AN URBAN FOREST IN A RURAL TOWN: BIODIVERSITY, ECOSYSTEM SERVICES, AND MANAGEMENT OF TREES ON THE APPALACHIAN STATE UNIVERSITY CAMPUS

A Thesis
by
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Abstract

AN URBAN FOREST IN A RURAL TOWN: BIODIVERSITY, ECOSYSTEM SERVICES, AND MANAGEMENT OF THE TREES ON APPALACHIAN STATE UNIVERSITY CAMPUS

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The objectives of this study were to: 1) identify all trees on campus, 2) determine the size distributions for each tree species, 3) assess the health and risk status of each tree, and finally, 4) to quantify and compare ecosystem services of trees on ASU's managed campus as well as the adjacent Nature Preserve using i-Tree Eco protocols.

A two-part assessment of the urban forests at Appalachian State University (ASU) in Boone, NC was conducted from 2010-2012. The first component compared the managed portions of the campus (85.8 ha) with the adjacent, unmanaged Nature Preserve (27.1 ha), both of which are part of the ASU campus. i-Tree Eco protocols were applied to all trees inventoried on the managed campus, as well as plot-based samples in the Nature Preserve. On the managed campus, 3,228 trees were inventoried representing 86 species. Diameter at breast height (DBH) ranged from 3 cm to 186 cm while tree height ranged from 2 m to 40 m. The Nature Preserve contains approximately 18,812 trees belonging to 25 species. Diameter at breast height there ranged from 4 cm to 79 cm while tree height ranged from 2 m to 38 m.

According to the i-Tree Eco model, the managed campus contains 1,334 mT of C, sequesters 39.5 mT of CO_2/year, and could potentially remove 1.8 mT of pollution/year, while in the Nature Preserve these values are 4,540 mT of C and 83 mT of CO_2/year, and potentially 2.1 mT of pollution/year, respectively.

The second portion of the project included a hazard assessment of every tree on the managed portions of campus, as well as suggested management practices. Eighty-two percent of all trees surveyed were classified as healthy, 13% were moderately healthy, and 5% were unhealthy. However, over half of all trees on the managed campus have the potential to impact at least one target (e.g., building, vehicle, pedestrian) if the tree were to fall. Zones with the highest use intensity contained the greatest abundance of healthy trees, likely due to increased management in response to higher risk hazard, while zones with the lowest use intensity contained the greatest abundance of dead/dying trees. Management practices, such as the suitable placement of species on specific sites, appropriate care (pruning), and accurate treatment with pesticides can all contribute to healthy urban/campus forests.

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The analysis of the forests on the campus of Appalachian State University was a collaborative effort between New River Light and Power, the Department of Biology, and the Physical Plant at Appalachian State University. Special thanks go to New River Light and Power for purchasing and providing the GPS technology and software. I would like to thank my advisor, Dr. Mike Madritch, who was a valuable mentor throughout this whole process, as well as my other committee members, Dr. Howard Neufeld and Dr. Zack Murrell for their support and guidance during the completion of the enormous endeavor of inventorying every tree on campus. Dr. Neufeld and Dr. Murrell are also responsible for initially suggesting that an analysis of ASU's urban forests would be something prudent to undertake. I would also like to thank Mr. Mike O'Connor, ASU's Physical Plant Director, as well as Mr. Jim Bryan and Mr. Edward Hyle, both Facilities Superintendents of Landscape Services, for help in the difficult identification of uncommon cultivars and hybrid plants. In addition, I would like to thank Andi Cochran Sigsbey, the GIS Lab Supervisor from the Department of Geography and Planning, for her tremendous help in the initial set up of the GPS units as well as for technical support throughout the course of this study.

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Foreward

Chapter 1 of this thesis is intended to be submitted to *Arboriculture & Urban Forestry*, an international peer-reviewed journal published by the International Society of Arboriculture; it has been formatted accordingly. Chapter 2 includes a hazard assessment and suggested management strategies and is intended to be submitted to Appalachian State University's Physical Plant, Landscape Services division.

Chapter 1: A Comparison of Biodiversity and Ecosystem Services within Appalachian State University's Managed and Unmanaged Urban Forests using i-Tree Eco Protocol

ABSRACT

An assessment of the urban forests at Appalachian State University (ASU) in Boone, NC was conducted from 2010-2012. The objectives of this assessment were to: 1) identify all trees on campus, 2) determine the size distributions for each tree species, 3) assess the health and risk status of each tree, and finally, 4) to quantify and compare ecosystem services of trees on ASU's managed campus as well as the adjacent Nature Preserve using i-Tree Eco protocols.

I compared the managed portions of the campus with an adjacent, unmanaged Nature Preserve, both part of ASU's campus. i-Tree Eco protocols were applied to all trees on ASU's 85.8 ha managed campus, as well as plot-based samples in the 27.1 ha Nature Preserve. The complete inventory included 3,228 trees with a canopy cover of 16% on the managed campus. The Nature Preserve contains an estimated 18,812 trees with a canopy cover of 100%. The managed portions of the managed campus consisted of 86 different species from 50 genera. Three species comprised the majority of the trees on the managed campus: white pine (*Pinus strobus*), Canadian hemlock (*Tsuga canadensis*), and sugar maple (*Acer saccharum*) were the most abundant species (39% of the population). Diameter at breast height (DBH) ranged from a 3 cm eastern flowering dogwood (*Cornus florida*) to a 186 cm silver maple (*Acer saccharinum*), while tree height ranged from a 2 m Japanese

snowbell (*Styrax japonicus*) to a 40 m Norway spruce (*Picea abies*). Sixteen exotic species were inventoried on the managed campus, including one invasive, totaling 16% of the population. The Nature Preserve was less diverse, with only 25 species representing 17 genera. Three species comprised the majority of trees in the Nature Preserve: red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), and black cherry (*Prunus serotina*) accounted for 54% of all trees in the Nature Preserve. Diameter at breast height ranged from 4 cm saplings to a 79 cm white oak (*Quercus alba*), while tree height ranged from a 2 m tall white pine to a red oak (*Quercus rubra*) and tulip poplar, which were both 38 m tall.

The i-Tree Eco model can be used to provide estimates of important ecosystem services for ASU's urban forests, such as the ability to offset C emissions through C storage and CO_2 sequestration, and to remove significant amounts of airborne pollutants. The managed forest on ASU's campus is estimated to contain 1,334 mT of C, sequester 39.5 mT of CO_2/year, and potentially removes 1.8 mT/year of pollution from the atmosphere. Using the same model, the Nature Preserve is estimated to contain 4,540 mT of C, sequester 83 mT of CO_2/year, and removes pollution at a rate of 2.1 mT/year.

1. INTRODUCTION

1.1 Urban Forests and Ecosystem Services

Urban forests consist of trees and other woody plants found within the boundaries of cities and suburbs. Urban forests are often undervalued; however, their ecological and economic contributions to urban life justify creating accurate forest inventories such that sound management plans can be enacted (Nowak 1993). Urban forests provide many environmental services, such as the ability to store carbon (C) in both wood and soils and to sequester atmospheric CO_2 annually (Beckett et al. 1998; Nowak et al. 2000; Nowak and Crane 2002; Birdsey 2006; Myeong et al. 2006; Pataki et al. 2006; Jindal et al. 2008) as well as increase local air quality via the absorption of atmospheric pollutants (Beckett et al. 2000; Yang et al. 2005; Nowak et al. 2006). Urban forests also create shade in the visible light spectrum and decrease penetration of ultraviolet-B (UVB) radiation (Heisler et al. 2003). Since UVB radiation has a high diffuse sky radiance and reflects easily it can arrive at a source from many directions. This means that the canopies of urban trees can generate a UVB shadow 20-30% larger than their visible light shadows (Heisler et al. 2003), which serves to protect people from excessive exposure. As a result of these ecosystem services, urban forests can mitigate multiple anthropogenic impacts on the urban environment and therefore, their management and evaluation merit careful consideration.

In addition to sequestering atmospheric CO_2, urban forests also reduce atmospheric CO_2 emissions from anthropogenic sources by lowering energy consumption required for infrastructure cooling via shading and evaporative cooling (Akbari and Taha 1992; Akbari 2002; Simpson 2002; Andrade and Vieira 2007; Donovan and Butry 2009). Urban forests also possess the capacity to offset, and even reverse, the urban heat island effect (Akbari et al. 2001). They also reduce the consumption of heating fuel by providing windbreaks that lower the loss of heat from buildings (Nowak et al. 2008a). Trees can reduce building energy consumption in the summer months and potentially decrease energy use in the winter months, depending on the location of the trees around the building. For example, evergreens that are planted in close proximity to buildings reduce the volume of cold and abrasive winds from impacting infrastructures (McPherson et al. 1997). The capacity for urban forests to alleviate energy consumption throughout the year provides a valuable incentive for cities to implement better urban forest management strategies.

Urban forests can also facilitate tree migration as forest communities respond to climate change. For instance, Woodall et al. (2010) found that most tree species native to the southeastern United States have been planted in northern urban areas. These northern, urban trees could in turn serve as a seed source for the migration of southern native tree species as their original habitats heat up due to global warming. McKenney et al. (2007) investigated the migration of sugar maple in response to climate warming. Sugar maples historically have tolerated the USDA climatic zones 4 through 8 (Mityga 2005) but in recent years, they have shown a significant shift in their range northward of approximately 1000 km (McKenney et al. 2007). Urban forests may therefore act as important reservoirs of trees and seed banks that could facilitate such migrations.

Urban forests can serve as a source for maintaining biodiversity within urbanized areas (Huston and Marland 2003; Nelson et al. 2009). Within the last decade, recent studies indicate that urban forests contain relatively high levels of biodiversity relative to surrounding rural forests, and also often include endangered species (Alvey 2006).

Maintaining urban forest biodiversity is essential for the improvement of long-term ecosystem functioning (Groombridge and Jenkins 2002).

Unfortunately, urban forests can also serve as reservoirs for the spread of non-native and invasive species (Woodall et al. 2010). Recent evidence suggests that climate change has increased the spread of non-natives from urban to natural forests (Dukes and Mooney 1999). If climate change favors some non-native species (Dukes and Mooney 1999), they could gain a competitive advantage over native species. Thus where possible, urban forests should be managed appropriately to mitigate this risk (Woodall et al. 2010), such as by planting only native species, or those that are non-invasive.

Urban trees, when planted in the proper locations, can improve water quality in streams by intercepting and absorbing storm water (Davis et al. 2003; Matteo et al. 2006; Seitz and Escobedo 2011), and reducing soil erosion (Wolman 1967). These same trees can decrease noise levels (Fang and Ling 2003; Fang and Ling 2005) and substantially increase property values within urban areas (Anderson and Cordell 1988; Tyrväinen et al. 2005). With regard to the latter, property values often rise with urban tree quantity and quality and can have potentially large impacts on local economies (Dwyer et al. 1992). The aesthetic quality of urban trees also promotes tourism by inducing repeated visits and longer stays which can increase revenue for cities (Dwyer et al. 1992; McCarthy and Pataki 2010). Lastly, detailed inventories of urban forests can be used to assess liability and risk of urban trees to the public, such as from falling branches or entire trees and limit liability costs for cities and suburbs (Matheny and Clark 2009).

Many urban forest inventories utilize the i-Tree Eco model, which was developed from the Urban Forest Effects (UFORE) model to estimate CO_2 sequestration rates and economic values of urban trees. UFORE was developed by the U.S. Forest Service (USFS) to quantify urban forest structure and function using common inputs of field, pollution, and meteorological data (Nowak and Crane 2000; Cumming et al. 2008). Currently, hundreds of users throughout the United States, and internationally, use i-Tree Eco (i-Tree 2013c, Figure 1.01). i-Tree Eco incorporates several additional aspects of urban forests in order to accurately quantify their impact on the environment; these include species composition and diversity, diameter distributions, tree density and health, leaf area, leaf biomass, and other structural characteristics (i-Tree 2013b). i-Tree Eco provides valuable assets to the user through creation of sample plots (Soares et al. 2011), urban and community forest inventories (Nowak and Greenfield 2009), modeling and quantifying urban forest structure (Nowak et al. 2008b; Escobedo et al. 2008; Huyler et al. 2010; Woodall et al. 2010; Martin et al. 2011), analyzing leaf area index (LAI; Millward and Sabir 2010), contrasting environmental benefits of large versus small trees (Sydnor and Subburayalu 2011), and modeling ecosystem services (Huyler et al. 2010; Martin et al. 2011). Accurate quantification of ecosystem services may encourage communities to strengthen their urban forest management and advocacy efforts (i-Tree 2013a).

1.2 Objectives

The objectives of this study were to: 1) identify all trees on campus, 2) determine the size distributions for each tree species, 3) assess the health and risk status of each tree, and finally, 4) to quantify and compare ecosystem services of trees on ASU's managed campus as well as the adjacent Nature Preserve using i-Tree Eco protocols (i-Tree 2013b). These data will assist with the creation of a long-term management plan, which will increase the aesthetic qualities of the campus, maximize the ecosystem services provided, and maintain campus safety. This process has been implemented and documented on other university campuses and has proven to be a valuable resource for grounds maintenance. Furthermore, ASU, along with the rest of the University of North Carolina System, will have a better understanding of the capacity for urban tree species to store C and sequester CO_2, aiding in sustainability efforts to become carbon neutral by 2050.

2. MATERIALS AND METHODS

2.1 Site Description

Managed Campus

The tree inventory was carried out on two different parts of the Appalachian State University campus, located in Boone, NC (36.2167° N, 81.6747° W) at an elevation of 1,016 m, making it the highest elevation university east of the Mississippi. The first area inventoried was the managed campus, which encompasses 86 ha and is located primarily along a low, flat valley in the middle of the town of Boone, through which flows Boone Creek (Figure 1.02). The second area sampled was the ASU Nature Preserve, 27 ha of unmanaged woodland adjacent to the managed campus. This area was used as a comparison to the managed campus (Figure 1.03).

Nature Preserve

The Nature Preserve is classified as a disturbed, successional, and mixed deciduous forest, with white oak (*Quercus alba)* being the only remnant from pre-disturbed dates. The Nature Preserve is used for educational research as well as for recreational purposes. As an official state Nature Reserve, no permanent buildings and no substantive alterations of the forest are allowed. Within this forest are several kilometers of hiking trails and old logging roads, as well as eight watersheds that feed several creeks and a pond. The Nature Preserve was chosen for comparison to the managed campus forest because it is a large contiguous forest and has a lack of intense management history for at least 50 yrs, as indicated by historical aerial photography from the Natural Agricultural Imagery Program.

2.2 Inventory and Sample Protocol

All managed portions of the managed campus were inventoried according to i-Tree Eco protocols using a Trimble GeoExplorer 2008 and 6000 series GPS (Trimble, Sunnyvale, CA). Real time correction and an external antenna were used to provide sub-meter accuracy (30 cm). Sampling was divided among six management zones designated by the Physical Plant according to use intensity and size (Figure 1.04). Using ArcMap10 and ArcPad10, a building and transportation shapefile was uploaded to the GPS units to aid in determining accurate tree location via visual reference.

The Nature Preserve was sampled via plots according to i-Tree Eco protocols. Using ArcMap10, a 600 m fishnet grid was overlaid onto a 2010 15.2 cm resolution aerial photograph of Watauga County, which was clipped to the size of the Nature Preserve. This 600 m grid created 13 plots (each 0.04 ha) within the study area perimeter. Around each center point, an 11.3 m radius was established to encompass each plot (i-Tree Eco protocol, i-Tree 2013b). The Nature Preserve shapefile, 600 m grid, all 13 plots, and an accessory trail map were uploaded to the Trimble GPS units.

2.3 Model Outputs

i-Tree Eco models urban forest function, based on species composition, tree density, tree health (crown dieback, tree damage), tree cover, and leaf area and biomass. Hourly pollution removal rates for CO, NO_2, O_3, PM, and SO_2 are also estimated. Additionally, the effect of trees on building energy use, the estimation of total C stored in pools, and the amount of CO_2 sequestered annually are all modeled. In addition, i-Tree Eco estimates the structural value of each tree, which is the cost of having to replace a particular tree with a similar tree. The susceptibility of trees to potential pests and diseases, annual rainfall interception by trees, and the exotic species composition of the urban forest are also provided (i-Tree 2013b).

Managed Campus

Field methods were based on i-Tree Eco protocols, which have been used successfully on other campuses (e.g., at Auburn: Huyler et al. 2010 and Martin et al. 2011) to quantify the economic value of urban forests. I also added a hazard assessment of each tree to provide data that could be used to improve campus safety and expedite hazardous tree management.

Data were collected from every tree on the managed campus with a DBH greater than or equal to 2.54 cm at standard height (1.37 m above the ground). Shrubs, as well as trees measuring less than 2.54 cm DBH, were not recorded. If trees forked, and codominate stems existed where the pith union was above ground level (e.g., more than one primary stem), the individual was considered to be one tree and the number of stems were recorded, along with their individual DBHs. In addition, where a standard DBH height was not achievable, I recorded the adjusted DBH height. Up to six separate DBHs on a single individual could be collected. If more than six stems were present, only the six largest were recorded. If the pith union was below ground level, each separate stem was considered as an individual tree and recorded as such. Additional information regarding specific measurement techniques on fallen trees or trees with defects are described in the i-Tree Eco user manual (i-Tree 2013b).

Trees were identified to species, sequentially assigned a unique identification number, and labeled with a biodegradable orange paint dot on the lower trunk to prevent duplicate sampling. The status of each tree was determined (planted, ingrowth, or unknown) as was actual land use (See i-Tree Eco protocol, i-Tree 2013b). Quantitative measurements were recorded for crown width, height to crown base, live height, total tree height, and distance to buildings. All height and distance measurements were determined using a TruPulse® 360 hypsometer (Laser Technology Inc, Centennial, CO) and recorded to the nearest meter. Crown width was measured to the nearest meter along two perpendicular crown diameters. Height to crown base was measured from ground level to the location on the main stem that was perpendicular to the lowest live branches of the main bole. Similarly, live height was measured from ground level to the highest living branches while total tree height included dead branches if they extended above the live ones. Distance to buildings was measured only for those trees measuring at least 6 m tall that were within 18 m of a building that was no more than 3 stories tall. Directions to buildings from each tree were also recorded in degrees via a handheld compass. Up to three different building measurements could be recorded for each tree.

