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Patterns of Urban Forest Composition in Utah's Growing Mountain Communities

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Abstract

Urban forests are an important element of the water budget in developing Western cities. Afforestation and its effect on the water budget are largely contingent on planting decisions made by planners and residents. The objective of this study was to characterize these decisions by identifying differences in tree community composition between four classes of neighborhoods from distinct developmental periods for Heber Valley, Utah. Public housing data and visual development characteristics were used to categorize residential and commercial areas, and standard forestry techniques were used to collect data on trees in a stratified random survey of lots in these categories. Older, established housing had the highest tree basal area and species richness per hectare, and exurban (rural, dispersed housing) developments also had significantly higher species diversity than new tract housing. Because it appears that exurban communities are being replaced by tract housing, there is evidence that tree diversity will be lost. Another important aspect of community structure in urban forests is the ratio of conifers to broadleaf trees because of fundamental differences in water use patterns. Twenty-five percent of the average lot basal area in exurban and thirty-five percent in established neighborhoods was that of conifers, as opposed to five percent in tract. The data suggest that tree diversity is likely to decrease while water demand is likely to increase with changes in urban forests in the coming decade.

Keywords: Urban forestry, development, water use

1. Introduction

Population growth and the accompanying development is a trademark of the American West. What began for European-American settlers as an ongoing resource-extraction boom is now a migration spurred by an amenity- and recreation-based economy and a culture of land speculation and development.[1] The population of the West has increased steadily since the 1850s, currently at 23.6% of the nation's population.[2,3] Many people, paradoxically, are drawn to the West by the very open spaces that they increasingly fill. Although wilderness and rangeland still exist in large measure in the West, urban and suburban development are spreading in this landscape, causing major shifts in land use.[4]

The overall pattern of ecological change with development has been similar within the intermountain west of the US. Historically, grasses and shrubs such as sagebrush and bunchgrasses dominated mid-elevation ecosystems[5]. European-American settlers introduced dryland and irrigated agriculture in the valleys, supplanting the native vegetation with crops such as hay and impacting the remaining communities with livestock grazing.[6,7] Now, subdivisions often replace cropland or rangeland, representing an even greater change.[8] The most direct ecological change represented by the shift from agricultural to residential land is afforestation, or the introduction of landscape trees onto the previously unforested land.[9] Afforestation increases some ecosystem services such as carbon sequestration, shade, and retention of runoff,[10] but irrigated forest has a structurally and functionally different ecological makeup than the native shrublands or seasonal cropland, with ecological costs as well as benefits.

In characterizing urban forest composition, previous studies have looked at correlations of composition to demographics[11] and land-use type,[12] but few have categorized neighborhoods by development patterns. This is particularly interesting in the West, where development has occurred in waves in an open landscape, resulting in layers of development based on timing, function, and location. These patterns in turn are likely to represent distinct urban forest communities. Travis (2007) identified several development categories in the West.[13] "Metrozones" are hotspots of residential and commercial development that sprawl out from multiple city centers, comprising suburbs characterized by homogeneous tract housing as well as older city cores made up of heterogeneous established housing. Another relevant category is the “exurbs,” or “dispersed, low density residential land” sought out by people who desire a rural lifestyle with access to city conveniences.

On a smaller scale, urban ecology can be characterized by a matrix-patch system.[14] Borrowing from traditional ecology terminology, patches are disconnected habitats and resource pools (such as residential yards) within the infrastructure of an urban area (the matrix), which animals must navigate to survive in the urban ecosystem[15]. Trends in these patches' broader neighborhoods influence patch characteristics, which in turn determine the possibilities for interactions in the urban ecosystem.[16] For example, species and structural (size, shape, age) diversity of vegetation in patches are important variables in habitat availability and thus faunal diversity.[17,18] More habitat diversity can provide more opportunities for the preservation of native animal species and rich interactions between them.[19] Urban biodiversity has aesthetic benefits for residents as well, from visual interest to education, and is generally desired. However, urban tree diversity isn't completely unambiguous in its benefits; high numbers of exotic species can lead to invasions, and ecological benefits vary by species.[20]

