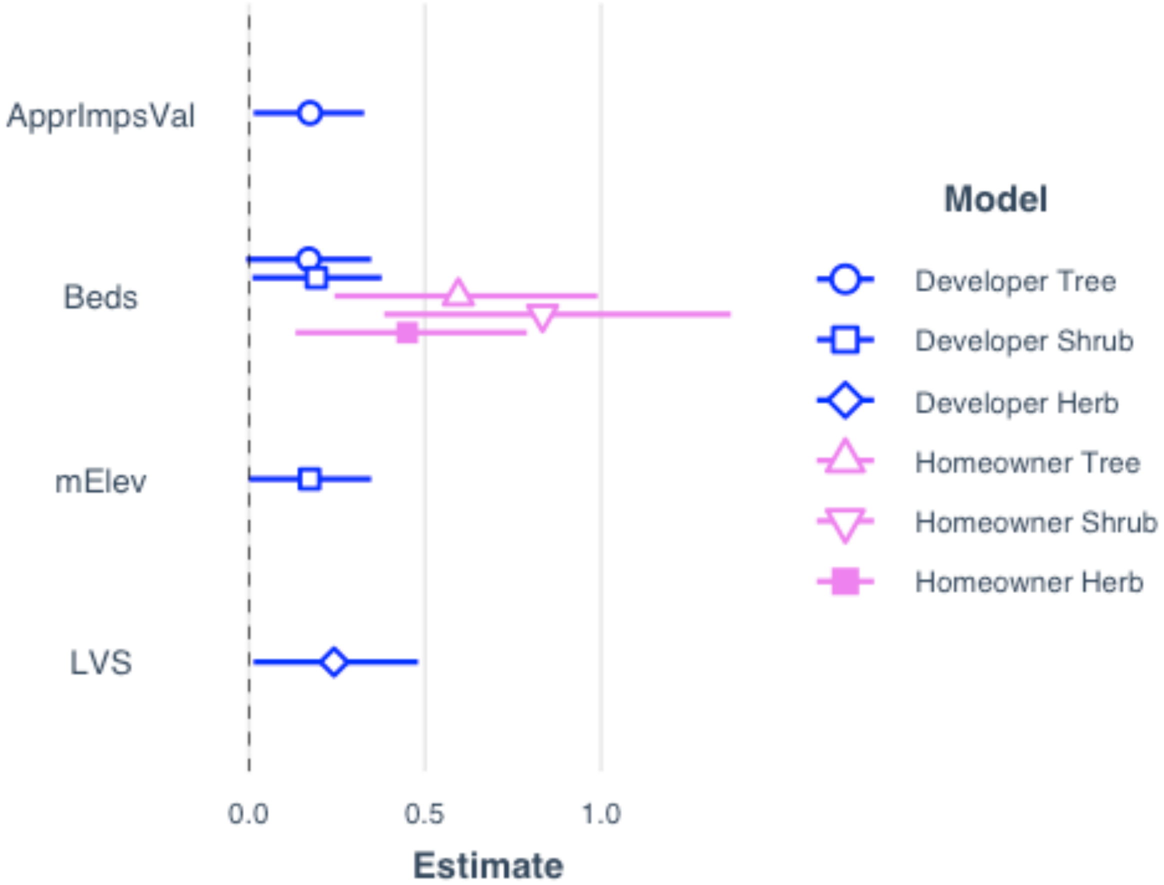


Figure 5.2. Standardized coefficient estimates for developer and homeowner planted species richness from final models based on parcel extent (Appendix D). Variable names: ApprImpsVal = Appraised improvement value; Beds = log 10 perennial bed area; mElev= elevation; LVS = land value ($/m^2 lot area) If a variable not plotted for model, then that variable was not included in the final model.

Using urban variables at the neighborhood extent, I detected a luxury effect for developer planted trees and homeowner shrub (Figure 5.3). For developers, perennial herb richness and residential density were also positively correlated.

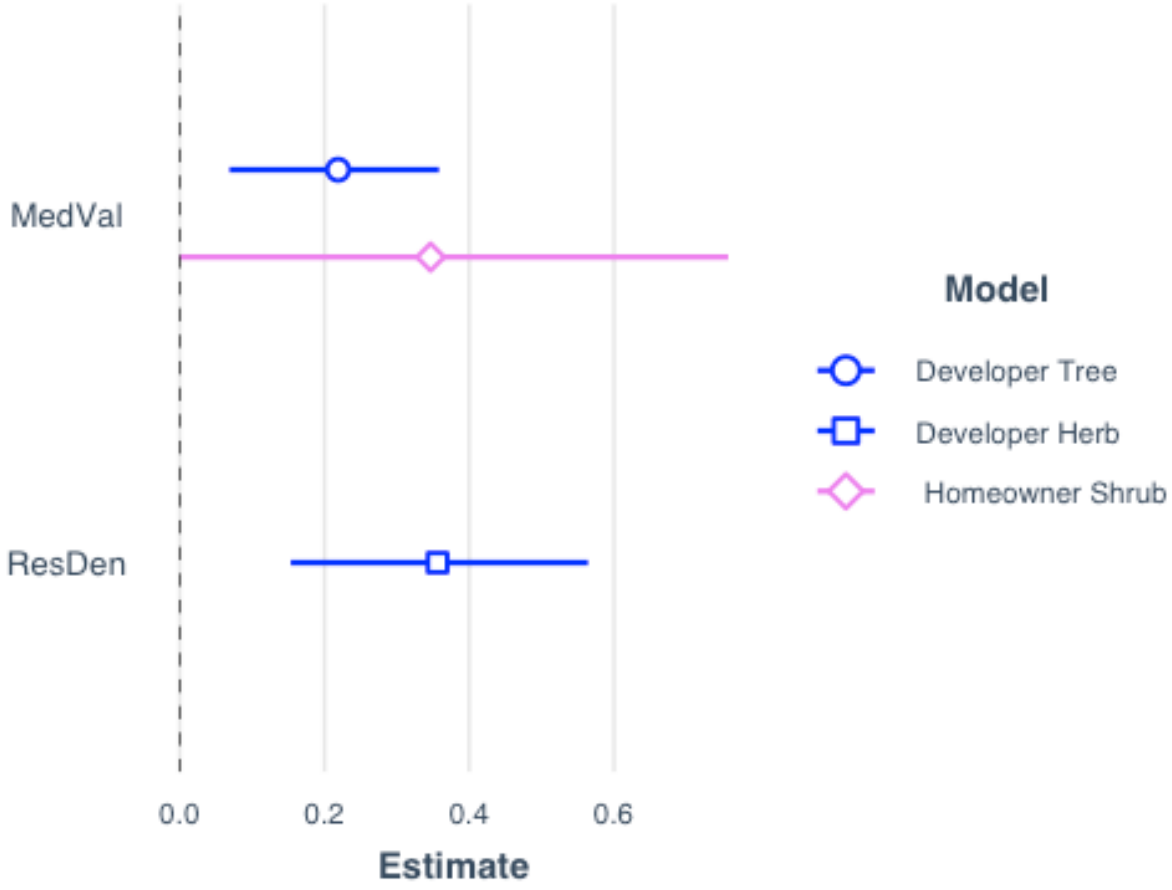


Figure 5.3. Standardized coefficient estimates for developer and homeowner planted species richness from final models based on Census Block Groups as neighborhood extent (Appendix D). Variable names: MedVal: median assessed value; ResDen = Residential Density; If a variable not plotted for model, then that variable was not included in the final model. Three models (developer shrub, homeowner trees, homeowner herbs) were intercept only and are not plotted above.

5.5.1 *Preferences as Drivers of Household Planted Species Richness*

Homeowner preferences are reflected in how many species they plant (Figure 5.4, Appendix D). For plant buying criteria models, *Unique* is positively correlated with tree, shrub, and herb richness. *Household Food* is positively correlated with shrub and herb richness, and *Inexpensive* is positively correlated with shrub richness. For yard goal models, *Habitat* was positively correlated with shrub and herb richness. *Neat* was negatively correlated with herb richness. No yard goal models predicted tree richness.

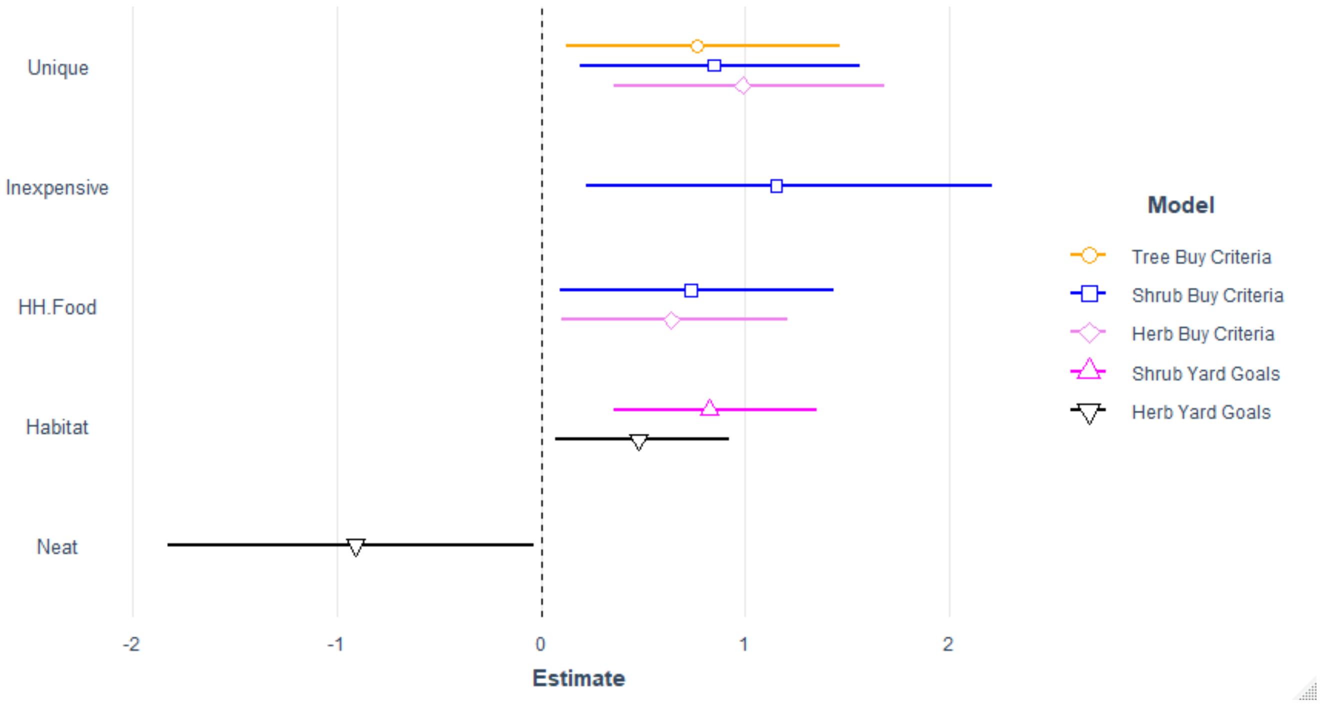


Figure 5.4. Scaled regression coefficient estimates for five final models predicting homeowner planted species richness (n=34). If a variable not plotted for a life form, then that variable was not included in the final model selected. Final yard goal model for trees was intercept only and is not plotted above.

5.5.2 *Homeowner Plant Removals*

Through homeowner conversations, site evidence, and presale photos, I documented the removal or death of 39 trees, 22 shrubs, and 46 herbaceous perennials.

About half of the trees were evergreen and half were deciduous. Nearly 75% of the removed evergreen trees were improperly planted *Thuja occidentalis* (arborvitae) or *Thuja plicata* (western red-cedar), which were dead or dying when the homeowner moved in. Five were very large native evergreen trees (*P. menziesii* and *A. menziesii)*. Removals of living trees were to address specific homeowner problems and concerns. None were diseased or hazardous. One homeowner removed three large native trees, because they were “too close to the house.”

Another reported removal of six developer-planted deciduous trees to fix a drainage problem in an otherwise inaccessible side yard. One homeowner removed a deciduous tree that was poorly sited, noting, "I got tired of whacking my head coming in from the mail."

In contrast to removing living trees to fix specific site problems, homeowners reported removing other live perennials for other reasons: they did not like the plant, or they changed how the space is used. A homeowner replaced 12 graminoids in a front planting strip with short evergreen trees and herbaceous flowers, because "they were these really gross yellow grassy things." Another removed five "weird, spiky plants." Another homeowner reported that they "hate ivy" and removed it (*Hedera hibernica*) to plant a rock wall with "something more appropriate." Two homeowners converted rain gardens to herb and vegetable beds.

In a particularly memorable case, a new homeowner removed front yard shrubs because she felt slighted by the builder. She complained that they gave her two very ugly shrubs "instead of a cool tree in the front yard." By reviewing surrounding yards with her, I determined that the landscapers had planted two variegated *Euonymus fortunei* (winter creeper) instead of *Acer griseum* (paperbark maple). She reported that her house and yard were one of the last to be built in the large subdivision and that the model home landscaping was "way better" and had "lots more plants." She plans to plant a tree to replace the ugly shrubs, but wants something "even cooler" than *A. griseum.* She said that she is still mad a year later.

5.5.3 *Changes in Composition & Abundance*

Most species in the floras have fewer than 15 individuals (Figures 5.5, 5.6). In general, woody perennial abundance changed less than that of herbaceous perennials.

*Buxus semperviren*s (common boxwood), *Thuja occidentalis (*arborvitae), and *Calluna vulgaris* (Scotch heather) were the most abundant woody perennials in both floras, ranging from about 150-250 individuals each. About 25% of the most abundant woody perennials were trees: *T. occidentalis*, x*Cuprocyparis leylandii* (Leyland cypress), *Acer palmatum* (Japanese maple), *Thuja plicata* (western red-cedar), and *Pseudotsuga menziesii* (Douglas-fir). Biggest changes in abundance of woody species were the increases of *Hydrangea macrophylla* (bigleaf hydrangea), *Euonymus* spp., *Viburnum tinus* (lauristinus), *Betula pendula* (European white birch), *Cornus serice*a spp. *sericea* (red osier dogwood), and T. *occidentalis*.

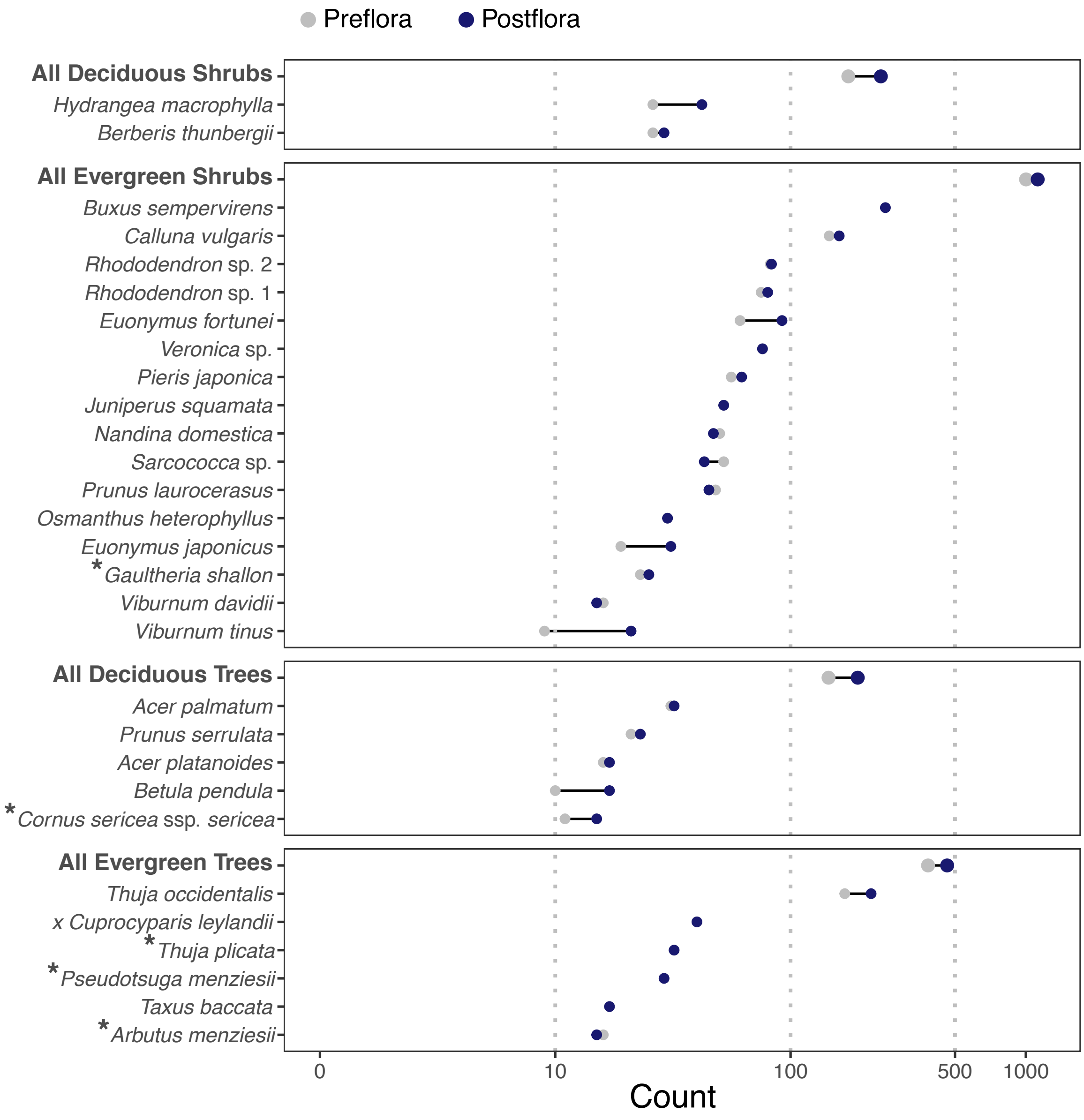


Figure 5.5. Total counts of the most abundant woody perennial taxa by flora. Dashed line represents a total count of 15 individuals, the minimum number for inclusion in the figure. Species marked with an asterisk (*) are Pacific Northwest natives.

