The Residential Urban Forest: Linking structure, function and management

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Abstract

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Vegetation provides a suite of ecosystem functions (e.g., carbon storage) which are partially determined by the forest structure. In urbanizing regions, homeowners play a key role in shaping the structure of the urban forest because residential land is the dominant land use. As cities expand, the influence of single-family residents' land management on urban forest structure and function will increase because most new urban development is in this land use. Yet, we know little about the structure, functions, and dynamics of highly managed residential parcels.

I focus on the Seattle Metropolitan Region to examine the patterns of urban forest that emerge from the interactions between biophysical factors and backyard land management attitudes of homeowners and the implications for current and future carbon storage. I use urban gradient analysis and plant functional trait classification systems to (1) characterize the forest structure on single-family residential lots in urban and suburban areas, (2) investigate factors associated with decisions to plant or remove trees and how these management actions have altered and will continue to transform the forest structure over time, and (3) estimate the current and future carbon storage benefits based on reported management actions and considerations. I use two functional plant traits—height potential at maturity and leaf senescence— selected based on their sensitivity to management decisions and for their role in controlling ecological functions (e.g., carbon cycling).

Suburban parcels had more trees than those in the urban area. However, after accounting for parcel size there was no significant difference in tree densities. Compared to suburban residences, urban residential landscapes have significantly fewer trees with large size potential and more deciduous trees with small size potential. Trees with large size potential contribute the majority of the carbon storage benefits, consequently urban residential landscapes store less carbon (as aboveground plant biomass). Surprisingly, the tree planting and removal activities of residents during their tenure resulted in no significant change in tree density. However, increase in total carbon storage in suburban lots will be insignificant from the expected increase in small deciduous trees.

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INTRODUCTION

In cities worldwide, plant communities play key ecological functions (e.g., carbon cycling) that provide essential services to the human population. These functions that benefit humans are referred to as ecosystem services (Pataki et al., 2011), and most of them are based on forest structure—the amount and density of plants, their spatial configuration, species mix, and age profiles. For example, tree density mitigates greenhouse gas emissions, which contribute to global climate change (U.S. Conference of Mayors, 2008; Pataki et al., 2011).

Human actions in cities create a novel urban forest structure, with plant abundance and community compositions that differ from the natural environment in which the city is situated (Smart et al., 2006; Kowarik, 2011; Perring et al., 2012). We are just beginning to empirically test how the complex web of land use, socioeconomic factors, and urban morphology interact with the biophysical factors to shape the two principal drivers of plant community structure across the landscape: resource availability and disturbances (Alberti, 2008). Scholars of urban ecology have explored plant community structure using two theoretical frameworks, which are gradient analysis (Whittaker, 1967; McDonnell and Pickett, 1990) and plant functional trait classification systems (Schimper, 1903; Knapp et al., 2008). Functional traits are any attributes that have an influence on the establishment, survival, and the fitness of a plant (Reich et al., 2003). Scholars have found that urban plant communities tend to have high densities of specific plant functional traits, such as seed morphologies suited to wind pollination (full review in Knapp et al., 2008). At the same time, scholars have identified and explained patterns in community composition (flora and fauna) and ecological processes based on location along a gradient of urban intensity (McDonnell and Hahs, 2008).

These findings suggest that urban and biophysical drivers act as filters on the landscape, selecting for species with functional traits that allow them to be successful in the novel set of urban conditions that vary across an urban gradient (Knapp et al., 2008; Duncan et al., 2011). However, there have been no attempts to link gradient analysis with plant functional trait classification systems in order to explicitly test this hypothesis, nor have researchers used the spatial distribution of plant functional traits to predict how ecological functions vary along the urban gradient. Furthermore, most urban gradient and functional trait assessments have been restricted to analysis of plot-level vegetation surveys in parks, remnant forest/vegetation patches, or street trees (Knapp et al., 2008; McDonnell and Hahs, 2008), or they have used remotely sensed data to represent plant abundance or greenness (e.g., Pickett and Cadenasso, 2006; Buyantuyev et al., 2007).

Remotely sensed metrics range from simple measures of canopy cover and measures of greenness (Tucker et al., 1985; DeFries and Townshend, 1994) to vegetation characteristics such as growth form, leaf type and duration, and the life history of dominant plants (DeFries et al., 1995; DeFries et al., 1999). While these metrics can be used to rapidly characterize the vegetation across the full urban extent, they have not been validated using ground-truthed data to determine how well they represent vegetation properties in urban regions that are highly heterogeneous (e.g. Jensen et al., 2004; Mennis, 2006; Troy et al., 2007; Luck et al., 2009; Zhou et al., 2009). Also, interpreting these measures is challenging since they are often biased, depending on the number of spectral bands and pixel resolution. For one thing, they over-represent the dominant species in the canopy, which means that less-dominant species or those found in the understory are not well represented (Woodcock and Strahler, 1987; Lam and Quattrochi, 1992; Goodchild and Quattrochi, 1997). Furthermore, the interpretation of simple vegetative measures such as canopy cover or greenness is somewhat ambiguous. For example, one large tree may generate the same tree canopy cover as many small trees clustered in space. In my project, I use measurements of vegetation structure collected on-site. This allows me to include the understory trees and less common species when characterizing the urban forest structure.

Parks, remnant forest/vegetation patches, and street trees constitute a very small percentage of land in cities (Dwyer et al., 2000), so we have limited information on urban forest structure across the majority of the urban landscape. Finally, although urban ecological theory recognizes the integrated nature of biophysical and social components in creating the urban landscape, few assessments of urban vegetation have represented the human role in creating and sustaining the urban forest because the studies are often conducted within semi-natural vegetation patches and focus on natural regeneration processes. However, progress is being made. Scholars with the Central Arizona–Phoenix Urban Long Term Ecological Research project in Phoenix are making important advances in understanding emergent patterns of urban vegetation in residential landscapes using coupled human-natural theoretical frameworks, vegetative data, and information regarding attitudes, values, and land management (Cook et al., 2012). Analysis of ecological and social survey data at the household scale of analysis suggests that a combination of demographic factors, values, attitudes, site and neighborhood characteristics, and regional urban processes interact in complex ways to produce the residential vegetative communities (e.g., Martin et al., 2003; Yabiku et al., 2008; Larson et al., 2009). These interactions are likely different in cities located in the semi-arid region of central Arizona vs. cities within temperate climates. In this project, I contribute to the body of knowledge about urban forest dynamics by assessing a city with a very different climate—Seattle, WA. The Pacific Northwest is characterized by a maritime temperate climate that supports a very different type of vegetation compared with a semi-arid climate. The native vegetation of this region is naturally carbon rich; western hemlock and Douglas-fir forests are among the highest in terms of carbon storage in plant biomass (McKinley et al., 2011).

I focused my research on the structure and management of single-family residential lands. Collectively, homeowners play one of the largest roles in shaping the structure of the urban forest because residential land is the dominant land use in urban regions (Dwyer et al., 2000; Irwin and Bockstael, 2007). As cities expand, the influence of single-family residential lands on ecological functions increases because most new development results from the demand for this land use (HUD, 2000; Heimlich and Anderson, 2001). Therefore, understanding why individual households plant and/or remove trees on their properties is critical for understanding urban forest dynamics at the landscape scale and the subsequent effects on ecological functions (and services) across urbanizing regions. In this research, I describe the patterns, relationships, and effects of three key elements of the residential urban forest system: forest structure, management activities, and one ecological service—carbon storage. I estimate carbon levels stored as above-ground plant biomass.

I use urban gradient analysis and plant functional trait classification systems in tandem to (1) describe patterns of the urban forest structure of single-family residential lands across the urban landscape, (2) investigate factors associated with land management decisions to plant or remove trees based on two functional plant traits and how these management actions have altered and will continue to transform the plant community composition over time, and (3) estimate the carbon storage benefits we receive from these lands now and how the provision of this service might change in the future as a result of reported management actions and considerations. In order to explicitly represent the link between land managers (homeowners) and vegetation patterns, I selected the parcel as my unit of analysis. Finally, I selected two functional plant traits—height potential of the tree at maturity and leaf senescence—based on their sensitivity to management decisions (Schroeder and Ruffolo, 1996; Summit and McPherson, 1998; Lohr et al., 2004; Flannigan, 2005; Heimlich et al., 2008) and because they play an important role in controlling ecological functions (such as carbon storage and rainfall interception).

In what follows, I present three papers. In the first paper, I characterized the structure of the residential urban forest in the Seattle Metropolitan Region using dominant plant functional traits. I used plant functional trait theory to aggregate the characteristics of individual plants across the region. The objective of this study was to characterize the structure of the urban forest in order to provide insight into the selective biophysical and socioeconomic forces determining the composition of tree communities and to inform estimates of ecological processes mediated by these traits. I addressed three overarching research questions:

1. How does tree abundance vary between urban and suburban areas?
2. How does plant functional trait abundance vary within and between urban and suburban areas?
3. What is the age distribution of trees, both in general and by functional trait group, in the urban and suburban areas?

In the second paper, I empirically examined how the current structure and long term maintenance of the residential urban forest in the Seattle metropolitan area translates into the provision of carbon storage as above-ground plant biomass. Then I linked residential behavior (tree planting and removal) with measures of forest structure and composition to determine current carbon storage of the residential landscape and project changes due to land management actions. I utilized remotely sensed data, field-based measurements of vegetation structure, and information from a mailed yard care survey to provide new insight into the structural and functional dynamics of the residential urban forest. The three research questions I posed were:

1. How do levels of carbon stored in above-ground plant biomass vary between urban and suburban areas?
2. How do patterns of functional trait group abundance affect carbon storage across the urban gradient?
3. How have residents altered (by planting and removing trees) the structure of the residential urban forest during their tenure at their current residence, and what are the consequences of these activities on the carbon storage capacity of these lands?

In the final paper, I assessed differences in attitudes toward trees and management actions (tree planting and removal rates) of single-family residential homeowners. I then explored how these stated attitudes, in addition to past land management behavior (tree removal) and characteristics of their property, are associated with their decisions to plant a tree. The research questions I addressed are:

1. How do perceptions about the benefits and challenges of maintaining trees on their property vary between urbanites and suburbanites?
2. What are the differences in tree planting and removal actions across the urban gradient?
3. Why are residents planting and/or removing these trees?
4. What structural and attitudinal factors are associated with tree planting actions?

CHAPTER 1.

Using Plant Functional Traits to Describe the Structure of the Residential Urban Forest Along an Urban Gradient

ABSTRACT

Understanding the vegetation dynamics of urban residential properties is critical for determining the ecological functions and processes of urbanizing regions. Residential land use is the predominant land use in urbanizing regions (Dwyer et al., 2000; Irwin and Bockstael, 2007), and its influence is ever-increasing as homes continue to be built on larger lots (NAHB, 2005) at the periphery of the city (Robinson et al., 2005). There is a high concentration of synanthropic plant and animal species in the urban core (McKinney, 2006). However, these findings are largely based on empirical studies conducted from only the part of the urban landscape that consists of semi-natural remnant vegetation patches (e.g., Bagnall, 1979; Airola and Buchholz, 1984; McBride and Jacobs, 1986; Burton et al., 2005; Williams et al., 2005; Hahs and McDonnell, 2007). We know very little about the composition of the urban forest in highly managed urban landscapes such as those found in residential parcels, and so in this study I assessed the structure of the residential urban forest across a gradient of urbanization. I linked urban gradient and functional trait theories to explore how forest structure affects ecosystem functions across the urban landscape, and I selected two plant functional traits that are both sensitive to land management decisions and influential in controlling ecosystem processes: tree size potential and average leaf life duration. As expected, there were more trees per parcel in the suburban area (39 ± 8 trees per parcel) as compared with the urban area (15 ± 5 trees per parcel), yet there was no difference in tree densities between these two areas after accounting for parcel size. On the other hand, there are significant differences in the composition of the urban forest between these two regions. Urban residential landscapes have significantly fewer trees with large size potential and more deciduous trees with small size potential . These results suggest that a complex suite of urban drivers (e.g., household preference) are selectively acting on specific functional traits of plants with important implications for the provision of ecosystem functions across the urbanizing region.

INTRODUCTION

Residential housing is the dominant land use in urban regions (Dwyer et al., 2000; Irwin and Bockstael, 2002; Irwin and Bockstael, 2007), and its subsequent development is consuming an ever-larger portion of the urban landscape, especially with detached, single-family houses (Heimlich and Anderson, 2001; NAHB, 2005). In the U.S., the majority of new urban development consists of the construction of these residences, and recent trends include larger homes on larger lots (NAHB, 2005). Despite the efforts of urban planners to increase the density of city centers and older suburban centers, most population growth in many urbanizing regions is occurring at the fringe, far outside the urban core (Daniels, 1999; Duany et al., 2000). This type of growth is not limited just to the U.S. Globally, urban land cover is expanding at a rate twice that of urban population growth—cities are becoming more expansive rather than more compact (Angel et al., 2010; Angel et al., 2011; Seto et al., 2012). Simultaneously, average household size (the number of people per house) is getting smaller (Mackellar et al., 1995; Liu et al., 2003). The implications of these residential land use trends are that the amount of urban land cover per person will likely continue to increase, with significant ecological consequences.

Given the land area occupied by single-family residences, homeowners' yard design and management activities collectively play a key role in shaping urban vegetation dynamics. For example, today grassy lawns cover a spatial extent greater than any other irrigated crop in the U.S. (Milesi et al., 2005). The design and care for vegetation in these yards has a strong influence on the subsequent level of services and disservices derived from urban green spaces. Studying vegetation on these urban residential properties is critical for understanding its ecological functions in urban regions. Ecosystem services are the benefits society derives from these functions (MEA, 2005), while ecosystem disservices are the costs or "negative consequences or trade-offs of implementing green infrastructure" (Pataki et al., 2011, p. 28).

Ecological functions are driven by the structure of the ecosystem, such as the composition of the urban forest (Christensen et al., 1996). Moll (1995, p. 12) defines the urban forest as "the area in and around the places we live that has or can have trees," while the structure refers to the amount and density of plants, their spatial configuration, species mix, and age profile. The plant community within the urban forest has high densities of plants with specific functional traits (Knapp et al., 2008) that are selected for by both social and biophysical drivers. For example, studies in Europe as early as 1597 documented the abundance of weedy species (ruderals) co-locating in human settlements (Sukopp et al., 2008). They noted that urban areas support synanthropic species at higher frequencies, especially in the older, more densely settled urban core or other high disturbance sites (Sukopp et al., 2008). However, most of these studies focused exclusively on plants that naturally propagated and established themselves, and they excluded the deliberate human selective forces, skipping over highly manicured areas. Scholars have only recently started to characterize the structure of the full extent of the urban forest (e.g. Dorney et al., 1984).

In the residential urban forest, developers and homeowners are the key drivers determining the spatial arrangement of resources and disturbances. During the development phase of a new residential lot, vegetation is often completely removed from the site, then once the infrastructure and buildings are completed the developer hires a landscaping company to construct a lawn with a community of plants preferred by urbanites (Rebele, 1994).

After development is completed and residents move in, homeowners manage and modify their yards in ways that reflect their socioeconomic status, landscaping preferences, and desired uses of the land (Walker et al., 2009; Cook et al., 2012). Factors commonly linked to how homeowners design and manage their landscape include balancing both desires for benefits (e.g., shade), annoyances with disservices (e.g., allergies), and constraints (e.g., financial). For example, in the City of Seattle, constraints, disservices, and competing land uses were better predictors of tree removal decisions than the reported benefits of trees (Dilley, 2010). Space limitations, required maintenance, and protection of views were the dominant reasons a household decided to remove trees (Dilley, 2010). Other factors influencing yard design and management include socioeconomic status and resources (e.g., Hope et al., 2003; Kinzig et al., 2005; Grove et al., 2006), aesthetic considerations (Summit and McPherson, 1998; Spinti et al., 2004), ease of maintenance (Martin et al., 2003), neighborhood norms (Zmyslony and Gagnon, 1998; Martin et al., 2003; Nassauer et al., 2009), and standard nursery stock available in national retail stores (Walker et al., 2009).

McKinney (2006) suggested that a continuum of selective pressures exists along the urban gradient, with the plant community composition more closely resembling the natural ecosystem with higher numbers of native species at the periphery. It has been well documented that urbanization is not a homogenous process (e.g., von Thunen, 1826). The densities of development, infrastructure, impervious surfaces, and human population are not evenly spread across the urbanizing region, but instead they vary along a complex gradient in space that changes over time (McDonnell et al., 1993; Medley et al., 1995; Alberti et al., 2001). As expected, the impact of urban processes on ecological patterns and processes co-vary along this gradient (McDonnell and Hahs, 2008). Urban gradient assessments have described the spatial variability of land values and land use, including the human dimensions and the geochemical and biotic patterns and functions (reviewed by Pickett and Cadenasso, 2006; McDonnell and Hahs, 2008). Urbanization results in a gradient of resources and disturbance conditions that filter and select individual plants with a specific set of traits suited to these conditions, resulting in a distinct community composition (McDonnell et al., 1997). However, empirical evidence to support this has been collected from natural or semi-natural remnant vegetation patches within the urban matrix (e.g., Burton et al., 2005; Williams et al., 2005; Hahs and McDonnell, 2007), and these lands occupy only an estimated 10–20% of the urban landscape(The Heinz Center, 2002). To further our knowledge of the full extent of the residential urban forest, I characterize the structure of the residential urban forest across a gradient of urban intensity, partitioned into two regions representing a well-developed urban core and the suburban periphery.

Urban gradient assessments can help provide mechanistic insights into the coupled dynamics of social and ecological patterns and processes (McDonnell and Hahs, 2008) and advance the study of urban ecosystems by facilitating comparisons within and among urban areas (Boone et al., 2012). However, these assessments need to use objective, indirect measures of urbanization to develop robust comparisons among cities (McDonnell and Hahs, 2008). A number of measures have been proposed to represent the variability of urbanization patterns and processes (Hahs and McDonnell, 2006). Early studies largely utilized very simple measures of Euclidian distance from the central urban core (Pouyat and McDonnell, 1991; Medley et al., 1995; Pouyat et al., 1997; Lovett et al., 2000; Wolf and Gibbs, 2004; King et al., 2005; Hutyra et al., 2011; Berland, 2012), disregarding the polycentric nature of metropolitan regions and obscuring the natural variation in the biophysical template (Alberti, 2008). Other common metrics have included measures of impervious surface area (Berland, 2012; Raciti et al., 2012), land use and population density (Blair, 1996), and landscape fragmentation metrics (Zhang et al., 2004; Hahs and McDonnell, 2006).

There is likely not a single standard set of metrics for quantifying variation in patterns and processes (McIntyre et al., 2000), although metrics that reflect the social, economic, and physical characteristics of human settlements have been proposed as a promising starting point (Hahs and McDonnell, 2008; Raciti et al., 2012). In this study, I selected three variables for defining an urban gradient that represent these components of urbanization: population density, elevation, and distance from urban centers. I used land cover and the natural spatial variation of the urban gradient to delineate an urban core and suburban area. Then I tested for differences in the structure of the urban forest between these two partitions.

Even with the plethora of urban gradient studies, as of yet only a handful have explicitly utilized functional trait schemes to describe the selective forces generating these patterns and the resultant ecological consequences (Williams et al., 2005). Those that have explicitly represented functional trait classification schemes have only assessed differences between urban and non-urban, rather than describing the variation along a gradient of urban influence. Few studies, if any, have investigated the functional traits of plants in the highly manicured lands and the management practices within urban areas, even though these lands are the dominant land cover in urbanizing regions. In this research, I linked functional trait classification schemes with an urban gradient analysis framework to characterize these understudied urban lands.

Functional traits are any attributes that have an influence on the establishment, survival, and fitness of an individual organism such as drought resistance or nitrogen fixing (Reich et al., 2003). The spatial arrangement of resources (light, water, nutrients), and stressors and disturbances (storms, temperature, trampling) across the biophysical template selects species with traits that are well suited to the site conditions and filters out those that are not (Schimper, 1903; Lavorel and Garnier, 2002). The plants that do succeed in establishing are important determinants of how the ecosystem functions because plants influence and control many ecosystem processes such as rainfall interception, carbon storage, and nutrient cycling. Scholars have used plant functional trait classification schemes to group plants with similar traits to characterize the plant community and to understand both how plant assemblages are created and the resultant effect on ecosystem processes (Lavorel and Garnier, 2002).

There are two important benefits of using a functional trait classification scheme: (1) because it is usually impossible to study all species living in an ecosystem at once, such a scheme represents a framework to aggregate species in order to characterize the basic building blocks of communities based on their ecological functions (Hawkins and MacMahon, 1989); and (2) such a scheme provides a common language of plant traits that can be used in the comparative study of communities across regions and scales (Terborgh and Robinson, 1986; Simberloff and Dayan, 1991). In addition, plant functional traits have been used to understand the landscape distribution of multiple ecosystem services (Lavorel et al., 2011) in order to build quantitative models of ecosystem service provision based on geographic data of environmental variables (Diaz et al., 2007) and to project future ecosystem service levels under alternative management strategies and future scenarios (Que´tier et al., 2007).

In this research, I characterized the structure of the residential urban forest in the Seattle Metropolitan Region using dominant plant functional traits. I use plant functional trait theory to aggregate the characteristics of individual plants across the region, focusing on two traits that are actively selected by urban regions, specifically by homeowners, and that play a key role in determining ecosystem functions: tree size potential and average leaf-life duration (evergreen vs. deciduous). The objective of the study was to characterize the structure of functional trait groups within the urban forest in order to provide insight into the selective biophysical and socioeconomic forces determining the composition of tree communities and to inform estimates of ecological processes mediated by these traits. I addressed three overarching research questions:

Question 1**.** How does tree abundance vary between urban and suburban areas?

Question 2**.** How does plant functional trait abundance vary within and between urban and suburban areas?

Null hypothesis: The residential urban forest will have an abundance of specific functional traits related to land management goals and landscape constraints (such as parcel size), but the density and abundance of plant functional traits will not vary between the urban and suburban areas. Given the theory that resources and constraints structure tree communities, I expect to see this pattern if there are no underlying spatial patterns of preferences for trees within specific functional trait groups or spatial patterns of household constraints, such as limited finances or physical constraints (parcel size can limit available growing space). To date, few have assessed how residents' preferences for functional traits and irritations with trees, such as blocked views, vary across an urban region. Williams and Cary (2002), however, found that there were no differences in preferences for native vegetation between urbanites and suburban residents, while (Kaplan, 1987; Gobster, 1994) posited that humans have evolved with a preference for savanna-like landscapes (expanses of grasses interspersed with large trees) because it is associated with both a sense of protection from the environment and keeping sightlines intact.

Urban gradient hypothesis: I expect tree densities and functional trait abundance to vary along a gradient of urbanization due to changes in resources and constraints across space (such as clustering of households with similar preferences for particular types of landscaping and trees). Tobler's (1970) first law of geography posits that things that are closer in space tend to be more similar than things that are further apart, which would suggest that residents with similar preferences, resources, and land management practices will be clustered along the urban gradient. Also, bid-rent theory (von Thunen 1826; Alonso, 1964) suggests that lot size, and therefore available growing space, will increase with distance from urban centers. The natural extension is that the distribution of trees, overall and aggregated by specific functional trait groups, will also vary along an urban gradient.

Question 3. What is the age distribution of trees, in general and by functional trait group, in the urban and suburban areas?

Null hypothesis: There are no differences in the age structure of trees between the urban and suburban environments. Residents are planting and removing trees at similar rates between the urban core and the suburbs, and there is no legacy effect evident in age distribution that may be explained by development history (i.e., suburban areas tend to be characterized by newer homes).

Urban gradient hypothesis: Trees in the suburban environment are younger than trees in the urban environment. Suburban homes tend to be more recently built than those in the urban core, and therefore I expect there will be more young and fewer old trees in the suburbs.

In the sections that follow I synthesize the studies on plant functional trait theory relevant to residential urban forest management. Next, I summarize my research design, detailing how I integrated plant functional trait classification schemes and gradient analysis to describe the structure of the residential urban forest. Finally, I present and discuss the major findings.

Plant functional traits

I considered plant functional traits that matched the following criteria established from the literature:

- Practicality for literature synthesis—the trait should be easily quantifiable (Westoby et al., 2002);
- Ecological significance—the trait plays an important role in ecosystem processes that are well understood by scientists (Westoby et al., 2002);
- Spread and consistency—there is variation in characteristics between species, and within species the range of variation is relatively low (Westoby et al., 2002); and
- Parsimonious—the traits contribute unique information, and trait dimensions are not redundant (Westoby and Wright, 2006).

Three trait dimensions of plants have emerged that meet these criteria—leaf economic spectrum based on leaf economies (higher leaf mass per leaf area); seed economic spectrum based on seed size, nutrition, etc; and size potential based on canopy height at maturity (Westoby, 1998; Weiher et al., 1999; Westoby and Wright, 2006). I chose not to assess seed functional traits in this project, but did include the other two traits.

I excluded seed characteristics since land management activities largely determine community composition in urban areas, which are highly controlled and manicured landscapes. Most trees in residential landscapes have been raised in nurseries and then planted and maintained by homeowners, which largely removes the selective role of drivers of urban plant community composition on seed economies in urban regions. Only 5% of the residential trees in Edmonton, Canada, were the result of natural reproduction from seed or suckers, while 72% were purchased from commercial nurseries (Waldron and Dyck, 1975).

In this project I broke the spectrum of leaf economies into two groups—deciduous and evergreen—determined by leaf longevity. Leaf economy represents the ratio of the costs to the plant associated with producing and maintaining a leaf compared with the benefits derived from the leaf (Wright et al., 2004). Leaf economy is often measured as leaf mass per leaf area because species with higher values tend to have longer average leaf life spans (Wright et al., 2004). I represented leaf economies in a more simplistic manner, as a dichotomy of either evergreen (durable leaves, long lifespan) or deciduous (short lifespan, and they shed their leaves at the end of the growing season). Evergreens tend to have durable leaves with a long lifespan, while leaves of deciduous trees have a short lifespan because they shed their leaves at the end of the growing season. Additionally, urbanites are familiar with these traits, which are very likely among the considerations in their yard management decisions.

The second trait I assessed was size potential—i.e., using the height of a one-story house as the cutoff point to demark large vs. small tree size potential (at maturity). Both of these functional traits have been reported as being sensitive to yard management decisions.

Effects of leaf economy and size potential on ecosystem functions

Evergreen and deciduous trees have distinct influences on ecosystem functions, including different nutrient cycling, growth, and decomposition rates (Aerts, 1995). Evergreen leaves are long lived and need to be resistant to environmental stress and herbivory, and these same traits also result in slow decomposition and nutrient cycling (Aerts, 1995). Deciduous leaves are associated with higher nutrient concentrations (nitrogen and phosphorous), fast gas-exchange rates, and faster decomposition rates (Reich et al., 1992; Reich et al., 1997; Wright et al., 2004).

The height of trees scales with total tree biomass, which means that taller trees are also larger trees (Enquist, 2002). At the most basic level, height is an indicator of competitive ability and a determinant of plant persistence (Weiher et al., 1999). Tree size (amount of plant biomass) is an important determinant of ecosystem processes, especially those associated with environmental regulating functions. Large trees sequester more carbon, have more canopy to intercept rainfall (stormwater benefits), and provide crucial habitat for urban wildlife (Stagoll et al., 2012) in comparison with trees that are small in stature at maturity.

Land management preferences

Researchers have explored the perceptions and attitudes of urban residents regarding tree types. The results have been limited and at times contradictory, especially with regard to tree size. Within the literature, the most-discussed traits that are distinct between evergreen and deciduous trees are required maintenance (e.g., leaf raking), brightly colored fall foliage, fruit, and flowers. Residents repeatedly rank the marking of changing seasons and fall color at the top of lists of tree benefits (Sommer et al., 1990; Schroeder et al., 2006). This may explain the results of a preference study that reported that residents tend to favor residential landscapes composed of trees with more coarse foliage (generally broadleaved trees) over trees with fine foliage (generally conifers) (Williams, 2002). Trees with fruit (Summit and McPherson, 1998) and/or flowers (Sommer et al., 1990) ranked high on stated preference lists of attractive tree characteristics, and these tend to be deciduous trees (e.g., Prunus and Pyrus species). Schroeder and Ruffolo (1996) found that the most desired tree species are those with attractive flowers, and ornamental trees with showy flowers and autumn color were reported as the most popular type of tree in southwest Scotland (Hitchmough and Bonugli, 1997). However, the results from previous studies indicate that a trade-off exists in maintaining deciduous trees between preferences for autumn color and yards that are easy to maintain. A commonly listed reason for tree removal from residential yards is that the tree was too messy to maintain (Summit and McPherson, 1998). Fallen leaves is consistently at the top of lists of annoyances homeowners feel toward trees, but they are typically ranked as only a minor annoyance (Sommer et al., 1990; Schroeder and Ruffolo, 1996; Schroeder et al., 2006).

Urbanites both appreciate and dislike some of the factors associated with maintaining large trees, and subsequent management and tree selection are influenced by a suite of trade-offs between benefits and annoyances that large trees provide. For example, large trees provide shade, which can be appreciated as protection from the sun or perceived to be a nuisance because they block the sunshine and make yards dark. In many studies, shade is commonly ranked as one of the highest benefits provided by trees and as a primary motivator for residents in selecting which type of tree species to plant in their yards (Sommer et al., 1990; Summit and McPherson, 1998). In preference surveys, residents ranked large trees, especially street trees, as more appealing than small trees (Kalmbach and Kielbaso, 1979; Sommer et al., 1993; Sommer and Summit, 1995). Tree size emerges as the most influential determinant when respondents characterized qualities that contributed to an attractive residential street scene, especially when larger trees canopied the street (Schroeder and Ruffolo, 1996).

Biophysical conditions may act on preferences and explain why results from studies in different regions of the world are contradictory. In opposition to the previously mentioned studies in which residents favored large, shade-providing trees, tree size has also been found to be one of the most prevalent reasons for tree removal (Summit and McPherson, 1998), with residents citing blocked views (Lohr et al., 2006; Schroeder et al., 2006) and dark streets and yards (Sommer et al., 1990; Schroeder et al., 2006) as annoyances associated with maintaining large trees. A more recent study by Summit and Sommer (1999) reported that residents have an overall preference for smaller trees, in contrast to their earlier work. In Melbourne, Australia, residents preferred medium-sized trees (Williams, 2002), while in three communities in southwest England residents showed a preference for smaller trees (Flannigan, 2005). Climate was suggested as a potential explanation for these differences—i.e., that the amount of sunlight plays a strong role in determining whether large trees are viewed as making streets too dark or providing shade (Flannigan, 2005). An alternate explanation for these discrepancies in preferences for large trees is the role of heritage on preferred tree forms. In a cross-cultural study conducted in Toronto, Canada, Fraser and Kenney (2000) found evidence that heritage may explain preference differences for large vs. small trees. At the same time, environmental constraints such as lot size may also play a role in how residents select trees based on size potential since a densely constructed urban environment limits available growing space for large-statured trees.

Schroeder and Ruffolo (1996) compared the perceptions of tree benefits and annoyances of residents living in neighborhoods characterized by sparse tree cover, many small trees, and many large trees. The urban forest structure explained differences in perceptions between neighborhoods. Residents in neighborhoods with a majority of small trees indicated that they would like more large trees, while those living in communities with many large trees were content with the size of trees in their neighborhoods (Schroeder and Ruffolo 1996). At the same time, residents in the neighborhood with large trees also reported many more tree annoyances than the residents in the other neighborhoods, including problems with surface roots, suckers, dripping sap, and falling leaves and debris (Schroeder and Ruffolo 1996). This study indicates that trade-offs exist, that they are presumably considered by homeowners in their choice to select and maintain large or small trees, and that the current structure of a yard is an important determinant of resident perceptions of tree benefits and annoyances.

METHODS

Study region

My study area includes single-family homes within King County, which currently contains 39 municipalities, the largest being the City of Seattle. Seattle originated as a port town, but subsequent growth has spread outward from the initial port locations. The Seattle-Tacoma-Bellevue metropolitan statistical area (Seattle MSA) extends beyond my study region to include Snohomish, Pierce, and Kitsap counties, in addition to King (U.S. Census, 2010). An estimated 3.5 million people live in the Seattle MSA, with the majority (2 million) residing in King County (U.S. Census, 2010).

The region lies within the *Tsuga heterophylla* (western hemlock) vegetation zone. Prior to European settlement, this landscape was dominated by conifer forests characterized by Douglas-fir (*Psuedotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) plant associations (Franklin and Dyrness, 1973). The forests of this region are unique for both the size potential and longevity of the dominant tree species. Typical species can live beyond 500 years and reach heights up to 75 meters at maturity (Franklin and Dyrness, 1973). These forests are naturally carbon rich, with plant biomass stores of 350 Mg C/ha (Harmon et al., 1990; McKinley et al., 2011). Large expanses of land on the eastern edge of the MSA remain as working forestlands and protected wildlands (refer to land cover in Fig. 1.1). Most of these forests are young, second-growth conifer stands that have regrown after the large-scale timber harvesting and clearing beginning at the turn of the century.

Local jurisdictions have invested in urban forestry work in this region, and the Seattle metropolitan region has many active urban forestry programs. For example, the City of Seattle has pledged to increase canopy cover to 30% by 2037 (City of Seattle, 2007). The city government of Seattle provides around 1,000 trees to homeowners each year for planting on private residential property because it recognizes that in order to achieve these canopy cover goals they will need to increase the number of trees on private lands, particularly single-family residential properties (Dilley, 2010).

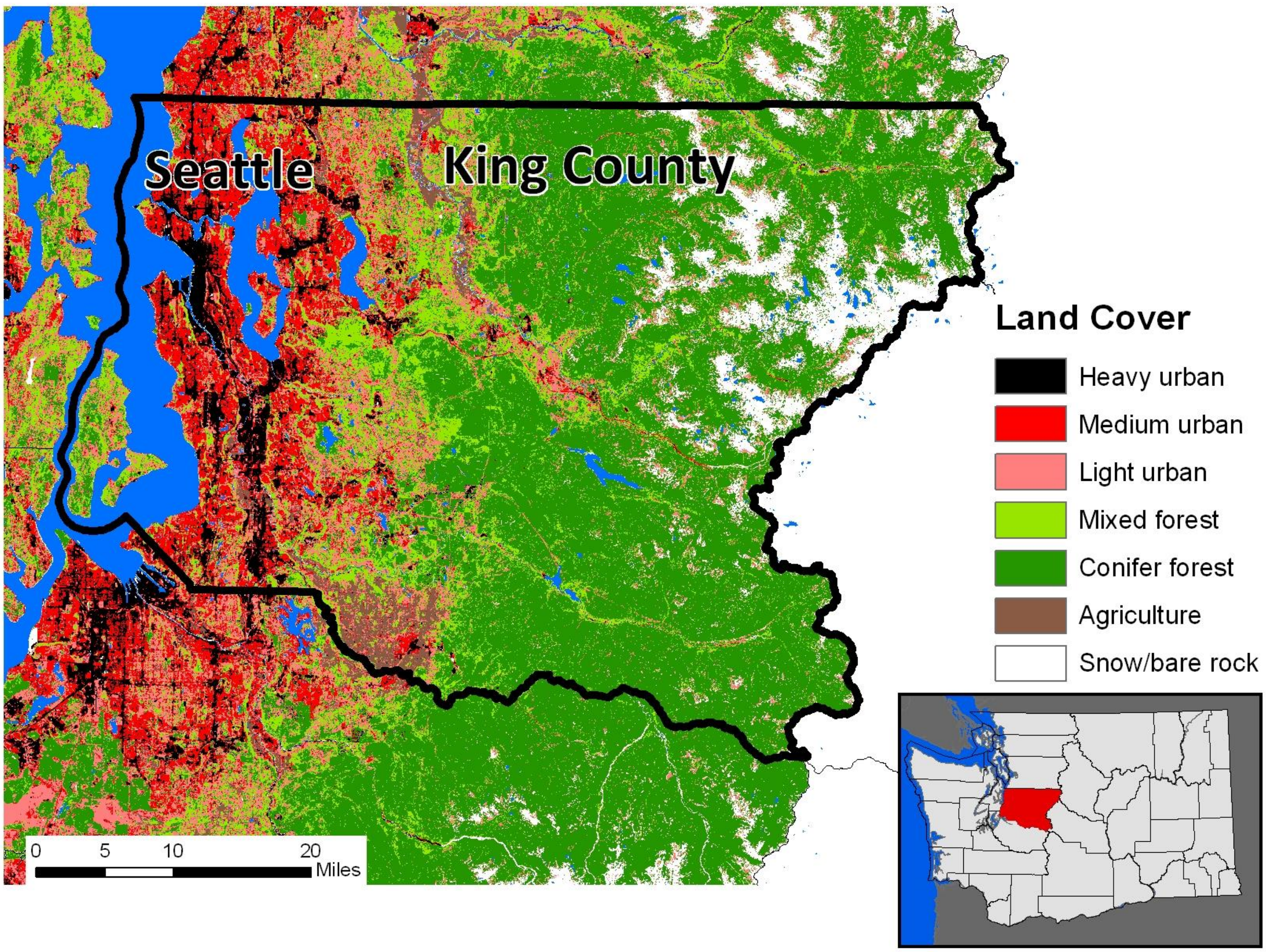


Figure 1.1. King County and the Seattle metropolitan region. Land cover data derived from LandSat TM imagery from 2007 (Marsik and Alberti, 2010).

Data collection

I collected data on the vegetation and parcel characteristics of 100 owner-occupied, single-family residential parcels within King County (Fig. 1.1). Land parcels were selected using a stratified random-sampling technique based on an urban gradient and the dominant land cover of the parcel as described in the next section.

Urban Gradient Stratification

In order to study ecological processes in the urban environment and to facilitate comparisons among cities, scientists must use appropriate objective, easily quantifiable, indirect measures of urbanization (McDonnell and Hahs, 2008). Urban gradient studies have utilized a plethora of measures to represent urban intensity gradients (McIntyre et al., 2000; Theobald, 2004). In this project, I developed an urban gradient for sampling purposes that takes into account the social, economic, and biophysical elements of the urban environment. I used principal-component analysis on three variables—distance from urban centers, population density, and elevation (the same as Alberti, 2008)—and I also defined the urban gradient using principal-component analysis. This creates one vector that accounts for as much of the variability in these three urban gradient variables as possible (Jolliffe, 2005). I normalized each variable by subtracting the mean and dividing it by the standard deviation, and I log-transformed population density. The final gradient vector explained 89% of the variation in the three variables. The principal-component equation is as follows:

Equation 1: Urban gradient = 0.5 * (elevation) - 0.58 * (log population density) - 0.64 * (distance from urban centers)

I used Jenk's natural-breaks classification method (Jenks, 1967) in the ArcGIS software package, version 9.1, and the distribution of land cover (from 2007) along the urban gradient to partition King County into three regions: heavily urbanized, suburban, and rural/exurban. The land cover data were created with supervised classification techniques at the University of Washington Urban Ecology Research Lab (overall accuracy of 62–89%) (Alberti et al., 2004; Alberti et al., 2006; Marsik and Alberti, 2010). Figure 1.2a illustrates the land cover composition along the urban gradient and the two division points that separate the urban, suburban, and exurban zones. The division between the urban and suburban zones is located where the amount of medium urban land cover is in decline while light urban land cover is approaching its peak. The break between the suburban and exurban zones is at the end of the light urban peak as the amount of conifer land cover is on the steep incline. The map of the final gradient partitions used for sampling is found in Fig. 1.2b.