Water use is one of the most important environmental costs to consider as a result of afforestation in the semiarid West. As climate change increases the possibility of summer water shortages,[21,22] landscaping continues to claim a large portion of the water budget—in Utah, outdoor water use was estimated at 64% of residential water use in 2010.[23] Landscaping choices for municipalities and individuals can be made looking to decrease water use while still maintaining the ecosystem services provided by trees. There are multiple ways to approach this, but plant functional traits play a large role tree water use, making species composition an important variable. A good example of a species-specific trait is its water-use efficiency, or the amount of water required for a given amount of growth.[24] Water use also differs between broad classes of trees: studies have shown conifers to have consistently lower transpiration rates, or sap flux, than angiosperms, which typically translates to lower whole-tree water use. This is likely due to conifers’ more restricted vascular structure as well as other aspects of wood anatomy,[25] and makes the conifer-angiosperm ratio a useful comparison when considering neighborhood tree water use. Differences also exist between angiosperm groups for similar anatomical reasons (specifically ring-porous vs. diffuse-porous[26]). This inherent variability in tree water use supports the need for examination of trends in species selection for landscape trees.

Afforestation, though only one aspect of ecological change, plays a critical role in urban biodiversity and resource use and has a dynamic relationship with the patterns of development. The Heber Valley in northern Utah, USA provides an ideal case study to examine this relationship and its consequences. Utah is the second fastest-growing state in the country by percentage[27] and Heber City is the seat of its fastest growing county at 7.1% annually[28]. Situated in a semiarid shrubland and agricultural zone, this area is part of the Salt Lake City-Park City metrozone with elements of exurban development. This region also displays several defined development layers characteristic of the West, from extremely low-density exurban housing to dense, young tract housing. Trees are dominant in its urban landscape; the Heber City General Plan establishes a standard of “well-landscaped, tree-lined streets.”[29] In this setting, we asked the question, Are there differences in basal area, stem density, species richness and evenness, and plant functional type in the urban forest of distinct classes of development? To address this, we used public housing data and visual development trends to categorize four classes of residential and commercial zones and design a stratified survey, and we used standard forestry techniques to collect data for trees in randomly selected lots in these categories. The results provide a baseline profile of the compositional patterns of Heber’s urban forest as well as indicators for developers and homeowners of the ecological implications of these patterns.

2. Methods

2.1 Study Area

Heber Valley is a rapidly growing suburban and rural community located on the east side of the Wasatch Mountains in Utah. Beginning in the 1860s, the region was supported by dairy farming and ranching.[30] Overgrazing substantially altered the ecology of the area and commercial farming also expanded, replacing native plant communities.[31,32]

Recreation had replaced agriculture as the mainstay of the community's economy by the 1970s, and cropland decreased by 25% between 1978 and 1987.[33] Farms were already being converted to subdivisions then,[34] and this is the trend now as well.[35] Heber Valley is essentially a residential extension of urban centers on the Wasatch Front and is also a tourism hub for the scenic region. In addition to Heber City, Midway and several other small towns occupy the valley. Our survey was centered in Heber City and Midway (Figure 1).