For herbaceous perennials (Figure 5.6), most of the abundant taxa are graminoids: *Carex oshimensis* (Oshima sedge), *Festuca glauca* (blue fescue), and *Carex testacea* (orange New Zealand sedge). *Lavandula* sp. (lavender) is the most dicotyledon in presale herbaceous flora. In the postsale flora, most of the increases are groundcovers (*Vinca minor* (periwinkle); *Fragaria* x *ananassa* (strawberry)) or plants with showy flowers: *Hemerocallis* spp. (day lily), *Iris* spp. (iris), *Dahlia* spp. (dahlia), and *Hosta* spp. (hosta). Other notable increases were *Yucca filamentosa* (Adam's needle),Sedum spp. (stonecrop), and *Rosamarinus officinalis* (rosemary).

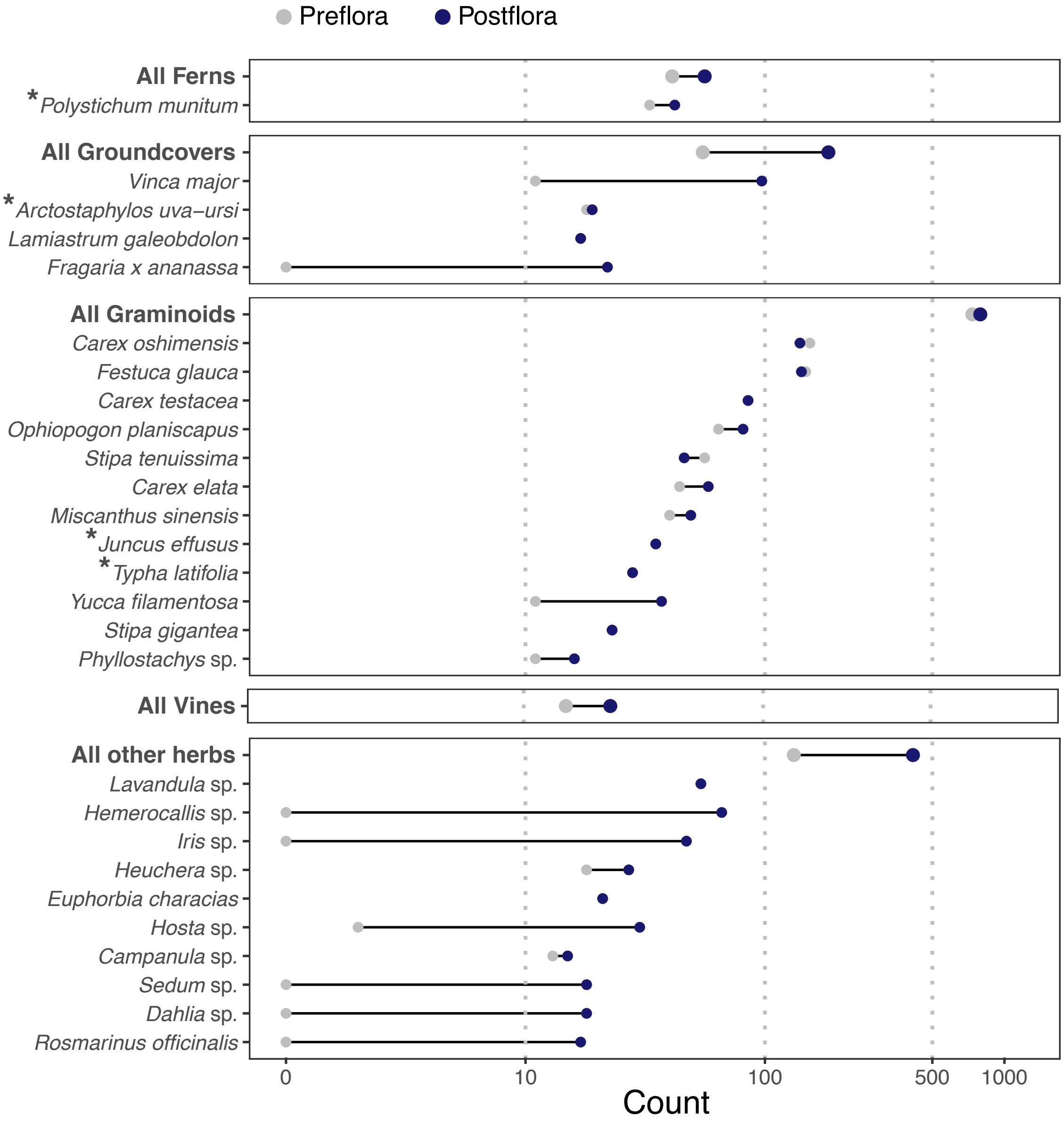


Figure 5.6. Total counts of the most abundant herbaceous perennial taxa by flora. Dashed line represents a total count of 15 individuals, the minimum number for inclusion in the figure. Species marked with an asterisk (*) are Pacific Northwest natives.

The postsale flora is more taxonomically diverse than the presale flora, increasing from 131 species in 48 families to 200 species in 68 families (Table 5.3). Total herbaceous species richness increased the most (79%). Effective species richness (ESR) for all taxa ranged about 2-10 species in the presale flora and about 3-14 species in the postsale flora. Depending on perennial group (all, trees, shrubs, or herbs), this represents a 13-59% increase in alpha diversity. Beta diversity for all taxa is 10-19 presale and 111-22 postsale. Whether using species richness or Shannon to calculate beta from gamma diversity, beta diversity is largest for tree species in both floras.

Table 5.3. Perennial diversity by flora for all perennials and for trees, shrubs, and herbs (n=58). Errors are standard deviation.

Diversity Metric	**Perennial**	**Presale Flora (#)**	**Postsale Flora (#)**	**% Change**
Gamma	Species	131	200	52.6
	Families	48	68	42.0
	Tree Species	48	67	39.6
	Shrub Species	40	57	42.5
	Herb Species	43	77	79.1
Effective Species Richness, order 0 (Mean Richness)	All Species	10.1 ± 5.1	13.9 ± 7.9	37.6
	Tree Species	3.3 ± 1.8	3.9 ± 2.5	18.2
	Shrub Species	4.2 ± 2.4	5.1 ±3.4	21.4
	Herb Species	3.4 ± 2.4	5.4 ± 3.9	58.8
Effective Species Richness, order 1 (Mean Shannon (exp (H’)))	All Species	7.1 ± 3.5	9.4 ± 5.1	32.4
	Tree Species	2.7 ± 1.4	3.1 ± 1.9	14.8
	Shrub Species	3.4 ± 1.8	4.0 ± 2.4	17.6
	Herb Species	2.8 ± 1.8	4.1 ±2.7	46.4
Effective Species Richness, order 2 (Mean 1/Simpson)	All Species	5.6 ± 2.8	7.1 ± 4.0	26.7
	Tree Species	2.4 ± 1.3	2.7 ± 1.6	12.5
	Shrub Species	2.9 ± 1.5	3.4 ± 2.0	17.2
	Herb Species	2.6 ± 1.5	3.5 ± 2.2	34.6
Beta as Gamma/Richness	All Species	12.9	14.4	11.6
	Tree Species	14.5	17.2	18.6
	Shrub Species	9.5	11.2	17.8
	Herb Species	12.6	14.2	12.7
Beta as Gamma/ exp (H’)	All Species	18.5	21.3	15.1
	Tree Species	17.8	21.6	21.3
	Shrub Species	11.7	14.3	22.2
	Herb Species	13.1	18.6	42.0

5.6 DISCUSSION

5.6.1 *Characterizing Developer Decisions*

Boone et al. (2009) noted that vegetation in newly built suburbs is more likely to be the perception of what the developer believes will satisfy buyers, rather than an expression of the neighborhood or residents' preferences. However, to subdivide land and to obtain building permits, residential developers must also comply with the local planning regulations (Kaiser 1978; Kim and Ellis 2009; Fraser, Bazuin, and Hornberger 2016). Some of these directly affect the vegetation composition and structure. Some jurisdictions, but not all, have tree protection rules, specific tree species planting requirements, and incentives for builders to manage storm water on the parcel by creating rain gardens. Other planning regulations more indirectly influence vegetation. If a jurisdiction requires specific setback distance, then a developer now has a specific front yard area to landscape. Thus, new residential landscaping needs to be good enough for sale, satisfying both planners and potential buyers, but is less likely to reflect any particular household's specific preferences.

To understand why residential developers choose "good enough" solutions, a phenomenon known as satisficing (Simon 1956), Mohammed (2006) incorporated lessons from behavioral economics (Hogarth 1991; Plous 1993; Rabin 1998), prospect theory (Kahneman and Tversky 1979; Tversky and Kahneman 1981), and mental accounting (Thaler 1980, 1985) to assess why developers might satisfice and focus on limiting costs. Broadly, given their risk aversion (Ligmann-Zielinska 2009; Westbrook 2010), relative changes in wealth are more influential in developer decision-making than absolute changes in wealth. Controlling costs after meeting predetermined project targets becomes more important than maximizing profit (Hepner 1983; Robinson and Robinson 1986; Magliocca et al. 2014). New residential landscaping, then, is more likely to be viewed as a cost to be controlled, rather than a way to increase sale price. Accordingly, many residential developers probably create the minimally acceptable landscape to meet planning regulations and expectations of target buyers.

The developer landscape satisficing decisions are a difficult to visualize legacy effect, but they lead to important outcomes in this study: 1) most of the native flora on a new parcel is from developer decisions, and 2) developers, not homeowners, are responsible for most of the woody perennials and graminoids. Because of developer preferences for evergreen trees, evergreen shrubs, and graminoids, along with a few reliable broadleaf species (e.g. *Acer* and *Lavandula* spp.), it is plausible that these perennials represent the safest, fastest way to create a finished, sellable landscape within the market in which they operate.

Other researchers have found neighborhood income to be positively associated with plant richness and abundance (Clarke, Jenerette, and Davila 2013; Hope et al. 2003; Jenerette et al. 2013; Leong, Dunn, and Trautwein 2018; Yang et al. 2017). In coining the luxury effect term, Hope et al. (2003, 8790) noted, we don't know whether "wealthier people create more diverse landscapes or simply acquire them." Newly built and sold residential landscapes, therefore, offer a unique case to answer this question. Results from this study suggest that developers do target wealthier homebuyers by planting more diverse landscapes. Although appraised improvement value increased herbaceous perennial richness, parcel density more strongly increased herbaceous richness. If limited by planting area in more dense neighborhoods, developers may replace tree richness with herbaceous perennial richness.

However, developer behavior is heterogeneous, even accounting for planted area. The fact that the urban metric models explain <20% of the deviation suggests that developer planting decision heterogeneity needs further investigation.

5.6.2 *Characterizing Homeowner Decisions*

Larsen and Harlan (2006) describe residential landscapes as realized "presentations of social class." Yards serve as transitional space, from public to personal, from the neighborhood to the household. Front yards represent the presented self, and backyards are the "personal pleasure ground." Yards are therefore managed to meet the specific needs and interests of the particular household: spaces for playing, relaxing, entertaining, and gardening. After moving into their new home, the homeowners manage and change their yards and obtain plants in ways that depend on neighborhood norms and socioeconomic status (Martin, Warren, and Kinzig 2004; Nassauer, Wang, and Dayrell 2009), household demographics (Fraser and Kenney 2000; Behe and Dennis 2009; Larson et al. 2009; Lin et al. 2017; Troy et al. 2007; Torres-Camacho et al. 2016), and how they intend to use the space (Brenzel 2007; Kruckeberg and Chalker-Scott 2019; Stoecklein 2011).

Yet, most urban residential ecology research has attempted to link observed floral diversity patterns to household socioeconomics and urban gradients created from datasets at coarser scales than the parcel or household. Commonly used neighborhood surrogates to explore patterns in residential floral diversity or household management preference are census based boundaries (Belaire, Westphal, and Minor 2015; Endsley, Brown, and Bruch 2018; Rodriguez, Peterson, and Moorman 2016) or Clarita's, Inc.'s PRIZM system (Grove, Locke, and O'Neil-Dunne 2014; Grove et al. 2006; Troy et al. 2007), which uses zip code boundaries. I did detect a luxury effect for homeowner planted shrub richness, in the form of median assessed value, which explained about 7% of the deviation. Individual household planting behaviors may not be easily predictable from coarsely aggregated socioeconomic measures. The multilevel models and the correlations suggest that household preferences and other factors more strongly influence landscaping behaviors than do urban drivers.

However, only a few studies have investigated the ways in which people's preferences actually shape residential floral composition and diversity. Researchers (Kendal, Williams, and Williams (2012), asked Australian residents which traits they used to select plants and evaluated whether expressed preferences for specific traits were reflected in their front yards. Specific plant-related traits included floral traits (flowering or not, flower size, color), leaf traits (size, shape, texture), plant form (shape, size, space filling). Resident preferences for these traits were evaluated with images of different plant species. They found that homeowner self-reported preferences for specific plant traits were weakly correlated with the actual plants in their front yards, and preferences for specific traits varied depending on which landscape type they had. Correlations were stronger for residents who had lived in the home for at least five years. Some traits used for plant selection were more related to plant management (low maintenance, drought tolerance, native) or specific useful functions (edibility, shade, screening, suppresses weeds, attracts birds, is fragrant), and others were more subjective (beauty, unusual, or personal reasons). Similarly, Cape Town, South Africa plant nursery shoppers reported selecting plants based on plant traits related to sensory appeal (appearance and scent), edibility, resource use (drought tolerance, ease of maintenance, native to area), and personal reasons relating to liking the plant, family history, or nostalgia (Goodness 2018). In Salt Lake City, UT, residents named aesthetics, shade, ease of maintenance, size and shape, and fruit as top reasons that a particular tree in their yard was their favorite (Avolio et al. 2018).

In this study, homeowners' preferences for using their new spaces were reflected in their planting decisions. Homeowners who ranked *Habitat* highly chose more diverse plantings, while ranking *Entertain, Easy,* or *Neat* highly led to less diverse plantings. Although *Habitat*, *Easy*, and *Neat* can be easily understood in terms of gardening interest, available resources, and concerns about yard appearance, *Entertain* is surprising. It could be that *Entertain* captures households who are satisfied with the overall structure of their yards and would rather use money and leisure time for socialization, rather than for gardening.

Homeowner plant buying criteria were also reflected in yards. Higher rankings of *Unique* were associated with greater species richness for trees, shrubs, and herbs. Households with higher rankings of *Household Food* and *Inexpensive* had greater species richness for shrubs and perennial herbs, but not trees. *Unique* and *Household Food* may be linked to gardening interest. *Inexpensive* suggests that price sensitive homeowners will buy inexpensive shrubs and herbs.

Understanding reasons that homeowners remove plants requires thinking about ecosystem services and disservices (Pataki et al. 2013), as well as considering how the unique household members want to use their new space or how they feel about particular plants. Removals may conflict with urban planning and conservation goals and incentives for preserving large urban trees(Ames and Dewald 2003; Le Roux et al. 2014) or managing urban stormwater via rain gardens (Ames and Dewald 2003; Tackett 2008; Walsh, Fletcher, and Burns 2012). Although developers left large trees on some parcels and constructed rain gardens on others, a few homeowners removed them soon after purchasing their homes.

The main reasons study participants removed perennials mostly related to perceived problems (death of improperly planted individuals, concerns about damage from really large trees, poorly sited trees), changing use of space, or disliking certain species. Of these, only hazard concerns could be considered an ecosystem disservice. Although aesthetic traits are commonly cited as a reason to choose plants, it is problematic to link measures of beauty to observed patterns in residential landscapes, because of survivor bias. Very ugly or particularly hated plants are removed and are therefore never detected in preference studies.

These results are similar to other studies of tree removals. In Salt Lake City, UT (Avolio et al. 2018), residents removed trees that died, were diseased, or were too big. A smaller proportion of homeowners removed trees because they didn’t like the particular species, or because they were poorly sited, was causing property damage, or required too much maintenance. Residents cited similar reasons for tree removals in King County, WA: tree health and hazard concerns, property damage, maintenance needs, and size (Tenneson 2013).

5.6.3 *Initial Composition & Abundance*

I view these floras as an example of preemptive floristics (Egler 1954; Wilson et al. 1992): whichever species and individuals are present in early stages tend to dominate, limiting the establishment and persistence of later arrivals. Therefore, whichever perennials the developer and homeowner establish initially sets the trajectory for other plant species might establish spontaneously as well as which plants someone else might plant later.

