ABSTRACT

Title of Thesis: THE INFLUENCE OF LAND-USE, ENVIRONMENT, AND SOCIOECONOMIC FACTORS ON TREE SPECIES DISTRIBUTION IN BALTIMORE, MARYLAND.

Degree Candidate: Kimberley Ellen Mead
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Directed By: Associate Professor Joseph H. Sullivan
Department of Plant Science and Landscape Architecture

With the exponential growth in human population and rapid increase in global urbanization, understanding changes in community dynamics and structure in human dominated landscapes is essential, yet, rarely studied. To determine what factors account for tree species composition and distribution in an urban setting, data from the 1999 UFORE Model vegetation survey of Baltimore, Maryland was analyzed. There was a diverse arboreal population found, comprised primarily of species native to the area. Detrended correspondence analysis did not show a clear pattern of species assemblages based on land-use, possibly indicating a homogenization of conditions across the urban environment. In canonical correspondence analyses, species distribution could not be explained by socioeconomic factors, however, there was a significant relationship of tree species assemblages and the physical environment, specifically with percent impervious surface cover. The amount of variance accounted for was small indicating that other factors may be involved in determining plant species assemblages.

THE INFLUENCE OF LAND-USE, ENVIRONMENT, AND SOCIOECONOMIC FACTORS ON TREE SPECIES DISTRIBUTION IN BALTIMORE, MARYLAND.

By

Kimberley Ellen Mead

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Advisory Committee:
Associate Professor Joseph H. Sullivan, Chair
Research Forester, United States Forest Service, Richard V. Pouyat
Associate Professor David Meyers

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Table of Contents

List of Tables

List of Figures

List of Illustrations

Chapter 1: Introduction

Few ecosystems are untouched by the direct and subtle effects caused by the development and expansion of human civilization (McDonnell and Pickett, 1993). In the United States, approximately 80% of the population lives in or near cities (USCB, 2005), while the surface area of urban areas is projected to almost double in the next 25 years to 9.2% (Alig et al., 2004). Worldwide, an estimated five billion people will be living in urban areas by the year 2030 (UN, 2005). Despite the increase in urban population, little research in North America has focused on understanding the community dynamics of city-dwelling plant species or ecosystem functioning within urban environments (Collins et al., 2000). In large part, this lack of attention stems from the fact that forests dominated by humans and urban infrastructure are rarely seen as functioning ecosystems by citizens and scientists alike as vegetation is forced to exist within disconnected forest remnants, street tree pits, and highly variable residential and commercial landscapes. In order for planners and both public and private land stewards to make informed decisions that will protect and improve environmental and, ultimately, human health and well-being, there must be a greater understanding of how human dominated systems function (Meiners et al., 2001).

The challenges for urban vegetation

Urban environments differ in many respects from more researched and understood rural and wilderness settings. Urban areas are defined here as areas containing more than 620 people per km^2 with an overall population greater than 50,000 (USCB, 1980). Typically, population density, the proportion of land apportioned to buildings, and road density are all highest near the urban core and decrease with distance outwards as the forest matrix becomes more dominant (Medley et al., 1995). Cities are often characterized by a low percentage of forested area (Medley et. al, 1995) with an average of 33% tree cover for cities in the northeast United States (Nowak and Crane, 2002) compared with surrounding rural areas characterized by about 80% tree cover, on average (Freedman et al., 1996). Land that is available for tree growth is broken into more numerous and smaller isolated fragments (Medley et al., 1995; Porter et al., 2001), reducing available space for the establishment and persistence of species adapted to the protection provided for by the forest interior.

In more natural forested areas, disturbance events include fire outbreaks and tree falls (Pickett et al., 1989). While in an urban environment, disturbance is commonly a result of land-use change and new construction. Practices in land management, such as lawn mowing, can provide for more frequent, smaller scale disturbances. However, while the actual pathways may be markedly different, urban forests and rural forests are similar in the mechanisms of vegetation community dynamics. As in forest species assemblages found in more rural settings, trees in urban forests are distributed based on generalized mechanisms of species replacement: 1) sites become available, 2) species are differentially available based on seed source or vegetative propagation, and 3) species are able to persist through adaptation and competition (Pickett et al., 1987).

Once space is available for tree growth, the species available to regenerate naturally are determined by the available seed source and by adjacent species able to vegetatively propagate and colonize the area. In cases where trees are being planted, species composition is in large part due to the availability of plant material, trends in landscaping, and personal preference. Only those native trees able to adapt to the transition from undisturbed forest to developed city will persist and regenerate in natural areas as well as spread into neglected and abandoned private land spaces.

Species composition and distribution in the urban environment can also differ when compared with surrounding areas due to the introduction of non-native species. Non-native species are defined as those species that were not found in the Baltimore area pre-European settlement and have since then been imported from areas of similar climatic characteristics, mainly portions of Asia and Europe, for landscaping, medicinal purposes and soil erosion control. Some of these non-native species may naturalize through environmental adaption and freely reproduce while others do not escape into the environment. Invasive species are those non-native species that aggressively spread and are found to cause economic and environmental harm or harm to human health (Swearingen, 2002).

There is often a larger stem densities of non-native plant species around developed areas that increases overall species richness (Burton and Samuelson, 2008; Lowenstein and Lowenstein, 2005; Sax and Gaines, 2003) and leads to biotic homogenization at small, large, and global spatial scales as cities are built to serve a single species, man (McKinney, 2006). Forests along an urban-rural gradient in New York were found to have lower stem densities and an increased proportion of invasive seedlings and saplings, as well as seed bank stores, at the urban end of the gradient (Cadenasso et al., 2007, McDonnell et al, 1997). Previous studies have shown that native plant communities in urban areas typically have decreased stem densities, lower species diversity, and decreasing overstory tree regeneration (Burton and Samuelson, 2008, Moffatt et al., 2004). Species composition in cities can be dominated by few species accounting for more than half of the tree population (Nowak, 1994d).

Finally, after a tree seed germinates, it has to be able to persist in that location. With the intensive construction and constant modification needed to support a large human population, urban areas are characterized by conditions challenging to some species of trees such as altered hydrology (Groffman et al., 2003) and a higher percentage of impervious groundcover affecting water flow and plant root growth (Medley et al., 1995). Soils are typically compacted and degraded with altered nutrient cycling (Groffman et al., 1995; Pickett et al., 1997), higher concentrations of heavy metals and organic matter, and reduced fungi and microinvertebrates (McDonnell et al., 1997; Pouyat et al., 1995). Urban areas are prone to the “heat island effect” where anthropogenic changes to land cover and pollution have resulted in temperatures higher than surrounding rural areas (Karl et al., 1988; Oke, 1995), possibly leading to longer growing seasons and altered flowering times for resident plant species (Luo et al., 2007). These factors, along with many others, including the unique history and development of each patch of land, may influence the plant species assemblages found within the urban environment.

Socioeconomic factors versus abiotic and biotic factors in determining plant composition and diversity

Urbanization has resulted in new definitions for plant community ecology and new parameters for species composition and spatial relationships. In natural systems, site characteristics such as climate, resource availability, hydrology, seed source proximity and dispersal, and topography are typically the dominant factors in determining species composition and spatial distribution (Brush, 1980; Chesson, 2000; Grimes, 1979; Lavorel, 2002). However, in an environment modified by and dominated by humans, abiotic and biotic factors become integrated, or sometimes replaced, with site history, socioeconomic status, cultural influences, and personal preferences.

Hope et al. (2003) found in planted landscapes that perennial plant diversity in urban gardens was affected by the "luxury effect", the relationship of wealth and plant diversity, in addition to elevation and land-use (Hope et al, 2003). Martin et al. (2004) investigated the sources of variation in perennial vegetation composition planted across the landscape of Phoenix, Arizona. Median family income accounted for most of the variation in plant richness in neighborhoods. Plant abundance in surrounding park land was best predicted by the time since last disturbance represented by the median age of the neighborhood.

Grove et al. (2006) investigated the importance of multidimensional social theories on vegetation cover in Baltimore, Maryland by extracting land cover from satellite imagery in terms of grass cover versus tree cover on residential areas located on private lands, public rights-of-way, and riparian areas. They found that tree canopy cover, on private lands and on public rights-of-way, was best predicted by the land management decisions aimed towards upholding prestige within the community, particularly when modeled with housing age.

While there have been some gains in the understanding of the interaction of humans and vegetation in urban environments, little has been investigated within urban areas on arboreal vegetation at the species level. Whitney and Adams (1980) found that age of housing on the property and the proximity to the center of Akron, Ohio greatly influenced the tree species present. They suggested that this may have been due to the changing recommendations by the nursery industry as plants go in and out of fashion over time. Plants in more developed areas closer to the city's central complex were more likely to be undesirable species, such as *Morus alba* and *Ailanthus altissima*, due to differential property upkeep, if any at all, as land management can be absent with vacant property in comparison to suburban areas. They also found correlates in income and occupation of the homeowner. Vallet et al. (2008) found that buildings and pavement areas were significant predictors of species composition.

In an effort to further research the drivers for tree species assemblages in an urban environment, tree survey data was collected and used in a series of multivariate analyses in order to evaluate chosen social and environmental factors found in previous studies to influence vegetation distribution.

Questions and hypotheses

Using data collected from a vegetation survey from the UFORE Model collected in Baltimore, Maryland in 1999 by the USDA Forest Service, the following analyses will attempt to describe the tree populations found, as well as the possible drivers for tree species composition, and their positioning in the urban landscape. UFORE, or the Urban Forest Effects Model, is a computer model developed in the 1990's by the USDA Forest Service Northeastern Research Station to quantify an urban forest's structure and function (Nowak and Crane, 2000).

Survey plots were grouped by land-use type as this can be an indicator of site history, degree of disturbance, and of land management practices. In this study, three questions will be addressed. What is the current tree population of Baltimore, MD and does land-use influence the spatial distribution of tree species? And finally, as the natural environment is heavily modified, do anthropogenic processes act as drivers for tree species composition and distribution? The following hypotheses will be tested with the purpose of answering these questions:

(H_1) Differences in species assemblages among the survey plots will be related to land-use classification.

(H_2) Socioeconomic data, specifically income, population density, and percent vacant housing, will be correlated with tree species distribution.

(H_3) Physical environmental data, represented by impervious surface cover and time since last major disturbance, will be significant to tree species distribution.

Chapter 2: Methods

Site description – Baltimore, MD

All plots surveyed were within the city limits of Baltimore, Maryland, located in the Mid-Atlantic region of the United States (Illustration 1). Baltimore City (lower left 39˚11'37" N, 76˚42'38" W and upper right 39˚22'30" N, 76˚31'42" W) is located on the Patapsco River, which empties into the Chesapeake Bay. The city is protected to the west by the Appalachian Mountain range, blocking northern winds and lake effect snows from the Great Lakes region. To the east, the Atlantic Ocean buffers the area from extreme freezing conditions. The average annual rainfall is 100-115 centimeters and is generally distributed evenly throughout the year with around 10 centimeters per month with the exception of late spring and early summer where there is a slight increase in precipitation (NOAA, 2004). The highest daily temperatures typically occur in July at an average of 32.8˚ C and lowest temperatures take place in January with an average low of 6.7˚ C. The record high was 42˚ C in 1985 and the record low was set in 1934 at -21.7˚ C (TWC, 2007). Primarily located within Plant Hardiness Zone 8, a small portion of zone 7 occupies the north-western part of the city according to the USDA Hardiness Zone map (USDA, 1990). The fall line, designating the meeting of two physiographic regions, the Atlantic Coastal Plain and the Piedmont, cuts through the city, nearly dividing Baltimore into half. The city's elevation ranges from sea level to 400 feet above sea level with the center of the city about 33 feet above sea level (USGS, 2008).

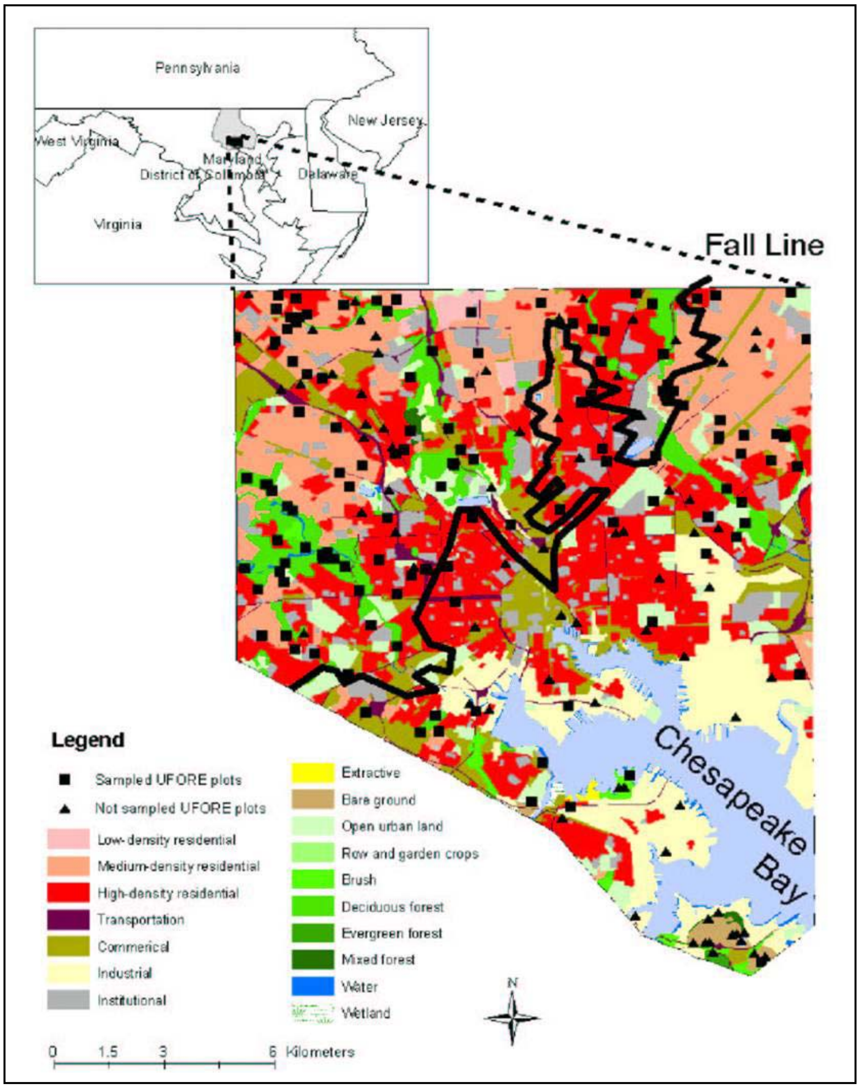


Illustration 1. A map of Baltimore City with the 1999 UFORE plots marked and land-use categories indicated (*Courtesy of the USDA Forest Service; Pouyat et al., 2007*).

Baltimore’s population peaked in the 1950’s as the sixth largest city in the United States and then began to decline as people moved into the surrounding suburbs. The population in 2000 was estimated to be 651,154 people by the United States Census Bureau, down 14.7% from 1990’s estimate of 763,014. Although still falling, the population decline has slowed in recent years to 631,366 in 2006. City revitalization projects including the renovation of the Inner Harbor, a popular tourist attraction, and increased residential building may have contributed to the reduced rate of population decline. Even with the recent renewal, a large percentage of the population lives below the poverty line with an unemployment rate of 22.9% and much of the city’s landscape is abandoned and unattended with a vacant housing estimate of 42,000 homes (Chapelle et al., 1986; US Census, 2008).

Description of the Urban Forest Effects Model (UFORE)

Data for this analysis have been provided by the USDA Forest Service from a vegetation survey in the summer of 1999 (UFORE, 2004c). The UFORE computer model was developed in the 1990’s by the United States Department of Agriculture Forest Service, Northern Research Station to allow researchers and land managers to quantify the structure, functions, and values of forests using vegetation data collected in the field and corresponding meteorological and pollution data (Nowak and Crane, 2000). The program began with a handful of large cities within the United States, such as New York, NY, Atlanta, GA and Baltimore, MD and has since been utilized in approximately 50 cities throughout the world. The UFORE model can provide information as to the current state of a city’s forest and management opportunities through species diversity, forest health, and age class distribution. In addition, the model has been used to predict the future health of the city's forest and to provide political ammunition and perhaps a will to enact policies that will preserve and improve a forest's current state. The model calculates a monetary valuation of an urban forest, the potential losses due to invasive trees, pests, and pathogens, and the environmental services provided by the city's forest including building temperature moderation and air pollution uptake (Nowak and Crane, 2002).

Survey design and plot selection

Urban landscapes are collections of patches of the landscape that differ physically, biologically, and socially. Research has suggested that, in urban landscapes, topography and climatic variables are overcome by anthropogenic factors and spatial connectivity when determining species presence (Guirado et al., 2008). In a city, land-use has an overall impact on the amount of tree cover (Nowak et al., 2002). Industrial sites, for example, can be predicted to have a smaller percentage of tree cover, a higher percentage of impervious groundcover, and to have greater degrees of environmental disturbance than other types of land-uses. In contrast, canopied forested sites can be expected to have little, if any, impervious groundcover, less disturbance, and higher tree stem density and species diversity than industrial sites and other highly developed land-uses. Therefore, these patches, if grouped by current overall land-use of the surveyed area, are more easily defined and studied, as well as potentially better managed for optimum tree health and survivability. With this in mind, experimental design of the UFORE vegetation analysis uses a land-use typology to stratify plot locations.

As part of the UFORE data collection process, 202 circular 1/10 acre stratified random plots were selected in 1999 within the city limits of Baltimore, Maryland. A map representing a modified Anderson Level II classification was entered into a UFORE random plot selection program developed by the US Forest Service as a tool in ArcGIS (ESRI, 2006). The number of plots in each land-use category was based on the relative proportions of the land-use classifications that existed within the city. These plot locations were then placed onto satellite maps detailing building and street locations in order to most accurately locate the plot centers from the ground. The land-use designation of the plot was affirmed or ratified on site the day of data collection.

The categories for land-use were as follows: Forested, Bare Ground, Open Urban, Institutional, Medium and High Density Residential, Commercial, and Industrial. There were two land-use categories, Low Density Residential and Wetland, with one plot each, that were omitted from the original data set for the purposes of this data analysis due to lack of replication, bringing the total to 200 plots. Forested plots were areas that were unmanaged and tree canopied. Open Urban areas included those plots managed for recreational purposes such as parks, golf courses, and sports fields, as well as vacant lots that were undergoing vegetation regeneration. Bare Ground plots were disturbed areas dominated by exposed soil and included sites such as landfills and constructions plots. Institutional plots were located on school grounds, cemeteries, hospitals, and nursing home facilities.

Medium Density Residential plots were located on the properties of single family homes and High Density Residential plots were multifamily plots of land located on the grounds of apartment complexes and row houses. Commercial plots were on properties of retail stores, strip malls, and buildings dedicated to the service industry, including parking lots for such purposes. While Industrial plots were located in areas dedicated to refining, building, or other types of industry.

If a plot fell on an area that was split between two or more land-uses, then the plot was classified as the dominate land-use. If plots were inaccessible due to impassable physical barriers or to the survey crew being denied right-of-way by the landowner, data were estimated when possible. If estimation was not possible, then plots were relocated randomly to the nearest accessible similar land-use property using a randomly-generated number table in conjunction with a gridded satellite map.