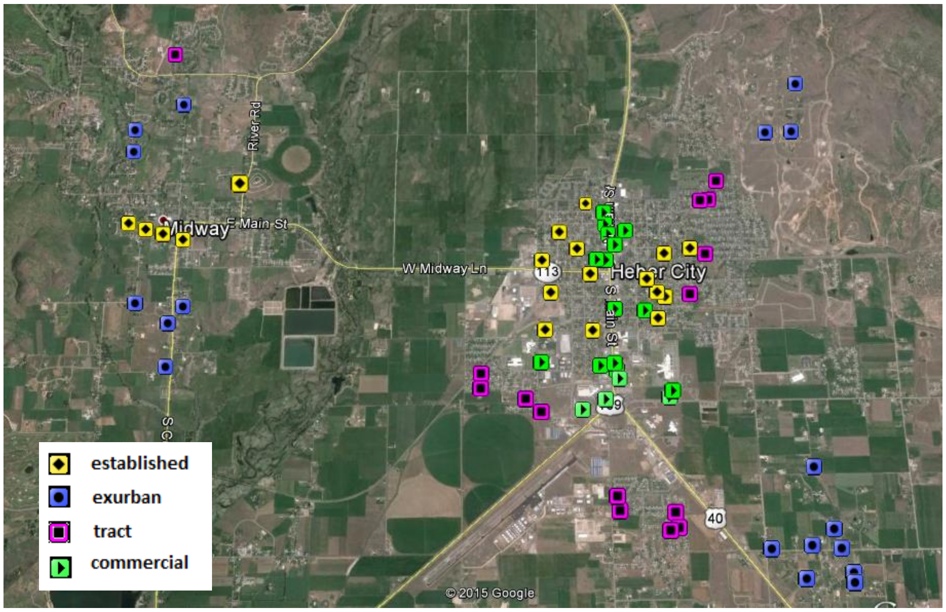

Figure 1. Survey points in the study area, Heber Valley, Utah, U.S. (Google Earth 2015).

2.2 Neighborhood Types

In order to designate neighborhood categories for a stratified survey, we examined satellite imagery of Heber City and Midway and accessed information including year built and lot size from the public real estate website Zillow for a sampling of houses.[36] Heber City (and to a lesser extent, Midway) has a distinct grid that makes up the core of the city and contains the oldest homes, from late nineteenth century to the early 1970s. We categorized this grid as established neighborhoods. Since roughly the 1970s, dispersed rural housing has been built away from the main city on large lots; e categorized this as exurban neighborhoods. In the last ten to twenty years, dense subdivisions have become common on the edges of the grid, making up an important new category, tract neighborhoods. Finally, a considerable part of Heber City is taken up by a commercial strip, which we also surveyed. With both spatial cues and housing data, we distinguished between four development categories: established, exurban, tract, and commercial.

2.3 Survey Design

We created a stratified random survey of lots in each neighborhood type from municipal and county GIS data (ArcGIS, ESRI, [Wasatch County, Utah]).[37] Once we defined neighborhood types, we drew boundaries around the developments in both Heber City and Midway. While established and commercial developments were fairly contiguous, the nature of tract and exurban housing required selective drawing so that acres of agricultural land wouldn't be included. We merged separate polygons within categories (and did not distinguish between Heber City and Midway) and generated thirty random points in each neighborhood polygon. We located the address closest to each point, and these addresses became the survey. At each selected lot we sought in-person consent from the owner, and if there was refusal or no reply we approached the next-closest lot until we gained permission to survey. Time did not permit surveying of all 120 lots; close to twenty lots in each category were surveyed for a total of 81 lots. One commercial lot, though surveyed, was not included in the data because it was an outlier in size, leaving 19 in that category.

2.4 Survey Technique And Data Collection

We measured the diameter at breast height (DBH, 1.3 m from the ground) of all trees > 2-m tall. For fruit trees and the species listed in the USDA Forest Inventory Handbook[38] as woodland species, we measured diameter at the root collar (DRC). Multi-stem tree diameters were approximated as a single stem using equation (1):

$$\text{SQRT [SUM (stem diameter}^2\text{)]} \tag{1}$$

including only stems at least 0.3 m in length and at least 2.8 cm in diameter 0.3 m up from the diameter measurement point.[39] For efficiency, when trees of the same species were very close in size, we chose one as a representative and applied its measurement to the others. We did not include shrubs in our survey. We measured the height of some trees using a clinometer and others with a Nikon 8381 Laser Forestry Pro Rangefinder; however, we did not make this measurement for every tree, so this data was chiefly a reference.
We made notes and took pictures of trees in order to later identify the species. The reference used to identify trees was the Oregon State University Landscape Tree Database[40]. For some trees only genus was a feasible level of identification. We determined the native status of tree species with information from the USDA PLANTS database[41] and from plant taxonomists.[42]