Crown dieback, percent crown missing, and crown light exposure (CLE) were estimated for each tree. Crown dieback is the amount of the crown that is dead and is measured by inspecting the proportion of the crown that is present but visibly dead. Dieback due to shading and self-pruning in the lower portions of the crown was not recorded. Measurements were estimated visually from 0-100% in 5% intervals by inspecting trees from all sides. Percent crown missing refers to the amount of the crown that was lacking branches or leaves. Percent crown missing was determined through visualizing what that species' natural silhouette should resemble and then estimating what portion was missing. Missing portions could be due to pruning, ice, or wind damage. Percent crown missing differs from crown dieback; percent crown missing signifies missing limbs or leaves, while crown dieback quantifies just dead limbs. Crown light exposure describes how many of the five sides (four lateral sides plus top of the crown) of a tree receive direct sun. Lastly, the date and tree site were recorded for each tree, with tree site indicating if the tree was a street tree or not (street trees were classified as trees located near roadways).

Nature Preserve

The center of each plot within the Nature Preserve was located using the overlain 600 m grid and the nearest tree was tagged with an aluminum forestry tag. Data were collected for all trees greater than or equal to 2.54 cm DBH within the 0.04 ha plot. Data collection was similar to the campus inventory, but with some modifications. Supplementary data collected included plot information, such as actual land use, percent of plot able to be measured, tree cover, shrub cover, and percent ground cover. Tree and shrub cover were measured in 5% intervals (i-Tree Eco protocol, i-Tree 2013b). The percent ground cover was determined for each of the different cover materials, e.g., rock, bare soil, mulch, herbs, grass, and water.

2.4 Data Management and Analysis

All measurements were stored on custom ArcPad data entry forms created specifically for ASU. Species composition data were analyzed for diversity using the Shannon-Weaver (S-W) index, evenness, richness, and a species area curve using PC-ORD. Similarity in species composition between the managed campus and the Nature Preserve was assessed using Whittaker's similarity index (Whittaker 1975). Whittaker's index states the coefficient of community (CC) is the proportion of species shared by two communities relative to the total number of species in both communities and is given by: $CC = 2*S_{ab} / (S_a + S_b)$ where S_a and S_b are the number of species on the managed campus and Nature Preserve, respectively, and S_{ab} is the number of species common to both areas (Whittaker 1975).

Additional data were formatted and submitted electronically to i-Tree for analysis. i-Tree Eco incorporated local hourly air pollution concentration and meteorological data from the nearest weather station, Bristol/Johnson/Kingsport Tri Cities Regional Airport (110 km away) to quantify urban forest function.

3. RESULTS

3.1 Species Composition

Diversity

ASU's managed campus contains a total of 3,228 trees with a canopy covering approximately 16% of the campus (Table 1.1; Figure 1.05). Eighty-six different species were identified with the most abundant being white pine (18%), Canadian hemlock (11%) and sugar maple (10%) (Table 1.2; Figure 1.06a; Appendix A). These three species comprised 39% of the total population on the managed campus. The 86 species inventoried represented 50 genera with the most common being maples (*Acer*, 18%), pines (*Pinus*, 18%), and hemlocks (*Tsuga*, 11%); 47% of the trees on the managed campus belong to just these three genera (Figure 1.07a).

Overall species evenness on the managed campus was 0.7 with a diversity of $H' = 3.3$ (Table 1.1). The majority of trees inventoried were located in zones 1, 2, and 3, which are the three largest (Figure 1.08; Figure 1.09). Zone 5 contained the greatest density of trees, 56 trees/ha, whereas zone 2 contained the least density of trees, 24 trees/ha (Table 1.3; Figure 1.10). Zone 2 had the greatest diversity of species ($H' = 3.2$; Table 1.3), whereas zone 1 contained the lowest diversity ($H' = 2.6$; Table 1.3).

A total of 308 trees were inventoried in the ASU Nature Preserve among the 13 sample plots (Table 1.1; Figure 1.05). Species area relationships in the Nature Preserve indicated adequate sampling with 25 species observed and first-order jackknife estimates of 27.8 (Figure 1.11). This extrapolates to a total estimate of 18,812 trees that are located within the Nature Preserve's 27 ha, giving a density of 697 trees/ha and a canopy coverage of approximately 100% (Table 1.1). Species richness was lower in the Nature Preserve, with only 25 different species identified. The most abundant species included red maple (22%), tulip poplar (20%), and black cherry (12 %) (Table 1.2; Figure 1.06b; Appendix B). Similar to the managed campus, the majority of tree abundance resided in just three species, which comprised 54% of all the trees in the Nature Preserve. The species sampled represented 17 genera with the most abundant being maples (*Acer*, 27%), tulip trees (*Liriodendron*, 20%), and oaks (*Quercus*, 13%), comprising 60% of the trees in the Preserve (Figure 1.07b). The overall diversity was also lower, although evenness was slightly higher ($H' = 2.4$, $E = 0.8$; Table 1.1).

The managed campus and the Nature Preserve shared a total of 91 species between them, and Whittaker's (1975) coefficient of community indicated a three percent similarity in species composition between the managed campus and Nature Preserve.

DBH Characteristics

On the managed campus, the smallest diameter tree recorded was a 3 cm eastern flowering dogwood and the largest a 186 cm silver maple. Approximately half of all the trees on the managed campus of ASU were smaller than 15.2 cm DBH (Figure 1.11a). Eight of the most abundant species on the managed campus had DBHs skewed toward small diameters (Figure 1.12). Trees in the Nature Preserve, in contrast, had a smaller range, from several 4 cm saplings to a 79 cm white oak (Figure 1.11b); and like trees on the managed campus, three of the most abundant species in the Nature Preserve had DBHs skewed toward smaller values, whereas the majority of the most abundant species had a normal distribution of DBHs (Figure 1.13).

Height Characteristics

Tree height on the managed campus varied from a 2 m Japanese snowbell to a 40 m Norway spruce (Figure 1.14a). Eight of the most abundant species on the managed campus had height distributions that were skewed toward shorter heights (Figure 1.15a). Tree height in the Nature Preserve was nearly identical to that on the managed campus, ranging from a 2 m white pine to a red oak and tulip poplar that were both 38 m tall (Figure 1.14b). In contrast to the managed campus, eight of the most abundant species in the Nature Preserve had normal height distributions (Figure 1.15b). The median DBH and height for both the managed campus and Nature Preserve were similar at 15 cm and 6 m, respectively (Table 1.1).

Exotic Species

There were 16 exotic species on the managed campus, which comprised 16% of all the trees (Table 1.4; Figure 1.17). Of these exotics, Norway maple (*Acer platanoides*) is the only tree on the managed campus that is characterized as invasive in North Carolina (Table 1.4). None of the tree species sampled within the Nature Preserve were identified as exotic or invasive in North Carolina.

3.2 Ecosystem Services

Managed Campus

According to the i-Tree Eco model, trees in the urban forest on ASU's managed campus constitute a pool size of C of 1,334 mT and they sequester 39.5 mT of CO_2/year from the atmosphere (Figure 1.18a and Figure 1.19a, respectively). Sugar maple, one of the most abundant trees on the managed campus, has the largest pool size of C (144 mT) and sequesters the most CO_2 (3.8 mT/yr) of all the species (approximately 28% of the total C stored each year). Trees on the managed campus store and sequester a median of 36 kg of C and 3 kg/year of CO_2, respectively. Additionally, ASU's managed forest collectively removes 0.9 mT/year of pollutants (CO, NO_2, O_3, PM, and SO_2), with a median tree removal rate of 0.1 kg/year (Figure 1.20a). Throughout campus, O_3 is the predominant pollutant removed according to the i-Tree analysis (Figure 1.20a).

Nature Preserve

The Nature Preserve has a pool size of C of 4,540 mT and sequesters 83 mT/year of CO_2 (Figure 1.18b and 1.19b, respectively). Tulip poplar, a dominant tree in the Nature Preserve, collectively stores and sequesters more C than any other species (approximately 24% of the total pool size of C and 39% of all annual CO_2 sequestered). The Nature Preserve removes a total of 2.1 mT/year of pollutants (Figure 1.20b). Similarly to the managed campus, pollutant removal in the Nature Preserve was also greatest for O_3 (Figure 1.20b).

3.3 Pest Management

Thirty-one pests were analyzed for their potential impact on ASU's urban forests and compared with pest range maps for the conterminous United States. Based on the geographic location of ASU, 12 species of pests have the potential to damage trees located on the ASU campus (Figure 1.21). On the managed campus, pests are tightly controlled through the use of preventative treatments, such as imidacloprid for hemlocks, and pesticides such as horticultural oils (personal communication with ASU Physical Plant, Landscape Services). Trees located on ASU's campus are estimated to be structurally worth $7.3 million (Figure 1.22), which more than justifies current pest management policies. In the Nature Preserve, the trees are unmanaged, allowing pests the potential to pose a significant threat to this forest.

One of the most damaging pests to Canadian and Carolina (*Tsuga caroliniana*) hemlocks is the hemlock woolly adelgid (HWA; *Adelges tsugae*), which has caused extensive mortality in the eastern United States (Ward et al. 2004). Hemlocks constitute 10% of the trees on the managed campus, whereas they comprise only 1% of the Nature Preserve. Currently all hemlocks on the managed campus are treated with soil injections of imidacloprid to prevent infestation by the HWA. However, even though the adelgid is present in the Nature Preserve, no spraying or treatment is done there (personal observation).

Several other pest species pose potential threats to the Nature Preserve. The Asian longhorned beetle (ALB; *Anoplophora glabripennis*) is an introduced insect from Asia that bores into and kills a wide range of hardwood species. Forty percent of the trees on the managed campus can potentially be affected by the ALB, whereas 29% of the trees can be affected in the Nature Preserve. The gypsy moth (GM; *Lymantria dispar*) is a generalist defoliator and one of the most destructive pests that feed on hardwoods (Lechowicz and Mauffette 1986). The gypsy moth causes widespread defoliation and tree death if outbreak conditions last several years (Ostfeld et al. 1996). This pest threatens 40% of the trees on the managed campus as well as 21% of those in the Nature Preserve. Oak wilt (OW), which is caused by a fungus (*Ceratocystis fagacearum*), is a prevalent disease among oak species (Juzwik et al. 2008; Horie et al. 2013) and is spread from diseased to healthy trees via insect vectors or vascular connections between roots. OW poses a threat to seven percent of the trees on the managed campus and 13% of those in the Nature Preserve.

4. DISCUSSION

ASU's urban forests support a large diversity of trees that provide numerous ecosystem services, including C storage and CO_2 sequestration, pollution removal, and enhancement of aesthetic qualities. A detailed tree inventory such as the one performed in this thesis will enable the implementation of sustainable management plans that consider strategic species selections and placement, ensuring the growth of larger, healthier, and more valuable trees that will maximize ecosystem services on the campus.

4.1 Community Composition

Size, Species Richness, Diversity and Evenness

The urban forest on the ASU campus is similar in some respects to that on the campus of Auburn University, in Auburn, Alabama as conducted by Huyler et al. (2010). Both campuses had similar size distributions skewed toward smaller trees, and canopy cover on both campuses was comparable in extent. There were some notable exceptions though. The Auburn University campus had many more trees than the ASU managed campus (7,345 vs 3,228, respectively) and greater species richness (139 vs 86 species, respectively). This is due partially to the fact that Auburn's campus is much larger than ASU's (~ 238 ha vs 86 ha, respectively) as well as the fact that Martin et al. (2011) tallied over 2,000 crepe myrtles (*Lagerstroemia indica*) while I did not count those shrubs in my survey. Additionally, Huyler et al. (2010) determined that the tree density at Auburn was 985 trees/ha via randomized plot based samples, which incorporated both managed and unmanaged plots, compared to ASU's 697 trees/ha via a complete tree inventory of only the managed campus.

The managed forest on campus differs strikingly from the adjacent Nature Preserve. For instance, of the 10 most abundant species located on the managed campus, only two are in common with the 10 most abundant species in the Nature Preserve. This difference in community composition is further accentuated by the low Community of Coefficient (~3%) which shows that among all species on the managed campus and in Nature Preserve, only three percent are found in both communities. This difference in communities is not due to planting nonnative trees, as the majority of trees found on the managed campus are native to the region, but rather due to different selection criteria. Tree species in the nature preserve are determined by species abundance and seed dispersal traits, whereas tree species on the managed portions of campus are chosen for characteristics such as climate hardiness, susceptibility to injury, growth characteristics, architecture, suitability, and/or aesthetic qualities.

Although plant species richness seems low within the Nature Preserve, with only 25 different species identified, my species area curve indicated that the 13 plots captured most of the tree species richness in the Preserve; jackknife estimates, for example, predicted total species richness should be ~28 (Figure 1.11). However, many plants were not sampled because their DBHs fell below the minimum sampling threshold of 2.54 cm, so community species richness is certainly underestimated to some extent (Whittaker 1956; Barden 1981; Zipperer et al. 1997; Beckage et al. 2000; personal observation). A study of cove forests in the Great Smoky Mountains National Park (Busing 1998) showed tree species richness varying between 10 and 20 species/ha, which is similar to, but slightly lower than, that found in the Nature Preserve. Whether species richness can be maintained is another matter, since many southern Appalachian forests are fire dependent (Reilly et al. 2006; Dumas et al. 2007; Holzmueller et al. 2009; Flatley et al. 2011) and in the absence of fire, species richness declines (Webster et al. 2005). Overgrazing by deer can also reduce species richness

(Webster et al. 2005). The natural area may face long-term declines in species diversity as fire is actively suppressed and deer populations are high throughout urban areas in the southeast (Webster et al. 2005).

Species richness is also likely underestimated for the managed portions for campus because I did not sample the large variety of small trees and large woody shrubs that have been planted throughout campus but which fell below the minimum DBH sampling threshold (personal observation). For instance, the shrubs rhododendron (*Rhododendron maximum and R. catawbiense*) and mountain laurel (*Kalmia latifolia*) are not included in the inventory, yet these species are abundant in flowerbeds on campus and dominate the eastern/western facing lower elevation slopes of the Nature Preserve.

Diameters and heights for both sampling areas are not normally distributed, but rather, are skewed toward smaller trees. Such skewed distributions are both typical of college campuses (Huyler et al. 2010; Martin et al. 2011) and southern Appalachian forests (Lorimer 1980; Clebsch and Busing 1989; Hedman and Van Lear 1995). Two primary reasons contribute to this on the managed campus. First, recent construction of new buildings has promoted the planting of many young trees. Second, lapses in management and poor tree placement in the past have caused many trees on campus to die prematurely. Consequently, many stressed and decaying trees have been removed recently and replaced with younger, smaller trees. Small trees predominate in the Nature Preserve due to the recent formation of canopy gaps during the winter months as a result of heavy accumulations of ice and snow that cause branch failure and tree falls. Such events encourage the germination and growth of younger trees to fill in the canopy gaps (Runkle 1998; Darwin et al. 2004).

Exotic Species

Urban forests are usually composed of a mix of native and exotic tree species (Zipperer et al. 1997; Woodall et al. 2010). Consequently, urban forests often have higher tree diversity than do surrounding native landscapes (Huston and Marland 2003; Alvey 2006). Increased tree diversity can minimize the overall impact or destruction by species-specific insects or diseases, but can also pose a risk to native plants if some of the exotic species are invasive and escape into the surrounding environment. Invasive plant species have been transferred from infested areas to non-infested areas accidentally via the horticultural industry for years (Westbrooks 1998). Invasive plant species are often characterized by their high vigor, ability to adapt to new habitats, a high reproductive capacity, and a lack of natural enemies, all of which enable them to often out-compete and displace native species (Callaway and Aschehoug 2000; Woodall et al. 2010). It makes sense then for urban foresters to adopt management plans that limit their planting of known invasive species.

4.2 Ecosystem Services

Urban trees can mitigate climate change by storing C in their wood and by annually sequestering atmospheric CO_2 (Nowak and Crane 2002). As tree biomass increases, their capacity to store and sequester atmospheric CO_2 also increases (Nowak and Crane 2002). The long-term C storage dynamics of urban trees change nonlinearly with tree size, and consequently, tree age. Trees with a DBH greater than 77 cm store as much as 1,000 times more C than do trees with a DBH less than 8 cm (McPherson et al. 1994). Likewise, large healthy trees annually sequester ~90% more CO_2 than do small healthy trees (McPherson et al. 1994). In contrast to earlier assumptions, increasing trends in C accumulation with tree age may continue for centuries in old-growth forests (Luyssaert et al. 2008).

Urban and native forests experience contrasting environmental constraints that regulate tree growth and development. Within natural forest settings, trees typically grow in dense stands allowing for a greater amount of C storage per hectare than in urban forests. Alternatively, urban settings have the capacity to foster large individual tree growth in short periods of time due to generous amounts of space allocated for each tree. On a per tree basis, trees that inhabit urban forests have the capacity to store and sequester four times as much atmospheric CO_2 as do trees in forested stands (Nowak and Crane 2002). The increase in CO_2 sequestration in urban trees is largely due to urban forestry practices that maintain large, healthy trees (McPherson et al. 1994). A similar pattern was demonstrated here, as managed trees stored more C per tree than did trees in the Natural Preserve (413.3 kg C/tree, and 241.3 kg C/tree, respectively). Without incorporating shrub data, belowground biomass, and soil C, the C storage and CO_2 sequestration capacity of ASU's managed campus and Nature Preserve are likely significantly under estimated (McPherson et al. 1994; Pouyat et al. 2002).