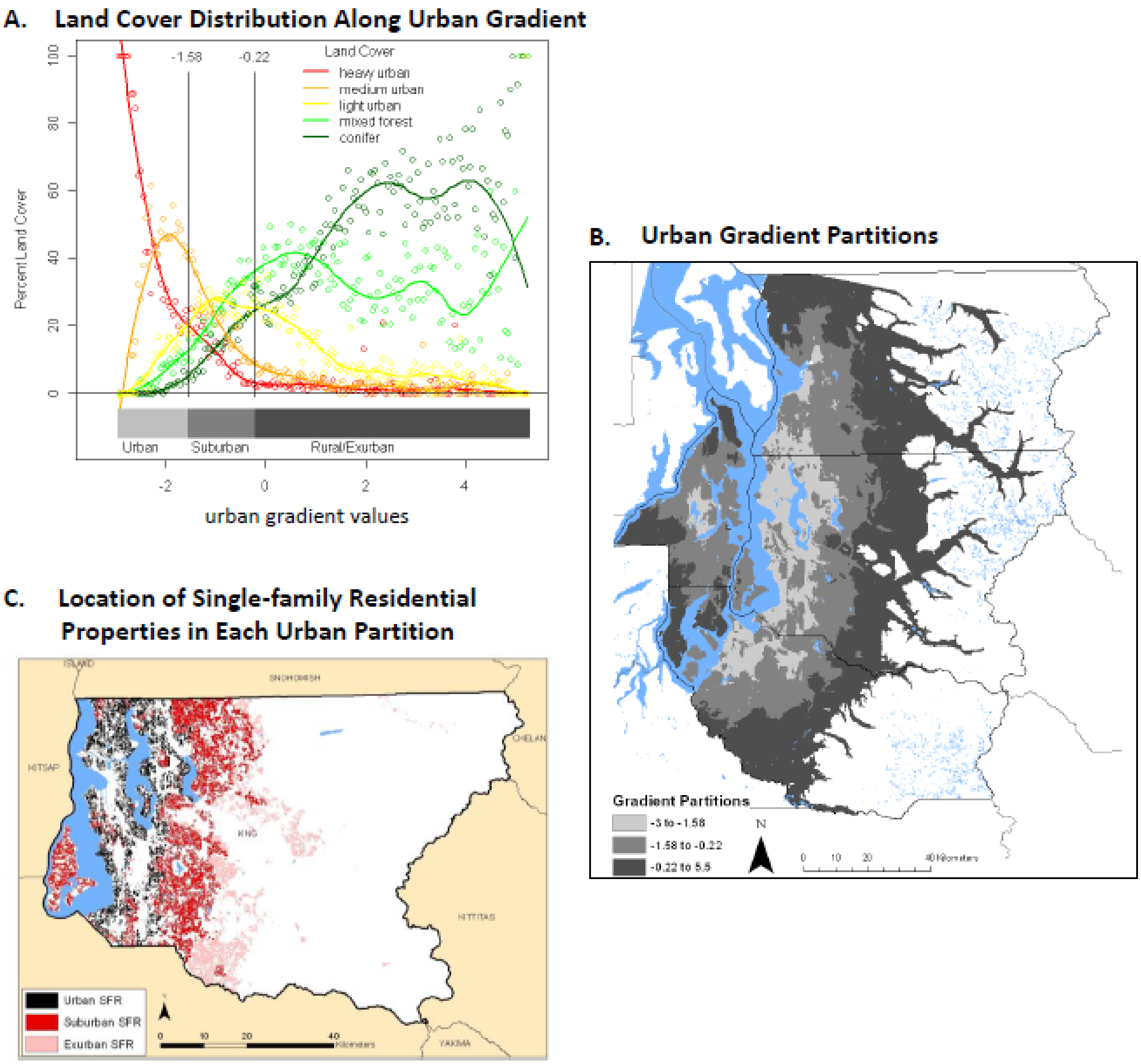


Figure 1.2. (A) The distribution of land cover classes along the urban gradient; (B) map of the resultant urban gradient partition across the Seattle metropolitan region; (C) map of the single-family residential properties in just King County in each urban gradient zone.

I calculated the urban gradient using data extending across the full four-county MSA, but in this research I used just the information for King County, which was my study region. In King County, there are approximately 461,000 parcels with a present land use listed as detached, single-family residential in the King County Tax Assessor parcel database (2008). Table 1.1 lists the descriptive statistics of these characteristics for the single-family residential parcels in each zone along the urban gradient, and Fig. 1.2 c shows the location of these parcels. Of these parcels, 64% are located in the urban zone, 31% in the suburban zone, and just 5% in the exurban zone (Table 1.1). Both the mean and median parcel size increase along the urban gradient, with the smallest parcels being located in the urban zone and the largest in the exurban zone (Table 1.1). Due to the low representation of single-family homes in the exurban zone, it was excluded from further analysis.

Table 1.1. Descriptive Statistics of the Single-Family Residential Parcel Characteristics in Each Urban Gradient Zone

	Urban	**Suburban**	**Exurban**
Parcel Count	295,000 (64%)	142,000 (31%)	24,000 (5%)
Mean parcel size	800 m^2 (0.2 acres)	3,000 m^2 (0.74 acres)	9,000 m^2 (2.2 acres)
Median parcel size	705 m^2 (0.17 acres)	954 m^2 (0.24 acres)	2,847 m^2 (0.7 acres)

Land Cover Stratification

In order to represent residences with both high and low forest-cover types, I stratified my urban and suburban samples using an additional variable—land cover—to ensure that I had a sample that represented yards with high and low tree cover. For each detached, single-family residential parcel in King County, I calculated the fractional percentage of land cover using the 14-class land cover geo-database with imagery from 2007 (Alberti et al., 2004; Alberti et al., 2006; Marsik and Alberti, 2010). Most parcel borders did not align directly with the border of the land cover grid, in which case only the proportion of the pixel that overlapped the parcel was included in the calculations (a weighted average based on the area of the pixel that overlapped the parcel). In the urban and suburban zones, most parcels were covered by one of five land cover types (refer to Figure 1.3). These predominant land cover types were heavy urban (>80% impervious surface coverage), medium urban (50–80% impervious surface coverage), light urban (<20–50% impervious surface coverage), mixed deciduous and conifer forest, and conifer forest. To simplify interpretation of the landscape, only parcels covered with one dominant land cover were selected, and the minimum threshold was set at 75% coverage.

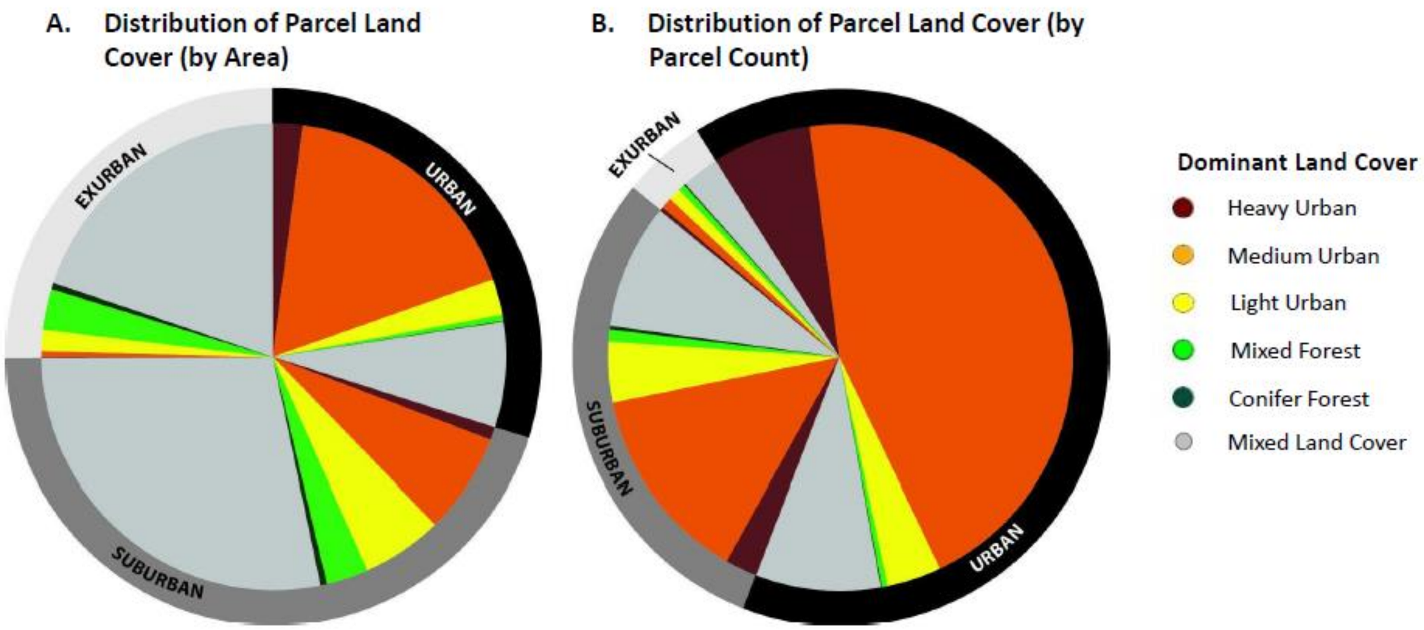


Figure 1.3. Distribution of land cover within the urban and suburban partition by (A) land area and (B) parcel count.

The final sample stratification design resulted in 10 sample partition groups: five land cover types (heavy urban, medium urban, low urban, mixed forest, and conifer forest) in the urban zone and the same five land cover type groups in the suburban zone (Fig. 1.4). For each of these groups, ten properties were randomly selected. Since single-family residential properties are privately owned, I needed to obtain permission to gain access to each property, so I sent a letter requesting access for research purposes to these randomly selected properties (a copy of the letter is presented in Appendix A, Fig. A1). The letter explained that participation only required granting a team of scientists permission to visit the property in order to collect information on the trees and vegetation located there. In an effort to increase the response rate, each letter was personally signed, the address on the envelope was hand written, and a postage-paid reply note card was included in the mailing Appendix A, Fig. A2 (Dillman, 2000; Dillman, 2009). Rounds of letters were mailed until I had received permission to access at least ten properties in each of the ten stratification zones, resulting in a total of 100 properties.

Figure 1.4. Aerial photos of typical properties in each of the sample partitions.

In total, I mailed approximately 500 letters to property owners, not including those letters returned due to vacant properties (Table 1.2). Overall, I had a 31% positive participation response rate. Surprisingly, the response rate for each of the sample stratification groups appeared quite different (Table 1.2; Fig. 1.5), indicating that both levels of stratification are appropriate in order to represent a diversity of properties with regard to the urban gradient and land cover types. In general, as the percentage of impervious surface coverage increased, positive participation response rates decreased, and this trend was more pronounced in the suburban area than the urban area. The lower response rate of residents on parcels with low tree cover (higher impervious surface coverage) suggests that these parcels may be under-represented in samples that are not stratified by land cover. A comparison of parcel size of the sample of properties where I was granted access vs. the full population shows that there was no significant difference, which suggests that the sample was representative of the population (Table 1.3).

Final plot locations are shown in Fig. 1.6 a, and households that either did not respond or denied property access are mapped in Fig. 1.6 b.

Table 1.2. Response Rates of Households Granting Property Access for This Research Project

	Heavy Urban (>80% IS)	**Medium Urban (<80–30% IS)**	**Light Urban (<30% IS)**	**Mixed Deciduous**	**Conifer**	**Total**
Urban	22% (11/51)	34% (13/38)	33% (16/48)	31% (10/32)	38% (11/29)	**47% (93/198)**
Suburban	11% (12/110)	14% (11/79)	43% (13/30)	25% (14/57)	50% (14/28)	**21% (64/304)**
Total	**14% (23/161)**	**29% (34/117)**	**37% (29/78)**	**27% (24/89)**	**44% (25/57)**	**31% (157/502)**

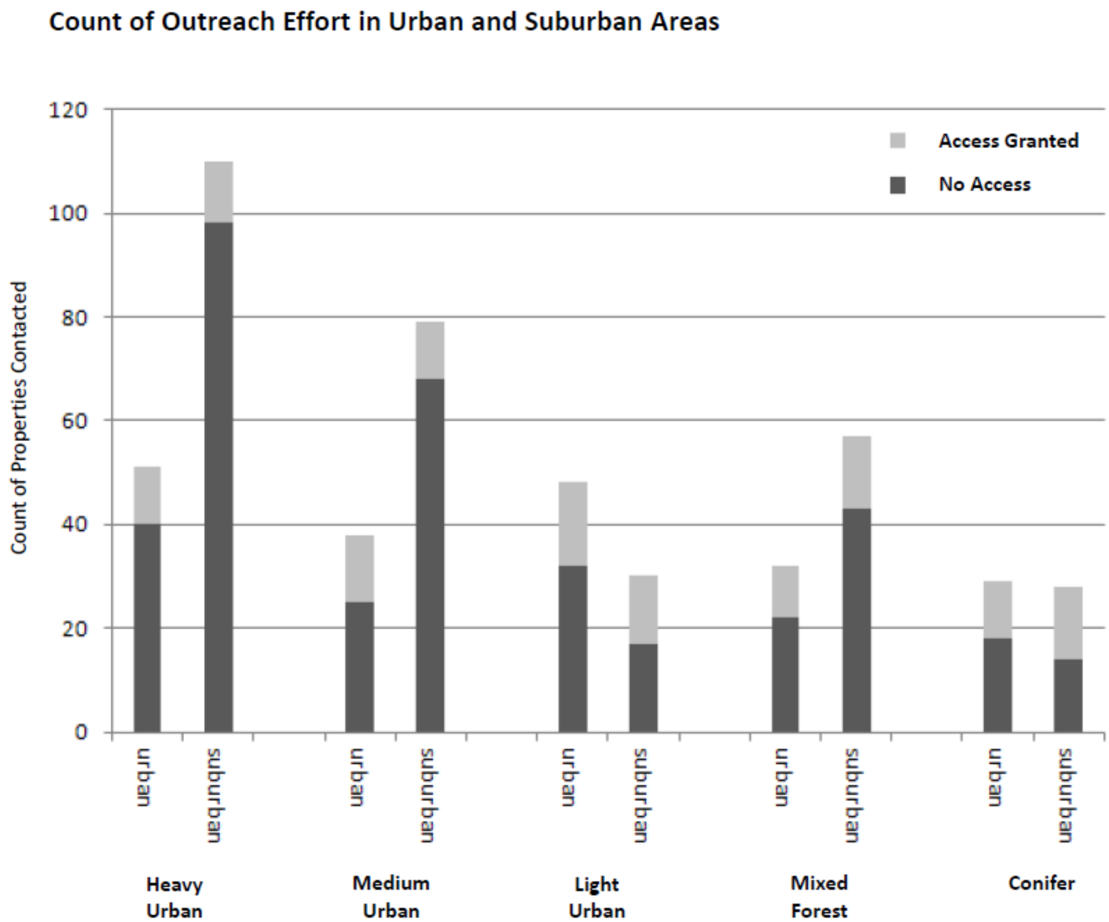


Figure 1.5. Positive and negative (including both access denied or no response) response rates for each sample group.

Table 1.3. Comparison of Parcel Characteristics Between the Sample and the Total Population

	Population: Mean Parcel Size (Acres)		Sample: Mean Parcel Size (Acres)	
	Urban	**Suburban**	**Urban**	**Suburban**
Heavy urban	0.14	0.19	0.11	0.17
Medium urban	0.19	0.24	0.14	0.2
Light urban	0.32	0.64	0.21	0.59
Mixed forest	0.49	1.6	0.59	1
Conifer	0.36	0.86	0.36	1

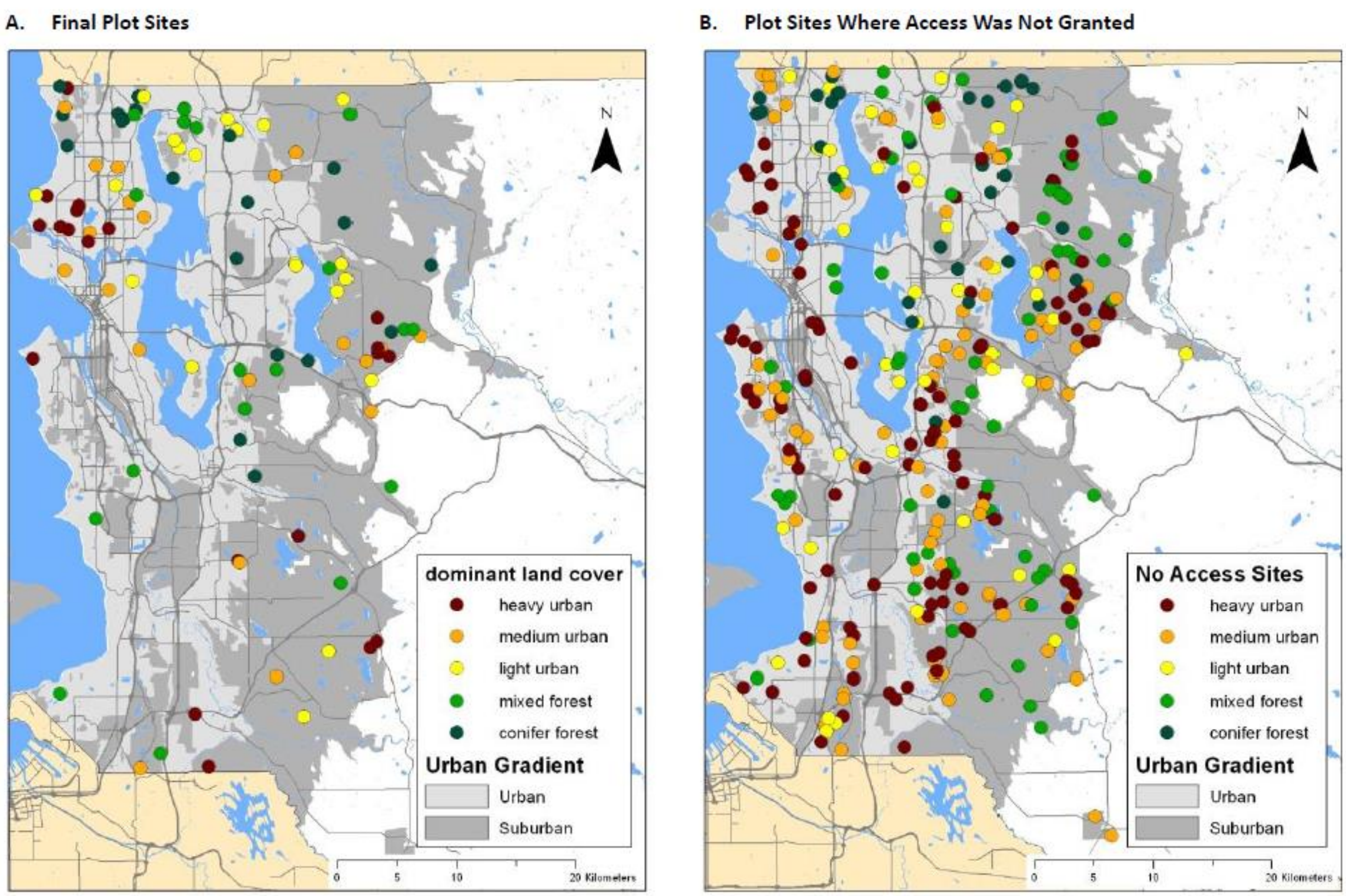


Figure 1.6. Map of the 100 sample locations, with the land cover and position within the urban gradient partition (A) and the locations of the properties that did not grant access (B).

Vegetation measurements

I identified and measured all woody stemmed plants with a diameter at breast height (DBH) greater than or equal to five cm. I split the tree-count densities into four functional trait type groups based on size potential and leaf-life duration (leaf economy, evergreen or deciduous). The cutoff point between the two tree-size groups was based on height potential at maturity, with a threshold of 9.1 meters (30 feet), roughly the height of a one-story house. The plot area was variable, as was the size of the single-family residential parcel where data were collected. However, if the parcel was large (> 1,000 m^2, or 0.25 acres), then a circular plot with a radius of 15 m was randomly placed within the property boundary. Average parcel size for each sample partition is listed in Table 1.3. All tree density measurements were calculated as the tree count at the plot divided by the plot area.

Analysis

Statistical analysis was performed using the "survey" package for the R statistical environment (Lumley, 2010), including the estimates of the community weighted mean and totals for each sample in the urban and suburban areas. Significance of differences in plant abundance measures were assessed using the generalized linear model function (svyglm, Gaussian family) and ANOVA/F tests, which were also in the survey package. Levels of significance were set at 5% ($\boldsymbol{\alpha}$ = 0.05).

RESULTS

Patterns between urban and suburban areas

Tree abundance in urban, single-family residential lots was 15 $\pm$ 5 per parcel and 39 $\pm$ 8 in suburban areas (Fig. 1.7 a). Overall, there were significantly more trees per parcel in the suburban partition in comparison with the urban area (Fig. 1.7 a). However there is no difference in tree density after normalizing by the size of the parcel (Fig. 1.7 b). The average parcel size of the homes in the suburban area is larger than those in the denser urban core: 3,000 m^2 (0.74 acres) and 800 m^2 (0.2 acres), respectively. After dividing the total tree count by the parcel size, the urban partition had 86 $\pm$ 24 trees per acre, while the suburban area had 73 $\pm$ 11. Plotting the density of trees by current size distribution is often used as a proxy for indicating the age structure of the forest (Bruce and Schumacher, 1950). After normalizing by parcel area, the distribution of tree sizes is quite similar between the urban and suburban areas (Fig. 1.7 d). The size distribution follows an inverse J-curve, which indicates that there are small trees that can replace the older, large trees as they age.

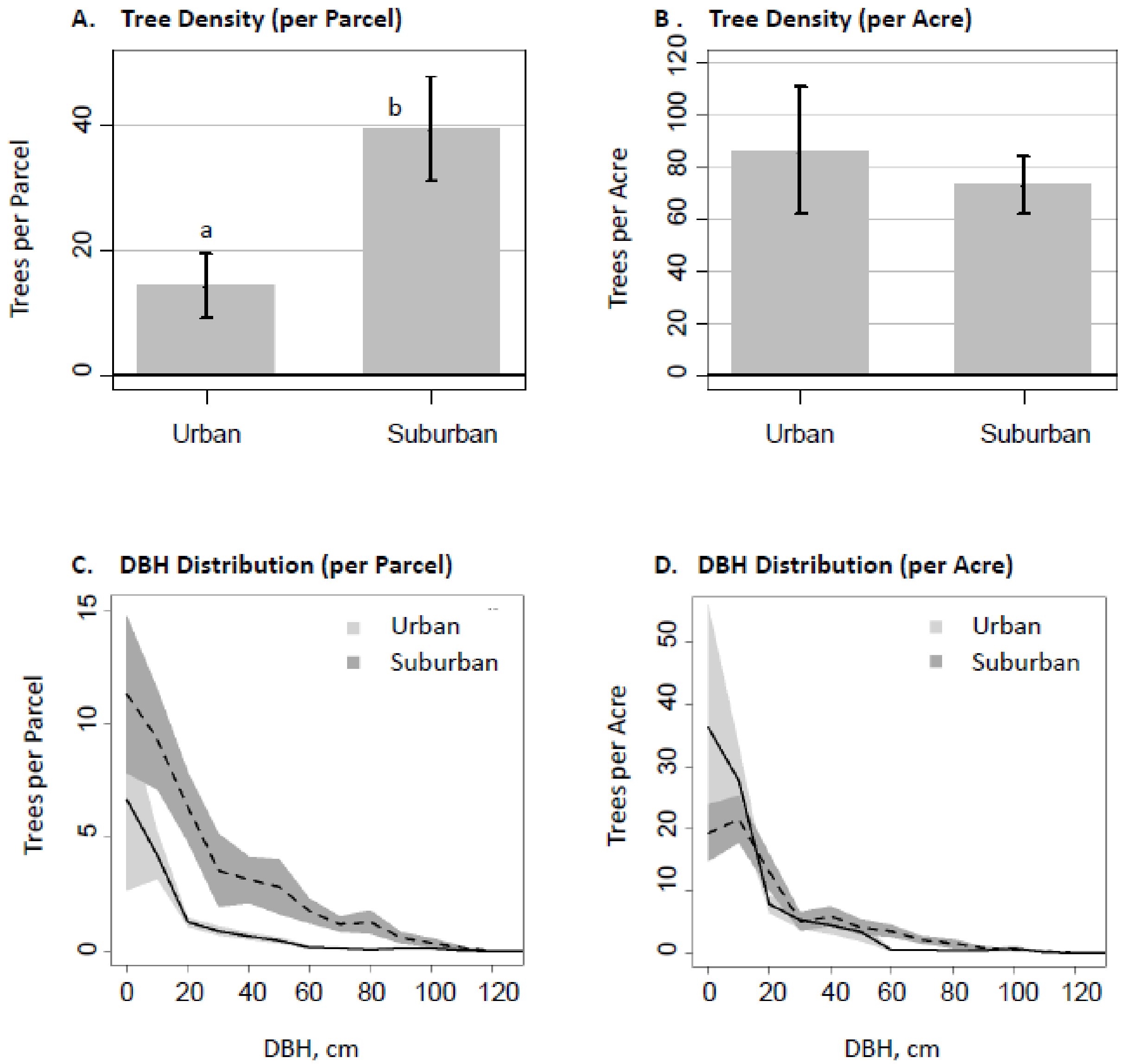


Figure 1.7. Count of trees per parcel (A) and overall tree density by area (B) in the urban and suburban residential landscapes. Error bars represent standard error. Letters (a, b) indicate significant difference in tree densities between urban and suburban partitions (α = 0.05). Distribution of trees by current stem size (DBH) in the urban and suburban residential landscapes (C, D), error intervals represent standard error.

Functional trait groups: size potential at maturity

There were more trees with large size potential (such as western red cedar, *Thuja plicata*) in the suburban area than in the urban core—29 more trees per parcel (Fig. 1.8 a) or 27 more trees per acre (Fig. 1.9 a). There was no significant difference between the two regions in single-family residential lands in the abundance of trees with small size potential, but there was much more natural variability in the density of small trees per acre in the urban area (Fig. 1.9 b).

Functional trait groups: Leaf economies

When I assessed the differences in the abundance of trees based on their leaf economies, whether they were deciduous or evergreen, between urban and suburban areas, I found that the number of deciduous trees per parcel in the suburban area was higher than in the urban core (Fig. 1.8 h). There were 11 more trees per parcel on suburban properties, but once the tree count was normalized by area of the parcel the difference in deciduous tree abundance was no longer significant (Fig. 1.9 h). There are no significant differences between evergreen tree abundance in the urban vs. suburban areas.

Functional trait groups: Intersection of size potential and leaf economies

There were more evergreen trees with large size potential in the suburban area than the urban area—18 more trees per parcel (Fig. 1.8 c) or 22 more per acre (Fig. 1.9 c), but there was no difference in counts of small (at maturity) evergreen trees. Much of the total variability in evergreen abundance in the urban partition is accounted for by the trees with small size potential (Fig. 1.9 d). There were more deciduous trees with a large size potential in the suburban area than the urban area at the parcel scale (Fig. 1.8 f), but once the count was normalized by area (parcel area) the difference was not significant (Fig. 1.9 f). On the other hand, on a per-acre basis there were more small deciduous trees in the urban area than in the suburban area (Fig. 1.9 g).

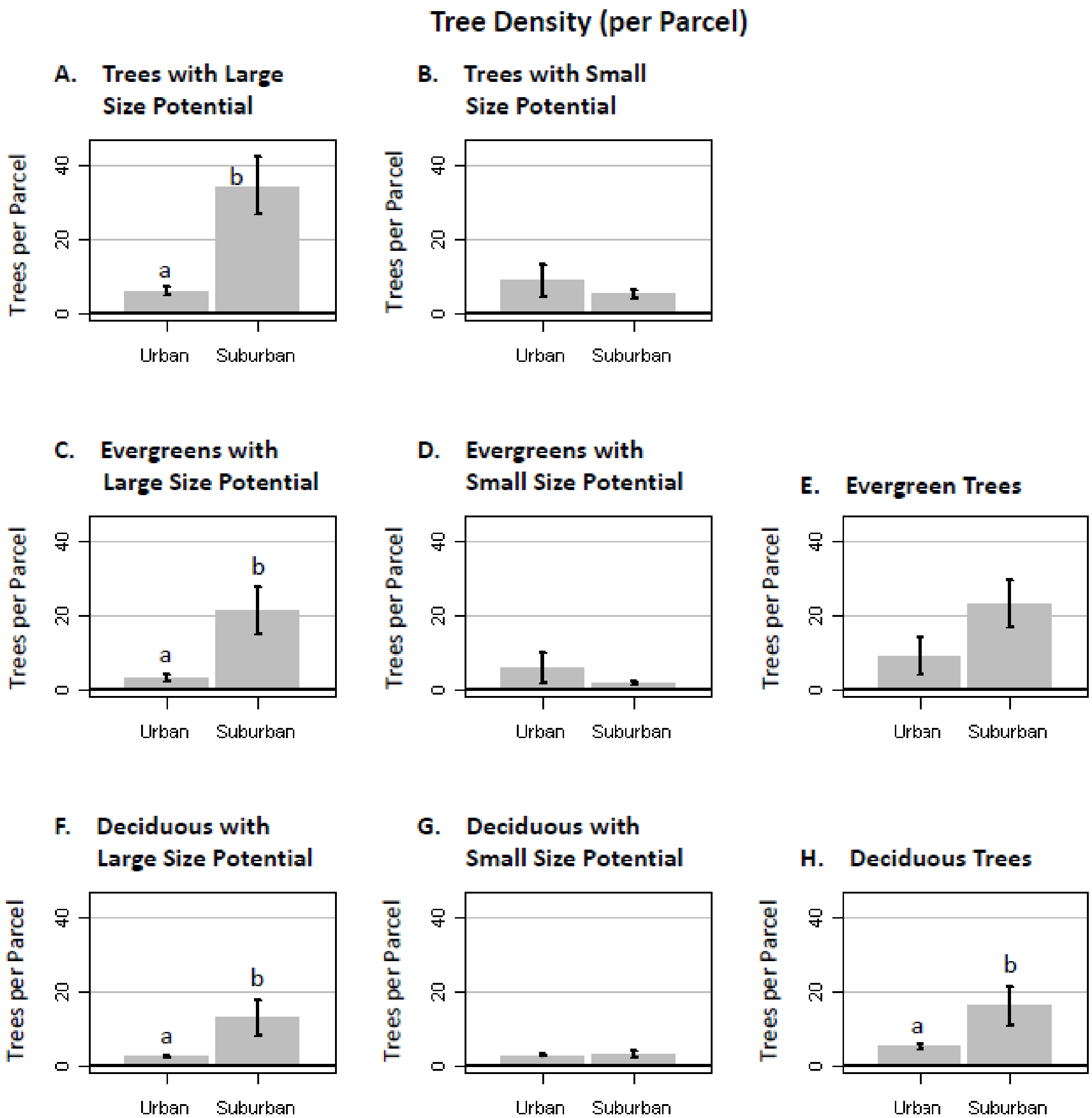


Figure 1.8. Tree density per parcel of the functional trait groups in the urban and suburban residential landscapes; error bars represent standard error. Letters (a, b) in panels indicate differences (α = 0.05) in tree densities between the urban and suburban areas.

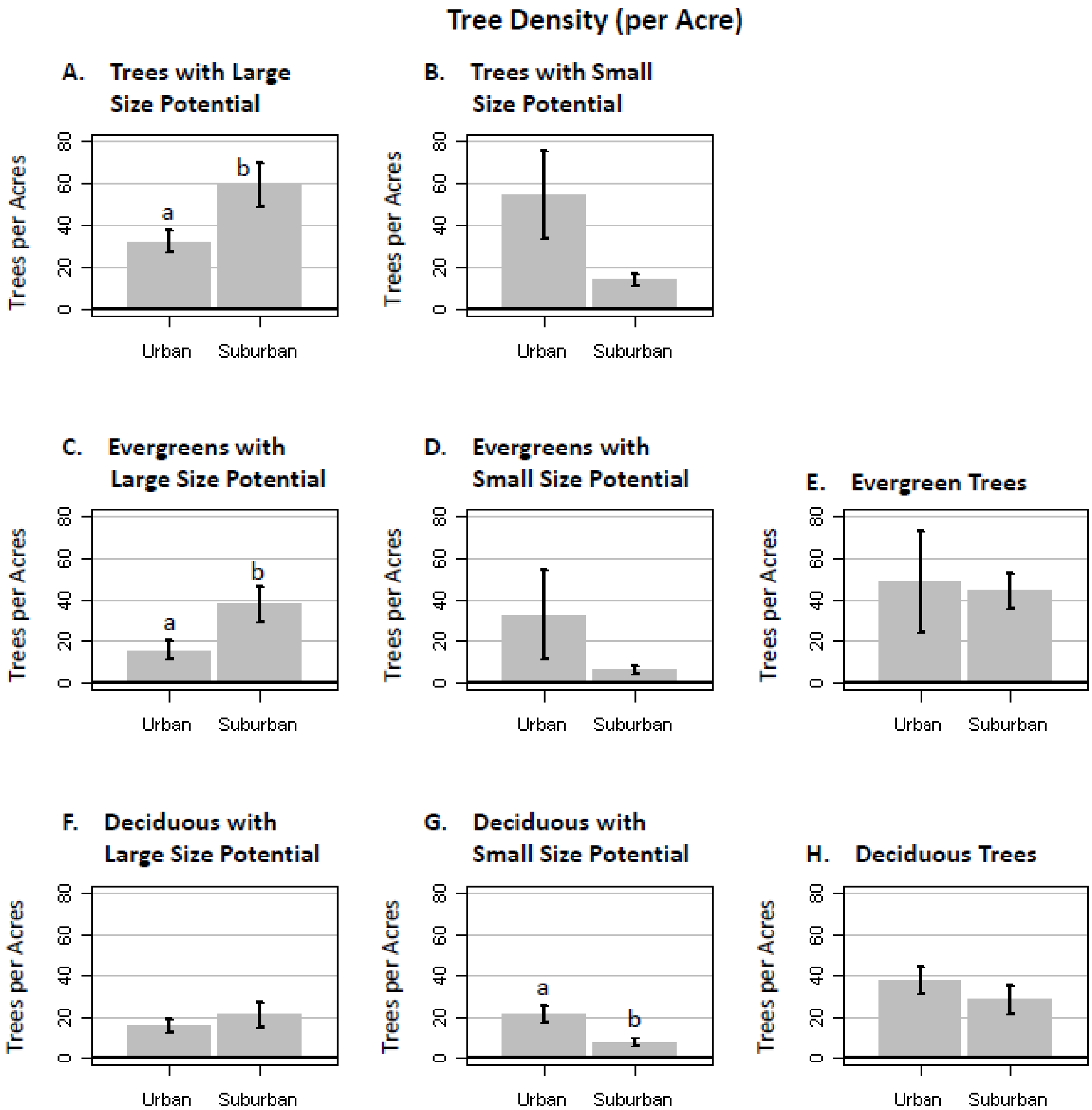


Figure 1.9. Tree density normalized by area of the functional trait groups in the urban and suburban residential landscapes; error bars represent standard error. Letters (a, b) in panels indicate differences ($\alpha = 0.05$) in tree densities between the urban and suburban areas.

In a breakdown of the distribution of evergreen trees by trunk diameter (DBH), a common proxy for age, I found that there were more evergreen trees with large size potential in almost all trunk-diameter classes in the suburban area as compared with the urban core (Figs. 1.10 a and 1.11 a). However, for the evergreen trees with small size potential I found that the urban partition had more (currently) small evergreen trees with small size potential than the suburban area per acre (Fig. 10 b). This distribution implies that over time the currently small tree stock will replace the aging trees of the small size potential evergreen functional trait group within the urban area (Fig. 1.10 b). The curve of the large (potential) evergreen trees in the urban and suburban partitions (Fig. 1.10 a and b) and the curve of the small (potential) evergreen size distribution of trees in the suburban partition (Fig. 9 b) are rather flat, indicating that the stock of young evergreen trees in these regions is not as abundant.

The size distribution of deciduous trees with both small and large size potential followed trends similar to the evergreen species. There were more small (currently) deciduous trees with a large size potential in the suburban area (per parcel) than in the urban area (Fig. 1.10 c), and there were more small (currently) deciduous trees with small size potential per acre in the urban area (Fig. 1.11 d). The distribution of deciduous trees with small size potential implies that there is an adequate stock of young trees within this functional trait group to replace the aging trees, but this is the case to a lesser extent in the suburban area (Fig. 1.11 d). The distribution of the deciduous trees with large size potential in the urban partition (Fig. 1.11 c) and the curve of the small (potential) deciduous size distribution of trees in both partitions (Fig. 1.11 d) are flatter than the others, indicating that the stock of small, young evergreen trees is not as abundant.