2.5 Data Processing

We obtained the precise lot sizes of survey addresses from Zillow and ArcMap. For exurban lots, we did not include land outside the cultivated yard even if it was part of the property, since this land did not represent the area planted with trees (for practicality's sake we did include the house or building itself in the area of all lots). We calculated basal area (area of trunk cross section) of the trees in m^2 from the DBH or DRC and summed this measurement for the total basal area of each lot, which we converted to m^2 per hectare. We also calculated the basal area per hectare for specific groups such as conifers and angiosperms and obtained their lot percentages for both basal area and count. We calculated species diversity using the Shannon diversity index, equation (2)[43] :

$$H' = -\sum_{i=1}^{R} p_i \ln p_i \tag{2}$$

and species richness based on the number of species present in each lot, both scaled to the hectare and unscaled.

2.6 Data Analysis

We compared neighborhood means for the following variables: number of trees per ha, basal area per hectare, conifer basal area per hectare, native basal area per hectare, species richness per hectare, and Shannon diversity. We did so using analysis of variance and Tukey's HSD post-hoc test in R.

3. Results

Basal area per hectare was highest in the established neighborhoods at an average of 10.0 m^2/ha. Exurban lots averaged roughly half this amount with 5.9 m^2/ha, followed by tract at 1.6 m^2/ha and commercial at 0.77 m^2/ha. Commercial basal area was found to be significantly different from both exurban and established housing. In addition, there was a significant difference between tract and established housing ($p<0.05$, Figure 2).

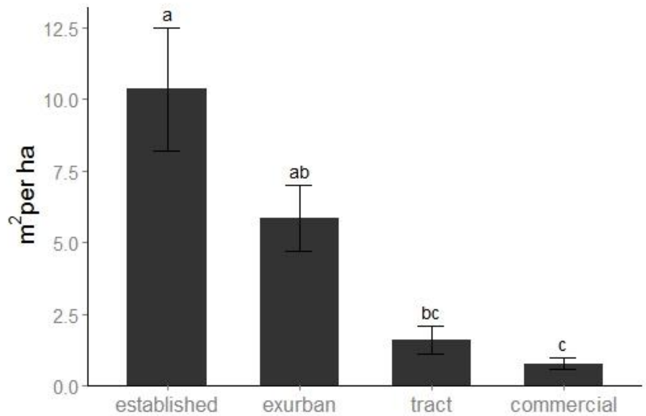

Figure 2. Average lot basal area per hectare (m^2/ha) for each neighborhood type; error bars with standard error of the mean.

Following a similar pattern, established housing had the highest average stem density at 159 trees/ha; next was exurban at 131 trees/ha, while tract had 75 trees/ha and commercial only 20. Again, significant differences were found between established and tract as well as between commercial and both established and exurban housing ($p<0.05$, Figure 3).

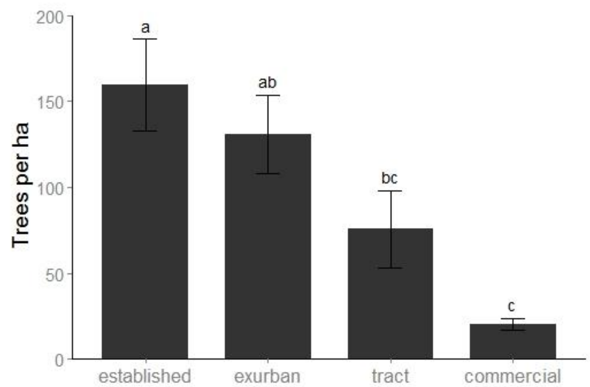

Figure 3. Average lot stem density (trees per ha).