Anthropogenic activities in urban environments cause stress and decrease the ability of urban forests to store C. For instance, pedestrian traffic compacts the soil, which increases soil bulk density (Nowak and McBride 1991), therefore reducing root growth and functioning. In urban environments, trees also experience significantly more wounding (Nowak and McBride 1991). As trees grow, the canopy widens and shades the lower branches, causing branch die off due to lack of light. Urban trees that are located in open spaces, such as courtyards and along roadsides, gather more sidelight. This additional light gathering capability assists the tree in preserving and maintaining the lower branches.

Nonetheless, unique stresses experienced by urban trees such as compromised roots (lack of space), low exploration of soil by roots, and surrounding land use, all directly affect their overall health. Typically, managed forests show signs of more stress resulting in large dead limbs and greater decay than comparable unmanaged forests (Nowak and McBride 1991). The increased level of stress negatively affects the ability of the trees to store C and sequester CO_2 as efficiently as they could otherwise.

Understanding the importance of tree quality versus tree quantity highlights the importance for proper management of high quality urban trees versus the planting of numerous young trees. My results demonstrated that C storage is not always directly related to species abundance. For instance, on the managed campus, Canadian hemlock is the second most abundant species, but ranks tenth in C stored.

Poor air quality is a common problem in many urban areas and can damage human health, landscape materials, ecosystem processes, and impact visibility (Beckett et al. 1998). Annual pollution removal per tree was greatest in the managed urban environment compared to the unmanaged Nature Preserve (0.6 kg/year, and 0.1 kg/year, respectively). Urban forests can improve air quality by reducing air temperature via transpiration, directly removing pollutants from the air, and reducing energy consumption in buildings, which indirectly reduces air pollutant emissions from regional power plants (Yang et al. 2005). While trees also emit volatile organic compounds that can contribute to O_3 formation, integrative studies have demonstrated that an increase in tree cover leads to reduced O_3 formation (Nowak et al. 2000). The easiest way to facilitate pollution removal in urban environments is to encourage better management practices that prolong the life of older trees, as well as implement the planting of more high quality, long-lived tree species.

Estimates of tree effects on energy usage were based on field measurements of tree distance and direction to space conditioned residential buildings (i-Tree 2013b). Energy savings throughout campus were miniscule due to tree location. Trees of adequate size were not close enough to buildings to reduce energy costs. Other i-Tree Eco studies (Huyler et al. 2010; Martin et al. 2011) failed to mention energy cost reductions, possibly for the same reasons. Therefore, management strategies must explicitly plan to locate trees strategically if the goal is to reduce cooling costs in the summer and mitigate heat loss in the winter (Huyler et al. 2010).

4.3 Pest Management

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value, and sustainability of urban forests (Alvey 2006). As pests tend to have differing tree hosts, the potential damage from, or risk of, each pest will differ among locales. Pests are strictly controlled throughout ASU's managed campus, but they can pose a significant threat to the untreated trees residing in the Nature Preserve. Currently the most important infestation is the hemlock woolly adelgid, which is a non-native pest and has become the greatest threat to both Canadian and Carolina hemlocks. The hemlock woolly adelgid can also infest ornamental hemlocks that are typically used in landscaping within urban settings (Cheah et al. 2004).

Hemlocks provide essential habitat for both aquatic and terrestrial fauna as well as play a crucial role in the ecology of the forest in the eastern United States (Ward et al. 2004). They are a shade tolerant, long-lived species with thick evergreen canopies that provide preferred habitat for many species of mammals and birds, and are fundamental riparian species (Ward et al. 2004). Shade created by these trees cools mountain trout streams, increasing benthic micro-invertebrates and the fecundity of native fishes (Ward et al. 2004). Imidacloprid is the most widely used insecticide that targets a wide range of pests including hemlock woolly adelgid (Ward et al. 2004). Imidacloprid can be applied as a soil treatment, trunk injection, or a foliar spray (Cowles et al. 2006). However, residual imidacloprid has the potential to harm non-target organisms, primarily aquatic ones, through the process of biomagnification (Priya and Maruthi 2010). In addition, chemical treatment is both labor intensive and expensive and as a result, there are no practical methods to treat entire stands of hemlocks safely and cost effectively.

Other pests that have the capability of infecting and spreading through the Nature Preserve include the Asian longhorned beetle, gypsy moth, and oak wilt.

4.4 Management Implications

Currently, resources should be primarily focused toward the upkeep of all mature trees on campus, since they provide the most environmental services. Secondly, Landscape Services should devote more time toward the planting of new trees in more appropriate locations where runoff, pedestrian traffic, and infrastructure will not pose risks to tree health. Trees planted on the ASU campus, which is located at 1,100 m elevation, must withstand severe winters on occasion. These winters are characterized by cold minimum temperatures, snow and ice, and often high winds. This means that tree species that are susceptible to cold, or have brittle wood which could snap or break off in the wind, should be avoided. For example, I would not recommend planting any *Pinus* species due to their tendency to buckle and crack under the weight of ice and snow, especially when grown as isolated individuals or in small stands as often occurs in urban environments. I would also discourage planting maples (*Acer* species) where runoff is common because of their susceptibility to de-icing salts, which can kill these species. Those trees that thrive well on campus tend to be the oaks (*Quercus* species), some maples (*Acer* species; if planted in the proper locations), and hornbeams (*Carpinus* species), which have very hard wood.

Currently, the majority of trees on the managed campus belong to just a few dominant species. Managed urban forests should adequately represent the native fauna in both species and abundance. Species and genera should be more evenly distributed throughout campus. Although diversity may not necessarily promote additional environmental services, it can prolong the life of urban forests due to lower susceptibility to pests (particularly specialists) and increase overall tolerance to weather events (Alvey 2006). Consequently, managers should consider species diversity when considering the long-term CO_2 sequestration ability of urban forests.

5. CONCLUSION

Appalachian State University has a large urban forest on its managed campus and on the State Nature Preserve located nearby, both of which are located in a primarily rural area in the southern Appalachian Mountains. These forests provide valuable environmental services such as C storage, CO_2 sequestration, and pollution removal. Although located adjacent to each other, the managed campus forest and the Nature Preserve forest represent two distinct communities, with only three percent similarity. Both locations represent deciduous mesophytic forests, which are characteristic of the southern Appalachian Mountains. Smaller trees dominate both communities. The Nature Preserve removes more pollution and C annually than does the managed campus due to the greater abundance of trees. The amount of C stored and CO_2 sequestered annually is represented in a few dominant species for both comminutes. Although certain species of trees may be more abundant, the C storage capacity is directly related to biomass and not necessarily abundance.

As trees grow in size, their above and below ground biomass have the capacity to provide increasing amounts of environmental services, such as C storage and CO_2 sequestration. The large number of small diameter trees that dominate this urban forest due to new plantings on the managed campus and recent canopy gaps in the Nature Preserve indicate that C storage and CO_2 sequestration will likely increase, as trees mature, if properly maintained. Additionally, further analysis of other properties owned by ASU such as the remaining small forested plots on campus, Gilley Property (Todd, NC), sustainability farms (Valle Crucis, NC; Ashe Co., NC), Dark Sky Observatory, Camp Broadstone, and other satellite locations will improve the inventory of university owned properties that contribute significant ecosystem services.

As the public becomes more environmentally conscious, there is a greater drive to be C neutral. Although CO_2 sequestration has largely been focused on agricultural lands, urban and suburban areas like Appalachian State University represent significant opportunities to offset C emissions. However, these areas have not been effectively explored for their full potential. In order for us to maximize the amount of C stored and CO_2 sequestered, as well as pollution removed from the atmosphere, we must protect the trees we have as well as implement strategic tree plantings around buildings for additional energy savings and services. The ability to better understand urban forests, as well as the overall benefits of specific trees, will aid land managers in mitigating negative impacts of an ever increasing human population.

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TABLES

Table 1.1 Summarization of urban forest inventory for the managed campus and Nature Preserve.

	Managed Campus	**Nature Preserve**
Number of trees	3,228	18,812
Number of species	86	25
Number of genera	50	17
Median DBH (cm)	15	15
Median tree height (m)	6	6
Median tree crown width (m)	5	5
Estimated canopy cover (%)	16	100
Species richness	86	25
Species evenness	0.75	0.77
Shannon-Weaver	3.3	2.4
Structural tree value (US $)	3,659,855	4,510,000

Table 1.2 Tree characteristics for the 10 most common species on the managed campus and Nature Preserve.

Species	No. Trees	Median DBH (cm)	Median Height (m)	Median Crown Width (m)
Managed Campus				
Pinus strobus	585	32	17	7
Tsuga canadensis	351	12	3	3
Acer saccharum	338	22	10	9
Cornus florida	146	14	5	6
Acer rubrum	144	17	9	7
Prunus serrulata	127	15	5	5
Quercus palustris	108	17	9	8
Ilex opaca	91	9	3	2
Prunus serotina	75	32	17	7
Amelanchier arborea	71	9	4	4
Nature Preserve				
Acer rubrum	4152	11	11	4
Liriodendron tulipifera	3728	26	22	5
Prunus serotina	2288	27	23	7
Quercus rubra	1779	15	16	6
Hamamelis virginiana	1356	5	4	3
Robinia pseudoacacia	1017	22	24	3
Acer pensylvanicum	847	6	6	4
Halesia carolina	678	19	16	8
Quercus prinus	508	54	24	12
Fraxinus pennsylvanica	424	39	23	9

Table 1.3 Tree inventory data for each zone on the managed portions of campus.

	No. Trees	No. Species	No. Genera	Trees/ha	S-W
Zone 1	686	44	28	45	2.6
Zone 2	412	41	25	24	3.2
Zone 3	663	46	28	36	3.1
Zone 4	393	48	31	33	3.1
Zone 5	665	53	34	56	3.1
Zone 6	409	46	31	36	3.1

Table 1.4 Exotic species found on the managed campus.

Scientific Name	Origin	% Abundance
Prunus serrulata	China, Japan, Korea	3.9
Cedrus atlantica	Northwest Africa	2.0
Carpinus betulus	Asia, Europe	1.9
Cornus kousa	Japan, Korea	1.8
Acer palmatum	China, Japan, Korea, Mongolia, Russia	1.7
Ginkgo biloba	China	1.4
Picea abies	Europe	1.1
*Acer platanoides**	Europe, West Asia	0.8
Chionanthus retusus	China, Japan, Korea	0.5
Acer griseum	Central China	0.4
Fagus sylvatica	Europe	0.2
Ulmus parvifolia	China, Japan, Korea	0.2
Styrax japonicus	China, Japan, Korea	0.1
Koelreuteria paniculata	China	0.1
Morus alba 'pendula'	China	0.0
Prunus cerasifera	Persia	0.0
	Total	**16%**

*Invasive in North Carolina

FIGURES

Figure 1.01. Map of i-Tree users as of January 2012 (773 users in the United States).

Figure 1.02. 2010 15.2 cm resolution aerial photograph of the main portions of Appalachian Sate University's managed campus.

Figure 1.03. 2010 15.2 cm resolution aerial photograph of Appalachian State University's Nature Preserve (outlined in blue).

Figure 1.04. Appalachian State University's zone map.

Figure 1.05. 2010 15.2 cm resolution aerial photograph of the complete inventory of Appalachian State University's managed campus and sampled Nature Preserve (oulined in blue). Individual dots indicate the trees where data were collected.

Figure 1.06. (a) Percent abundance of the 25 most common species inventoried on the managed campus and (b) all species sampled in the Nature Preserve.

Figure 1.07. (a) Proportion of the population for the 10 most abundant genera for the managed campus and (b) Nature Preserve.

Figure 1.08. Proportion of tree abundance for each zone on the managed campus.

Figure 1.09. Proportion of the population for the 10 most abundant species for each zone on the managed campus.

Figure 1.10. Number of trees per hectare for each zone on the managed campus.

Figure 1.11. Species area curve for the plots sampled in the Nature Preserve.

Figure 1.12. (a) Percent abundance of tree population by DBH class on the managed campus and (b) Nature Preserve.

Figure 1.13. Percent abundance of tree population by DBH class for the 10 most abundant species on the managed campus. Arranged from most abundant to least abundant (left to right).

Figure 1.14. Percent abundance of tree population by DBH class for the 10 most abundant species in the Nature Preserve. Arranged from most abundant to least abundant (left to right).

Figure 1.15. (a) Percent abundance of tree population by height class on the managed campus and (b) Nature Preserve.

Figure 1.16. Percent abundance of tree population by height class for the 10 most abundant species on the managed campus. Arranged from most abundant to least abundant (left to right).

Figure 1.17. Percent abundance of tree population by DBH class for the 10 most abundant species in the Nature Preserve. Arranged from most abundant to least abundant (left to right).

Figure 1.18. 2010 15.2 cm resolution aerial photograph of the managed campus with exotic trees represented with blue dots.

Figure 1.19. Carbon storage (columns) and associated monetary value (points) for the 10 most abundant trees on (a) the managed campus and (b) the Nature Preserve.

Figure 1.20. Carbon dioxide sequestration rates for the most significant contributing species on the managed campus (a) and Nature Preserve (b).

Figure 1.21. Structural values of the most common species found on the managed campus.

Figure 1.22. Annual pollution removal (columns) and associated monetary value (points) for trees on the managed campus (a) and Nature Preserve. Pollutants: CO (carbon monoxide), NO_2 (nitrogen dioxide), O_3 (ozone), PM_{10} (particulate matter less than 10 microns), $PM_{2.5}$ (particulate matter less than 2.5 microns).

Figure 1.23. Pests that have the potential to cause devastating effects to the trees within the Nature Preserve. Black indicates that the pest is within the county; medium grey indicates that the pest is within 402 km (250 mi) of the county; light grey indicates that the pest is within 1207 km (750 mi) of the county; and white indicates that the pest is > 1207 km away.

Figure 1.01

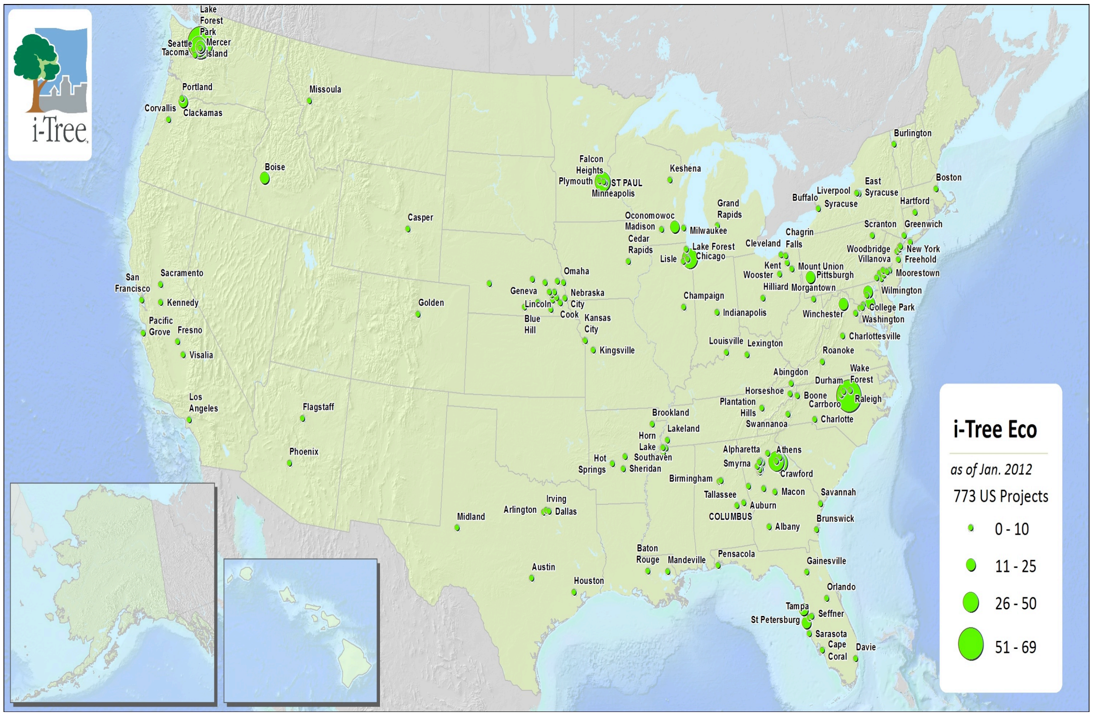

i-Tree
i-Tree Eco
as of Jan. 2012
773 US Projects
0 - 10
11 - 25
26 - 50
51 - 69

Figure 1.02

Figure 1.03

Figure 1.04

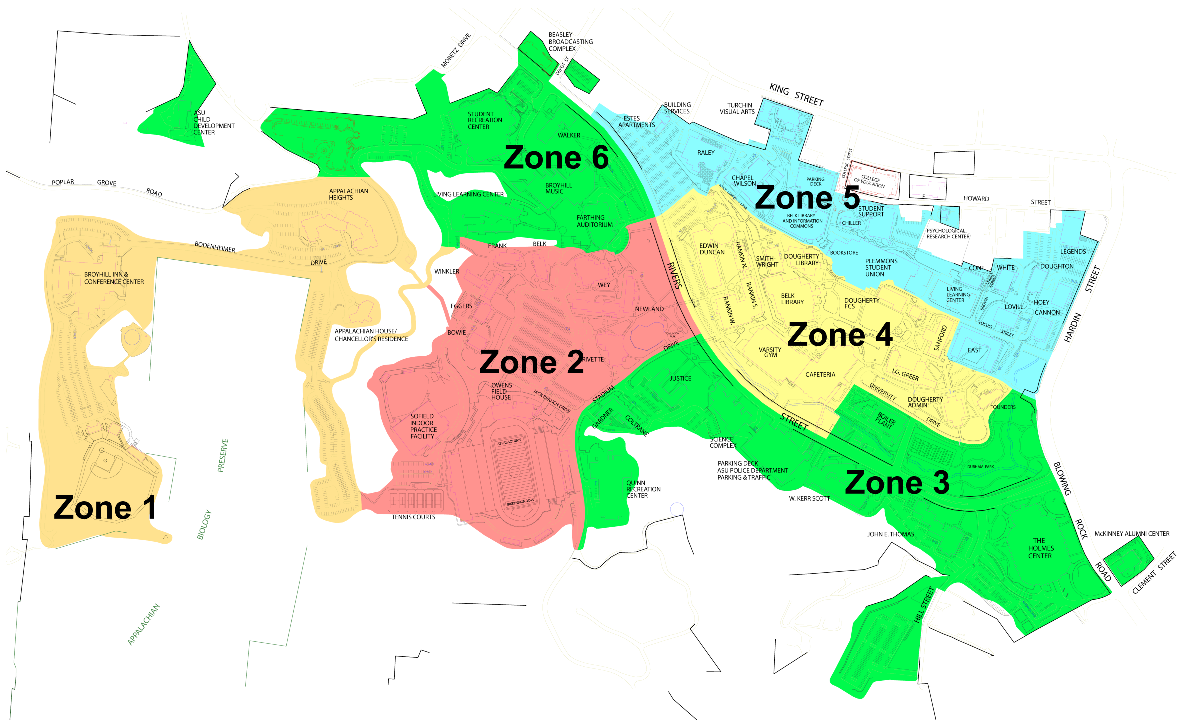

Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
KING STREET
HOWARD STREET
HARDIN STREET
BLOWING ROCK ROAD
RIVERS STREET
POPLAR GROVE ROAD
BODENHEIMER DRIVE
APPALACHIAN BIOLOGY PRESERVE
BROYHILL INN & CONFERENCE CENTER
APPALACHIAN HEIGHTS
APPALACHIAN HOUSE/ CHANCELLOR'S RESIDENCE
ASU CHILD DEVELOPMENT CENTER
STUDENT RECREATION CENTER
BEASLEY BROADCASTING COMPLEX
LIVING LEARNING CENTER
BROYHILL MUSIC
FARTHING AUDITORIUM
WALKER
TENNIS COURTS
SOFIELD INDOOR PRACTICE FACILITY
OWENS FIELD HOUSE
QUINN RECREATION CENTER
SCIENCE COMPLEX
JOHN E. THOMAS
THE HOLMES CENTER
McKINNEY ALUMNI CENTER
CLEMENT STREET
HILL STREET
BELK LIBRARY
PLEMMONS STUDENT UNION
DOUGHERTY LIBRARY
VARSITY GYM
CAFETERIA
DOUGHERTY ADMIN.
EDWIN DUNCAN
TURCHIN VISUAL ARTS
ESTES APARTMENTS
BUILDING SERVICES
RALEY
CHAPEL WILSON
PSYCHOLOGICAL RESEARCH CENTER
LEGENDS
DOUGHTON
HOEY
CANNON
LOVILL
WHITE
EAST
JUSTICE
NEWLAND
WEY
WINKLER
EGGERS
BOWIE
FRANK
BELK