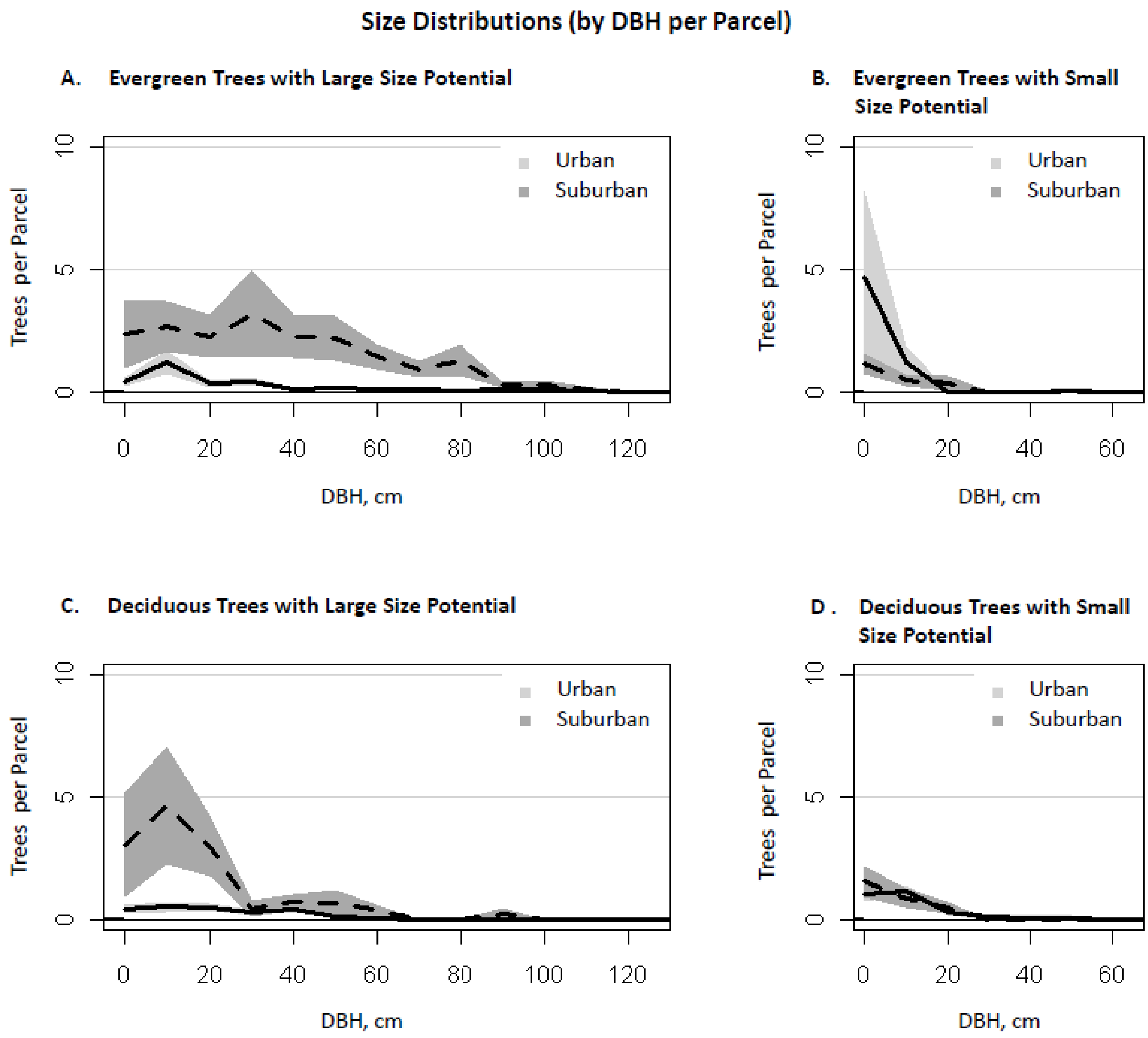


Figure 1.10. Distribution of trees per parcel in each functional trait group by size (DBH) in the urban and suburban residential landscapes; error intervals represent standard error.

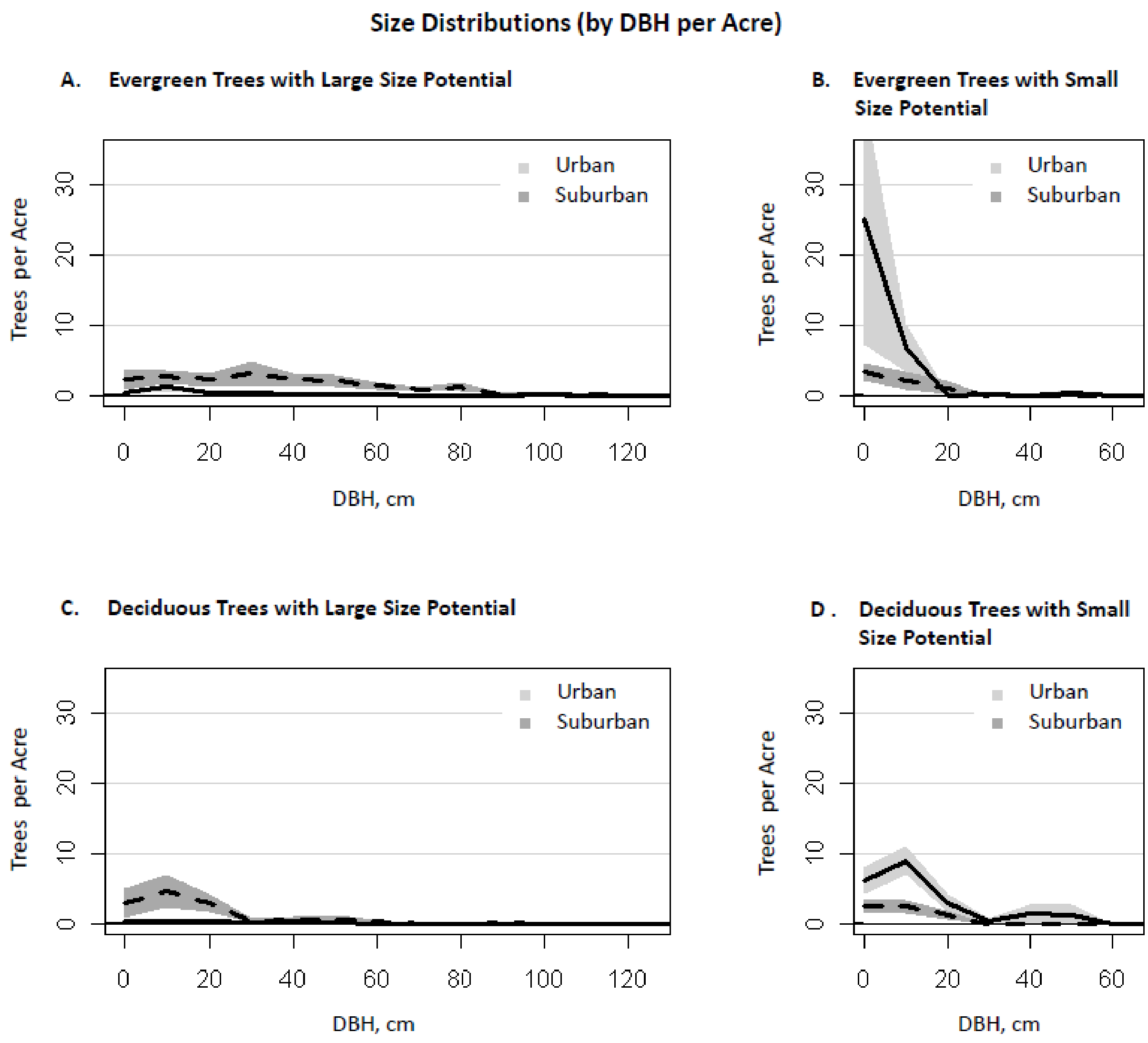


Figure 1.11. Distribution of trees per acre in each functional trait group by size (DBH) in the urban and suburban residential landscapes; error intervals represent standard error.

Size distribution of dominant species in each functional trait group

The size distributions of the two or three dominant species in each functional trait group are plotted in Figs. 1.12 and 1.13. Douglas-fir (*Pseudotsuga menziesii*), western hemlock *(Tsuga heterophylla*), and western red cedar (*Thuja plicata*), are the dominant evergreen species with large size potential found within the residential urban forest. These three are native, and the predominant species found in the forestlands of the region (western hemlock and Douglas-fir forests). There were far more of these trees across the majority of the size classes in the suburban area as compared with the homes in the urban zone (Fig. 1.12 a, b, and c).

The three most common deciduous species with large size potential are bigleaf maple (*Acer macrophyllum),* red alder (*Alnus rubra),* and the flowering and fruiting trees in the Rosaceae family, the *Prunus* and *Pyrus* species. The first two (bigleaf maple (*Acer macrophyllum)* and red alder (*Alnus rubra)*) are also native to this region but are not dominant. They naturally establish in areas of disturbance such as in riparian forests. There are more bigleaf maple (*Acer macrophyllum)* and red alder *(Alnus rubra)* trees in the suburban area (Fig. 1.12 d and e). However when I investigated patterns of fruiting and flowering trees I found that there were similar numbers between the two regions in most of the size-class bins (Fig. 1.12 f).

The two most common evergreen trees with small size potential were the northern white cedar (*Thuja occidentalis)* and *Camellia* species (Fig. 1.13 a and b). Northern white cedar *(Thuja occidentalis)* is a common evergreen hedge. Plants in the *Camellia* genus are flowering evergreen trees and shrubs. There were more camellias in most age classes in the urban partition, but there was very little difference between the abundance of northern white cedar *(Thuja occidentalis)* across the gradient (Fig. 1.13 a and b). The common deciduous trees with small size potential are both maples—vine maple (*Acer circinatum)*, a native tree to the region and Japanese maple (*Acer palmatum)*. The urban partition had more large vine maples (*Acer circinatum),* and Japanese maples *(Acer palmatum*) than the suburban area but there was considerable variability around these estimates (Fig. 1.13 c and d).

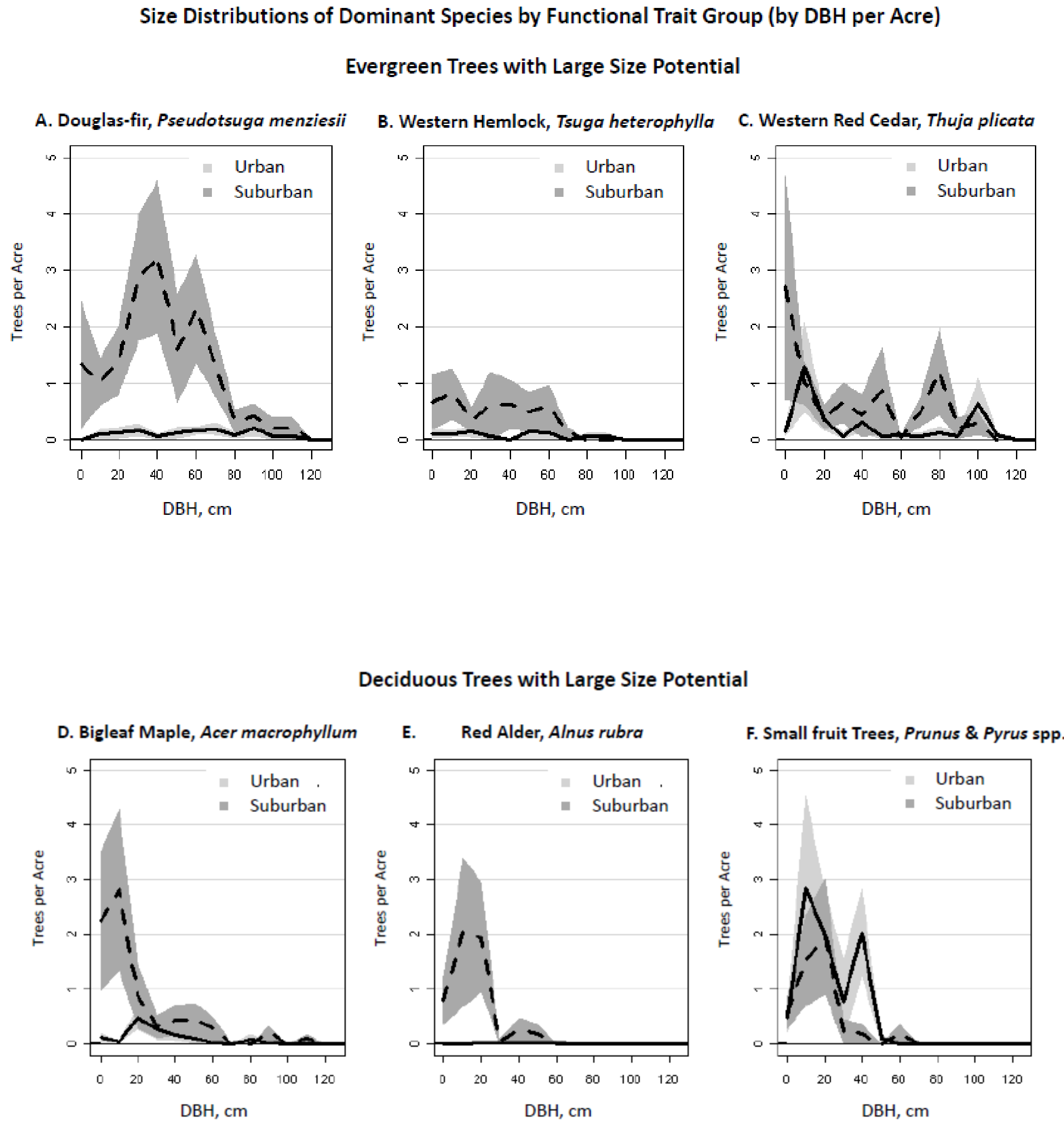


Figure 1.12. Distribution of the three most common trees in the large size potential functional trait group (large evergreen species are on the top, large deciduous species on the bottom row). Light grey bands indicate the error interval (standard error).

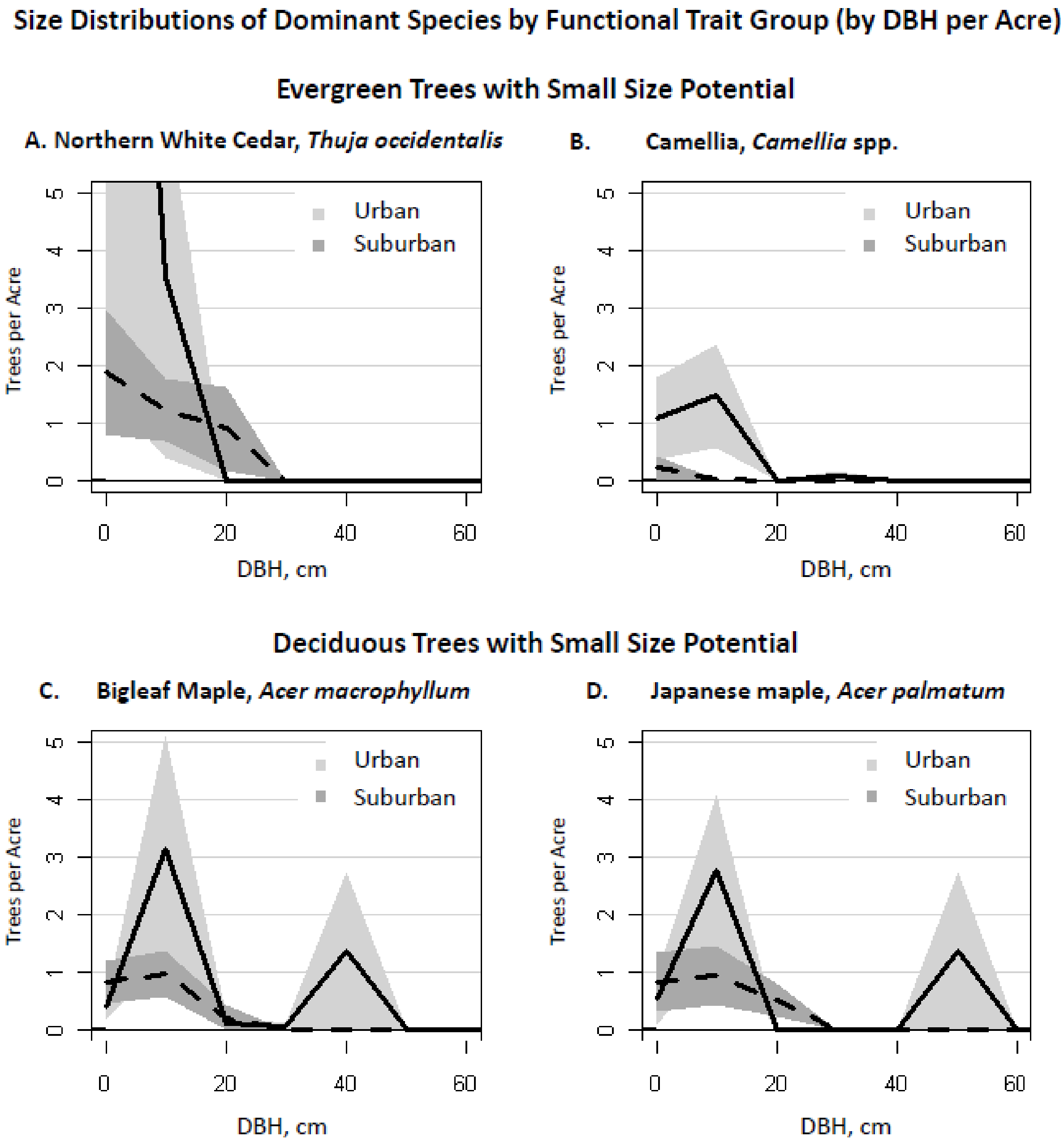


Figure 1.13. Distribution of the three most common trees in the small size potential functional trait group (small evergreen species are on the top, small deciduous species on the bottom row). Light grey bands indicate the error interval (standard error).

DISCUSSION

In this study, I assessed the structure of the residential urban forest across a gradient of urbanization. There was no significant difference in tree density between the urban and suburban areas after parcel area (lot size) was taken into account. This supports the theory that we humans design the urban environment to meet our preferences for a specific type of habitat, and therefore urban patterns such as tree densities would be expected to be homogeneous across the landscape. Dwyer et al. (2000) reported that urban regions in semi-arid landscapes have 9% tree cover, grassland systems have 18%, while once-forested urban regions have reduced tree cover to 34%. These trends perhaps indicate that urban areas are converging toward an "ideal" moderate canopy cover preferred by residents across the U.S.

Studies have reported very slight differences in tree cover along an urban gradient (Dwyer et al., 2000). Tree cover in the sample of greater metropolitan regions was 33% (se ± 17%) and just 27% (se ± 13%) in the associated urban core; however, the two regions were not mutually exclusive, and the distinction is based on political boundaries and population densities (Dwyer et al., 2000). Looking at estimates of just residential land, Chicago had 15% tree cover within the city limits, but the average residential tree cover in the greater Cook and DuPage counties was 24.4% and 25.3%, respectively (Dwyer et al., 2000). While canopy cover does not directly relate to tree density because trees with larger canopies cover the same area as multiple small trees, the two are correlated (Hudack et al., 2006). However, it is not a one-to-one comparison, so the results from these studies are loosely comparable to my reported measures of tree density.

There are two comparable studies in which the scholars measured tree densities by land use (Waldron and Dyck, 1975; Dorney et al., 1984; Richards et al., 1984). There were on average 14 trees per residential lot in Edmonton, Canada; 10 in Winnipeg, Canada (Waldron and Dyck, 1975); and between 1.9 and 14.3 trees per lot (3.9 was the median value) in Syracuse, NY (Richards et al., 1984). Dorney et al. (1984) reported tree density per area in Shorewood (a suburb of Milwaukee, WI), which had on average 57 trees per hectare (23 trees per acre) in single-family residential lands. The average lot area of the homes in a Syracuse, NY, study was 618 (sd ± 193) m^2 (0.15 ± 0.05 acres) (Richards et al., 1984), so median tree density was around 26 trees per acre. In suburban owner-occupied single family residential lots in Bloomington, IN, average tree density was 59.43 (sd ± 53) trees per acre; estimates ranged from 3.24 to 242.6 trees/acre (Schmitt-Harsh et al., 2013). These reported residential tree densities are smaller than my tree-density estimates in both the highly urbanized area and the suburban area. I found that lots in the urban core had on average 15 ± 5 trees per lot, and there were 39 ± 8 in suburban areas. The urban partition had 86 ± 24 trees per acre, while the suburban area had 73 ± 11.

The differences between my results and those of previous studies may be due to a number of factors related to urban form and measurement methods. Differences in lot size may also play an important role in explaining differences between tree-density estimates, but lot sizes were not reported in the Waldron and Dyck (1975) study, for example. Differences in methods are also likely important in describing discrepancies in tree-count estimates. Neither Waldron and Dyck (1975) nor Richards et al. (1984) provided their definition of what they considered to be a tree. However, Dorney et al. (1984) included only woody plants with a DBH of at least 10 cm, a DBH threshold that is twice as large as the one I used in this project. Therefore, my methods included more plants in my definition—all trees with a DBH between 5 cm and 10 cm, which likely resulted in a higher tree-density estimate. Schmitt-Harsh and colleagues (2013) had a much smaller DBH at 2.5 cm, so this study includes more trees in comparison to my work.

The observed tree densities (tree counts per acre) in my study region also aligned with visual preference results in a comparison of dense forest scenes, sparse forests, and open spaces (Schroeder and Green, 1985). Respondents preferred images of municipal parks with moderate numbers of trees in the range of 40–77 trees per acre (Schroeder and Green, 1985). However, these densities were slightly lower than the observed densities in the residential urban forest in this study (86 ± 24 and 73 ± 11 trees per acre in the urban and suburban areas, respectively). In another study, a group of students and rural woodland owners were asked to rate the attractiveness of different landscapes, and both groups also preferred scenes with large, mature trees, thinly dispersed, with some open spaces (Rutherford and Shafer, 1969). While these studies did not specifically address the types of environments people prefer to maintain in their yards, they provided evidence that humans have a natural preference for a moderate density of trees. It has been suggested that our preferences for a mid-density, savanna-like landscape is rooted in our bio-evolutionary history (Kaplan, 1987) because these qualities provide open areas so sightlines are preserved, but the trees also provide protective cover (Gobster, 1994).

I found differences in the composition of trees present in urban and suburban lands, as observed by the densities of functional trait groups. The suburban area had more trees that will reach a large size at maturity, while the urban area had more small deciduous trees per acre. These patterns are consistent with the assumption that suburban residents seek out landscapes that are quite different from those present in the urban core. Kaplan and Austin (2004) reported that suburbanites prefer regions that mimic native forestlands and provide open spaces. Indeed, I found that the suburban area had higher densities of large trees. In suburban areas, large trees were predominantly composed of species native to the region such as Douglas-fir (*Pseudotsuga menziesii),* western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra)*. Simultaneously, the urban environment had larger numbers of small deciduous trees, but the predominant native species of the region were sparse. However, we do not know the extent to which this pattern is indicative of suburban residents preferring a different type of forest composition than residents in the urban core.

In fact, the difference in forest composition between the two regions might simply be determined by the difference in the characteristics of the built environment. In the urban core, the fine grain of the built environment and the limited growing space may constrain the types of trees that can be supported in this region. It is more likely that both factors played a role in determining the composition of the urban forest, in addition to other social and biophysical drivers. Chowdhury et al. (2011) proposed that the emergent properties of urban residential landscapes are shaped by the interplay between homeowner choices and behavior, regional institutions (such as homeowners' associations), and regional development processes. Regardless of the drivers determining the composition of the residential urban forest, it is evident that plant communities in these landscapes are not homogeneous across the urban landscape.

Finally, these observed patterns provide some evidence in support of McKinney's (2006) hypothesis that the biotic homogenization of urban landscapes increases with urban intensity. McKinney (2006) posited that lands in the urban core are characterized by synanthropic species (urban exploiters), while the suburban area has more urban adaptors and avoiders (McKinney, 2006). Little work has been done to assess the influence of biotic homogenization on ecosystem patterns and functions, but by characterizing the forest with the use of functional trait classification schemes we can begin to infer and test selection mechanisms and ecological consequences of urbanization and yard design on the urban forest. Additionally, by focusing on the specific functional traits that are selected for, we can monitor and empirically test whether the community structure of suburban areas will converge to resemble the forest within the urban core over time. Or perhaps suburban areas are a novel ecosystem of their own, with a distinct set of drivers and feedbacks determining the urban forest composition. Then again, more simply, suburban residents may desire and maintain an urban environment that looks and operates fundamentally different from that of the urban core.

Long term implications

To shed light on how the forest may age in both the urban and suburban areas, I plotted the size distribution of the urban forest using two plant functional traits. The current sizes of trees, when coupled with species-specific information such as growth potential, can be used as a proxy for the age profile of the forest community (Meyer, 1952). This information can also shed light on what homeowners may have recently planted to assist researchers in determining how the abundance of functional traits may change as the forest matures and how these dynamics may influence ecosystem functions.

The DBH distribution of all trees on residential properties (Fig. 1.7) is very similar to the distribution of trees in owner-occupied single family residential lots in suburban neighborhoods in Bloomington, IN, after accounting for differences in methodologies (DBH cutoff of 2.5 cm used in Bloomington, 5 cm in this project) (Schmitt-Harsh et al., 2013). In an unevenly aged natural forest, if there are ample small (younger) trees in the population, these younger trees will, as the forest matures, replace the larger trees as they reach the end of their life span. An inverse J-shape distribution (the majority of trees have a small-diameter trunk at breast height), indicates that the population will sustain itself over time (Meyer, 1952). Currently, the suburban area has an abundance of small deciduous trees that have the potential to reach large sizes (Fig. 1.11 c), which indicates that they will be persistent in the landscape over time. The majority of these trees are native bigleaf maple (*Acer macrophyllum)* and red alder (*Alnus rubra)* species (Fig. 1.13 d and e), and cherry and pear trees (Fig. 1.13 f).

The size distribution for large evergreens is much flatter, indicating that there may not be a sufficient number of young evergreens with large size potential to replace the current stock as they age (McPherson and Rowntree, 1989). There is a clear peak in the density of Douglas-fir (*Pseudotsuga menziesii)* trees with a current DBH between 20–60 cm, although there are far fewer small (young) trees of the same kind. According to Meyer (1952), this indicates that the population of evergreens with large size potential may decline over time as there are not enough young trees (represented by a small DBH) to grow and replace aging ones. However, the assumption that urban forests have community dynamics similar to those of unevenly aged natural stands is yet to be tested. Young trees in unevenly aged natural forests have a high mortality rate. Given the active role of land management in caring for planted trees, it is very likely that there will be less mortality of currently young trees. Therefore, urban forests may not require as many young trees to replace aging trees. Leak (2001) investigated whether other diameter distributions emerge under different forest management conditions, and the same sort of empirical analysis could be implemented in urban forests to determine whether the inverse J-shaped distribution adequately represents a sustainable population.

Making the assumption that urban forest dynamics can be inferred from unevenly aged natural stands (inverse J-shaped distribution), my work indicates that there may be a shift in forest composition with an increase in the number of deciduous trees (both small and large) with a loss of the regional, native, large-stature evergreens iconic to this region. Urban forest policies and programs could be initiated with the objective of increasing tree planting rates in order to sustain the populations of these natives and their associated ecosystem functions. Research that addresses the reasons why residents with the yard space for large evergreen trees are not planting these species, such as assessing homeowner constraints and barriers, could assist in tailoring programs to better meet these goals.

Future research directions

In this study, I tested the applicability of functional trait classification systems to characterize the vegetation across the urban landscape. I found that the use of leaf lifespan and the size potential of tree species were functional traits responsive to urbanization. Urban forest structure is the result of complex interactions between biophysical and socioeconomic conditions (Chowdhury et al., 2011; Cook et al., 2012). Wu (2008) argued that a landscape ecology approach could be used to link human land management actions occurring at a fine grain scale with the resultant aggregate landscape patterns and ecosystem functions. Meanwhile, the coupling of an urban gradient assessment with functional traits provides insight into the differential preference and selection of tree types across the urban gradient and could be used to formulate hypotheses and experiments to explain how land management practices structure the urban forest.

McKinney (2006) suggested categorization criteria for urban biota based on their presence (urban avoiders, adapters, and exploiters), but using functional trait classification systems more adequately represents traits that are being selected for and their impacts on ecological processes. In addition, functional trait classification schemes provide a common language to describe the urban forest composition for use in comparative urban gradient analysis designed to test the theory of the homogenizing effects of urbanization between cities. A comparative urban gradient approach has been proposed as a method to identify and test generalities of urban form and process across cities in order to improve our understanding of how cities function (Boone et al., 2012). When we put these together, we can begin to shed light on the hypothesis that urban ecosystems are undergoing functional homogenization (Olden and Poff, 2003), in addition to becoming homogenized in terms of biotic assemblages (McKinney, 2006).

Finally, trait based classification of vegetative communities can be paired with remotely sensed imagery (e.g., NDVI) to model and map ecological processes and ecosystem services across the full spatial extent of the urban region (Lavorel et al., 2011; Ustin and Gamon, 2010) under a suite of alternative future scenarios. Subsequent fruitful research directions include the integration of functional trait group structure across the urban gradient with models of ecosystem functions under alternative future trajectories derived from scenario planning efforts in order to provide better understanding of urban ecosystem dynamics.

CHAPTER 2.

Implications of urban land management on ecosystem function:

A landscape scale analysis of the consequences of residential yard care design choices on carbon storage in the Seattle, WA region

ABSTRACT

Urban areas contribute 80% of global fossil-fuel emissions, a key driver of climate change (Churkina, 2008). Decision makers are adopting strategies to both reduce and mitigate emissions, and recognizing the role that trees can play in sequestering and storing carbon as plant biomass, many municipalities are adopting goals to increase urban forest cover (U.S. Conference of Mayors, 2008). In order to achieve these goals, the importance of single-family residential lands is becoming apparent. This is the predominant land use in urban areas in the U.S. (Dwyer et al., 2000; Irwin and Bockstael, 2007), so residential lands can have a substantial impact on the urban forest. Few studies have assessed carbon storage on residential lands (Raciti et al., 2012; Ciecko et al., 2012; Schmitt-Harsh et al., 2013), and none have translated the effect of tree planting and removal activities into carbon storage losses and gains.

In this project, I estimated the current carbon storage within the residential urban forest and used plant functional trait classification systems to explain the differences in carbon stocks between the urban and suburban areas. I then assessed how residents alter the amount and composition of the urban forest during their tenure, and I explored the net effect these decisions could have on long term carbon storage potential. I found that suburban landscapes store more carbon as above-ground plant biomass than residential parcels in the urban core due to differences in the composition of the urban forest. Suburban areas have more tree species with large size potential, which contribute the majority of the carbon storage benefits. Surprisingly, planting and tree removal reported by residents resulted in no significant change in tree density, with the exception of slight gains in tree abundance of one functional trait group—small-stature deciduous trees—in the suburban area. However, given the small biomass of these tree types, these increases will likely not result in a significant gain in carbon storage due to management decisions.

INTRODUCTION

Urbanization can play an important role in reducing greenhouse-gas emissions, a driver of global climate change, while simultaneously housing an ever-growing population. To plan for future population increases while reducing greenhouse-gas emissions, cities are designing and adopting climate action plans (Kousky and Schneider, 2003; Wheeler, 2008; Bassett and Shandas, 2010). Often, these plans pair strategies to reduce emissions, such as smart growth development principles, with tools to mitigate them (Betsill, 2001). Goals to increase urban forest cover in order to take advantage of the carbon storage benefits of trees have attracted much attention from scientists and are popular with policy makers aiming to offset fossil-fuel emissions (U.S. Conference of Mayors, 2008; Bassett and Shandas, 2010; Pataki et al., 2011).

Increasing canopy cover provides additional economic, environmental, and human health and well-being co-benefits (Bolund and Hunhammer, 1999). For example, urban forests reduce storm water runoff (Xiao and McPherson, 2002), which in turn reduces loads to storm-water treatment facilities. Urban forests also support overall human well-being through such things as the reduction of stress levels (Ulrich, 1984), enhancement of neighborhood aesthetics (Schroeder, 1989), and the strengthening of a sense of community by facilitating neighbor-to-neighbor interactions (Kweon et al., 1998; Austin, 2002).

However, only taking into account the role the urban forest can play in sequestering carbon and other co-benefits is not adequate to inform the selection of strategies for the climate action portfolio. When setting policy objectives and designing best management practices, costs and trade-offs must be articulated and considered. While the multiple co-benefits are well documented in the literature, far less attention has been paid to identifying and quantifying the full suite of costs associated with tree establishment and maintenance and the disservices that trees produce (Lyytimäki and Sipilä, 2009; Pataki et al., 2011). Resource inputs (e.g., irrigation and fertilizers) and ecological impacts (e.g., fertilizer and pesticide application) associated with establishing and maintaining trees in the urban region need to be considered.

The competition for space between trees and the built infrastructure should be factored in as an opportunity cost. Building compact urban areas can reduce greenhouse-gas emissions associated with transportation and energy use (Betsill, 2001). For example, worldwide on a per-capita basis, greenhouse-gas emissions of residents in urban regions are lower than emissions of the (respective) country's total population (Dodman, 2009). This difference is attributed to the high density of urban development patterns and effective public transportation systems. However, a densely developed city may not provide ample space for a dense urban forest. Further, conditions in densely developed urban areas have been shown to cause stress to trees, resulting in slower growth and decreased lifespan (Celestian and Martin, 2005; Close et al., 1996), which means that replacement costs should also be considered.

Alternatively, lower-density suburban-style development patterns are characterized as highly consumptive landscapes (Newman and Kenworthy, 1999; Ewing and Rong, 2008; Brownstone and Golob, 2009; Bart, 2010; Glaeser and Kahn, 2010). At the same time, their larger lot designs offer the potential to support a dense forest that can mitigate some of these impacts. Large homes and long work commutes are typical in suburbs, generating more household energy and traffic-related emissions compared with households located in compact urban areas (Newman and Kenworthy, 1999; Ewing and Rong, 2008; Brownstone and Golob, 2009; Bart, 2010; Glaeser and Kahn, 2010). In addition to generating higher per-capita emissions, homes established in suburban areas typically have a large portion of their lots maintained as high-chemical-input lawns (Robbins and Birkenholtz, 2003). Thus, these households could mitigate their emissions and perhaps reduce impacts from high-chemical yard care practices by maintaining a yard with high tree cover. Articulating economic and societal trade-offs in maintaining green infrastructure in urban areas, while simultaneously recognizing the importance of location and urban form, can better inform the decision making process.

Residential land use is a key driver of urban forest structure and related ecological functions, services, and disservices—i.e., carbon storage benefits. It is the dominant land use in urban regions (Dwyer et al., 2000; Irwin and Bockstael, 2002; Irwin and Bockstael, 2007), and its spatial coverage is on the rise (HUD, 2000; Heimlich and Anderson, 2001). Despite compact urban design initiatives and regulations, development of urban land in the U.S. is proceeding at a rate faster than population growth—urban growth is more expansive than compact (U.S. HUD, 2000; Heimlich and Anderson, 2001). Regardless of strategies aimed at increasing the density of city centers and older suburbs, the majority of population growth in many urbanizing regions around the world is occurring at the fringe, far outside the urban core (Daniels, 1999; Duany et al., 2000). Residential development will become even more expansive due to the trend toward larger lots and homes in the U.S. (Heimlich & Anderson, 2001; NAHB, 2005). Simultaneously, households are getting smaller (Mackellar et al., 1995; Liu et al., 2003). Therefore, understanding the role of residential lands in creating and sustaining trees is critical to meeting canopy cover goals.

Households collectively play one of the largest roles in designing and managing the urban forest. Unlike vegetation dynamics in natural systems, which are largely determined by biophysical conditions, plant dynamics in urban systems are predominantly driven by urban form and land management activities (McDonnell and Pickett, 1990; Kaye et al., 2006). Residential yards are highly manicured and intensely managed landscapes.

The type and amount of vegetation, particularly trees, planted and maintained by homeowners plays a large role in determining the level of ecosystem services, particularly the carbon storage capacity of these lands. For example, a mature Douglas-fir tree (*Pseudotsuga menziesii)* can grow to be 260 feet tall (Franklin and Dyrness, 1973), whereas the Pacific rhododendron (*Rhododendron macrophyllum)* grows up to only 15 feet (USDDA, NRCS, 2013). These size differences are directly proportional to the carbon storage potential of each species. Therefore, understanding how households design and manage the vegetation in their yards, specifically by planting and removing trees, is imperative for determining how well the urban forest will be able to mitigate carbon emissions in the future—providing critical information for the design of urban greening programs and climate action plans. Yet, despite the important role of landowners in collectively designing and managing the urban landscape, quantifying the implications of their behavior on structuring the landscape and altering ecosystem functions has received limited attention. Scholars are just beginning to assess the coupled dynamics between homeowners' preferences and activities and ecological patterns and functions (Cook et al., 2012).

In this study, I empirically examined how the current structure and long term maintenance of the residential urban forest in the Seattle metropolitan area translates into the provision of carbon storage as above-ground plant biomass. Then I estimated how household land management behavior has affected and may alter the forest structure and the subsequent provision of carbon storage. I addressed three research questions:

1. How do levels of carbon stored in above-ground plant biomass vary between urban and suburban areas?
2. How do patterns of carbon storage differ in urban and suburban lots by plant functional trait groups?
3. How have residents altered (by planting and removing trees) the structure of the residential urban forest during their tenure at their current residences, and what are the consequences of these activities with respect to the carbon storage capacity of these lands?

I used multiple methods to link residential behavior with measures of forest structure and composition to determine the current carbon storage of the residential landscape, and I projected changes due to land management actions. I utilized remotely sensed data, field-based measurements of vegetation structure, and information from a mailed yard care survey to provide new insight into the structural and functional dynamics of the residential urban forest. I focused specifically on the potential unintended long term consequences of land management activities on the carbon storage capacity of the residential urban forest across the urbanizing region in King County, WA.

This integrative approach has potential application in other research efforts that explore the ecological functions and dynamics of coupled human-natural systems. In addition, this work can inform climate action and green infrastructure policies and programs by increasing our understanding of how residents are mitigating their household and transportation carbon emissions through the design of their yard landscapes. Given our current sprawling residential development patterns, this research can assist urban planners in designing policies aimed at retrofitting these lands to increase ecosystem services and offset impacts of current large-lot, large-home development trends.

In the following section, I review the urban carbon cycle, the role the residential urban forest plays in carbon storage and sequestration, and the ways in which residential development patterns and yard care actions may influence carbon stocks. In this study, I focused on tree planting and removal activities by households. I present my results, estimating how the current urban residential forest structure translates into a carbon storage signature, using plant functional trait schemes to highlight differences between the urban and suburban areas. Then I discuss the changes that residents have reported making to trees on their properties during their tenure and the changes that they are considering making in the future. I estimated the net effect of these actions on carbon storage potential. I conclude with considerations for policy and the potential applications of this research design to examine the effect of land management on other ecological functions, and I suggest future research directions.

Urban carbon cycle

Urbanization alters the carbon emission and carbon storage processes. Urban areas are responsible for more than 80% of the anthropogenic release of carbon dioxide, a greenhouse gas (Churkina et al., 2010). Land use and land cover changes associated with urbanization and urban activities are the main drivers of emissions in the U.S., and they are mediated by urban form (e.g., clustered vs. sprawling, house sizes) and infrastructure (e.g., public transit, highways) (Kaye et al., 2006). Travel and residential use are the sources of roughly 40% of the total North American fossil-fuel emissions (Pataki et al., 2006). Public transit is one strategy to reduce transportation emissions, but the feasibility of these systems are dependent upon population density and land use mix (Frank and Pivo, 1994). The low-density characteristics of typical suburban development patterns have been linked to increasing fossil-fuel emissions per capita from transportation and residential energy use in the U.S. (Brownstone and Golob, 2009; Glaeser and Kahn, 2010).

In addition to influencing emissions, urbanization affects carbon sequestration and storage processes by the plant communities. Urban land cover change modifies net primary productivity and terrestrial carbon stocks (Imhoff et al., 2004). With urban development, vegetation is cleared and replaced with impervious surfaces (transportation networks, rooftops, etc.) and a highly modified community of plants (Rebele, 1994). While scientists and policy makers have suggested that urban landscaping can mitigate fossil-fuel emissions by storing carbon as plant biomass, studies are confirming that the relative intake by these landscapes is small compared with urban carbon emissions (Pataki et al., 2006; Pataki et al., 2011). Eddy covariance measurements at suburban sites have demonstrated that urban vegetation does play a role in mitigating local carbon emissions, especially during the active growing season (review by Velasco and Roth, 2010), but the effect was minimal in comparison with emission peaks during rush-hour traffic (Coutts et al., 2007). Indeed, evidence is mounting that it is unlikely that vegetation buffers in urban areas can offset the associated use and emissions of fossil fuels (Pataki et al., 2006; Pataki et al., 2011)—but there is still a lot to learn.