Evergreen perennials (Cupressaceae, Ericaceae, Pinaceae, Berberidacee, and Buxacaeae) and graminoids (Cyperaceae, Poaceae, Asparagaceae) dominate the floras. Other frequently represented families are Sapindaceae (*Acer* spp.), Rosaceae, and Lamiaceae. As the new homeowners began to manage their new space, they began to fill in the space according to their preferences and available resources. Thus, herbaceous perennials increased overall, as well as did the frequency of plant families with showy flowers: e.g. Rosaceae, Hydrangeaceae, Grossulariaceae, Iridaceae, and Asteraceae. Some of the frequency increase may be because the family is species rich (e.g. Rosaceae, Asteraceae), and some may be because new homeowners favor certain taxa (*Iris* spp. (Iridiaceae), *Hydrangea macrophylla* (Hydrangeaceae), *Ribes sanguineum* (Grossulariaceae).

The J-shaped abundance curve I found for all is typical for residential floras, with most taxa occurring only rarely. For example, in 328 yards in Bangalore, India (Jaganmohan et al. 2012), most species occurred in 5% or fewer of the surveyed yards; only six species occurred in more than 20% of sites. Similarly, 82% of the cultivated species in 120 gardens in southeastern France were represented by fewer than 50 individuals (Marco et al. 2008). In Trabazon, Turkey (Acar et al. 2007), 52/274 ornamental species occurred only once; only three taxa occurred at 45% or more sites: *Rosa* sp., *H. macrophylla*, and *Nerium oleander*.

Other studies of residential landscapes have found much greater tree gamma diversity (43 presale; 62 postsale vs. 109-145 species other studies) and slightly greater alpha diversity (2.3 - 3.1 vs 3.4-6.8), depending on the measure (Clarke, Jenerette, and Davila 2013; Conway and Bourne 2013; Cubino, Subirós, and Lozano 2016; Avolio et al. 2018). However, these studies represent a mix of development ages and are not easily comparable the very new yards in this study.

Although vegetation cover in my sample will likely increase over time from vegetative growth, it is unclear how much species diversity may change. Given that most of the increase in species richness from homeowner plantings is from herbaceous perennials, it seems likely that species richness of woody perennials would stay relatively stable but that species richness of herbaceous perennials may continue to increase. Summit and McPherson (1998) found that homeowners planted the most trees within the first 5 years of tenure. Planting rates for shrubs and herbaceous perennials are not well documented in the literature and need further scrutiny.

Urban species pools in general and residential landscapes in particular support a large proportion of non-native species (Groffman et al. 2014; Pearse et al. 2018). In this study, all three species pools (retained, developer, and homeowner) consist mostly of non-native perennials. The proportion of non-native taxa for the retained (61%) and developer (79%) pools is within the range found for other studies of residential landscapes, but the household selected proportion (90%) is greater than in other studies. For European yards, non-native taxa comprised 70% of the flora in United Kingdom studies (Loram et al. 2008; Smith et al. 2006), 80% in southeastern France (Marco et al. 2008), and 68-77% in Spain (Cubino, Subirós, and Lozano 2014, 2016). In Puerto Rican yards (Torres-Camacho et al. 2016), a multitude of interacting factors shape the relative frequency of native plants in residential landscapes: historical plantings, informal exchanges of plants from friends and family, natural dispersion processes, and the low availability of native plants in nurseries.

5.6.4 *Strengths & Limitations*

Although the small size limits generalizability, the sample is a drawn from a larger probability sample of newly built homes and yards. This cohort-based approach allowed investigation of the different choices that people make within the same real estate market. I chose to deliberately oversample parcels developed by small firms, in order to evaluate a variety of decisions of development firms and homeowners who choose different locations and development types across the urban gradient. Homeowners who are more interested in gardening may have been more likely to give permission, so results could be biased towards those homeowners who have an interest in plants.

The multilevel models validated the use of using plant characteristics linked to how plants are actually recommended and sold to consumers in large retail stores and nurseries. Some of these plant structure groups are commonly used in the residential landscape literature (e.g. leaf habit, height), while others relating to herbaceous perennials are not. By accounting for missing structure groups in planting decisions, I found distinct differences in developer and homeowner behaviors and preferences for certain groups overall. Because developers planted most of the woody vegetation, other urban ecology researchers should consider how they separate homeowner retention decisions from planting decisions. Otherwise, researchers may attribute urban ecosystem drivers of woody perennial composition and diversity to the wrong agent.

Because the urban drivers at the parcel and neighborhood extents explained <20% of deviations, it seems likely that individual preferences and other constraints of developers and homeowners also drive species richness patterns. Because I had homeowner preference data, I was able to find stronger predictors of household planted species richness. However, I did not have similar preference data for developers.

Removals are the most error prone of the three actions (retention, planting, removal), because they are not easy to detect. The true number of removals is likely to be larger. Plant identifications of removed plants were much better for woody perennials. Stumps were easy to see, and larger plants were more obvious in photos. Removal of woody species also seemed more memorable to homeowners, because of the effort, time, and money involved.

5.7 CONCLUSIONS

This study is one of the first assessments of how developer and homeowner decisions together shape the flora of residential landscapes. Using plant groups to reflect ways that plants are listed in gardening literature and marketed in stores and nurseries allowed me to detect distinct differences in the types of plants each agent chose. More research on new residential landscapes in other regions is needed to assess variability of landscaping decisions of the developers and homeowners.

Plant choice heterogeneity has important implications for urban planners, ecologists, and modelers, and others who seek to understand urban landscape change. First, developers are responsible for most of the woody perennials and graminoids, and homeowners are responsible for more of the other herbaceous perennials. Researchers should ask current homeowners or residents to identify which perennials they have planted and which were already present. Second, most of the native flora results from developer decisions. Conservation efforts to increase native flora on private lands may require work with stores, nurseries, and households in specific locations to increase native flora availability and desirability. Third, planning regulations and incentives in some jurisdictions led to developers retaining large trees and installing rain gardens to manage storm water on site. However, this does not mean that the new homeowners keep the large trees or the rain gardens. Urban greening goals and strategies may need to be adjusted to account for potential removals. Fourth, longer term cohort studies are needed to understand vegetation dynamics across urban landscapes and within cohort heterogeneity.

A large body of research links neighborhood wealth data to patterns of plant species richness, particularly for woody perennials. Most homeowners did not plant trees and shrubs; developers did. Therefore, it is the retention decisions of homeowners, rather than their planting decisions, driving a large proportion of woody species richness in yards. Landscaping decisions appear to be driven by how homeowners want to use their yards and how they select plants. More work is needed to understand planting decisions of developers.

Chapter 6. CONCLUSIONS & IMPLICATIONS

6.1 THEORETICAL FRAMEWORK

I investigated the emergence of new residential landscape patches and plants, by drawing on urban complexity theory and urban ecology (Machlis, Force, and Burch 1997; Pickett et al. 2001; Alberti et al. 2003; Cadenasso, Pickett, and Schwarz 2007; Liu, et al. 2007). Specifically, I view residential developers and homeowners as two distinct kinds of urban ecosystem engineers (Jones, Lawton, and Shachak 1994; Wu 2008), creating and maintaining new urban patch mosaics. The resulting patches and plant communities on single family residential parcels are the outcomes of human decisions interacting in urban ecosystem at multiple scales (Aronson et al. 2016; Cadenasso, Pickett, and Schwarz 2007; Chowdhury et al. 2011; Cook, Hall, and Larson 2012; Pearse et al. 2018).

To incorporate the relevant drivers of residential land cover patterns, plant communities, and human decisions, I incorporated elements and approaches from several disciplines: urban land economics (Harvey 1996, Dong et al. 2014, Magliocca et al. 2015), landscape ecology (Forman and Godron 1981; Godron and Forman 1983; Wu 2008; Turner 2010), real estate (Peiser 1990; Healey 1992; Coiacetto 2007; Logan and Molotch 2007; Westbrook 2010; Brown 2015; Kohlhepp and Kohlhepp 2018), and research on household preferences and decision-making (McFadden 1978; Schwanen and Mokhtarian 2005; Walker and Li 2007), urban vegetation (Sanders 1984; Hope et al. 2003; Williams et al. 2009; Aronson et al. 2016; Pearse et al. 2018), plant functional trait classifications (Diaz, Cabido, and Casanoves 1998; Bernhardt-Römermann et al. 2008; Violle and Jiang 2009; Pataki et al. 2013; Kalusová and Ecosyst 2017, and gardening (Behe 2006; Brenzel 2007; Stoecklein 2011; Kruckeberg and Chalker-Scott 2019).

6.2 RESEARCH OVERVIEW & CONTRIBUTIONS

1. I studied a cohort of 60 new homes and yards within a rapidly urbanizing watershed within the Seattle Metropolitan Area. Drawing from a stratified random sample of 1,258 parcels within the lower Green-Duwamish Watershed (Chapter 2), I used multiple lines

of evidence to reconstruct what the developers had built or installed and what the homeowners had changed, added, or removed.

2. My research expands our knowledge of urban ecology by considering how developers and homeowners and their interactions shape observable patterns on residential parcels. Developers set the template for what is possible by allocating space and by establishing the initial plant communities. The new homeowners then select a home and yard and modify those spaces based on neighborhood norms, their own preferences, life stage, and available resources. In my research, I asked three main questions: 1) Who did what? 2) Why? and 3) How do those decisions influence the observed patches and plant communities?
3. By applying both a patch and plant community approach, I show that developer and homeowner decisions are shaped by urban form variables and economic considerations measured at the parcel and neighborhood extent.
4. Homeowners self-reported preferences and management regimes appeared to be strong drivers of observed patterns in lawns (Chapter 4) and planted perennials (Chapter 5). However, the extent to which heterogeneity in developer preferences drives observed patterns is unknown.

6.3 CHAPTER 3 SUMMARY & CONCLUSIONS

New residential development is an act of patch creation, resulting from complex decisions and tradeoffs made by residential developers. As key agents of urban land transformation, residential developers can be seen ecosystem engineers (Healey 1992; Wu 2008; Brown 2015). The product is a finished house and yard. Newly created patch types include both impervious (buildings and other pavement) and pervious cover types (vegetation, mulches, rocks of various sizes, and bare soil).

I reconstructed two different decisions of residential developers operating in a single real estate market: 1) allocating space on the developed area of the lot to buildings, other pavement, and nine different yard patch types; and 2) estimating how much each developer spent on plant materials by yard and by vegetated patch type. Then, I tested whether urban form and economic factors influenced their decisions.

In making space allocation decisions, developers appeared to respond to underlying urban gradients and modify them. Developer decisions thus become incorporated into observed urban gradients. As land value increased, developers allocated a larger proportion of the developed area of the parcel to buildings and pavement. Because parcel sizes and subdivision rules relate to the underlying land rent gradient, this is expected. For yard patch types, developers appeared to consider economic values and the initial yard size in their decisions. As land value or neighborhood assessed value increased, proportion of area allocated to different patch types shifted from turfgrass lawns (*Lawn*) and mulch patch types (*Mulch*, *Gravel/Mulch*) to mixed perennial (*Mix*), tree (*Tree*), single plant species (*Mono*), and gravel/cobble (*Gravel/Cobble*) patches increased. As yard area increased, *Tree* patch allocation increased.

Developers who built more expensive homes (appraised improvement value) and/or who built in more expensive neighborhoods (median assessed value) spent more on non-lawn patches. The most expensive landscapes were an order of magnitude more costly than the least expensive landscapes.

6.4 CHAPTER 4 SUMMARY & CONCLUSIONS

Because lawns are so intensely managed to meet household and neighbor expectations for appearance and management (Robbins 2007; Mustafa et al. 2010; Fraser et al. 2013), I documented the homeowner yard goals, lawn care regimes, and the vascular flora of new residential lawns. Then, I examined possible drivers of species richness patterns, using built environment characteristics and homeowner preferences. Finally, I tested whether for correlations between drivers of species richness patterns and homeowner lawn care regimes. I found that yard goals and built environment variables influenced lawn species richness patterns.

I focused on species identity and richness of non-turfgrass species, rather than turfgrasses themselves. I assumed that new homeowners manage their lawn to maintain the new turfgrass cover and to exclude all other plant species, in order to have a uniform, weed-free appearance. Thus, the presence of other species is an indicator of how tightly the household opts into the traditional lawn aesthetic. A typical new lawn has low species richness: about 4-6 non-turfgrass species. Overall, the flora is temperate and cosmopolitan, consisting of disturbance adapted lawn species tolerant of the intensive management regime. Few are Pacific Northwest native species.

Of the 58 yards with lawns in my sample, 11 were turf-grass monocultures. I defined turf-grass monoculture yards very narrowly: every single lawn patch in the yard had to support turf-grass species only. All other yards were coded as having polyculture lawns. I found three factors that increased the probability that the yard had a turf-grass monoculture: 1) the yard was in a neighborhood with larger than average yards; 2) the homeowners reported that they value having a yard that is a place for Kids (*KidSpace*), and 3) they value having a yard that provides wildlife habitat (*Habitat*). Conversely, the probability that the yard had a monoculture lawn decreased if the homeowner reported that they valued an easy to manage yard (*Easy*).

Of the 47 polyculture lawns in my sample, I found four factors that decreased lawn species richness: 1) parcel elevation, 2) parcel improvement value, 3) neighborhood median assessed value, and 4) *Habitat*. Conversely, only parcel lawn area increased species richness.

Lawn diversity patterns result from complex interactions of households selecting their new homes and managing their yards to meet their expressed preferences. The three yard goal types appear to have different lawn care regimes and to have selected different housing types. Homeowners who value *KidSpace* have more intensive lawn care regimes, select parcels with bigger lawns, and live in neighborhoods with larger yards. Homeowners who value *Easy* and *Habitat* more appear to fertilize, water, and mow less than those who value *KidSpace*. *Habitat* is negatively correlated with lawn area and improvement value, and *Easy* is positively correlated with elevation and negatively with improvement value. The *KidSpace* pattern appears to be a standard, intensive, suburban lawn care regime, resulting from individual and neighborhood norms (Robbins 2007; Robbins and Sharp 2008; Fraser et al. 2013).

Like other researchers (Carrico et al. 2018; Law, Band, and Grove 2004; Robbins and Sharp 2008), I found that homeowners in wealthier neighborhoods applied fertilizer more frequently.

6.5 CHAPTER 5 SUMMARY & CONCLUSIONS

Developers and homeowners make specific decisions about what perennials to keep, remove, and plant in residential landscapes. To understand how these perennial floras assemble across scale, filters, and decisions (Williams et al. 2009; Chowdhury et al. 2011; Cook, Hall, and Larson 2012; Aronson et al. 2016; Pearse et al. 2018), researchers need to know what each agent typically does, as well as knowing how heterogeneous those agents and actions are across spatial and temporal gradients.

Using a cohort of newly developed perennial landscapes, I documented whether perennials were retained, developer planted, or homeowner planted. I evaluated whether developers chose different types of perennials than homeowners, and whether parcel or neighborhood variables influenced planted species richness patterns. For homeowners, I also tested whether their yard goals or plant selection criteria were reflected in their planting decisions. Finally, I evaluated how their landscaping decisions influenced the overall patterns of perennial species richness at two time periods: pre-sale and post-sale.

To test whether developers and homeowners choose different kinds of plants, I classified all perennials found in the study by origin (Hitchcock and Cronquist 2018) and plant traits as recommended to consumers. I chose Stoecklein's (2011) plant trait groups (evergreen and deciduous trees, evergreen and deciduous shrubs, groundcovers, vines, ferns, graminoids, and other herbaceous perennials). These trait groups are consistent with how garden stores and nurseries market and display perennials. They are also consistent with woody perennial traits in urban ecology literature (e.g., Summit and McPherson 1998; Williams and Cary 2002; Tenneson 2013; Avolio et al. 2015, 2018). Then, I reduced groups down to trees, shrubs, and herbs to look for links between planted species richness.

Most of the native perennial flora results from developer decisions. Native perennials are most frequently either retained species (trees and ferns) or planted by developers. Homeowners plant natives very infrequently. Developers plant more woody perennials and graminoids than homeowners who tend to plant more herbaceous perennials. Neither group plants many vines.

Planting area influenced planting decisions for developers and homeowners. Developer planted tree and shrub species richness, but not that of herbs, is greater if planting areas are larger. Homeowners responded to larger plantable areas by increasing planted richness for trees, shrubs, and herbs.

Both developers and homeowners exhibited planting behavior consistent with the luxury effect (Hope et al. 2003), where wealthier households or neighborhoods have more plant species richness, particularly for woody perennials (Clarke, Jenerette, and Davila 2013; Schwarz et al. 2015; Yang et al. 2017). Developers of higher value homes (parcel appraised improvement value) appeared to plant more diverse mixes of trees. If land values were higher, then developer planted perennial herb richness was higher. In more expensive neighborhoods, developer tree richness and homeowner shrub richness was greater.

Homeowner planting decisions appear to be driven self-reported preferences for how they want to use their yards and how they select perennials to buy. A high ranking of providing wildlife habitat (*Habitat)* and homeowner planted richness for trees, shrubs, and herbs were strongly positively correlated. In contrast, wanting a neat-appearing yard (*Neat*) and planted herb species richness were negatively correlated. In terms of planting criteria, wanting plants that are unique or interesting (*Unique*) increased planted species richness for all groups. Higher rankings of inexpensive plants (*Inexpensive*) and providing food for the household (*Household Food*) also increased species richness for shrubs and for herbs.

Homeowners reported many reasons for removing plants. For woody species, removed plants were poorly planted, prevented access, or were too close to the house. Homeowners removed herbaceous perennials, because they did not like the species or because they wanted to change how they were using the space.