The average percentage of basal area that was made up by conifers (the remainder being angiosperm/broadleaf trees) was again highest in established lots: 34.6%. There was no significant difference between commercial and exurban, with 15.6% and 17.4%, respectively. Tract had an average of 5.2%, which is significantly different from established housing. ($p<0.05$, Figure 4)

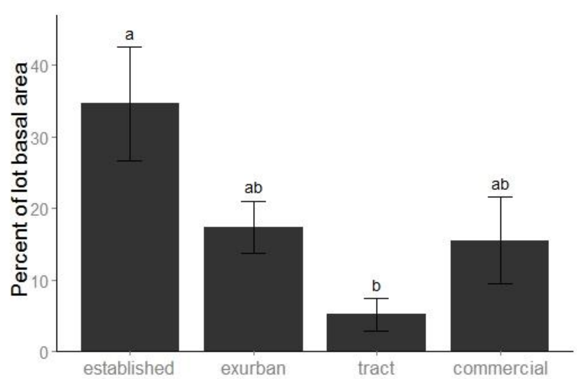

Figure 4. Average percentage of lot basal area comprised by conifers.

Native trees' basal area percentage was nearly 50% in established housing, followed by 36.2% in exurban, 29.6% in tract, and 14.6% in commercial. The only significant difference was between established and commercial ($p<0.05$, Figure 5).

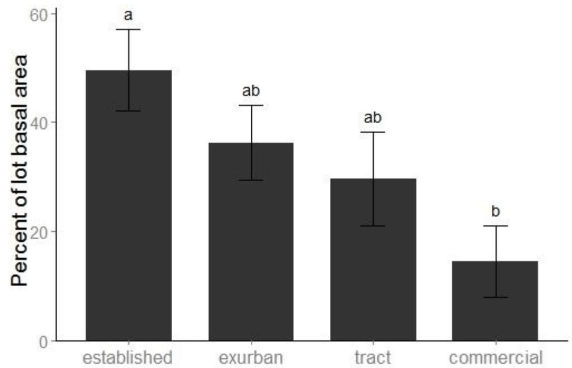

Figure 5. Average percentage of lot basal area comprised by native trees.

Species richness was also highest per hectare in established neighborhoods, with an average of 44 species per hectare (unscaled, 5.8 species per lot). Exurban and tract housing means were nearly identical at 24.7 and 24.8 species per ha, respectively (unscaled numbers were 9.8 per lot for exurban and 3.0 per lot for tract). Commercial species richness was much lower at 7 species per ha (2.7 per lot). Significant differences for species richness per hectare were found between established and all other categories ($p<0.05$, Figure 6).

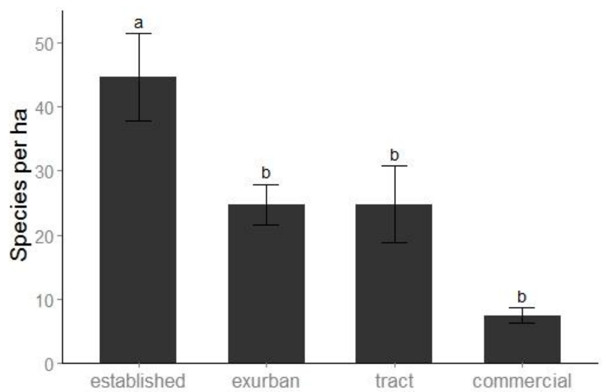

Figure 6. Average lot number of tree species per hectare.

Exurban housing had the highest average Shannon diversity index, 1.6. This was significantly different at $p<0.05$ from established housing's index, 1.2, as well as from tract at 0.72; it was significantly different from commercial, 0.76, at $p = 0.068$. Tract was also found to differ from established housing at $p<0.05$ (Figure 7).

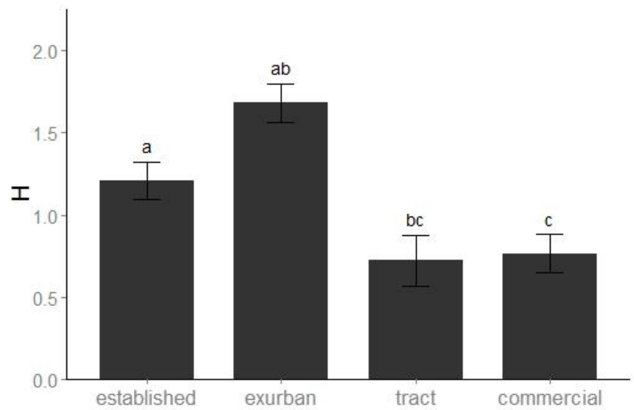

Figure 7. Average lot Shannon diversity index (H).