Vegetation data collection

Vegetation data were collected in 1999 from June through October according to the UFORE protocol (Nowak et al., 2008; Nowak et al., 2005). Plot center was established based on the satellite imagery and related to two reference points and a street address, when possible. If reliable reference points were not available, as with interior forested plots, GPS coordinates of the plot center were noted for plot relocation. In order to be within the 1/10 acre plot, any part of the tree's trunk had to be within the delineated plot boundary. Trees were differentiated as any woody vegetation above 1 foot in height and greater than 1 inch at dbh (diameter at breast height or 4.5 feet). Species meeting this definition but known to more characteristically to have a shrub-like habit, such as *Berberis thunbergii*, *Lindera benzoin,* and *Syringa* and *Forsythia* cultivars (Dirr, 1998), were omitted from the data set used in this analysis.

Tree measurements began with the tree at the northern-most compass direction and followed with all individuals in a clockwise direction. For each tree included, individuals were identified to the species level if possible for all trees except for the *Ulmus*, *Carya*, and *Fraxinus* genera, which were challenging to correctly discriminate from closely related taxa, particularly when foliage and twigs were unreachable, and were therefore grouped within their respective genera. The diameter at breast height (dbh) was measured with dbh tape at 4.5 feet.

Ground point measurements were taken for each plot in order to determine impervious surface areas. Beginning at plot center and then progressing toward north on a transect in the zero degree compass direction, ground cover at 9 feet, 18 feet and 27 feet from plot center was noted. This was repeated for seven other transects within the plot at 45 compass degree increments and at direct plot center resulting in 24 total ground points per plot. Pervious ground cover categories included maintained and wild grass, herbaceous plants, bare soil, duff, and gravel. Impervious ground cover categories included tar, cement, brick, rock and categories of roofing materials. Percent impervious and percent pervious surfaces were calculated by extrapolating the entire plot surface cover by the sampling point percent totals.

Data analysis: Importance values and species diversity

Calculations for species importance values were performed through a compilation of data from identified species from all of the plots. Six genera were also included in these calculations: *Ulmus, Fraxinus, Prunus, Malus, Magnolia,* and *Malus*. Importance values were calculated as:

Importance value = Relative frequency + Relative density + Relative Dominance

Derived from the following equations:

$$\text{Relative frequency} = \frac{\text{Frequency of a species} * 100}{\text{Sum of all species frequencies}}$$

$$\text{Relative density} = \frac{\text{Density of a species} * 100}{\text{Sum of all species densities}}$$

$$\text{Relative dominance} = \frac{\text{Dominance of a species} * 100}{\text{Sum of all species dominances}}$$

The frequency for each species was calculated as the number of plots that the species was found over the total number of plots (200). Density was calculated as the number of trees in the species or genus divided by the total plot acreage of the survey or 20 acres. The dominance for each species was calculated as the sum of the basal areas for all individuals of that species divided by the total area of the survey (20 acres). Basal area for each species was determined by the sum of the basal areas for all of the individual trees within that species as π*diameter at breast height/4. If an individual tree had more than one trunk stem, then the basal areas of all of the stems were summed and assigned to that tree. The maximum value each for relative frequency, relative density, and relative dominance is 100, therefore, the maximum value for the importance value for each species is 300 (Kent, 1992; Kuers, 2005).

Raw data from the UFORE plots data collection was organized into a table of plot number by tree species matrix containing the number of stems. There were 200 plots entered for the purposes of this analysis. Of those, 87 plots did not have tree species. Species diversity indices, richness, and evenness were determined through plot row summary analysis of PCORD (McCune and Mefford, 1999) for all of the plots separately, by land-use, and for all plots total.

Data analysis: Detrended correspondence analysis

As the environmental gradient is complex and nonlinear on the landscape, particularly an urban patchwork landscape with integrated anthropogenic and natural factors (McDonnell and Pickett, 1993; Porter et al., 2001), multivariate analysis was utilized to quantify tree species distribution. Detrended correspondence analysis (DCA) is an indirect gradient analysis technique that allows for environmental gradients to be inferred from species composition data by positioning sample units based on covariation and association of the species. DCA is a modification of Correspondence analysis (CA), created for ecological data sets that calculates site and species scores iteratively one based on the other in order to reduce redundant information within the dataset (Hill and Gauch,1980; McCune and Grace, 2002).

In DCA, numbers called site scores are arbitrarily assigned to all of the plots. Species scores are then assigned to each species based on the weighted averaging of the site scores weighted by the abundances of the species within each plot. Species scores are re-standardized and then new site scores are calculated based on the weighted averages of the scores of the species found within those sites. Reciprocal averaging continues with site and species scores until there is no noticeable difference in the numbers through the iterations. In addition to the steps of correspondence analysis described above, DCA removes the "arch effect" found in CA by a detrending step that divides the first segment into segments and resetting the averages of the scores on the second axis to zero. A subsequent rescaling step corrects the compressed axis ends found in CA. DCA then ordinates plots and species simultaneously, allowing the plot and species scores to be used to possibly infer the gradient of vegetation change (Hill, 1979; Hill and Gauch, 1980).

DCA was applied to the plot by species matrix as the main matrix using a debugged version of DECORANA (Hill, 1979; Hill and Gauch, 1980) in PCORD version 4.41. DCA was applied with detrending by segments and non-linear rescaling. A plot by land-use matrix was added as a second matrix in order to evaluate the influence that land-use may have on tree species distribution.

As multivariate analyses used were sensitive to outliers such as rare species and low stem densities, species that occurred in less than 5 plots and plots with less than 5 species were removed. Finally, Bare Ground (3 plots) and Industrial plots (4 plots) were left out of data analysis as only 1 and 2 plots remained within those categories, respectively, after the previously mentioned eliminations. The option to downweight rare species during analysis was applied.

Data analysis: Canonical correspondence analysis relating census information

Along with environmental gradients, social theories and demographics may influence the distribution of tree species. Species-environment relationships can be inferred using community composition data and measured habitat variables through canonical correspondence analysis (CCA), a multivariate analysis technique that can relate species composition to known environmental variation (Ter Braak, 1986; Ter Braak, 1988).

Canonical correspondence analysis is a direct gradient analysis technique. Like DCA, CCA is also a modification of CA. In CCA, species composition is directly related to measured environmental variables in such a way that the former is explained by a linear combination of the latter. Essentially, CCA constrains the ordination of a main matrix, here a matrix of species abundances, by a multiple linear regression on variables in a second matrix.

In CCA, species scores are calculated from weighted averages of arbitrarily assigned initial site scores. Then, new site scores are assigned as weighted averages of the species scores. Site scores are used as dependent variables and environmental variables as independent variables in a multiple linear least-squares regression. New site scores are then assigned from the regression equation and then centered and standardized. These steps are repeated until the scores reach steady values (McCune and Grace, 2002; Ter Braak, 1986).

Species scores and site scores can then be simultaneously plotted in a biplot graph where the chosen environmental variables can be viewed as arrows overlaid onto the ordination plot. The scatterplot shows surveyed plots nearly central to the species that it contains. The length and direction of an environmental variable arrow indicate the importance of the environmental variable and the correlation with species composition axes, respectively. Environmental characteristics can be inferred from the position of the sites in relation to the arrows and locations of species could be used to infer environmental preferences of each species. The angle between arrows indicates correlation of the environmental variables.

A CCA was used to analyze the species abundances in relation to sets of chosen environmental variables using PCORD Version 4.41 (McCune and Mefford, 1999). The rows and columns were standardized through centering and normalizing and the scores for graphing were linear combinations of attributes. The analysis was done with 1000 runs.

In order to determine if there was any correlation of tree species with demographic data, the plot by tree species matrix containing species abundances was analyzed along with the 2000 108th Congressional District 2000 Baltimore City census in a CCA. Demographic information used in the CCA for each plot was attained via calculations using census data from the census tract that housed that plot. Plot locations were projected onto a Baltimore City map of census tracts supplied by the US Census Bureau as a TIGER (Topographically Geographic Encoding and Referencing Database) geographic layer (U.S. Census Bureau, 2007) within ArcGIS. A database was created with Census data gathered in 2000 (U.S. Census Bureau,

2000) matched with each plot through its associated census tract. Census information that was gathered for each tract included total population, median household income, median age of structure on site, and percent vacant housing. With the original plot by species matrix, this database was used as a second matrix in a CCA.

Chapter 3: Results

The genera and species composition of trees found in the Baltimore City survey

The urban tree population found in Baltimore, MD can be classified as an oak-beech-maple-ash forest as these genera dominated, collectively accounting for 41% of the 1503 trees used in this analysis from the Baltimore City 1999 survey (Figure 1).

Quercus, represented by 10 species, was the most common genus encountered with 13% of the trees measured. *Fagus* was the second largest genus represented, accounting for 10% of all trees counted, and, unlike the previous diverse genus, consisted of a single species, *Fagus grandifolia*. Six species of *Acer* were found and two species of *Fraxinus* were observed representing 10% and 8% of the total number of trees in the plots, respectively. *Prunus* species, encompassing substantial numbers of individuals of *Prunus serotina* as well as several species of unidentified flowering cherries, were a large portion of the trees, accounting for 8% of the total tree population. *Ulmus*, consisting of 3 species of elm, was also present and represented 8% of the survey tree population.

Trees of moderate presence levels were genera comprised of a single species each: *Sassafras albidum* (6%), *Cornus florida* (6%), and *Liriodendron tulipifera* (4%). Present in lower numbers than those genera stated previously, but still present in sufficient numbers to be mentioned, was a grouping of genera representing a single species each that are invasive to the Baltimore region: *Ailanthus altissima* (6%),

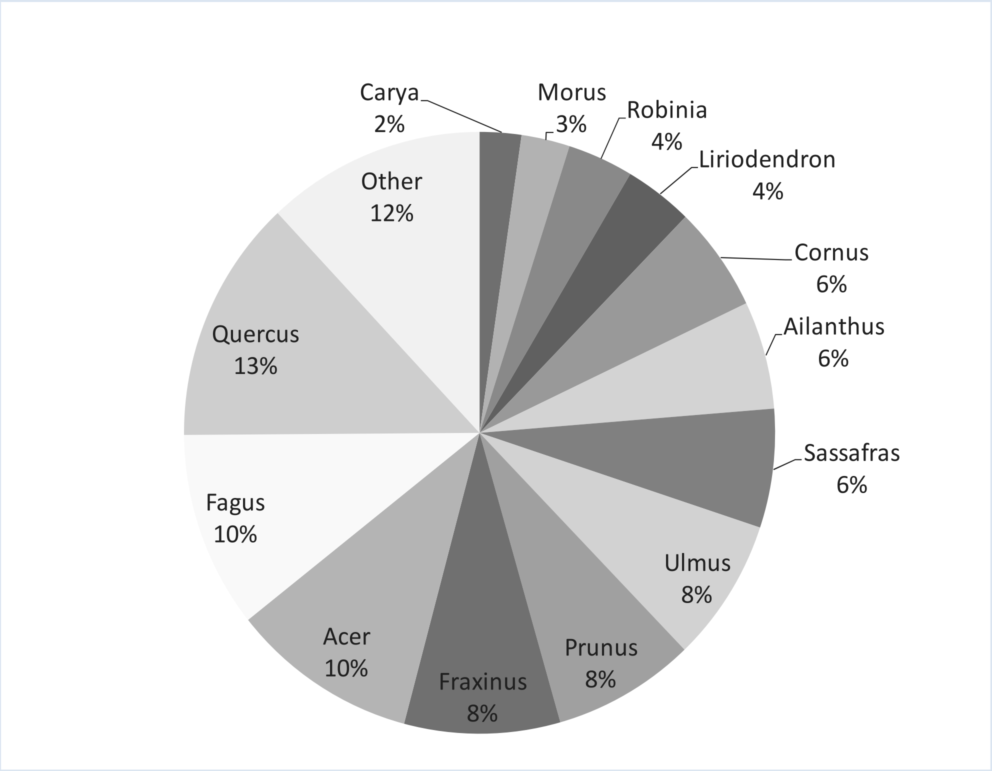


Figure 1. Relative proportions of genera surveyed in Baltimore, Maryland in 1999 as part of the UFORE survey.

Robinia pseudoacaia (4%), and *Morus alba* (3%). Finally, genera that were present in amounts less than 3% of the total tree sampling were compiled into the category labeled as "Other", with the exception of the genus *Carya*, representing 2% of the surveyed tree population and enumerated because it included several notable native species of hickory. The genera "Other" category, together accounting for 12% of the trees surveyed, included a wide range of exotic trees as well as less frequently encountered native trees such as *Asimina triloba* and *Cercis canadensis*.

A total of 48 tree species were identified in the survey (Table 1). In addition, there were 7 genera that could not be correctly identified to species level at the time of the survey or were in doubt at the time of data analysis.

Tree species prevalence

Of the 1503 individuals determined to be trees, 48 species were identified (Table 1). There were 123 trees that were labeled as unknown species and were not included in the analysis leaving 1355 trees.

Populations of *Fraxinus pennsylvanica* and *Fraxinus americana* were combined under the genus name, *Fraxinus*, as correct separation of the two species during the survey became suspect in analysis. Subsequent personal observations in the Baltimore region suggest that the large majority of this group were likely to have been *Fraxinus pennsylvanica*, therefore, *Fraxinus* has been included here with the individual species. *Fraxinus* accounted for 7.7% of the surveyed population, with 116 trees and an importance value of 23.6.

Fagus grandifolia, found less frequently than *Fraxinus*, was the most common individual species encountered with 144 trees, or 9.6% of all trees measured, resulting in an importance value of 22.7. *Quercus rubra* had notably fewer trees than the previously mentioned species with only 64 individuals. However, with a large

CODE	**Number of total trees**	**Number of plots species is found**	**Density (Num. of trees/acre)**	**Total basal area (ft^2)**	**Average basal area per tree (ft2)**	**Dominance (ft^2 per acre)**	**Import-ance Value**
Fraxinus species (*F. pensylvanica* and *F. americana*)	116	28	5.80	85.52	0.74	4.28	**23.61**
Fagus grandifolia	144	17	7.20	83.30	0.58	4.17	**22.66**
Quercus rubra	64	19	3.20	75.01	1.17	3.75	**16.58**
Liriodendron tulipifera	51	16	2.55	88.87	1.74	4.44	**16.21**
Prunus serotina	96	22	4.80	29.73	0.31	1.49	**15.32**
Ulmus species *(U. rubra* and *U. americana)*	83	21	4.15	41.00	0.49	2.05	**15.20**
Acer saccharinum	29	19	1.45	77.76	2.68	3.89	**14.31**
Morus alba	36	16	1.80	58.98	1.64	2.95	**12.27**
Ailanthus altissima	79	16	3.95	22.92	0.29	1.15	**11.93**
Quercus alba	54	13	2.70	48.11	0.89	2.41	**11.78**
Cornus florida	74	17	3.70	13.59	0.18	0.68	**10.93**
Robinia pseudoacacia	49	9	2.45	48.63	0.99	2.43	**10.46**
Sassafras albidum	87	9	4.35	11.33	0.13	0.57	**9.64**
Acer rubrum	40	18	2.00	21.49	0.54	1.07	**9.47**
Acer negundo	34	10	1.70	33.39	0.98	1.67	**8.17**
Prunus species (ornamental cherries)	14	12	0.70	19.61	1.40	0.98	**5.90**
Carya species	31	12	1.55	6.34	0.20	0.32	**5.86**
Quercus phellos	26	6	1.30	23.95	0.92	1.20	**5.68**
Quercus velutina	13	6	0.65	32.82	2.52	1.64	**5.59**
Nyssa sylvatica	35	7	1.75	5.51	0.16	0.28	**4.82**
Acer platanoides	21	10	1.05	7.20	0.34	0.36	**4.72**
Picea abies	16	6	0.80	19.04	1.19	0.95	**4.49**
Pinus strobus	17	7	0.85	15.44	0.91	0.77	**4.47**
Juniperus virginiana	9	3	0.45	24.00	2.67	1.20	**3.70**
Acer palmatum	7	6	0.35	17.14	2.45	0.86	**3.65**
Malus species	3	3	0.15	19.77	6.59	0.99	**2.86**
Magnolia species	3	3	0.15	18.19	6.06	0.91	**2.71**
Platanus occidentalis	8	3	0.40	13.55	1.69	0.68	**2.63**
Pyrus calleryana	9	6	0.45	4.41	0.49	0.22	**2.58**

CODE	Number of total trees	Number of plots species is found	Density (Num. of trees/acre)	Total basal area (ft^2)	Average basal area per tree (ft2)	Dominance (ft^2 per acre)	Import-ance Value
Acer saccharum	7	6	0.35	4.35	0.62	0.22	**2.43**
Carpinus caroliniana	13	5	0.65	1.08	0.08	0.05	**2.30**
Thuja occidentalis	7	5	0.35	5.53	0.79	0.28	**2.29**
Ulmus parvifolia	22	1	1.10	2.35	0.11	0.12	**2.07**
Quercus palustris	9	2	0.45	6.74	0.75	0.34	**1.80**
Quercus prinus	7	2	0.35	5.45	0.78	0.27	**1.53**
Catalpa speciosa	7	3	0.35	1.11	0.16	0.06	**1.37**
Celtis occidentalis	2	1	0.10	8.89	4.45	0.44	**1.25**
Salix x*chrysocoma*	1	1	0.05	9.62	9.62	0.48	**1.24**
Tilia americana	6	3	0.30	0.56	0.09	0.03	**1.24**
Populus deltoides	1	1	0.05	9.25	9.25	0.46	**1.21**
Ilex opaca	5	3	0.25	0.31	0.06	0.02	**1.14**
Juglans nigra	3	2	0.15	2.45	0.82	0.12	**0.95**
Quercus falcata	1	1	0.05	6.01	6.01	0.30	**0.90**
Hibiscus syriacus	4	2	0.20	0.63	0.16	0.03	**0.85**
Picea species	2	2	0.10	1.72	0.86	0.09	**0.81**
Liquidambar styraciflua	2	2	0.10	1.68	0.84	0.08	**0.81**
Hamamelis virginiana	7	1	0.35	0.38	0.05	0.02	**0.79**
Gleditsia triacanthos	3	2	0.15	0.16	0.05	0.01	**0.73**
Cercis canadensis	6	1	0.30	0.35	0.06	0.02	**0.72**
Tilia cordata	1	1	0.05	3.35	3.35	0.17	**0.64**
Cedrus libani	1	1	0.05	2.22	2.22	0.11	**0.54**
Quercus coccinea	2	1	0.10	1.25	0.62	0.06	**0.52**
Ostrya virginiana	2	1	0.10	0.17	0.08	0.01	**0.41**
Asimina triloba	2	1	0.10	0.02	0.01	0.00	**0.40**
Quercus acutissima	1	1	0.05	0.11	0.11	0.01	**0.33**

Table 1. The 48 identified species along with 7 genera found in the 1999 Baltimore UFORE survey along with the total number of trees found within each species and the number of plots where the species was found out of 200 plots. The Density for each species was calculated as the total number of trees within that species divided by the total survey area of 20 acres. The total basal area represents the sum of all trunks of all trees within that species calculated as ($\prod$*dbh^2/4). The average basal area per species was calculated as the total basal area divided by the total number of trees for each individual species in order to represent the average diameter of the species. The Dominance for each species was calculated as the total basal area divided by the total area of the plots (20 acres). The formula for the Importance Value is detailed in the Methods as the (Relative Frequency + Relative Density + Relative Dominance) and has a max value for each species of 300.

number of more mature trees, *Q. rubra* had a high combined basal area and a relatively high importance value of 16.6. *Liriodendron tulipifera*, commonly found as a dominant tree in Baltimore's canopy, also had a relatively large number of mature trees. *L. tulipifera* was found 51 times, only 3.4% of the surveyed trees, but with a combined basal area of 88.9 ft^2, the species had an importance value of 16.2. *Prunus serotina*, considered a "weedy", or undesirable native species, was also heavily present in the Baltimore area as 6.4% of the surveyed trees with 96 counts. The importance value of *P. serotina* was 15.3. *Ulmus,* consisting of *Ulmus rubra* and *Ulmus americana*, as was the case was *Fraxinus,* was left at the genus level as correct identification between the two species was in doubt after the survey was completed. Together, they represented with 83 individuals. *Acer saccharinum* had a relatively large importance value of 14.3 with only 29 individual trees, or 1.9% of the survey, indicating that there were a small number of large trees present. As further evidence, *A. saccharinum* had one of the largest average basal areas for a species with 2.7 square feet per tree on average compared with the average size of trees in the survey, which was only 0.8 square feet in basal area.