As a result of developer decisions, a few evergreen and graminoid plant families dominate the floras, along with a few deciduous woody families. As the new homeowners plant more species, herbaceous perennial richness increases, particularly those from plant families with showy flowers. In general, species richness is lower than other studies of residential landscapes. It is unclear if the lower diversity is only because the yards are all new. The developers may be choosing from a limited palette of species reliably available in the needed quantities,. Alternatively, they may be so price sensitive and risk averse, that they are satisficing (Mohamed 2006; Simon 1956) in their landscaping decisions by standardizing on a landscape that is not too expensive but is good enough to meet buyer expectations and planning regulations.

6.6 OVERLAPS IN APPROACHES & FINDINGS OF EACH EMPIRICAL STUDY

I chose patches and parcels as my observational units, because developers and homeowners actively create and manage residential patches on individual patches and parcels. I sought to link management activities and preferences to observed patterns, whether the patterns are observations of patches (Chapter 3, Developer Patches), spontaneous flora of a particular patch type (Chapter 4, Lawns), or retained or planted perennials (Chapter 5). Within a single parcel, vegetated patches can contain considerable plant diversity, are of very different sizes (depending on patch type), and are often irregularly shaped. Larger yards may have more patch types (Smith et al. 2005). Moreover, patches are not randomly located within yards (Richards et al. 1984, Daniels and Kirkpatrick 2006, Brenzel 2001). Therefore, I decided that vegetation plots and transects were not appropriate for my research questions.

In fact, placing plots or transects is particularly problematic in residential landscapes. Traditional vegetation plots and transects are either placed systematically or randomly within the area to sample (Gayton 2013, Stohlgren 1998), placed along an environmental gradient (Whittaker 1967; Ludwig and Cornelius 1987), or placed in a location that consists mostly of homogeneous vegetation (Whittaker et al. 1979; Shmida 1984, Stohlgren 1998). The structure of residential parcels often makes traditional placements such approaches difficult or infeasible for four main reasons: 1) the central location of buildings and large areas of impervious surfaces within the parcel makes the systematic or random placement of plots and transects impossible; 2) standard size plots and transects do not easily fit in irregularly-shaped and -sized patches and yards; 3) no clear and reliably present gradients inside residential parcels; and 4) residential vegetation is not homogeneous.

To assess how the built environment influenced observed patches, lawn floras, and perennial floras, I tested whether urban variables at the parcel or neighborhood extent were correlated with the patterns that I observed. In all three studies, I found results consistent with the *luxury effect* (Hope et al. 2003, Leong et al. 2018). Developers who constructed more expensive homes spent more on non-lawn vegetation patch types (Chapter 3) and planted more perennial species (Chapter 5). Homeowners who purchased more expensive homes actively reduced species richness in lawns (Chapter 4) but promoted it in their shrubs (Chapter 5).

In Chapter 4 and 5, I evaluated homeowner self-reported preferences as potential drivers of plant community composition. In both chapters, I found that yard goal models explained more deviation in species richness patterns than did urban variables. In particular, I found *Habitat* (provide wildlife habitat as a yard goal) to appear to influence floral species richness. However, the pattern for lawns was different than that of homeowner planted perennials. Valuing *Habitat* was negatively correlated with lawn species richness but positively correlated with homeowner planted perennial species richness.

6.7 RESEARCH LIMITATIONS

Although the small sample size (n=60) limits generalizability, I did select sites via a stratified random sample, which allowed me to produce unbiased estimates (Lumley 2010) of certain parameters of interest: developer land covers and plant spending (Chapter 3) and perennial species diversity (Chapter 5). I chose to deliberately oversample parcels developed by small firms, in order to evaluate a variety of decisions of development firms and homeowners who choose different locations and development types across the urban gradient.

Because wealthier households are more likely to agree to participate in urban studies (Chaix et al. 2011), be homeowners (Di, Belsky, and Liu 2007), and garden (Behe 2006), my sample could be skewed to wealthier residents within the study area.

Only 35/60 homeowners returned the yard questionnaire (Appendix 1). Despite this, homeowner preferences appeared to strongly shape the lawn (Chapter 4) and perennial (Chapter 5) plant communities. Creating a simpler questionnaire focusing on preferences and management might have increased the response rate.

Although I had preference data for homeowners, I had none for developers. I found that homeowner preferences strongly influenced the plant communities, and I suspect that developer preferences (other than land values and controlling costs) are also important.

6.8 CHALLENGES & OPPORTUNITIES OF WORKING IN RESIDENTIAL LANDSCAPES

I encourage urban ecologists to think specifically about the challenges of working in urban systems at all phases of the study: site selection, obtaining permission, collecting and managing data, and reporting results. Unlike more traditional wildland ecology studies, where potential sites are typically managed by public land management agencies, working on private property in urban ecosystems brings with it a whole host of ethical, logistical, and scientific challenges (Dyson et al. 2019). Research designs that fail to incorporate the human element may anger residents, endanger researchers, fail to detect rare or less common species, may mischaracterize vegetation patterns, or may fail to consider the underlying human values and management creating the observed patterns.

Homeowners and residents are the main land managers of residential systems. To obtain a sample size of 60 different parcels owned and managed by 60 different homeowners, I asked

209 homeowners for permission (Chapter 2). I had to be very thoughtful about my parcel sampling strategy and develop a tracking system for responses. I had originally planned to sample 100 parcels, with 25 parcels/strata. Low response rates in some strata made that unlikely. So, I dropped my numbers to 15 per strata. I also switched to in-person requests for permission. Because I went down the selection list in recruiting sites by strata, drive trips were not grouped geographically. I had to drive back to neighborhoods where I had been earlier in the day. Before granting permission, several homeowners wanted to make sure that I would not dig holes in the yard, core trees, or otherwise injure plants. Although I was interested in plant-water relations in yards, conducting predawn water potential measurements seemed neither possible nor safe. Instead, I decided to ask homeowners how often they watered by season.

Researcher preparation and identity matter when dealing with people in urban ecology fieldwork (Dyson et al. 2019). Researchers with different backgrounds will have different experiences in accessing private urban space and working there safely. The majority of my interactions with people while doing field work were positive. I dressed in a bright orange field vest, carried university business cards with my contact info, and had a letter explaining my research. For more than half of the field work, I was on crutches from a stress fracture. I had many conversations about crutches, my recovery process, and the wisdom of doing field work with mobility challenges. Two neighbors were suspicious and repeatedly asked me if I had permission and when I was going to be done. Another called neighborhood security (not police) on me. I had to explain myself, my work, and demonstrate that I had permission. Luckily, I was able to do so. In my fieldwork planning, I standardized on carrying homeowner contact information and a signed permission card with me for each place I worked.

Fieldwork plans depended on traffic patterns, homeowner schedules, and comfort with me being in private spaces (their comfort and mine). How much fieldwork I could get done in one day was not dependent on how hard or long I was willing to work. Going to and from field sites required specifically accounting for commute patterns and checking for accidents. Most homeowners wanted to be present during site visits, and I wanted to talk to them about their yards and yard management. A few would not allow access until all adults were home. I always asked whether they had dogs. If so, I requested that the dogs not be in the yard with me, for the animal’s safety and mine. In my trunk, I always carried extra shoes and a bag for dog waste soiled field shoes.

Homeowners are more than study participants. Asking permission made me realize that the individual homeowners are the ultimate customers of my research at the parcel scale. Many wanted to know more about their yards and how their yards compared to others in the study. In a typical wildland system, the ecology researcher would provide study results back to the land manager, which is typically only a single agency (or perhaps a few agencies). In urban systems, a large proportion of the land is privately owned and managed. I have 60 individual land managers who have their own values and preferences. Urban scholars and planners need to think carefully about the many different reasons why households may or may not grant access. What incentives or disincentives do they have for participating? What information do they need or want? How should the researcher best provide such information?

Working in yards was a tremendous opportunity for me to engage with homeowners, their children, and their neighbors in research. Adults and children wanted to know what I was doing, why, and how. I tailored my message, depending on who was asking. Participating homeowners took pride in their yards, explained what they had done, which plants they planted, and why. For example, one homeowner explained that the roses they planted were from cuttings from their grandparents' yard. Most people wanted to know how their yards compared to others in my study. When I explained that I wanted to know what the developers had done, some took the opportunity to complain about the many ways in which the developers had done a poor job in installing the initial landscaping. From these complaints, I learned that new homeowners deeply resented ugly yards, dead/dying trees and shrubs, too much mulch, and cheap plants. Two homeowners of redeveloped parcels showed me where the developer had laid fresh turfgrass sod over previous concrete. Unsurprisingly, these lawns died.

These homeowner conversations gave me the idea to reconstruct the developers' investment decisions, given developers' tendency to focus on controlling project costs (Mohammed 2006). Is landscaping a cost to be controlled? I decided to think specifically about developer plant spending and not just focus on plant choices, traits, and species richness. The perennial plant spending analysis (in Chapter 3) is a direct result of rethinking my plant ecology approach and learning from interacting with the new homeowners. How might one detect a "cheap" landscape, which many homeowners deeply resented?

6.9 IMPLICATIONS FOR PLANNING

Managing urban ecosystems is not simple. Urban planners and decision-makers aim to make urban development and infrastructure decisions in the public interest, to ensure the health and well-being of residents, and on the basis of principles of design and natural resource protection. To understand and mitigate negative effects of development, urban planners, conservationists, and researchers will need to continually monitor the changing urban landscape and adjust plans accordingly.

By closely examining new residential land cover, I provided empirical evidence of the outcomes of residential land use plan implementation across multiple jurisdictions within the study area. Excluding roads, each newly developed parcel generates about 276 m^2 of impervious surfaces and 115 m^2 of lawn. These residential land covers prioritize human uses, providing little space for other species. Developers appear to target wealthier homeowners with more diverse and expensive yard patches and plants (Chapter 3, Chapter 5). Wealthy households actively manage plant heterogeneity to reduce it in their lawns (Chapter 4) and promote it in their perennials (Chapter 5).

Urban greening goals and strategies need to be carefully considered and possibly adjusted to these newly created urban forms and to account for behaviors of both developers and homeowners. Developers plant most of the woody species and native plants. Homeowners tend to plant herbs and few native species. However, I have shown that the vast majority of the lot provides very little habitat or planted species diversity. The fact that the *luxury effect* was detected in both developer and homeowner decisions in very young urban landscapes represents an explicit equity challenge for planners to consider. Do these behaviors change desired functions, or are they purely wealth signifiers? Which are the planning goals - increasing woody species diversity, increasing woody plant abundance, or increasing shade?

Although developers retained large trees and installed rain gardens on some parcels, some homeowners removed them. Conservation efforts to increase native flora on private lands may require several different strategies: working with landscaping firms who subcontract with developers, evaluating plant materials at stores and nurseries, and working within specific neighborhoods to promote the benefits of native plants to homeowners.

Because *Kid Space*, *Habitat*, *Entertain*, and *Easy* link household preferences and yard management to observed floral patterns, they represent ways for urban planners and conservationists to craft different strategies to appeal to specific types of homeowners. For example, households who reported valuing *Kid Space* appear to have a more intensive lawn care regime than do households valuing *Habitat* or *Easy*. Conservation efforts focused on lawns and lawn care should have different messages and approaches for households with the different yard goals. Messages to *Kid Space* households should focus on helping them to develop a less intensive lawn care regime that relies on fewer chemicals. I also suspect that *Kid Space* households probably use more herbicides than do the other two household types, given their already intensive lawn care regimes. In contrast, both *Habitat* and *Easy* households may be more responsive to efforts that promote lawn polycultures that provide nectar sources and are easier to maintain than traditional turfgrass monocultures.

6.10 Future Research Directions and Questions

To understand patterns of residential land cover and plant communities in particular, urban ecologists need to explicitly represent in studies and plans the key agents of pattern formation: developers and residents. On a newly developed residential parcel, developers set the template: site and construct the buildings and pavement, and layout and install the features of the yard. New homeowners may or may not alter that original template, depending on their resources, values, and interests (Behe 2009). In a heterogeneous urban environment, we cannot assume that observed variation in land cover is from age effects or from land use alone. If neighborhoods of different ages have different morphology or plant community structures, is it age alone? How are we linking neighborhood age to human decisions and preferences? What about effects of different developers, different homeowner values, different planning regulations, different home and yard fads, or some combination of all of these? To better understand the effects of time, spatial heterogeneity, and urban plan implementation, more cohort studies by land use class are needed.

Rather than rely solely on only on aggregated urban form and socioeconomic data to understand patterns of residential landscapes, urban scholars should also ask developers and residents about their values, preferences, and yard care practices. Other than risk aversion (Mohamed 2006; Peiser 1990; Westbrook 2010), we know little about developer preferences.

More work is needed to understand developer preferences in the urban ecology and urban planning literature. I found that plant material cost appeared to matter to developers, as would be predicted by developers controlling costs (Mohammed 2006), targeting specific home buyer types (Coiacetto 2006, 2007), and the *luxury effect* (Hope et al. 2003). Developers of the most expensive homes spent more money on non-lawn plant patches. More traditionally, researchers have attempted to value landscaping by examining home sales and disaggregating features of the yard from other home attributes to estimate price (hedonic models), or they asked consumers how much more they would be willing to pay for different simulated landscaping features compared to the base model (conjoint analysis). Other researchers should attempt to replicate actual costs as I did: identify all the perennials, reconstruct who planted them, and then estimate total spent. Having these results for other U.S. markets, other countries, and non-temperate biomes would help us look for similarities and differences in behaviors, given different incentives and plant materials.

To link homeowner preferences to species richness, actual amount spent on plants, or time spent on yard work, other researchers could also repeat elements of my studies. Reuse the strongest self-reported predictors of perennial and lawn floristics to develop a much simpler, focused questionnaire. Recruit a cohort of homeowners, identify which perennials they planted, and estimate total amount spent on plant materials. Some of the homeowners I interviewed still had receipts and nursery tags for the plants they purchased. Vegetation patterns in lawns (Chapter 4) and perennials (Chapter 5) strongly reflected homeowner self-reported preferences. Homeowners who rated *Kid Space*, *Habitat*, and *Easy* differently had different lawn care regimes. *Habitat* was also a strong predictor of homeowner planted species, as was Unique (choosing plants that are Unique or Interesting). We don’t know whether or not these preferences are true in other urban areas or for yards of different ages. Do these preferences change over time as the household or neighborhood demographics change?

Kid Space and *Habitat* households were more likely to have turfgrass monoculture lawns. Given their weed-free lawns, herbicide application seems likely but contrary to their self-reported values. Although I asked homeowners whether they applied herbicides, I was unable to use these data for further analysis. Most households reported no herbicide use. However, several of these also reported applying a product that contained both fertilizer and herbicide to their lawns. Understanding actual use may require a multi-prong approach: providing a list of specific products, conducting an inventory of yard products with the homeowner, and/or collecting soil samples to test for the presence of a suite of commonly applied products.

For all three studies, understanding actual patterns I observed in urban systems required collecting and analyzing both qualitative and quantitative data. I interviewed the homeowners about what they had done and why, and I described the resulting plant communities. Using their responses, permit data that I could obtain, and real estate photos, I reconstructed what the developers had done. I believe that the individual decisions of developers and homeowners are different enough that they should be analyzed separately in residential landscape studies. Urban ecosystem frameworks (Chapter 1) need to begin to account for behavioral differences in urban ecosystem engineers (Jones, Lawton, and Shachak 1994; Wu 2008) and not just view people as interchangeable agents of urban disturbance (Grimm et al. 2017).

Teasing apart who had done what allowed me to demonstrate that developers, not homeowners, were responsible for the increased tree species richness in more expensive neighborhoods. Although the luxury effect in urban trees has been well documented across multiple cities (Leong et al. 2018), no one else had considered whether developers might be responsible, despite the fact that they build the majority of neighborhoods and homes in many of the urban areas we study.

Paying attention to pattern, not just species counts by life form, also me to recognize the unusual, near ubiquity of *Hypochaeris radicata* (spotted cat's ear) in study area lawns. Although this cosmopolitan, weedy species is present in other lawn studies, it is nowhere else as frequent or abundant. More observations and analyses combining potential human and ecosystem components and drivers are needed to determine why.

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APPENDIX A. YARD MANAGEMENT QUESTIONNAIRE

Thank you for participating in our new home yard study. Answers to these 18 questions will help us understand how homeowners manage the “average” new yard in western Washington. Please have the person/people in your household who are most responsible for the yard answer the questions. You may decline to answer any question. For most questions, you should be able to answer immediately. You may need look up a yard product brand.

Your Yard, Plants, and Maintenance - We’d like to know what you do in your yard and how often you do these activities.

1. Where do you buy plants? Circle all that apply, and add other places if needed.

Home Depot
Lowe’s
Furney’s
Flower World
Molbak’s

West Seattle Nursery & Garden
Rosso Gardens
Walmart
Fred Meyer

Other:

2. Do you have to comply with a homeowner association’s yard standards?
Yes No

3. Please circle the importance of the following yard management goals.

Goal	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Looks beautiful	1	2	3	4	5
Looks neat/tidy	1	2	3	4	5
Easy to maintain	1	2	3	4	5
Provides wildlife habitat	1	2	3	4	5
Place to grow food	1	2	3	4	5
Place to entertain	1	2	3	4	5
Place for children	1	2	3	4	5
Place for pets	1	2	3	4	5
Other:	1	2	3	4	5

4. Please circle the importance of the following plant selection criteria.

Goal	**Very Unimportant**	**Unimportant**	**Neither Important Nor Unimportant**	**Important**	**Very Important**
Looks beautiful	1	2	3	4	5
Is unique or interesting	1	2	3	4	5
Provides privacy	1	2	3	4	5
Important to my family, previous home, culture	1	2	3	4	5
Is inexpensive	1	2	3	4	5
Provides food for household	1	2	3	4	5
Provides nectar for birds and butterflies	1	2	3	4	5
Provides other food for wildlife	1	2	3	4	5
Low maintenance	1	2	3	4	5
Drought tolerant	1	2	3	4	5

5. Mark your typical planting work at this property by how often you perform them. Circle the most active planting season(s).