4. Discussion

The goal of this study was to compare characteristics of the urban forest from different layers of development in the Heber Valley, Utah, USA. This layering effect had the potential to provide a space-for-time substitution, with different developments representing distinct temporal periods. However, it also creates functionally different neighborhoods. For example, although tract and exurban housing is sometimes the same age, exurban lots are inherently larger than tract lots because of their purpose. Our results indicate that varying development patterns do lead to differences in urban forest makeup, whether as a result of functional or temporal differences between neighborhoods. The most marked temporal difference was between established housing and the other categories, particularly tract housing. Established and tract housing share similar lot sizes and close proximity within city boundaries, but are clearly separated by age. Age is likely to explain established housing's high basal area per hectare, as trees have had decades to grow, as well as high stem density, as more trees are planted over time. Differences in composition, however, may result from changing preferences and practices. Lower species richness and Shannon diversity index in tract indicate a distinctive level of homogeneity in tract urban forest. As an evenness marker, tract's average Shannon index probably reflects a tendency to plant trees in identical groups or rows, a planting pattern less common in the gradually subdivided city core. By total basal area, the top five occurring species in tract were quaking aspen (*Populus tremuloides*), flowering pear (*Pyrus calleryana*), black cottonwood (*Populus trichocarpa*), Colorado blue spruce (*Picea pungens*), and silver maple (*Acer saccharinum*). In established, the top five species were boxelder (*Acer negundo*), Colorado blue spruce (*Picea pungens*), wild plum (*Prunus americana*), Fremont cottonwood (*Populus fremontii*), and aspen (*Populus tremuloides*). Although there is some overlap, new species appear to have gained popularity in tract developments. The significantly lower conifer proportion in tract lots seems to reflect a change in preference as well.

Commercial development, at the lowest diversity markers, also shows significant homogeneity. The top five occurring species by number in the category, which were Austrian pine (*Pinus nigra*), green ash (*Fraxinus pennsylvanica*), flowering pear (*Pyrus calleryana*), Norway maple (*Acer platanoides*), and chokecherry (*Prunus virginiana*), represented 59.9% of all trees sampled in commercial lots. With trees often planted in identical rows at the fringes of parking lots, commercial green spaces do not represent a rich source of urban biodiversity.

Exurban housing overlaps in timing with all other categories but stands apart in landscaped lot area and its extremely low housing density, often outside of city limits. Its most distinct forest characteristic was its high Shannon index and lot-based species richness. Although stem density (scaled to the hectare) fell below levels of the established neighborhoods, the size of lots gave the exurban category as a whole the highest total number of trees and species. The top five species with highest basal area in exurban housing were Colorado blue spruce (*Picea pungens*), Eastern cottonwood (*Populus deltoides*), narrowleaf cottonwood (*Populus angustafolia*), quaking aspen (*Populus tremuloides*), and silverleaf poplar (*Populus alba*). Rather than revealing a time-based trend, this difference likely highlights the functional distinctness of exurban housing, with its size and rural aesthetic.

Exurban and established housing areas have tree diversity levels that provide unique opportunities for urban biodiversity. Not only do they have the highest diversity, but that diversity is more even than in tract and commercial development areas. This pattern increases possible interactions with other species, and the range of sizes, ages, and placement of trees (e.g., dense stands of volunteers or dead patches) within lots, especially large exurban lots, increase habitat availability. This is an obvious contrast to typical tract and commercial lots with only a few trees drawn from a smaller species pool. Again, however, this recalls the dilemma of urban biodiversity—high diversity can increase ecological interaction, but how much of it is supplied by exotic species? The average established lot's percentage of native basal area, 50%, represents a noteworthy native presence, while exurban, at 36%, is less well-populated with natives. However, these numbers weren't significantly different, indicating high variability between lots. Although tract lots' native percentage was even lower by our samples, some of the same native species found in established and exurban lots had high occurrence in tract as well. Three of tract housing's top five species by basal area were native species: quaking aspen (*Populus tremuloides*), and black cottonwood (*Populus trichocarpa*), and Colorado blue spruce (*Picea pungens*). were both in tract's overall top three species by basal area.