The few non-native species that accounted for large numbers of trees were *Ailanthus altissima* and *Morus alba* at 79 trees (5.3) and an importance value of 11.9 and 36 trees (2.4%) with an importance value of 12.3, respectively. *Robinia pseudoacacia* trees were found 49 times in the survey with an importance value of 9.94. *Robinia pseudoacacia*, while native to the western part of Maryland, is a non-native invasive species to the Baltimore region (Little, 1971).

Cornus florida, found both naturally and in the landscape, was found 74 times with a relatively lower importance value for the number of trees at 10.93, as these trees are normally smaller, with an average basal area of 0.2 square feet in this survey. *Sassafras albidum*, more commonly found in forested areas, had a large number of trees with 87 individuals, but was less frequent and more clustered, with only 9 plots containing the species.

Maples in the survey were found with similar statistics even if they generally have different niches in the urban forest. *Acer rubrum*, an adaptable species found in many conditions and used frequently as a street and landscape tree, was found 40 times resulting in an importance value of 9.47. While *Acer negundo*, a species more confined to wet and disturbed areas outside of the landscape, was found 34 times with an importance value 8.17.

Other notable species found in the survey were oaks and, with importance values in parentheses, these included *Quercus alba* (11.78), *Quercus phellos* (5.68), *Quercus velutina* (5.59), *Quercus palustris* (1.80), and *Quercus prinus* (1.53). Maple species, besides the ones already mentioned, included *Acer platanoides* (4.72), *Acer palmatum* (3.65), and *Acer saccharum* (2.43).

Evergreen species were not common and were represented by *Picea abies* (4.49), *Pinus strobus* (4.47), *Juniperus virginiana* (3.70), *Tsuga canadensis* (2.51), *Thuja occidentalis* (2.29), *Ilex opaca* (1.14) and *Cedrus libani* (0.54).

Several other tree species found in small numbers throughout the city were uncommon native species and select non-native desirable species sold in the nursery industry. A single *Quercus acutissima* was found resulting in an importance value of 0.33 for the species. Two native understory trees, *Asimina triloba* and *Ostrya virginiana*, were found with importance values of 0.40 and 0.41. Two trees of *Quercus coccinea,* as well as one tree each of *Cedrus libani* and *Tilia cordata,* were found in the landscape with importance values of 0.52, 0.54, and 0.64, respectively. *Cercis canadensis* and *Hamamelis virginiana*, sometimes found as a shrub or small tree, were found 6 and 7 times, respectively, with small trees averaging 0.06 and 0.05 ft^2 per tree in basal area.

Tree species origins

There were, by far, more native tree species found in the urban mosaic of land-use patches of Baltimore City than non-native species (Figure 2). As previously mentioned, exotic species are defined as those species that were not found natively in the Baltimore area prior to European settlement. Invasive plants are non-native and, by definition, are able to spread aggressively and cause environmental harm outside of their native ranges. Invasive species tend to thrive in cities, yet, were found in relatively low numbers as they accounted for only 13% of the surveyed tree population.

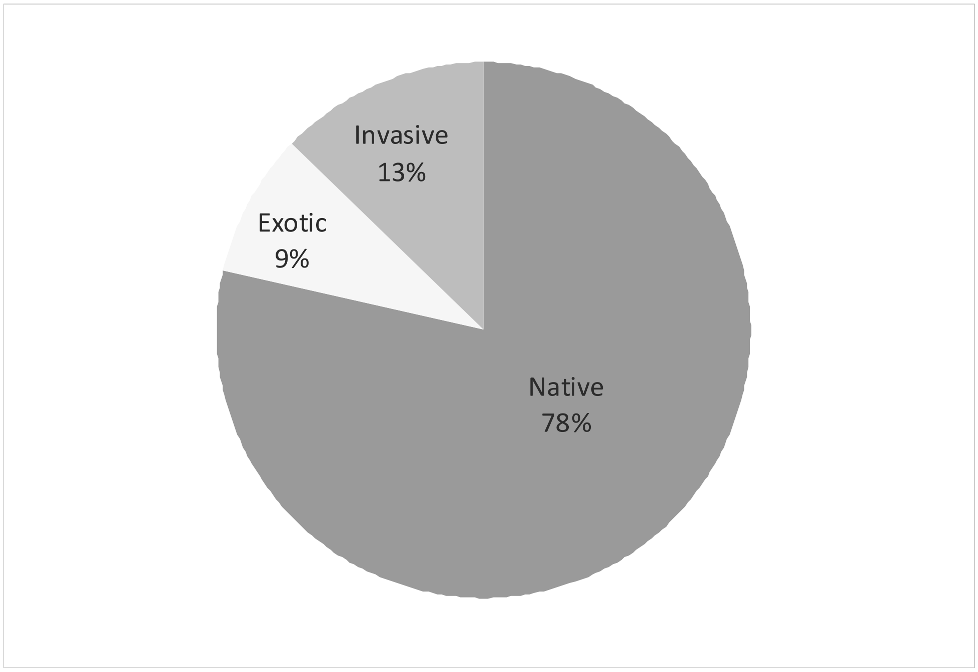


Figure 2. The relative proportions of the invasive, non-invasive exotic, and native trees identified to species level in the Baltimore UFORE survey.

Of those invasive species present, most of the trees were *Ailanthus altissima*, comprising 36% of the invasive species surveyed (Figure 3). *Robinia pseudoacacia*, as mentioned previously, is not native to the Baltimore region and, therefore, was treated here as an invasive plant. *R. pseudoacacia* was found to represent nearly one quarter of the invasive species present. *Morus alba* accounted for 17% of the invasive plants. In smaller amounts, *Ulmus parvifolia, Acer platanoides*, *Pyrus calleryana*, and *Quercus acutissima* were the only popular nursery and landscape species that accounted for a portion of invasive plants at 10%, 10%, 4% and less than 1% of the total number of invasive trees, respectively.

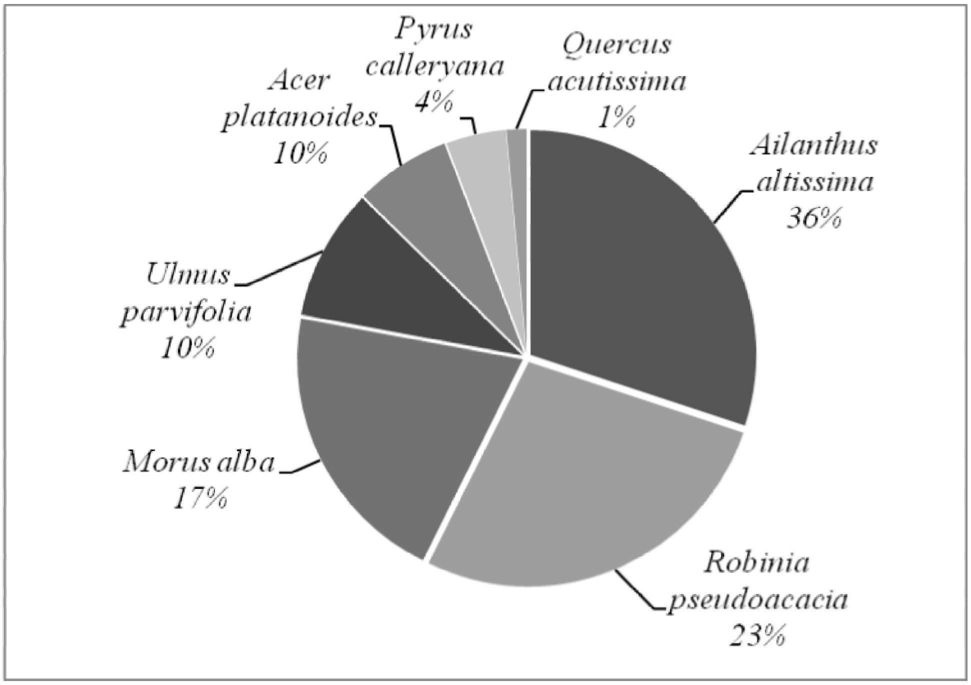


Figure 3. The relative proportions of trees by species that are considered invasive in the Baltimore, Maryland area found in the UFORE survey. Tree species codes can be found in Appendix 1.

Tree species frequency

In examining tree species frequency, *Fraxinus* (generally *Fraxinus pennsylvanica* as previously mentioned) was the most ubiquitous, appearing in 28 of the 200 plots (Table 1). *Prunus serotina* was found in 22 plots, the most for any individual species. Species commonly found naturally regenerating in the Baltimore region, as well as in the landscape, were present in a large number of plots and included *Quercus rubra*, *Acer saccharinum*, and *Acer rubrum*, found in 19, 19, and 18 plots each, respectively. Notable species also frequently encountered in a relatively large percentage of the 200 plots were *Fagus grandifolia* (17 plots), *Cornus florida* (17 plots), *Liriodendron tulipifera* (16 plots), *Ailanthus altissima* (16 plots), *Morus alba* (16 plots), and *Quercus alba* (13 plots).

Species found less frequently included a mix of trees with different origins. Several native species that can also be found sold in the landscape industry, but are generally uncommon in both instances, were *Cercis canadensis, Populus deltoides, Quercus falcata, Celtis occidentalis,* and *Hamamelis virginiana*, all found in a single plot each. Other rare native species that are generally only found naturally, and are rarely seen sold commercially, were *Ostrya virginiana* and *Asimina triloba* which were also found in single plots. Less prevalent trees that are found in the landscape trade were *Gleditsia triacanthos* (2 plots), *Hibiscus syriacus* (2 plots), and *Ulmus parvifolia* (1 plot).

Tree species prevalence across Baltimore City was also evaluated across land-uses. Only 6 of the 48 species were found to occur in 5 or more of the 9 designated land- uses. *Ailanthus altissima*, an aggressive invasive species, was found in 6 of the 9 land-uses (Table 2). The other 5 species, all found in 5 land-use categories were species native to Baltimore. These tree species included *Quercus saccharinum* and *Prunus serotina*, both more likely to be volunteer, or naturally regenerating, trees.

SPECIES	**NUMBER AND TYPE OF LAND-USES THAT SPECIES WAS ENCOUNTERED**	
Ailanthus altissima	6	Forested, High Density Residential, Industrial, Medium Density Residential, Open Urban, and Transportation
Acer rubrum	5	Forested, High Density Residential, Medium Density Residential, Open Urban, and Transportation
Acer saccharinum	5	Forested, High Density Residential, Medium Density Residential, Open Urban, and Transportation
Fraxinus species (generally *Fraxinus pennsylvanica*)	5	Forested, High Density Residential, Medium Density Residential, Open Urban, and Transportation
Prunus serotina	5	Bare Ground, Forested, High Density Residential, Medium Density Residential, Open Urban
Quercus rubra	5	Commercial, Forested, High Density Residential, Medium Density Residential, Open Urban

Table 2. A summary of the species found in 5 or more land-use classes and the land-use classes in which they were found as part of the UFORE analysis of Baltimore, Maryland.

Also included were *Acer rubrum* and *Quercus rubra*, two species that are found throughout the region naturally, in the landscape, and as street trees. Trees found within only one land-use are not shown as there was an extensive list of nineteen tree species mostly localized within either the forested or medium density residential sites. Included with these were generally those trees typically found only within forested interiors and are not commonly found in the nursery or landscape industries, such as *Asimina triloba* and *Nyssa sylvatica*.

Conversely, many of the trees only found within one land-use, the medium density residential class, were generally those trees that are not native to the

Baltimore area and are found here through nursery distribution. Species within this group included *Picea abies*, *Ulmus parvifolia*, and *Acer palmatum*, a species mentioned earlier as one of the species with a high number of individuals represented in the survey.

Land-use classifications of the plots

The largest proportion of plots was dedicated to residential areas. High Density Residential plots had the greatest number of plots surveyed with 49 plots and had a relatively low 14 trees per acre on the average (Table 3). Medium Density

Land-use class	Number of plots total	Number of plots with trees	Total number of trees	Number of trees per acre
Bare Ground	12	1	5	4
Commercial	15	4	4	3
Forested	28	28	871	311
High Density Residential	49	26	69	14
Institutional	11	2	4	4
Industrial	9	2	6	7
Medium Density Residential	43	37	135	31
Open Urban	23	13	230	100
Transportation	10	4	31	31

Table 3. Summary of land-use classes and the number of plots and trees within each of those classes from 200 plots surveyed as part of the UFORE analysis in Baltimore, Maryland. Number of trees per acre was calculated as the total number of trees in the land-use divided by the land area of that land-use (number of plots * 1/10 acre).

Residential plots, in comparison, with a similar number of plots of 43, had more than double the tree density with 31 trees per acre. The 28 Forested plots had a substantially higher tree density, as would be expected, with 311 trees per acre, over three times the next highest density of 100 for the 23 Open Urban plots. The Transportation plots had 4 of the 10 plots with trees and a combined tree density of 31 trees, rivaling that of the Medium Density Residential plots. Only 2 of the 9 Industrial plots had trees with 4 trees per acre, while the 4 of 15 Commercial plots that had trees averaged out to 3 trees per acre. The remaining land-uses, Institutional and Bare Ground, were similar in number of plots and in tree density with 4 trees per acre.

Tree species diversity within land-use classifications

A full recording of species by land-use classification can be found in Appendix 2. An annotated version of this table has been included in Table 4 for convenience that lists the 5 most common species of the residential, Forested, Open Urban, and Transportation plots.

The 37 Medium Density Residential plots with trees included trees originating from nurseries as well generally undesirable species to use in the landscape. Some of the most frequently encountered trees within this land-use were popular evergreen landscape trees, such as *Picea abies* with 11.9% and *Tsuga canadensis* with 5.9% of the trees within these Medium Density Residential plots. Deciduous trees popular in the landscape were *Acer palmatum* (5.2%), *Cornus florida* (3.0%), and ornamental *Prunus* species, found in respectable numbers with 1.5%. Also found were most

LAND-USE	SPECIES	NUMBER OF TREES	PERCENTAGE OF LAND-USE TOTAL
High Density Residential	*Ailanthus altissima*	14	20.3%
	Acer saccharinum	8	11.6%
	Morus alba	7	10.1%
	Acer rubrum	6	8.7%
	Quercus prinus	4	5.8%
Medium Density Residential	*Picea abies*	16	11.9%
	Acer saccharinum	12	8.9%
	Fraxinus spp.	9	6.7%
	Prunus serotina	9	6.7%
	Tsuga canadensis	8	5.9%
Forested	*Fagus grandifolia*	143	16.4%
	Sassafras albidum	83	9.5%
	Cornus florida	67	7.7%
	Prunus serotina	65	7.5%
	Fraxinus spp.	63	7.2%
Open Urban	*Fraxinus* spp.	40	17.4%
	Robinia pseudoacacia	28	12.2%
	Ulmus parvifolia	22	9.6%
	Quercus alba	20	8.7%
	Ulmus species	19	8.3%
Transportation	*Ailanthus altissima*	19	61.3%
	Fraxinus species	2	6.5%
	Ulmus species	2	6.5%
	Acer rubrum	2	6.5%
	Quercus phellos	2	6.5%

Table 4. A listing of the 5 most prevalent tree species found within 5 of the most populated land-use classes in the 1999 Baltimore UFORE survey. A complete listing of species found within land-uses can be found in Appendix 2.

likely volunteer trees that were allowed to persist: *Acer saccharinum* was highly prevalent with 12 trees (8.9%), *Prunus serotina* (6.7%), and *Ailanthus altissima* had 6 individuals in the survey and 4.4% of the trees in this land-use. Species that could either have been planted or have germinated naturally as they are native species included 9 *Fraxinus* trees (6.7%) and 4 *Ulmus* trees (3.0%).

High Density Residential plots, generally less maintained and less planted with "luxury" species when compared with Medium Density Residential plots, were composed of undesirable native and invasive tree species more so than of planted landscape trees. *Ailanthus altissima* was present in the greatest numbers across these plots with 14 trees and 20.3% of the trees counted within this land-use. *Acer saccharinum* and *Morus alba* were the next most common tree species with 11.6% and 10.1%, respectively. As with the Medium Density Residential plots, there were several tree species that are native regenerating species and are also sold in the landscape industry: *Acer rubrum* (8.7%), *Fraxinus* species (2.9%), and *Quercus rubra* (2.9%). Other tree species most likely planted, but could also possibly be volunteer species, were a few to several trees each of *Pyrus calleryana* (4.3%) and *Cornus florida* (2.9%).

As expected, there were more trees in the land-use type designated "Forested" than in any other land-use class. *Fagus grandifolia* was the most prevalent tree by nearly 2:1 over the next species with 143 individuals, or 16.4% or the trees within this land-use. *Sassafras albidum* was second with 9.5% of the trees, although the vast majority of these were a single densely populated Forested plot along Hilton Avenue. Common native forest trees found throughout the plots with similar numbers of individuals (between 50 and 70) included *Fraxinus* at 7.2%, the understory species *Cornus florida* at 7.7%, as well as the light-obligate *Prunus serotina* (7.5%), and the dominant canopy species, *Liriodendron tulipifera* (5.7%). Only one invasive species was present in numbers in the Forested plots worthy of mention, and this was *Ailanthus altissima* with 32 individuals at 3.7% of the Forested trees.

Open Urban plots contained markedly different species than the Forested plots as there were generally more disturbed conditions and edge effects that have determined tree species composition. *Fraxinus*, consisting largely of *Fraxinus pennsylvanica*, was the most common Open Urban tree with 40 individuals and 17.4% of the total tree count within this land-use. Edge species that were present in large numbers included *Robinia pseudoacacia* (12.2%), *Prunus serotina* (7.4%), *Morus alba* (6.1%), and *Ailanthus altissima* (1.7%). *Ulmus parvifolia,* with 9.6% of the trees, was found in a single plot. *Quercus alba*, found 20 times in these plots, was 8.7% of the trees.