Few studies have assessed carbon storage from above-ground plant biomass on residential lands (Raciti et al., 2012). Also, the role of yard design and land management activities on the urban carbon cycle are sparsely quantified (Jo and McPherson, 1995; Golubiewski, 2006; Zirkle and Augustin, 2011), and those studies that do so have limited their scope to activities such as tree and shrub pruning, lawn mowing, and resource input regiments (e.g., water, fertilizers). None of these land management assessments have included tree planting and removal.

Role of the urban forest in the carbon cycle

Undoubtedly, urban trees have been one of the most well studied aspects of carbon storage within cities (Pataki et al., 2006). McPherson (1998) estimated that urban forest systems store about half as much carbon as native forests. However, new research calls the simplicity of this work into debate, with findings such as the observed increases in carbon storage potential of resource limited lands—e.g., semi-arid regions—and decreases in metropolitan areas located in regions once characterized by closed-canopy forests (Imhoff et al., 2004). In some places, the conversion of agricultural lands to urban uses has resulted in gains in canopy cover (Berland, 2012) which translates to associated gains in carbon storage as tree biomass.

Both the density and composition of the urban forest influences the carbon storage potential. In urban regions, the most obvious modification that influences tree density is the increased levels of impervious surfaces (Elvidge et al., 2007) and replacement of natural vegetation with lawns and gardens (Rebele, 1994). In Dayton, OH, Sanders and Stevens (1984) found that approximately 40% of the total land area is covered with impervious surfaces and thus is unavailable for trees. Tree cover decreased with increases in impervious surfaces and population density (Medley et al., 1995; Iverson and Cook, 2000; Nowak et al., 2001). In Boston, live biomass decreased with increases in levels of impervious surfaces due to loss of potential growing space (Rao et al., 2013). Yet, there were no observed, direct relationships with vegetated land cover and building lot size, two proxies for the amount of space available for trees (Stone, 2004; Smith et al., 2005; Conway and Hackworth, 2007), perhaps due to the ubiquity of lawns in metropolitan regions, especially in suburbs. In the U.S., lawns cover an area three times larger than any irrigated crop (Milesi et al., 2005), and coverage increases in proportion to gains in lot size (Robbins and Birkenholtz, 2003). The grasses in these landscapes fix significant amounts of carbon in the soil, especially with aggressive water and chemical intensive yard care practices (Zirkle et al., 2011). Even so, the carbon sequestration potential is quite small in comparison with the carbon potential of the average urban forest. Average yearly sequestration rates are estimated at .19 to 0.51 M C per acre on by U.S. lawns (Zirkle et al., 2011) compared with average sequestration rates of 1.12 M C per acre on by urban forests in the U.S. (Nowak et al., 2013).

Residential urban forest dynamics

The replacement of aging trees by new, younger stock in the residential urban forest is largely determined by residents (Waldron and Dyck, 1975). However, there is limited knowledge about how residents are managing trees in their yards and how these actions will change the forest structure over time. Nor have there been investigations of how these types of behavior translate into change in ecosystem functions, such as the long term carbon storage potential of the urban forest. Two factors that affect carbon storage by the urban forest are tree density and the size of trees. An assessment of tree planting behavior in the City of Seattle found that residents have favored planting trees with small size potential (Dilley, 2010). Residents have planted more trees with small size potential, such as vine maples, than large ones (e.g., Douglas-fir, *Pseudotsuga menziesii*), and reports of tree management actions they are considering in the future show the same trends continuing (Dilley, 2010). Only 22.4% and 16.5% of the 751 survey respondents reported that they have planted a large tree in the past or are considering planting one in the future, respectively, compared with 58.2% and 64.4% who have or are considering planting a small tree (Dilley, 2010). Pearce and colleagues (2013) used size-class analysis to deduce how the residential urban forest will age in suburban areas outside Melbourne and Hobart, Australia, and they found that there are only a few species in the small (young) age classes that have the capacity to reach a large size potential.

These limited studies have indicated that a potential shift in the composition of the urban forest could occur from selective land management actions, resulting in more trees with a small stature at maturity. However, additional studies need to be conducted across different cities characterized by distinct climates with different potential vegetation to test this hypothesis before these results can be generalized. In addition, as evidenced by differences in values for benefits of trees (e.g., the valuation of the shade properties of large deciduous trees) discussed in Chapter 1, the demographics and values of residents may also vary between cities.

Few scientists have assessed the role of management on ecosystem functions despite its impact, and no studies to my knowledge have assessed how management actions vary between urban and suburban areas. Further, I am not aware of any studies that have attempted to translate tree management actions into ecological outcomes such as changes in carbon storage. I expected that carbon storage would be greater in the suburban areas as compared with the urban partition, which would be explained by space limitations constraining the abundance of large-stature trees that can grow in the densely developed urban core. Also, household landscape preferences and land management constraints may also vary along the urban gradient. Kaplan and Austin (2004) found that suburban and exurban residents preferred and indicated the highest community satisfaction from developments with ample forest coverage compared with landscapes with low tree density such as manicured lawn areas; however, the authors did not include residents within the urban core in their study. An examination of preferences for arrays of native vegetation between urban residents and rural landowners identified more commonalities than differences (Cary and Williams, 2000), which supports an alternative hypothesis in which no differences in tree planting and removal rates along the urban gradient are observed.

METHODS

Study Region

King, Snohomish, Pierce, and Kitsap counties make up the Seattle-Tacoma-Bellevue metropolitan statistical area (Seattle, WA MSA) (U.S. Census, 2010), but in this research I focused on the most populous county, King County. An estimated 3.5 million people live in the Seattle MSA, 2 million of whom are located in King County (U.S. Census, 2010).

Prior to European settlement, this landscape was dominated by conifer forests of western hemlock (*Tsuga heterophylla*), Douglas-fir (*Psuedotsuga menziesii*), and western red cedar (*Thuja plicata*) (Franklin and Dyrness, 1973). The Pacific and southern regions in the U.S. have the highest forest carbon density in the country (McKinley et al., 2011). The forests in the Pacific Northwest are unique for the size potential and longevity of these dominant tree species, which can live more than 500 years and reach heights up to 245 feet (75 meters) (roughly equivalent to a 15-story building, or almost half the height of the Seattle Space Needle) at maturity (Franklin and Dyrness, 1973). Due to the large size potential of the dominant species in these forests, the system is naturally carbon rich, storing 139–144 M C per acre on average (Harmon et al., 1990). Since European settlement, the native forests have been heavily modified from large-scale timber harvesting, land clearing for development, and agricultural activities. The resulting urbanized landscape can be considered a novel ecosystem, characterized by a new community of plants, especially pioneer, cultivated, ornamental, and non-native species (Rebele, 1994; Sukopp, 2008; Perring et al., 2013). As such, I expected these regions to store far less carbon than the native Pacific

Northwest forests, but these large tree species are still predominant in urban and suburban residential lands (Chapter 1, Fig. 1.12).

King County currently is home to 39 municipalities, the largest of which is the City of Seattle. The Seattle metropolitan region is an interesting case study because of the involvement of many governing agencies committed to addressing global climate change by developing and implementing programs to reduce local greenhouse-gas emissions. King County provides a transfer-of-benefit rights program and climate preparedness activities aimed at assisting residents in creating landscape management plans. In addition, the City of Seattle has been a world leader in climate action for many years. In, 2011, the Seattle Mayor and City Council adopted an ambitious and long term climate protection vision (Resolution 31312) (City of Seattle, 2011) and (Resolution 31447) (City of Seattle, 2013).

Sample Design

I collected vegetation and household data on 100 owner-occupied single-family residential parcels. I randomly sampled residential properties in King County, WA, stratified by the dominant land cover (Marsik and Alberti, 2010) and location on an urban gradient. For sampling purposes, I created an urban gradient vector using principal-component analysis, a technique that aims to represent the maximum variability of a set of metrics. The three urban gradient metrics I included in the sample gradient are distance from urban centers, population density, and elevation. I then randomly selected 50 homes in the urban and suburban zones, allocating an equal number of samples to five dominant land cover types (heavy urban, medium urban, light urban, mixed deciduous and conifer forests, and conifer forest land cover derived from LandSat imagery (Marsik and Alberti, 2010)). Refer to Chapter 1 for complete details.

Vegetative Field Data Collection

I measured and recorded vegetative characteristics at each property. Vegetation measurements included DBH and the identity of all trees to the species level (some horticultural cultivars were only identified to the genus level), and trees were defined as woody-stemmed vegetation with a 5-cm or greater DBH. Each tree species was classified according to leaf senescence patterns and size potential at maturity. Leaf senescence refers to the natural aging and shedding of leaves. Deciduous trees shed all their leaves in the fall, with examples including red alders (*Alnus rubra*), maples (*Acer spp)*; and ashes

(*Fraxinus spp)*. While evergreens continuously shed a small portion of their leaves (or needles) throughout the year, they do so in such a way that it appears that full leaf cover is maintained year round. Both deciduous and evergreen trees can be either broadleaf or conifer. The most common deciduous trees are broadleaf, except for a small number of larches (*Larix spp)*. The majority of the evergreens in this region are conifers. I further classified the tree species based on size potential at maturity, and in this classification system small trees are those that do not grow taller than 30 feet (roughly the height of a one-story house) and large trees exceed 30 feet in height at maturity.

Yard Care Survey

A yard care survey was mailed to all residents in the study. The survey included questions about household demographic characteristics, tenure at current residence, perceptions regarding the benefits and challenges of trees present on the residents' property, yard use and activity priorities, land management constraints, and tree care history (a copy of the survey instrument is presented in Appendix B, Fig. B1). Questions included in the survey addressed perceived benefits and challenges of the trees on the household's property, prioritization and status of yard use and activities, tree planting and removal history, constraints on land management, and demographic information.

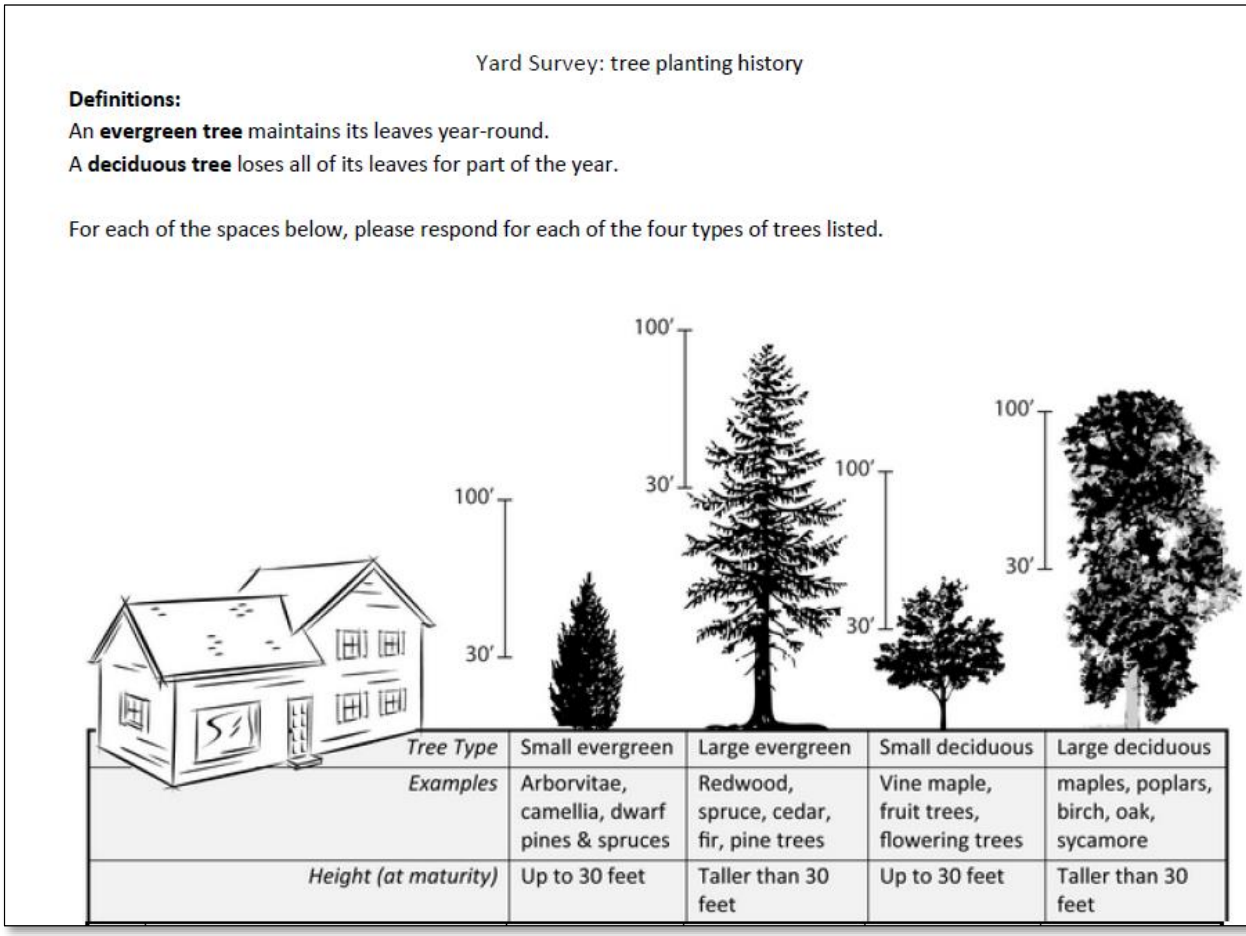
The survey was administered, following the tailored-design method (Dillman, 2000; Dillman, 2009), to the 100 homes in King County that agreed to participate in the vegetation research. The tailored-design method includes sending out a pre-notice postcard mailing (Appendix, Fig. B2) one week before the postage-paid survey questionnaire is delivered (Appendix, Figs. B1 and B3). Then, after one week a reminder postcard is mailed to all nonrespondents (Appendix, Fig. B4). This is followed by a replacement questionnaire to the remaining nonrespondents (Appendix, Fig. B5). The average sample group response rate was 8 out of 10 returned surveys—81% overall (Table 2.1).

Table 2.1. Number of Surveys Returned per Sample Partition

	Urban	Suburban
Heavy urban	8/10	7/10
Medium urban	9/10	8/10
Light urban	10/10	8/10
Mixed forest	8/10	8/10
Conifer	7/10	8/10

In this chapter, I focus on a selected set of survey questions that address how many trees residents are considering planting or removing and have planted or removed during their tenure at their current residence, using four tree type categories based on tree size at maturity and leaf senescence (Fig. 2.1). No timeline was included in the question with regard to future tree removal or planting considerations. I assumed that for each household the timeline for planting was the same as for tree removal, and therefore the difference between planting and removal considerations per household can be used to infer short term potential changes to the structure of the urban forest.

The ability of residents to accurately differentiate between evergreen and deciduous is perhaps more difficult for some with small tree sizes. Many of the common small evergreens in this region are broadleaf, including rhododendrons, cherry laurels, and camellias. I suspect that some residents may have erroneously classified their broadleaf evergreen species as deciduous trees. Within my tree sample, the large evergreens in the region are primarily conifer trees, while large deciduous trees are mostly broadleaf.



Yard Survey: tree planting history

Definitions:

An **evergreen tree** maintains its leaves year-round.

A **deciduous tree** loses all of its leaves for part of the year.

For each of the spaces below, please respond for each of the four types of trees listed.

Tree Type	Small evergreen	Large evergreen	Small deciduous	Large deciduous
Examples	Arborvitae, camellia, dwarf pines & spruces	Redwood, spruce, cedar, fir, pine trees	Vine maple, fruit trees, flowering trees	maples, poplars, birch, oak, sycamore
Height (at maturity)	Up to 30 feet	Taller than 30 feet	Up to 30 feet	Taller than 30 feet

Figure 2.1. Illustration of the four tree type categories from the yard care survey packet.

Carbon models

I used the measurements from the vegetation survey to derive carbon storage estimates from allometric models. To estimate above-ground plant biomass patterns of the residential urban forest in urban and suburban lots, I used published regional, allometric equations (described in Hutyra et al., 2011) and the structural characterization of the urban forest (described in Chapter 1).

The allometric models I used to estimate tree biomass were developed in traditional closed-canopy forests (Gholz et al., 1975; Binkley, 1983; Singh, 1984; Jenkins et al., 2003). McHale and colleagues (2009) tested and discussed the applicability of these models for use in urban regions, and they found that the biomass estimates were similar, although there was a large range of variability depending on location, scale, and species (McHale et al., 2009). The allometric models used in this research were specific to the study region, so the potential error from different biophysical conditions was reduced—although some growing conditions are still quite dissimilar in urban regions compared with natural forests. In addition, many of the species found in urban regions do not have models developed for them specifically. In my project, 607 of the 2,228 trees measured did not have a species- or genus-specific model available, so the biomass for these trees was estimated using the miscellaneous hardwood equation from the study by Jenkins and colleagues (2003). Until additional research specific to urban regions is completed, these are the best models to use to scale from trunk measurements to tree biomass estimates. Finally, to account for the differences in growth form between closed-canopy and open-grown trees (Nowak, 1994) I reduced biomass estimates for open-grown trees by 20%. Error propagation in the conversion of trunk measurements to whole plant biomass estimates was not quantified in the error estimates, so these likely under-represent actual model error.

To assess the consequences of land management actions, I explored changes in carbon storage potential of the net change in tree numbers by multiplying the difference between reported planting and tree removal actions (both past and intended actions) per household by the average carbon stored per tree in each of the four functional trait groups in the suburban and urban areas.

I made the following assumptions in this simulation: (1) all respondents planted and removed the trees in accordance with what they reported, (2) the planted trees persist in the landscape, (3) over time, the carbon storage of these planted trees will mimic the average carbon storage distribution of trees in the same functional trait group currently on the landscape, and (4) residents are removing trees of an average size. The average carbon storage per tree in each functional trait group is presented in Table 2.2.

Analysis

I used analysis of variance and univariate, generalized, logistic regressions (family = normal distribution) to compare estimates between the urban and suburban areas. I conducted the analysis using the survey package software in R because I can specify analysis weights according to my stratified random sample design. Weights were assigned based on the total area covered by each sample partition group (e.g., refer to Chapter 1, Fig. 1.4). Regression models were used to determine the differences in structure, planting, and tree removal rates, as well as the carbon storage between the urban and suburban areas. All reported dispersion estimates were the standard error, and the levels of significance were set at 5% ($\boldsymbol{\alpha}$ = 0.05).

RESULTS

The effect of urban forest structure on carbon storage

The urban core stores 3 ± 0.7 M carbon (C) per parcel or 13 ± 2.6 M C per acre, while the suburban area stores 17 ± 4.4 M C per parcel or 28 ± 5.5 M C per acre. There was significantly more carbon stored in above-ground live plant biomass per parcel in the suburban area than in the urban core (Fig. 2.2 a), which was expected because there are more trees in the yards of suburban homes compared with urban residences (Fig. 2.3 a). It is surprising, however, that the trend is also observed after normalizing by area (per acre) (Fig. 2.2 b), considering that tree densities are not significantly different between the urban and suburban areas once the parcel area is taken into account (Fig. 2.3 b).

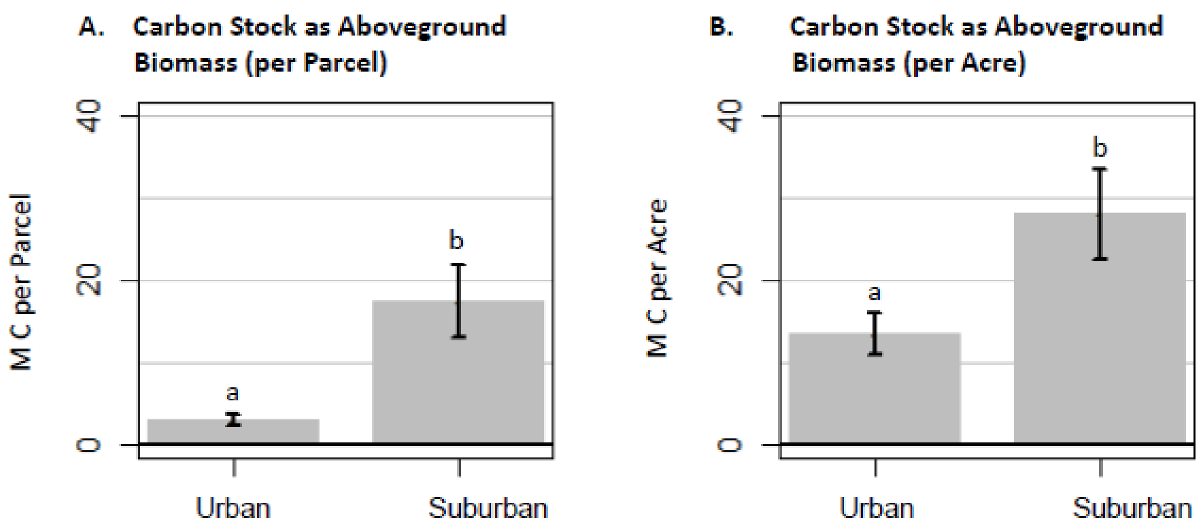


Figure 2.2. Overall amount of carbon stored by above-ground live plant biomass in the urban and suburban residential landscapes by parcel and also normalized by area. Error bars represent standard error. Letters (a, b) indicate significant difference in storage between urban and suburban partitions (α = 0.05).

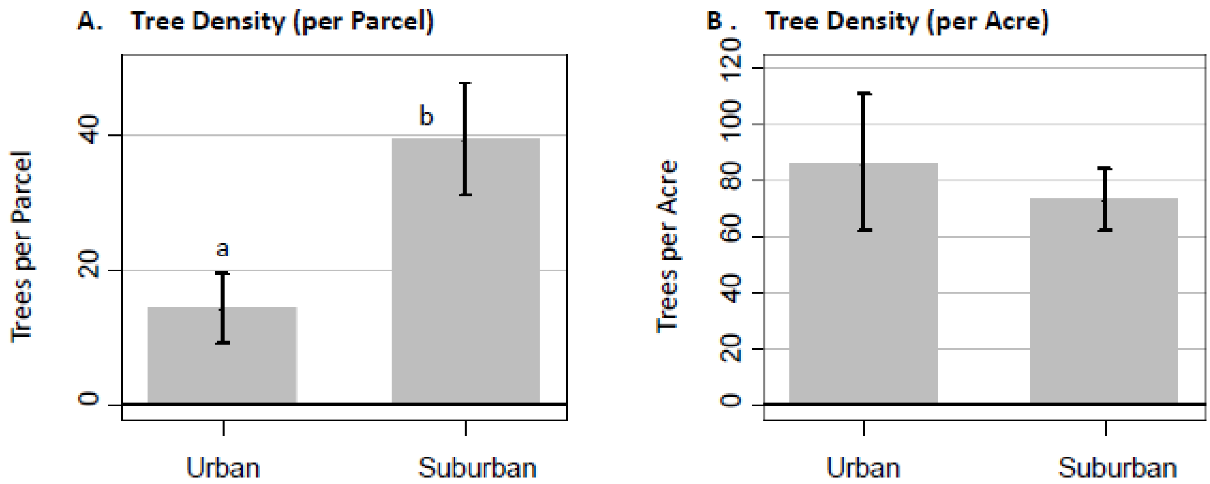


Figure 2.3. Count of trees per parcel and overall tree density by area in the urban and suburban residential landscapes. Error bars represent standard error. Letters (a, b) indicate significant difference in tree densities between urban and suburban partitions (α = 0.05).

The difference in forest structure, and specifically the abundance of trees with large size potential, between the urban and suburban areas results in significantly different carbon storage values per acre. There is no difference in the density of trees when measured as tree count per acre of land (Fig. 2.3 b). However, the abundance of plants with certain functional traits between lots in the urban and suburban areas does vary and translates to a very different carbon signature. The difference in carbon storage is largely explained by the number of trees with large size potential, particularly large evergreen trees (Figs. 2.4 a, c, and e; Figs. 2.5 a, c, and e).

It is interesting to note that while the suburban area has significantly more deciduous trees per parcel with large size potential (light grey bars in Fig. 2.4 f), the difference is not significant in terms of carbon storage. This may be explained by the abundance of young (small) trees within this functional trait group in the suburban area, while those in the urban core are likely to be older and therefore larger (refer to Fig. 1.10 c in Chapter 1). The opposite trend is apparent in the number of deciduous trees that retain a small stature even at maturity. There are more young (currently small) deciduous trees with small size potential per acre in the urban core (refer to Fig. 1.11 d in Chapter 1), but since they will remain small even at maturity the carbon storage consequences are minor (Fig. 2.5 g).

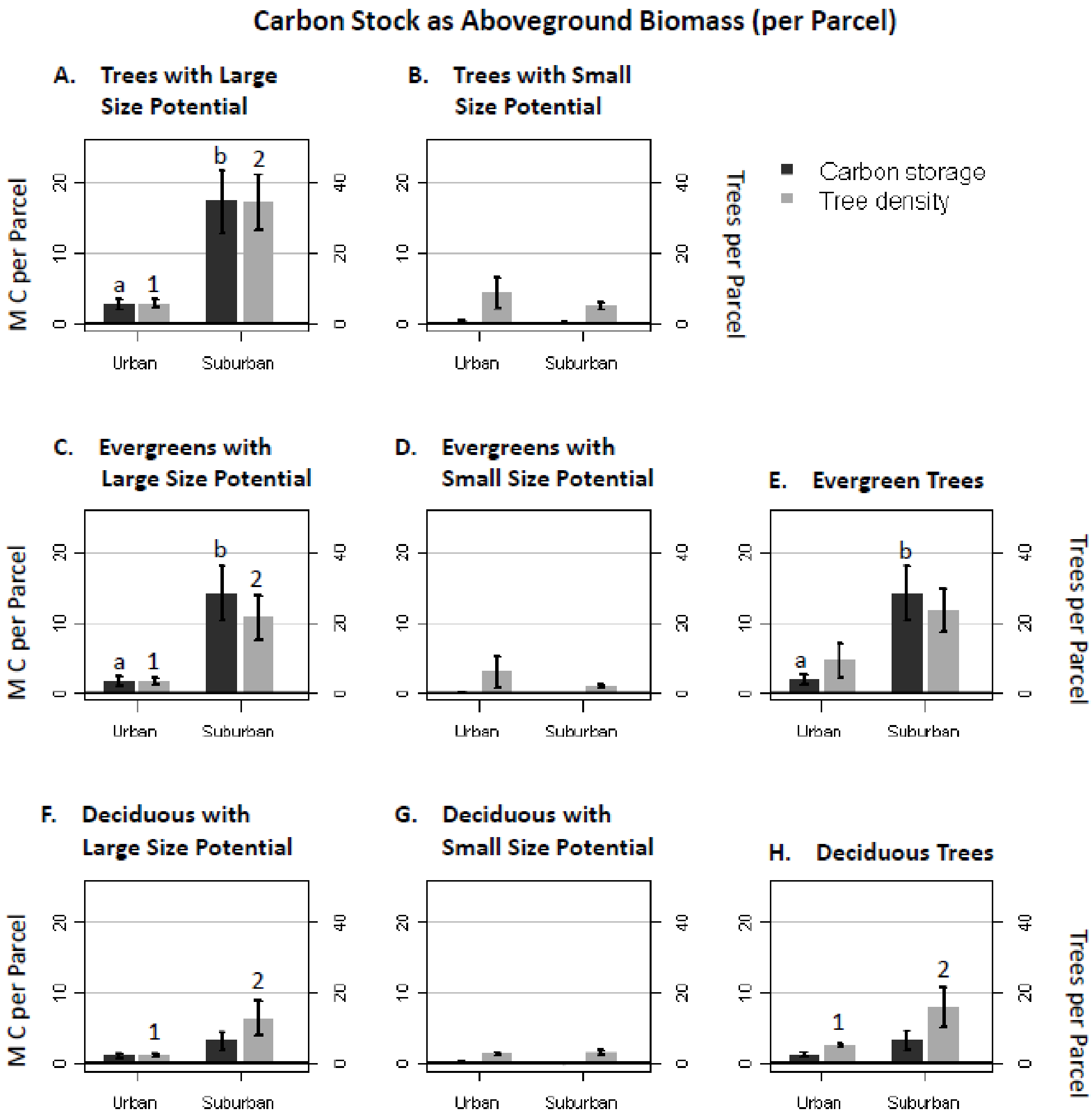


Figure 2.4. Carbon storage (dark grey bars, axis units represented on left-hand side of plot) and tree counts (light grey bars, axis units represented on right-hand side of plot) per parcel for each of the functional trait plant groups in the urban and suburban residential landscapes; error bars represent standard error. Letters (a, b) in panels indicate significant differences ($\alpha = 0.05$) in carbon storage between the urban and suburban areas, while numbers (1, 2) indicate differences in tree counts.

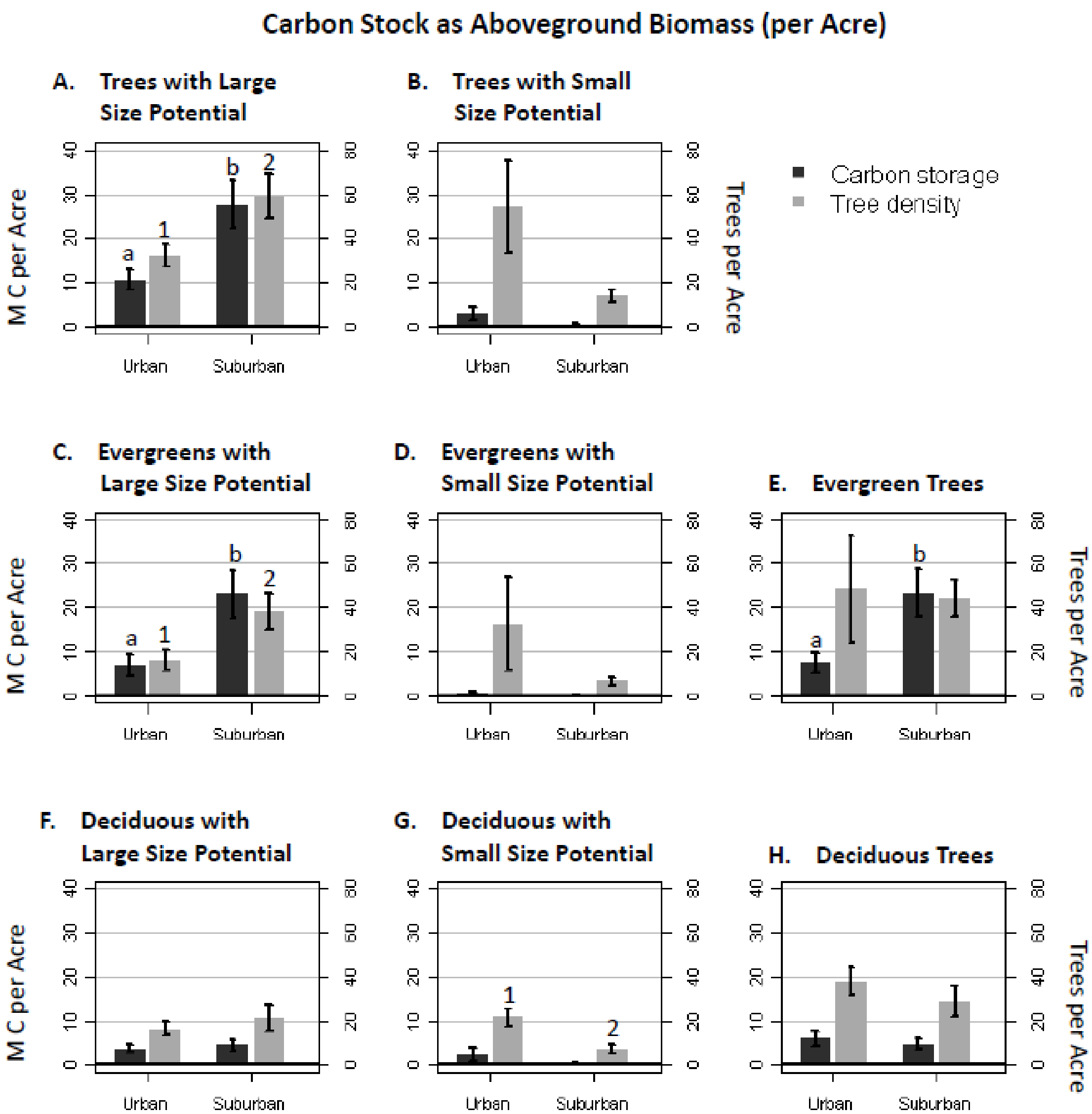


Figure 2.5. Carbon storage (dark grey bars, axis units represented on left-hand side of plot) and tree counts (light grey bars, axis units represented on right-hand side of plot) normalized by parcel area provided by each of the functional trait plant groups in the urban and suburban residential landscapes; error bars represent standard error. Letters (a, b) in panels indicate significant differences (α = 0.05) in storage between the urban and suburban areas, while numbers (1, 2) indicate differences in tree counts.

Change in tree abundance due to resident planting and removal patterns

There was no change in overall tree density per parcel based on tenants' reported past planting and tree removal actions or the actions they were considering in the future in either the urban or suburban area (Fig. 2.6 a). Tree density by area shows that there will be a significant increase in the number of trees on the landscape in the suburban area if residents plant and remove the trees they reported to be considering in the future (Fig. 2.6 b). In addition, there was a significant net gain in trees per acre (as opposed to per-parcel measurements) from past land management in the urban area from past actions, at an alpha of 0.1.

In a comparison of changes in tree density from household planting and tree removal activities between the urban and suburban areas, there was no difference (from past actions or those they are considering). Suburban residents have removed more trees than those in the urban core; but there was no difference in the number of trees that have been planted (Fig. 2.6 c and d). Nor were there any differences in the number of trees residents were considering planting or removing in the future.

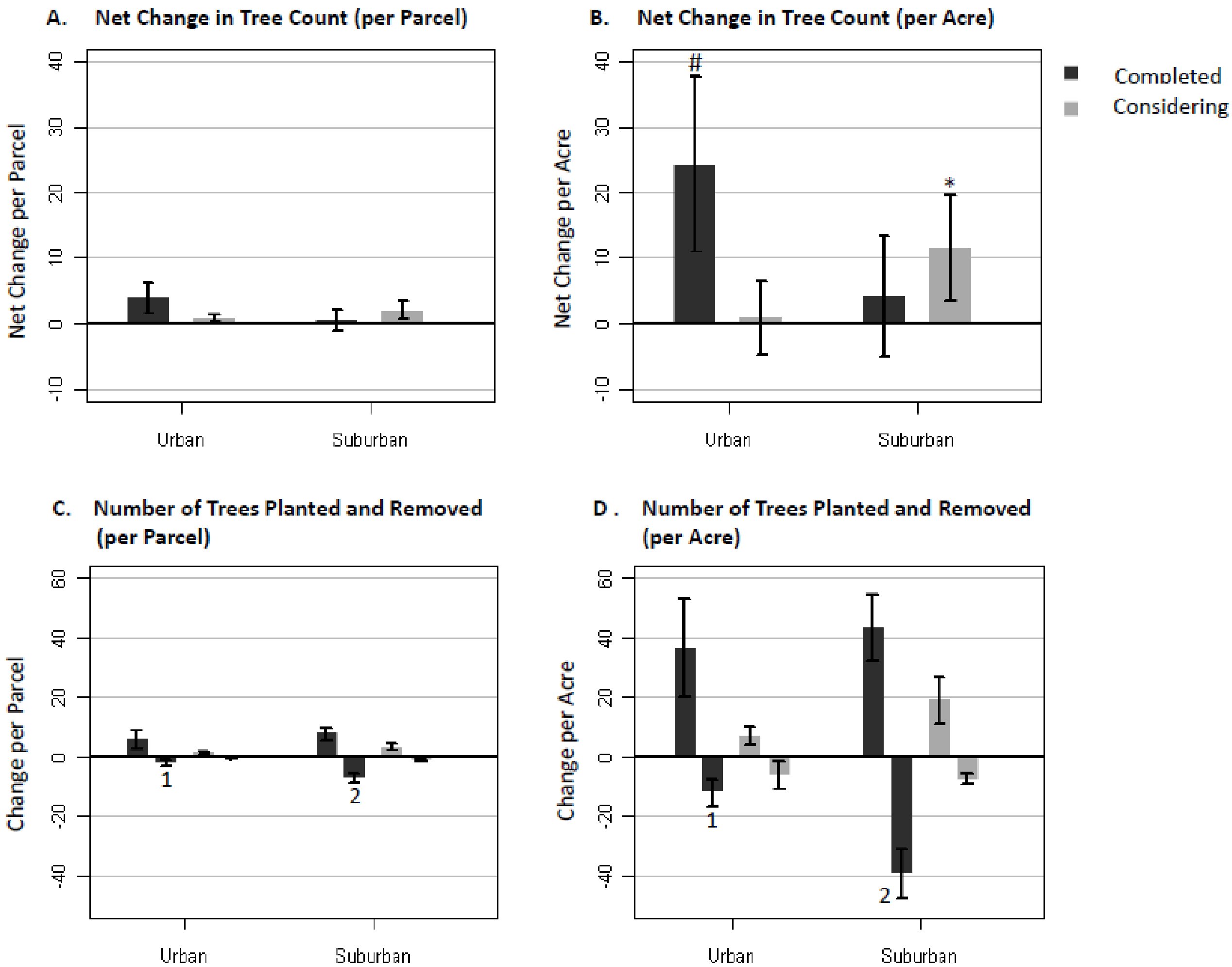


Figure 2.6. The net change in tree count—the number of trees planted minus trees removed (A and B)—and the number of trees households planted (positive axis) and removed (negative axis) (C and D). The dark gray bars indicate tree change that has already occurred, and the light gray bars indicate the number that residents are considering planting or removing in the future. The numbers (1, 2) in the panels indicate differences (α = 0.05) in counts of trees removed between urban and suburban areas. Signs (*, #) in the panels indicate a significant difference in tree densities compared with 0 (α = 0.05; α = 0.1).

Change in forest composition due to resident planting and removal patterns

The actions of residents do vary by functional trait groups. In both the urban and suburban areas, residents have planted more deciduous trees with small stature potential than they have removed during their tenure, so there has been a net increase in this functional trait group (Fig. 2.7 a and b). Future yard management considerations show that there may be an increase in the number of small deciduous trees, although only in the suburban area, not the urban core (Fig. 2.8 d).