Figure 1.05

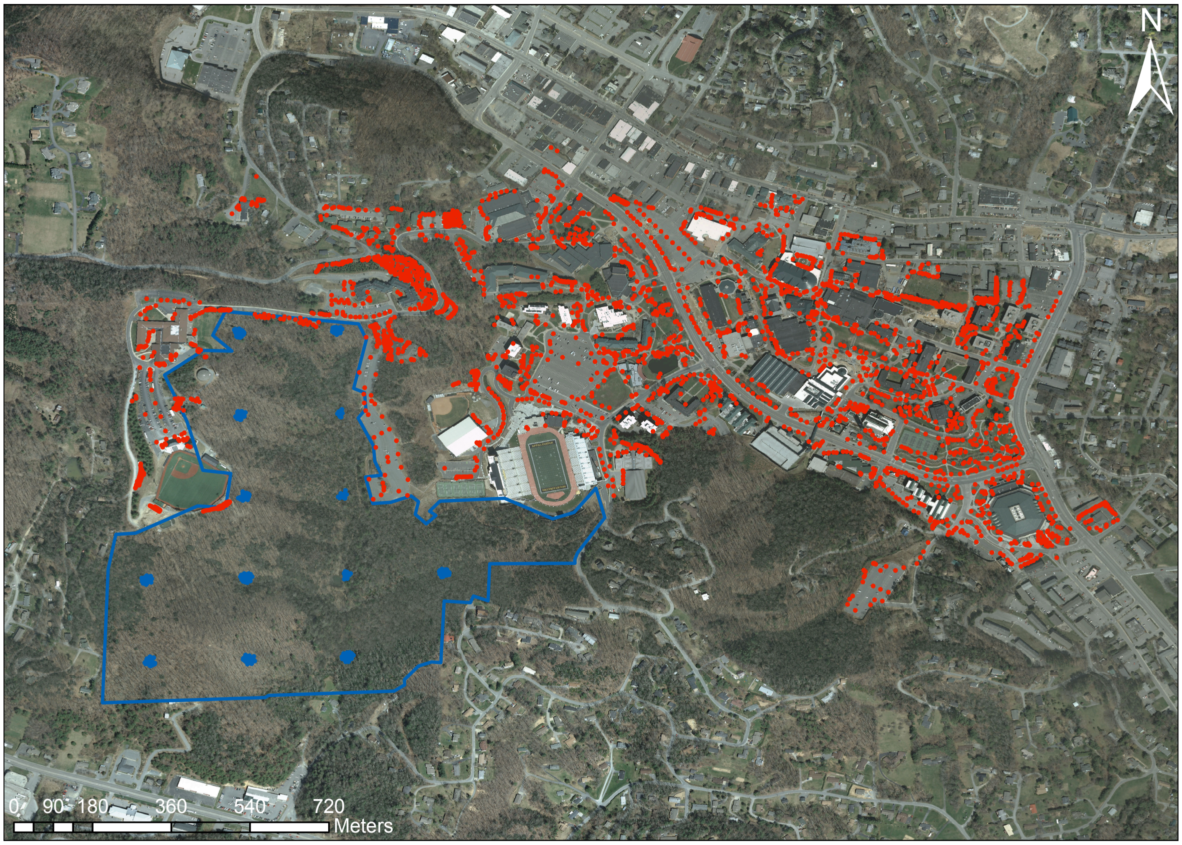
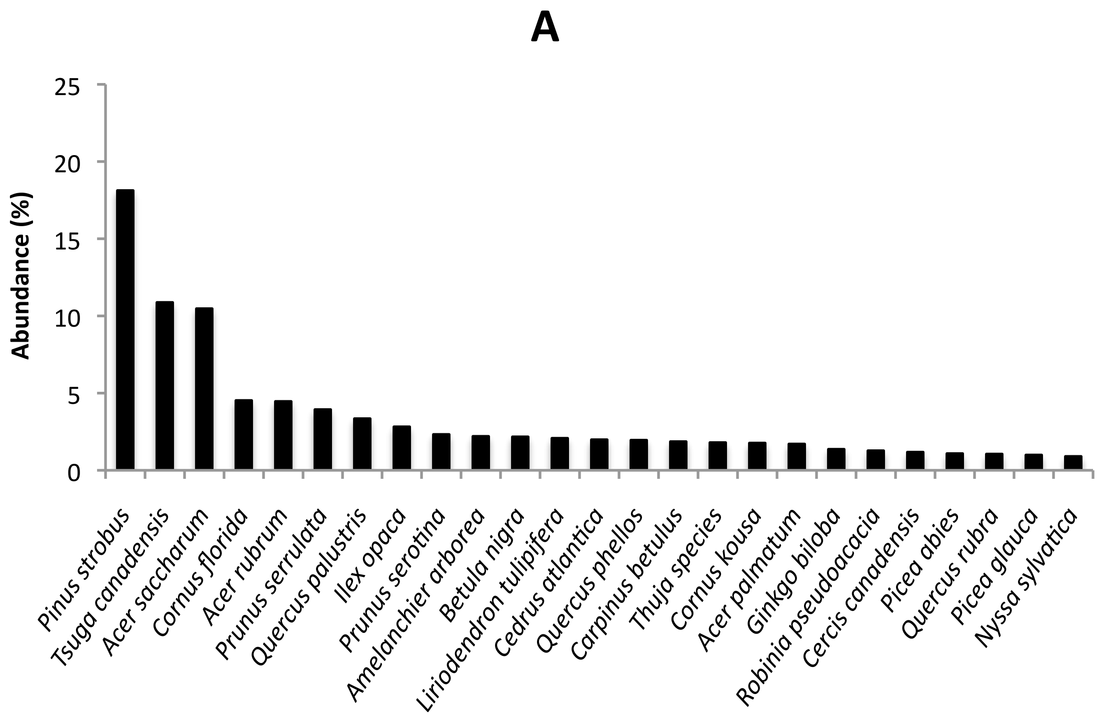


Figure 1.06


A
25
20
15
10
5
0
Abundance (%)
Pinus strobus
Tsuga canadensis
Acer saccharum
Cornus florida
Acer rubrum
Prunus serrulata
Quercus palustris
Ilex opaca
Prunus serotina
Amelanchier arborea
Betula nigra
Liriodendron tulipifera
Cedrus atlantica
Quercus phellos
Carpinus betulus
Thuja species
Cornus kousa
Acer palmatum
Ginkgo biloba
Robinia pseudoacacia
Cercis canadensis
Picea abies
Quercus rubra
Picea glauca
Nyssa sylvatica

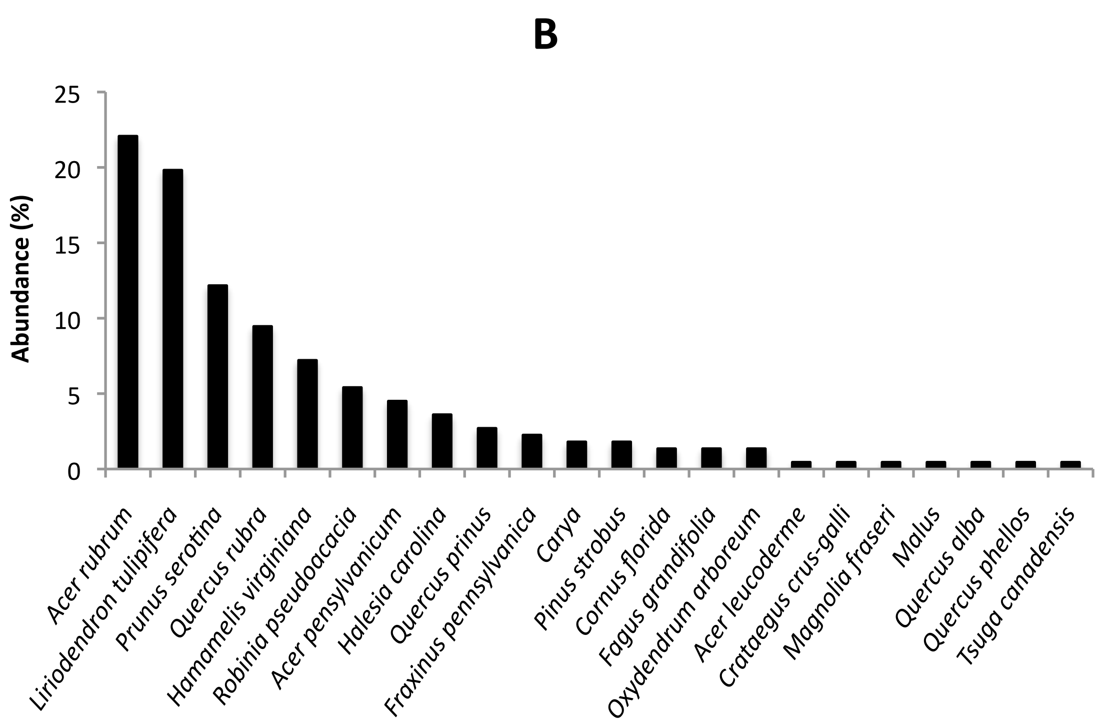

B
25
20
15
10
5
0
Abundance (%)
Acer rubrum
Liriodendron tulipifera
Prunus serotina
Quercus rubra
Hamamelis virginiana
Robinia pseudoacacia
Acer pensylvanicum
Halesia carolina
Quercus prinus
Fraxinus pennsylvanica
Carya
Pinus strobus
Cornus florida
Fagus grandifolia
Oxydendrum arboreum
Acer leucoderme
Crataegus crus-galli
Magnolia fraseri
Malus
Quercus alba
Quercus phellos
Tsuga canadensis

Figure 1.07

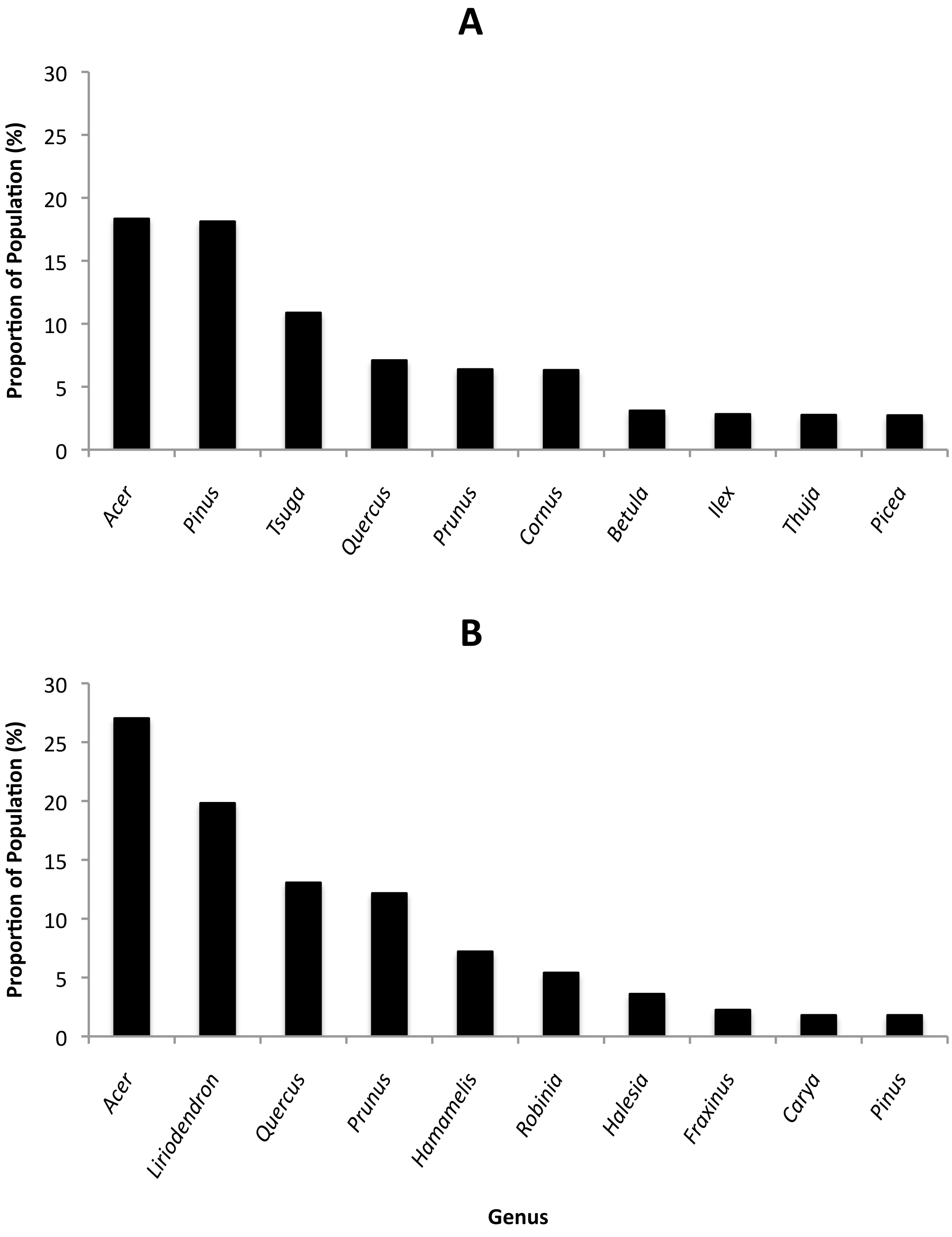

A
30
25
20
15
10
5
0
Proportion of Population (%)
Acer
Pinus
Tsuga
Quercus
Prunus
Cornus
Betula
Ilex
Thuja
Picea
B
30
25
20
15
10
5
0
Proportion of Population (%)
Acer
Liriodendron
Quercus
Prunus
Hamamelis
Robinia
Halesia
Fraxinus
Carya
Pinus
Genus

Figure 1.08

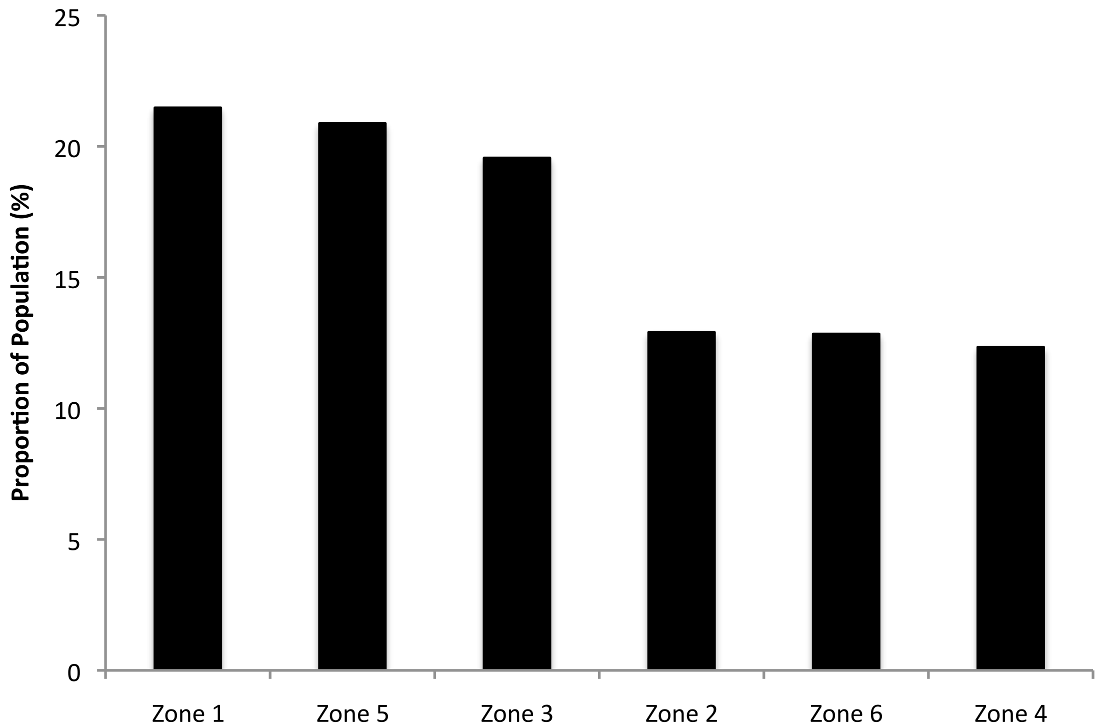

25
20
15
10
5
0
Proportion of Population (%)
Zone 1
Zone 5
Zone 3
Zone 2
Zone 6
Zone 4