Transportation sites, or plots located adjacent to major highways or median strips, were dominated by *Ailanthus altissima* with 19 total trees, or 61.3% of the trees in this land-use. There were several species represented by only by 2 individuals, representing 6.5% of the trees that may have been planted as street trees: *Fraxinus* species, *Quercus phellos*, *Prunus* species, *Acer platanoides*, and *Acer rubrum*.

Not illustrated in Table 4 were land-use classes with less than five tree species each. Bare Ground sites consisted of 1 plot with trees comprised of 3 naturally regenerating native species with a total of 5 individual trees. These species within the single treed Bare Ground plot were *Prunus serotina*, *Liquidambar styraciflua*, and *Sassafras albidum*. Two Institutional plots contained a total of 4 individuals encompassing 3 commonly sold landscape industry species of *Pyrus calleryana*, *Pinus strobus*, and flowering *Prunus* trees. Four Commercial plots each contained a single tree and single unique species with *Acer platanoides*, *Acer saccharum*, *Pyrus calleryana*, and *Quercus rubra*. And, finally, two industrial sites collectively contained *Ulmus* species, *Ailanthus altissima*, and *Quercus acutissima* trees.

With the exception of the Forested land-use class, all other land-use classes had plots without tree species (Table 5). An Open Urban plot, a densely packed regenerating edge stand, had the greatest number of trees with 105 trees counted. The greatest number of trees found within a Forested plot was 76 trees. The Institutional and Commercial plots were the least canopied with a maximum of 2 trees and 1 tree each.

The Medium Density Residential plots as a whole had the greatest richness with 35 tree species out of 48 total species found in Baltimore, followed closely by the Forested plots with 33 species. Open Urban plots and High Density Residential plots each had relatively intermediate richness values with 25 and 22 species, respectively. The remaining land-use classes all had richness values below 10 with Industrial, Institutional, and Bare Ground plots all having a richness of 3.

Tree species evenness, a measure of species distribution equity across plots, was a value of 1 for the Commercial plots as there were 4 species with 1 individual each. Institutional plots had the second highest evenness with a value of 0.946.

Transportation plots collectively had the lowest evenness value with 0.660, largely due to the overwhelming number of *Ailanthus altissima* trees.

Land-use	Minimum trees per plot	Maximum trees per plot	Richness	Evenness	Shannon's Diversity	Simpsons Diversity
Bare Ground	0	5	3	0.865	0.95	0.56
Commercial	0	1	4	1.000	1.38	0.75
Forested	2	76	33	0.841	2.94	0.92
High Density Residential	0	7	22	0.889	2.74	0.91
Industrial	0	5	3	0.921	1.01	0.61
Institutional	0	2	3	0.946	1.04	0.62
Medium Density Residential	0	13	35	0.908	3.22	0.94
Open Urban	0	105	25	0.829	2.67	0.91
Transportation	0	21	9	0.660	1.45	0.60

Table 5. Measures of tree species richness and diversity across 9 land-use classes surveyed during the 1999 Baltimore UFORE survey.

When the land-uses were compared across plots, the highest diversity indices were found in the Medium Density, Forested, and High Density plots with Shannon's diversity indices of 3.22, 2.94 and 2.74, respectively (Table 5). The land-use types with the lowest diversity values were the Industrial, Institutional, and Commercial land-use plots, although the Commercial plots had a higher Shannon's Diversity Index (1.38) than the other two classes with values around 1. Understandably, the Bare Ground sites had the lowest diversity as only one plot had three species resulting in a Shannon's diversity index of 0.95. Simpson's Diversity Index, interpreted as a probability of encountering a species again in an area, is included in the data set as it is more intuitive. The index and the relative rankings are not discussed as results were similar to the Shannon's Diversity Index.

Detrended correspondence analysis of tree species across land-uses

A DCA ordination (Figure 4) was used to examine possible environmental gradients influencing tree species distribution based on land-use classification. The total variance accounted for in the species data, or the inertia, was 9.196. There are no significance tests associated with DCA to report.

In a DCA scatterplot, Axis 1 explains the principal sources of compositional variation while higher order axes explain progressively less of the variation. As a modified reciprocal averaging ordination, environmental gradients affecting the species compositional response, or other factors, may be indicated by positioning along Axis 1. In essence, species that are found in similar habitats should be found within close proximity along Axis 1, while plots that are similar in tree composition should be grouped in a similar fashion. If Hypothesis 1 is correct and plots of the same land-use contained similar species, then there should be a clear pattern of plots being arranged by land-use, clustered horizontally along Axis 1.

In this analysis, however, the distribution of plot scores across the first axis yielded no obvious visual pattern of plots clustering based on land-use classification. The large amount of overlap of land-uses along Axis 1 (Figure 4A) indicated that either contrasting environmental or management conditions that would be assumed to

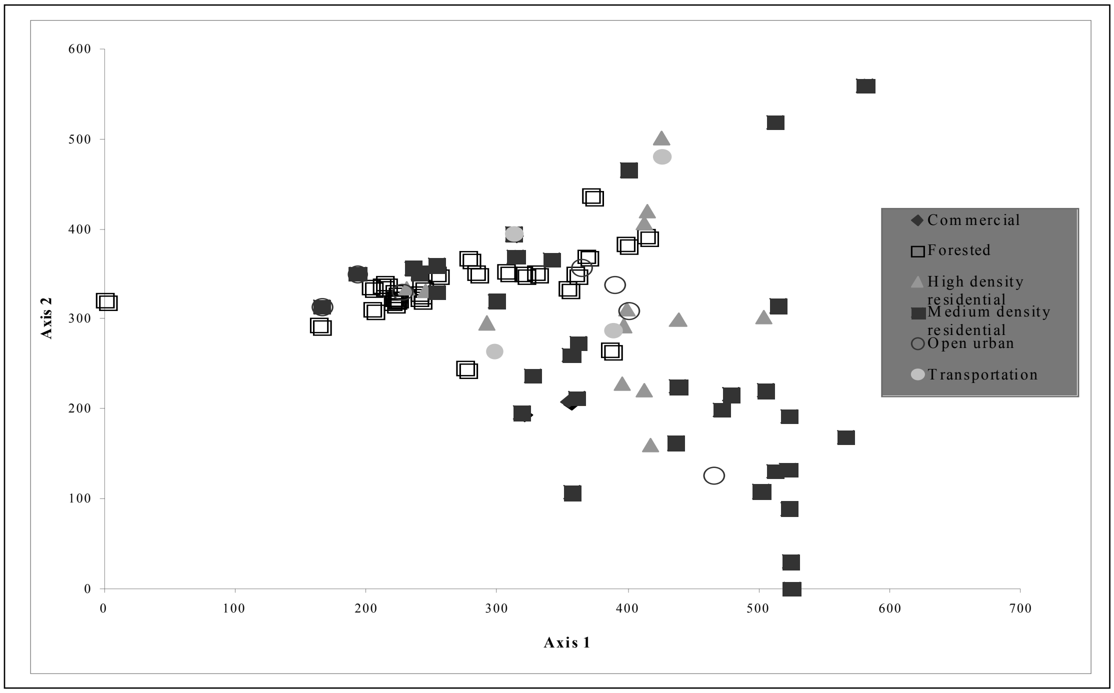
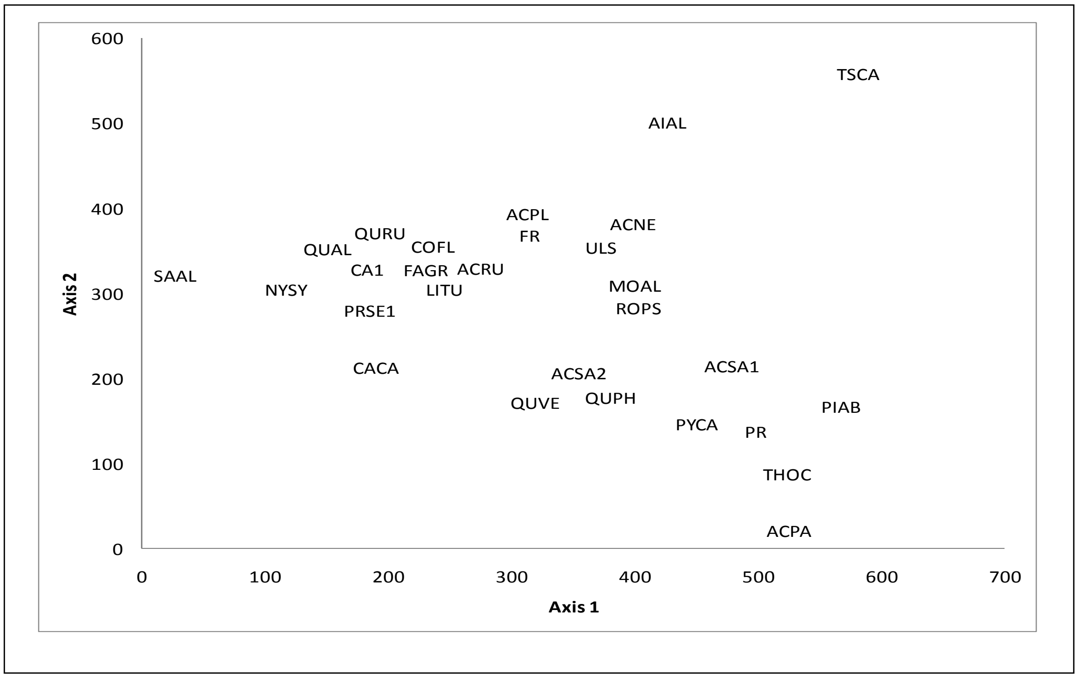


FIG. 4a and 4b. A Detrended Correspondence Analysis ordination graph of the vegetation data from the UFORE survey of Baltimore, MD in 1999. The first two axes DCA ordination axes from PCORD Version 4.41. Axes are scaled in 100 3 SD beta diversity units (Hill and Gauch, 1980). (A) Sample scores for 100 plots within 6 land-use types. (B) Species scores for 28 tree species (see App. 1).



characterize the different land-uses does not appear to explain tree species distribution or that the cityscape is too homogenized across land-uses to produce discrete compositional groups.

Perhaps the only exception was Medium Density Residential plots, which appear to cluster slightly at the right hand side of Axis 1 around the score of 500 standard deviation units. This may be due to the presence of a number of unique exotic species that were planted by homeowners that could not be found elsewhere in other land-uses as they do not naturalize in the area.

Tree species scores within this ordination (Figure 4B) may, however, present a slight pattern indicating that there a possibility that land-use classification may partly explain tree species distribution. There was a general grouping of tree species towards the left side of Axis 1 that are usually almost exclusively found in forested areas including *Fagus grandifolia*, *Liriodendron tulipifera*, *Carpinus caroliniana*, and *Nyssa sylvatica*. There was also a second clustering of species found generally only within planted landscapes in the Baltimore region that can be found to the far right section of axis 1 including *Acer palmatum*, *Thuja occidentalis*, and *Picea abies*. A third clustering of species generally confined to the edges of forests, disturbed areas, roadsides, and fenced yards can be found in between the two mentioned previously groups. These disturbed and edge-site dwelling species consisted of *Robinia pseudoacacia*, *Morus alba*, and *Ailanthus altissima*. Two outlying species were *Sassafras albidum* and *Tsuga Canadensis*.

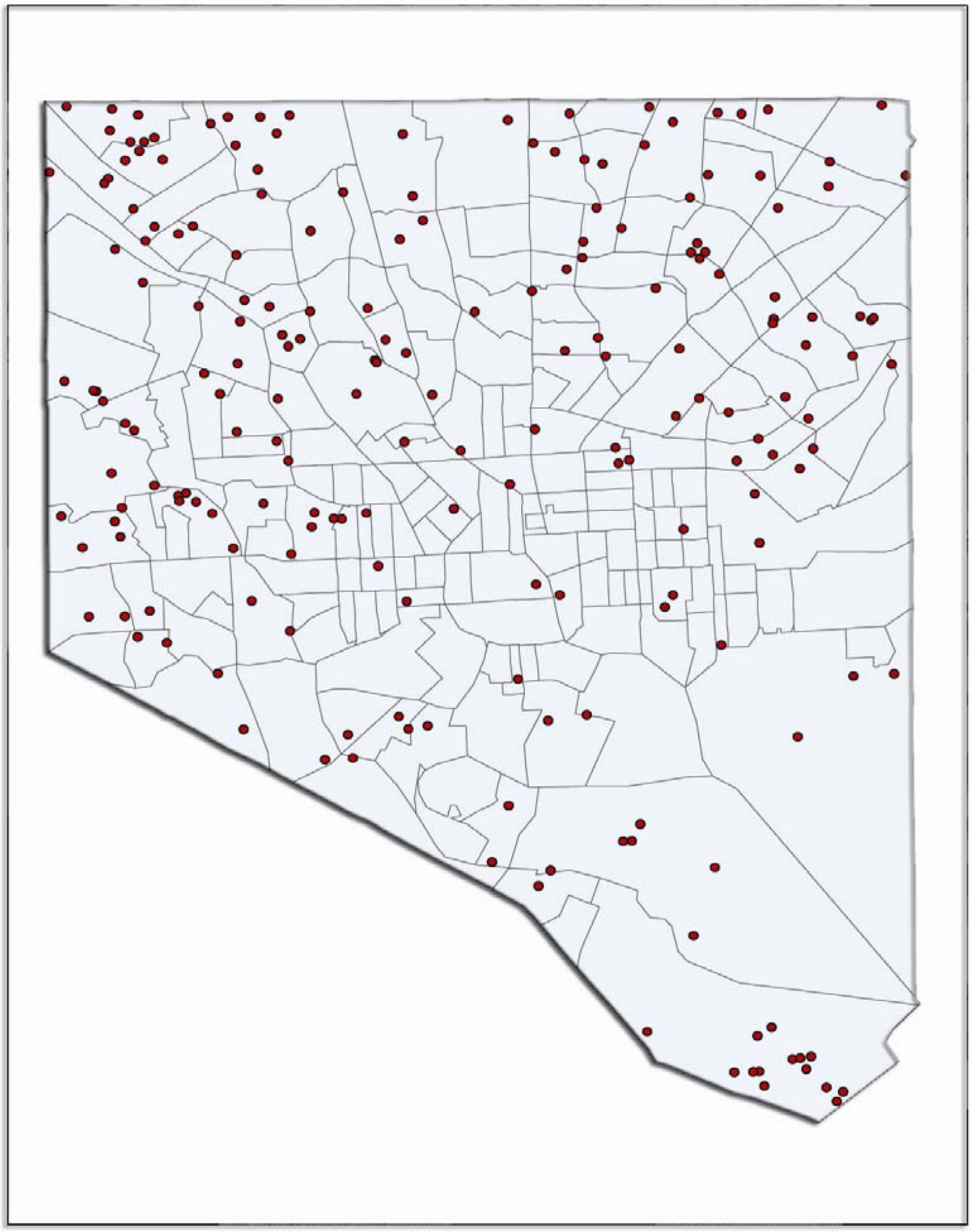


Figure 5. A map of Baltimore City's census tracts used in the 2000 US Census and the corresponding locations of the 200 plots from the 1999 UFORE vegetation survey.

The relationship between socioeconomic variables and tree species composition

Canonical correspondence analysis was utilized in order to evaluate the correlation of social economic factors and non-natural environmental factors with the distribution of tree species. Data was taken from the 2000 United States Census based on data for census tracts to represent plot socioeconomic data with the assumption that census tracts are relatively small, homogenous areas that are comparable for statistical purposes (Figure 5).

2000 Census Bureau Data Variable	**Range Present in Baltimore City**
Population Density	1.6 - 41.4 people per acre
Median Household Income	$11,840 - $71,771 per year
Percent Vacant Housing	0 - 30%
Median Age of Structure on Property	27 - 68 years
Percent Impervious Surface on Plot	0 - 100%

Table 6. Variables used in canonical correspondence analysis taken in the 2000 United States Census of Baltimore City, MD

The first canonical correspondence analysis was run using socio-economic variables from the 2000 Census (Table 6). Variables in this analysis related to the tree species abundance matrix included: population density, median annual household income, and percent vacant housing (Table 6). The locations of the plots, represented by triangles on a CCA scatterpoint graph, indicate the environmental characteristics of the plot and the positions of the species on the plot, represented by both plus signs and the species codes, indicate the relationship of the variables and the tree species. Plot locations spatially reflect similarities in species composition and in environmental variable values (Jongman, 1987).

In the ordination biplot, variables are represented by vectors shown as arrows on the plot. The magnitudes of the arrows indicate importance of the environmental variables in accounting for the variation in species composition within the plots. Visually, the CCA graph of the census information of the plots (Figure 6) shows short arrow lengths that encompass only a fraction of the plots in the ordination and do not appear to be important in explaining tree species distribution. The direction of the arrow indicates the correlation of the variable with the axes and with other variables, with smaller angles between vectors and axes indicating closer association. By direction, Population Density and Median Household Income were not correlated. Percent Vacant Housing did not appear on the biplot as it was not important in the first two axes.

The total variance or inertia, or the total amount of variability in the community matrix that could potentially be explained, was 12.5359 with 3 canonical axes interpreted. Eigenvalues represent the variance in the community matrix accounted for by each axis as well as the correlation of the species scores and the site scores with a value near 1 indicating a strong relationship. As expected, the eigenvalue was greatest for the first axis at 0.321, and then decreased for the second and third axes at 0.252 and 0.160, respectively.