	Fall, Winter, Spring, Summer	**1x per week or more**	**2-4x per month**	**1x per month**	**1x per season**	**1-3x per year**	**Never**
Example: Plant Seeds	**F W [✓ Spr] Sum**		**X**				
Plant seeds	**F W Spr Sum**						
Plant new vegetables	**F W Spr Sum**						
Plant new shrubs	**F W Spr Sum**						
Plant new trees	**F W Spr Sum**						
Re-seed lawn	**F W Spr Sum**						

6. Mark your typical maintenance work at this property by how often you perform them. Circle the most active maintenance season(s).

	Fall, Winter, Spring, Summer	**1x per week or more**	**2-4x per month**	**1x per month**	**1x per season**	**1-3x per year**	**Never**
Example: Hand Weed	**F W [✓ Spr] [✓ Sum]**	**X**					
Hand weed	**F W Spr Sum**						
Weed whack	**F W Spr Sum**						
Apply herbicides	**F W Spr Sum**						
Add compost or organic matter	**F W Spr Sum**						
Fertilize lawn	**F W Spr Sum**						
Fertilize other plants	**F W Spr Sum**						
Mow	**F W Spr Sum**						
Edge	**F W Spr Sum**						
Harvests produce	**F W Spr Sum**						
Cut dead plants/plant parts	**F W Spr Sum**						
Prune	**F W Spr Sum**						
Rake/remove leaves	**F W Spr Sum**						

7. Circle how often and how you water your lawn. If you do not have a lawn, circle n/a. N/A

Spring Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never

Summer Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never

Fall Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never

Winter Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never

Circle water system: Irrigation system Hose Other:

8. If you fertilize, what kinds/brands do you apply? Write brand names or write n/a if you answered “Never” in question 5 or if you don’t have that planting type.

Lawn	Vegetables/Fruit	Other Plantings

9. Circle how often and how you water your trees, shrubs, and other plants.

Season	**Trees & Shrubs**	**Other** plants (not trees, shrubs, or lawn)
Spring	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never
Summer	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never
Winter	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never
Fall	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never	Daily 2-3x/week 1x/wk 2-3x/month 1x/month 1x/season Never

Circle water system: Irrigation system Hose Other:

10. If you use herbicides, what kinds/brands do you apply? Write brand names or write n/a if you answered “Never” in question 5.

Lawn	Vegetables/Fruit	Other Plantings

About You - We’d like to ask a few questions about you and your household members.

11. Please enter information about all household members and pets.

# Adults	**# Children**	**# Dogs**	**# Cats**	**# Other**

12. Of the people in this household who do yard work, what is their age, gender, and highest level of education?

Person	**Age**	**Gender**	**Highest level of education?** 1 = No High School Diploma 2 = High School Diploma 3 = Some College 4= Associate Degree 5 = Bachelor Degree 6 = Graduate Degree
1			
2			
3			
4			
5			
6			

13. What is the zip code of the residence you lived in previously? If you lived outside of the United States, please provide the city/town name and country.

14. Of the people above, who does the following planting jobs? Estimate the percent work that person does. If you hire someone for the task, please write "HIRE" and estimate percent. Write N/A if it does not apply to your yard.

Person	Makes plant purchases	Designs landscape/decides where to put plants	Plants seeds, bulbs, annuals, small perennials	Plants pots and containers	Digs deep holes, plants large shrubs, trees
Example 1: 2:	70% 30%	50% 50%	N/A	0% 100%	HIRE 100%
1					
2					
3					
4					
5					
6					

15. Of the people above, who does the following yard jobs? Estimate the percent work that person does. If you hire someone for the job, please write "HIRE" and estimate percent.

Person	Waters by hose or with a water can	Manages irrigation system	Harvests produce	Removes dead plants and small plant parts	Applies fertilizer or herbicide	Applies mulch or compost	Mows, edges, runs chain saw or other power tools
Example 1: 2:	N/A	70% 30%	N/A	50% 50%	0 100%	HIRE 100%	HIRE 100%
1							
2							
3							
4							
5							
6							

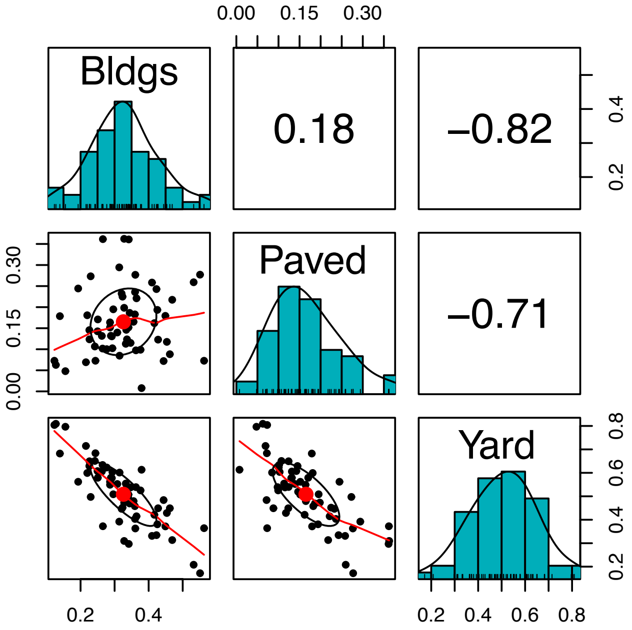
16. Please circle your yearly household income, before taxes.

Less than $50,000
$50,000 - $99,999
$100,000 - $149,999
$150,000 - $199,999
$200,000 - $249,999
$250,000 - $299,999
More than $300,000
Prefer not to say

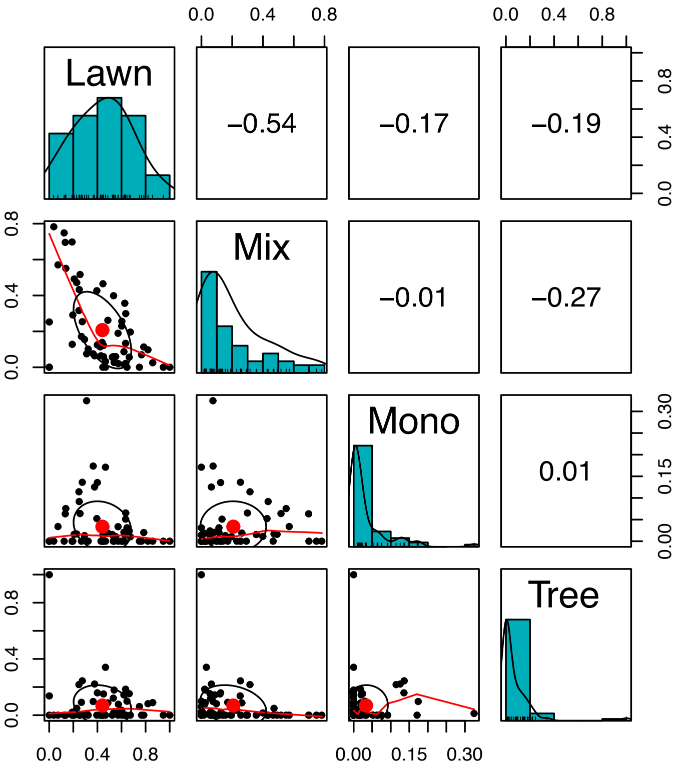
17. Is there anything that the builder did in the yard that you would like to tell us about? (Yard likes/dislikes, species planted, use of gravel or bark, plants that died, other)

18. Is there anything else that you would like to tell us? (More detail about your yard, the plants in your yard, your current yard management, future yard plans, other)

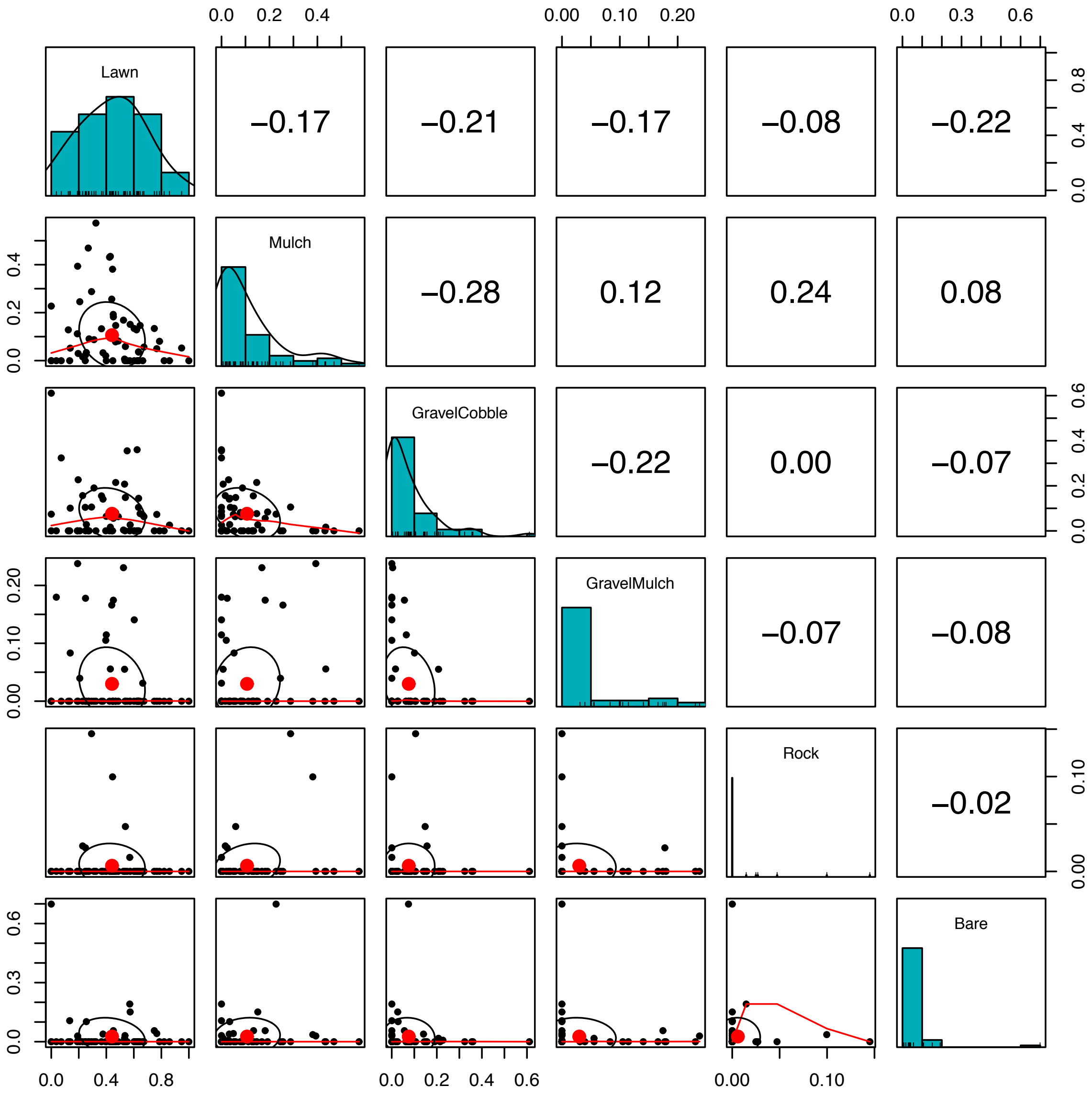
APPENDIX B. DEVELOPER PATCH SUPPLEMENTARY INFORMATION



Appendix Figure A1. Developer space allocation decisions for built patches. The scatterplot matrix (Revelle 2019) presents histograms and density curves for the patch types, as well as fitted regressions, correlation ellipses, and Pearson correlation coefficients between the patches.



Appendix Figure A2. Developer space allocation decisions for vegetated yard patches. The scatterplot matrix (Revelle 2019) presents histograms and density curves for the patch types, as well as fitted regressions, correlation ellipses, and Pearson correlation coefficients between the patches. Patch types: *Lawn* = turfgrass lawn; *Mix* = mixed perennials; *Mono* = single, short stature perennial; *Tree* = majority of vegetation is developer retained or developer planted woody species <2m tall.



Appendix Figure A3. Developer space allocation decisions for lawn and non-vegetated yard patches. The scatterplot matrix (Revelle 2019) presents histograms and density curves for the patch types, as well as fitted regressions, correlation ellipses, and Pearson correlation coefficients between the patches. Patch types: *Lawn* = turfgrass lawn; *Mulch* = wood chips, bark, mulch, or sawdust; *Gravel/Cobble* = gravel and/or cobble; *Gravel/Mulch* = narrow strip of gravel and mulch used for edging; Rock = rock walls or boulders; and *Bare* = bare mineral soil.

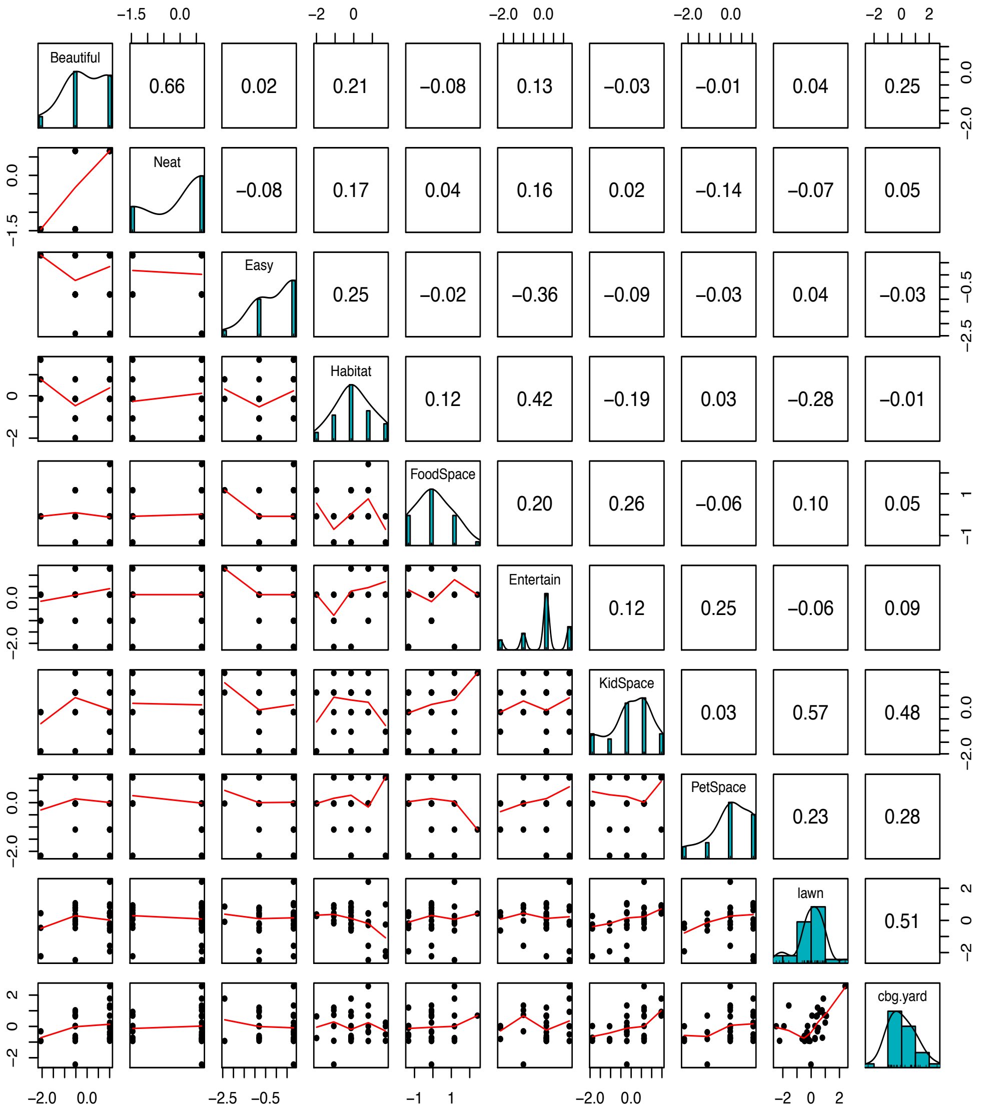
Appendix Table A1. Vegetated yard patch cost model selection overview. Final model italicized. All models negative binomial to account for right skew. AICc = Akaike Information Criterion corrected for small sample size. P = calculated probability from likelihood tests. Marginal and conditional R^2 calculated via delta method.