Figure 1.09

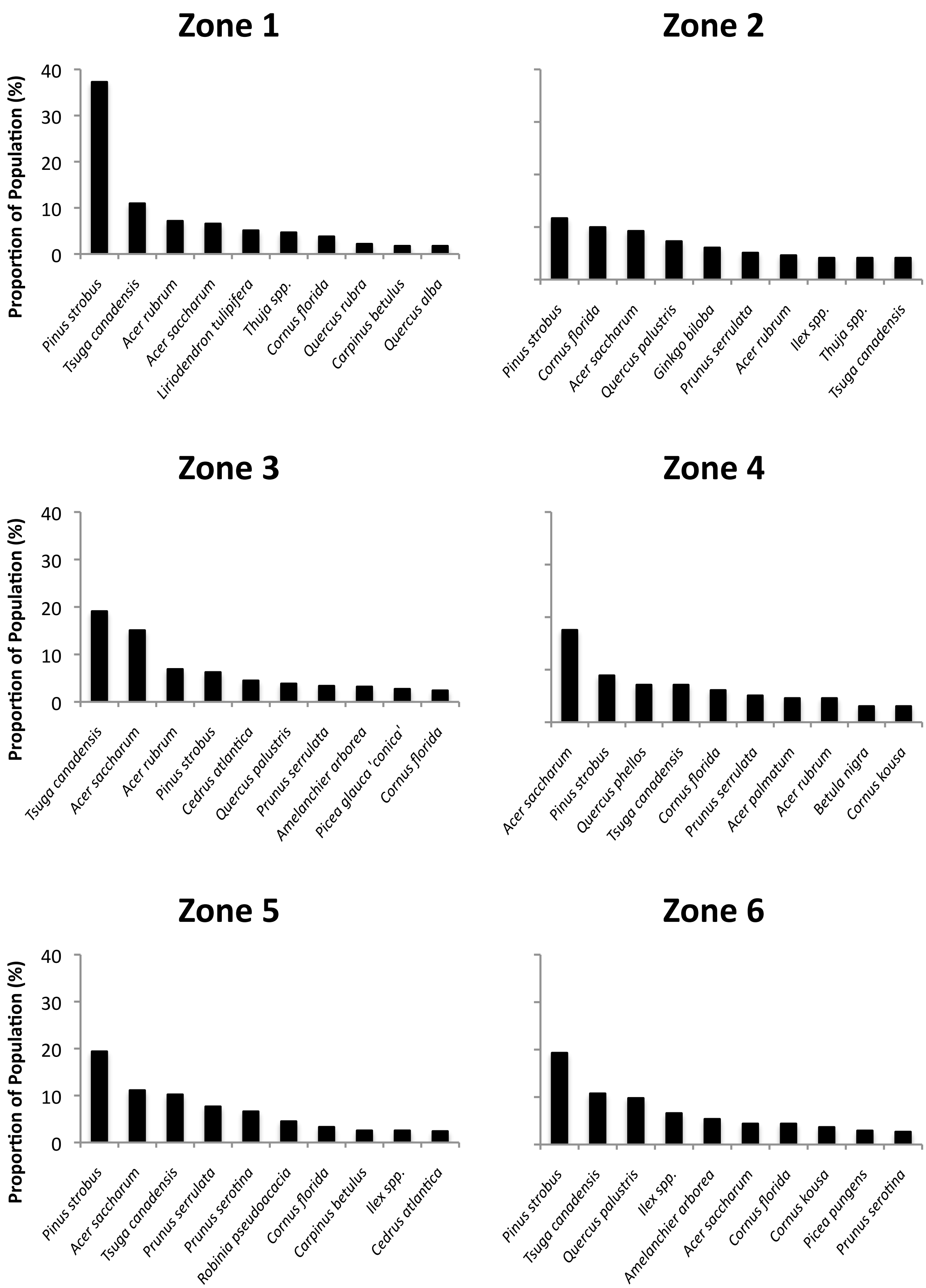
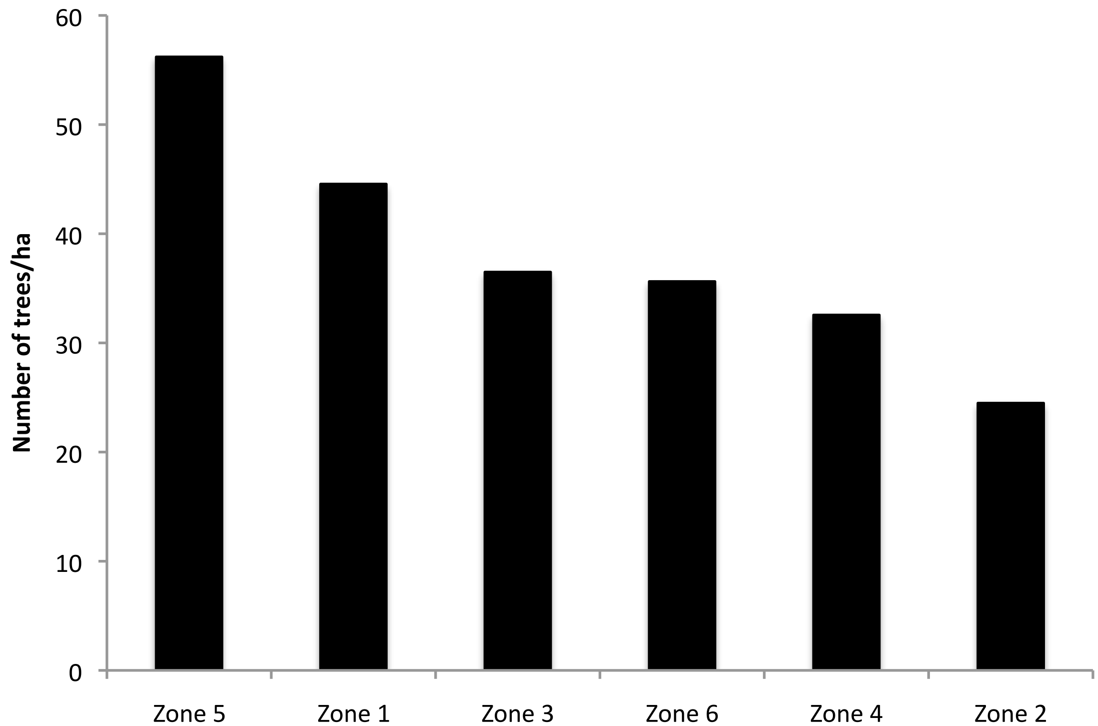

Zone 1
Proportion of Population (%)
40
30
20
10
0
Pinus strobus
Tsuga canadensis
Acer rubrum
Acer saccharum
Liriodendron tulipifera
Thuja spp.
Cornus florida
Quercus rubra
Carpinus betulus
Quercus alba
Zone 2
Pinus strobus
Cornus florida
Acer saccharum
Quercus palustris
Ginkgo biloba
Prunus serrulata
Acer rubrum
Ilex spp.
Thuja spp.
Tsuga canadensis
Zone 3
Proportion of Population (%)
40
30
20
10
0
Tsuga canadensis
Acer saccharum
Acer rubrum
Pinus strobus
Cedrus atlantica
Quercus palustris
Prunus serrulata
Amelanchier arborea
Picea glauca 'conica'
Cornus florida
Zone 4
Acer saccharum
Pinus strobus
Quercus phellos
Tsuga canadensis
Cornus florida
Prunus serrulata
Acer palmatum
Acer rubrum
Betula nigra
Cornus kousa
Zone 5
Proportion of Population (%)
40
30
20
10
0
Pinus strobus
Acer saccharum
Tsuga canadensis
Prunus serrulata
Prunus serotina
Robinia pseudoacacia
Cornus florida
Carpinus betulus
Ilex spp.
Cedrus atlantica
Zone 6
Pinus strobus
Tsuga canadensis
Quercus palustris
Ilex spp.
Amelanchier arborea
Acer saccharum
Cornus florida
Cornus kousa
Picea pungens
Prunus serotina

Figure 1.10



60
50
40
30
20
10
0
Number of trees/ha
Zone 5
Zone 1
Zone 3
Zone 6
Zone 4
Zone 2

Figure 1.11

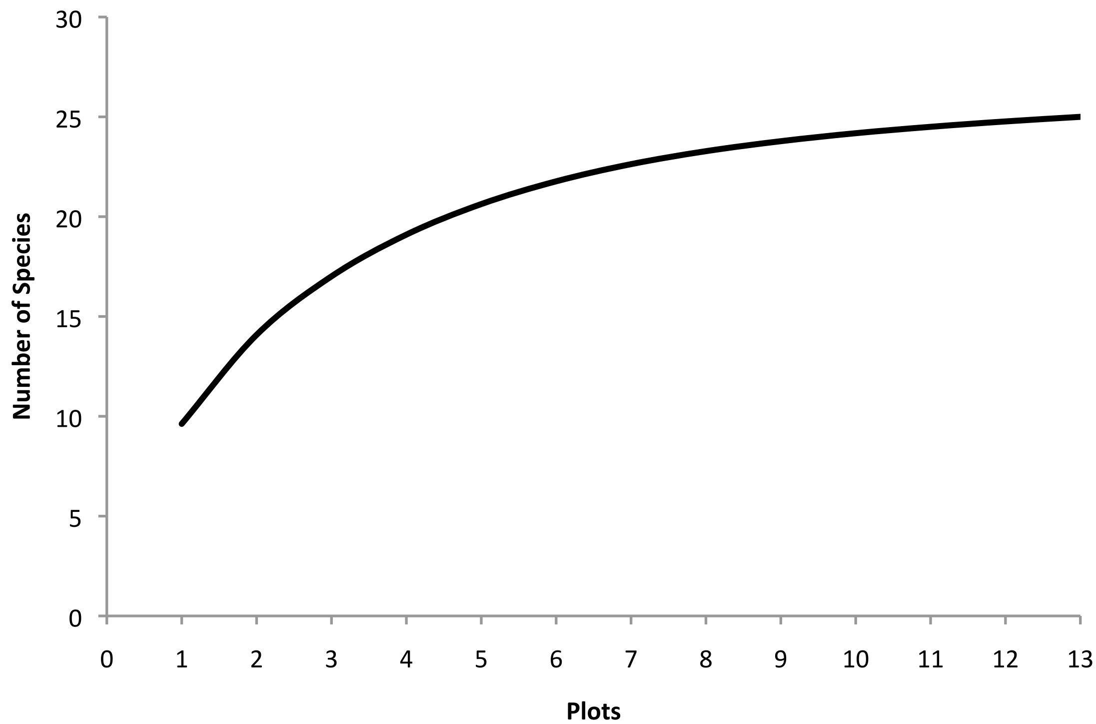
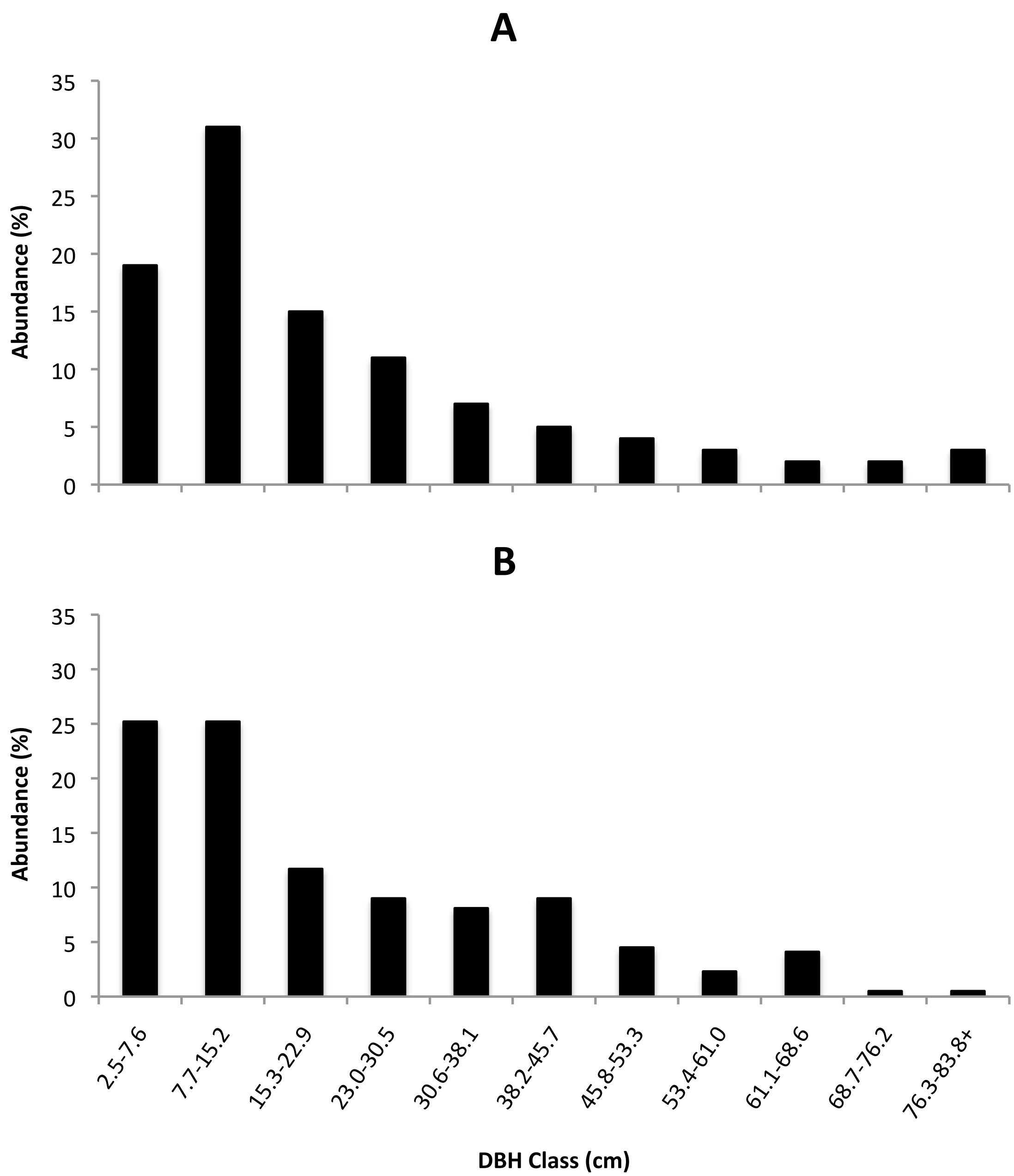
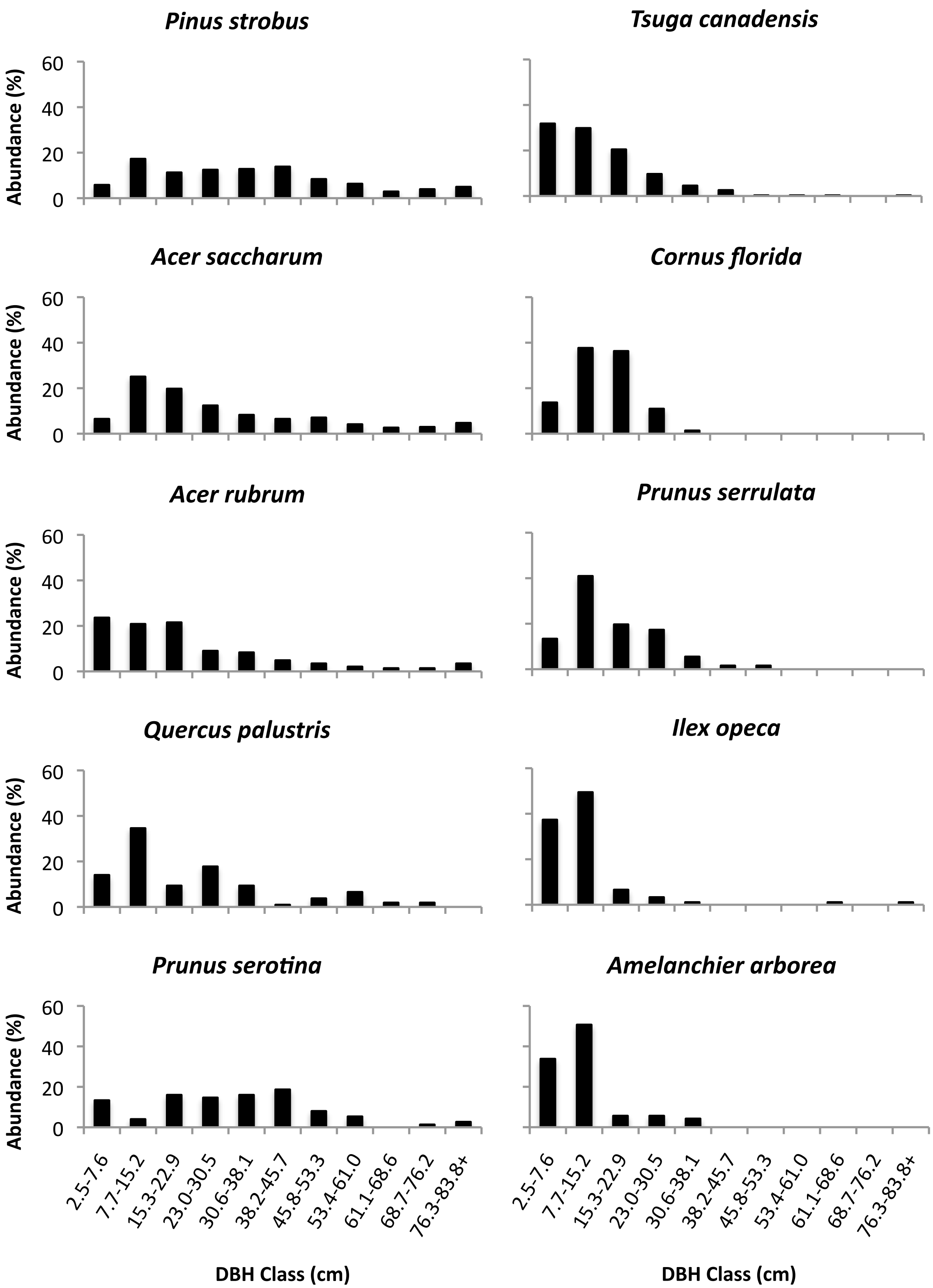