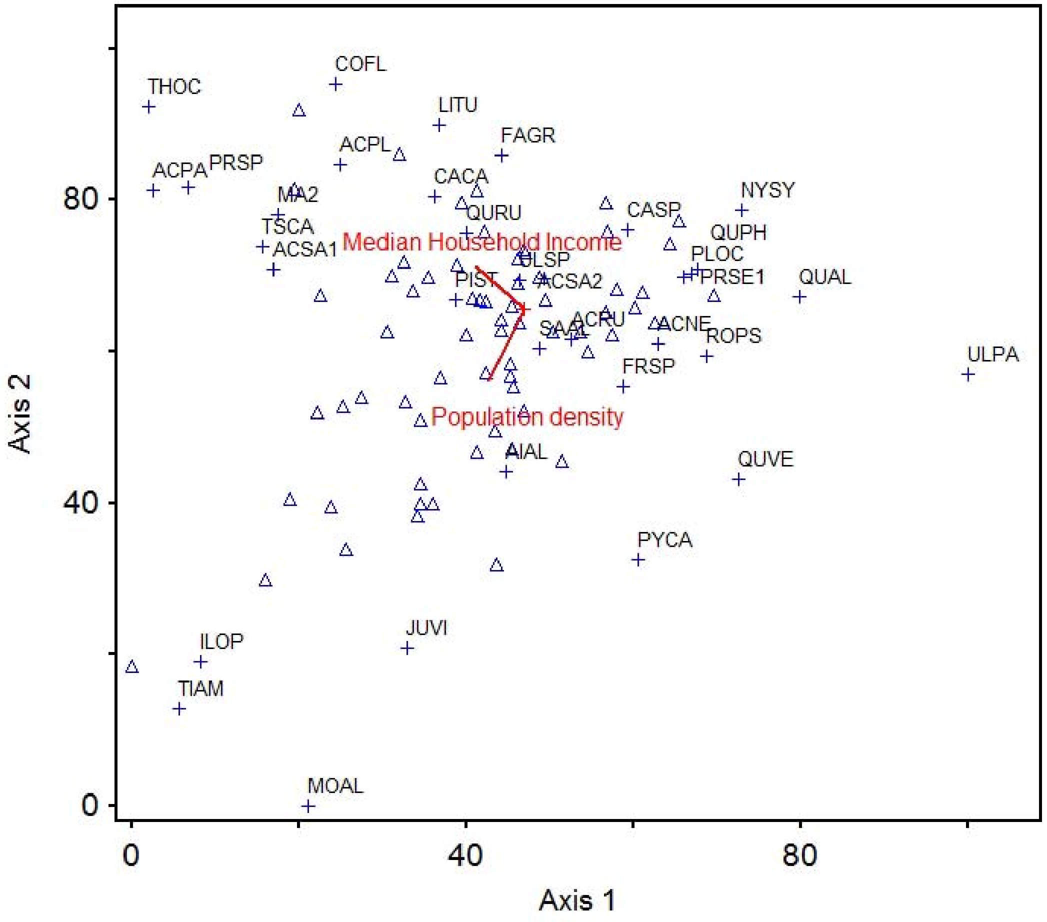


Figure 6. Canonical correspondence analysis biplot of 2000 Baltimore City Census Data figures for Population Density, Median Household Income, and Percent Vacant Housing. The symbols are as follows: Δ represent plots, + represent tree species.

Table 7 shows the canonical coefficients and the correlation coefficients, or the intraset correlations. The canonical coefficients are the correlations between the variables and the species scores, representing the contributions of individual variables (McCune and Grace, 2002). The intraset correlations are the correlations between the variables and the axes, indicating the importance of each variable in the ordination. The first axis was defined by Median Household Income, but the other two variables were almost of similar significance with regards to axis 1, indicating that there was no clear overriding factor accounting for variation among the variables. We can also infer from the differences in importance values that the areas with lower median household incomes have a high percentage of vacant housing. The second axis was defined clearly by Population Density and the third axis that was not shown in the biplot was defined by Percent Vacant Housing.

	Canonical coefficients		**Correlation coefficients**	
	Axis 1	Axis 2	Axis 1	Axis 2
Population density	-0.369	-0.370	-0.385	-0.919
Median household income	-0.562	0.216	-0.541	0.555
Percent vacant housing	0.401	0.107	-0.240	0.069

Table 7. Canonical coefficients (standardized) and correlation coefficients (intraset correlations) of the 2000 US Census socioeconomic data variables with the first two axes of CCA.

The relationships between environmental factors and species composition can be tested using Monte Carlo permutation with 999 runs employed at the 5% significance level (Ter Braak and Smilauer, 2002). The Monte Carlo permutation test will test the significance of the first axis eigenvalue (ter Braak, 1990). The first hypothesis will test the null hypothesis that there is no linear relationship between matrices, or in other words, that the community composition is unrelated to the environmental variables. The Monte Carlo tests for this analysis had a p-value of 0.1790, indicating that the variance is not explained by these variables. Also, the Species-Environment Correlation had a non-significant p-value of 0.2770, therefore, the matrices are not correlated and sites with the same social economic factors do not have the same species. Correlates are not discussed as there was no relationship found.

As some of the land-uses may not be sensitive to socioeconomic impacts on tree species composition and may confound the results of those that are, a secondary CCA was utilized with data solely from the residential plots. Medium Density and High Density Residential vegetation data was entered separately as the main matrix along with the same census information as above. For this analysis, trees that occurred in more than 3 plots and with more than 4 total individuals, totaling 21 species within 56 plots, were included.

The joint biplot again shows arrows that are short of encompassing all of the sites (Figure 7). Unlike the previous analysis, the variable percent vacant housing appears on the biplot. The total variance in the species data was 10.7017 with 3 canonical axes. The eigenvalue of the first axis was 0.472 and accounted for 4.4% of

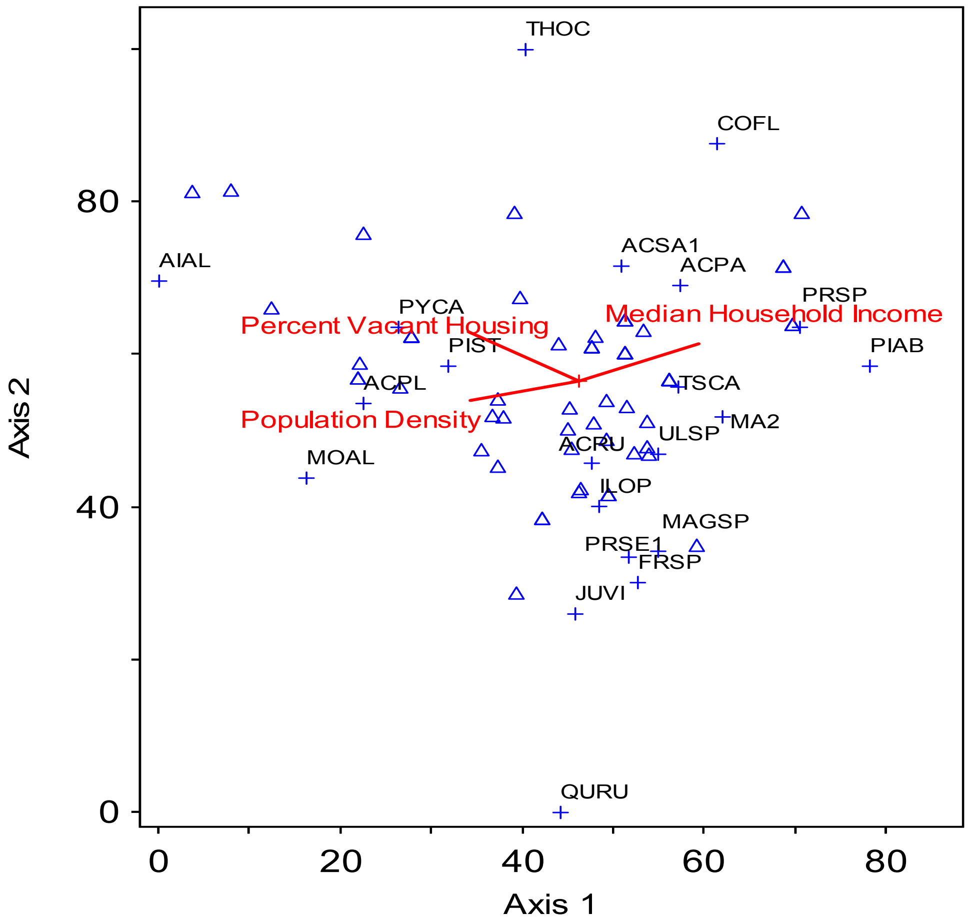


Figure 7. Reduced canonical correspondence analysis biplot using High Density and Medium Density Residential plots with the 2000 Baltimore City Census Data figures for Population Density, Median Household Income, and Percent Vacant Housing. The symbols are as follows: Δ represent plots, + represent tree species.

the variance explained by this analysis. The first axis was explained by Median Household Income, while the second axis, unlike the previous analysis with all land-uses, was explained by Percent Vacant Housing.

The first hypothesis test of the Monte Carlo results had a significance of 0.0420 and the variance summarized by the first axis could be meaningfully interpreted. The second test showed that there was not a significant relationship between the species compositions and the socioeconomic data with a p value of 0.1910. Therefore, socioeconomic factors alone could not account for the variance in data in the residential plots.

The relationship between anthropogenic environmental variables and tree species composition

A canonical correspondence analysis was performed with the species matrix using the non-natural environmental factors median age of structure and percent impervious surface cover. Median age of structure on property, taken from data from the 2000 US Census, is used here as an indication of the last time that a construction disturbance occurred on the plot. For example, newer residential developments on the edges of the city could be expected to have had recent major land-clearing projects, whereas residential developments constructed earlier in the century or prior may have less disturbed landscape areas. Percent impervious surface of the individual plots was taken directly from the survey data and indicates the amount of concrete, paved roadways and driveways, and building. The average percent of impervious surface by land-use is shown in Table 8.

Land-use	**Avg % imp. surface**
Commercial	76%
Industrial	64%
High Density Residential	61%
Institutional	50%
Transportation	44%
Medium Density Res.	44%
Open Urban	22%
Forested	10%
Bare Ground	0%

Table 8. The average percent surface impervious cover calculated from groundpoints for each land-use of the 200 plots counted in the Baltimore, MD UFORE vegetation survey.

The biplot indicated that there was no correlation between the two variables as their directions were nearly perpendicular and the correlation among the variables was very low (Figure 8); the weighted correlation being -0.027 (data not shown). The environmental variables are related to the first axis fairly well (Table 9), and are poorly related to the second axis. The first axis is defined by percent impervious surface cover (Table 10) and the second axis is defined by median structure age on

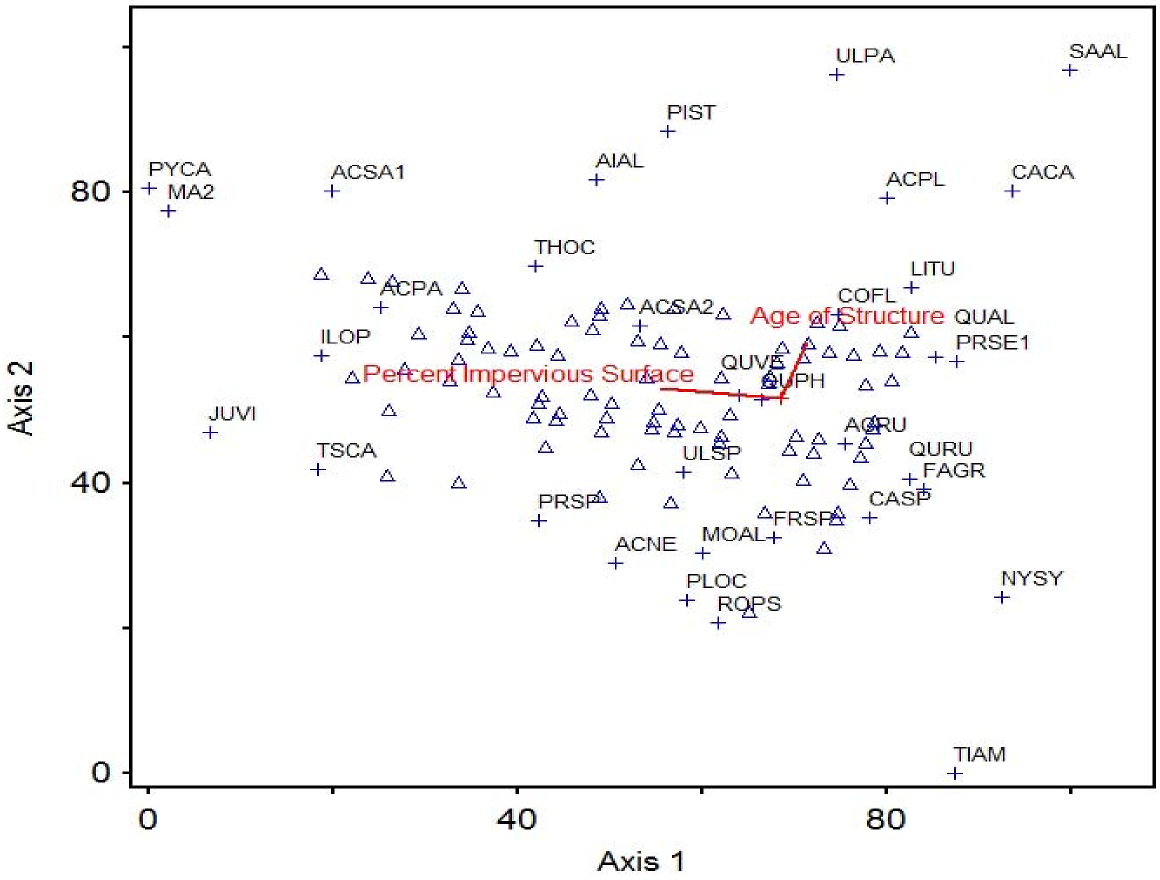


Figure 8. Canonical correspondence analysis of 2000 Baltimore City Census Data figures for Median Age of Structure and Percent Impervious Surface of the pot. The symbols are as follows: Δ represent plots, + represent tree species.

	Axis 1	**Axis 2**
Eigenvalue	0.401	0.128
Variance in species data % explained	3.2	1.0
Pearson Correlation, species-environment	0.33	0.506

Table 9. Eigenvalues and Pearson Species-Environment correlation coefficients for the first two axes of the CCA analysis of tree species abundances with anthropogenic environmental coefficients.

property. The total variance, or inertia, of the species data was 12.536, and the percent variance explained for the first axis was 3.2%.

A Monte Carlo Test did indicate a significant result with the Eigenvalue having a p-value of 0.0100 and the Species-Environment Correlation with a p-value of 0.0300. The hypothesis of no relationship between the species data and the environmental data is rejected as the eigenvalue for the first axis, representing the variance in the community matrix accounted for by the first axis, is much higher than expected by chance. Percent Impervious Surface Cover was apparently more of a factor in this significant result as the canonical coefficients for this variable was -0.983 with Axis 1 and Median Age of Structure was only 0.209 for Axis 1 (Table 10). This indicates that some of the variance can be explained by the amount of

	Canonical coefficients		**Correlation coefficients**	
	Axis 1	Axis 2	Axis 1	Axis 2
Percent Impervious Surface over	-0.620	0.075	-0.983	0.183
Median Age of Structure on Property	0.116	0.352	0.209	0.978

Table 10. Canonical coefficients and intraset correlations of anthropogenic environmental variables with the first two axes of CCA.

impervious surface cover on the plots, essentially describing the degree of urbanization, and that plots with similar amounts of impervious surface cover had similar species.

This can be seen with the species denoted on the biplot (Figure 8). Species at the opposite end of the arrowhead of percent impervious cover are those that would likely be found in plots with little impervious surface. These species include a variety of species generally confined to forested environments, such as *Fagus grandifolia*, *Nyssa sylvatica*, and *Carya* species. While species at the opposite end, such as *Ailanthus altissima*, *Pyrus calleryana*, and *Acer saccharinum,* are species typically found near areas of high percentages of impervious groundcover.

The impact of soil properties on tree species compositions

Forested area species composition is influenced by both natural and anthropogenic factors. This study has focused primarily on anthropogenic-based urban ecological concepts, however, more traditional forest environment ecological principles could influence species assemblages in urban environments. With permission to access soil data collected in 2002 on many of the UFORE sites provided by the USDA Forest Service, 22 Forested plots with complete soil data were used in a canonical correspondence analysis along with 26 species and 7 soil variables, including: bulk density, texture (represented by percent sand), pH, organic matter content, and the nutrients phosphorous, potassium, and calcium (Figure 9).

The total variance in the species data accounted for by the data was 4.9856 with 3 canonical axes. The eigenvalue of the first axis was 0.598 with 12% of the variance accounted for by the analysis. The Monte Carlo test for the eigenvalues resulted in a p of 0.278. The Monte Carlo test for the species-environment correlation was 0.3470 indicating that the soil data used did not account for the variation in tree species distribution.

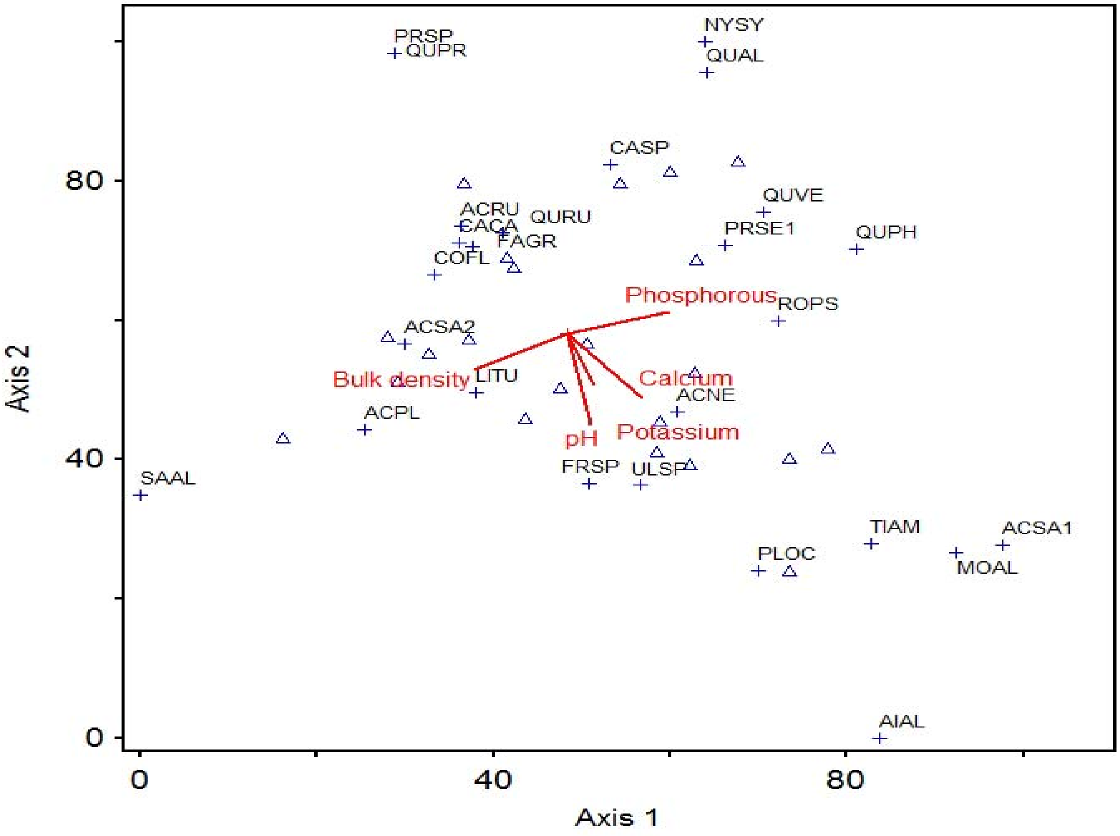


Figure 9. Canonical correspondence analysis of soil properties taken in 2002 by the USDA Forest Service in select Forested Baltimore City UFORE plots. The symbols are as follows: Δ represent plots, + represent tree species.

Chapter 4: Discussion

The history of dominant trees in Baltimore

Just prior to European settlement, the Eastern Deciduous Forest stretched from Maine to Florida, dominated by broadleaf species of *Ulmus*, *Castanea*, and *Quercus*, with a small number of coniferous species interspersed (Barnes, 1991). Baltimore, Maryland, straddling the two physiographic provinces of the Atlantic Coastal Plain and the Piedmont, was the meeting of two vast forests: the Northern pine-oak forest and the oak-hickory forest (Kricher, 1998).