Cost of All Vegetated Patch Types (y=$) **408 patches on 58 sites**		
Model	AICc	P
M0: Intercept Only Model	5000.8	n/a
M1: Patch Type	4962.8	<0.0001***
M2: Log 10 Patch Area	4911.7	<0.0001***
M3: Patch Type + Log 10 Patch Area	4767.8	<0.0001***
M4: Developer on Site Random Effect	4994.2	<0.0001***
M5: Patch Type+Log10 Patch Area + Random Effect	4758.2	<0.0001***

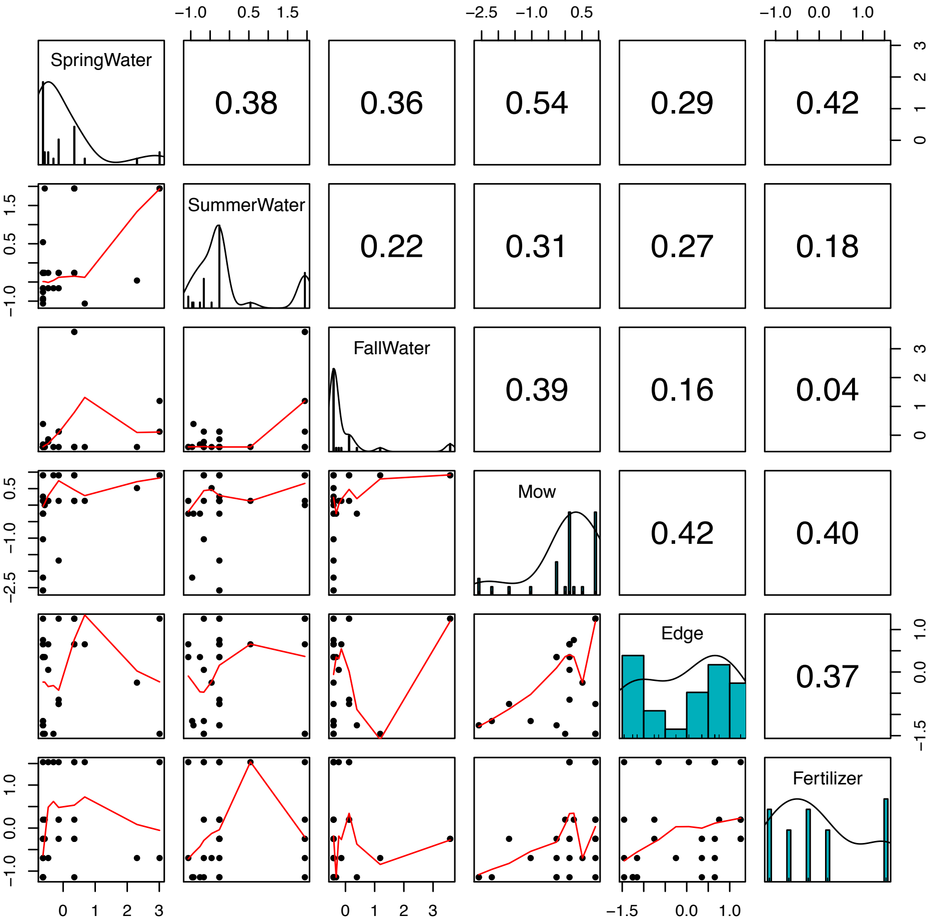
Vegetated Yard Patch Spending Including Lawns (p=<0.0001***) Marginal Pseudo R^2 = 0.155; Conditional Pseudo R^2= 0.5700				
Fixed Effects	**Estimate**	**Std. Error**	**z value**	**P**
Intercept (*Lawn*)	4.107	0.0811	50.67	<0.0001***
Mixed Perennials (*Mix*)	1.2800	0.1020	12.54	<0.0001***
Single Species, Short Perennial (*Mono*)	0.6848	0.1544	4.435	<0.0001***
Tree	1.3873	0.1641	8.46	<0.0001***
Log10 Patch Area	0.7455	0.0474	15.74	<0.0001***
Random Effects	**Variance**	**Std. Dev**		**ICC**
Developer on Site	0.0693	0.2632		0.1373

Significance: *p≤0.05, **p ≤ 0.01; *** p < 0.001

APPENDIX C. LAWN SUPPLEMENTARY INFORMATION



Appendix Figure A4. Density plots, scatterplots with fitted line (red), and Spearman rank correlations of yard goals, log parcel lawn area (lawn), and log median Census Block Group yard (cbg.yard). Data are for responding households who have a lawn (n=33). Yard goals selected for lawn diversity analysis: *Neat*, *Easy*, *Habitat*, *FoodSpace*, and *KidSpace*.



Appendix Figure A5. Density plots, scatterplots with fitted line (red), and Spearman rank correlations of lawn management activities. All activities are counts estimated from homeowner questionnaire responses. Watering estimates are by season. All other activities are annual estimates. Data are for responding households who have a lawn (n=33).

Appendix Table A2. Species found in study lawns, by scientific name and family, frequency in study area (# sites) and other cities (# cities); and presence (1= present) in other studies of lawn floras. Species marked with asterisk (*) are native to the Pacific Northwest (Hitchcock and Cronquist 2018). Blank cells indicate that species was not found on species list in other study.

Scientific Name & Family	10 Cities from 5 other lawn studies: 1: Whitney 19865 (USA), 2 - Wheeler et al. 2019 (USA); 3 - Thompson et al. 2004 (United Kingdom), 4: Bertoncini et al. 2012 (France), 5: Stewart et al. 2009 (New Zealand). Cities: BA=Baltimore; BO=Boston; CHR= Christchurch; LA=Los Angeles; MI=Miami; MP= Minneapolis; St. Paul; PA=Paris; PX = Phoenix; SC = Salt Lake City; WO=Wooster.											
	Study #		1	2	2	2	2	2	2	2	3	4	5
	Seattle Sites (#)	Other cities (#)	WO	BA	BO	LA	MI	MP	PX	SC	SH	PA	CH
*Acer macrophyllum** (seedling) Sapindaceae	2	0											
*Alnus rubra** (seedling) Betulaceae	1	0											
Capsella bursa-pastoris Brassicaceae	1	5	1	1					1			1	1
Cardamine hirsuta Brassicaceae	5	2		1					1			1	
Centaurea cyanus Asteraceae	1	0	1										
Cirsium arvense Asteraceae	6	4	1								1	1	1
Cirsium vulgare Asteraceae	8	3				1				1	1	1	
Convolvulus arvensis Convolvulaceae	4	4	1										1
Convolvulus sepium Convolvulaceae	4	1	1								1	1	1
Conyza Canadensis Asteraceae	1	6		1	1		1	1		1		1	
Daphne laureola Thymelaeaceae	1	0											
Epilobium ciliatum Onagraceae	9	1									1		

Scientific Name & Family	10 Cities from 5 other lawn studies: 1: Whitney 19865 (USA), 2 - Wheeler et al. 2019 (USA); 3 - Thompson et al. 2004 (United Kingdom), 4: Bertoncini et al. 2012 (France), 5: Stewart et al. 2009 (New Zealand). Cities: BA=Baltimore; BO=Boston; CHR= Christchurch; LA=Los Angeles; MI=Miami; MP= Minneapolis; St. Paul; PA=Paris; PX = Phoenix; SC = Salt Lake City; WO=Wooster.											
	Study #		1	2	2	2	2	2	2	2	3	4	5
	Seattle Sites (#)	Other cities (#)	WO	BA	BO	LA	MI	MP	PX	SC	SH	PA	CH
Escholtzia californica Papaveraceae	2	1							1				
Euphorbia glyptosperma Euphorbiaceae	4	0											
*Galium aparine** Rubiaceae	3	1								1			1
Geranium molle Geraniaceae	10	1									1		
Geranium robertianum Geraniaceae	5	0											
Gnaphalium uliginosum Asteraceae	3	3		1						1	1		
Hedera hibernica Araliaceae	5	0											
Hieracium sp. Asteraceae	1	2		1							1		
Holcus lanatus Poaceae	6	4			1						1	1	1
Hypochaeris radicata Asteraceae	38	1									1		
Ilex aquifolium Aquifoliaceae	2	4	1	1					1	1			
Lactuca serriola Asteraceae	2	1									1		
Lamium amplexicaule Lamiaceae	4	1							1				
Lapsana communis Asteraceae	1	1									1		
Leucanthemum vulgare Asteraceae	3	4	1	1				1			1		
Malva neglecta Malvaceae	5	5		1	1	1				1		1	

Scientific Name & Family	10 Cities from 5 other lawn studies: 1: Whitney 19865 (USA), 2 - Wheeler et al. 2019 (USA); 3 - Thompson et al. 2004 (United Kingdom), 4: Bertoncini et al. 2012 (France), 5: Stewart et al. 2009 (New Zealand). Cities: BA=Baltimore; BO=Boston; CHR= Christchurch; LA=Los Angeles; MI=Miami; MP= Minneapolis; St. Paul; PA=Paris; PX = Phoenix; SC = Salt Lake City; WO=Wooster.											
	Study #		1	2	2	2	2	2	2	2	3	4	5
	Seattle Sites (#)	Other cities (#)	WO	BA	BO	LA	MI	MP	PX	SC	SH	PA	CH
Matricaria discoidea Asteraceae	1	0											
Medicago lupulina Fabaceae	6	7	1	1		1		1		1	1	1	
Mycelis muralis Asteraceae	2	0											
Oxalis corniculata Oxalidaceae	2	7		1		1	1	1		1	1	1	
Plantago lanceolata Plantaginaceae	15	6	1	1	1						1	1	1
Plantago major Plantaginaceae	12	6	1	1	1			1			1	1	
Poa annua Poaceae	1	9	1	1	1	1		1	1		1	1	1
Polygonum aviculare Polygonaceae	4	7	1	1	1			1			1	1	1
Prunella vulgaris Lamiaceae	1	6	1		1			1			1	1	1
Ranunculus repens Rancunulaceae	14	3			1						1	1	
Rubus bifrons Rosaceae	15	1									1		
Rumex acetosella Polygonaceae	2	4	1	1	1						1		
Rumex cripsus Polygonaceae	8	4	1	1							1		1
Senecio jacobaea Asteraceae	3	2									1	1	
Senecio vulgaris Asteraceae	10	4			1				1		1	1	
Solanum dulcamara Solanaceae	1	1			1								

Scientific Name & Family	10 Cities from 5 other lawn studies: 1: Whitney 19865 (USA), 2 - Wheeler et al. 2019 (USA); 3 - Thompson et al. 2004 (United Kingdom), 4: Bertoncini et al. 2012 (France), 5: Stewart et al. 2009 (New Zealand). Cities: BA=Baltimore; BO=Boston; CHR= Christchurch; LA=Los Angeles; MI=Miami; MP= Minneapolis; St. Paul; PA=Paris; PX = Phoenix; SC = Salt Lake City; WO=Wooster.												
	Study #		1	2	2	2	2	2	2	2	3	4	5
	Seattle Sites (#)	Other cities (#)	WO	BA	BO	LA	MI	MP	PX	SC	SH	PA	CH
Solanum nigrum Solanaceae	1	1	1										
Solidago canadensis Asteraceae	2	3	1		1			1					
Sonchus arvensis Asteraceae	6	0									?		
Stellaria media Caryophyllaceae	4	8	1	1	1	1		1	1		1	1	
Tanacetum vulgare	1	0											
Taraxacum officinale Asteraceae	34	9	1	1	1	1		1	1	1	1		1
Trifolium repens Fabaceae	29	8	1	1	1			1		1	1	1	1
Turfgrasses Poaceae	58	10	1	1	1	1	1	1	1	1	1	1	1
Vicia sativa Fabaceae	5	1										1	
Viola tricolor Violaceae	1	0											
Xanthium strumarium Asteraceae	2	0											
# Seattle species in study		42	20	19	17	8	3	14	9	10	30	23	11
% of species occurred in other city		76	36	35	31	15	6	26	16	18	55	42	20

Appendix Table A3. Comparison of model fit and final model parameters for turfgrass monoculture logistic regressions for parcel and Census Block Group variables. Models: M0 = intercept only, M1 = full model; M2 = selected by the stepAIC function. AICc=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions. Final models are in bold and italics.

Lawn Monoculture Parcel Variable Models (n=58)			
Model #	**Model Description**	**AIC_c**	**p**
M0	***Monoculture ~ Intercept Only***	***58.4***	***1***
M1	Monoculture ~ Elevation + Land Value + Improvement Value + Perennial Bed Area	62.0	Not calculated
M2	Monoculture ~ Elevation	58.6	0.12

Parcel Final Model: Lawn Monoculture; Pseudo $R^2 = 0$				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	-1.4523	0.3349	-4.336	<0.0001***

Lawn Monoculture: Census Block Group Models (n=58)			
Model #	**Model Description**	**AIC_c**	**p**
M0	Monoculture ~ Intercept Only	58.4	1
M1	Monoculture ~ Residential Density + Median Age + Median Log 10 Yard Area	58.9	Not calculated
M2	***Monoculture ~ Median Log 10 Yard Area***	***53.5***	***0.0079****

Census Block Group Final Model: Lawn Monoculture; Pseudo $R^2 = 0.1638$				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	-1.6559	0.3853	-4.298	<0.0001***
Median Log10 Yard Area	0.9426	0.4022	2.343	0.0191*

Significance levels: .p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A4. Comparison of model fit and final model parameters for turfgrass monoculture logistic regressions for yard goals and lawn care practices. Models: M0 = intercept only, M1 = full model; M2 = selected by the stepAIC function. AICc=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions. Final models are in bold and italics.

Lawn Monoculture: Homeowner Yard Goals (n=33)			
Model #	**Model Description**	**AIC_c**	**p**
M0	Monoculture ~ Intercept Only	38.7	1
M1	Monoculture ~ Neat + Easy + Habitat + FoodSpace + KidSpace	29.6	Not calculated
M2	***Monoculture*** **~ Easy + Habitat + KidSpace**	***25.1***	***0.0199****

Yard Goals Final Model: Lawn Monoculture; Pseudo R^2 = 0.5700				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	-6.289	7.408	-0.849	0.3959
Easy	-2.633	1.448	-1.818	0.0690**.**
Habitat	2.768	1.152	2.403	0.0163*
KidSpace	2.024	1.066	1.898	0.0577**.**

Lawn Monoculture: Lawn Management (n=33)			
Model #	**Model Description**	**AIC_c**	**p**
M0	Monoculture ~ Intercept Only	38.7	1
M1	Monoculture ~ SpringWater + SummerWater + FallWater + Mow + Fertilizer	37.7	Not calculated
M2	***Monoculture ~ SummerWater + Fertilizer***	***31.3***	***0.01323****

Yard Goals Final Model: Lawn Monoculture; Pseudo R^2 = 0.328				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	-1.7887	0.6638	-2.694	0.00705**
Summer Water	1.2488	0.5292	2.360	0.01830*
Fertilizer	1.2872	0.6007	2.143	0.03213*

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A5. Comparison of model fit and final model parameters for non-turfgrass richness in lawns. *M0* = intercept only, *M1* = full model; *M2* = selected by stepAIC. binomial regressions. AIC_c=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions. Final models are in bold and italics.

Non-Turfgrass Species Richness: Parcel Variable Models (n=47)

Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept	271.4
M1, M2	***Richness ~ Elevation + Improvement Value + Log10 Lawn Area***	***259.5***
M1.lag, M2.lag	Richness ~ Elevation + Improvement Value + Log10 Lawn Area + Spatial Lag	262.1

Parcel Final Model: Lawn Species Richness; p= 0.0601; Pseudo R^2 = 0.337

Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	1.82835	0.09011	20.29	<0.0001***
Elevation	-0.36012	0.09667	-3.725	<0.001***
Appraised Improvement Value	-0.19816	0.10288	-1.926	0.0540**.**
Log10 Lawn Area	0.36821	0.09920	3.712	<0.001***

Non-Turfgrass Species Richness: Census Block Group Models (n=47)

Model #	**Model Description**	**AIC_c**
M0, M2	Richness ~ Intercept Only	272.1
M1	Richness ~ Residential Density + Median Age + Median Assessed Value + Median Log 10 Yard Area	274.6
M1.lag	Richness ~ Residential Density + Median Age + Median Assessed Value + Median Log 10 Yard Area + Spatial Lag	273.2
M2	Richness ~ Median Assessed Value	269.5
M2.lag	**Richness ~ Median Assessed Value + Spatial Lag**	**265.6**

Census Block Group Final Model: Non-Turfgrass Species Richness; n=58; p=0.0122, Pseudo R^2 = 0.2006

Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	1.86718	0.09541	19.570	<0.0001***
Median Assessed Value	0.23065	0.10453	-2.207	0.02734*
Spatial Lag	1.69904	0.63213	2.688	0.00719**

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A6. Comparison of model fit for negative binomial regressions of yard goals and richness of non-turfgrass species (n=34). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. Higher number models created to test M2 fit. Yard AIC$_c$=Akaike Information Criterion corrected for small sample size. Final models are in bold and italics.

YARD GOALS: TREE RICHNESS		
Model	**Description**	**AICc**
M0	Richness ~ Intercept Only	141.6
M1	Richness ~ Neat + Easy + Habitat + FoodSpace + KidSpace	150.4
M1.lag	Richness ~ Neat + Easy + Habitat + FoodSpace + KidSpace + Spatial Lag	152.8
M2	Richness ~ Habitat	141.4
M2.lag	***Richness ~ Habitat + Spatial Lag***	***136.0***

Yard Goals Final Model: Non-Turfgrass Species Richness; n=25; p=0.00414, Pseudo R^2 = 0.3693				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	1.6716	0.1270	13.162	<0.0001***
Habitat	-0.2298	0.1256	-1.829	0.06742.
Spatial Lag	-1.9315	0.6340	-3.046	0.00232**

APPENDIX D. PERENNIAL SUPPLEMENTARY INFO

Appendix Table A7. Frequency of retained and planted woody perennials by source. Frequency values are number of sites at which the taxon occurs (n=58). Taxa are alphabetical by family and scientific name within family. Group: TE = evergreen trees; TD = deciduous trees; SE = evergreen shrubs; SD = deciduous shrubs. Taxa marked with an asterisk (*) are native to the Pacific Northwest. Source: Ret= Taxa present on site before development and retained by developer; Dev= Taxa planted by developer; HH= Taxa by planted by household.