There are some differences in both tree planting and removal rates by functional trait groups between the urban and suburban areas. Residents in the suburbs have planted and removed more evergreen tree species with large size potential than residents in the urban core (Figs. 2.7 c and d). When asked about the trees that residents are considering removing in the future, those in the suburban partition indicated that they are considering removing more deciduous tree species with large size potential than did residents in the urban area (Figs. 2.8 c and d)

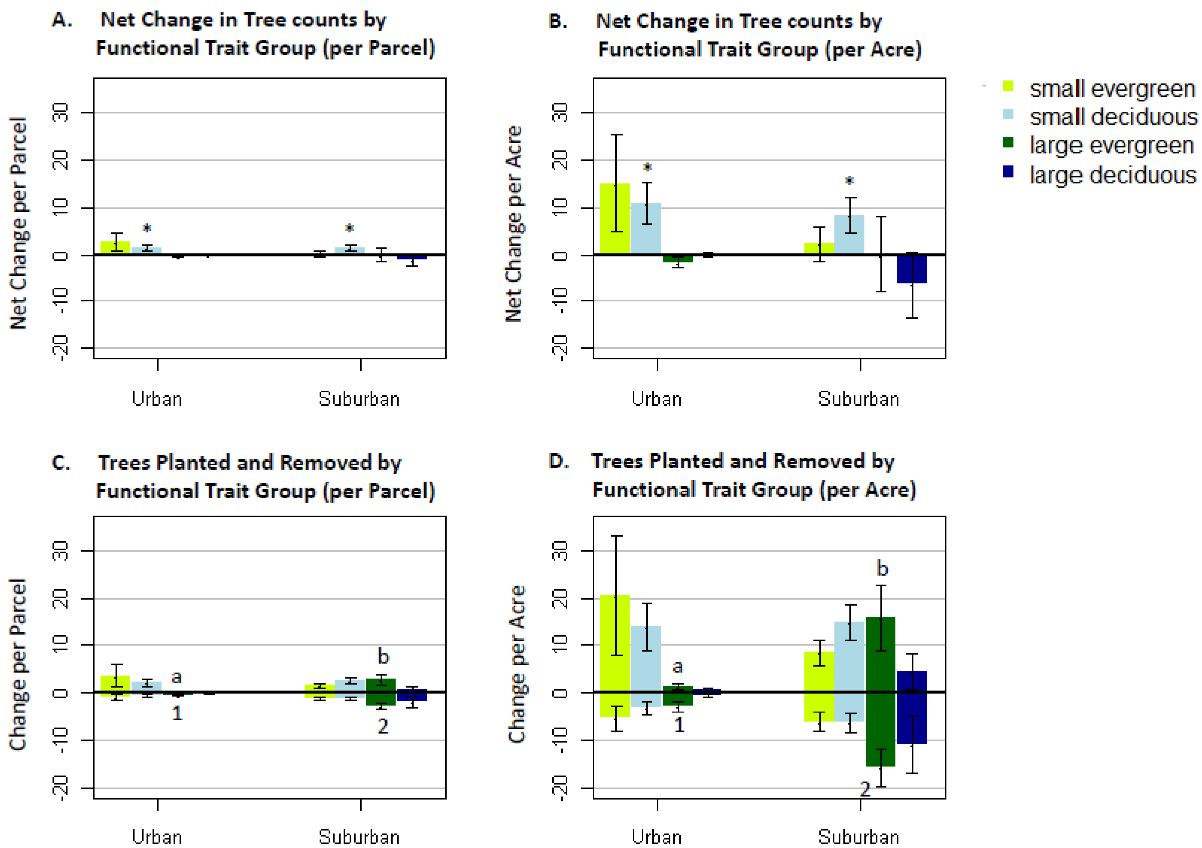


Figure 2.7. The resultant net change in tree count of each functional trait group from landowner activities (panels A and B) and the number of trees households planted (positive axis) and removed (negative axis) (panels C and D) during their tenure at their current residence. The letters (a, b) in the panels indicate differences (α = 0.05) in counts of trees planted between the urban and suburban areas; the numbers (1, 2) indicate differences (α = 0.05) in counts of trees removed between the urban and suburban areas. Signs (*, #) in the panels indicate a significant difference in tree densities compared with 0 (α = 0.05; α = 0.1).

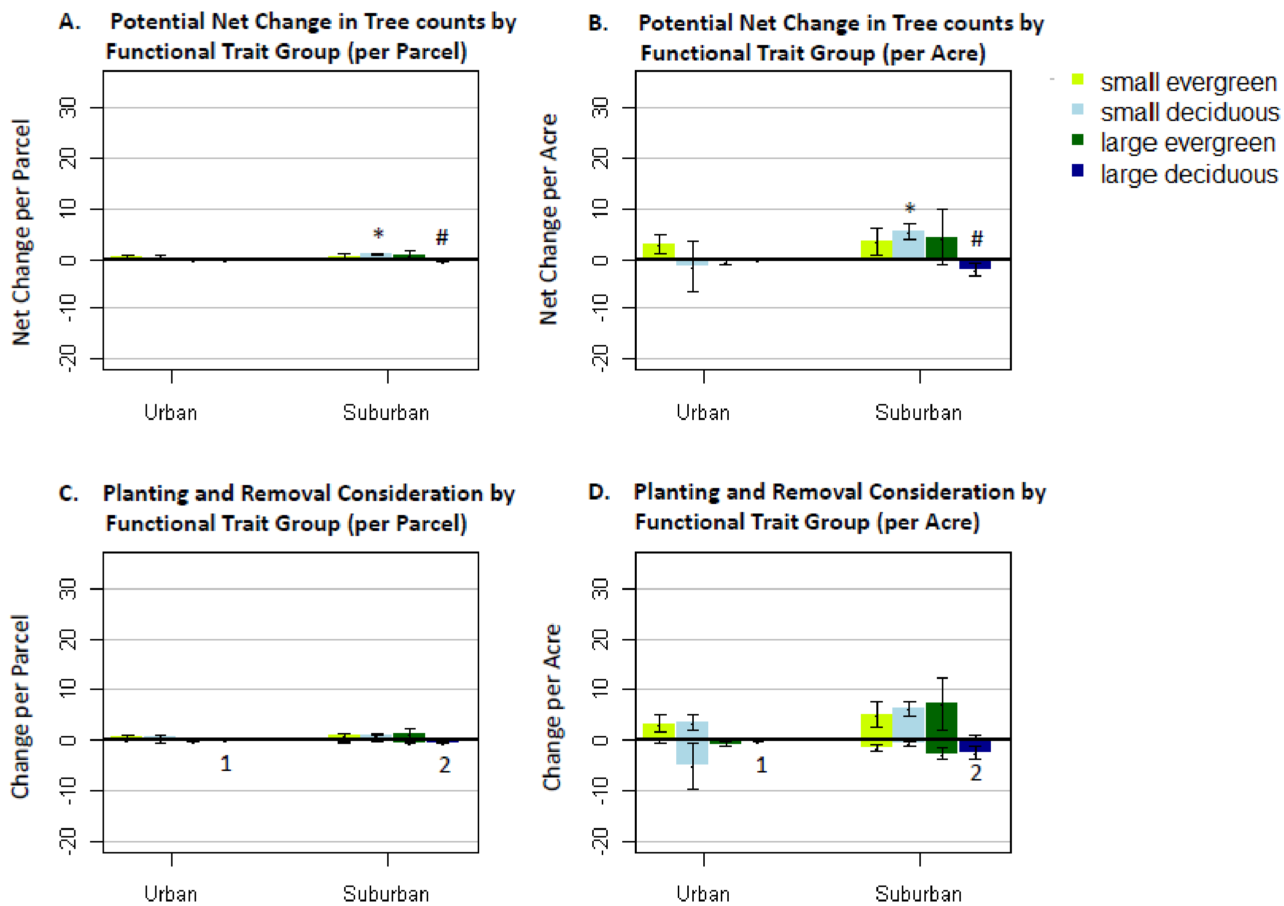


Figure 2.8. The potential resultant net change in tree count in each functional trait group that households are considering planting and removing during their tenure at their current residence (panels A and B) and number of trees residents are considering planting (positive axis) and removing (negative axis) (panels C and D). The numbers (1, 2) indicate differences (α = 0.05) in tree removals that residents are considering between the urban and suburban areas. Signs (*, #) in the panels indicate a significant difference in tree densities compared with 0 (α = 0.05; α = 0.1).

Implications of household activities on carbon storage potential

I modeled the carbon implications of these management decisions into the future, assuming that the trees planted by residents grow to be the average size of trees currently observed in each functional trait group and that residents were also removing trees of an average size. The average carbon storage per tree in each functional trait group is presented in Table 2.2.

Table 2.2. Average Carbon Storage per Tree in Each Functional Trait Group in the Urban and Suburban Residential Urban Forest (With Standard Error)

	Urban	**Suburban**
Large evergreens	0.55 ± 0.3	0.65 ± 0.1
Large deciduous	0.14 ± 0.02	0.21 ± 0.05
Small evergreen	0.018 ± 0.01	0.0046 ± 0.001
Small deciduous	0.036 ± 0.01	0.017 ± 0.004

After accounting for trees residents intended to remove, there was no expected change in carbon storage from the growth of past tree planting or new planting considerations in the future (Fig. 2.9). With the exception of slight gains in carbon storage potential from deciduous trees with small size potential (Fig. 2.10), none of the other extrapolated carbon estimates due to land management actions by functional trait group are significantly different from zero, indicating that there is no expected change in carbon storage based on residents' reported future tree planting and removal considerations—or from reported past management actions (Fig. 2.10). This is surprising because there is an overall increase in tree density per acre from past management actions, albeit a small one. However, the gains in tree abundance come from those with small size potential, and the carbon benefits from these trees are not large enough to outweigh the loss of trees with large size potential (Fig. 2.10 a and b).

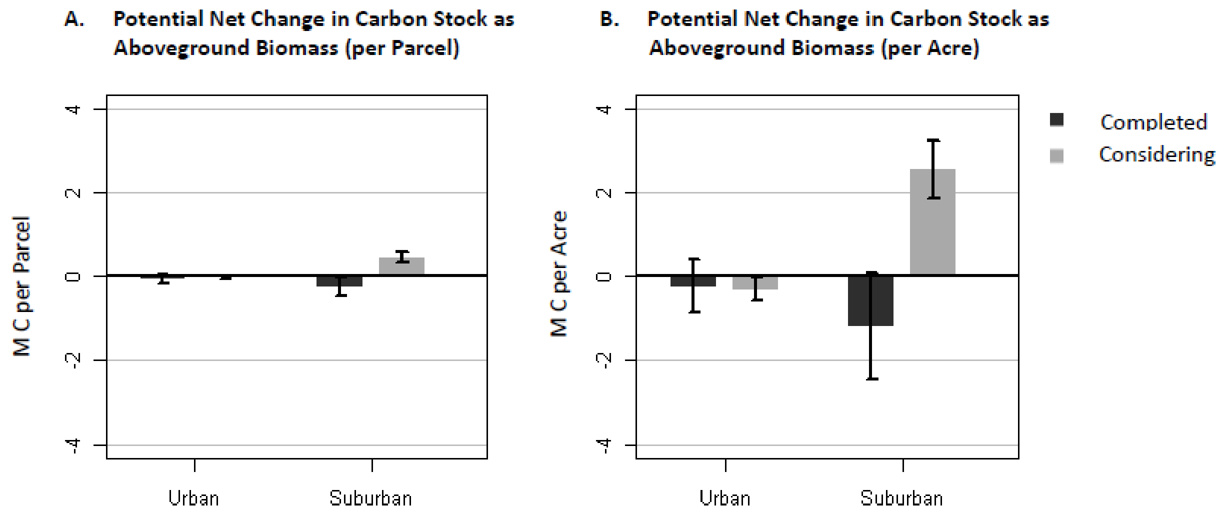


Figure 2.9. The expected resultant long term change in carbon storage due to changes in tree counts from planting and removal activities. Signs (*, #) in the panels indicate a significant difference in tree densities compared with 0 (α = 0.05; α = 0.1).

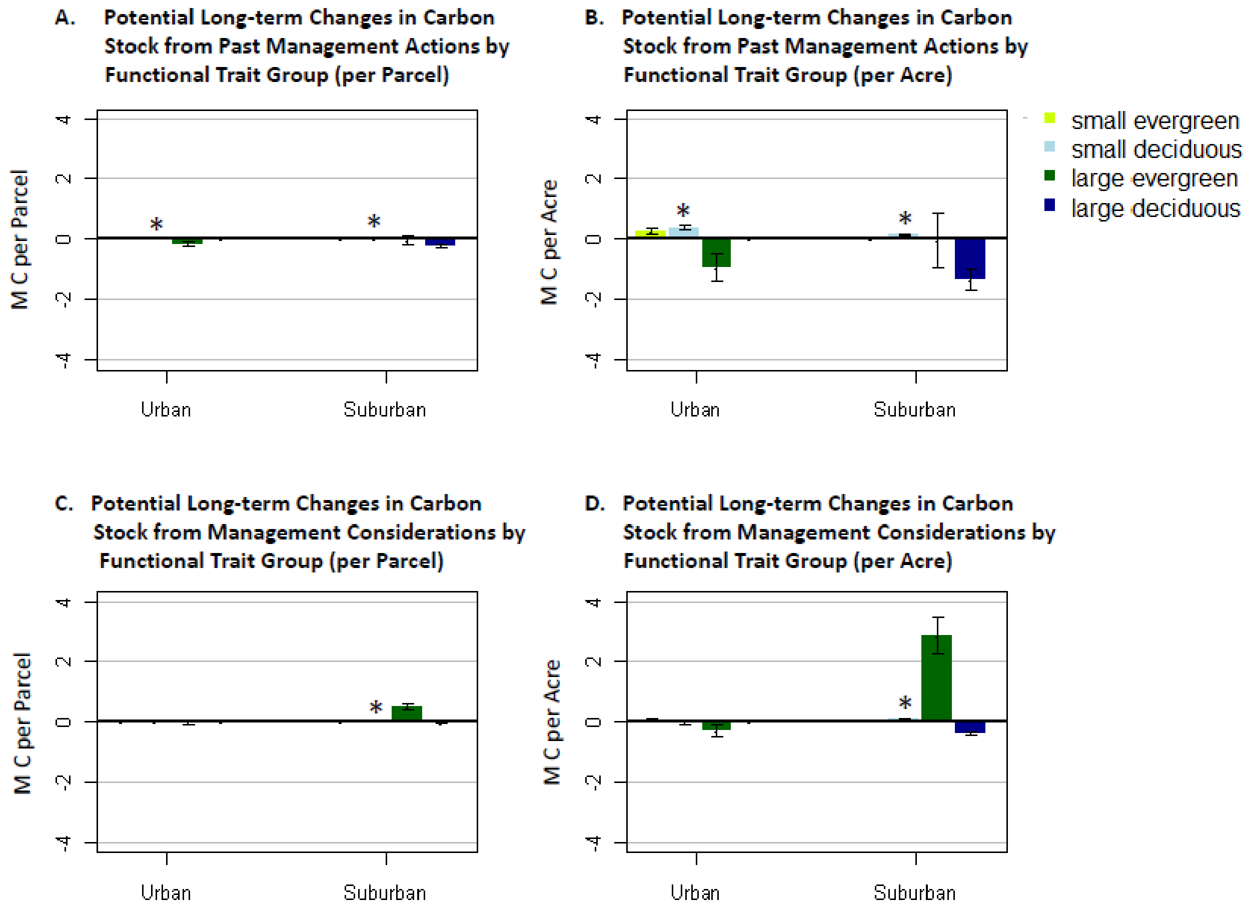


Figure 2.10. The expected long term change in carbon storage due to changes in tree counts from planting and removal activities broken down by plant functional trait groups. The top row indicates the results of past actions (panels A and B), and the bottom row indicates change from planting and removal considerations (panels C and D). Signs (*, #) in the panels indicate a significant difference in tree densities compared with 0 ($\alpha = 0.05$; $\alpha = 0.1$).

DISCUSSION

Carbon storage

Carbon stored in live, above-ground plant biomass in residential lands in King County is more abundant on properties in the suburbs compared with those in the urban core—both carbon storage per parcel and per acre. These results are consistent with other assessments of carbon stocks across urbanizing regions. In an assessment of all urban land uses in the Seattle metropolitan region, Hutyra et al. (2011) reported gains in carbon stock with increasing distance from downtown Seattle. Yards in the urban core of King County store 13 $\pm$ 2.6 M C per acre, a figure rather similar to the average—9.3 M C per acre—of other urban regions in the U.S. (Nowak and Crane, 2002) and to the average carbon storage within the City of Seattle political boundaries—10 M C per acre, (Ciecko et al., 2012). (It should be noted that neither of these comparative estimates are specific to residential land use, but rather they include all urban land uses.) Raciti et al. (2012) reported residential carbon storage as 7.7 $\pm$ 1.6 M C per acre in highly populated areas and 17 $\pm$ 1.6 M C per acre in sparsely populated areas. They also examined different definitions of "urban" and cautioned that comparing estimates of urban vegetative carbon stock between studies is challenging because inconsistent definitions and delineations of urban environments can have a large effect on carbon estimates (Raciti et al., 2012).

The similarity of carbon storage estimates between urban regions supports the hypothesis that urban regions are undergoing biotic homogenization of ecosystem functions regardless of climatic and geographic differences as residents design their landscapes to meet their human habitat needs and preferences (Kühn and Klotz, 2006; McKinney, 2006; Grimm et al., 2008). For example, yards are often managed to provide curb appeal, privacy, shade, and places to relax (Dwyer et al., 2000; Irwin and Bockstael, 2002; Irwin and Bockstael, 2007). Therefore, I expected highly urbanized areas to more closely resemble each other in both structure and function than to resemble the native system that they have replaced. This is supported by other investigations of carbon cycling (Imhoff et al., 2004). For example, arid and semi-arid regions have higher urban vegetative carbon stocks than the adjacent native system (Kaye et al., 2005; Buyantuyev and Wu, 2009), while regions once covered by closed-canopy forests exhibit a reduced carbon stock (Hutyra et al., 2011; Rao et al., 2013).

McKinney (2006) further hypothesized that with increasing distance from the urban center the ecosystem patterns and functions will be a blend of the urban and the native forest systems. Indeed, residential lands in the suburban area of King County have significantly more carbon than in the urban core: 28 ± 5.5 M C per acre. The carbon storage on these properties is almost three times more than the national urban average (Nowak and Crane, 2002). These carbon stock values more closely resemble the average carbon storage of natural forests in the U.S., which is 22 M C per acre (Nowak and Crane, 2002); however, the carbon storage of these yards is not even half of what a 60 year old forest native to this region stores (western hemlock and Douglas-fir forests). Pacific Northwest forests have been reported to store 64 M C per acre 60 years after clearing, while an old-growth western hemlock and Douglas-fir forest stores 139–144 Mg C per acre (Harmon et al., 1990).

The carbon signatures, broken down by plant functional trait groups, of the suburban yards are dominated by plant biomass stored in evergreen species with large size potential. This functional trait group consists mostly of the native conifer species that once blanketed the region, such as Douglas-fir (*Pseudotsuga menziesii),* western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata)*. The deciduous trees with large size potential also mostly consist of native species in the suburban area (Chapter 1, Fig. 1.13). These deciduous trees are also more prevalent in the smaller size classes than the evergreen species with large size potential, implying that over time these deciduous trees with large size potential will slowly replace the native conifers (Chapter 1, Fig. 1.11). Meanwhile, the carbon storage services provided by the deciduous and evergreen trees with small size potential are very small. These are the predominant trees in the urban core, so I expected the carbon storage potential in this region to be rather low, especially in comparison with forests composed of carbon rich native tree species. Finally, the ratio of carbon storage of deciduous trees with large size potential to their total density in the urban area is much smaller than that in the suburban area. While the trees in the urban core do have a large size potential, as of yet they are still rather small (Chapter 1 Fig. 1.11 c).

Yard management behavior

Reported management behavior showed no net change in overall tree abundance per yard, or per acre, since past tree planting rates have been keeping up with tree removal rates between the urban and suburban areas. Because future urban forest modifications show the same trends (Fig. 2.7 a and b) based on reported tree planting and removal considerations, I do not expect to see a reduction in tree density over time due to land management activities.

Residents reported more tree modifications during their tenure than they planned to change in the future. Similarly, Summit and McPherson (1998) found that tree planting rates are the greatest early in the tenure of a home. Possible reasons for my results include the fact that the average tenure of the sample population (14 years) is longer than the time frame they are considering when reporting tree planting and removal. Alternatively, new homeowners may be more inclined to re-design their yards to their desired specifications. Then they may not be interested in redesigning the landscape further.

In residential yards, vegetation is highly managed, and homeowners' tree planting and removal activities replace the succession process that is present in more natural systems (Waldron and Dyck, 1975; Dwyer et al., 2000). Considering how large the native conifer trees are capable of growing in the Pacific Northwest, tree planting and removal activities have the potential to substantially alter the carbon storage potential of the landscape. However, my results do not indicate that that will occur in this region. The functional traits of the trees that residents were selecting to plant and remove will likely result in only very subtle changes in the composition of the urban forest over time. Residents in both the urban core and the suburban areas reported that they have planted more deciduous trees with small size potential than they have removed, although the difference is only significant for future management considerations in the suburban area.

In addition, growth simulations indicated that previous tree planting and removal activities will yield insignificant gains in carbon storage. The simulation of carbon storage potential from future tree planting and removal considerations also indicated no significant net change in carbon storage capacity (Fig. 2.9). This was somewhat surprising given that there were gains in small deciduous trees from land management in the suburban area. However, the carbon benefits provided by these species were small in comparison with the trees with large size potential. While there is the potential for large, unintended consequences of replacing native giant evergreens with small trees in terms of carbon storage, it did not appear that there was a loss of these trees. Instead, residents were adding small-stature trees to the mix. However, there is considerable uncertainty when making predictions about future conditions. For example, the assumption that all planted trees will grow to the average size of trees currently on the landscape would need to be verified. These estimates do, however, provide a glimpse of potential consequences of land management actions with regard to carbon storage.

Bigger picture: Development patterns

Residential landscapes with high densities of native conifer species could offer substantial gains in carbon storage, but maintaining high densities of large trees in an urban environment comes with other costs and trade-offs. These costs and trade-offs with alternative land uses and management actions should be recognized and accounted for to better inform land management policies and programs (Dobbs et al., 2011; Escobedo et al., 2011; Pataki et al., 2011; Gomez-Baggethun and Barton, 2013). There is competition for space between trees and built infrastructure, especially in dense urban areas that are designed to support and encourage lower impact choices (e.g., public transit). In addition, when setting policy objectives and designing best management practices, resource investments (e.g., irrigation) and ecological impacts (e.g., fertilizer application and pesticide) associated with establishing and maintaining trees in the urban region need to be considered. The urban environment presents stressful growing conditions that can slow tree growth and result in early mortality (Celestian and Martin 2005, Close and others 1996), so replacement costs should also be considered. Articulating economic and societal trade-offs in maintaining green infrastructure in urban areas can better inform the decision making process.

In addition, it is important to consider the urban-suburban dichotomy when setting land use objectives, programs, and policies. Studies suggest that replacing up to one-third of agricultural lands with intensively managed forests could offset 10–20% of current U.S. fossil-fuel emissions (Jackson and Schlesinger, 2004; McKinley et al., 2011). Simultaneously, urban areas around the U.S. are converting these same lands into low-density urban land cover, primarily as large-lot residential properties (Daniels, 1999; Duany et al., 2000; Heimlich and Anderson, 2001; Robinson et al., 2005; Theobald and Romme, 2007).

Given how persistent land cover change trends and preferences for homes in the suburban area are in the U.S. (Daniels, 1999; Duany et al., 2000; Storper and Manville, 2006), it is important that decision makers and planners consider and implement policies and programs to reduce and mitigate the higher per-capita emissions associated with this type of development (Newman and Kenworthy, 1999; Ewing and Rong, 2008; Brownstone and Golob, 2009; Bart, 2010; Glaeser and Kahn, 2010). One example is to increase the carbon storage capacity of the residential urban forest, the objective of which would be to offset, or at least mitigate, higher levels of greenhouse-gas emissions associated with suburban lifestyles through the development and maintenance of a residential urban forest composed of tree species with high carbon storage potential such as Douglas-fir (*Pseudotsuga menziesii)* or western red cedar (*Thuja plicata)*.

These high-carbon-yielding native conifer species could offer substantial gains in carbon storage with little human input due to our productive growing conditions in the Seattle metropolitan region. However, new exurban residential development in this region is largely occurring on lands that are currently forested (Robinson et al., 2005), so new development should also preserve as many of these trees as possible. Robinson and colleagues (2005) also reported increases in suburban and exurban development at the expense of rural and wildland covers in the Seattle metropolitan region and single-family development as the primary cause of land conversion (Robinson et al., 2005). Sprawling low-density housing in these rural lands constituted 72% of total land developed in the study area (Robinson et al., 2005). These trends are not isolated to the Seattle region—privately owned forests are being converted to commercial and residential use at the periphery of many other U.S. cities (Stein et al., 2005; Stein et al., 2006), potentially resulting in increased carbon emissions from forest clearing.

Examples of potential land management programs aimed at maintaining and increasing carbon storage capacity in suburban lawns include developing neighborhood forest easements, offering subsidies or tax incentives to homeowners for planting trees, and financing tree planting programs. The latter would require the development and ongoing maintenance of partnerships with suburban residents to ensure that their lands are indeed being maintained in a manner that will optimize these offsets. Finally, a more thorough understanding of the factors influencing residents' yard design and management decisions could assist in these outreach efforts. Knowing residents' motivations and their experience of barriers to tree planting and removal, especially with regard to selection based on functional traits (e.g., size potential), is a critical piece of information in shaping a successful suburban ecosystem service-provision partnership in these residential lands.

This study contributes critical information about the carbon dynamics in residential yards through the lens of a coupled human ecological framework. Integrating data sets from remote sensing, field plots, and household surveys offers great promise in the continued exploration of urban dynamics of the tightly coupled human-natural residential landscape. Following up with an assessment of the motivations influencing resident selection of trees and decisions to plant or remove them would provide additional insight for scientists and decision makers that would be important to the design of successful tree planting and maintenance programs.

CHAPTER 3.

Assessing the influence of household motivations and constraints in management of the urban forest in the Seattle metropolitan region

ABSTRACT

Residential yards play a key role in determining ecosystem functions in cities because they occupy a large portion of the urban landscape. Municipalities and utility companies recognize that the ways in which residents manage their properties can play a major role in providing local ecosystem services, which are determined largely by the quantity and composition of trees in the urban environment. We are beginning to understand the structure and function of urban forests, but we still know very little about urban forest dynamics, particularly about the role of residential land management. There is no systematic study of what trees residents are planting and removing and why and of the motivations and constraints that influence their decisions. Household attitudes and values, landscape preferences, land use priorities, available resources, institutional constraints, and environmental context have all been found to play a role in influencing land management decisions. Also, while researchers have described differences in ecological functions associated with urban form across an urban gradient, few studies have examined potential differences in residents' yard care practices, preferences, and attitudes toward trees along the gradient. I integrate reported yard management behavior and attitudes toward ecosystem services and disservices provided by trees from a mailed yard care survey with measurements of the respondent's yard characteristics in order to characterize tree planting and removal patterns and the factors that influence these decisions. I found that urbanites and suburbanites agree with respect to the benefits that trees provide. However they differ in perceptions about the issues and challenges of maintaining trees on-site. Aesthetics, privacy screens, and low maintenance were the most frequently listed considerations in selecting trees to plant, and motivations varied by functional traits of the planted trees (e.g., small evergreens were planted to provide a privacy screen). Residents' decisions to plant a tree were associated with their locations along the urban gradient, whether they believed they had space for additional trees, and the current count of trees with a small size potential. Models investigating decisions to plant trees by functional trait groups showed differences between tree type groups. How residents design and manage their yard landscapes can inform policies and programs aimed at increasing tree

cover on private lands and provide insights on how the residential urban forest and its ecosystem services might change over time.

INTRODUCTION

Urban areas occupy a small fraction of the land worldwide, and in the U.S. estimates range from just 5% to 18% (Imhoff et al., 2004; USDA NRCS, 2009). This small area of land houses over 80% of the U.S. population (U.S. Census, 2010). Urban land use is steadily expanding in spatial extent (Seto et al., 2011), and planners recognize that reducing the rates of conversion of natural and semi-natural lands at the periphery of cities is important to achieve more sustainable cities, as urbanites rely on the import of many of the benefits, or ecosystem services, provided by the ecological functions of these areas (Rees, 1992; Rees and Wackernagel, 1996). More recently, planners have begun realizing the importance of simultaneously working to manage green spaces in developed regions to provide additional on-site ecosystem services for residents. Urban vegetation can also reduce the urban ecological footprint and can improve the wellbeing and quality of life for urbanites (Escobedo et al., 2011; Jansson, 2013).

The vegetation within urban regions provides a number of benefits to urbanites, such as shade (Larson et al., 2009) and a daily connection to nature (Miller and Hobbs, 2002; Bernhardt and Palmer, 2007). Understanding how urban lands are designed and managed by landowners will assist planners in the maintenance of local urban ecosystem services. Cities are primarily designed to house and provide services to meet human needs, and as such the urban environment is markedly different than the ecosystem upon which it was built, with different structure, functions, and processes (Kaye et al., 2006). Humans modify and manage their landscape with the implicit objective of creating a favorable habitat (Kareiva et al., 2007), such as a moderate microclimate.

Many of these benefits are the result of ecological functions and processes that are mediated by the qualities of the plant community (e.g., abundance and plant composition); trees specifically play a large role in providing a number of these services (e.g., Bolund and Hunhammer, 1999). Due to their large size, trees are important regulators of many ecological processes, from primary production (McKinley et al., 2011) to water flows (Hewlett, 1969). An awareness of how land management activities could change the abundance and composition of the urban forest is critical in understanding how urban ecosystems function currently and can improve our ability to estimate the provision of these functions in the future. The use of plant functional traits to characterize the trees which residents are removing and planting allows for the inference of how ecological processes, which are mediated by these traits, might change over time based on yard care decisions. Functional traits are features such as growth form that are used to group species in response to environmental conditions or their impacts on ecosystem processes (Gitay and Noble, 1997; Lavorel et al., 1997).

Unlike vegetation in natural systems, which is largely determined and structured by biophysical conditions, urban forest dynamics are largely driven by urban form and land management activities interacting with the biophysical characteristics (McDonnell and Pickett, 1990; Kaye et al., 2006; Williams et al., 2009). Trees are long lived, and therefore the composition of the forest today likely reflects both past ecological sorting processes and the ability of trees to survive changes in their environment (Reich et al., 2003). Additionally, trees that establish on residential land (homeowners' yards) are mostly planted and cared for by residents as opposed to naturally propagating (Waldron and Dyck, 1975).

Individual household land management actions play one of the largest roles in structuring urban vegetation because single-family residential lands account for the majority of the urban land use in metropolitan regions (Dwyer et al., 2000; Irwin and Bockstael, 2002; Irwin and Bockstael, 2007). The impact of these lands on vegetation structure and ecosystem service provision will only continue to increase over time. Most new urban development in U.S. cities is construction of additional detached, single-family residences (NAHB, 2005; Robinson et al., 2005) that often replaces agricultural and wildlands at the periphery of the metropolitan region (Daniels, 1999; Duany et al., 2000; Heimlich and Anderson, 2001; Theobald and Romme, 2007). Lawns are estimated to account for a quarter of urban land cover (Robbins and Birkenholtz, 2003), surpassing areal coverage of any other irrigated crop (Milesi et al., 2005). Simultaneously, households are getting smaller (Liu et al., 2003), while lot and house sizes are increasing (NAHB, 2005), resulting in a bigger per capita footprint on the landscape.

To contribute to our understanding of residential urban forest dynamics and resultant ecosystem functions, I describe and investigate motivations for past and potential residential forest management actions at the household-level. I ask: How many and what types of trees have residents planted and removed from their property during their tenure? What actions are they considering in the future? What influenced their tree selection? I focus on two plant functional traits: size potential at maturity and leaf senescence (deciduous or evergreen).

A multitude of factors operating at different spatial and temporal scales influence residents' management choices (Cook et al., 2012). At the household-level, these include the values, lifestyle factors, landscape preferences, and land use priorities of the residents. Place-based context (e.g., urban form) and formal and informal institutions (e.g., homeowner's associations, neighborhood norms, and political economy) are important neighborhood-level drivers. Yard characteristics match residents' values, attitudes, and land management actions (Law et al., 2004; Larson et al., 2010). These relationships have been established in empirical studies conducted primarily in semi-arid regions (e.g., Larson et al., 2010). Other studies have explored lawn care inputs such as fertilizer rates (Law et al., 2004; Nielson and Smith, 2005) or watering frequency (Askew and McGuirk, 2004; Nielson and Smith, 2005). However, no studies to my knowledge have been conducted in temperate ecosystems which test the relationships between residents' tree planting and removal decisions and the suite of land management factors suggested in the literature (Cook et al., 2012). In addition, few have examined the differences in attitudes and land management actions across a gradient of urban intensity. Those that did have focused on yard care chemical applications (Blaine et al., 2012; Martini et al., 2013) or perceptions of native species (Cary and Williams, 2000)—i.e., to my knowledge none have examined tree management actions across an urban gradient.

The objective of this project was to empirically assess differences in reported attitudes and management actions of single-family residential homeowners in the urban core and outlying suburban areas. I used data from a mailed yard care survey to characterize household perceptions about the benefits and challenges of maintaining trees (any, deciduous, and evergreen), then I measured how many residents had planted or removed a tree and described what motivated these actions. Finally, I augmented information from the yard care survey with field data and spatial data representing the site characteristics to explore which of the following factors are associated with a residents' decision to plant a tree: the relative influence of attitudes toward tree benefits and limitations, tree traits (size potential and leaf senescence), past tree removal decisions, and property characteristics. My research questions were:

1. How do households feel about the benefits and challenges of maintaining trees on their property, and are there differences in attitudes between urbanites and suburbanites?
2. What are the differences in reported tree planting and removal actions across the urban gradient?
3. Why are residents planting and/or removing trees?
4. What structural and attitudinal factors are associated with tree planting actions?

In the following sections I review the literature describing the relationships between yard care management and household demographics, attitudinal factors, and site characteristics. Household demographic characteristics that influence perceptions and management of yards include cultural background (Fraser and Kenney, 2000; Larsen and Harlan, 2003; Martin et al., 2003; Yabiku et al., 2008; Luck et al., 2009), residents' life stage (Martin et al., 2003; Troy et al., 2007; Yabiku et al., 2008), whether residents rent or own their homes (Heynen and Lindsey, 2003; Perkins et al., 2004; Larson et al., 2009), gender (Yabiku et al., 2008; Kirkpatrick et al., 2012), and socioeconomic status (Osmond and Platt, 2000; Robbins et al., 2001; Heynen and Lindsey, 2003; Jensen et al., 2004; Law et al., 2004; Martin et al., 2004; Grove et al., 2006; Hope et al., 2006; Larsen and Harlan, 2006; Mennis, 2006; Luck et al., 2009; Zhou et al., 2009; Kirkpatrick et al., 2012). In the attitudinal factor literature review, I briefly discuss findings regarding the role of broad life values, environmental attitudes, group identity, social pressures on yard design preferences, and management actions. I then focus on what we know about individuals' preferences and beliefs about the benefits and annoyances of trees (all trees and specific functional traits). Finally, I address the role that site-specific factors related to the built environment play in yard management behavior at multiple spatial scales, from the parcel-level constraints (e.g., lot size) to more regional factors (e.g., the urban gradient). The literature review provides a survey of the empirical and theoretical assessments linking yard care management, yard design preferences, household demographics, attitudinal factors, and site characteristics.

Household-level demographics

Household demographics have been shown to have complex relationships with landscape preferences and management actions (Table 3.1). Culture and place attachment, life stage, tenure type (owner vs. renter), gender, and socioeconomic status have all been documented to influence yard design perceptions and preferences, and together they partially explain yard management actions. For example, the landscape preferences, activities, and yard design of three Canadian immigrant communities closely resembled characteristics of the landscape of the respondents' native countries (Fraser and Kenney, 2000). In Arizona, life-style factors explained landscape preferences: women and residents with children younger than seven years of age favored lawns over desert landscapes (Yabiku et al., 2008), which is probably due to play area priorities and perceptions about the safety of prickly arid plants. Larson and colleagues (2009) found that household preferences reflect a desire for "landscapes of leisure"—places to relax, play, socialize, and garden.

Socioeconomic status is associated with a plethora of ecological structure indicators, ranging from plant biodiversity to vegetation abundance (Table 3.1). Harris and colleagues (2012) conclude that household yard practices of suburbanites in three metropolitan regions are the result of constraints and opportunities. Residents with high levels of resources, such as income, tend to live on properties with high ecological qualities (ecosystem functions and services) (Heynen and Lindsey, 2003; Jensen et al., 2004; Grove et al., 2006; Martin et al., 2004; Mennis, 2006; Zhou et al., 2009). Scholars in Baltimore, MD, refer to this as "an ecology of prestige" (Grove et al., 2006); while in Phoenix, AZ, researchers refer to the luxury effect (Hope et al., 2003; Kinzig et al., 2005). This phenomenon is hypothesized to be a result of the purchasing power of households with higher incomes—i.e., given ample resources, residents can purchase or create their preferred green, high diversity yard landscapes. Conversely, financial constraints may explain why a resident's actual landscape does not always match their preferred design (Larsen and Harlan, 2006).

Perkins et al. (2004) assessed a free tree program for Milwaukee residents and found that more trees were planted in owner-occupied properties than rental properties. Renters may lack the authority and resources to plant trees (Behe, 2006), and the high mobility or temporary status of renters may deter them from investing in the long term benefits (market and social) of planting trees. A comparison of yard care and preferences between renters and homeowners would advance our knowledge of urban dynamics, especially considering the differences in home-ownership structure between cities in the U.S. and other global cities. However, in this study I have assessed yard management behavior of only residents of owner–occupied, detached, single-family residential homes. These properties cover far more area than rental properties in the U.S., which suggests that their influence on urban ecological structure and functions is greater than that of rental properties.

Many studies have assessed associations between demographic qualities and yards, and we are starting to learn a considerable amount about these relationships. However, most assessments represent household demographics using data sets that are aggregated to coarser spatial units at inappropriate levels, such as U.S. Census data (Jensen et al., 2004; Mennis, 2006; Luck et al., 2009) or Claritas, Inc.'s PRIZM™ (Potential Rating Index for Zipcode Markets) categorization system available at the zipcode level (Claritas, 1999; Grove et al., 2006; Troy et al., 2007; Troy, 2008; Zhou et al., 2009; Boone et al., 2010).

While household characteristics tend to cluster, it is not appropriate to make inferences about households using data collected at a different scale. Few studies have assessed these relationships at the appropriate scale of analysis (e.g., Fraser and Kenney, 2000; Williams et al., 2002; Larson et al., 2010; Kirkpatrick et al., 2012)—i.e., the scale of the agent of change, which in this case is the household operating at the parcel scale. In this study, I set the parcel and household as my unit of analysis in order to better understand the mechanisms explaining the urban forest structure and the dynamics of change.

Another limitation in many of these studies is the characterization of the ecological structure of the landscape, and more specifically of the plant communities, in residential lands with the use of simple vegetation indices derived from remotely sensed metrics such as canopy cover or the normalized difference vegetation index (NDVI), without validating how well these metrics represent vegetation properties of interest in urban regions (Jensen et al., 2004; Mennis, 2006; Troy et al., 2007; Luck et al., 2009; Zhou et al., 2009). Remotely sensed metrics range from simple measures of canopy cover and measures of greenness (Tucker et al., 1985; DeFries and Townshend, 1994) to vegetation characteristics such as growth form, leaf type and duration, and life history of dominant plants (DeFries et al., 1995; DeFries et al., 1999). Remote sensing can be used to rapidly characterize the vegetation, even down to functional types of plant communities, across large spatial extents, and technology advances have improved the capacity to distinguish the structure and condition of vegetative communities (Ustin and Gamon, 2010). However, there are a number of limitations in the interpretation of these measures, especially in highly heterogeneous urban regions.