30
25
20
15
10
5
0
Number of Species
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Plots

Figure 1.12



A
B
35
30
25
20
15
10
5
0
Abundance (%)
2.5-7.6
7.7-15.2
15.3-22.9
23.0-30.5
30.6-38.1
38.2-45.7
45.8-53.3
53.4-61.0
61.1-68.6
68.7-76.2
76.3-83.8+
DBH Class (cm)

Figure 1.13



Pinus strobus
Tsuga canadensis
Acer saccharum
Cornus florida
Acer rubrum
Prunus serrulata
Quercus palustris
Ilex opeca
Prunus serotina
Amelanchier arborea
Abundance (%)
60
40
20
0
2.5-7.6
7.7-15.2
15.3-22.9
23.0-30.5
30.6-38.1
38.2-45.7
45.8-53.3
53.4-61.0
61.1-68.6
68.7-76.2
76.3-83.8+
DBH Class (cm)

Figure 1.14

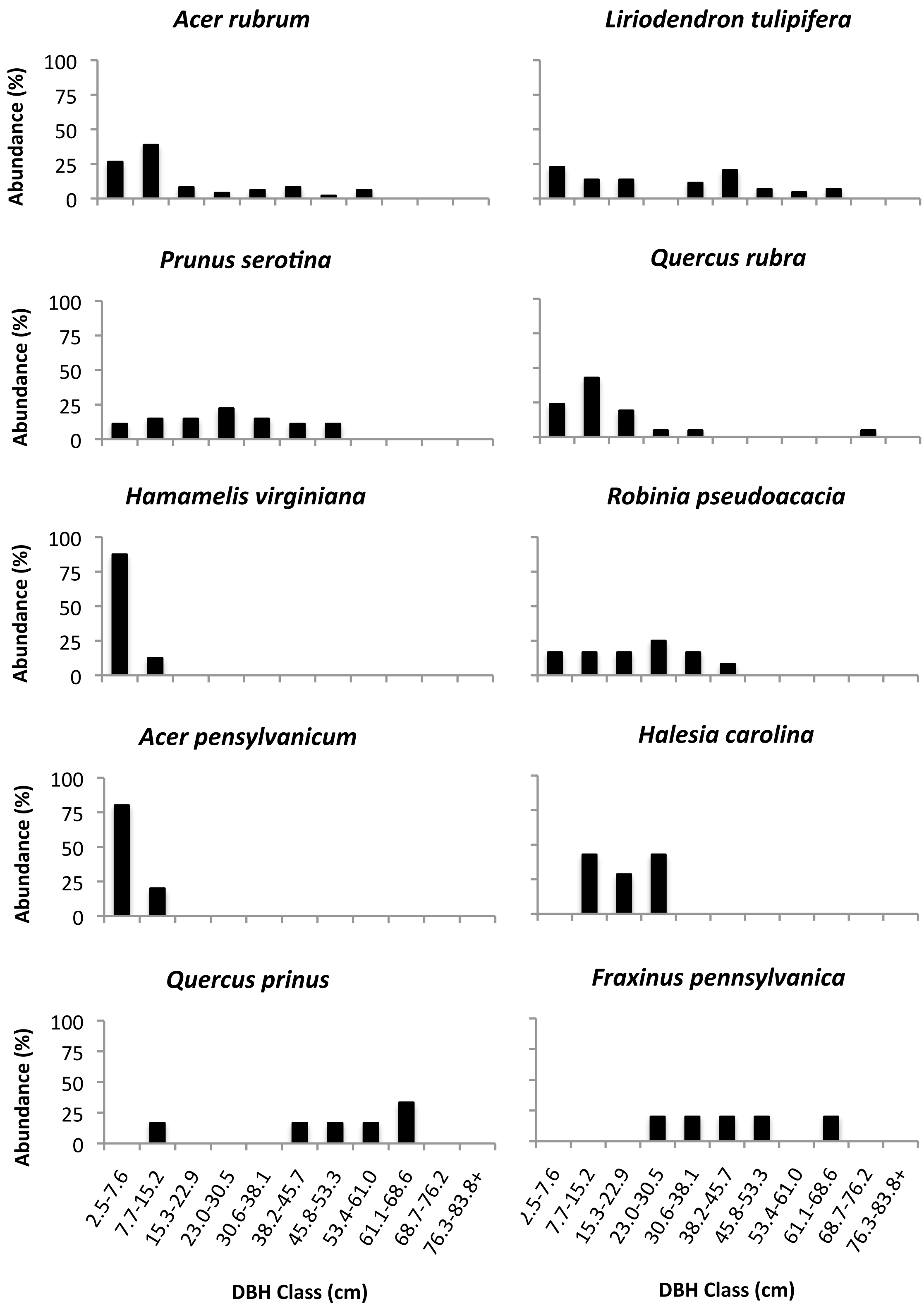

Acer rubrum
Liriodendron tulipifera
Prunus serotina
Quercus rubra
Hamamelis virginiana
Robinia pseudoacacia
Acer pensylvanicum
Halesia carolina
Quercus prinus
Fraxinus pennsylvanica
Abundance (%)
100
75
50
25
0
2.5-7.6
7.7-15.2
15.3-22.9
23.0-30.5
30.6-38.1
38.2-45.7
45.8-53.3
53.4-61.0
61.1-68.6
68.7-76.2
76.3-83.8+
DBH Class (cm)

Figure 1.15

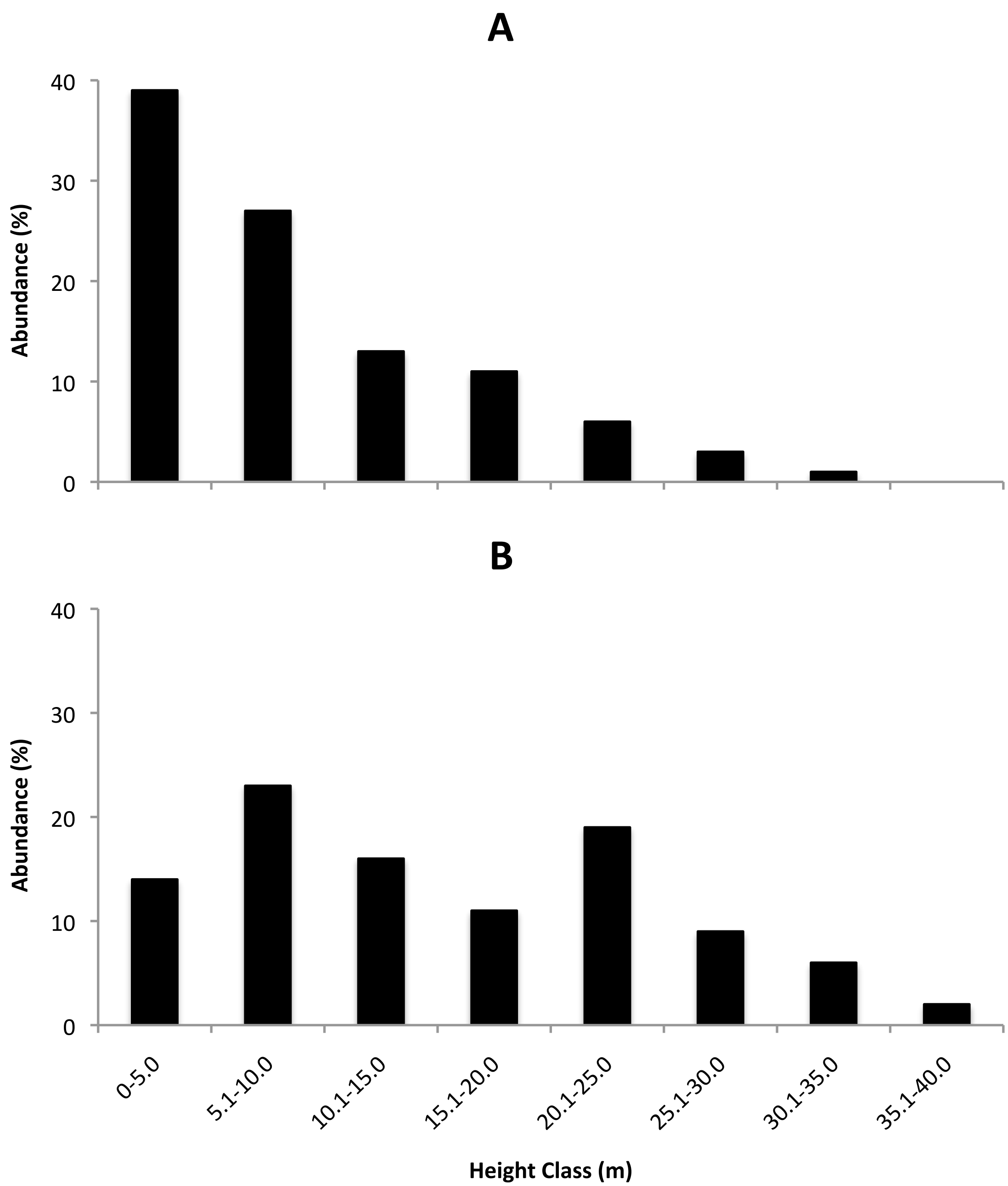

A
B
40
30
20
10
0
Abundance (%)
0-5.0
5.1-10.0
10.1-15.0
15.1-20.0
20.1-25.0
25.1-30.0
30.1-35.0
35.1-40.0
Height Class (m)

Figure 1.16

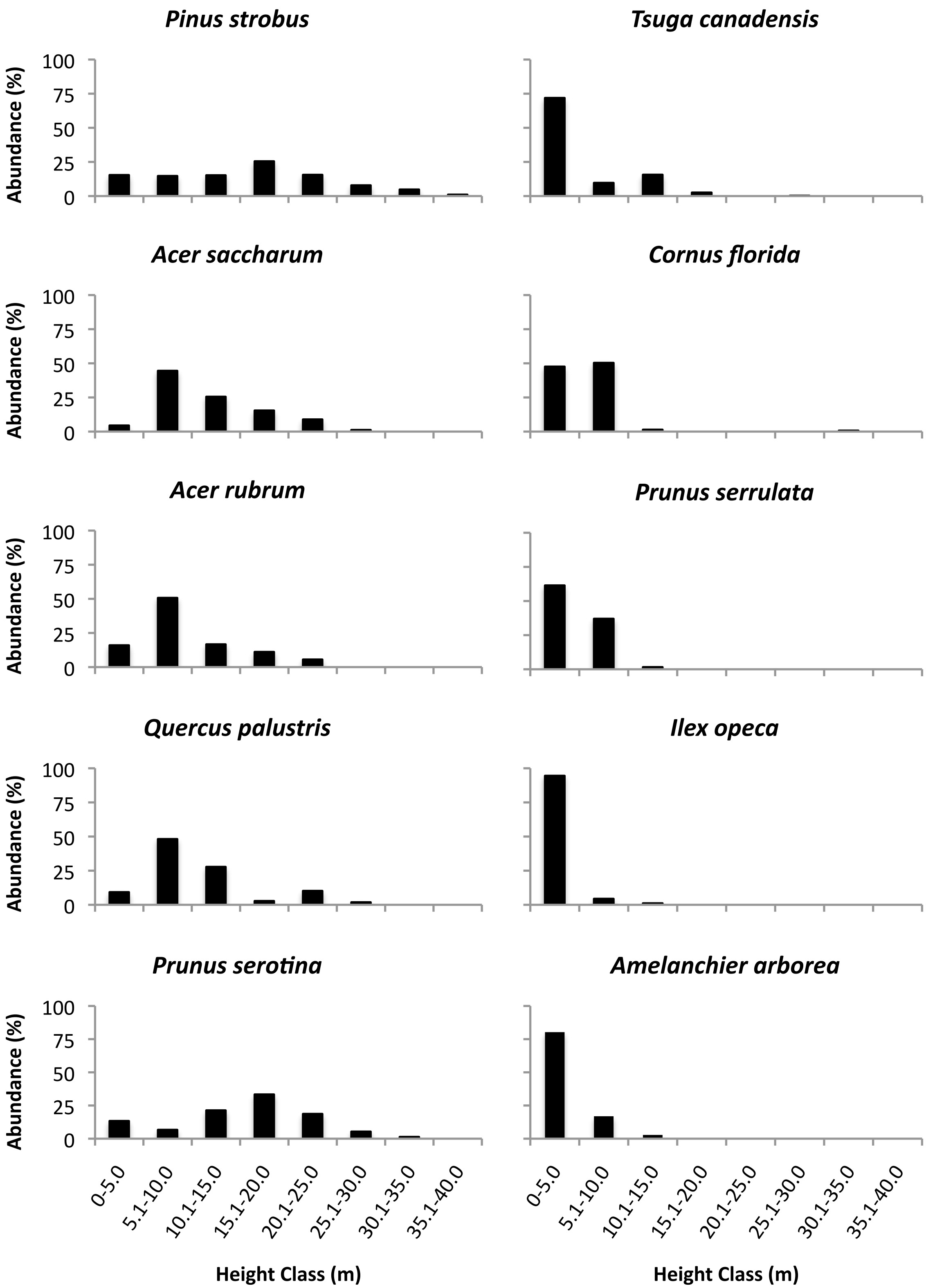
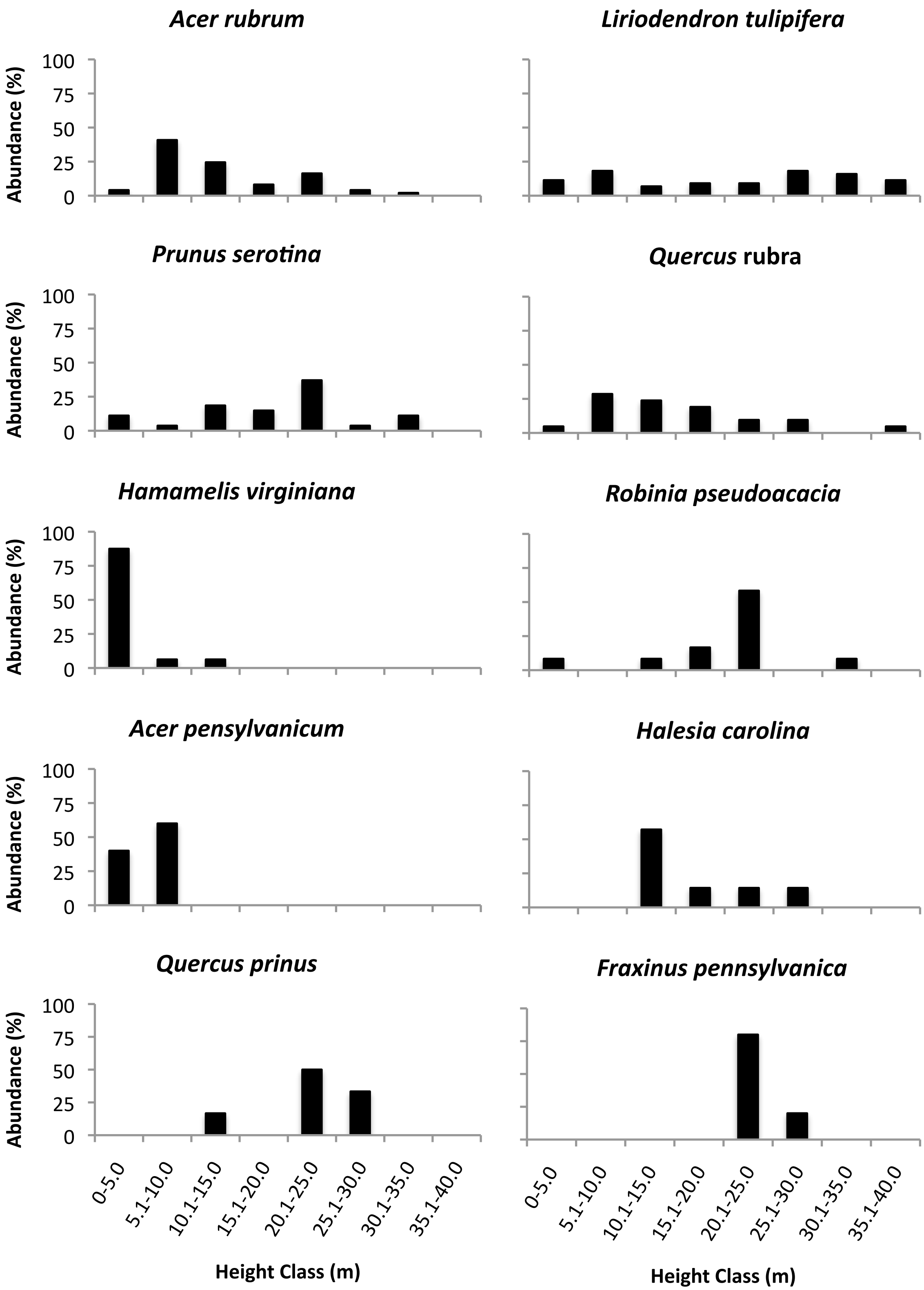