On the eastern side, from the fall line to the Atlantic Ocean, the Coastal Plain is an area dominated by low elevation and exists as an underlying material of unconsolidated sediments including sand, silt, clay, and gravel, over crystalline bedrock. Conditions vary throughout the area with wetlands and impervious fragipan as well as well-drained gravel sites (Brush et al., 1980). Pre-European vegetation was dominated by pitch pine, Virginia pine, and Eastern red cedar over highbush blueberry and mountain laurel.

To the west, the Piedmont extends from the fall line to the Catoctin Mountains. The Piedmont soils consist of older igneous and metamorphic rock, including gneiss, schist, and serpentine (Brush et al., 1980). Nut producing trees historically dominated at the time of European settlement and included Northern red, black, chestnut, and white oaks, as well as mockernut, pignut, shagbark and bitternut hickories, along with tulip trees, American beech, red maples, boxelder, ironwood, sassafras, and flowering dogwoods. *Castanea dentata*, or American chestnut, once dominated the forests in Baltimore and to the north, but was decimated in numbers in the early part of the twentieth century as the result of the introduction of chestnut blight (*Cryphonectria parasitica*).

Trees in Baltimore today

The unbroken forest of these trees present in Baltimore several hundred years ago is now a complex landscape, comprised of patches of residential property, commercial sites, industrial areas, and new and remnant forest patches, each with a unique history. Settlement and development led to a redesigned landscape and redefined species dominance in the region. Those native trees that could adapt to, or at least tolerate anthropogenic alterations as well as new species imported for aesthetic and commercial reasons began to dominate the region.

This study revealed that many native species that were historically present such as *Quercus*, *Acer*, and *Fraxinus* had survived Baltimore's drastic land alterations, and in fact, were still dominant in the landscape over imported species. All three of these genera contain species that are common in the forested sections of Baltimore as native, regenerating trees in a variety of site conditions. There are also species within each genus that are commonly used as landscape trees and quite frequently as street trees, such as *Fraxinus pennsylvanica*, *Acer rubrum*, and *Quercus rubra*. Genera of moderate presence levels, such as *Sassafras*, *Liriodendron*, and *Ulmus*, were found almost exclusively as forested trees and were rarely seen in the landscape unless a volunteer tree remained, commonly near the property boundary or fence's edge.

Fagus grandifolia was found to be the most dominant species in the Baltimore landscape, even though it does not typically do well in developed areas. The root system of *F. grandifolia* is typically shallow in the soil profile and does not tolerate disturbed or compacted soils with less than 10-15% oxygen (Dirr, 1998). In addition, the species has a large taproot, making it difficult to transplant and a poor choice as a nursery tree (Dirr, 1998). *F. grandifolia* was, therefore, found almost exclusively in forested locations within the city with only a single tree found in a High Density Residential site that likely contained forested area before development. The high number of individuals found for this species and that only 28 of the 200 plots were Forested indicates that *F. grandifolia* was highly prevalent throughout the Forested sites.

Fraxinus was not identified to species level in this analysis, but the two representative species found in the Baltimore region, *Fraxinus pensylvanica* and *Fraxinus americana*, were both found naturally and used in the landscape. Many of the individuals in this study have been assumed to be *F. pensylvanica* from personal observation and from the adaptability differences between the two species. *F. pensylvanica* is the most widely distributed of the American ashes (Dirr, 1998). A facultative wetland species, it is typically found along moist bottomlands, but is tolerant of climatic extremes and long-term flooding (Simmons et al,, 2007). It is also one of the most commonly cultivated trees in the United States as it is highly tolerant of urban conditions, has a beautiful shade tree shape, and is relatively resistant to diseases and insects (Burns and Honkala, 1990). *Fraxinus americana*, in contrast, is less common in the forest and limited to well-drained soils. Since many remnant forests surround streams and rivers, land acceptable to *F. americana* may be more limited than that suitable for *F. pensylvanica*. *F. americana* is also only occasionally used in cultivation. The prominence of the genus *Fraxinus*, may be attributed at least in part from being a wind-dispersed species, allowing it to spread without dependence on wildlife that may not be present in disturbed urban areas or areas stripped of vegetation (Shea and Chesson, 2002).

Quercus, a genus that became highly prevalent in the Eastern Deciduous Forest with the downfall of *Castanea dentata* was found in the Baltimore survey as a diverse and widely distributed genus. *Quercus* trees were found equally within the natural environment and planted in the landscape. All of the *Quercus* species found, with the exception of a single species, *Q. acutissima*, were native to the region. The Quercus trees found in Baltimore were about an equal mix of those species that are typically only found naturally in the forested sections and those species that are used frequently in the landscape.

Quercus alba and *Quercus rubra*, widely different in use in the cityscape, were the most prominent, and were found almost equally present. *Q. alba* is found in a variety of soil conditions, moisture levels, and site aspects in native environments (Burns and Hankala, 1990; Kricher, 1998). *Q. alba* seedlings produce a taproot during development and have a slower growth rate, making them undesirable nursery plants (Dirr, 1998). *Quercus rubra*, in contrast, is easily transplanted, has good form, colorful fall color, and a dense canopy of foliage, making the species highly desirable as a residential and commercial landscape plant in addition to being found quite often in the forests with *Q. alba*.

In similar contrast, *Quercus phellos* and *Quercus velutina*, with approximately half as many individuals as the oaks previously mentioned, were found with similar importance values to one another. *Q. phellos*, rarely found naturally, is quite often found as a street and landscape tree due to its elegant shape and colorful fall foliage. With a shallow root system, the species is easily transplantable. Whereas *Q. velutina* possesses a taproot, is rare to find in the nursery trade, and is generally found naturally on dry, poor hillsides (Burns and Hankala, 1990). Finally, there is a similar relationship between the heavily used street tree, *Q. palustris*, and the naturally found slow-growing *Q. prinus*, found mostly on rocky ridges in the area.

It is important to note that correct identification of *Quercus* species becomes complicated by the frequent hybridization among the oak species and that there should be caution in interpreting oak population numbers (Young, 1979).

The future composition of the oak forests is unclear and considerable evidence suggests that oak regeneration is failing across much of their range in part due to fire suppression and consequential replacement by faster growing species such as *Acer rubrum*, *Acer saccharinum*, and *Prunus serotina* (Abrams, 1992; Smith, 1992). These species were commonly found in Baltimore's tree population. Another threat to the *Quercus* trees in the forests and in the residential landscapes of Baltimore has been the introduction of the aggressive fungal pathogen, oak wilt, distributed over much of the eastern United States (Shigo, 1958). Further loss of existing *Quercus* dominated forests could lead to a dramatic change in the forest composition and in the landscape species used in Baltimore.

The genus *Acer* was comprised of a variety of maples with different origins and uses and was found heavily represented in the UFORE 1999 survey. *Acer rubrum* was the most numerous maple species found in the survey. *A. rubrum* is a fast growing species found on a wide variety of microhabitat sites and is a subclimax species able to sprout in full sun or shade (Dirr, 1988). With the degree of fire suppression common in cities, *A. rubrum* has flourished in forested areas (Smith, 1992). While it is one of the most common, adaptable, and widespread trees in North America naturally (Hutnick, 1961), *A. rubrum* is also a frequently planted street and landscape tree with numerous cultivars exhibiting brilliant fall color.

Acer saccharinum, similar to *A. rubrum*, is common, widespread, and adaptable to urban conditions and is native to areas just west of Baltimore city. *A. saccharinum* grows quickly but lacks the desirable fall color of *A. rubrum*. Although *A. saccharinum* can be found in the nursery trade, personal observations suggest that many of the trees in this study were volunteer trees that were allowed to persist through neglect of the property. In contrast, *Acer negundo* was observed in similar numbers to the previously mentioned maples, is a species that is rarely found commercially (Burns and Hankala, 1990), and is generally only found along forest edges, along streamsides, and in disturbed sites.

Acer saccharum was less prevalent than the other *Acer* species. Often associated in the forest with *Fagus grandifolia* (Kricher, 1988), *A. saccharum* both benefits and suffers from urban development. The species is not tolerant of pollution or heat stress, both symptoms of urban environments and is on the southern edge of its natural range in Baltimore (Dirr, 1998; McClenahen, 1978). *A. saccharum* is being displaced in the forest as a shade tolerant understory species and in the landscape by the more urban tolerant *Acer platanoides*, an introduced invasive species commonly used as a street tree and landscape tree throughout the region due to its adaptability and dense foliage. Conversely, *A. saccharum* benefits from disturbance and responds quickly to gaps in the canopy with rapid growth. *A. saccharum* also benefits from fire suppression as mentioned previously since it is sensitive to fire. The species is presently invading in areas traditionally dominated by oaks and hickories when long periods between fires have been documented (Davis, 1998; Frelich, 2002).

Liriodendron tulipifera, a dominant native tree in Baltimore's forests and once an important lumber tree was also common in Baltimore. It is one of the tallest trees in the Eastern forest and is highly adaptable to any soil type except for the extremes of very dry or very wet conditions. Commonly thought of as an early successional species, it is fast growing, shade-intolerant, and benefits from disturbance. The species can be long-lived and persist in the canopy until later successional stages (Busing, 1995; Burns and Honkala, 1990). A number of sites that were reclaimed farmland cleared during the early part of the twentieth century appear to be dominated by *L. tulipifera* in Baltimore's forests. The regenerative power of *L. tulipifera* has been documented with positive responses such as sprouting and rapid growth after clearcutting (Boring et al., 1981; Elliott et al., 1997) and, along with opportunistic species like *Acer rubrum*, replaces oak species after disturbance. Cadenasso et al. (2007) found similar results along an urban-rural gradient in New York where more shade intolerant species dominated at the urban end of the gradient, perhaps due to the larger number of gaps in the forest canopies. As one of the more common species in Baltimore's tree population, *L. tulipifera* is rarely found outside of forested areas in the United States perhaps because they are considered undesirable landscape species with unusual forms and lower branches that shed (Eyre, 1980; Rogers, 1935).

Prunus serotina, one of the more common native species found in the survey, is seen more as an undesirable native species outside of the lumber industry (Dirr, 1998). It is typically not found in the nursery trade since it has a poor form and loose and open foliage (Burns, 1935). Naturally, it is a pioneer species that thrives in urban disturbed conditions and is not nearly as prevalent in suburban areas (Cadenasso et al., 1997) and can be an invader in European and Asian landscapes (Verheyen et al., 2007). The species was found numerous times along forested edges, in canopy gaps, in vacant lots, and in neglected landscapes.

There was a variety of native tree species found naturally and in the commercial landscape trade including *Cornus florida*, *Pinus strobus, Platanus occidentalis, Tilia americana*. *Cercis canadensis* is easily spotted flowering in the spring before leaf-out in the Eastern forest that has become popular in the nursery trade. *C. canadensis* was not, however, as popular as other native understory trees such as *Cornus florida.* Other species commonly observed in the forests of Baltimore, but not usually sold in the neighborhood nursery include *Sassafras albidum*, *Nyssa sylvatica*, *Juniperus virginiana*, and *Carpinus caroliniana*. Several new cultivars of *Nyssa sylvatica* have been produced in the last few decades and this species appears to be on the way to becoming prominent in the nursery trade in the near future. *Juniperus virginiana* is also found cultivated, but from personal observation, is typically found in the Baltimore landscape as a remnant or volunteer individual.

Finally, in significantly smaller numbers than the native species, there were exotic species in the survey that have been imported from Europe and Asia as important landscape plants. These included ornamental *Prunus* species, *Picea abies*, and *Acer palmatum*, all present in residential, recreational, and commercial properties in Baltimore.

Most of the species that were found in Baltimore become established without human intervention, continuously reproducing in their native range or freely naturalizing as a non-native species.

Invasive species in Baltimore

Invasive species common to urban and disturbed environments, such as Baltimore, are typically imported for medicinal and/or commercial purposes that spread aggressively, cause ecological harm, and replace native plants (Mack, 2000). Species can also be brought into the country unintentionally with nursery stock or in packaging material. Invasive plants are typically fast-growing, rapidly reproducing species and may benefit from an absence of natural controls, such as herbivores and pathogens that may be found in their native environment (Shea and Chesson, 2002). Invasive species are niche opportunists, meaning they benefit from the disruption of communities, particularly when the original population is not as well adapted to the newly disturbed conditions. The increasing amount of urbanization has been shown to lead to an increase in invasive species as well as a corresponding decrease in native species (McKinney, 2006; Shea and Chesson, 2002).

These invasive trees, primarily represented by *Ailanthus altissima* and *Morus alba*, are not usually found in the nursery industry currently, but were planted in the landscape in the past and have since naturalized and spread throughout the region in large numbers.

Morus alba was brought to the United States from China for the silkworm industry. It can be found cultivated in the nursery industry, but is generally seen as an undesirable species that spreads quickly along forest edges and fences through bird dissemination (Dirr, 1998; Swearingen, 2002). *Ailanthus altissima*, spread across the greatest number of land-uses, was imported in the late 1700's from China as an unusual looking ornamental. *A. altissima* grows quickly, is able to produce seeds as a one year old sapling, and spreads vegetatively through rhizomes to form pure, dense stands (Bory and Clair-Maczulajtys, 1980; Hu, 1979). *Ailanthus altissima* produces an allelopathic chemical that has long been theorized to be a competitive tool to exclude other trees and influence plant community structure (Mergen, 1959). The species is shade-tolerant and is not competitive in intact interior forest (Inderjit and Duke, 2003). Both of these species are known to flourish in urban soils, to thrive in edge environments, and to withstand drought and pollution better than many species of trees (Dirr, 1998; McDonald and Urban, 2006). As mentioned of *Acer* and *Fraxinus* species, *A. altissima* may benefit by being a wind-dispersed species with millions of seeds being produced by a single, mature female tree (Shea and Chesson, 2002, Swearingen, 2000). Also landscape species from Asia, *Ulmus parvifolia* was found dominating one site in the survey and *Quercus acutissima* was found once in the survey, both species considered invasive (Swearingen, 2002).

Robinia pseudoacaia is a native tree to Maryland, but not to the Baltimore region, and was present in relatively large numbers. A member of the Fabaceae family, *Robinia* is a shade-intolerant, nitrogen fixing species that will colonize any condition of soil except permanently wet soils and it has naturalized throughout the United States (Burns and Honkala, 1990). The species is commonly found on roadsides and disturbed edges with poor, dry soil where few other species would survive and has been found to have a strong growth response to elevated CO_2 levels (Mohan et al., 2007), a condition common in urban environments.

Pyrus calleryana is an invasive species that is frequently planted in the landscape. Once self-incompatible and a favorite cultivated tree in the nursery industry, the species has started to dominate disturbed areas as new cultivars have been able to reproduce (Culley and Hardiman, 2007). *P. calleryana* has become a widespread pest species in many northern cities including New York City, Boston, and Philadelphia (USDA, 2004a; USDA, 2004b).

In summary, considering the long history of disturbance, habitat fragmentation, and land-clearing throughout the Baltimore area, only 13% of the trees counted in the 1999 survey were considered invasive to the region. Invasive species such as *Ailanthus altissima*, *Morus alba*, and *Robinia pseudoacacia* are pollution tolerant, able to grow in compacted and sterile soils, and are able to spread quickly (Dirr, 1998; Hu, 1979; Swearingen, 2002). These species may outcompete native species and dominate disturbed areas such as roadsides, forest edges, and abandoned properties and unmaintained landscapes. Therefore, it was surprising that they were not present in larger numbers. In Boston, Massachusetts, for example, *Acer platanoides* alone accounted for over 17% of all trees surveyed (USDA, 2004a) and in New York City, *Ailanthus altissima* accounted for 9% of all trees surveyed (Table 11). In total, 78% of the trees in Baltimore were native to the region, while in New York and Boston, 55% and 57.5% of the trees were native, respectively.

New York, NY	Percent of trees surveyed	Boston, MA	Percent of trees surveyed
Ailanthus altissima	9%	*Acer platanoides*	17%
Prunus serotina	8%	*Quercus rubra*	12%
Liquidambar styraciflua	8%	*Acer rubrum*	11%
Quercus rubra	8%	*Tsuga canadensis*	4%
Acer platanoides	6%	*Prunus serotina*	3%
Morus alba	6%	*Ulmus americana*	3%
Percent of native trees	55%	Percent of native trees	57.5%

Table 11. The most common trees found in New York and Boston in a survey performed in 1996. Data from the USDA Forest Service (USDA, 2004a; USDA, 2004b).

With a large proportion of the population, native species appear able to compete with aggressive invasive species and maintain dominance. Baltimore City is unique with a relatively large expanse of interconnecting forested areas including Gwynns Falls Park, Patapsco Valley State Park, and Herring Run Park. These areas may retain forest species and act as a seed bank for native trees in Baltimore City. Native species retention is crucial to resistance of exotic species invasion in medium to high intensity disturbance (Mandryk and Wein, 2006).

Tree species and groundcover by land-use

A large portion of land in Baltimore City is dedicated to residential housing and this was reflected in the Baltimore UFORE plot assignments as almost half (46%) of the plots occurred on nearly even numbers of Medium Density and High Density Residential sites. Most of the Medium Density Residential plots had trees (86%) while only slightly more than half (53%) of the High Density Residential sites had trees present in the plots.

High Density Residential plots were those plots located on the properties of apartment building, condominiums, and of rowhouses. Some of these plots occurred in the alleys behind rowhouses; land that was generally neglected and where species were allowed to grow uncontrolled. There was also a number of rowhouses that were abandoned or temporarily vacant where the plantable space on the property was not maintained. Property that was maintained for an apartment or condominium complex was generally sparse and consisted, on the average, mainly of mown grass (24%), building space (23%), sidewalks and cemented areas (20%), and parking lots (19%) (groundpoint data not shown). These plots averaged only one tree per plot.

There were a total of 55 individual trees and 22 species found in the High Density Residential plots. Most of the species found on these plots were undesirable regenerating native species, invasive species, and a few landscape species sold in the trade. *Ailanthus altissima* dominated on these sites, accounting for 29% of the trees found in this land-use category. Seven of the 55 trees were *Morus alba*, another invasive species from China. This species is generally not planted, but sprouts along forest edges and fences through bird dissemination. *Acer saccharinum* accounted for 16% of the trees found and is also typically not a planted species, but one that spreads quickly by winged, wind-dispersed fruit and may have been allowed to remain through neglect. Several native species found in these plots and it is not certain if they were volunteer or planted: *Cornus florida*, *Quercus rubra*, and one of the *Fraxinus* species. *Thuja occidentalis*, also observed twice in the plots, was likely planted. There were individuals of species found (data not shown) that may indicate that some of the plots occurred at the edge of an adjacent remnant portion of forest as they are forested species that are rarely found planted, including *Fagus grandifolia*, *Quercus velutina*, and *Acer negundo*.

The Medium Residential plots contained the most diverse groups of trees as this land-use had the greatest Shannon's Diversity Index and the greatest number of species, both more so than the Forested plots. The plots contained only about 15% of the individual trees of the Forested plots with 135 trees, indicating that there were many small counts of a large number of species. Throughout these plots, there were native trees as well as a wide variety of imported species, leading to 35 total species. In these plots, there were a large number of desirable trees that are assumed to be planted. One of the few coniferous trees in the survey, *Picea abies*, a large-sized and expansive tree, dominated these plots with 16 individuals. Another evergreen species, *Thuja occidentalis*, normally found naturally in the more northern regions of the eastern United States, was also observed in this land-use. Of the planted deciduous species, there were exotic flowering cherries found as well as the popular nursery plant, *Acer palmatum*.