Remotely sensed data provide information on the dominant species in the canopy overstory, but little information is received about the structure of the understory or, depending on the number of spectral bands and pixel resolution, less dominant species (Woodcock and Strahler, 1987; Lam and Quattrochi, 1992; Goodchild and Quattrochi, 1997). Given the high heterogeneity of urban regions (Grimm et al., 2000), I posit that they may be more prone to higher misclassification of plant functional groups due to problems with classifying pixels with plant communities that exhibit naturally high variability of functional traits. Few of the applications of these measurements in urban areas have been validated with ground data. Furthermore, the interpretation of simple vegetative measures such as canopy cover or greenness is somewhat ambiguous. For example, one large tree may generate the same tree canopy cover as many small trees clustered in space. In my project, I use measurements of vegetation structure (tree density) collected onsite for each respondent, which allows for clear interpretation of the role of forest structure on attitudes toward maintaining trees and the residents' land management actions.

Table 3.1. A Review of the Role of Demographic Factors With Yard Preferences, Structure, and Management Decisions

Demographics	Yard Preferences	Ecological Structure of Landscape	Yard Management
Culture and place attachment	The British like shade trees; the Chinese prefer few trees; the Italian and Portuguese communities prefer fruit trees and vegetable gardens (Fraser and Kenney, 2000); Arizona natives preferred mesic landscapes more than domestic migrants did (Martin et al., 2003); There was no relationship between landscape preference and length of residence in the city (Larsen and Harlan, 2006); Long term Arizona residents were more averse to dry, desert landscapes (Yabiku et al., 2008).	In backyards, the British had the most shade and ornamental trees, Italians had predominantly fruit trees and the largest vegetable gardens. No differences in frontyard design (Fraser and Kenney, 2000). Vegetation abundance was higher in southeastern Australia neighborhoods with more non-Australian residents (Luck et al., 2009).	The British had planted and were more willing to plant shade trees, the Italian and Portuguese planted fruit trees, and the Chinese planted the fewest trees (Fraser and Kenney, 2000).
Life stage	Grassy areas rated higher among families with young children (Yabiku et al., 2008).	Homeowners with children had a higher tendency to have turfgrass in their backyards; those without children were more likely to have a desert design with no lawn (Martin et al., 2003); Vegetation coverage related to average family size (Troy et al., 2007).	
Renters vs. homeowners	Renters prefer grassy lawns (Larson et al., 2009).	Canopy cover (Heynen and Lindsey, 2003).	The majority of trees planted as part of a public/private tree planting program were located on owner-occupied properties (Perkins et al., 2004); Renters spent less money and time on yard care, with income interactions present (Behe, 2006).

Table 3.1 (cont). A Review of the Role of Demographic Factors With Yard Preferences, Structure, and Management Decisions

Demographics	**Yard Preferences**	**Ecological Structure of Landscape**	**Yard Management**
Gender	Women were more averse to dry, desert landscapes (Yabiku et al., 2008).		Gender influenced the types of trees planted by residents (Kirkpatrick et al., 2012)
Education		Canopy cover positively correlated with education (Heynen and Lindsey, 2003); Vegetation abundance increased with education level (Luck et al., 2009).	Environmental awareness positively correlated with lawn chemical use (Robbins et al., 2001); Tertiary education influenced types of trees planted by residents (Kirkpatrick et al., 2012).
Wealth	Xeric landscape preference for front yards increased with income (Larsen and Harlan, 2006).	Vegetation abundance positively associated with socioeconomic status (Jensen et al., 2004; Grove et al., 2006; Mennis, 2006); There was no relationship between canopy cover, and income; (Heynen and Lindsey, 2003); Plant diversity positively associated with socioeconomic status (Martin et al., 2004); Lawn greenness (weak) positively correlated with lawn-care expenditures (Zhou et al., 2009); Financial resources related to whether residents have a yard (Templeton et al., 1999).	Intermediate house value associated with highest fertilizer-application rates (Osmond and Platt, 2000; Law et al., 2004); High-input lawn chemical usage increased with wealth (income, house value) (Robbins et al., 2001; Blaine et al., 2012; Fraser et al., 2013); High-input lawn chemical usage increased with time scarcity (income, house value) (Templeton et al., 1999); Median family income correlated with plant diversity (Martin et al., 2004; Hope et al., 2006); Income influenced types of trees planted by residents (Kirkpatrick et al., 2012); Financial resources related to whether residents managed and cared for their yard (Templeton et al., 1999; Behe, 2006).

Preference, attitude, and value factors

Kollmus and Agyeman (2010) reviewed the leading proposed frameworks and models that explain pro-environmental behavior. These models have evolved considerably over time. The simple linear framework in which theorists describe environmental knowledge increases environmental concern, which results in pro-environmental behaviors has been replaced by more complex models that take into account a suite of other factors, including consideration the role of situational factors (economic constraints, social pressures, and available opportunities) (Hines et al., 1986), altruistic orientations, and others (Kollmus and Agyeman, 2010). In the section that follows, I present results from investigating the impact of broad life values, environmental attitudes, group identity and social pressures, and attitudes toward specific vegetation characteristics on land management actions, preferences, and relationships to cohesion with yard design (e.g., whether residents' yard design matches their preferred landscapes).

Given the complex nature of how individuals make decisions, it is not surprising that measures of broad life values do not strongly relate to specific land management decisions (Larson et al., 2010). Additionally, measures of environmental attitudes (knowledge, awareness, or concern) exhibit a complex relationship with yard preferences and management (Larsen and Harlan, 2006; Yabiku et al., 2008; Larson et al., 2010). Environmental awareness and attitudes are represented in the literature in a number of ways; from simple metrics, such as membership in environmental organizations (Templeton et al., 1999), to multi-dimensional scales such as the New Environmental Paradigm Scale (Dunlap and Van Liere, 1978; Dunlap et al., 2000). Regardless of the metrics used, environmental awareness and attitudes often have not been significant in describing ecologically friendly landscaping practices. Contrary to expectations, many studies have found that an individual's actions are not explained by, and sometimes are even in contradiction with, stated environmental awareness and attitudes (e.g., Templeton et al., 1999; Dunlap and Jones, 2002; Kollmuss and Agyeman, 2002; Martin et al., 2003; Larsen and Harlan, 2006; Yabiku et al., 2008; Larson et al., 2009). For example, homeowners with heightened environmental awareness or concern managed their yards with higher-than-average quantities of chemicals, such as pesticides (Robbins et al., 2001; Blaine et al., 2012).

The disconnect between behavior with high ecological impacts and environmental awareness and attitudes is hypothesized to be a result of action constraints, such as limited resources and the ways in which individuals prioritize conflicting interests, such as the higher importance of other lifestyle ideals or adherence to social pressures to maintain lush, green lawns (e.g., Templeton et al., 1999; Robbins et al., 2003; Larsen and Harlan, 2006; Bamberg and Möser, 2007; Larson et al., 2010). Residents may prioritize belonging to certain "social classes" or adhering to collective values more than they value practicing ecologically sustainable landscaping practices. Maintaining a high-input chemical lawn care regime is perceived as a capital investment to maintain neighborhood property values (Robbins et al., 2001), especially in frontyards (Robbins and Sharp, 2003), as a moral obligation (Jenkins, 1994; Robbins et al., 2001), or as a matter of personal pride (Jenkins, 1994; Nielson and Smith, 2005).

Measurement discrepancies in which broad attitudes (e.g., appreciation of the environment, concern for climate change) are linked to specific actions (recycling, driving) may explain the weak relationships or findings of non-significance in previous empirical studies (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980). Therefore, in this project I narrowed my target attitude measurement to the action of interest—tree planting and removal. I focused my attitude research questions exclusively on exploring how residents feel about trees, specifically investigating attitudes toward a suite of benefits and challenges associated with maintaining trees, including both trees in general and those with specific functional traits.

Previous research examining preferences for landscape design consistently has reported aesthetics (Summit and McPherson, 1998; Martin et al., 2003; Spinti et al., 2004; Yabiku et al., 2008; Larson et al., 2009), ease of maintenance (Martin et al., 2003, Larson et al., 2009), and neighborhood norms or landscape mimicry (Zmyslony and Gagnon, 1998; Martin et al., 2003; Nassauer et al., 2009) as the most influential factors associated with yard design preferences. Appearance attributes that residents favor include greenery, color, ordered naturalness, and abundant vegetation. Shade and cooling effects were also rated highly, especially in semi-arid regions (Larson et al., 2009).

In addition to studies examining factors associated with household preferences for general landscape types, there is an extensive body of research that explores preferences for specific tree characteristics. Shade is commonly one of the highest-ranked benefits provided by trees and a motivator cited in tree-species selection when residents are considering planting one in their yard (Sommer et al., 1990; Summit and McPherson, 1998). Commonly listed challenges to maintaining trees include health issues such as allergies (Larson et al., 2009), structural damage and safety concerns due to trees falling, blocked views (Lohr et al., 2006; Schroeder et al., 2006), and dark streets and yards (Sommer et al., 1990; Schroeder et al., 2006).

Table 3.2. A Review of the Role of Preference, Attitude, and Value Dimension Associated With Yard Preferences, Structure, and Management Decisions

Preference, Attitude, and Value Factors	**Yard Preferences**	**Ecological Structure Of Landscape**	**Yard Management**
Broad life values	Preferences for mesic design higher in populations with anthropocentric worldviews (Yabiku et al., 2008); Homeowners' preference for yard designs affected by social norms (Nassauer et al., 2009).		General life values not related to land management decisions (Larson et al., 2010).
Environmental attitudes	Landscape preference and environmental concern are not related (Larsen and Harlan, 2006); Environmental attitudes did not result in preferences for water-conserving landscapes but did have an effect on preference for turf grass abundance (Yabiku et al., 2008).		Environmental awareness related to higher chemical use (Robbins et al., 2001); Lawn care chemical use negatively correlated with perceptions of impacts on the environment (Blaine et al., 2012); Relationships with water use and environmental values were complex and counterintuitive (Larson et al., 2010).
Group identity and social pressures	Neighborhood norms for front yards affected homeowners' preference for yard designs (Nassauer et al., 2009)		Chemical use and normative social pressures at neighborhood and regulatory scale were positively associated (Robbins et al., 2001; Nielson and Smith, 2005; Blaine et al., 2012; Carrico et al., 2013).
Attitudes toward specific vegetation characteristics	Phoenix residents prefer oasis design type (Martin et al., 2003); Considered desert landscapes aesthetically pleasing, but chose high-water landscapes for their own yards (Yabiku et al., 2008); Landcape designs that are easy to maintain were preferred over others (Larson et al., 2009; Blaine et al., 2012).	Phoenix residents have a front yard with a desert design type; backyard is oasis (Martin et al., 2003).	Negative experiences with trees influenced types of trees planted by residents (Kirkpatrick et al., 2012).

As these studies allude to, trees provide both services (shade) and disservices (e.g., blocked views) (Table 3.3) (Escobedo et al., 2011). Services are far more frequently assessed in urban forest disciplines. However, in line with the work done on supporting pro-environmental behavior by McKenzie-Mohr and Smith (1999) I hypothesize that disservices are far more influential in influencing management actions. Therefore, it is vital to include measures of both services and disservices in the exploration of land management motivations. Pataki and colleages (2011) defined ecosystem disservices as the costs or "negative consequences or tradeoffs of implementing green infrastructure (p. 28)." Lyytimäki and Sipiliä (2009) define it as the "functions of ecosystems that are perceived as negative for human well-being (p. 311)." Examples range from discomforts and annoyances such as the presence of nuisance pests (Bixler and Floyd, 1997; DeStefano and Deblinger, 2005), maintenance costs (Tyrväinen, 2001), and blocked views (Lohr et al., 2006; Schroeder et al., 2006) to more serious issues such as health risks (pollen production increasing cases of allergies and asthma) (D'Amato, 2000; Moro et al., 2009; Paoletti, 2009), monetary costs (damage incurred from trees falling) (McPhearson, 2013)), and fear and safety concerns (Koskela and Pain, 2000; Jorgensen and Anthopoulou, 2007; Jorgensen et al., 2007). Often the same ecosystem function can be perceived as either, or sometimes both, an ecosystem service and a disservice depending on the individual or community (Escobedo et al., 2011).

There are few studies (Dilley, 2010; Kirkpatrick et al., 2012) that explore the motivations and constraints of residents in their selection and planting of specific tree types or characteristics, such as size profiles. A survey of homeowners in the City of Seattle reported that households have planted far more deciduous ornamental trees that will retain a small stature, even at maturity, than large evergreen or large deciduous trees, and survey responses for future tree planting considerations indicate that the trend will persist into the future (Dilley, 2010). There are a number of tree-preference surveys (e.g., Kalmbach and Kielbaso, 1979; Sommer et al., 1993; Sommer and Summit, 1995; Schroeder and Ruffolo, 1996; Fraser and Kenney, 2000; Williams et al., 2002; Flannigan, 2005). The results from these can be used to infer motivations behind tree-selection decisions, and more specifically with regard to tree size potential and leaf duration characteristics.

Table 3.3. A List of the Services and Disservices Associated With Vegetation Functions (modified from Gómez-Baggethun and Barton, 2013; McPhearson, 2013)

Functions	Services	Disservices
Pollination and seed dispersal	Flowers Fruit	Allergies (Larson et al., 2009)
Habitat provision	Wildlife and bird watching opportunities	Attracts nuisance pests, insects, snakes and scorpions (Larson et al., 2009)
Photosynthesis	Carbon sequestration	Emits volatile organic compounds
Tree growth (photosynthesis and evapotranspiration), biomass accumulation	Carbon storage Temperature regulation (shade) Climate regulation Privacy screen	Blocks views Screens house (responses to same high-canopy image by two cultural groups—dislike because it conceals front of house vs. prefer because of greater privacy (Fraser and Kenney, 2000)) Makes the yard too dark Damages infrastructure
Hydrologic function (rainwater interception and storage)	Storm water management	
Aging and decomposition		Potential hazard and damage from tree falling (Escobedo et al., 2009)

Individuals find large trees, especially street trees, more appealing than small trees (Kalmbach and Kielbaso, 1979; Sommer et al., 1993; Sommer and Summit, 1995). In characterizing qualities of an attractive street scene, residents listed tree size as the most important, stating that streets were especially attractive when larger trees canopied the road (Schroeder and Ruffolo, 1996). However cross-cultural studies suggest that there may be differences in preferences for tree size based on landscapes common to the resident's country of origin (Fraser and Kenney, 2000). Residents preferred medium-sized trees in Melbourne, Australia (Williams et al., 2002) but favored smaller trees in southwest England (Flannigan, 2005). Climate may explain these differences—e.g., temperatures and sunlight typical to a region play a strong role in determining whether large trees are viewed as making streets too dark or as providers of shade. Alternatively, residents may prefer landscapes that remind them of their childhood (Fraser and Kenney, 2000). Finally, it is interesting to note that residents in a neighborhood characterized by large trees ranked tree annoyances higher than neighborhoods with smaller trees; these annoyances included problems with surface roots, suckers, dripping sap, and falling leaves and debris (Schroeder and Ruffolo, 1996). Size was also cited as one of the most prevalent reasons for tree removal (Summit and McPherson, 1998). These studies suggest that trade-offs exist and that they are presumably considered by homeowners in their choice to support large or small trees.

Few, if any, studies have specifically addressed preferences regarding deciduous trees vs. evergreens. However, we can infer some preferences from the literature for characteristics of deciduous trees, including fall color, edible fruit, and flowering trees, in contrast to the coarse foliage typical of evergreen trees. The marking of changing seasons and fall color also appear at the top of lists of benefits that residents value (Sommer et al., 1990; Schroeder et al., 2006). This may explain the results of a preference study that reported that residents favor trees with more coarse foliage (generally broadleaved trees) over trees with fine foliage (generally conifers) (Williams, 2002). Fruit (Summit and McPherson, 1998), and flowering trees (Sommer et al., 1990), which tend to be deciduous trees (e.g., Prunus and Pyrus species), also ranked high on lists of pleasing tree characteristics. Schroeder and Ruffolo (1996) found that the most desired tree species were those with attractive flowers, and ornamental trees with showy flowers and autumn color were reported as the most popular type of tree in southwest Scotland (Hitchmough and Bonugli, 1997). There are also trade-offs associated with trees that produce vibrant fall colors, fruit, and flowers, and a commonly listed reason for tree removal was messiness (Summit and McPherson, 1998). Indeed, fallen leaves were consistently at the top of the lists of annoyances homeowners feel with regard to trees, but it is typically ranked as a minor annoyance

(Sommer et al., 1990; Schroeder and Ruffolo, 1996; Schroeder et al., 2006). In sum, residents like the aesthetics of deciduous trees (especially those with fruit, flowers, and colorful fall leaves) while recognizing that they require work to maintain.

Although most people will likely agree with the many benefits that trees provide, I do not expect that these benefits will explain a household's history of yard care practices. Rather, I hypothesize that land management constraints and the perceived challenges and issues with trees will be better predictors of tree management history. I expect that the household's stated challenges and issues with yard management will vary across a gradient of urbanization. For example, space will likely be a significant constraint to tree planting and removal in the dense urban core but will be less important in the suburban areas characterized by large lots.

Regional, neighborhood, and parcel characteristics

Several ecological and urban characteristics and processes vary, often non-linearly, along an urban gradient: (1) mean parcel area (Alberti, 2008), (2) urban and forest land cover aggregation (Alberti, 2008), (3) building density (Alberti, 2008), (4) primary productivity (Gregg et al., 2003), (5) soil carbon dynamics and gas exchange (Koerner and Klopatek, 2002; Pouyat et al., 2002), (6) litter decomposition, and (7) soil nitrogen dynamics (Groffman et al., 1995; Pouyat et al., 1997; Hope et al., 2005). Although previous studies imply or assume that suburbanites prioritize the abundance of open space over proximity to urban amenities more heavily than residents living more centrally within the city (Kaplan and Austin, 2004; Nassauer et al., 2009), no one has examined how urbanites sort themselves along an urban to rural gradient based on these desires. In addition, very few studies have characterized the social dimensions, such as yard preferences, across the urban gradient. Williams and Cary (2002) assessed overall preference patterns for five types of native vegetation categories of urban and rural residents and found that more similarities than differences exist between the two groups. In this project, I begin to address this knowledge gap by testing for differences in yard preferences and tree management actions between suburban and urban residents.

McKenzie-Mohr and Smith (1999) proposed that while behavior is influenced by a person's values and belief system, constraints or challenges with regard to a given action also need to be taken into account to explain the behavior. In the City of Seattle, Dilley (2010) found that constraints and competing uses were better predictors of tree removal decisions than the perceived benefits of trees. Space limitations, required maintenance, and protection of views were reasons a household decided to remove trees (Dilley, 2010). Given the differences in urban form across a gradient of urbanization, especially with regard to lot size, I expect that the influence of constraints on tree planting and removal as a result of the structure of the built environment will vary considerably.

Other characteristics are also spatially correlated at the neighborhood scale. Tree planting and removal policies are usually adopted and implemented at the municipal scale, and they are more common in larger municipalities (Kenney and Idziak, 2000; Conway and Urbani, 2007). These policies may include rules that address tree protection (regulations restricting tree cutting, preservation agreements such as heritage tree programs), the creation of management plans, assistance in the replacement of dead or injured trees, planting requirements in new subdivisions, and tree planting outreach programs (Conway and Urbani, 2007). The majority of these policies regulate tree removal, not replacement or maintenance (Andresen, 1977; Conway and Urbani, 2007). However Conway and Urbani (2007) noted an increase in policies that support the planting of trees on private properties. An assessment of vegetation dynamics using remotely sensed data found no relationship between changes in tree canopy and municipal policies (Conway and Urbani, 2007), so the influence of municipal policies were not considered in this project. Homeowner associations' covenants, codes, and restrictions (CC&Rs) on landscaping practices do influence the structure and composition of residential vegetation in Phoenix, AZ (Martin et al., 2003). Therefore, I did investigate whether CC&Rs were in place in the Seattle metropolitan area.

Finally, the current structure of yards can also determine the feasibility of some landscaping practices and thereby shape residents' perceptions about yard designs. For example, urbanites with a street tree in front of their home were more likely to think that trees were important compared with residents without street trees (Gorman, 2004). Parcel characteristics that I included in this study were tree density, parcel size, amount of impervious surface coverage, and presence of a view.

Table 3.4. A Review of the Role of Site, Neighborhood, and Regional Characteristics That May Influence Yard Preferences, Structure, and Management Decisions

Site, Neighborhood, and Regional Character	**Yard Preferences**	**Ecological Structure of Landscape**	**Yard Management**
Legacy		Professional occupation, pre-WWI housing, post-WWII housing, and population density correlated with current tree coverage (Boone et al., 2010); Time lag between neighborhood socioeconomic character and vegetation response (Luck et al., 2009); Greening increases as young neighborhoods age (Mennis, 2006; Luck et al., 2009) Median year of neighborhood development correlated with vegetation abundance (Martin et al., 2004); Housing age, current and former land use correlated with plant diversity (Hope et al., 2006); Canopy cover positively correlated with age of housing stock (Heynen and Lindsey, 2003).	
Urban gradient	More commonalities than differences between urban and rural residents in their preferences for native species (Williams and Cary, 2002).	Lawn area increases at periphery of city (Robbins et al., 2001).	High-input lawn chemical usage increases at suburban periphery (Robbins et al., 2001); Application of lawn-care chemicals was higher in the urban and suburban areas than in the rural areas (Blaine et al., 2012); Application of lawn fertilizer higher in suburban households than in urban households (Martini et al., 2013).

Table 3.4 (cont.). A Review of the Role of Site, Neighborhood, and Regional Characteristics That May Influence Yard Preferences, Structure, and Management Decisions

Site, Neighborhood, and Regional Character	**Yard Preferences**	**Ecological Structure of Landscape**	**Yard Management**
Institutions	Households with CC&Rs preferred desert design more than those without CC&Rs (Martin et al., 2003).	Yards with CC&Rs that had landscape provisions had fewer trees, less turf, more shrubs, and groundcover (desert design) (Martin et al., 2003).	Canopy cover correlated with planning and zoning status, Tree City status (Heynen and Lindsey, 2003). Canopy cover correlated with homeowner associations, income, percent owner-occupied dwellings, and housing type (Conway et al., 2011); Fertilizer rates higher in HOA (Fraser et al., 2013).
Parcel characteristics		Canopy cover positively correlated with steep slopes and stream density (Heynen and Lindsey, 2003)	Rock-based, low-water yards had higher application rates of pesticides (Larson et al., 2010); New homes had higher rates of fertilization (Law et al., 2004).

METHODS

Data collection

For this project, I used three data sets: a field based vegetation survey, a mailed yard care survey, and geospatial data sets. I collected field data at one-hundred detached, single-family residential owner-occupied homes across King County. Parcels were selected using a stratified random sample selection process based on dominant land cover (Marsik and Alberti, 2010) and location along an urban gradient (refer to Chapter 1 for details). The included homeowners agreed to participate in the vegetation research as described in Chapter 1, and they also had the option to participate in the yard care survey. The majority of the residents at the sites of the vegetation survey sites (81%) responded to the mailed survey (refer to Chapter 2 for a breakdown of respondents per sample stratification layer). Schroeder (1984) reviewed previous studies of environmental perception and found that satisfactory intergroup reliability can be achieved with 15–25 respondents, so the sample size should be sufficient to make comparisons of yard care and perceptions of tree benefits and challenges between urban and suburban areas.

The field based vegetation survey included measurements and the identification (to the species level) of all woody plants with a diameter at breast height (DBH) greater than 5 cm. Each tree in the sample was categorized based on two functional traits: tree size potential at maturity (based on a tree height above or below 30 feet) and leaf senescence (deciduous or evergreen). These functional traits have been documented to be both home-owner selected traits and as being important in determining the magnitude of a suite of ecosystem functions and processes as summarized in Chapter 1.

I mailed the yard care survey to each household. It included questions about attitudes regarding benefits and challenges of maintaining trees, household landscape practices, and demographic information (a copy of the survey instrument is presented in Appendix B). The design of the survey was informed by a literature review and copies of surveys used in similar studies (Martin et al., 2003; Larson et al., 2009; Dilley, 2010; Fissore et al., 2011; Dilley and Wolf, 2013).

In the survey, residents indicated whether they agreed with a number of statements about the benefits and challenges of trees present on their property. The selection of benefits and challenges was based on a similar survey conducted within the City of Seattle only (Dilley, 2010; Dilley and Wolf, 2013), with an option to specify either deciduous or evergreen trees. Potential issues included in the survey were: trees pose a potential hazard, are messy, block views, can cause conflicts with neighbors, make the yard too dark, require too much space, and attract nuisance pests. Benefits included the provision of habitat for wildlife, improved appearance, provision of privacy, improved property values, provision of shade, ease of maintenance in comparison with alternative yard designs, and provision of soil stability.

Residents were also asked to describe the number of trees (in each functional type group) that they had planted or removed or were considering planting or removing from their yards and what motivated them to do so. In addition, respondents indicated whether their homes had a view (such as a view of Mount Rainier, Lake Washington, etc.), which is one of the on-site urban form variables included in the tree planting predictive model.

The survey was administered in accordance with the Tailored Design Method (Dillman, 2000; Dillman, 2009), which included sending out a pre-notice postcard one week prior to sending a postage-paid survey questionnaire. One week after sending the questionnaire, a reminder postcard was sent to non-respondents. Finally, this was followed up with a replacement questionnaire that was sent to those who still had not responded two weeks after the reminder postcard was mailed.

I represented the urban gradient as a binary data set (urban or suburban). Refer to the Methods section in Chapter 1 for the urban gradient design methods. Parcel area was derived from the King County Department of Assessments property geodatabase, downloaded in 2008 (to match the date of the land cover data set used in the sample stratification process, refer to the sample design methods in Chapter 1). Impervious surface was estimated using the LandSat data (Marsik and Alberti, 2010).

Data analysis

I ran statistical tests using the survey package (Lumley, 2010) in R because it allows for the specification of weights according to sample design methods when conducting statistical tests. I assigned weights to represent the number of households present in each sample stratification group in all statistical tests in this chapter (weights were assigned based on area coverage in the statistical tests conducted in Chapters 1 and 2). I ran multivariate, generalized linear regressions, analyses of variance, chi-square tests, and Wald tests to assess the influence of predictor variables on response variables. Depending on the distribution of the variable of interest, I specified binomial logit (e.g., if respondent agrees or disagrees with statement), normal distribution (e.g., parcel size), or the Poisson family (e.g., total number of trees planted) links. I used generalized linear regression models to accomplish the following:

1. Test if there are significant differences in urban form, demographic characteristics, resident attitudes toward trees and planting, and removal patterns between the urban and suburban gradient. For example, I expected that if there was already a high density of trees in a homeowner's yard it would be likely that they would agree with the statement that there is no more room for additional trees.
2. Evaluate the roles played by urban form, household demographics, landscape attitudes, and yard use and activities in explaining household tree planting and removal activities.

Residential tree planting models were selected using a forward stepwise process based on Chi-square and Wald tests (regTermTest). The suite of potential structural constraining variables, such as lot size, were modeled first. Then I assessed whether tree removal behavior provided further explanatory power in the model. Finally, the perceived challenges and benefits of maintaining trees were added to the model and explanatory power was assessed.

RESULTS

Household and property characteristics

In order to validate the accuracy of the partitioning of the urban gradient into suburban and urban areas, households were asked to describe their neighborhoods as either urban, suburban, rural, or small town. Most of the households that had been characterized as urban in the sample design classification scheme also agreed that their homes were in an urban area (Table 3.5). The majority of respondents in the suburban partition classified their environments as either suburban, rural, or small town.

Table 3.5. Descriptive Statistics of Respondent Perceptions of the Urban Character of Their Neighborhood The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	Classified as Urban	**Classified as Suburban**	**Difference Between Urban and Suburban**
Residents perceived their neighborhood to be urban	81% $\pm$ 10	4% $\pm$ 3	p = 1.4 e- 5 ***
Residents perceived their neighborhood as suburban or rural	19% $\pm$ 10	96% $\pm$ 3	p = 1.4 e- 5 ***

On average, respondents had lived in their current residences for 14 years and plan to remain for at least another 5 years (Table 3.6). More suburban residents own property that is part of a neighborhood or homeowner association, but very few of these associations have and enforce rules or covenants relating to vegetation management. Roughly half of the households in the urban area have a viewshed (e.g., of Mt. Rainier or Lake Washington). There were no significant differences in the presence of views, the age of the house, household size, or coverage by impervious surfaces between homes in the urban and suburban areas. Lot sizes in the suburban area were roughly twice as large as those in the urban core.

Table 3.6. Descriptive Statistics of Household Characteristics

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	Classified as Urban	Classified as Suburban	Difference Between Urban and Suburban
Average tenure	14.2 years $\pm$ 2.2	13.5 years $\pm$ 1.6	
Expected future tenure > 5 years	89% $\pm$ 9	82% $\pm$ 9	
View	52% $\pm$ 14	37% $\pm$ 12	
Lot size	614 $m^2 \pm$ 51	1,385 $m^2 \pm$ 157	p = 1.46e-05 ***
Year built	1943 $\pm$ 7	1966 $\pm$ 17	
Belong to homeowner or neighborhood association	14% $\pm$ 9	62% $\pm$ 13	p = 0.02 *
Homeowner or neighborhood association has and enforces rules regarding yard design	0% $\pm$ 0	3% $\pm$ 3	p < 2 e-16 ***
Household size	2.5 $\pm$ 0.2	2.9 $\pm$ 0.2	
Households with a member younger than 17 years of age	24% $\pm$ 12	53% $\pm$ 12	
Assessed home value			
Impervious surface coverage (check units)	2.8 $\pm$ .3	2.7 $\pm$ 0.4	

Homes in the urban partition had, on average, 14 (± 6) trees in their yard, while those in the suburban area had 25 (± 5) (Table 3.7). Note, these tree density estimates are different than those presented in Chapter 1, because the weighting scheme used to calculate sample averages is based on parcel count (as opposed to area covered).

Table 3.7. Descriptive Statistics of Urban Forest Characteristics at the Household Level
The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	Classified as Urban	**Classified as Suburban**	**Difference Between Urban and Suburban**
Total tree count per household	14 ± 6 per household	25 ± 5	
Count of trees with large size potential per household	5 ± 1 per household	21 ± 5	p = 0.001 **
Count of trees with small size potential per household	9 ± 5 per household	4 ± 1	
Count of deciduous trees per household	5 ± 1 per household	9 ± 3	
Count of evergreen trees per household	9 ± 6 per household	16 ± 4	
Count of deciduous trees with large size potential per household	2 ± 0.4 per household	6 ± 2	p = 0.085 .
Count of evergreen trees with large size potential per household	3 ± 0.9 per household	15 ± 4	p = 0.002 **
Count of deciduous trees with small size potential per household	3 ± 0.3 per household	2 ± 0.9	
Count of evergreen trees with small size potential per household	7 ± 5 per household	2 ± 0.6	

Attitudes

As mentioned, respondents answered questions about the benefits of trees, including statements about improvement in property values and appearance, provision of habitat for wildlife, soil stability, shade, privacy, and ease of maintenance compared with other landscape alternatives. Overall, most respondents agreed that trees provide all the benefits included in the yard care survey instrument (Table 3.8), except for the statement that trees help reduce soil erosion. Respondents also did not support as much the statement that trees are easier to maintain than other types of landscaping. In addition, respondent agreement with the benefits in question varied by tree type—56% of respondents agreed that trees (evergreen and deciduous) are easier to maintain, while 75% agreed with this statement for evergreen trees only.

Agreement with statements that addressed the challenges and issues associated with trees was on average lower. The statement that had the highest level of agreement among respondents (58%) was that trees can pose a potential hazard. Only 14% of respondents agreed with the statement that trees attract nuisance pests, which was the issue with the lowest respondent agreement in the survey. Deciduous trees were ranked as messy by 40% of respondents, but just 27% ranked evergreens as messy. More suburban respondents agreed that evergreen trees make the yard too dark, pose a potential hazard, and cause conflict with neighbors in comparison with deciduous trees.

Urban and suburban respondents had some differences in perceptions of benefits and potential problems with trees in their yards (Tables 8 and 9). Generalizing the responses to all trees, I found that the only difference in attitudes of residents in the urban vs. suburban area was the benefit of privacy (although most ranked this as a benefit in each group) and the association with nuisance pests. Among urban residents, 19% indicated this as a potential problem, which was much higher than the 2% of suburbanites. There are few differences in attitudes about the benefits provided by trees, both overall and by functional trait group, between respondents in the urban and suburban areas (Table 3.8). The only difference is evident in the question of whether trees provide privacy and screen undesirable views—more suburbanites agreed with this statement, especially with regard to evergreen trees.

There are some additional differences in response rates between urban and suburban residents with regard to the issues and challenges of maintaining trees (Table 3.9). More urbanites agreed that trees attract nuisance pests, especially deciduous trees. Fewer than 1% of suburbanites agreed with this statement, but 19% of the urbanites were in agreement. Also, more urbanites than suburbanites felt that there was not enough room in their yards for a deciduous tree and agreed that these trees could cause a conflict with neighbors.

Table 3.8. Percentage of Residents Who Agree With the Following Statements About the Benefits of Trees Near Their Home.

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees**	**Evergreen Trees**
Provide habitat for wildlife	Overall: 98% ± 1 Urban: 98% ± 2 Suburban: 98% ± 2	Overall: 97% ± 1 Urban: 97% ± 2 Suburban: 98% ± 2	Overall: 97% ± 1 Urban: 98% ± 2 Suburban: 97% ± 2
Improve appearance	Overall: 90% ± 7 Urban: 90% ± 9 Suburban: 90% ± 8	Overall: 88% ± 7 Urban: 90% ± 9 Suburban: 83% ± 9	Overall: 90% ± 7 Urban: 90% ± 9 Suburban: 90% ± 8
Provide privacy	Overall: 90% ± 7 Urban: 87% ± 9 Suburban: 98% ± 2 **p = 0.09 .**	Overall: 80% ± 8 Urban: 85% ± 9 Suburban: 67% ± 12	Overall: 90% ± 7 Urban: 87% ± 9 Suburban: 98% ± 2 **p = 0.09 .**
Improve property values	Overall: 90% ± 7 Urban: 88% ± 9 Suburban: 69% ± 12	Overall: 80% ± 7 Urban: 86% ± 9 Suburban: 64% ± 13	Overall: 83% ± 7 Urban: 88% ± 9 Suburban: 69% ± 12
Provide shade	Overall: 88% ± 7 Urban: 87% ± 9 Suburban: 90% ± 8	Overall: 83% ± 7 Urban: 86% ± 9 Suburban: 78% ± 11	Overall: 86% ± 7 Urban: 87% ± 9 Suburban: 82% ± 11
Are easier to maintain	Overall: 75% ± 8 Urban: 80% ± 9 Suburban: 61% ± 13	Overall: 56% ± 10 Urban: 59% ± 13 Suburban: 48% ± 13	Overall: 75% ± 8 Urban: 80% ± 9 Suburban: 61% ± 13
Provide soil stability	Overall: 0% ± 0 Urban: 0% ± 0 Suburban: 0% ± 0	Overall: 0% ± 0 Urban: 0% ± 0 Suburban: 0% ± 0	Overall: 0% ± 0 Urban: 0% ± 0 Suburban: 0% ± 0

Table 3.9. Percentage of Residents Who Agree With The Following Statements About Challenges and Potential Problems With Trees Near Their Home

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees**	**Evergreen Trees**
Are a potential hazard	Overall: 58% ± 10 Urban: 60% ± 13 Suburban: 55% ± 13	Overall: 43% ± 11 Urban: 51% ± 14 Suburban: 24% ± 9	Overall: 57% ± 10 Urban: 58% ± 13 Suburban: 55% ± 13
Are messy	Overall: 45% ± 11 Urban: 49% ± 14 Suburban: 34% ± 12	Overall: 38% ± 11 Urban: 40% ± 14 Suburban: 34% ± 12	Overall: 24% ± 10 Urban: 27% ± 13 Suburban: 15% ± 9
Block views	Overall: 38% ± 11 Urban: 42% ± 14 Suburban: 26% ± 11	Overall: 34% ± 11 Urban: 39% ± 14 Suburban: 22% ± 11	Overall: 35% ± 11 Urban: 42% ± 14 Suburban: 18% ± 9
Can cause conflicts with neighbors	Overall: 37% ± 11 Urban: 42% ± 14 Suburban: 24% ± 11	Overall: 34% ± 11 Urban: 42% ± 14 Suburban: 12% ± 8 **p = 0.09 .**	Overall: 36% ± 11 Urban: 41% ± 14 Suburban: 24% ± 11
Make the yard too dark	Overall: 25% ± 9 Urban: 21% ± 12 Suburban: 36% ± 13	Overall: 17% ± 9 Urban:, 20% ± 12 Suburban: 11% ± 8	Overall: 25% ± 9 Urban: 21% ± 12 Suburban: 36% ± 13
There is no room for trees in my yard	Overall: 24% ± 10 Urban: 28% ± 13 Suburban: 13% ± 8	Overall:, 20% ± 10 Urban: 28% ± 13 Suburban: 2% ± 2 **p = 0.007 ** **	Overall: 17% ± 9 Urban:, 19% ± 12 Suburban: 13% ± 8
Attract nuisance pests	Overall: 14% ± 9 Urban:, 19% ± 12 Suburban: 0.5% ± 0.5 **p = 0.003 ** **	Overall: 14% ± 9 Urban:, 19% ± 12 Suburban: 0.5% ± 0.5 **p = 0.003 ** **	Overall: 8% ± 7 Urban: 11% ± 9 Suburban: 0.5% ± 0.5 **p = 0.03 ***

There are significant correlations between some site characteristics with respondents' perceptions of shade, privacy, and ease of maintenance (Table 3.10). Having small evergreens on-site increased the likelihood that respondents would agree that trees—particularly evergreen trees—provide shade and screen out undesirable views. Lot size was correlated with a respondent's perception of trees contributing to a sense of privacy.

Table 3.10. Relationship Between Perceived Benefits From Trees and the Property Characteristics

	All Trees	**Deciduous Trees**	**Evergreen Trees**
Improve property values			
Improve appearance			
Provide soil stability			
Provide habitat for wildlife			
Provide shade	Count of evergreen trees with small size potential $p = 3e{-5}$; $\beta = -0.1$	Count of trees with small size potential $p = 0.0002$; $\beta = -0.08$	Tree count of evergreens with small size potential $p = 6e{-5}$; $\beta = -0.1$
Provide privacy	Count of evergreen trees with small size potential $p = 2e{-8}$; $\beta = -0.17$ and lot size $p = 0.06$; $\beta = 0.005$	Count of trees with small size potential $p = 0.0002$; $\beta = -0.08$	Tree count of evergreens with small size potential $p = 3e{-7}$; $\beta = -0.14$
Are easier to maintain		Tree count of evergreens with small size potential $p = 0.09$; $\beta = 0.06$	

Likewise, site characteristics were significantly correlated with some of the reported challenges and issues associated with trees (Table 3.11). Residents with trees that maintain a small size at maturity were more likely to agree with the statements that trees are messy, attract nuisance pests, block views, and are a potential hazard. Respondents with a view from their house were also more likely to agree with the statement that trees block views. Without more information it is impossible to describe the relative degree to which the correlation is explained by residents designing an environment that they prefer or by the selected environment influencing their attitudes toward trees.