Pinus strobus
Tsuga canadensis
Acer saccharum
Cornus florida
Acer rubrum
Prunus serrulata
Quercus palustris
Ilex opeca
Prunus serotina
Amelanchier arborea
Abundance (%)
100
75
50
25
0
0-5.0
5.1-10.0
10.1-15.0
15.1-20.0
20.1-25.0
25.1-30.0
30.1-35.0
35.1-40.0
Height Class (m)

Figure 1.17



Acer rubrum
Liriodendron tulipifera
Prunus serotina
Quercus rubra
Hamamelis virginiana
Robinia pseudoacacia
Acer pensylvanicum
Halesia carolina
Quercus prinus
Fraxinus pennsylvanica
Abundance (%)
100
75
50
25
0
0-5.0
5.1-10.0
10.1-15.0
15.1-20.0
20.1-25.0
25.1-30.0
30.1-35.0
35.1-40.0
Height Class (m)

Figure 1.18

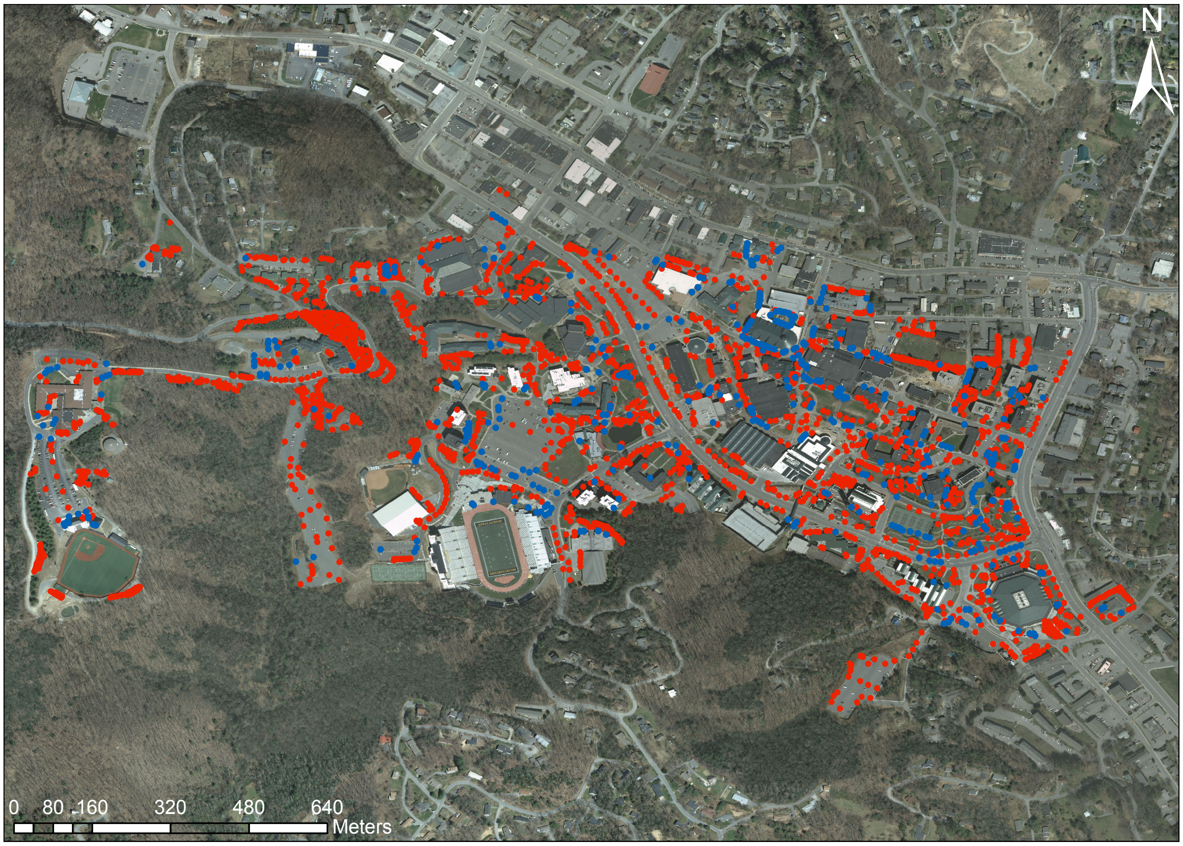
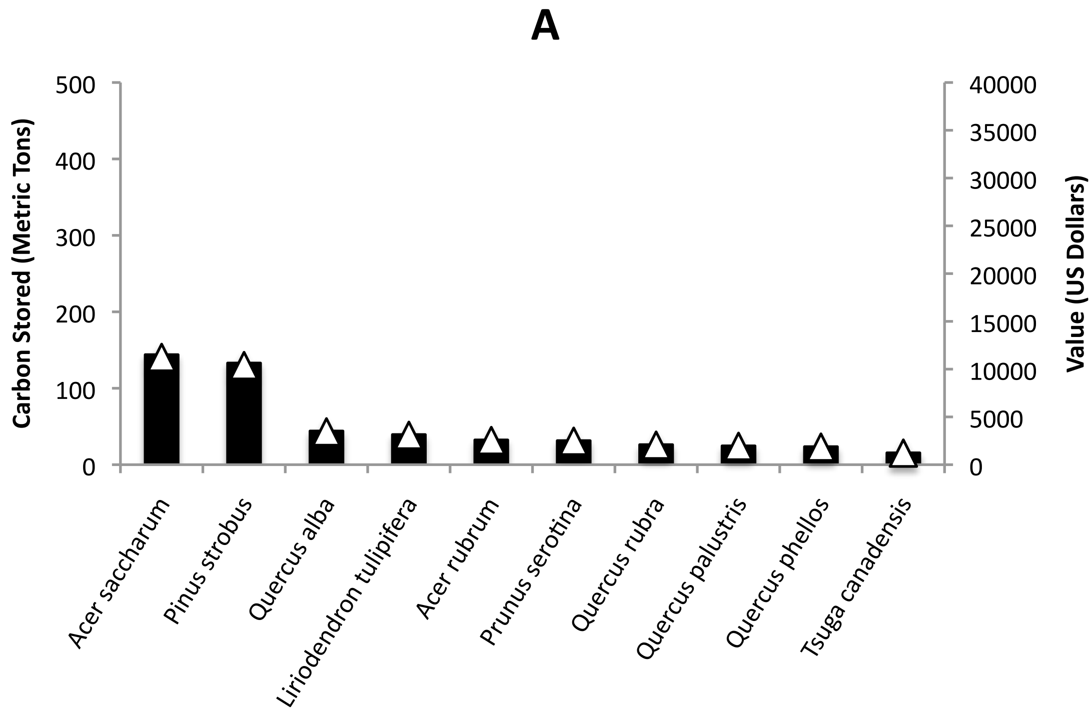


Figure 1.19


A
Carbon Stored (Metric Tons)
Value (US Dollars)
500
400
300
200
100
0
40000
35000
30000
25000
20000
15000
10000
5000
0
Acer saccharum
Pinus strobus
Quercus alba
Liriodendron tulipifera
Acer rubrum
Prunus serotina
Quercus rubra
Quercus palustris
Quercus phellos
Tsuga canadensis

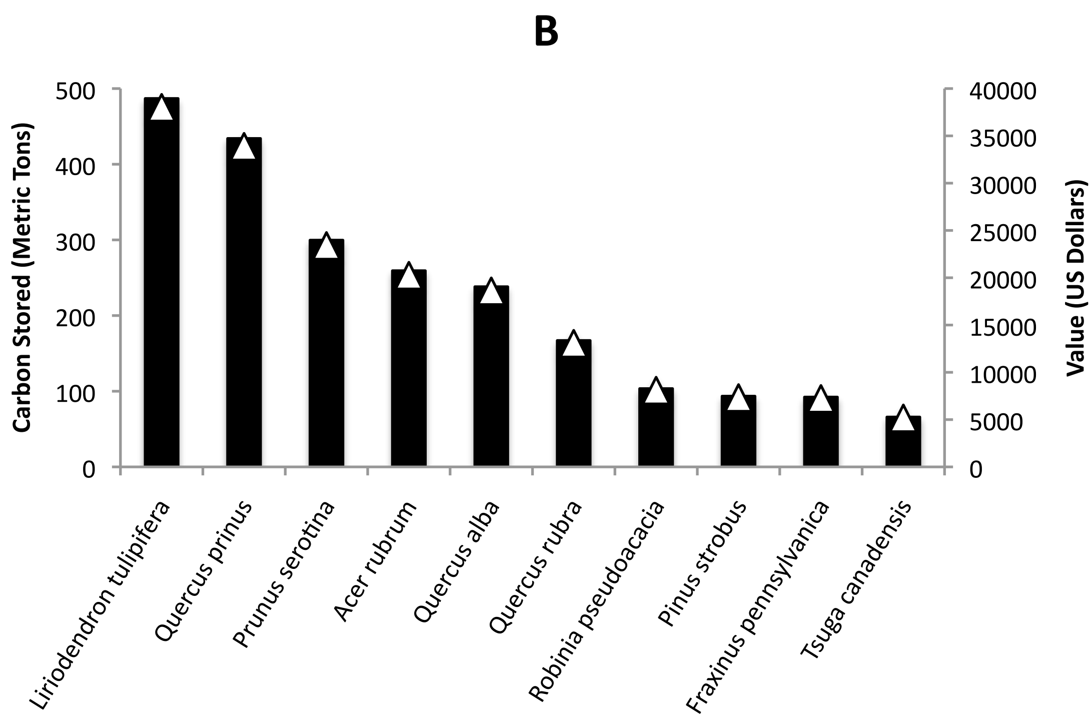

B
Carbon Stored (Metric Tons)
Value (US Dollars)
500
400
300
200
100
0
40000
35000
30000
25000
20000
15000
10000
5000
0
Liriodendron tulipifera
Quercus prinus
Prunus serotina
Acer rubrum
Quercus alba
Quercus rubra
Robinia pseudoacacia
Pinus strobus
Fraxinus pennsylvanica
Tsuga canadensis

Figure 1.20

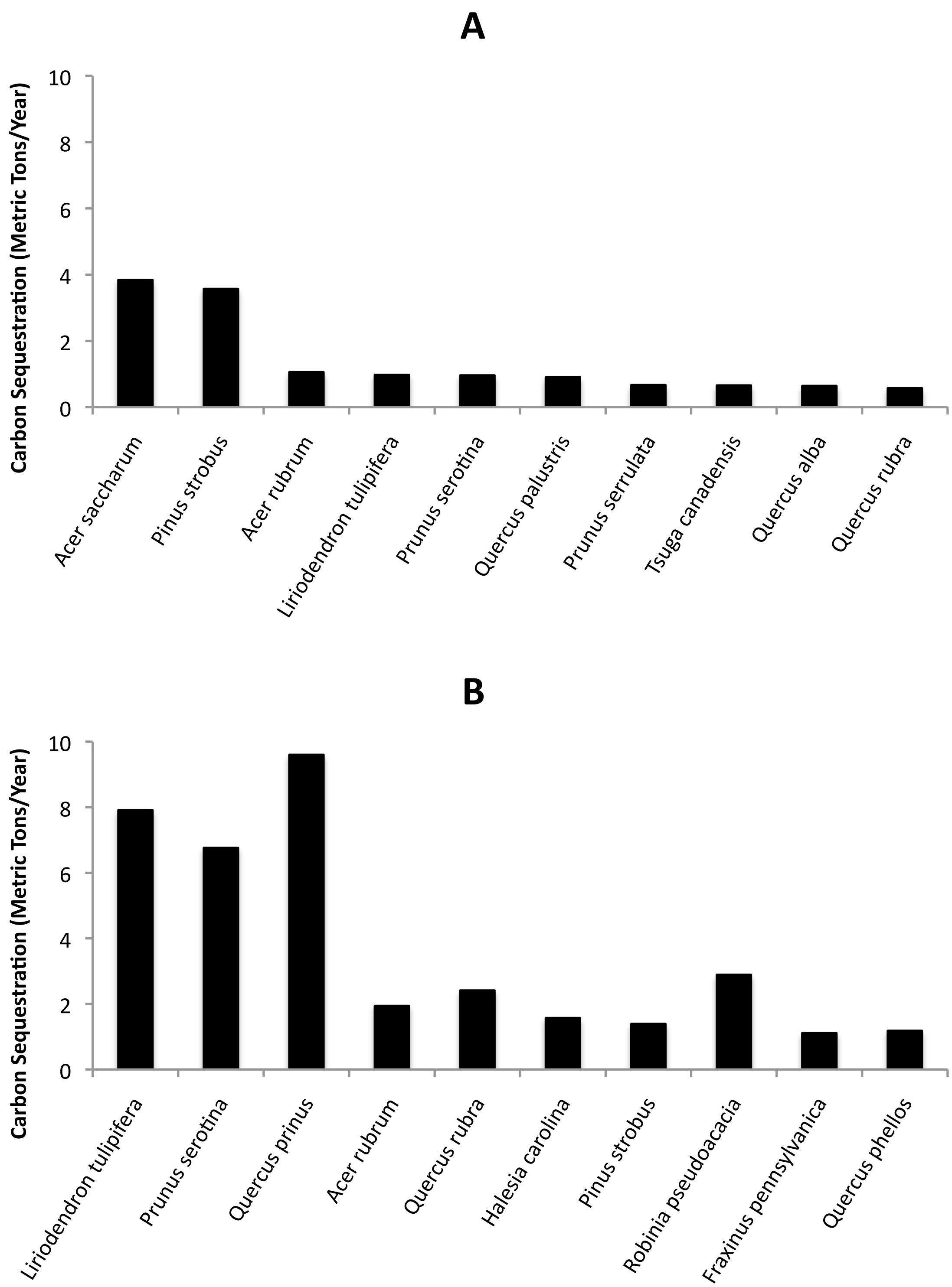
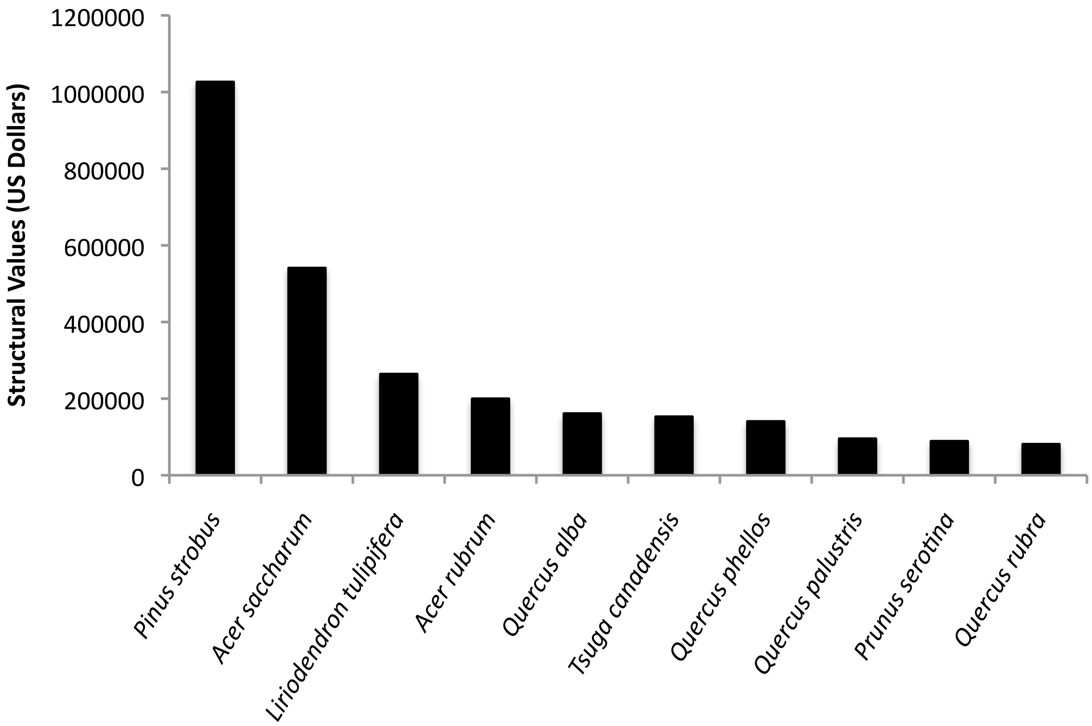
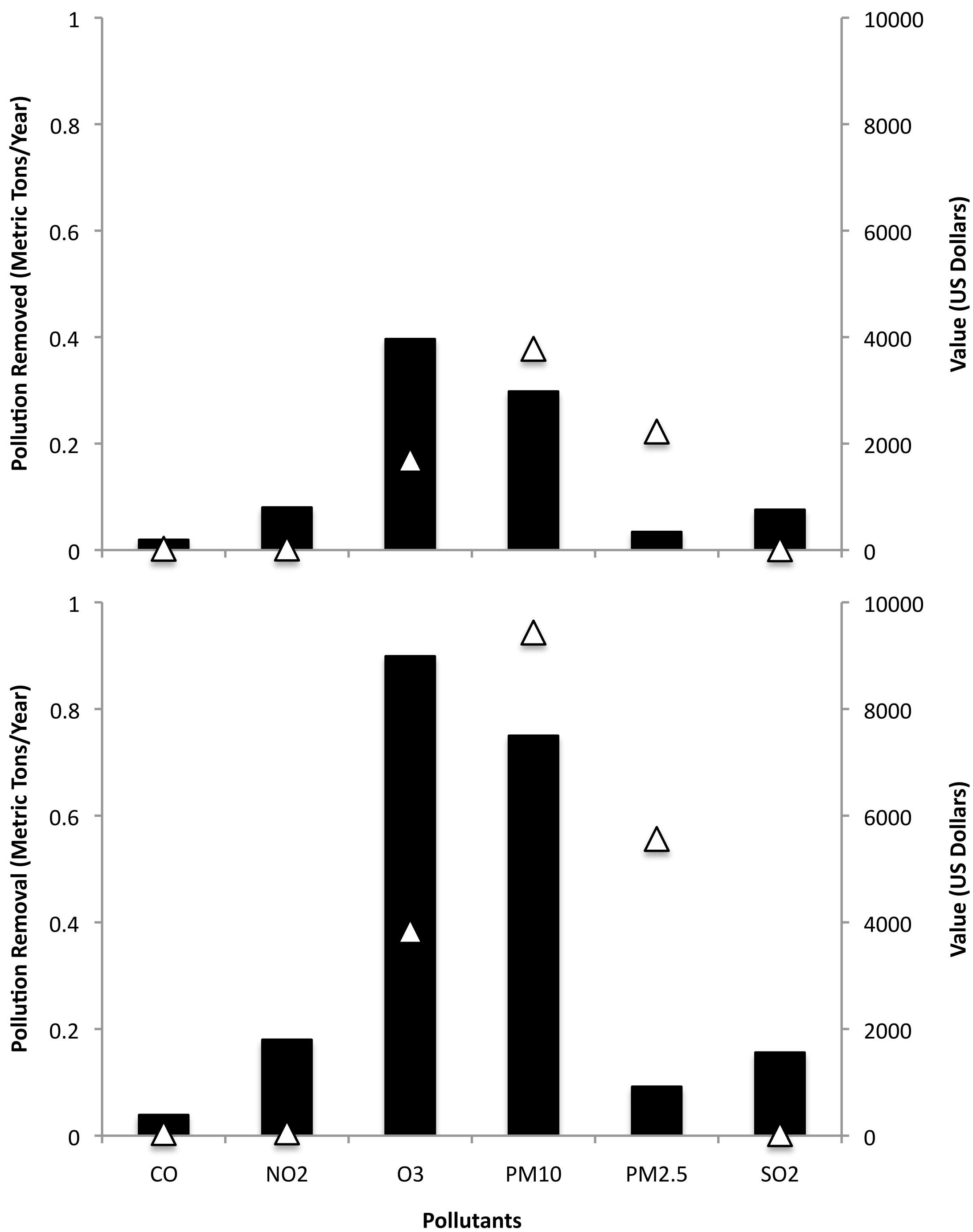