The Medium Density Residential plots also contained horticulturally undesirable native and invasive trees, but to a lesser degree than the High Density Residential plots. The only invasive species, *Ailanthus altissima*, was present as 7.5% of the trees surveyed. The undesirable native species were *Acer saccharinum* and *Prunus serotina*, representing together nearly a quarter of the trees in these plots. Most likely, these trees were volunteer trees at the edge of a tree line on the property or along a fence, however, there were larger sized individuals of *A. saccharinum* that may have been planted or allowed to remain (data not shown). Finally, there were a couple of desirable native species that are not known to have been planted or to be volunteer. *Fraxinus* trees and the smaller tree, *Cornus florida*, are both popular in the nursery industry and were likely planted and maintained by homeowners. As with the High Density Residential plots, there were individuals of forested species that may have occurred due to the presence of remnant trees or forested sections adjacent to the residential property that was included in the plot, including *Liriodendron tulipifera*, *Quercus velutina*, *Carpinus caroliniana*, and *Carya* species.

Forested plots were represented by 28 of the 200 plots and held most of the trees in the survey with 871, or more than half of the 1355 trees used in this analysis. There was a minimum of 2 trees per plot, which may have happened at the edge of a forest or if the plot occurred in a forest gap, and a maximum of 76 trees in one plot. Forested plots had a high Shannon's Diversity Index of 2.94 and a richness of 33 tree species, second only to Medium Density Residential but with a much larger number of trees. *Fagus grandifolia* was found 143 times within these plots and was only found one other time in the survey outside of the forest, and that was in 1 High Density Residential plot. The second most common species in the Forested plots was *Sassafras albidum*, found 83 times, deceptively making the species appear to be widespread. However, 71 of these individuals were found in a single plot. The other native trees found were equal parts slow-growing and dominant canopy trees, including *Quercus* species, as well as fast-growing, light obligate species, such as *Liriodendron tulipifera* and *Prunus serotina* that benefit from canopy gaps and forest edges. The only species that overlapped with planted residential landscapes were those native species sold in the trade, including *Cornus florida*, *Fraxinus* species, and *Quercus rubra*. There were few invasive species found competing with the native species, and these were likely found in disturbed areas or along edges as supported by edge theory that predicts that increased disturbance and edge will favor the establishment of invasive species (Brothers and Spingarn, 1992; Harris and Sanderson, 2000). There were 32 *Ailanthus altissima* trees, a small number out of the large number of trees found in Forested plots. There were also about half as many each of *Robinia pseudoacacia* and *Morus alba*. The only invasive tree that is capable of competing in the forest interior was *Acer platanoides* and these were found with 12 individuals within the Forested sites. In total, the invasive trees represented 8% of all trees counted in the Forested plots, less than the 13% invasive trees found throughout the city and there were none of the non-invasive exotic species counted in the Forested plots.

The results for the Forested sections in the Baltimore survey were similar to those found in natural areas in a vegetation survey by Brush et al. (1980). The majority of natural areas surrounding Baltimore City were classified as a *Liriodendron tulipifera* association. Species included in this association were *Acer rubrum*, *Cornus florida*, *Nyssa sylvatica*, *Quercus alba*, *Sassafras albidum*, *Prunus serotina*, and *Carya tomentosa*. This association was found in the bottomlands with *Robinia pseudoacacia*, *Carpinus caroliniana*, and *Prunus serotina* or in the upland forests with *Carya*, *Fagus grandifolia*, and *Cornus florida*. The other large association found in the surrounding areas of Baltimore City was a *Quercus prinus*-*Quercus stellata*-*Quercus marilandica* group consisting of *Acer rubrum*, *Nyssa sylvatica*, *Quercus alba*, *Sassafras albidum*, *Quercus velutina*, *Fagus grandifolia*, *Liquidambar styraciflua*, *Carya tomentosa*, and *Prunus serotina*,

Open Urban sites, representing parks, including areas of unmaintained edge forest adjacent to recreational areas, sports fields, and vacant lots, had 23 plots in the survey with more than half (57%) containing trees. As these sites can be highly disturbed and recently regenerating, there was a maximum tree count of 105 trees per plot, more than one third greater than any of the Forested plots. There was a relatively high diversity and richness values for these plots. The species found were a mixture of native forested species, invasive species, and undesirable native species. These species were dramatically different than the forested plots, even thought the Open Urban plots could have contained some edge forest. This may, in large part, be due to the presence of these edge forests as edge effects can often result in dramatically different species composition with an increase in invasive species when a seed source is available nearby (McDonald and Urban, 2006).

The largest population of trees within a genus in the Open Urban plots belonged to *Fraxinus* and it is unknown if these were planted or naturally regenerating trees. There were also a large number of *Robinia pseudoacacia*, only otherwise found in small amounts in the Medium Residential sites and the Forested sites. *R. pseudoacacia* is an early successional species that thrives in abandoned fields and degraded woodland areas with full sun exposure that is common in this land-use category. *Morus alba*, another invasive tree, was also found in large amounts in the Open Urban plots with 14 individuals while *Ailanthus altissima* was only found 4 times in the survey in these plots.

The native species found, other than those of the genus *Fraxinus*, were mature forest species such as *Quercus alba* and *Quercus rubra* that may have been planted in the parks or allowed to remain as remnant trees. Large canopy trees that were likely not planted were *Q. velutina* as well as a relatively large number of trees within the *Carya* genus otherwise only seen in any substantial numbers in the Forested sites indicating that there may have been edge-forests present in these sites or adjacent forested patches. There were also native pioneer species such as *Acer negundo*, *Sassafras albidum*, *Prunus serotina*, as well as understory species such as *Cornus* *florida* and *Acer saccharum* that may or may not have been planted. There were about 19 individuals in the *Ulmus* genus that may have been small, surviving *U. americana*, as there are some mature trees of American elm in the city that have not yet fallen to Dutch elm disease acting as seed sources, or individuals of *U. rubra*. In essence, it appears that the Open Urban plots consisted largely of a mixture of edge-loving, fast-growing native species, invasive tree species, as well as native forest trees that either appeared in edge forests or were planted as park trees. Unlike the residential plots, there were no exotic non-invasive trees counted within the Open Urban plots.

At the other end of the spectrum in terms of diversity and species richness were the more “urban” sites. Unlike residential areas, where planting trees may be encouraged for aesthetic reasons, for upholding prestige, or for increasing the value of the property, these remaining land-uses include sites devoted to Commercial or Industrial purposes, as well as highly disturbed Bare Ground sites, and Institutional locations. These property managers may have motivation to prevent volunteer and invasive species from occurring, mostly in terms of safety.

Transportation plots were located adjacent to roadways or encompassed completely by highways. These sites could have included median strips with planted street trees maintained with regular intervals of mowing or have been bordered by completely neglected pieces of edge forest. The latter is indicated as, of the 29 trees counted in the plots, two-thirds were the invasive tree *Ailanthus altissima*. The remaining species were probably planted as street trees, including *Quercus phellos*, *Acer platanoides*, *Acer rubrum*, *Acer platanoides*, and a single ornamental cherry.

The Industrial plots were largely without trees as included were petroleum storage areas and manufacturing sites that were prohibited from allowing vegetation on the premises. The 2 plots of 9 that did have trees were apparently slightly lax in land management and allowed a few weedy species to sprout. These plots had only one native species, one in the *Ulmus* genus, likely a volunteer tree, and 2 invasive tree species, *Ailanthus altissima* and *Quercus acutissima*.

There were only 4 plots with trees of the 15 Commercial plots and these were likely parking lot trees or planted near a storefront for aesthetic reasons. Each plot had one tree of one species, *Acer platanoides*, *Acer saccharum*, *Pyrus calleryana*, and *Quercus rubra*. There is a chance that any of these were counted at the edge of the commercial property and were volunteer trees.

Institutional plots occurred on school property, on cemetery lots, or on golf courses; all highly managed properties, where more land space is dedicated to mown lawn than planted space. These plots had 3 ornamental species planted, including an invasive, a native, and a non-native exotic; *Pyrus calleryana*, *Pinus strobus*, and a flowering *Prunus* tree.

The Bare Ground plots are arguably the most disturbed sites in the city. These construction sites and landfills consist mainly of compacted, and generally infertile, bare soil. These plots were all recently disturbed, allowing for only volunteer species, and surprisingly, the species found were all native species instead of the expected occurrence of invasive trees. It is assumed that there is a nearby source of seeds in an adjacent forest for these native trees: *Prunus serotina*, *Liquidambar styraciflua*, and *Sassafras albidum*.

There would appear to be distinct patterns to the trees found within and among the land-use classifications in Baltimore's vegetation survey as maintenance and motivation for planting may be key factors in the tree composition in most of the plots. In general, it would appear that the Medium Density Residential plots were mostly a combination of desirable exotic species and undesirable native species while the High Density Residential plots were dominated by invasive tree species and undesirable and quickly regenerating natives. The high levels of diversity in the Medium Density plots were likely due to the combination of landowners planting a range of exotic trees from nurseries in combination with volunteer trees that sprouted near fence lines and property boundaries. Forested plots were mainly rich in native species across different environments such as riparian areas, bottomland forests, and upland forests as well as a small cropping of invasive species along the forest edges. The Open Urban plots contained many fast-growing edge species, invasive and native, as well as some large, planted park species. The Transportation plots were lined with colonies of *Ailanthus altissima* and a few species of planted street trees. The few Institutional and Commercial plots that contained trees had planted landscape trees, both native and exotic. The Industrial plots that were treed had a few invasive species while the Bare Ground plots exclusively had native volunteer trees.

Detrended correspondence analysis of species distribution related to land-use

While there were possible patterns in species distribution by land-use classification through the tree population data above, multivariate analysis was not conclusive. The plot scores of the detrended correspondence analysis did not indicate a pattern of species composition within the plots based on land-use alone, leaving Hypothesis 1 that tree species distribution is based on land-use unsubstantiated. However, the species scores, when plotted alone, may have revealed a general pattern where trees are expected to be found in the urban landscape. The species that are generally only located in forested environments were found to be grouped at the left end of the first axis and those that can only be expected to be found in planted landscapes were found at the right hand side.

There may be several reasons for the discrepancy between a pattern existing for the species scores and not for the plot scores. Plot locations and the size of the land-use type patches where the plot was located were highly variable. For example, commercial plots located in a strip mall at the urban core can be very different from a small store located in a residential area with regards to plantable space and desired aesthetic appearance. It is possible that the land-use designation was not specific enough in order to account for different management regimes or disturbance event type and frequency. Also, the location of each plot varied in proximity to the nearest seed source for volunteer trees, such as the distance to the nearest forest patch or the nearest regenerating vacant lot. Another confounding factor was the percentage of land area within the plot dedicated to the assigned land-use classification. Some of the plots fell on two or more land-uses, but each was designated based on the greatest portion of land. For example, a plot that was 60% forest, but also 40% residential was still designated as a Forested plot. This was corrected in subsequent UFORE vegetation surveys as percentages of land-uses were noted. That could not be accounted for here as some of the plots had been lost and relocated or had changed land-use status since the original 1999 survey. Further examination of the patch sizes and the proximity of each plot to the nearest seed source would be useful analyses in the future.

While there was an apparent grouping of some of the species by their DCA species scores along the first axis, there were not completely clear distinctions of species origins or preferred habitat. The species that are found mostly in forested environments, such as *Fagus grandifolia*, were clustered at the beginning of the axis, while the planted exotic species typically found only in residential areas were at the end of the species scores. A large grouping of species in the middle of the ordination had no such clear pattern. There are perhaps several reasons for an overlapping of species origins and uses. For one, there is a homogenization of species across cites, and even across the globe, due to highly adaptable, urban tolerant species that are planted universally (McKinney, 2006). Homogenization is mostly caused by invasive species or weedy native species that are found across many land-uses, including *Ailanthus altissima* and *Prunus serotina* (Results, Table 3). The real determining factor is only whether they are allowed to remain and land management can vary highly, not only between different land-uses, but also within the classifications based on vacancy status, site history, and current degree of management. The source of the trees may have also blurred any distinguishable pattern in the DCA analysis as it was not noted during the survey whether or not each tree was planted or was volunteer. Many native species are sold in the nursery industry and planted in the landscape leading to a larger seed bank than normally would be present. Planted *Quercus rubra* individuals would tend to be found in residential areas, along street edges and in yards, and around parking lots of commercial plots while naturally regenerating individuals may only be found in forest environments or in Open Urban recreational areas. If the planted individuals had been separated by source, a clearer pattern might have emerged in species distribution based on land-use classification. Later UFORE surveys did include this information, but as mentioned before, it was impossible to reference this information to the 1999 survey as some of the plots had been relocated and trees were removed or planted since that time. To test how much of an impact this might have, a secondary DCA was performed that separated certain species into planted and volunteer categories assuming that they would generally be one or the other based purely on land-use classification. For example, *Quercus rubra* was entered as planted for residential sites and volunteer for Forested sites and Open Urban sites. This was also done for trees such as *Fraxinus*, *Cornus florida*, and *Acer rubrum*. The DCA performed provided the same results as the original DCA reported, indicating that the source of trees may not a factor in the results.

There is no obvious environmental gradient observed, if the species are analyzed individually by preferred soil moisture, normal pH range, or disturbance tolerance. For example, species that tend to be found in dry, rocky sites were mixed with species that are found almost exclusively in moist, bottomland settings along the first axis. This could be due, in small part, to a difference in the role that competition plays. Species that are confined to bottomland areas because they are unable to compete with upland species may be able to grow in drier sites, but are not able to compete naturally. These species could be planted in drier sites through landscaping and may thrive in such conditions. It is also unknown which individual trees were maintained, perhaps watered regularly in an environment that they were not accustomed, and which species were existing on their own.

With urban environments and the amount of disturbance, there tends to be a disruption of normal environmental gradients. Soil conditions change through such changes as soil compaction, organic matter removal, altered hydrology affecting drainage, and the addition of heavy metals. The existence of an environmental gradient, therefore, is difficult to detect without knowledge of site characteristics of each plot.

With respect to the two different physiographic regions that Baltimore encompasses, there could have been obvious differences in soil conditions due to the parent material. In a separate DCA (not shown), plots were analyzed based on their location with respect to the fall line. There was no apparent contribution to tree species distribution based on the physiographic region.

In a discussion of the analyses used, it is important to note that the ordination methods themselves may have inherent issues that prevent the detection of existing patterns. One of the problems facing an ordination method based on weighted averaging, such as DCA or CCA, is assumption of a symmetric, unimodal response. Species response curves can often deviate from a simple unimodal shape when analyzed for environmental gradients (Ejrneas, 2000; Minchin, 1987). DCA is also highly sensitive to outlying samples or species (Jongman et al., 1987), can be unstable with certain types of data (Minchin, 1987), and rescales and detrends the data, basically manipulating the data to fit a mold, or a pattern, that may not really exist (Ter Braak, 1986). However, there is sufficient evidence that DCA is robust against violation of its assumptions and, in spite of DCA's failings, the ordination method has been shown to be useful in analyses such as the one presented here (Okland, 1990a). In this case in particular, in its function as a general sweep of species and samples without measured environmental factors, the results of the DCA analysis here have been accepted as sufficiently reliable.

The function of DCA is to act as a predictive tool in choosing environmental variables for subsequent modeling with other forms of analyses and there is indications with the results presented that environmental factors, such as soil compaction, soil type, or seed source proximity should be considered in subsequent research.

It has been suggested in some literature sources that other ordination techniques would be preferred over DCA (McCune and Grace, 1999), such as non-metric multi-dimensional scaling (NMS) or should be used in combination with DCA (Minchin, 1987). Therefore, NMS was performed on the dataset. The NMS analysis was similar to the DCA results, and as DCA is more intuitive in interpretation, only those results were presented.

The analysis of socioeconomic and environmental variables through canonical correspondence analysis

Canonical correspondence analysis was performed in order to evaluate the influence of measured anthropogenic variables on the distribution of tree species. These tests were related to hypotheses 2 and 3. CCA is more flexible with regards to response shapes than DCA as it directly models species with measured environmental variables. It may, however, suffer some of the same complaints mentioned of DCA, such as the assumption of a unimodal gradient. CCA also relies on the knowledge that the most important underlying factors are being tested as variables, and this may lead to distortion by unaccounted for secondary gradients.

Hypothesis 2 was that that population density, percent vacant housing, and median household income would be significant in determining tree community distribution. There is an assumption here that houses in areas of lower density would have more plantable space for trees and that areas of higher income would have more resources available to purchase and maintain trees.

Socioeconomic factors were tested through CCA in terms of population density, percent vacant housing, and median household income. The hypothesis that these socioeconomic factors would account for the variation in the data was found to be unsubstantiated. Simply defining tree spatial patterns by population and income in a complex interaction of human influence as well as environment was not effective.

There are a number of reasons that concluding results, if there were any to find between social status and vegetation patterns, were not attained including that the analysis is a simplification of a complex environment. Another reason that the relationship was not found could be that there is a temporal lag between a time that a neighborhood's economic status changes and the vegetation changes that appropriately follow (Grove, 1996; Vogt et al., 2002). It should also be considered that a census tract may not be homogenous enough to be used as a representation for a located within its boundaries. Baltimore is a highly diverse city and, at times, crossing the street can bring one into a completely different income bracket. The median average income and population density information is also a calculated value from census surveys and may not represent the area in and surrounding the plot well enough or may not have captured many enough of the population as census surveys may not account for people of all socioeconomic statuses.

It is not known if there is an easy solution for these issues involving the socioeconomic analysis. In an ideal situation, information for individual homeowners who live on the property containing the plot would be available. However, many people were suspicious of simply having their trees measured at the time of the survey and were concerned that the information would be used to impact their taxes or for other nefarious purposes. It is doubtful that such private information could be attained.

As motivation for planting vegetation cover has been shown to reach beyond income and population levels for many communities (Grove et al., 2006; Hope et al., 2003), further research into the lifestyle behaviors and social stratifications of these plots in relation to tree species composition could prove fruitful.

Regardless if significant results were found, there were indications from the biplot that patterns, in part, could exist. Species located the furthest distance from the arrowhead of an environmental variable have the lowest weighted average with respect to that variable. When looking at the biplot in Figure 6, the species that occur at the sites with the highest median incomes are those that would be expected to be desirable species. This was true as the species grouped at the highest income levels were those species such as *Acer palmatum* and ornamental *Prunus* species. This was not true at the end of the gradient as there was a mixture of species of different uses and origins. There is also a suggestion of a pattern with population density as *Ailanthus altissima* is at the higher end of the gradient, while forested species such as *Carya* species and *Liriodendron tulipifera* are found at the opposite end. This clustering appears for only a fraction of the species, and does not appear to be the general rule.

In the CCA analysis with environmental variables, Hypothesis 3, that anthropogenic environmental factors accounted for tree species distribution, was tested using the amount of plot surface area covered by impervious service was analyzed with the average age of structure on the property.