Exotic species raise concerns about invasion,[44] particularly with species such as Russian olive (*Elaeagnus angustifolia*)[45] and the genus *Tamarix*. Even native trees, however, have drawbacks.[46] Most native landscaping trees used in this region are riparian, like cottonwoods, or grow at higher elevations than the populated valleys, like aspen (Kuhns, 1998). Although native trees have a better chance of attracting native fauna, they may require just as much maintenance as nonnatives or have just as many health issues. This points to the importance of selecting species based on their suitability for the landscape, not simply based on native status.

Water use and water use efficiency are some of the most important traits to consider in assessing tree suitability. One possible indicator of current tree water use trends is the conifer-angiosperm ratio in each category. Tract, at an average of 20% less conifer basal area in a lot than established lots, appears to be giving less preference to conifers in landscaping, perhaps because of their slow growth or because of aesthetic preferences. With the exception of blue spruce (*Picea pungens*), conifers are well-outnumbered by more commonly seen flowering pear trees (*Pyrus calleryana*); trees from the genus *Populus*, including cottonwoods, poplars, and aspen; chokecherry (*Prunus virginiana*); and crabapples (*Malus spp*.). Many of these species are riparian, meaning they are adapted to a large subsurface water supply. These species, excepting flowering pear, are also common in established and exurban housing, but are somewhat more balanced by spruce and pine species. This aesthetic, unlike that of tract, lends itself to more conservative tree water use.

Trees have multiple strategies for water use efficiency in an irrigated environment, and so water-minded selection of species need not be strictly low-growth. McCarthy *et al.* (2011) found that urban trees could have high water use efficiency at low water use and high growth, such as the lacebark tree (*Brachychiton discolor*), as well as high water use and high growth, such as the laurel fig (*Ficus microcarpa*). Knowing these tendencies for specific trees allows developers and homeowners to make decisions about the tradeoffs between water use and growth; further research of species-specific water use would be beneficial for developers in their decision-making.[47] Irrigation scheme also makes a difference;[48,49] a preliminary study has found daily transpiration to be an order of magnitude greater in irrigated blue spruce (*Picea Pungens*) than in unirrigated spruce in this study area.[50]

There are other drivers of urban forest composition than those we directly measured. Other urban forest surveys have addressed social correlates,[51] multiple land use types (e.g. parks, pristine remnants, industrial)[52,53,54,55], and additional response variables such as canopy cover and biomass.[56] This study is useful, however, in addressing the patterns of development unique to the West. While Turner *et al.* (2005) in Nova Scotia, Canada, did not find significant differences in diversity and other variables between neighborhoods in different age classes, there were clear differences between the categories in our study. This shows that individual cities are different, but also suggests that the West's afforested landscape has distinctive patterns not seen in other regions.

As Western cities continue to expand, these patterns will shift, with implications for the urban forest. As tract housing expands, it may replace exurban neighborhoods (which, in Heber, is explicitly planned[57]), bringing its homogeneous planting patterns with it. However, it is most likely that the herbaceous, irrigated cropland will remain the primary zone for exurban development, potentially introducing new trees and diversity in these patches. Meanwhile established housing will remain at the core of cities, but may experience infill development,[58] and trees will be replaced over time. These changes will still be restricted to the same dense configurations, but will be open to a wide range of species selection. Commercial development will surely also continue with population growth, limiting the potential for variety in landscaping. Above all, the processes shaping the urban forest and its effect are complex, and developers face many tradeoffs in ecosystem services. With a goal of identifying these tradeoffs, continued development in the West can be informed by deliberate decisions about the makeup of the urban forests.

5. Acknowledgements

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