Table 3.11. Relationship Between Perceived Challenges of Trees and Respondent's Property Characteristics

	All Trees	**Deciduous Trees**	**Evergreen Trees**
Trees are messy	Count of evergreen trees with small size potential p = 0.03; β = 0.04	Count of trees with small size potential p = 0.01; β = 0.07	
Attract nuisance pests			Tree count of deciduous trees with small size potential p = 0.07; β = 0.1
Make the yard too dark			
Block views	Count of evergreen trees with small size potential p = 0.05; β = -0.07 and has a view p = 0.06; β = 2		
Are a potential hazard	Count of trees with small size potential p = 0.02; β = -0.07	Tree count of evergreen trees with small size potential p = 0.08; β = -0.05	Tree count of evergreens with small size potential p = 0.02; β = -0.07
There is no room for trees in my yard	Count of trees with small size potential p = 0.006; β = 0.1	Tree count of trees with small size potential p = 0 0.002; β = 0.09	
Can cause conflicts with neighbors			

Land management (tree planting and removal) summary

With regard to planting a tree during their tenure at their current house, 62% said they had, while 44% were considering planting one in the future (Table 3.12). Only 18% of respondents had planted a tree that has the potential to reach a large size at maturity, while 60% indicated they had planted a tree that will remain small in stature at maturity. More suburbanites had planted a tree than the residents living in the urban core—84% vs. 53%, respectively—although there is no difference between the urban and suburban respondents in the number of trees they were considering planting in the future.

Table 3.12. Percent of Respondents Who Reported Planting a Tree

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	Plant	**Considering Planting a Tree**
Any tree	Overall: 62% ± 11 Urban: 53% ± 14 Suburban: 84% ± 9 **p = 0.08**	Overall: 44% ± 10 Urban: 37% ± 14 Suburban: 61% ± 11
Trees with large size potential	Overall:, 19% ± 7 Urban: 16% ± 9 Suburban: 27% ± 11	Overall: 3% ± 2 Urban: 2% ± 2 Suburban: 5% ± 3
Trees with small size potential	Overall: 60% ± 11 Urban: 53% ± 14 Suburban: 79% ± 9	Overall: 42% ± 10 Urban: 35% ± 14 Suburban: 61% ± 11
Deciduous trees	Overall: 56% ± 11 Urban: 50% ± 14 Suburban: 70% ± 11	Overall: 39% ± 10 Urban: 32% ± 13 Suburban: 58% ± 11
Evergreen trees	Overall: 37% ± 9 Urban: 29% ± 12 Suburban: 58% ± 13	Overall: 24% ± 9 Urban: 24% ± 12 Suburban: 24% ± 11
Deciduous trees with large size potential	Overall: 6% ± 3 Urban: 3% ± 2 Suburban: 12% ± 9	Overall: 1% ± 1 Urban: 0% ± 0 Suburban: 2% ± 2 **p = 0.001 *** **
Evergreen trees with large size potential	Overall: 15% ± 7 Urban: 14% ± 9 Suburban:, 19% ± 9	Overall: 3% ± 2 Urban: 2% ± 2 Suburban: 5% ± 3
Deciduous trees with small size potential	Overall: 56% ± 11 Urban: 50% ± 14 Suburban: 70% ± 11	Overall: 39% ± 10 Urban: 32% ± 13 Suburban: 58% ± 11
Evergreen trees with small size potential	Overall: 32% ± 9 Urban: 26% ± 12 Suburban: 50% ± 12	Overall: 23% ± 9 Urban: 23% ± 12 Suburban: 24% ± 11

The top four reasons that people planted the tree type that they did were aesthetics, fruit provision, privacy screening, and because someone gave them a tree (Table 3.13). The top-cited reason that respondents planted a deciduous tree with large size potential was because they liked how it looked and wanted a shade tree. Low maintenance and aesthetics were the main things respondents reported as motivation for planting an evergreen tree with large size potential. Respondents who planted evergreen trees with small size potential indicated that they wanted a privacy screen and a low-maintenance tree, in addition to aesthetic improvement. Finally, respondents planting deciduous trees that maintain a small stature at maturity most frequently indicated aesthetics and fruit the most as their motivation. There were only two significant differences in the stated reasons for planting trees between the urban and suburban areas. Residents in the urban core indicated more frequently than suburban residents that they were planting trees with the intention of attracting birds and wildlife and providing shade.

Table 3.13. Stated Reasons That People Planted Trees and the Percentage of Respondents Who Reported Planting a Tree Who Cited Each Reason.

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees With Large Size Potential**	**Evergreen Trees With Large Size Potential**	**Deciduous Trees With Small Size Potential**	**Evergreen Trees With Small Size Potential**
Aesthetics	Overall: 53% ± 13 Urban: 52% ± 18 Suburban: 54% ± 14	78% ± 15	23% ± 16	47% ± 14	58% ± 18
Fruit	Overall: 27% ± 11 Urban: 20% ± 16 Suburban: 40% ± 14			30% ± 12	
Privacy	Overall: 25% ± 11 Urban: 24% ± 16 Suburban: 27% ± 13	1% ± 1	62% ± 19	1% ± 1	38% ± 17
Opportunistic	Overall: 23% ± 11 Urban: 25% ± 16 Suburban:, 19% ± 12	9% ± 9	4% ± 4	16% ± 11	7% ± 7
Low maintenance	Overall: 15% ± 10 Urban: 22% ± 16 Suburban: 3% ± 3	1% ± 1	48% ± 24	1% ± 1	25% ± 17
Attract birds and wildlife	Overall: 14% ± 10 Urban: 23% ± 16 Suburban: 0% ± 0 **p < 2 e -16**	1% ± 1	8% ± 8	14% ± 11	3% ± 4
Size	Overall: 11% ± 5 Urban: 5% ± 4 Suburban: 20% ± 10	7% ± 8	16% ± 11	7% ± 4	4% ± 3

Table 3.13 (cont.). Stated Reasons That People Planted Trees and the Percentage of Respondents Who Reported Planting a Tree Who Cited Each Reason.

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees With Large Size Potential**	**Evergreen Trees With Large Size Potential**	**Deciduous Trees With Small Size Potential**	**Evergreen Trees With Small Size Potential**
Property value	Overall: 5% ± 4 Urban: 3% ± 3 Suburban: 10% ± 10			2% ± 2	10% ± 8
Replace tree – match	Overall: 5% ± 4 Urban: 1% ± 1 Suburban: 10% ± 10				8% ± 7
Shade	Overall: 3% ± 2 Urban: 4% ± 3 Suburban: 0% ± 0 p < 2 e -16	21% ± 18		3% ± 2	
Appropriate to region (native)	Overall: 1% ± 1 Urban: 1% ± 1 Suburban: 1% ± 1	2% ± 2	1% ± 1		1% ± 1

With regard to removing a tree during their residence, 57% said they had, and 27% are considering removing at least one (or one more) in the future (Table 3.14). With regard to size, 32% of residents removed a tree with large size potential and 41% removed one with small size potential. More suburbanites had removed deciduous trees with large size potential than the residents living in the urban core—26% vs. 2%, respectively.

Table 3.14. Percentage of Respondents Who Reported Removing a Tree

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	Remove	**Considering Tree Removal**
Any tree	Overall: 57% ± 11 Urban: 52% ± 14 Suburban: 71% ± 12	Overall: 27% ± 9 Urban: 21% ± 12 Suburban: 41% ± 12
Trees with large size potential	Overall: 32% ± 9 Urban: 27% ± 12 Suburban: 47% ± 12	Overall: 17% ± 7 Urban: 12% ± 9 Suburban: 29% ± 11
Trees with small size potential	Overall: 41% ± 10 Urban: 37% ± 14 Suburban: 50% ± 13	Overall: 17% ± 9 Urban: 18% ± 12 Suburban: 14% ± 9
Deciduous trees	Overall: 40% ± 10 Urban: 37% ± 14 Suburban: 47% ± 13	Overall: 18% ± 9 Urban:, 19% ± 12 Suburban: 15% ± 9
Evergreen trees	Overall: 50% ± 11 Urban: 46% ± 14 Suburban: 59% ± 12	Overall: 16% ± 7 Urban: 12% ± 9 Suburban: 29% ± 11
Deciduous trees with large size potential	Overall: 9% ± 3 Urban: 2% ± 1 Suburban: 26% ± 11 **p = 0.0006 *** **	Overall: 5% ± 2 Urban: 1% ± 1 Suburban: 14% ± 9 **p = 0.007 ** **
Evergreen trees with large size potential	Overall: 31% ± 9 Urban: 25% ± 12 Suburban: 46% ± 12	Overall: 13% ± 7 Urban: 11% ± 9 Suburban: 18% ± 9
Deciduous trees with small size potential	Overall: 36% ± 10 Urban: 35% ± 14 Suburban: 37% ± 13	Overall: 13% ± 9 Urban: 18% ± 12 Suburban: 1% ± 1 **p = 0.004 ** **
Evergreen trees with small size potential	Overall: 31% ± 10 Urban: 31% ± 13 Suburban: 30% ± 11	Overall: 4% ± 2 Urban: 1% ± 1 Suburban: 14% ± 9 **p = 0.01 * **

The most commonly cited reasons for removing a tree were perceptions of bad health, damage from storms, maintenance, and property damage that had already occurred or was believed to be likely to happen in the future (Table 3.15). Concerns about tree health were at the top of the list for both small deciduous and small evergreen trees and for deciduous trees with large size potential at maturity. Storm damage was the most commonly listed reason for removal of large evergreen trees, followed by fear of property damage, concerns about tree health, and removing a tree that had already fallen. Additional reasons that residents removed deciduous trees with large size potential included storm damage, appearance, and perceptions of hazards. Finally, deciduous trees with small size potential were removed because of issues with insects and maintenance (in addition to health concerns). Issues with maintenance, fallen trees, and insects were more commonly cited as reasons for tree removal by urban residents than suburbanites, while the size of trees, tree falls, poor location, perceptions of hazard, and appearance were more commonly cited by suburban residents.

Table 3.15. Stated Reasons That People Removed Trees and the Percentage of Respondents Who Reported Removing a Tree for Each Reason

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees With Large Size Potential**	**Evergreen Trees With Large Size Potential**	**Deciduous Trees With Small Size Potential**	**Evergreen Trees With Small Size Potential**
Health	Overall: 67% ± 12 Urban: 71% ± 16 Suburban: 61% ± 14	73% ± 13	27% ± 11	33% ± 17	51% ± 20
Storm damage	Overall: 28% ± 12 Urban: 24% ± 16 Suburban: 36% ± 14	36% ± 21	39% ± 17	6% ± 4	4% ± 4
Maintenance	Overall: 26% ± 13 Urban: 37% ± 19 Suburban: 4% ± 2 **p = .01 ***	8% ± 6	22% ± 17	22% ± 16	
Property damage	Overall: 24% ± 12 Urban: 23% ± 16 Suburban: 28% ± 14	7% ± 6	31% ± 18	8% ± 6	2% ± 1
Size	Overall: 15% ± 6 Urban: 3% ± 2 Suburban: 38% ± 14 **p = .002 ****	6% ± 6	9% ± 7	6% ± 6	16% ± 10
Fell	Overall: 15% ± 11 Urban: 22% ± 16 Suburban: 2% ± 1 p = .02 *	3% ± 2	24% ± 17		4% ± 4

Table 3.15 (cont.). Stated Reasons That People Removed Trees and the Percentage of Respondents Who Reported Removing a Tree for Each Reason

The p value indicates whether there is a significant difference between the urban and suburban residents (signif. codes: *** = 0.001, ** = 0.01, * = 0.05, . = 0.1).

	All Trees	**Deciduous Trees With Large Size Potential**	**Evergreen Trees With Large Size Potential**	**Deciduous Trees With Small Size Potential**	**Evergreen Trees With Small Size Potential**
Insects	Overall: 14% ± 11 Urban: 21% ± 16 Suburban: 0% ± 0 **p < 2 e - 16 *** **			23% ± 16	
Bad location	Overall: 11% ± 5 Urban: 4% ± 2 Suburban: 24% ± 14 **p = 0.04**	9% ± 6	9% ± 7	2% ± 2	8% ± 7
Hazard	Overall: 10% ± 5 Urban: 2% ± 1 Suburban: 27% ± 14 **p = 0.009 ** **	27% ± 21	18% ± 10		
Remodeling projects	Overall: 7% ± 3 Urban: 3% ± 3 Suburban: 14% ± 6	2% ± 2	3% ± 2	4% ± 3	10% ± 5
Appearance	Overall: 7% ± 4 Urban: 3% ± 2 Suburban: 16% ± 11 **p = 0.09**	34% ± 21		2% ± 1	3% ± 2
Shade, too dark	Overall: 7% ± 3 Urban: 7% ± 4 Suburban: 8% ± 5		6% ± 4	3% ± 3	4% ± 2

Factors associated with the decision to plant a tree

A number of site characteristics, tree removal actions, and attitudes toward trees were significantly correlated with whether or not a resident decided to plant a tree during their tenure in their current residence (Table 3.16). Both the location based on the urban gradient (urban, suburban dichotomy) and the count of trees with small size stature at maturity were associated with whether residents planted trees. Finally, residents' perceptions of whether there was room for additional trees improved the model. Neither lot size nor the presence of a view was associated with tree planting decisions, but other structural characteristics were.

The significant model variables varied depending on which kind of trees residents were planting. Impervious surface coverage, number of large deciduous trees removed, and whether a resident felt that trees attract nuisance pests were significant explanatory factors associated with a resident's decision to plant a tree that reaches a large size at maturity (Table 3.17). While the total number of trees removed and a resident's perception of whether there was room for additional trees were correlated with the choice to plant trees that maintain a small stature at maturity. It is interesting to note that none of the listed benefits were significant in the model describing a resident's choice to plant a large tree, although shade, privacy, and low maintenance considerations were associated with the choice to plant a small-stature tree. All perceived issues and challenges that trees pose from the survey were correlated with the decision to plant trees that achieve a large size at maturity, while attracting nuisance pests was the disservice variable with the most explanatory power.

None of the built environment characteristics were important in describing whether a resident planted a deciduous or an evergreen tree (Table 3.16). However, current tree count and tree removal rates were associated with decisions to plant these types of trees. The motivations of residents who planted deciduous trees were associated with the total count of trees with a small size potential, the number of large evergreens removed from the property, perceptions that there is no room in the yard for more trees, and that trees are easier to maintain than other types of landscaping (Table 3.13). The factors associated with the planting of evergreen trees included the perception that trees are hazardous, the total number of trees removed from the property, and a sense that trees provide a privacy screen.

Table 3.16. Built Environment Factors Associated With the Decision to Plant A Tree (Generalized Linear Model With a Binomial Logit Link, Forward Model Selection Via a Chi-Square Test (Regtermtest)).

		All Trees	**Large Trees**	**Small Trees**	**Deciduous Trees**	**Evergreen Trees**
Urban Form	Gradient, suburban	p = 0.08 (+)				
	Parcel area					
	Impervious surface coverage (ISC)		p = 0.08 (-)			
	View					
Tree Counts	All trees				p = 0.09 (+)	p = 0.07 (+)
	Large					
	Small	With gradient p = 0.04 (+)			p = 0.08 (+)	p = 0.02 (+)
	Deciduous					
	Evergreen					

Table 3.16 (cont.). Built Environment Factors Associated With the Decision to Plant A Tree (Generalized Linear Model With a Binomial Logit Link, Forward Model Selection Via a Chi-Square Test (Regtermtest)).

		All Trees	**Large Trees**	**Small Trees**	**Deciduous Trees**	**Evergreen Trees**
Trees Removed	Total trees removed		With ISC; p = 0.06	p = 0.07 (+)	p = 0.05 (+)	p = 0.0005 (+)
	Large evergreen (LE)				With small tree count; p = 0.06 (+)	With small tree count; p = 0.005 (+)
	Large deciduous (LD)		With ISC; p = 0.04 (+)			With small tree count; p = 0.005 (+)
	Small evergreen (SE)					p = 0.02 (+)
	Small deciduous (SD)					p = 0.002 (+)

Table 3.17. Adding in Attitudinal Responses to the Models Populated by Built Environment Factors Associated With the Decision to Plant a Tree

The most parsimonious model with the lowest p value is indicated in bold print.

		All Trees	Large Trees	Small Trees	Deciduous Trees	Evergreen Trees
Perceived benefits	Property values					
	Appearance	With gradient and small tree count; p = 0.03 (+)				
	Habitat for birds and wildlife					
	Shade	With gradient and small tree count; p = 0.03 (-)		With total removed and no room; p = 0.001 (-)		With potential hazard and total trees removed; p = 9 e -9 (-)
	Privacy	With gradient and small tree count; p = 0.02 (-)		With total removed and no room; p = 0.002 (-)		**With potential hazard and total trees removed; p = 7 e -10 (-)**
	Easier to maintain	With gradient and small tree count; p = 0.008 (+)		With total removed and no room; p = 0.003 (+)	**With small tree count, number of large evergreens removed, no room in yard; p = 0.0009 (+)**	

Table 3.17 (cont.). Adding in Attitudinal Responses to the Models Populated by Built Environment Factors Associated With the Decision to Plant a Tree

The most parsimonious model with the lowest p value is indicated in bold print.

		All Trees	Large Trees	Small Trees	Deciduous Trees	Evergreen Trees
Perceived challenges	messy	With gradient and small tree count; p = 0.006 (-)	With ISC; p = 0.0008 (-)	With total removed; p = 0.02 (-)	With count of all trees removed, no room in yard; p = 0.003 (-)	
	Nuisance pests	With gradient and small tree count; p = 0.002 (-)	**With ISC and LD removed; p < 2 e -16 (-)**	With total removed; p = 0.008 (-)	With small tree count and large evergreens removed; p = 0.003 (-)	
	Make yard too dark	With gradient and small tree count; p = 0.002 (-)	With ISC and LD removed; p = 8 e -8 (-)	With total removed; p = 0.02 (-)	With small tree count, large evergreens removed, no room in yard; p = 0.001 (-)	
	Block views		With ISC and LD removed; p = 0.001 (-)			With total removed; p = 0.0001 (-)
	Potential hazard	With gradient and small tree count; p = 0.03 (-)	With LD removed; p = 0.001 (-)		With small tree count, large evergreens removed, no room in yard; p = 0.001 (-)	With total removed; p = 6 e -7 (-)
	No room	**With gradient and small tree count; p = 0.0001 (-)**	With ISC; p = 4 e -6 (-)	**With total removed; p = 0.0008 (-)**	**small tree count and large evergreens removed, easier to maintain; p = 0.0009 (-)**	With total removed; p = 6 e -5 (-)
	Conflict with neighbors		With ISC; p = 0.0009 (-)			With total removed; p = 0.0004 (-)

DISCUSSION

Attitudes toward trees between urban and suburban areas

Residents overwhelmingly agreed with most of the benefits in the yard care survey, which is consistent with other assessments of attitudes about urban trees. Although very few studies have explored how residents feel about trees in their yard, many studies have measured perceptions and attitudes about urban street trees (Sommer et al., 1989; Sommer et al., 1990; Schroeder and Ruffolo, 1996; Williams, 2002). Respondents' attitudes about street trees are remarkably consistent with my findings in that the majority of residents agreed with the benefits in question (Sommer et al., 1989; Sommer et al., 1990; Schroeder and Ruffolo, 1996; Williams, 2002). Lohr and colleagues (2004) found that urbanites from 112 metropolitan regions in the U.S. agreed with their full list of statements regarding the benefits of having trees in cities, with the importance of shade and cooling from trees ranking the highest. Shade and aesthetics were ranked highest in cities in California (Sommer et al., 1989; Sommer et al., 1990). In my study, 90% of residents agreed that trees in their yard improve the appearance of their home and 88% agreed that they provide shade. One surprising result is that the provision of habitat for birds and wildlife was the benefit from trees that most residents agreed with (98% of respondents). Although the importance of habitat was not included in many of the North American attitude surveys (Sommer et al., 1989; Sommer et al., 1990; Schroeder and Ruffolo, 1996), Crow et al. (2006) included a question about wildlife and birds in their assessment of attitudes of residents toward trees in the Chicago metropolitan region. This benefit had much lower endorsement from residents than the other benefit categories. The difference between the Chicago results and my own may be in the wording of the question. Crow et al. (2006) asked about "watching wildlife", and I used a more general "provision of habitat for wildlife."

Agreement rates were higher for tree benefits than for tree challenges, which is consistent with other investigator findings about tree annoyances (Crow et al., 2006; Schroeder et al., 2006). The potential hazards and messiness of trees were the most agreed with annoyances (48% and 45%, respectively). Residents in the United Kingdom and in California also ranked the messiness of trees highest (e.g., fallen leaves in the autumn and general debris). However, the ranking was still pretty low, and residents rated it as only a minor annoyance (Sommer et al., 1990; Schroeder and Ruffolo, 1996; Schroeder et al., 2006). An earlier survey of residents just within the Seattle boundary reported much lower agreement with the statement that trees are too messy (Dilley, 2010). Only 13% of my respondents agreed (Dilley, 2010).

Urbanites and suburbanites were mostly similar in their attitudes and perceptions about the benefits and challenges of maintaining trees in their yards. The observed differences included feelings about the benefits related to creating a sense of privacy and screening undesirable views (Table 3.8), associations with nuisance pests, available growing space, and potential to cause conflict with neighbors (Table 3.9). These results are interesting in that we were able to observe differences between the urban and suburban areas. However, the gradient is just a proxy that can be used to test for differences in patterns of ecological and social structure, functions, and processes under different levels of urban intensity. The gradient does not provide information on the relative influence of the complex suite of factors associated in residents' formation of attitudes toward trees or how residents sort themselves on the urban gradient via household location choices. It has been suggested that attitudes are informed by the spatial environment surrounding the individual (Downs and Stea, 1977). In an exploration of the influence of the built environment and forest structure, I did find that response rates regarding the privacy screening benefit of trees was better described by the structure of the landscape than by the dichotomy of the urban gradient (Tables 10 and 11). For example, rates of agreement about the benefits trees provide in creating a privacy screen are more highly correlated with lot size and the count of small evergreen trees. The lot size may indicate the residents' desire for a privacy screen given the closer proximity to their neighbors, and the count of small evergreen trees may be reflective of a residents' ability to select or design a landscape that suits their needs. Other differences in attitudes about trees between urban residents and suburbanites are not explained by built environment characteristics such as the potential to cause conflict with neighbors.

Understanding residents' attitudes and perceptions of maintaining trees in their landscape is important because this population has the potential to be the most influential in designing the urban forest. I hypothesized that the urban forest patterns in residents' yards would be a reflection of their attitudes and perceptions about the benefits and challenges of maintaining trees. In many cases, the results from the vegetative surveys and yard care questionnaires support this, for example, as evidenced by the association between attitudes about trees blocking views and the abundance of small trees. However, this is not always the case. We would expect that residents who perceive large trees as a potential hazard would have fewer large trees in their yards, but there was not a significant relationship between these two metrics. This may suggest that households are not prioritizing this potential risk as high as other benefits and costs when considering the multitude of trade-offs associated with tree selection in their yard design choices. These findings align with the idea that attitudes are formed and influenced by socioeconomic status, culture, and experiences with the biophysical template (Balram and Dragicevic, 2005).

Land management

During their tenure, 62% of the respondents had planted a tree, and 44% were considering planting one in the future. With regard to removing trees, 57% of respondents reported removing at least one tree during their tenure, but only 27% were considering removing one in the future. These numbers are fairly similar to rates reported from studies conducted in the western United States. Dilley (2010) reported that 73% of Seattleites planted trees, and 64% removed at least one tree. In Sacramento, CA, 68% of respondents added trees to their property; although 66% had removed at least one tree (Summit and McPherson, 1998). Respondents most frequently cited aesthetics as their reason for tree selection, but perceptions about degrading tree health was the most frequently listed factor for tree removal. The same motivations emerged from respondents in California (Summit and McPherson, 1998) and eastern Australian cities (Kirkpatrick et al., 2012). In Australia, 84% listed beauty as a motivator to plant trees, although 77% cited disease or advanced age as the reason for tree removal (Kirkpatrick et al., 2012). Shade and aesthetics were the most consistently reported reasons that residents planted trees in Sacramento, although 61% reported removing a tree because it was dead or dying (Summit and McPherson, 1998).

The breakdown of tree planting, removal, and motivators is quite different when we assess patterns by functional trait groups. Although 62% of respondents had planted a tree, only 19% had planted a tree with large size potential. This number drops to just 3% of respondents considering planting a tree with large size potential in the future. An earlier study conducted within just the municipal boundary of Seattle reported similar behavior rates, in which only 9% of respondents planted a deciduous tree with large size potential and 14% planted an evergreen with large size potential (Dilley, 2010). However 58% planted small deciduous ornamentals (Dilley, 2010), which is also similar to the rate reported in this study (56%). These results suggest that we will be observing significant changes in both the structure and functions of the residential urban forest as it maturates, with a potential shift toward a forest composed of trees with small stature. These results run counter to the majority of preference studies, which have reported that residents favor landscapes with large trees (Kalmbach and Kielbaso, 1979; Sommer et al., 1993; Sommer and Summit, 1995; Williams, 2002), suggesting that residents are prioritizing other factors when designing their yard landscapes.

The stated motivations influencing tree selection varied depending on the tree type that residents planted, which supports the notion that residents are selecting trees that fill a specific function or role in their yards. It also helps us gain insight into how residents feel about the functions provided by trees in each functional plant trait group. Aesthetics was a frequently cited motivator for each of the four plant trait groups, but there was some variation in the list of other frequently mentioned reasons. For example, residents who planted evergreens (both large and small) often listed low maintenance, privacy, and screening of views as the motivations influencing tree selection, while respondents who planted deciduous trees that get large at maturity listed shade benefits as a primary motivator—a function that was never mentioned by those planting evergreen trees.

Tree removal patterns by functional trait group are rather similar. Overall, 31%, 36%, and 31% of residents had removed an evergreen with large size potential, a deciduous tree with small size potential, or an evergreen with small size potential, respectively. The removal rates of deciduous trees with large size at maturity were somewhat lower and vary between urban and suburban areas. Only 2% of urbanites had removed one of these trees, although 26% of suburbanites had removed one. The same difference in rates between urban and suburban areas appears in the considerations of future tree removal for this tree type. Reasons listed for the removal of this type of tree included perceptions about degrading health, appearance, and damage from storms. There is no significant difference in future tree removal rates for evergreen trees with large size potential, which is surprising since there are more of these trees present in the suburban residential landscape. The reasons for removing this tree type included health and storm damage considerations, which were similar to the group that removed deciduous trees with large size potential, but also included maintenance and property damage issues and perceptions of the hazard associated with tree fall.

Removal patterns of trees with small size potential also show some differences between urban and suburban areas. With regard to the future, more urbanites were considering removing a deciduous tree with small size potential than suburbanites, although the opposite trend emerges for tree removal considerations of evergreen trees with small size potential. Again, perceptions about the degrading health of trees was the commonly cited motivation behind the removal of trees with small stature, which was also a main reason cited for the removal of trees with large size potential at maturity. Residents also listed issues with insects and high maintenance needs as reasons for removing deciduous trees with small size potential. This is interesting to note and may foreshadow future issues residents will encounter with a maturing urban forest as we see increases in this type of tree from planting behavior (over half of the residents were planting this type of tree in their yards), especially with the increase in fruit trees.

Factors associated with tree planting behavior

Behavior is influenced by constraints (spatial and financial), compromise, and prioritization of a suite of trade-offs associated with decision making. Therefore, in an attempt to assess potential relationships between residents' attitudes toward trees, planting, and tree removal behavior on the one hand, and the landscape structure on the other, I explored the degree to which these items were correlated using generalized linear models. I hypothesized that landscape constraints (parcel size, tree count) and the perceived challenges of trees would be negatively correlated with tree planting, although past tree removal and perceived benefits of trees would be positively associated with tree planting decisions. The first model selection step assessed how the built environment and tree removal behavior were associated with planting decisions (Table 3.16). For each of the functional trait group categories, at least one of these was significantly correlated with planting patterns. Overall, the decision to plant a tree was influenced by location along the urban gradient (whether urban or suburban) and the count of small trees. Suburbanites with many small-stature trees were more likely to plant a tree. Once attitude factors regarding the benefits and challenges or issues associated with trees in resident's yards were added to the constraint model, a number of attitude factors became significant in explaining planting patterns.

Again, we see differences in the factors associated with planting behaviors by tree functional trait groups. The area of the parcel that was covered by impervious surfaces was negatively associated with whether or not a resident planted a tree with large stature at maturity. The physical characteristics of the parcel were not significantly correlated with planting patterns of trees with a small stature at maturity, either deciduous or evergreen types. The total count of trees removed was positively associated with this planting decision. The total number of trees removed was positively associated with decisions to plant trees in all four functional trait groups. More specifically, the count of large deciduous trees that were removed is positively associated with the decision to plant a tree with large stature at maturity. These results are likely a reflection of the fact that many residents are replacing trees that they have removed.

An exploration of the relationships between physical constraints, attitudes, and tree planting patterns can help shed light on the types of trees residents are selecting and why. For planting patterns of evergreen trees with large size potential, it is interesting that none of the benefit categories are associated with their choice to plant these trees. Most of the responses regarding potential issues with trees are significant in explaining the choice to plant a tree that will get large at maturity, but residents who agreed with the statements about the challenges and issues of having trees on their property were less likely to have planted this type of tree during their tenure. Residents who indicated that the trees in their yards provided shade and a sense of privacy were less likely to plant a small tree or an evergreen. Although residents valued the shade provided by tree canopy, it appears as though they might also be considering their desire for sun and light in their yard when assessing the trade-offs with regard to adding trees to their landscape. The benefit of easy maintenance was positively correlated with planting patterns of small and deciduous trees. Agreement with the issues was consistently negatively correlated with planting behavior. As expected, issues associated with blocked views and the potential hazard that trees pose were both negatively correlated with whether residents planted a tree that achieves a large size at maturity and evergreen trees. Messiness, attraction of nuisance pests, and perceptions that the yard was too dark were issues negatively associated with deciduous tree planting patterns. Residents' perceptions of available space in the yard were important for tree planting behavior of all tree types.

The immediate practical significance of these findings includes new information about the roles of constraints and disservices that may be acting as motivators for tree removal and barriers to residential tree planting. Residents regularly cited tree health, safety, and structural damage concerns as reasons why they had removed trees from their yards, especially large trees. Improving information on how to ascertain tree health and the potential risks could possibly reduce the removal of healthy trees that are incorrectly perceived by homeowners to be under duress. In addition, information on space requirements and appropriate spacing from buildings and structures could prevent poor planting placements from being repeated and subsequent tree removal down the road. Alternatively, planners could work at the development level, offering incentives for forested easements with subdivision of land. These wooded areas could be set back with a buffer the width of an average tree height, and shrubs and small stature trees could be planted along the periphery.

Finally, it is important to remember that residents design and manage their landscapes to achieve multiple social and ecological objectives (Chowdhury et al., 2011; Cook et al., 2012). This research has focused on just two functional traits, which we can use to represent a suite of functions (associated with both services and disservices), but other traits may also be important in a resident's tree selection process and subsequent provision of ecosystem services. For example, an assessment of traits that are associated with aesthetic preferences, such as flowers and fruit, could further our understanding of motivations to plant specific types of trees and could be used to quantify the resultant services that are less well studied, such as cultural benefits derived from the urban forest. This is especially important since outreach messages that address the environmental benefits of yards, such as carbon storage, are likely to be less successful in bringing about desired societal change in yard management because other benefits, disservices, and uses may be more highly prioritized by residents.

In terms of trade-offs, single-objective programs (such as increasing canopy cover) may have to address other perceived problems. For example, climate change mitigation strategies that utilize trees for carbon sequestration and storage should address concerns that large trees make yards too dark. The development of outreach programs and policies that take into account multi-objective thought processes and interests involved in decision making such as constraints, disservices, and use considerations are likely to be more successful in bringing about the desired change. Further, by integrating behavioral research with landscape ecology methods and agent based models we can begin to estimate the long term social and ecological consequences of our land management decisions, which can be used to inform policy by making decision makers aware of potential unintended consequences of land management actions and behavior.

Environmental perception research can further describe and disentangle the process by which residents prioritize a series of tradeoffs in the management of the landscape, such as including the role of financial, institutional, and biophysical constraints. This project contributes to our understanding of how attitudes, land management decisions, and the built environment interact, while pointing out the difficulty of uncoupling these relationships and determining causal mechanisms. The relationships between resident attitudes and experiences, actions, and physical structure are complex and dynamic. So, for example, residents that are planting large evergreen trees also have a tendency to agree with the shade benefits trees provide, although some of these findings may be explained by self-selection. Without more information, we are unable to assess the relative degree to which the correlation is explained by residents designing an environment that they prefer or whether their selected environment influences their attitudes toward trees.

Future research agendas could strive to further disentangle these relationships, such as through the use of structured equation models or temporal yard care and attitudinal data collection efforts. One additional research direction could be an evaluation of the role of the landscape design (land management legacies) in household location choice vs. residents actively redesigning and managing their yards to achieve their desired objectives. The role of available resources is likely a contributing factor in determining whether and how (purchase or design) a household is capable of achieving their preferred landscape—i.e., whether they purchase it, passively inherit it, or actively create and change it. Understanding the likelihood that residents will modify or maintain their landscapes can shed light on the distribution of resources for establishing landscape design criteria for new developments or investing in outreach and incentive programs for homeowners to assist in the ecological redesign of existent developments.

Long term implications

In unmanaged forests, sapling and seedling counts indicate future forest composition (Meyer, 1952). However, in residential yards vegetation is highly managed; homeowners' management activities replace the succession process present in more natural systems (Waldron and Dyck, 1975; Dwyer et al., 2000). The planted trees will mature and eventually will replace the aging ones already present on the landscape. In this project, I have found that more than half (62%) of the residents have planted a tree during their tenure; most (56% of the total respondents) residents have planted at least one deciduous tree with a small size potential. At the same time, 44% of respondents reported that they are considering planting a tree in the future; again deciduous trees with small stature at maturity are popular among residents with future tree planting considerations. Just 36% and 13% of the respondents have removed or are considering removing a deciduous tree with a small size potential.

These results suggest that the population of deciduous trees with small size potential will be sustained over time. However, it is important to take into account the number of trees residents are planting and removing in addition to the number of respondents taking action. In Chapter 2, tree planting and removal trends confirm that residents are increasing the number of small deciduous trees in the residential landscape in both the urban and suburban areas (Fig. 2.7). However, there is not net increase in total tree counts in the suburban area (Fig. 2.6). Additionally, residents are replacing trees that they remove from the landscape with new plantings. Based on these reported actions, I expect to see a persistence of trees in all functional trait groups. I also expect a slight increase in trees with a small stature.

The City of Seattle has set a goal to increase canopy cover within the city to 30% by 2037, and recognizes that tree planting on private properties, especially single-family residential properties, is critical in achieving this goal (City of Seattle, 2007). The results of my study suggest that additional efforts will be necessary to increase tree densities, as currently tree planting and removal trends results in no net change to the residential urban forest (since the City of Seattle is fully within the urban partition). Although tree density and canopy cover are related, they are not equivalent. Encouraging residents to plant and maintain trees with a large size potential will, if successful, result in larger canopy cover gains than getting residents to plant an equivalent number of trees with small size potential. A better understanding of the motivations to plant specific types of trees, including constraints and barriers, could assist in tailoring programs to better meet these goals. For example, the specification of the tree planting predictive model indicates that it is important to design a planting program message that takes into account lot level constraints and disservices of trees with large size potential. The message should address available planting space and the potential for nuisance pests associated with large trees.

RESEARCH SUMMARY AND CONCLUSIONS

INTRODUCTION

In this project, I used plant functional trait classification systems and urban gradient theory to (1) characterize the urban forest structure in single-family residential lands, (2) investigate the role that attitudes (e.g., perceptions of tree benefits and nuisances) and constraints (e.g., available growing space) play in motivating residents to plant trees, and (3) estimate the current above-ground carbon storage from tree biomass and the potential change as a result of reported management considerations (tree planting and removal).

My research contributes to the knowledge of urban ecosystem dynamics in a number of ways. First, urban ecologists have characterized urban plant communities using two theoretical frameworks: gradient analysis (Whittaker, 1967; McDonnell and Pickett, 1990) and plant functional trait classification systems (Schimper, 1903; Knapp et al., 2008). However, to my knowledge none have linked these approaches to describe the urban forest structure across an urban region or to infer how social and biophysical drivers select for species with specific plant functional traits. Furthermore, most urban gradient and functional trait assessments have been restricted to either the analysis of plot-level vegetation surveys in parks, remnant forest/vegetation patches, or street trees (Knapp et al., 2008; McDonnell and Hahs, 2008), or have used remotely sensed data to represent plant abundance or greenness (e.g., Pickett and Cadenasso, 2006; Buyantuyev et al., 2007). In this project, I addressed these limitations by focusing on an under-studied but prevalent urban land use—single-family residences. In addition, I utilized data sets from a variety of sources to more completely represent the finer-level details of urban forest structure and dynamics. These included remotely sensed geodatabases, on-the-ground vegetation assessments, and yard care surveys.

Few assessments of urban vegetation have acknowledged the human role in creating and sustaining the urban forest. Urban ecological theory has posited that a combination of demographic factors, values, and attitudes; site and neighborhood characteristics; and regional urban processes interact in complex ways to produce and maintain the residential vegetative communities across the landscape (Chowdhury et al., 2011; Cook et al., 2012). Yet, most urban forest research projects have focused on just one aspect—either social components (e.g., visual-preference surveys) or biophysical structure (e.g., plant composition of remnant forest stands, DBH distribution). Only a few studies have integrated biophysical and social factors (e.g., land management) to describe and explain emergent urban vegetation patterns, and even fewer have assessed these relationships at the appropriate unit of analysis—i.e., the scale of the agent of change, which in this case is the household operating at the parcel scale (Fraser and Kenney, 2000; Martin et al., 2003; Larsen and Harlan, 2006; Yabiku et al., 2008; Larson et al., 2009; Larson et al., 2010; Zirkle et al., 2011; Kirkpatrick et al., 2012). Of these studies, most have been conducted in just one city, Phoenix, AZ, located in a semi-arid climate (Martin et al., 2003; Larsen and Harlan, 2006; Yabiku et al., 2008; Larson et al., 2009; Larson et al., 2010).