The age of structure on property was used here as an indication of the time since disturbance in the area. It is a general age for a complex patch of land and may not reliably indicate the time since disturbance for every structure on every plot within that census tract, but it is taken as a sign of time since development and disturbance within that area. If assumed to be true, the age of structure on the property can greatly affect the species planted. Previous research has found that time since neighborhood development is important in predicting species abundance for perennials (Martin et al., 2004). For understory vegetation, stand age after clearcutting was found, along with site moisture, to be the most important measured environmental variable related to species distribution in Maryland (York et al., 2000).

For the trees in Baltimore, it is hypothesized that the time since disturbance will have an impact on the species composition. Older sites tend to have mature trees, dominated by non-native species that may have been popular in an earlier era, while younger sites are affected by a renewed interest in native species in new developments and buffer zones, and have a smaller biomass as younger trees are recently planted (Detwyler and Marcus, 1972; Freedman et al., 1996).

If the impervious surface area is taken as an estimation of urbanization, it can easily follow that the less plantable space a plot has, the less the number of species that would be able to tolerate that environment. The trees planted in an area largely composed of parking lot and sidewalk would most likely have to be urban tolerant street trees, landscape trees, or volunteer invasive species and weedy native species that survive with little resources, minimum root space, a tolerance for high levels of solar radiation, and are able to withstand soil compaction.

There was a large range in the average impervious surface cover of plots by land-use. There is a general sense that this a measure of urbanization as Commercial and High Density Residential plots dominate the city's core, and along with Industrial plots, have the least amount of plantable space and the greatest proportions of undesirable and fast growing native species and invasive tree species . The nearly total pervious surfaces of the Bare Ground plots deceptively reflect plantable space as these areas were recently disturbed or kept unvegetated. Bare Ground plots ranged from 0 to 4% impervious surface cover extrapolated from groundpoint data while Forested plots were between 0 and 52% with most being at 0% impervious surface (Table 8). Commercial plots ranged from 36 to 100%. The rest of the land-uses had an extrapolated percent impervious surface area between 0 and 100%.

This second CCA using the age of the structure on the property and the amount of impervious surface cover on the plots was found to yield significant results. About 12% of the total variance in the species data was accounted for by these variables. The first axis accounted for most of the variance among the axes with 3.2% of the total variance. Both Monte Carlo tests were found to be significant. These tests determined that the impervious surface area and age of structure on the property accounted for some of the variance in the data, and plots with similar values for these variables have similar species. The amount of impervious surface cover was the more significant variable found as it was calculated to have considerably greater correlation than age of structure.

A similar result was found in France as Vallet et al. (2008) analyzed land cover of buffer zones surrounding woodland areas and the response of plant assemblages. A canonical correspondence analysis found that buildings and pavement areas were the most significant predictors of plant species composition, indicating that the proportion of impervious surface surrounding the sites was the most important factor.

A major concern with the results of this CCA analysis is that, even though statistically significant, the model explains little of the variation as seen by the short extracted gradients. Therefore, the probability of a species occurring increases or decreases monotonically, not unimodally, along the gradients and this violates one of the assumptions of CCA (Ter braak, 1986). In spite of this, the CCA analysis appeared to have run appropriately. The amount of total variance in the community matrix accounted for with this analysis was relatively small indicating that there are more contributing factors to species distribution. Plantable space, or pervious area, may also be a factor of wealth and status as areas of lower economic standing presumably have less plantable space, a greater housing density, more parking lots and streets, and less resources and political power to uphold the community aesthetics.

Finally, a CCA was run for some of the Forested sites with soil properties in order to evaluate the possible influence of natural factors more traditionally responsible for species assemblages. Many factors, including soil properties, biogeochemical processes, and biological properties, interact in order to determine conditions suitable for a species to establish and grow (Hutchison, 1957). Van Breeman et al. (1997) found that *Fraxinus americana* occurred on sites high in Ca and Mg, while, conversely, sites with *Quercus rubra* and *Fagus Americana* were low in Ca and Mg. Soil pH levels, at the forest floor especially, was greatest under *Acer saccharum* and *Fraxinus Americana*, and decreased under *Acer rubrum* and *Fagus americana*, with the lowest pH under *Quercus rubra* and *Tsuga canadensis*. A similar pattern was found with exchangeable Ca and Mg.

There is also sufficient evidence to establish the case that, in a plant-soil feedback loop, plant species often change conditions due to leaf chemistry and selective uptake that further amplifies the effect of the soil on plants (Augusto et al., 2001; Binkley and Giardina, 1998; Ehrenfeld et al., 2005; Reich et al., 2005). Trees influence soil acidity and exchangeable cations (Alban, 1982) and differentially take up cations, produce organic acids, and have different rates of decomposition (Finz, 1998). Regardless, a relationship can exist between environmental conditions and species composition.

This final analysis of soil factors in the Forested plots (Figure 9) was run in order to detect any contrast with the previous analyses that focused on anthropogenic variables. Very little of the variance was accounted for by this analysis. The number of soil variables was reduced and run in numerous combinations to assure, along with the analysis output, that there was no evident interaction among the variables. Some of the variables were related in the analysis output, as shown by the relationships of the variables, as they would obviously be in the physical world, such as the level of magnesium present and the pH of the soil, but this did not appear to affect the results shown.

There were only a small number of plots with data available in this analysis and data from only 22 of the 200 plots were used. There is good reason to believe that tree species differences were likely due to plot location, history, and disturbance factors rather than soil properties. For example, those plots that occurred at the edge of a forest can be markedly different from those in the intact interior, regardless of soil properties (Godefroid and Koedam, 2003). In conclusion, the results with this CCA indicate that tree species assemblages in Baltimore City are likely due to anthropogenic factors.

Trees, generally seen to be an afterthought in urban planning, are essential elements of the urban forest and the underappreciated mitigators of urban pollution woes. The populations of trees in a city environment are often poorly understood and are rarely seen as a functioning component of the urban ecosystem. The ecological services provided to a city are, therefore, often undervalued. The arboreal community provides valuable services to the human population of a city with environmental services such as the moderation of the heat island effect with the reduction of albedo and solar radiation (Oke, 1989), the absorption of airborne particulate matter and nonpoint water pollution to improve health conditions (Beckett, et al., 1998; Borin, et al., 2004; Freer-Smith, et al., 1997; Nowak, 1994b; Tabacchi et al., 2000), carbon sequestration (Nowak, 1994c; Freedman et al., 1996), stream bank stabilization, the moderation of storm water flow and the corresponding decrease in soil erosion, and the reduction of heating and cooling needs for adjacent buildings (Nowak, 1993).

Understanding how tree species are distributed within a city environment is useful only with the knowledge that the population is constantly changing along with the way the land is being used. On the small scale, plants continue to move in and out of favor with homeowners and city designers, and change with the tastes of new owners and managers as properties change hands. On a larger scale, epidemics such as emerald ash borer killing off large expanses of *Fraxinus* trees to the north (Poland and McCullough, 2006) and sudden oak death (Rizzo et al. 2002; Stokstad, 2004) destroying forests of oak trees to the west, threaten to wipe out entire populations of important tree species in both the forest and the landscape on the scale of Dutch elm disease. Only through the knowledge of what trees are present and how they are changing can proper land management decisions be made to preserve the biodiversity and, consequently, maintain a healthy and functioning urban forest.

Conclusion

Based on the tree survey in Baltimore, MD, the vast majority of species was native to the region, found in the forests before European settlement and throughout the subsequent land-use changes that resulted from a changing cityscape. Less than a quarter of the trees surveyed were non-native to the area, brought in mostly as species sold in the nursery industry currently, or were imported in the city's early history.

There was a mixture of trees found within the city including those such as *Fagus grandifolia* that generally are confined to more natural and undisturbed forested areas, as well as those species that are adaptable to many types of soils and disturbance conditions, such as *Fraxinus pensylvanica*. There was also a combination of species that dominated the canopies of a mature forest in the Eastern Deciduous Forest, such as those of the genera *Quercus* and *Carya*, as well as a number of fast-growing, light-obligate pioneer species such as *Liriodendron tulipifera* and *Prunus serotina*. These latter species were likely not as present in the forests of Baltimore before European settlement, but with disturbance and canopy openings that came with the growth of a major metropolitan area, they have flourished and gained importance.

Surprisingly, there was not a monopolization of the tree species population by any of the cross-over species, meaning those that are found regenerating natively in the forested areas as well as found sold in the nursery trade. These species, such *Acer rubrum* and *Quercus rubra*, have two sources of new recruits. Regeneration of these species happens through native tree seed sources and through saplings being planted in the landscape by public agencies, landscape companies, and homeowners.

Also present in smaller amounts than might be expected in a highly urbanized region, were invasive species. The invasive species in Baltimore accounted for 13% of the tree population in Baltimore city. This was a lower percentage than found in comparable cities in the eastern United States (see Table 10).

With the multivariate analyses performed, there was no clear indication of overriding factors that was driving the city's biodiversity. Tree species distribution could not be explained based on land-use classification of the plots alone. Socioeconomic factors were also not significant in explaining vegetation patterns. There was a trend that suggested that the amount of impervious surface area was related to species distribution. However, many factors probably contributed to this finding. There is inherent complication of multiple, inter-related factors, environmental and socioeconomic combined, that, together, may contribute to tree species distribution across the urban landscape. This may have contributed to the unclear partitioning of plots across land-uses. Further information on patch size and location, of specific plot socioeconomic and environmental information would be helpful in forming conclusive explanations for what determines tree species composition and distribution in an urban environment.

Appendix 1: Species Codes

CODE	SCIENTIFIC NAME	COMMON NAME	Native/ Invasive or Exotic to Baltimore
ACNE	*Acer negundo*	boxelder	Native
ACPA	*Acer palmatum*	Japanese maple	Exotic
ACPL	*Acer platanoides*	Norway maple	Invasive
ACRU	*Acer rubrum*	red maple	Native
ACSA1	*Acer saccharinum*	silver maple	Native to areas just west of Baltimore
ACSA2	*Acer saccharum*	sugar maple	Native
AIAL	*Ailanthus altissima*	tree of heaven	Invasive
ASTR	*Asimina triloba*	common paw-paw	Native
CACA	*Carpinus caroliniana*	ironwood, American hornbeam	Native
CA1	*Carya* species	hickory	Native
CASP	*Catalpa speciosa*	northern catalpa	Exotic
CECA	*Cercis canadensis*	eastern redbud	Native
CELI	*Cedrus libani*	cedar of Lebanon	Exotic
CEOC	*Celtis occidentalis*	hackberry	Native
COFL	*Cornus florida*	flowering dogwood	Native
FAGR	*Fagus grandifolia*	American beech	Native
FR	*Fraxinus* species	ash	Native
GLTR	*Gleditsia triacanthos*	honeylocust	Exotic
HAVI	*Hamamelis virginiana*	common witchhazel	Native
HISY	*Hibiscus syriacus*	rose of sharon	Exotic
ILOP	*Ilex opaca*	American holly	Native
JUVI	*Juniperus virginiana*	eastern redcedar	Native
LIST	*Liquidambar styraciflua*	sweetgum	Native
LITU	*Liriodendron tulipifera*	tulip tree, yellow poplar	Native
MA2	*Malus* species	crabapple	Exotic
MA1	*Magnolia* species	magnolia	Exotic
MOAL	*Morus alba*	white mulberry	Invasive

CODE	**SCIENTIFIC NAME**	**COMMON NAME**	**Native/ Invasive/ or Exotic to Baltimore**
NYSY	*Nyssa sylvatica*	blackgum	Native
OSVI	*Ostrya virginiana*	American hophornbeam	Perhaps native to western portions
PIAB	*Picea abies*	Norway spruce	Exotic
PIST	*Pinus strobus*	eastern white pine	Native
PLOC	*Platanus occidentalis*	American sycamore	Native
PODE	*Populus deltoides*	eastern poplar	Uncertain
PR	*Prunus* species	flowering cherry	Exotic
PRSE1	*Prunus serotina*	black cherry	Native
PYCA	*Pyrus calleryana*	Callery pear	Invasive
QUAC	*Quercus acutissima*	sawtooth oak	Invasive
QUAL	*Quercus alba*	white oak	Native
QUCO	*Quercus coccinea*	scarlet oak	Native
QUFA	*Quercus falcata*	southern red oak	Native
QUPA	*Quercus palustris*	pin oak	Native
QUPH	*Quercus phellos*	willow oak	Native
QUPR	*Quercus prinus*	chestnut oak	Native
QURU	*Quercus rubra*	red oak	Native
QUVE	*Quercus velutina*	black oak	Native
ROPS	*Robinia pseudoacacia*	black locust	Exotic
SAAL	*Sassafras albidum*	sassafras	Native
THOC	*Thuja occidentalis*	American arborvitae	Exotic
TIAM	*Tilia americana*	basswood	Exotic
TICO	*Tilia cordata*	littleleaf linden	Exotic
TSCA	*Tsuga canadensis*	eastern hemlock	Exotic
ULPA	*Ulmus parvifolia*	chinese elm	Invasive
ULSP	*Ulmus* species	elm	Native

* The category of Native/Exotic/Invasive was determined through personal knowledge and with the aid of Burns and Honkala (1990).

Appendix 2: Species by land-use

LAND-USE	SPECIES	NUMBER OF TREES	PERCENTAGE OF LAND-USE TOTAL
Bare Ground	*Prunus serotina*	3	60.0%
	Liquidamabar styraciflua	1	20.0%
	Sassfras albidum	1	20.0%
Commercial	*Pyrus calleryana*	1	25.0%
	Acer platanoides	1	25.0%
	Acer saccharum	1	25.0%
	Quercus velutina	1	25.0%
Forested	*Fagus grandifolia*	143	16.4%
	Sassfras albidum	83	9.5%
	Cornus florida	67	7.7%
	Prunus serotina	65	7.5%
	Fraxinus species	63	7.2%
	Quercus rubra	57	6.5%
	Ulmus species	55	6.3%
	Liriodendron tulipifera	50	5.7%
	Quercus alba	33	3.8%
	Ailanthus altissima	32	3.7%
	Acer rubrum	27	3.1%
	Quercus phellos	23	2.6%
	Carya species	21	2.4%
	Nyssa sylvatica	18	2.1%
	Robinia pseudoacacia	18	2.1%
	Acer platanoides	15	1.7%
	Acer negundo	15	1.7%
	Carpinus caroliniana	12	1.4%
	Morus alba	12	1.4%
	Quercus velutina	9	1.0%
	Quercus palustris	8	0.9%
	Hamamelis virginiana	7	0.8%
	Catalpa speciosa	6	0.7%
	Cercis canadensis	6	0.7%
	Tilia americana	6	0.7%
	Acer saccharinum	5	0.6%
	Acer saccharum	3	0.3%
	Quercus prinus	3	0.3%
	Asimina triloba	2	0.2%
	Ostrya virginiana	2	0.2%
	Platanus occidentalis	2	0.2%
	Quercus coccinea	2	0.2%

LAND-USE	SPECIES	NUMBER OF TREES	PERCENTAGE OF LAND-USE TOTAL
Forested (continued)	*Prunus* species	1	0.1%
High Density Residential	*Ailanthus altissima*	14	20.3%
	Acer saccharinum	8	11.6%
	Morus alba	7	10.1%
	Acer rubrum	6	8.7%
	Quercus prinus	4	5.8%
	Pyrus calleryana	3	4.3%
	Cornus florida	2	2.9%
	Prunus serotina	2	2.9%
	Fraxinus species	2	2.9%
	Quercus rubra	2	2.9%
	Pinus strobus	2	2.9%
	Celtis occidentalis	2	2.9%
	Juniperus virginiana	2	2.9%
	Thuja occidentalis	2	2.9%
	Tsuga canadensis	2	2.9%
	Fagus grandifolia	1	1.4%
	Acer negundo	1	1.4%
	Quercus velutina	1	1.4%
	Catalpa speciosa	1	1.4%
	Prunus species	1	1.4%
	Magnolia species	1	1.4%
	Pyrus calleryana	2	50.0%
	Pinus strobus	1	25.0%
	Prunus species	1	25.0%
	Ulmus species	3	50.0%
Industrial	*Ailanthus altissima*	2	33.3%
	Quercus acutissima	1	16.7%
Medium Density Residential	*Picea abies*	16	11.9%
	Acer saccharinum	12	8.9%
	Prunus serotina	9	6.7%
	Fraxinus species	9	6.7%
	Tsuga canadensis	8	5.9%
	Acer palmatum	7	5.2%
	Ailanthus altissima	6	4.4%
	Prunus species	6	4.4%
	Juniperus virginiana	6	4.4%

LAND-USE	SPECIES	NUMBER OF TREES	PERCENTAGE OF LAND-USE TOTAL
Medium Density Residential (continued)	*Ilex opaca*	5	3.7%
	Ulmus species	4	3.0%
	Cornus florida	4	3.0%
	Acer platanoides	4	3.0%
	Morus alba	3	2.2%
	Thuja occidentalis	3	2.2%
	Robinia pseudoacacia	3	2.2%
	Malus species	3	2.2%
	Pyrus calleryana	2	1.5%
	Pinus strobus	2	1.5%
	Acer rubrum	2	1.5%
	Quercus rubra	2	1.5%
	Magnolia species	2	1.5%
	Carya species	2	1.5%
	Acer saccharum	2	1.5%
	Gleditsia triacanthos	2	1.5%
	Prunus species	2	1.5%
	Acer negundo	1	0.7%
	Quercus velutina	1	0.7%
	Liriodendron tulipifera	1	0.7%
	Quercus alba	1	0.7%
	Carpinus caroliniana	1	0.7%
	Quercus palustris	1	0.7%
	Cedrus libani	1	0.7%
	Populus deltoides	1	0.7%
Open Urban	*Fraxinus* species	40	17.4%
	Robinia pseudoacacia	28	12.2%
	Ulmus parvifolia	22	9.6%
	Quercus alba	20	8.7%
	Ulmus species	19	8.3%
	Prunus serotina	17	7.4%
	Acer negundo	17	7.4%
	Morus alba	14	6.1%
	Pinus strobus	12	5.2%
	Carya species	8	3.5%
	Platanus occidentalis	6	2.6%
	Ailanthus altissima	4	1.7%
	Acer saccharinum	3	1.3%
	Acer rubrum	3	1.3%

LAND-USE	SPECIES	NUMBER OF TREES	PERCENTAGE OF LAND-USE TOTAL
Open Urban (continued)	*Quercus rubra*	3	1.3%
	Sassafras albidum	3	1.3%
	Cornus florida	2	0.9%
	Thuja occidentalis	2	0.9%
	Acer saccharum	1	0.4%
	Prunus species	1	0.4%
	Quercus velutina	1	0.4%
	Quercus phellos	1	0.4%
	Liquidamabar styraciflua	1	0.4%
	Quercus falcata	1	0.4%
	Tilia cordata	1	0.4%
Transportation	*Ailanthus altissima*	19	61.3%
	Fraxinus species	2	6.5%
	Ulmus species	2	6.5%
	Acer rubrum	2	6.5%
	Quercus phellos	2	6.5%
	Acer saccharinum	1	3.2%
	Prunus species	1	3.2%
	Acer platanoides	1	3.2%
	Gleditsia triacanthos	1	3.2%

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