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
SD	*Viburnum carlesii* Korean spice viburnum	Adoxaceae	0	0	1
SE	*Viburnum davidii* David viburnum	Adoxaceae	0	4	0
SE	*Viburnum tinus* Laurustinus	Adoxaceae	0	2	2
SD	*Cotinus coggygria* Smoke bush	Anacardiaceae	0	1	3
SE	*Ilex* x *meserveae* Blue prince Blue holly	Aquifoliaceae	0	0	1
SE	*Fatsia japonica* Japanese fatsia	Araliaceae	0	0	2
TE	*Trachycarpus fortunei* Windmill palm	Arecaceae	0	0	2
SE	*Mahonia aquifolium** Tall Oregon-grape	Berberidaceae	0	3	0
SE	*Mahonia nervosa** Cascade Oregon-grape	Berberidaceae	0	1	0
SD	*Berberis thunbergii* Japanese barberry	Berberidaceae	0	9	3
SE	*Nandina domestica* Heavenly bamboo	Berberidaceae	0	16	0
TD	*Betula pendula* European white birch	Betulaceae	0	10	6
TD	*Betula utilis* var. *jacquemontii* Himalayan birch	Betulaceae	0	1	1
TD	*Corylus cornuta** Hazelnut	Betulaceae	1	4	1
SE	*Buxus sempervirens* Common box	Buxaceae	0	14	3
SE	*Sarcococca* sp. Sweet box	Buxaceae	0	8	0

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
SD	*Symphoricarpos albus** Common snowberry	Caprifoliaceae	0	1	1
SD	*Weigela florida* Weigela	Caprifoliaceae	0	0	1
SD	*Euonymus alatus* Winged burning bush	Celastraceae	0	1	1
SE	*Euonymus fortunei* Wintercreeper euonymus	Celastraceae	0	14	4
SE	*Euonymus japonicus* Japanese euonymus	Celastraceae	0	7	3
TD	*Cercidiphyllum japonicum* Katsura tree	Cercidiphyllaceae	0	3	0
TD	*Cornus florida* Flowering dogwood	Cornaceae	0	1	0
TD	*Cornus kousa* Kousa dogwood	Cornaceae	0	0	1
TD	*Cornus mas* Cornelian cherry dogwood	Cornaceae	1	3	0
SD	*Cornus sericea* ssp. *sericea** Red osier dogwood	Cornaceae	0	4	1
TE	*Callitropsis nootkatensis** Alaska yellow-cedar	Cupressaceae	0	7	0
TE	*Chamaecyparis obtusa* Hinoki cypress	Cupressaceae	0	1	2
TE	*Chamaecyparis pisifera* 'Sungold' Sawara cypress	Cupressaceae	0	0	1
TE	*Cryptomeria japonica* Japanese cypress	Cupressaceae	0	0	1
TE	*Cupressus macrocarpa* Monterey cypress	Cupressaceae	0	3	1
TE	*Cupressus sempervirens* Italian cypress	Cupressaceae	0	1	1
TE	*Juniperus squamata* ‘Blue Star’ Single seed juniper	Cupressaceae	0	7	0
TE	*Sequoia sempervirens* Coast redwood	Cupressaceae	1	0	0
TE	*Taxodium distichum* Bald cypress	Cupressaceae	0	0	1
TE	*Thuja occidentalis* Arborvitae	Cupressaceae	0	22	3

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
TE	*Thuja plicata** Western red-cedar	Cupressaceae	1	8	2
TE	x *Cuprocyparis leylandii* Leyland cypress	Cupressaceae	2	3	0
TD	*Diospyros kaki* Japanese persimmon	Ebenaceae	0	0	1
TE	*Arbutus menziesii** Pacific madrona	Ericaceae	6	1	0
SE	*Calluna vulgaris* Scot's heather	Ericaceae	0	16	2
SE	*Gaultheria shallon** Salal	Ericaceae	2	1	2
SE	*Kalmia latifolia* Mountain laurel	Ericaceae	0	0	1
SE	*Pieris japonica* Japanese andromedea	Ericaceae	0	17	1
SE	*Rhododendron* sp. 1 Evergreen rhododendron	Ericaceae	0	21	2
SE	*Rhododendron* sp. 2 Azalea	Ericaceae	0	19	1
SD	*Vaccinium corymbosum** High-bush blueberry	Ericaceae	0	0	3
SE	*Vaccinium ovatum** Evergreen blueberry	Ericaceae	0	3	0
SD	*Vaccinium* x Sunshine Blue Sunshine blue blueberry	Ericaceae	0	0	1
TD	*Albizia julibrissin* Silk tree mimosa	Fabaceae	0	0	1
SE	*Cytisus scoparius* Scot's broom	Fabaceae	1	0	0
TD	*Robinia pseudoacacia* Black locust	Fabaceae	1	0	1
TD	*Carpinus betulus* Common hornbeam	Fagaceae	0	0	1
TD	*Quercus coccinea* Scarlet oak	Fagaceae	0	0	1
TD	*Ginkgo biloba* Maidenhair tree	Ginkgoaceae	0	0	1
SD	*Ribes sanguineum** Red-flowered currant	Grossulariaceae	0	4	1

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
SD	*Ribes uva-crispa* Gooseberry	Grossulariaceae	0	0	1
TD	*Liriodendron tulipifera* Tulip tree	Magoliaceae	1	0	0
TE	*Magnolia grandiflora* Southern magnolia	Magoliaceae	0	0	1
SD	*Ficus carica* Fig	Moraceae	0	0	1
TD	*Fraxinus latifolia** Oregon ash	Oleaceae	1	0	0
SE	*Osmanthus heterophyllus* Holly olive	Oleaceae	0	4	0
SD	*Syringa vulgaris* Lilac	Oleaceae	1	0	0
TE	*Abies grandis* *Grand fir*	Pinaceae	1	0	0
TE	*Cedrus atlanticus* Blue atlas cedar	Pinaceae	0	2	2
TE	*Cedrus libani* Cedar of Lebanon	Pinaceae	0	0	1
TE	*Larix kaempferi* Japanese larch	Pinaceae	0	2	0
TE	*Picea abies* Norway spruce	Pinaceae	0	3	1
TE	*Picea glauca* White spruce	Pinaceae	0	3	1
TE	*Picea pungens* Colorado spruce	Pinaceae	0	1	1
TE	*Pinus flexilis* Limber pine	Pinaceae	0	1	0
TE	*Pinus mugo* Swiss mountain pine	Pinaceae	0	5	0
TE	*Pinus nigra* Austrian pine	Pinaceae	1	5	0
TE	*Pinus strobus* Eastern white pine	Pinaceae	0	1	0
TE	*Pseudotsuga menziesii** Douglas-fir	Pinaceae	10	0	0
TE	*Tsuga heterophylla** Western hemlock	Pinaceae	1	0	0

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
TE	*Tsuga mertensiana** Mountain hemlock	Pinaceae	0	1	2
SE	*Ceanothus thyrsiflorus* California lilac	Rhamnaceae	0	1	2
TD	*Amelanchier alnifolia** Western serviceberry	Rosaceae	0	1	0
SE	*Cotoneaster franchettii* Grey cotoneaster	Rosaceae	1	0	1
TD	*Malus* sp. Apple cultivars	Rosaceae	1	0	2
TD	*Prunus aviuum* Bird cherry	Rosaceae	1	1	2
TD	*Prunus cerasifera* Cherry plum	Rosaceae	1	0	3
TD	*Prunus domestica* Plum	Rosaceae	0	0	1
TD	*Prunus laurocerasus* Laurel cherry	Rosaceae	2	4	0
TD	*Prunus persica* Peach	Rosaceae	0	0	1
TD	*Prunus serrulata* Flowering cherry	Rosaceae	3	1	1
TD	*Prunus* x *yedoensis* Yoshino cherry	Rosaceae	0	1	1
TD	*Prunus* x *cistena* Purple leaf sand cherry	Rosaceae	0	0	1
TD	Pyrus calleryana ‘Bradford’ Callery pear	Rosaceae	0	0	1
TD	*Pyrus pyrifolia* Chinese pear	Rosaceae	0	0	1
SD	*Rosa gymnocarpa** Bald hip rose	Rosaceae	1	1	0
SD	*Rosa* sp. Rose cultivars	Rosaceae	0	3	5
SD	*Rubus bifrons* Himalayan blackberry	Rosaceae	2	0	0
SE	*Rubus leucodermis** Blackcap	Rosaceae	0	0	1
SD	*Spiraea* sp. Spiraea	Rosaceae	0	1	0

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
TE	*Tsuga mertensiana** Mountain hemlock	Pinaceae	0	1	2
SE	*Choisya* x *dewitteana* ‘Aztec Pearl’ Mexican orange	Rutaceae	0	1	1
TD	*Populus trichocarpa** Black cottonwood	Salicaceae	1	0	0
SD	*Salix integra* 'Hakuro-nishiki' Dappled willow	Salicaceae	0	0	2
SD	*Salix sitchensis** Sitka willow	Salicaceae	1	0	0
TD	*Acer circinatum** Vine maple	Sapindaceae	1	4	0
TD	*Acer griseum* Paperbark maple	Sapindaceae	0	1	1
TD	*Acer macrophyllum** Big leaf maple	Sapindaceae	1	0	0
TD	*Acer palmatum* *Japanese maple*	Sapindaceae	0	25	3
TD	*Acer platanoides* Norway maple	Sapindaceae	0	7	1
SE	*Escallonia* x *rigida* Escallonia	Saxifragaceae	0	3	1
SD	*Buddleja davidii* Butterfly bush	Scrophulariaceae	1	0	0
TE	*Taxus baccata* English yew	Taxaceae	0	2	0
SE	*Camellia* sp. Camellia	Theaceae	0	3	1
SE	*Daphne laureola* Spurge-laurel	Thymelaeaceae	0	1	0
SE	*Daphne* x *burkwoodii* Winter daphne	Thymelaeaceae	0	0	2
SE	*Lantana* sp. Lantana	Verbenaceae	0	0	1
SE	*Tasmannia lanceolata* Tasmanian pepper	Winteraceae	0	0	1

Appendix Table A8. Frequency of retained and planted herbaceous perennials by source. Taxa are alphabetical by family and scientific name. Frequency values are number of sites at which the taxon occurs (n=58). Group: G = graminoids; GC = ground covers; F = Ferns; V = Vines; OP = other perennials. Taxa marked with an asterisk are native to the Pacific Northwest. Source: Ret= Taxa present on site before development and retained by developer; Dev= Taxa planted by developer; HH= Taxa by planted by household.

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	**Dev**	**HH**
OP	*Delosperma* sp. Ice plant	Aizoaceae	0	0	3
OP	*Agapanthus* sp. Lily of the Nile	Amaryllidaceae	0	0	1
A	*Foeniculum vulgare* Fennel	Apiaceae	0	0	1
A	*Vinca major* Greater periwinkle	Apocynaceae	0	0	1
A	*Vinca minor* Common periwinkle	Apocynaceae	0	3	6
A	*Zantedeschia aethiopica* Calla lily	Araceae	0	0	5
A	*Hedera hibernica* Ivy	Araliaceae	2	0	0
A	*Hosta* sp. Hosta	Asparagaceae	0	1	11
A	*Muscari armeniacum* Grape hyacinth	Asparagaceae	1	0	0
A	*Ophiopogon planiscapus* 'Nigrescens' Black mondo grass	Asparagaceae	0	8	2
A	*Yucca filamentosa* Adam's needle	Asparagaceae	0	4	3
A	*Phormium tenax* New Zealand flax	Asphodelaceae	0	1	4
A	*Anaphalis margaritacea** Pearly everlasting	Asteraceae	0	1	0
A	*Cynara cardunculus* Artichoke	Asteraceae	0	0	1
A	*Dahlia* sp. Dahlia	Asteraceae	0	0	6
A	*Erigeron* sp. Fleabane	Asteraceae	0	0	1
A	*Rudbeckia fulgida* Black-eyed Susan	Asteraceae	0	0	1

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
GC	*Epimedium* sp. Bishop’s hat	Berberidaceae	0	1	0
OP	*Iberis sempervirens* Candytuft	Brassicaceae	0	0	2
OP	*Campanula poscharskyana* Serbian bellflower	Campanulaceae	0	1	0
OP	*Campanula* sp. Bellflower	Campanulaceae	0	1	2
V	*Humulus lupulus* Hops	Cannabacaee	0	0	1
OP	*Canna* sp. Canna lily	Cannaceae	0	0	2
OP	*Heptocodium miconoides* Seven son flower	Caprifoliaceae	0	0	1
V	*Lonicera* sp. Honeysuckle	Caprifoliaceae	0	0	1
OP	*Sedum* sp. Stonecrop	Crassulaceae	0	0	5
G	*Carex elata* ‘Aurea’ Bowles’ golden sedge	Cyperaceae	0	8	1
G	*Carex oshimensis ‘Evergold’* Japanese evergold sedge	Cyperaceae	0	22	0
G	*Carex testacea* Orange New Zealand sedge	Cyperaceae	0	15	0
OP	*Cycas revoluta* Sago palm	Cycadaceae	0	0	1
F	*Athyrium* x 'Ghost' Ghost painted fern	Dryopteridaceae	0	1	4
F	*Athyrium filix-femina** Lady fern	Dryopteridaceae	0	1	0
F	*Dryopteris pulcherrima* Chinese woodfern	Dryopteridaceae	0	0	1
F	*Polystichum munitum** Sword fern	Dryopteridaceae	3	6	2
GC	*Arctostaphylos uva-ursi** Bearberry	Ericaceae	0	3	1
OP	*Euphorbia characias* Mediterranean spurge	Euphorbiaceae	0	6	0
V	*Wisteria* sp. Wisteria	Fabaceae	0	0	1

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
G	*Juncus acuminatus** Tapered rush	Juncaceae	0	3	0
G	*Juncus ensifolius** Dagger-leaf rush	Juncaceae	0	3	0
OP	*Mentha x villosa* Mojito mint	Lamiaceae	0	0	1
OP	*Oriagnum vulgare* Oregano	Lamiaceae	0	0	2
OP	*Plectranthus scutellarioides* Coleus	Lamiaceae	0	0	2
OP	*Hibiscus syriacus* Rose of Sharon	Malvaceae	0	0	1
OP	*Sidalcea* sp. Mallow	Malvaceae	1	0	1
OP	*Musa basjoo* Hardy banana	Musaceae	0	0	1
V	*Jasminum nudiflorum* Winter jasmine	Oleaceae	0	0	1
GC	*Fragaria* x *ananassa* Strawberry cultivars	Rosaceae	0	0	8
OP	*Heuchera* sp. Coral bells	Saxifragaceae	0	6	3
OP	*Bacopa* sp. Water hyssop	Plantaginaceae	0	0	2
OP	*Veronica* sp. Veronica or here	Plantaginaceae	0	11	0
G	*Deschampsia caespitosa** Tufted hairgrass	Poaceae	0	1	1
G	*Festuca glauca* Blue fescue	Poaceae	0	18	0
G	*Miscanthus sinensis* Chinese silvergrass	Poaceae	0	9	3
G	*Pennisetum alopecuroides* Fountain grass	Poaceae	0	3	0
G	*Pennisetum setaceum* ‘Rubrum’ Purple fountain grass	Poaceae	0	3	0
G	*Phalaris arundinacea* Reed canarygrass	Poaceae	0	0	1
G	*Phyllostachys nigra* Black bamboo	Poaceae	0	0	1

Group	Scientific Name Common Name	Family	Frequency by Source		
			Ret	Dev	HH
G	*Phyllostachys* sp. Bamboo	Poaceae	1	2	2
G	*Stipa arundinacea* New Zealand windgrass	Poaceae	0	1	0
G	*Stipa gigantea* Giant needle grass	Poaceae	0	6	0
G	*Stipa tenuissima* Mexican feathergrass	Poaceae	0	6	1
OP	*Phlox* sp. Phlox	Polemoniaceae	0	1	0
OP	*Cyclamen* sp. Cyclamen	Primulaceae	0	0	3
V	*Clematis* sp. Clematis	Ranunculaceae	0	1	2
V	*Clematis vitalba* Old man's beard	Ranunculaceae	1	0	0
OP	*Rosmarinus officinalis* Rosemary	Lamiaceae	0	1	6
OP	*Salvia officinalis* Sage	Lamiaceae	0	0	1
OP	*Stachys byzantina* Lamb's ears	Lamiaceae	0	0	2
OP	*Thymus vulgaris* Garden thyme	Lamiaceae	0	1	0
GC	*Rubus calycinoides* Creeping raspberry	Rosaceae	0	1	2
GC	*Rubus ursinus** Dewberry	Rosaceae	2	0	0
G	*Typha latifolia** Cattail	Typhaceae	0	1	0
V	*Vitis vinifera* Grape	Vitaceae	0	0	1
OP	*Hemerocallis* sp. Daylily	Xanthorrhoeaceae	0	0	6
OP	*Kniphofia* sp. Red-hot poker plant	Xanthorrhoeaceae	0	0	1

Appendix Table A9. Comparison of model fit and final model parameters for developer planted tree species richness (n=58). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. Models with higher numbers are simpler models than M2 to evaluate M2 fit. AIC_c=Akaike Information Criterion corrected for small sample size. P = P value.