I contribute to the body of knowledge by integrating social and biophysical data sets to explore vegetation dynamics within a tightly coupled human-natural landscape: urban residential lands. I explicitly represented the link between land managers (homeowners) and vegetation patterns by using the parcel as my unit of analysis. I selected two functional plant traits—height potential of the tree at maturity and leaf senescence—based on their sensitivity to both management decisions and ecological processes. My contribution adds to the study of urban vegetation in a region characterized by a temperate maritime climate and naturally carbon-rich native vegetation consisting primarily of western hemlock and Douglas-fir forests (McKinley et al., 2011). Finally, my study provides an initial exploration of how land management actions (tree planting and removal) may alter the forest composition over time and the resultant consequences for ecosystem functions, specifically carbon storage. In the following sections, I review my research findings and discuss the implications for land management and urban planning actions.

FOREST STRUCTURE

In Chapter 1, I characterized the structure of the residential urban forest across a gradient of urbanization using dominant plant functional traits. The objectives of this study were to provide insight into the selective biophysical and socioeconomic forces determining the compositions of tree communities and to inform estimates of ecological processes mediated by these traits.

I found no significant difference in tree density between the urban and suburban areas after parcel area (lot size) was taken into account. The observed tree densities (tree counts per acre) in my study region supported visual preferences for moderate tree densities (Rutherford and Shafer, 1969; Schroeder and Green, 1985). Kaplan (1987) suggested that human preferences for these patterns (a mid-density, savanna-like landscape) is rooted in our bio-evolutionary history, in which trees provided protective cover yet allowed for maintaining sightlines for safety (Gobster, 1994).

While there was no difference in tree densities between the urban and suburban areas of my study area, the abundance of trees with specific functional traits was significantly different between parcels in urban vs. suburban lands. The residential suburban lands had a higher abundance of trees with a large size potential, while the urban area was characterized by a higher density of deciduous trees with small size potential. The difference in forest composition between the two regions could be explained by the structure of the built environment. In the urban core, the fine grain of development and limited growing space may restrict the types of trees that can be supported in this region since lot size is significantly larger in the suburban area (see Chapter 3, Table 6).

Alternatively, the hypothesis that suburban residents seek out and design landscapes that are quite different from those present in the urban core could explain these differences (e.g., Kaplan and Austin, 2004). However, I found only slight differences in agreement rates between urban and suburban residents with regard to the perceived benefits of trees. In Chapter 3, I present the percentage of residents who agree with a number of statements regarding tree benefits and nuisances. For most benefits, respondent agreement in the urban area was not significantly different than for respondents in the suburban area—i.e., most agreed with the benefits that trees provide (Chapter 3, Table 8). However, there were some significant differences in respondent agreement rates regarding nuisance conditions that trees can create. These differences in agreement rates pertained mainly to the potential for trees to cause conflict with neighbors and attract nuisance pests (Chapter 3, Table 9). These differences in perceptions regarding tree disservices may explain why there are differences in the abundance of trees with specific functional traits between urban and suburban areas since it can be expected that urban forest patterns in residents' yards will match their perceptions about the benefits and challenges with maintaining trees. Indeed, there was a statistically significant relationship between attitudes about trees blocking views and abundance of small trees (Chapter 3, Table 11), indicating that residents interested in preserving viewsheds have yards composed of trees that will not encroach on their sightlines as they mature.

It is likely that both factors—urban form and differences in attitudes (e.g., perceptions of tree benefits and nuisances) between urban and suburban areas—play a role in determining the composition of the urban forest in addition to other social and biophysical drivers. Furthermore, the built environment and resident attitudes and perceptions about trees are also interrelated (Downs and Stea, 1977). For example, the only tree benefit with a statistically different agreement rate between urban and suburban respondents had to do with trees providing a sense of privacy and screening out undesirable views (Chapter 3, Table 8). Undoubtedly, the characteristics of the urban form (such as proximity to neighbors) influence the need for this service, thus indirectly influencing whether residents value this benefit that trees provide. For example, rates of agreement about the benefits trees provide in creating a privacy screen are more highly correlated with lot size and the count of small evergreen trees than resident location along the urban gradient partition (Chapter 3, Table 10). Lot size may indicate residents' need for a privacy screen given the closer proximity to their neighbors, while the count of small evergreen trees indicates the residents' ability to select or design a landscape that suits their needs. Although I did not test the role of this potential determinant of urban vegetation structure, Chowdhury et al. (2011) proposed that vegetation in urban residential landscapes is also shaped by the interplay of regional institutions (such as homeowners' associations) and development processes. Regardless of the suite of drivers determining the composition of the residential urban forest, it is evident that the abundance of trees with specific plant traits varies across the urban landscape.

Long term changes to forest structure

In unmanaged forests, sapling and seedling counts indicate future forest composition; however, in residential yards, vegetation is highly managed, and homeowners' yard care activities replace the succession processes of more natural systems (Waldron and Dyck, 1975; Dwyer et al., 2000). With proper care, the majority of trees that residents plant will mature, and in time they will replace aging ones already present on the landscape. However, we have limited knowledge about how residents are managing trees in their yards and how these actions will change the forest structure over time.

In this project, I used two methods to shed light on how the forest structure may change over time. The first was an assessment of the size distribution of the urban forest by plant functional trait groups (Chapter 1, Figs. 9-12). The current sizes of trees, when coupled with species-specific information such as growth potential, can be used as a proxy for the age profile of the forest community (Meyer, 1952). In Chapter 2, I present tree planting and removal rates of single-family residential homeowners.

Currently, the suburban area has an abundance of small deciduous trees that have the potential to reach large sizes (Chapter 1, Fig. 10c), indicating that trees in this functional trait group will persist on the landscape. The size distribution for large evergreens is much flatter, indicating that there may not be a sufficient number of young evergreens with large size potential to replace the current stock as they age. If we make the assumption that urban forest dynamics mimic those of an unevenly aged natural stand, my work indicated that there may be a shift in forest composition. There will be an increase in the density of deciduous trees (both small and large) and a reduction in the native, large-statured evergreens iconic to this region. However, given the active role of land management in caring for planted trees, it is very likely that this assumption is not valid because there was a much lower mortality of young trees in the urban environment. Therefore, urban forests may not require as many young trees to replace aging trees.

To get a better sense of the change in forest structure that has occurred as a result of land management, I investigated the number and types of trees residents have planted and removed from their landscapes and the actions they are considering taking in the future. In Chapter 2, tree planting and removal trends showed that residents have increased the number of small deciduous trees in the residential landscape in the urban area (Chapter 2, Fig. 12 a, b). However, there was no net increase in the suburban area. Future yard management considerations showed that there may be an increase in the number of small deciduous trees, although only in the suburban area, not the urban core (Fig. 13 d). Additionally, residents have been replacing trees that they have removed from the landscape with trees that have the same functional traits. Based on these reported actions, I did not expect to see a reduction in the density of trees in any of the four functional trait groups due to land management activities. I did expect a slight increase in trees with small stature in the suburban area but no net change in the urban partition.

There are many other factors that I did not take into account in this research project that may influence forest dynamics, such as climate change (Dukes and Mooney, 1999; Dale et al., 2001) and pest outbreaks (Dreistadt et al., 1990; Liebhold, 2012). In addition, residents may decide to plant and –remove trees differently than what they indicated on the survey. For example, residents listed issues with insects and high maintenance needs as reasons for removing deciduous trees with small size potential. This may foreshadow future issues residents will encounter with a maturing urban forest, especially considering the increases in this type of tree from past planting activities (over half of the residents were planting this type of tree in their yards). These issues may deter residents from planting additional deciduous trees with small size potential, while at the same time motivating them to remove those present on their property.

In this study, I tested the applicability of functional trait classification systems to characterize the vegetation across the urban landscape, and I found that the use of leaf lifespan and size potential of tree species were functional traits responsive to urbanization, and they were indeed differentially selected between urban and suburban areas. Coupling plant functional trait schemes to an urban gradient framework can be used to formulate hypotheses and experiments to explain how land management influences the structure of the urban forest.

Further results in Chapter 2 confirmed that the abundance of these functional traits are influential in determining carbon storage. Given their role in many other ecosystem functions (see review in Chapter 1), they offer promise in the exploration and mapping of additional ecosystem functions, services, and disservices. Functional trait classification schemes provide a common language to describe the urban forest composition and infer function and land management selection forces, and as such they are a promising tool to represent urban forests in comparative urban gradient analyses between cities. A comparative urban gradient approach has been proposed as a method for identifying and testing generalities of urban form and ecosystem processes across cities in order to improve our understanding of how these environments function (Boone et al., 2012).

MOTIVATIONS FOR AND CONSTRAINTS TO LAND MANAGEMENT ACTIONS

Residents make tree planting and removal choices for a variety of reasons, and these choices influence community composition dynamics and ecological processes. Research that addresses the reasons why residents are planting and removing trees could assist planners and urban foresters tailor programs to better meet their goals, such as the adoption of best management practices and increases in canopy cover. In Chapter 3, I explore the interrelationships between land management, attitudes about trees, household demographics, and built-form characteristics, and I conclude the chapter with a model exploring tree planting actions using stated perceptions about benefits and issues with tree maintenance, past land management behavior (e.g., tree removal), and characteristics of residents' properties (location along gradient, parcel area, tree counts, etc.). In the following section, I review my findings and then discuss their relevance to land management and urban planning activities.

Motivations for tree removal

Of the respondents to the yard care survey, 57% reported removing at least one tree during their tenure, and 27% were considering removing one in the future. Perceptions about the declining health of trees were a commonly cited motivation regardless of functional trait group. Other reasons varied by the functional traits of the trees removed. These were:

- For deciduous trees with large size potential, they included perceptions about declining health, appearance, and damage from storms.
- For evergreen trees with large size potential, they included perceptions about health, storm damage, maintenance issues, concern for property damage, because they had fallen, and perceptions of the hazard associated with tree fall.
- For deciduous trees with small size potential, they included perceptions about health, issues with insects, and high maintenance needs.
- For evergreen trees with small size potential, they included perceptions about health, tree size, and because they were part of a remodeling project.

Factors associated with tree planting

Of the respondents, 62% had planted a tree, but only 19% had planted a tree with large size potential. This number drops to just 3% of respondents with regard to planting a tree with large size potential in the future. An earlier study conducted within just the municipal boundaries of Seattle reported similar planting rates, in which only 9% of respondents had planted a deciduous tree with large size potential and 14% had planted an evergreen with large size potential (Dilley 2010). Of the respondents in the earlier survey, 58% indicated they had planted small deciduous ornamental trees (Dilley 2010), which is very similar to the number from this study (56%).

Respondents most frequently cited aesthetics as their reason for tree selection. However, other motivations influencing tree selection were listed, and they varied depending on the tree type that residents had planted. These differences suggested that residents were selecting trees to fill a specific function or role in their yard. The most frequently cited motivations for planting a tree in each plant functional group were:

- For deciduous trees with large size potential, they included aesthetics and shade benefits.

- For evergreen trees with large size potential, they included aesthetics, privacy, screening out of views, and low maintenance.
- For deciduous trees with small size potential, they included aesthetics, fruit, and opportunity (e.g., receiving trees as gifts).
- For evergreen trees with small size potential, they included aesthetics, privacy, and low maintenance.

This list of reported tree planting motivations only tells a partial story of land management considerations. First, it includes information only from respondents that had planted a tree because residents were not asked to describe reasons why they had not planted a tree. Furthermore, the literature documents that land management decisions are influenced by constraints (spatial and financial), compromise, and prioritization of a suite of trade-offs (Cook et al., 2012). In my yard care survey, respondents were not asked to report on the constraints or prioritization of trade-offs that may have influenced their decisions.

Therefore, I utilized other sources of data to assess how these factors were associated with respondents' decisions to plant a tree. I modeled the likelihood a resident had planted one or more trees for each functional trait group using generalized linear modeling methods, and as explanatory variables I included characteristics of the built environment, tree removal, and attitude factors regarding the benefits and challenges associated with having trees in the residents' yards. Model results demonstrated differences in the factors associated with planting behavior by tree functional trait groups (Chapter 3, Tables 16 and 17). For example, residents who thought trees blocked views were less likely to plant a tree with the potential of reaching a large size at maturity, while respondents who indicated trees were messy and attracted nuisance pests were less likely to plant a deciduous tree.

Finally, a more thorough understanding of residents' motivations and the barriers to tree planting and removal, especially with regard to selection based on functional traits (e.g., size potential), is a critical piece of information necessary to target behavior change. Understanding constraints and motivations for specific land management choices is an important step in getting landowners to adopt best management practices as they design and care for their yards (Chowdhury et al., 2011; Cook et al., 2012; Goddard et al., 2010; Kendal et al., 2010). For example, voluntary incentive-based policies are likely to fail if they do not address both resident concerns (e.g., attraction of nuisance pests, blocked views) and barriers to achieving the desired action (e.g., financial constraints) (McKenzie-Mohr and Smith, 1999). Results from the linear modeling—associating the likelihood a resident will plant a tree with characteristics of the built environment, tree removal, and attitude factors regarding the benefits and challenges associated with having trees in the residents' yards—presented in Chapter 3 (Tables 3.16 and 3.17) can inform program managers how to tailor their programs in order to help residents overcome barriers in order to promote desired land management practices. Creative design strategies may play a role in addressing residents' concerns with specific inconveniences of maintaining trees. For example, concerns with obstructed views was significant in determining whether a resident would plant a tree with a large size potential (Chapter 3, Table 3.17); thus a tree planting programs should advise for the strategic placement of trees with large size potential in order to protect residents' views. Finally, understanding the differences in tree planting and removal patterns across the urban environment (e.g., large lot vs. small lot) and by household demographics can inform a location-specific message targeted to specific user groups (Gomez-Baggethun and Barton, 2013).

LINKING LAND MANAGEMENT ACTIONS, STRUCTURE, AND FUNCTIONS—CARBON STORAGE

Land management activities have the potential to substantially alter ecological structure and function. Yet few studies have linked land management, forest structure, and function. In Chapter 2, I do just this. I examined how the current structure and long term maintenance of the residential urban forest in the Seattle metropolitan area translates into the provision of carbon storage as above-ground plant biomass. I then explored how residential behavior (tree planting and removal activities) could change the forest composition and the resultant long term impact on carbon storage of the residential landscape. The findings provide new insight into the structural and functional dynamics of the residential urban forest, and indicate that policy intervention is needed in order to achieve private property land management actions that will increase carbon storage on single-family residential lots.

Carbon storage

Carbon stored in live, above-ground plant biomass in residential lands in King County is greater on properties in the suburbs compared with those in the urban area (Chapter 2, Fig. 2.2). Even so, and perhaps not surprisingly, the carbon storage of these yards is not even half of that in a 60 year old forest native to this region (western hemlock and Douglas-fir forests). After breaking the carbon storage signatures down into components based on plant functional trait group abundance, it became apparent that the presence of these large, native evergreen trees are influential in providing the bulk of carbon storage in the residential suburban forest (Chapter 2, Figs. 2.4 and 2.5). Meanwhile, the carbon storage per tree provided by deciduous and evergreen trees with small size potential—the predominant trees in the urban core—is quite low (Chapter 2, Table 2.2). Therefore, it is not surprising that the carbon storage potential in this region is less than its suburban counterpart given their abundance of native tree species with large carbon storage potential.

Carbon storage and land management

Tree planting and removal choices can substantially alter the carbon storage potential of the landscape, especially considering how large the native conifer trees of this region are capable of growing. Resident planting and removal actions will likely result in very subtle changes to the composition of the urban forest over time. Residents in both the urban core and suburban areas have reported that they have planted more deciduous trees with small size potential than they have removed (Chapter 2, Fig. 2.10 a and b); although for future management considerations only residents in the suburban area indicated they are considering actions that would continue this trend toward an increase in deciduous trees with small size potential (Chapter 2, Fig. 2.10 c and d).

To assess the consequences of these land management actions, I explored changes in carbon storage potential of the net change in tree numbers that would result if: (1) all respondents plant and remove the trees in accordance with what they reported, (2) the planted trees persist in the landscape, and (3) over time the carbon storage of these trees will mimic the current carbon storage distribution of trees in the functional trait group currently on the landscape. Even though there were reported gains in small deciduous trees, the simulation results indicated this would not result in a significant (net) change in carbon storage capacity per acre across the urban landscape (Chapter 2, Fig. 2.9). This was due to the limited carbon storage potential of these small tree species. Additionally, while there is the potential for large unintended consequences of replacing native giant evergreens with small trees in terms of carbon storage, as well as many other regulating services such as rainfall interception, it does not appear that we are losing these trees. Instead residents are simply increasing the number of small-stature trees present on the landscape.

While I focused on just one ecosystem service in this project, future research efforts could contribute to better decision making and long range planning (Escobedo et al., 2011; Pataki et al., 2011;

Gomez-Baggethun and Barton, 2013) by quantifying the full spectrum of ecosystem services (provisioning, regulating, supporting, and cultural) and disservices. Only then can trade-offs with alternative land uses, management actions, and values be fully recognized and result in better land management decisions (Dobbs et al., 2011; Escobedo et al., 2011; Pataki et al., 2011; Gomez-Baggethun and Barton, 2013).

FUTURE RESEARCH DIRECTIONS

It is apparent that residential landscapes with abundant densities of substantial carbon-yielding native conifer species could offer substantial gains in carbon storage with little human input due to our productive growing conditions in the Seattle metropolitan region. However, maintaining high densities of large trees in an urban environment comes with other costs and trade-offs. There is competition for space between trees and the built infrastructure, especially in dense urban areas that are designed to support and encourage lower-impact choices (e.g., public transit). In addition, when setting policy objectives and designing best management practices, resource investments (e.g., irrigation) and ecological impacts (e.g., application of fertilizer and pesticides) associated with establishing and maintaining trees in the urban region need to be considered. The urban environment presents stressful growing conditions that can slow tree growth and result in early mortality (Celestian and Martin 2005, Close and others 1996), so replacement costs should also be considered. Further research which identifies and quantifies economic and societal trade-offs associated with the creation and on-going maintenance of green infrastructure in urban regions can better inform the decision making process.

Perceptions of services and disservices emerge at different spatial scales. For example, the land manager perceives costs and benefits at the parcel level, while municipal and regional managers consider costs and benefits across the urban landscape. Gomez-Baggethun and Barton (2013) illustrated a suite of ecosystem valuation metrics and the scale at which they occur and discussed how they could be applied to urban planning issues at each scale, from the small scale of litigation (damage and compensation claims), to instrument design (setting incentive levels, user fees), priority setting (land use zoning), accounting (representing green infrastructure as a municipal asset), and raising awareness (Gomez-Baggethun and Barton, 2013).

On the finer-level parcel scale, exploring the full suite of costs, disservices, and services can help us understand the trade-offs and land management priorities of residents which can inform land management programs, such as tree planting incentives. For example, at the parcel level, shade trees compete for space with gardens, lawn spaces for recreation, and solar energy panels. Avoided costs are another consideration to take into account—comparing the costs of urban temperature regulation from shade trees to the costs provided by technological cooling functions (e.g., air conditioning). Finally, an ecosystem function can be perceived as a service or a disservice—or sometimes both—depending on the individual or community and the presence of site-specific stressors (high air pollution, noise, etc.) (Escobedo et al., 2011; Gomez-Baggethun and Barton, 2013).

To scale up parcel-based measures and household land management actions occurring at a fine-grain scale to the landscape scale, Wu (2008) argued for a landscape ecology approach. By pairing remotely sensed imagery (e.g., normalized difference vegetation index (NDVI)) with measures of the tree community, such as functional trait abundance at the parcel scale, we can interpolate forest structure across the urban landscape (Lavorel et al., 2011; Ustin & Gamon, 2010), and this can be integrated with models of ecological and land management processes to map and predict the distribution of services and disservices across the full spatial extent of the urban region to empirically explore urban ecosystem dynamics and land management consequences. Modeling a suite of ecosystem functions will help us understand how services and disservices of green infrastructure are bundled in space (Raudsepp-Hearne et al., 2010). Unintended consequences of land management can manifest themselves as synergies in which multiple services are simultaneously enhanced by management, or, alternatively, management to enhance one service can result in the degradation of another (Raudsepp-Hearne et al., 2010). These integrated models can be used to explore an uncertain future. When run under a suite of alternative future conditions and trajectories derived from scenario planning efforts, and modeling the output can help us to anticipate potential unintended consequences of land management and planning decisions and to plan for plausible future conditions.

Bennett et al. (2009) proposed three directives to guide empirical data collection and analysis to deepen our understanding of ecosystem services and improve planning: integrated social-ecological approaches; investigation and characterization of the mechanisms, or more simply the processes that structure the relationships between services; and management of relationships among ecosystem services. This can inform adaptive management of multiple services in urban systems, by setting expectations of when, where, and under what circumstances losses of ecosystem functions and services might occur given our actions. Ideally, this can help us better design our environment and develop plans that reduce trade-offs and create and increased synergies among services now and in the future.

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APPENDIX A: Private Property Access Outreach Materials

UNIVERSITY OF WASHINGTON
College of Built Environments
DEPARTMENT OF URBAN DESIGN AND PLANNING

October 18, 2010

Dear Resident,

We would like your help in conducting some of our research — not money and or time — just permission to count and measure the trees on your property.

We are a research team at the University of Washington's Urban Ecology Research Laboratory studying trees and quantifying benefits they provide to the environment, such as stormwater retention and carbon storage. By measuring the height and diameter of your neighborhood trees, we can begin to estimate the benefits that your neighborhood provides to maintain and improve the quality of life in Seattle.

We respect your privacy and the plant life on your property, and will not damage or mark your trees in any way. Even with your permission, we will knock on your door before beginning our work and would be happy to answer questions or address your concerns. If you return the enclosed card granting permission, but are not home at the time of our visit, we will leave you a note indicating we stopped by and measured your trees.

We will spend about 20 minutes measuring trees in your yard. Your property was selected at random. Any results shared with the public or scientific community will be represented in a manner that ensures your property and participation remains anonymous (for example we will aggregate results up to the neighborhood level). We will never share with anyone outside of the study any information about your individual property characteristics.

If you authorize us to count and measure your trees, please sign and check "YES" on the enclosed postage-paid card and drop it in the mail — and accept our deep appreciation for assisting with this critical research.

Sincerely,

Karis Tenneson-Puruncajas, Ph.D. Candidate

GOULD HALL 432 - BOX 355740
SEATTLE WA 98195-5740 USA
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E-MAIL: KARIST@U.WASHINGTON.EDU
WWW.STUDENTS.WASHINGTON.EDU/KARIST

Figure A1. Cover Letter, Property Access Request Materials

Urban Ecology Research Laboratory
at the University of Washington

☐ **YES,** I authorize a visit from a graduate student of the Urban Ecology Research Laboratory at the University of Washington to measure the diameter of trees on my property.

☐ **NO,** I do NOT authorize the Urban Ecology Research Laboratory to conduct their research on my property and please do not contact me again.

Signature:____

Notes:____

UNIVERSITY OF WASHINGTON

Urban Ecology Research Laboratory
Attn: Karis Tenneson Puruncajas
University of Washington
Box 355740
Seattle, WA 98195

WWW.URBANECO.WASHINGTON.EDU

Figure A2. Postage-Paid Return Response Postcard, Property Access Request Materials

Urban Ecology Research Laboratory
at the University of Washington

Hello Resident,

Today, I came by to count, identify and measure your trees. Sorry I missed you!

This is part of a research project assessing trees in urban residential areas and quantifying the stormwater and carbon storage benefits they provide to the environment

To learn more, visit us online at:

www.students.washington.edu/karist

Or

Email Karis Tenneson-Puruncajas at karist@uw.edu.

Figure A3. Postcard Left for Resident When They Were Not Present at the Time of Vegetative Sampling

APPENDIX B: Yard Care Survey Instrument and Supporting Documents

Yard Survey Instructions

November 7, 2012

Dear Resident,

Thanks in advance for taking part in our survey. The survey will take roughly 15 minutes to complete.

Your participation is completely voluntary. Please answer all of the questions to the best of your ability; however do keep in mind that you can choose to skip any questions that you feel uncomfortable answering. Your responses will not be shared with the public; they are confidential. Any results shared with the public or scientific community will be represented in a manner that ensures your property and participation remains anonymous (for example we will group results to represent a neighborhood).

Once you have completed the survey, use the enclosed sticker to seal the survey closed, making sure that the address and postage stamp are visible. Then place the survey in the mail.

If you have any questions, concerns or would like to find out more about this research, please contact Karis Tenneson at the Urban Ecology Research Lab at the University of Washington (karist@uw.edu or by phone at 206-200-7739).

Thanks again for your time and support. I am excited to hear your story!

Sincerely,

Karis Tenneson-Puruncajas, PhD Candidate

Interdisciplinary PhD Program in Urban Design and Planning
Urban Ecology Research Laboratory
University of Washington
karist@uw.edu
(206) 200-7739

Figure B1. Yard Care Survey, Survey Instrument, page 1 of 8

Yard Survey: your neighborhood

Question 1.

Do you rent or own your home?

- ☐ Own
- ☐ Rent

Question 2.

How many additional years do you plan to live in your home?

- ☐ Less than a year
- ☐ 1-5 years
- ☐ More than 5 years

Question 3.

Is your property part of a homeowners' or neighborhood association?

- ☐ Yes
- ☐ No
- ☐ Not sure

Question 4.

If your home is part of a homeowners association, are there restrictions regarding how you can landscape the property?

- ☐ Yes. There are landscaping restrictions but they are not enforced.
- ☐ Yes. There are landscaping restrictions and they are enforced.
- ☐ No. There are no landscaping restrictions.
- ☐ Not sure
- ☐ Not applicable. I/we do not belong to a homeowner's association.

Question 5.

How would you describe the neighborhood where you currently live?

- ☐ Urban area
- ☐ Suburban area
- ☐ Small town
- ☐ Rural area
- ☐ Other: ________________________________

Question 6.

Does your house have a view (of the Puget Sound, Lake Washington, mountains, etc)?

- ☐ Yes
- ☐ No

Question 7.

List 2-3 sources of information you consult with about your yard care (e.g. Extension office, internet, garden clubs, local nursery).

____

Page 1

Figure B1. Yard Care Survey, Survey Instrument, page 2 of 8

Yard Survey: factors related to tree planting and removal

Question 8. Please mark if these statements influence whether you plant, keep or remove trees from your property.

	agree	disagree	not applicable
a) Trees provide shade	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
b) Trees increase property values	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
c) Trees provide wildlife habitat	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
d) Trees help stabilize the soil on steep slopes	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
e) Trees provide privacy and/or screen undesirable views	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
f) Trees make my yard too dark	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
g) Trees are a potential hazard (e.g. tree fall)	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
h) Trees are too messy (fallen leaves and branches, sap drips, rotten fruit)	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
i) There is not enough room in my yard for trees	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
j) Trees cause conflict with my neighbors	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
k) Trees attract nuisance animals to my yard	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
l) Trees are easier to maintain than other types of landscaping	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
m) Trees block my view	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐
n) Trees improve the visual appearance of my property	☐ all trees ☐ evergreen trees ☐ deciduous trees	☐	☐

Page 2

Figure B1. Yard Care Survey, Survey Instrument, page 3 of 8

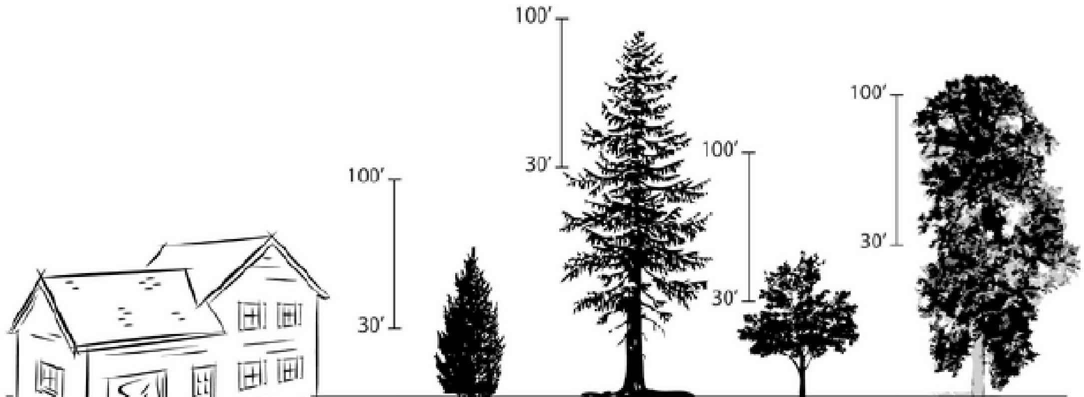
Yard Survey: tree planting history

Definitions:

An **evergreen tree** maintains its leaves year-round.

A **deciduous tree** loses all of its leaves for part of the year.

For each of the spaces below, please respond for each of the four types of trees listed.



	Tree Type	Small evergreen	Large evergreen	Small deciduous	Large deciduous
	Examples	Arborvitae, camellia, dwarf pines & spruces	Redwood, spruce, cedar, fir, pine trees	Vine maple, fruit trees, flowering trees	maples, poplars, birch, oak, sycamore
	Height (at maturity)	Up to 30 feet	Taller than 30 feet	Up to 30 feet	Taller than 30 feet
9.	How many trees, if any, have you (or hired help) planted on your property during your residence?	______ small conifer trees	______ large conifer trees	____ small deciduous trees ____ of these were fruit trees	____ large deciduous trees
10.	List 2-3 reasons you selected this type of tree.	____________ ____________ ____________	____________ ____________ ____________	____________ ____________ ____________	____________ ____________ ____________
11.	Would you like to add trees of this type in the future? How many would you like to plant?	O no O yes ________ trees	O no O yes _________ trees	O no O yes ________ trees	O no O yes _________ trees

Page 3

Figure B1. Yard Care Survey, Survey Instrument, page 4 of 8

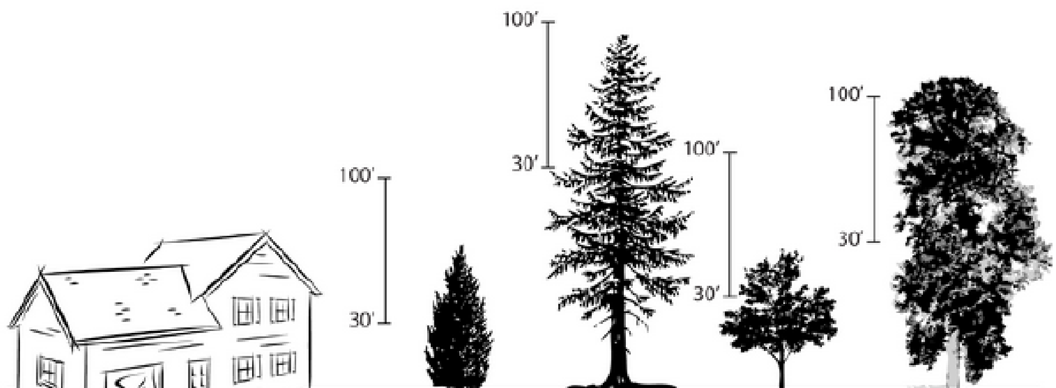
Yard Survey: tree removal history

Definitions:

An **evergreen tree** maintains its leaves year-round.

A **deciduous tree** loses all of its leaves for part of the year.

For each of the spaces below, please respond for each of the four types of trees listed.



	Tree Type	Small evergreen	Large evergreen	Small deciduous	Large deciduous
	Examples	Arborvitae, camellia, dwarf pines & spruces	Redwood, spruce, cedar, fir, pine trees	Vine maple, fruit trees, flowering trees	maples, poplars, birch, oak, sycamore
	Height (at maturity)	Up to 30 feet	Taller than 30 feet	Up to 30 feet	Taller than 30 feet
12.	How many trees, if any, have fallen or been cut down from your property during your residence?	______ small conifer trees	______ large conifer trees	____ small deciduous trees ____ were fruit trees	____ large deciduous trees
13.	What were the 2-3 most common reasons for removing these trees?	____________ ____________ ____________	____________ ____________ ____________	____________ ____________ ____________	____________ ____________ ____________
14.	Are there more trees of this type that you are considering removing in the future? How many?	O no O yes ________ trees	O no O yes ________ trees	O no O yes ________ trees	O no O yes ________ trees

Page 4

Figure B1. Yard Care Survey, Survey Instrument, page 5 of 8

Yard Survey: household information

Question 15. Please select (up to) the most 5 important activities, uses or considerations in how you maintain your yard. Then rank them in order of importance.

	Not very important				Extremely important	
a) growing vegetables or herbs	1	2	3	4	5	not applicable
b) growing fruit	1	2	3	4	5	not applicable
c) having mixed garden beds (flowers, shrubs, etc)	1	2	3	4	5	not applicable
d) wildlife viewing and habitat (butterflies, birds, etc)	1	2	3	4	5	not applicable
e) recreation (kid's play area, pool, trails, etc)	1	2	3	4	5	not applicable
f) relaxing	1	2	3	4	5	not applicable
g) spending time with family and friends	1	2	3	4	5	not applicable
h) pet area (dog, chickens, etc)	1	2	3	4	5	not applicable
i) how it looks	1	2	3	4	5	not applicable
j) maintaining property values	1	2	3	4	5	not applicable
k) fitting in with the neighborhood	1	2	3	4	5	not applicable
l) other: ________________________________	1	2	3	4	5	not applicable

Question 16. Think about the major constraints you have when it comes to yard care. Mark whether you agree or disagree with the following statements.

	agree	disagree	not applicable
a) I do not have enough information to know how to properly plant trees.	☐	☐	☐
b) I do not have enough information to know how to properly select trees for my yard.	☐	☐	☐
c) I do not have the time to care for trees in my yard.	☐	☐	☐
d) I do not have the resources to care for trees in my yard.	☐	☐	☐

Page 5

Figure B1. Yard Care Survey, Survey Instrument, page 6 of 8

Yard Survey: household information

Question 17.

Which category best describes your current situation? Mark all that apply.

- ☐ Employed – Full time, part time, seasonal, self
- ☐ Unemployed
- ☐ Homemaker
- ☐ Student
- ☐ Retired
- ☐ Other: please specify ________________________

Question 18.
How many people are in your household (including yourself)?
____________________ people

Question 19.
Are there any members of your household under the age of 17?

- ☐ Yes
- ☐ No

Question 20.
Is there anything else that you would like to share regarding your yard care?

____

____

Question 21.
Would you like to receive updates with my findings? If so, please provide your email address.

____

Alternatively if you would like to receive a copy of my findings but don't have internet access, please check the box below and I will mail you a paper copy.

☐ Yes, please send me a paper copy summarizing this research project with final results.

Thank you for participating in this project!

Page 6

Figure B1. Yard Care Survey, Survey Instrument, page 7 of 8

Fold this flap down first.

place sticker
here to seal

Urban Ecology Research Laboratory
Attn: Karis Tenneson-Puruncajas
University of Washington
Box 355740
Seattle, WA 98195

WWW.URBANECO.WASHINGTON.EDU

Yard Survey

place sticker
here to seal

Figure B1. Yard Care Survey, Survey Instrument, page 8 of 8

December 12, 2013

Dear resident,

Thank you again for granting me access to measure the trees on your property. While collecting this information I enjoyed hearing from many of you and learning about the rich history of your property's landscape. Each person has different preferences and uses for their landscape.

I am excited to follow up my field work with a survey exploring how homeowners enjoy and care for their yard. In the next few days, you will receive an invitation to participate in this research by responding to a survey.

Sincerely,

Karis Tenneson-Puruncajas, Ph.D. Candidate

Urban Ecology Research Laboratory
Attn: Karis Tenneson-Puruncajas
University of Washington
Box 355740
Seattle, WA 98195

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Figure B2. Yard Care Survey Pre-notice Postcard

UNIVERSITY OF WASHINGTON
College of Built Environments
DEPARTMENT OF URBAN DESIGN AND PLANNING

December 12, 2013

Dear resident,

Please accept my invitation for the person in your household who makes most of the decisions about lawn, garden and tree care **to participate in a Residential Yard Survey.** The enclosed survey will take approximately 15 minutes to complete. Once you have finished answering the questions, please fold and seal the survey in the mail. The postage is already included.

The information I collect from this survey will be used to complete my dissertation research on the structure, functions and management of the residential forest. You may remember that you participated in this research project earlier this year (or last) by allowing me access to measure the trees present in your yard. As a follow up, I am investigating how homeowners use and care for their yards. If you are interested in learning more about this research, please visit http://www.urbaneco.washington.edu/UERL_biosketches/ktenneson.html.

While I was out collecting tree information, I was able to meet many of you and talk to you about your yard care. It was a pleasure to learn from many of you about the rich history of your property's landscape and tree history. I am excited to follow up that field work with this survey. The information you provide will help me better understand how households manage the vegetation around their home and connect to their landscape.

Whether you have just recently moved into your house, or have lived in and cared for the property for decades, I am interested in hearing your story! I also recognize that some properties are large and completely forested, while others may have absolutely no trees. Regardless of your yard's characteristics, your story matters!

Thanks in advance for your participation in this study!

Sincerely,

Karis Tenneson-Puruncajas, PhD Candidate
Interdisciplinary PhD Program in Urban Design and Planning
Urban Ecology Research Laboratory
University of Washington
karist@uw.edu
(206) 200-7739

GOULD HALL 432 - BOX 355740
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WWW.STUDENTS.WASHINGTON.EDU/KARIST

Figure B3. Yard Care Survey Cover Letter

December 12, 2013

Two weeks ago I mailed a survey seeking your opinions about landscaping choices and yard care to you.

If you have already completed and returned the survey to me, please accept my sincere thanks. If not, please do so today. I am especially grateful for your help because it is only by asking people like you to share your experiences that we can understand how people decide to maintain and care for their lawns and the associated benefits and challenges of doing so.

If you did not receive a survey, or if it was misplaced, please call me at 1-206-200-7739 or email karist@u.washington.edu and I will get another one in the mail to you today.

Karis Tenneson-Puruncajas, Ph.D. Candidate

Urban Ecology Research Laboratory
Attn: Karis Tenneson-Puruncajas
University of Washington
Box 355740
Seattle, WA 98195

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Figure B4. Yard Care Survey Reminder Postcard

UNIVERSITY OF WASHINGTON
College of Built Environments
DEPARTMENT OF URBAN DESIGN AND PLANNING

August 1, 2012

Dear resident,

I have enclosed another copy of the yard care survey I sent earlier this summer. You may remember you participated in the first phase of this research last year by allowing me access to measure the trees in your yard. I am wrapping up my data collection soon, and wanted to give you one last chance to respond to this second phase of the research.

Your input is very important to my dissertation project. I am investigating tree patterns, such as how many and what types of trees are found in residential neighborhoods. Then attempting to understand how these tree patterns influence how homeowners care for their yard. If you are interested in learning more about this research, please visit http://www.urbaneco.washington.edu/UERL_biosketches/ktenneson.html.

I have received a number of completed surveys from homeowners across King County, but I am still missing information about some key household types, such as households in more suburban and rural landscapes. Your household represents a key yard type characteristic that I would like to learn more about. It is my goal to ensure voices and preferences of residents from all household yard types are heard.

Thank you in advance for your participation in this study!

Sincerely,

Karis Tenneson-Puruncajas, PhD Candidate
Interdisciplinary PhD Program in Urban Design and Planning
Urban Ecology Research Laboratory, University of Washington
karist@uw.edu
(206) 200-7739

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Figure B5. Replacement Yard Care Survey Cover Letter