Developer Planted Tree Species Richness: Parcel Variable Models

Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	221.0
M1	Richness ~ Elevation + Land Value + Improvement Value + log 10 Vegetated Area	220.3
M2	***Richness ~ Improvement Value + log 10 Perennial Bed Area***	***218.7***
M3	Richness ~ = Improvement Value	219.7
M4	Richness ~ log 10 Perennial Bed Area	220.5

Parcel Final Model: Developer Planted Tree Species Richness; p= 0.067.; Pseudo R^2 = 0.105

Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	0.7982	0.0912	8.749	<0.0001***
Improvement Value	0.1733	0.0799	2.169	0.0301*
Log 10 Perennial Bed Area	0.0170	0.0901	1.883	0.0596.

Developer Planted Tree Species Richness: Census Block Group Models

Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	221.0
M1	Richness ~ Residential Density + Median Age + Median Assessed Value + log 10 Median Yard Area – does not converge	218.2
M2	***Richness ~ Median Assessed Value***	***215.3***

Census Block Group Final Model: Developer Planted Tree Species Richness; n=58; p=0.0050; Pseudo R^2 = 0.0931

Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	0.80346	0.0888	9.054	<0.0001***
Median Assessed Value	0.2188	0.0737	2.968	0.003**

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A10. Comparison of model fit and final model parameters for developer planted shrub species richness (n=58). Final models are bold and italicized. *M0* = intercept only, *M1* = full model; *M2* = selected by stepAIC. AIC$_c$=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions.

<table>
<tr><th colspan="5">Developer Planted Shrub Species Richness: Parcel Variable Models</th></tr>
<tr><td>Model #</td><td colspan="3">Model Description</td><td>AIC$_c$</td></tr>
<tr><td>M0</td><td colspan="3">Richness ~ Intercept Only</td><td>268.0</td></tr>
<tr><td>M1</td><td colspan="3">Richness ~ Elevation + Land Value + Improvement Value + log10 Perennial Bed Area</td><td>270.1</td></tr>
<tr><td><i>M2</i></td><td colspan="3"><i>Richness ~ Elevation + log 10 Perennial Bed Area</i></td><td><i>265.3</i></td></tr>
<tr><td>M3</td><td colspan="3">Richness ~ Elevation</td><td>267.2</td></tr>
<tr><td>M4</td><td colspan="3">Richness ~ log 10 Perennial Bed Area</td><td>266.7</td></tr>
<tr><td colspan="5">Parcel Final Model: Developer Planted Shrub Species Richness; p= 0.053.; Pseudo R^2 = 0.103</td></tr>
<tr><td>Variables</td><td>Estimate</td><td>Std. Error</td><td>Z Value</td><td>P</td></tr>
<tr><td>Intercept</td><td>1.2867</td><td>0.08755</td><td>14.70</td><td><0.0001***</td></tr>
<tr><td>Elevation</td><td>0.1721</td><td>0.8878</td><td>1.939</td><td>0.0525.</td></tr>
<tr><td>Log 10 Perennial Bed</td><td>0.1916</td><td>0.0872</td><td>2.197</td><td>0.0280*</td></tr>
<tr><td colspan="5">Developer Planted Shrub Species Richness: Census Block Group Models</td></tr>
<tr><td>Model #</td><td colspan="3">Model Description</td><td>AIC$_c$</td></tr>
<tr><td><i>M0, M2</i></td><td colspan="3"><i>Richness ~ Intercept Only</i></td><td><i>268.0</i></td></tr>
<tr><td>M1</td><td colspan="3">Richness ~ Residential Density + Median Age + Median Assessed Value + log 10 Median Yard Area</td><td>274.9</td></tr>
<tr><td colspan="5">Census Block Group Final Model: Developer Planted Shrub Species Richness; n=58; p=1; Pseudo R^2 = 0</td></tr>
<tr><td>Variables</td><td>Estimate</td><td>Std. Error</td><td>Z Value</td><td>P</td></tr>
<tr><td>Intercept</td><td>1.3148</td><td>0.9075</td><td>14.49</td><td><0.0001***</td></tr>
</table>

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A11. Comparison of model fit and final model parameters for developer planted perennial herb species richness (n=58). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. AIC_c=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions.

Developer Planted Perennial Herb Species Richness: Parcel Models		
Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	252.3
M1	Richness ~ Elevation + Land Value + Improvement Value + log 10 Perennial Bed Area	252.5
M2	***Richness ~ Land Value***	***242.9***

Parcel Final Model: Developer Planted Perennial Herb Species Richness; p= 0.041; Pseudo R^2 = 0.063				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	0.9373	0.1142	8.209	<0.0001***
Land Value	0.2415	0.1039	2.323	0.0232*

Developer Planted Herb Species Richness: Census Block Group Models		
Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	252.3
M1	Richness ~ Residential Density + Median Age + Median Assessed Value + log 10 Median Yard Area	245.1
M2	***Richness ~ Residential Density***	***241.1***

Census Block Group Final Model: Developer Planted Perennial Herb Model; n=58; p=0.0002; Pseudo R^2 = 0.157				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	0.9716	0.1039	9.352	<0.0001***
Residential Density	0.3756	0.0958	3.919	<0.0001***

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A12. Comparison of model fit and final model parameters for homeowner planted tree species richness (n=58). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. M3-M4: Simpler models than M2, evaluated for fit. AIC$_c$=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions.

<table>
<tr><td colspan="6">**Homeowner Planted Tree Species Richness: Parcel Variables Models**</td></tr>
<tr><td>**Model #**</td><td colspan="4">**Model Description**</td><td>**AIC$_c$**</td></tr>
<tr><td>M0</td><td colspan="4">Richness ~ Intercept Only</td><td>162.8</td></tr>
<tr><td>M1</td><td colspan="4">Richness ~ Elevation + Land Value + Improvement Value + log 10 Perennial Bed Area</td><td>159.8</td></tr>
<tr><td>***M2***</td><td colspan="4">***Richness ~ log 10 Perennial Bed Area***</td><td>***155.1***</td></tr>
<tr><td colspan="6">**Parcel Final Model: Homeowner Planted Tree Species Richness; p= 0.0016**; Pseudo R^2 = 0.173**</td></tr>
<tr><td colspan="2">**Variables**</td><td>**Estimate**</td><td>**Std. Error**</td><td>**Z Value**</td><td>**P**</td></tr>
<tr><td colspan="2">Intercept</td><td>-0.2060</td><td>0.1976</td><td>-1.042</td><td>0.2972</td></tr>
<tr><td colspan="2">Log 10 Bed Area</td><td>0.5946</td><td>0.1958</td><td>3.037</td><td>0.0024**</td></tr>
<tr><td colspan="6">**Homeowner Planted Tree Species Richness: Census Block Group Models**</td></tr>
<tr><td>**Model #**</td><td colspan="4">**Model Description**</td><td>**AIC$_c$**</td></tr>
<tr><td>***M0***</td><td colspan="4">***Richness ~ Intercept Only***</td><td>***162.8***</td></tr>
<tr><td>M1</td><td colspan="4">Richness ~ Residential Density + Median Age + Median Assessed Value + log 10 Median Yard Area</td><td>167.5</td></tr>
<tr><td>M2</td><td colspan="4">Richness ~ Residential Density + log10 Median Yard Area</td><td>163.6</td></tr>
<tr><td>M3</td><td colspan="4">Richness ~ Residential Density</td><td>164.4</td></tr>
<tr><td>M4</td><td colspan="4">Richness ~ log10 Median Yard Area</td><td>164.0</td></tr>
<tr><td colspan="6">**Census Block Group Final Model: Homeowner Planted Tree Species Richness; n=58, p=1**</td></tr>
<tr><td colspan="2">**Variables**</td><td>**Estimate**</td><td>**Std. Error**</td><td>**Z Value**</td><td>**P**</td></tr>
<tr><td colspan="2">Intercept</td><td>-0.01739</td><td>0.2068</td><td>-0.084</td><td>0.933</td></tr>
</table>

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A13. Comparison of model fit and final model parameters for homeowner planted shrub species richness (n=58). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. Models with higher numbers evaluated for M2 fit. AIC_c=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions.

Homeowner Planted Shrub Species Richness: Parcel Variables Models		
Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	172.5
M1	Richness ~ Elevation + Land Value + Improvement Value + log 10 Perennial Bed Area	166.3
M2	Richness ~ Land Value + log 10 Perennial Bed Area	161.7
M3	Richness ~ Land Value	174.5
M4	***Richness ~ log 10 Perennial Bed Area***	***161.8***

Parcel Final Model: Homeowner Planted Shrubs Species Richness; p= 0.0003; Pseudo R^2 = 0.226				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	-0.1420	0.2182	-0.651	0.51511
Log 10 Perennial Bed Area	0.8192	0.2176	3.765	0.00017***

Homeowner Planted Shrub Species Richness: Census Block Group Models		
Model #	**Model Description**	**AIC_c**
M0	Richness ~ Intercept Only	172.5
M1	Richness ~ Residential Density + Median Age + Median Assessed Value + Median Yard Area	178.1
M2	***Richness ~ Median Assessed Value***	***171.1***

Census Block Group Final Model: Homeowner Planted Shrub Species Richness; n=58; p=0.058; Pseudo R^2 = 0.0686				
Variables	**Estimate**	**Std. Error**	**Z Value**	**P**
Intercept	0.0594	0.2192	0.271	0.7863
Median Assessed Value	0.3466	0.2067	1.677	0.0935.

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A14. Comparison of model fit and final model parameters for homeowner planted herbaceous perennial species richness (n=58). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. Models with higher numbers evaluated for M2 fit. AIC_c=Akaike Information Criterion corrected for small sample size. P = P value. All models negative binomial regressions.

<table>
<tr><th colspan="5">Homeowner Planted Perennial Herb Species Richness: Parcel Variables Models</th></tr>
<tr><th>Model #</th><th colspan="3">Model Description</th><th>AIC_c</th></tr>
<tr><td>M0</td><td colspan="3">Richness ~ Intercept Only</td><td>240.5</td></tr>
<tr><td>M1</td><td colspan="3">Richness ~ Elevation + Land Value + Improvement Value + log 10 Vegetated Patch Area</td><td>241.2</td></tr>
<tr><td>***M2***</td><td colspan="3">***Richness ~ log 10 Perennial Bed Area***</td><td>***235.5***</td></tr>
<tr><th colspan="5">Parcel Final Model: Homeowner Planted Herbaceous Perennial Species Richness; p= 0.007*; Pseudo R^2 = 0.113</th></tr>
<tr><th>Variables</th><th>Estimate</th><th>Std. Error</th><th>Z Value</th><th>P</th></tr>
<tr><td>Intercept</td><td>0.7564</td><td>0.1653</td><td>4.577</td><td><0.0001***</td></tr>
<tr><td>Log 10 Perennial Bed Area</td><td>0.4495</td><td>0.1684</td><td>2.669</td><td>0.076**</td></tr>
<tr><th colspan="5">Homeowner Planted Perennial Herb Species Richness: Census Block Group Models</th></tr>
<tr><th>Model #</th><th colspan="3">Model Description</th><th>AIC_c</th></tr>
<tr><td>***M0, M2***</td><td colspan="3">***Richness ~ Intercept Only***</td><td>***240.5***</td></tr>
<tr><td>M1</td><td colspan="3">Richness ~ Residential Density + Median Age + Median Assessed Value + log 10 Median Yard Area</td><td>247.7</td></tr>
<tr><th colspan="5">Census Block Group Final Model: Homeowner Planted Herbaceous Perennial Species Richness; n=58; p=1</th></tr>
<tr><th>Variables</th><th>Estimate</th><th>Std. Error</th><th>Z Value</th><th>P</th></tr>
<tr><td>Intercept</td><td>0.8595</td><td>0.1743</td><td>4.932</td><td><0.0001***</td></tr>
</table>

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A15. Comparison of model fit for negative binomial regressions of yard goals and household planted tree, shrub, and herb species richness (n=34). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function. Higher number models created to test M2 fit. Yard AIC_c=Akaike Information Criterion corrected for small sample size. Final models are in bold and italics.

YARD GOALS: TREE RICHNESS		
Model	**Description**	**AICc**
M0, M2	***Richness ~ Intercept Only***	***103.9***
M1	Richness ~ Neat + Easy + Habitat + FoodSpace + KidSpace	114.6
YARD GOALS: SHRUB RICHNESS		
M0	Richness ~ Intercept Only	107.8
M1	Richness ~ Neat + Easy + Habitat + FoodSpace + KidSpace	105.5
M2	***Richness ~ Habitat***	***99.9***
YARD GOALS: HERB RICHNESS		
M0	Richness ~ Intercept Only	141.9
M1	Richness ~ Neat + Easy + Habitat + FoodSpace + KidSpace	143.6
M2	*Richness ~Neat + Habitat + FoodSpace*	*140.7*
M3	***Richness ~Neat + Habitat***	***140.1***
M4	Richness ~Neat + FoodSpace	142.5
M5	Richness ~Habitat + FoodSpace	142.5
M6	Richness ~Neat	142.3
M7	Richness ~Habitat	141.4

Appendix Table A16. Final negative binomial regression yard goal models for household planted tree, shrub, and herb species richness (n=34). Predictive yard goal estimates are standardized from homeowner rankings of goals, where 1 = very unimportant and 5 = very important. Yard Goals: *Easy* = Yard is easy to maintain; *Habitat* = Yard provides wildlife habitat; *Neat* = yard is neat/tidy.

Model & Variables	**Estimate**	**Std. Error**	**Z value**	**P**
Household Planted Tree Species Richness, p=1; Pseudo R^2 = 0				
Intercept	-0.1159	0.2354	-0.492	0.6266
Household Planted Shrub Species Richness; p=0.0013; Pseudo R^2 = 0.29				
Intercept	-0.1057	0.2663	-0.397	0.6914
Habitat	0.8725	0.2649	3.293	<0.0001***
Household Planted Herb Species Richness, p=0.0486; Pseudo R^2 = 0.180				
Intercept	0.6800	0.2222	3.060	0.0022**
Neat	-0.4450	0.2199	-2.024	0.0430*
Habitat	0.5098	0.2279	2.237	0.2529*

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001

Appendix Table A17. Comparison of model fit for negative binomial regressions of plant selection criteria and household planted trees, shrub, and herb species richness (n=34). Final models are bold and italicized. Models: *M0* = intercept only, *M1* = full model; *M2* = selected by the stepAIC function.

PLANT CRITERIA: TREE RICHNESS		
Model	**Model Description**	**AICc**
M0	Richness ~ Intercept Only	103.9
M1	Richness ~ Unique + Privacy + Inexpensive + Low Maintenance + Household Food	110.5
M2	***Richness ~ Unique***	101.2
PLANT CRITERIA: SHRUB RICHNESS		
M0	Richness ~ Intercept Only	107.8
M1	Richness ~ Unique + Privacy + Inexpensive + Low Maintenance + Household Food	106.0
M2	***Richness ~ Unique + Inexpensive+ Household Food***	***101.2***
M3	Richness ~ Unique + Inexpensive	103.2
M4	Richness ~ Unique + Household Food	104.2
M5	Richness ~ Inexpensive+ Household Food	104.2
PLANT CRITERIA: HERB RICHNESS		
M0	Richness ~ Intercept Only	141.9
M1	Richness ~ Unique + Privacy + Inexpensive + Low Maintenance + Household Food	140.2
M2	Richness ~ Unique + Inexpensive + Household Food + Low Maintenance	133.6
M3	***Richness ~ Unique + Inexpensive + Household Food***	***133.1***
M4	Richness ~ Unique + Inexpensive + Low Maintenance	135.0
M5	Richness ~ Inexpensive + Household Food + Low Maintenance	140.6
M6	Richness ~ Unique + Inexpensive	135.9
M7	Richness ~ Unique + Household Food	133.2
M8	Richness ~ Inexpensive + Household Food	140.1

Appendix Table A18. Final negative binomial regression plant selection criteria models for household planted tree, shrub, and herb species richness (n=34). Predictive criteria estimates are standardized from homeowner rankings of criteria, where 1 = very unimportant and 5 = very important.

Model & Variables	**Estimate**	**Std. Error**	**Z value**	**P**
Household Planted Tree Species Richness; p=0.003; Pseudo R^2 = 0.146				
Intercept	-0.04678	0.2459	-0.190	0.8491
Unique	0.5865	0.2354	2.491	0.0127*
Household Planted Shrub Species Richness; p=0.03; Pseudo R^2 = 0.385				
Intercept	-0.3330	0.2965	-1.123	0.2614
Unique	0.6529	0.2631	2.482	0.0131*
Inexpensive	0.7361	0.2959	2.487	0.0129*
Household Food	0.6099	0.2680	2.276	0.0229*
Household Planted Herb Species Richness, p=0.0925; Pseudo R^2 = 0.388				
Intercept	0.4284	0.2214	1.935	0.0530.
Unique	0.7292	0.2082	3.502	0.0005***
Inexpensive	0.4012	0.2345	1.711	0.0872.
Household Food	0.5119	0.2062	2.483	0.0130*

Significance levels: **.**p <0.1; *p≤0.05, **p ≤ 0.01; *** p < 0.001