A
Carbon Sequestration (Metric Tons/Year)
10
8
6
4
2
0
Acer saccharum
Pinus strobus
Acer rubrum
Liriodendron tulipifera
Prunus serotina
Quercus palustris
Prunus serrulata
Tsuga canadensis
Quercus alba
Quercus rubra
B
Carbon Sequestration (Metric Tons/Year)
10
8
6
4
2
0
Liriodendron tulipifera
Prunus serotina
Quercus prinus
Acer rubrum
Quercus rubra
Halesia carolina
Pinus strobus
Robinia pseudoacacia
Fraxinus pennsylvanica
Quercus phellos

Figure 1.21



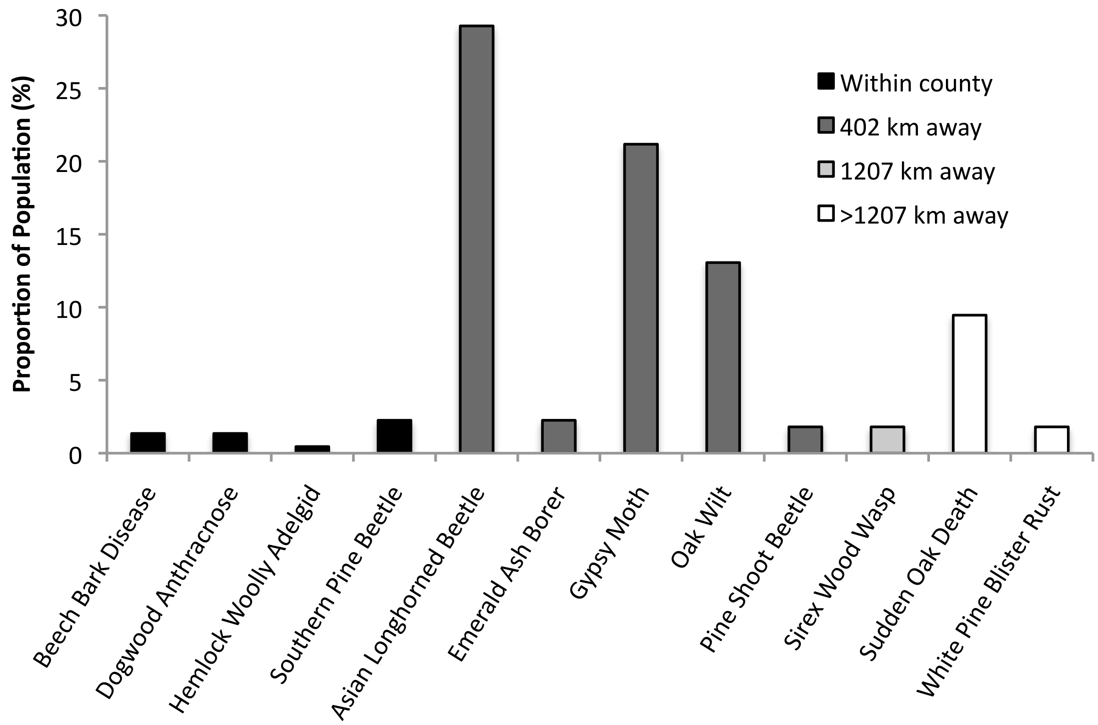
Structural Values (US Dollars)
1200000
1000000
800000
600000
400000
200000
0
Pinus strobus
Acer saccharum
Liriodendron tulipifera
Acer rubrum
Quercus alba
Tsuga canadensis
Quercus phellos
Quercus palustris
Prunus serotina
Quercus rubra

Figure 1.22



1
0.8
0.6
0.4
0.2
0
Pollution Removed (Metric Tons/Year)
10000
8000
6000
4000
2000
0
Value (US Dollars)
1
0.8
0.6
0.4
0.2
0
Pollution Removal (Metric Tons/Year)
10000
8000
6000
4000
2000
0
Value (US Dollars)
CO
NO2
O3
PM10
PM2.5
SO2
Pollutants

Figure 1.23


30
25
20
15
10
5
0
Proportion of Population (%)
Within county
402 km away
1207 km away
>1207 km away
Beech Bark Disease
Dogwood Anthracnose
Hemlock Woolly Adelgid
Southern Pine Beetle
Asian Longhorned Beetle
Emerald Ash Borer
Gypsy Moth
Oak Wilt
Pine Shoot Beetle
Sirex Wood Wasp
Sudden Oak Death
White Pine Blister Rust

Chapter 2: Hazard Assessment and Management Recommendations for Appalachian State University's Managed Urban Forest

ABSTRACT

A hazard assessment was conducted in addition to the biodiversity and ecosystem services assessment (Chapter 1) on the campus of Appalachian State University (ASU) in Boone, NC from 2010-2012. Hazard assessment protocols were established by the Landscape Services branch of ASU's Physical Plant and applied to all the managed trees on the 85.8 ha managed campus. The complete inventory included 3,228 trees, 61% of which contained at least one target, reinforcing the need for proper tree placement and management. Approximately 82% of all trees were considered healthy. Seventy-two percent of the trees were inventoried in high intensity zones, 13% in moderate, and 15% in low intensity zones. Within just these high intensity zones, 82% of the trees were considered healthy. Poor health trees were concentrated in low use intensity zones.

Specific management strategies are suggested for maintaining a healthy urban forest. Large healthy urban trees are most valuable and provide the most environmental services. The appropriate species, when planted in suitable locations, require the least amount of maintenance and have low cost. Pines (*Pinus* sp.) are susceptible to damage from ice accumulation in the winter while maples (*Acer* species) are prone to damage from de-icing salts, whereas oaks (*Quercus* sp.), hornbeams (*Carpinus* sp.), and hollies (*Ilex* sp.) all thrive in urban environments despite these stressors. Urban (campus) trees that are selected for

planting should have a combination of both aesthetics and long-term growth that maximize the benefits while minimizing the risks to users.

1. INTRODUCTION

Urban forests provide numerous environmental services (Nowak 2006), and increase aesthetics (Dwyer et al. 1992). The aesthetic qualities of urban trees promote tourism by inducing repeated visits and longer stays, which can increase revenue for cities (Dwyer et al. 1992; McCarthy and Pataki 2010). Trees within urban setting should provide high benefit to cost ratios, low maintenance, resistance to disease, and lack susceptibility to stressors such as ice/snow, wind, and de-icing salts. Combining these characteristics with aesthetics is the trick. Trees planted should handle the former, and then, and only then, should aesthetics come into play.

Management efforts should focus on the deliberate planting of native species in more suitable locations on the managed campus in order to maximize the ecosystem services while minimizing invasive species spread. Urban forests have been shown to serve as reservoirs for the spread of non-native and invasive species (Woodall et al. 2010). Native species should be given precedence during species selection for planting due to the capacity for urban forests to serve as seed banks for native tree migrations (McKenney et al. 2007).

As part of my thesis research, I conducted a hazard assessment of all the trees on the managed campus. The objective of this assessment was to improve campus safety by identifying and tracking hazardous trees in order to facilitate proper management practices, e.g., removing trees that pose an imminent danger to the public and could constitute a liability for the university (Matheny and Clark 2009). Hazard assessment was not conducted within the Nature Preserve, as this area is not intensively managed for pedestrian traffic, although hazardous trees are cleared away to protect the public.

2. MATERIALS AND METHODS

Hazard assessment and management protocols were conducted according to the specifications of the Landscape Services branch of ASU's Physical Plant. Hazard data were collected and recorded on the same ArcPad10 custom data entry form created for the campus inventory. The hazard assessment data included general observations, as well as information on roots, main stem, and crown. General information included the GPS location, pedestrian use intensity, and overall health of the tree. Root data included notes regarding girdling roots, whether excavation was required, if the root zone was compromised, and the presence of ground heaving. Main stem data included the presence of pests or pathogens; appearance of wounds, cracks, or cavities; column of decay, codominate stems, or the presence of lean. Crown data included information on included and exfoliating bark, if crown cleaning was necessary, hangers or targets present, and accessibility (Appendix C). Use intensity was estimated by the volume of foot traffic and classified as high, moderate, or low (personal observation). Overall health was determined through a visual analysis of the tree's characteristics. Ratings varied from a 1 = dying/dead (e.g., >75% crown missing, significant dieback, severe structural issues, or dead) to a 5 = very healthy (e.g., full crown, little to no dieback, no signs of additional structural issues). If structural issues were suspected but not obvious, the tree was inspected internally via a Resistograph (IML Inc., Orange Park, FL).

Trees were inventoried by zones (see Chapter 1). Zone 1 was located around the baseball field, Broyhill Conference Center, and greenwood parking lot; Zone 2 involved the football field, indoor soccer field, and stadium parking lot; Zone 3 was located around Durham Park and the campus south of Stadium Drive; Zone 4 constituted the center of campus around Sanford Mall, the cafeteria, and varsity gym; Zone 5 was composed of the northeast portion of campus including Legends, the student union, and Raley Hall; and finally, Zone 6 was located at the northwest portion of campus and included the student recreation center, living and learning center, and Farthing auditorium. Zones with the highest foot traffic are high intensity areas that require the most maintenance and management. These high intensity zones were inventoried first.

Data were backed-up daily and hosted on ASU’s server. Public availability of data for every tree on the managed campus is now in the trial phase. Soon, each tree as well as general data will be available for visualization via Google ™ Map and Google ™ Earth.

3. RESULTS

ASU's managed campus contained 3,228 trees, 87% of which are easily accessible for management via crews on the ground or in a bucket truck. The remaining 13% must be accessed by a certified climbing arborist (Table 2.1). Over half of all trees inventoried contained at least one target that could be impacted if the tree, or a part of the tree, were to fall, whereas 15% contained two targets, 6% contained three targets, and 2% contained four targets (Table 2.1; Figure 2.01). The majority of trees on campus (82%) were assigned a health rating of four or five, therefore indicating a relatively healthy campus forest (Figure 2.02). Two percent of the trees on campus were assigned a health score of one (Figure 2). The majority of trees that were categorized as healthy were the younger, newly planted trees. Canadian hemlock was the most abundant tree species on campus for those receiving a health score of one (Figure 2.03).

A normal distribution existed among the top 10 species on campus that were given a health rating of five (Figure 2.03) and each zone had a similar health distribution where trees with a health rating of four to five predominated (Figure 2.04).

Approximately 72% of all managed trees were planted in high intensity areas, whereas moderate intensity areas contained the least percentage of trees, 13% (Figure 2.05). Within the high intensity areas, 82% of trees inventoried were assigned a health of four to five, while only four percent were assigned a health rating of one to two (Figure 2.06). Interestingly, the low intensity areas contained the greatest abundance of poor health trees (Figure 2.06).

4. DISCUSSION

The importance of proper species selection and placement in urban environments determines their longevity and health. Tree species on the managed portions of campus are chosen for characteristics such as climate hardiness (USDA 2006), susceptibility to injury, growth characteristics, tree architecture, and/or suitability. If a tree meets these prior characteristics, then the land manager can consider aesthetic qualities that can contribute to the appearance of the campus. For example, lacebark elm (*Ulmus parvifolia*) and kwanzan cherry (*Prunus serrulata*) are often selected because of their attractive bark all year round, while the kousa (*Cornus kousa*) and eastern flowering dogwoods are selected for their floral arrangement and color (personal observation). A combination of these characteristics determines whether or not species will both flourish in urban settings, with minimal maintenance, low risk to the public while providing the public with aesthetic satisfaction.

Tree architecture is a particularly important characteristic of a tree species to be considered for planting on the managed ASU campus due to the relatively severe winter months in this region. Trees that are selected must be capable of withstanding harsh winds and heavy snow/ice accumulations without branch failure. Those that require significant amounts of care, such as isolated white pine (*Pinus strobus*) should be replaced with hardier and more structurally sound oaks and maples in order to reduce management costs.

Other characteristics that are important when selecting tree species for planting on campus include growing to an appropriate height, reaching a suitable size at maturity, and having a relatively long life span. For example, trees planted along a sidewalk below a power line should be a smaller size at maturity; a species meeting this requirement would be Japanese maple (*Acer palmatum*), which often remains below 5 m in height. Likewise, when selecting a tree species to use as a privacy barrier, an evergreen with dense foliage that is wide maturity, like an arborvitae cultivar (*Thuja* sp.), would be appropriate.

Drought also plays a major role in urban species tree selection. Trees may experience increased drought stress in campus environments due to reduced soil moisture availability (Berrang et al. 1985). Many factors contribute to soil-moisture-related drought stress in urban environments, including a large amount of non-permeable surfaces which increases run-off at the expense of penetration, increased soil bulk density due to heavy foot and vehicle traffic, and limited soil volumes due to the placement of the tree (e.g., along sidewalks or in planters) (Cregg and Dix 2001). Low soil moisture also effectively concentrates de-icing salts that run off from nearby roads during the winter months (Fluckiger and Braun 1981). Environmental pollutants can also be concentrated in droughty soils, with deleterious consequences for tree growth and survival. If soils get too dry, the rate of transpiration from tree crowns can exceed the capacity for roots to absorb water, thereby decreasing the water potential of the trees (Kozlowski 1987) and negatively affecting growth.

5. MANAGEMENT

Resources should be focused toward the maintenance of all mature trees on campus because mature trees provide the most environmental services (Chapter 1) and are the most valuable. Large trees have a greater capacity to store C in their wood and to sequester CO_2 from the atmosphere (Nowak & Crane 2002). Additionally, the planting of new trees should be in appropriate locations where runoff, pedestrian traffic, and infrastructure will not pose a risk for the healthy, unimpeded development of urban trees. Managing mature trees and proper site and species selection for new trees will maximize benefits while reducing long-term costs. General species selection, as well as site determination, should be based on USDA's Urban Tree Planting Guide (USDA 2006).

The planting of pines (*Pinus* sp.) is not recommended due to their inherent ability to buckle and crack under the weight of ice and snow, specifically in isolated stands such as campus environments. Maples (*Acer* species) cannot tolerate heavy applications of de-icing salts, and therefore should not be planted in locations prone to runoff. Trees that thrive well on campus are oaks (*Quercus* sp.), maples (*Acer* sp.; when planted in the proper locations), hornbeams (*Carpinus* sp.), hollies (*Ilex* sp.), cherries (*Prunus* sp.), arborvitae (*Thuja* sp.), serviceberries (*Amelanchier* sp.), and dogwoods (*Cornus* sp.; again, when planted in the proper location). The eastern flowering dogwood (*C. florida*) and Japanese dogwood (*C. kousa*) are the predominate dogwoods on the managed campus (Chapter 1, Figure 1.03). Flowering dogwoods thrive on campus if they are planted in full sun locations but when planted in partial sun, they are more susceptible to dogwood anthracnose, a disease caused by the fungus *Discula destructiva* (Carr and Banas 2000). If a location on campus is in the shade, then Japanese dogwoods could be planted due to their natural resistance to *D.*

destructiva (Carr and Banas 2000). Although Canadian hemlocks (*Tsuga canadensis*) do well on campus, they should be avoided due to the costs associated with the required management of the hemlock wooly adelgids, which attacks both the Canadian and Carolina hemlocks, often killing them within just a few years. Treatments against the adelgids are both labor intensive and expensive and so future planting schemes should avoid these species.

Currently, the bulk of trees belong to only a few dominant species (Chapter 1). Managed urban forests should adequately represent the native fauna in both species and abundance. Species and genera should be more evenly distributed throughout campus.

5.1 Tree Campus USA

A thorough tree inventory will help Landscape Services in managing the health of the trees on the ASU campus as well as allowing ASU to become a "Tree Campus USA." Tree Campus USA is a program that recognizes college and university campuses that effectively manage their campus trees. This recognition is hard to achieve and several standards must be met. Standards 1-3 will be fulfilled with this campus tree inventory. The remaining objectives are will be completed by 2014.

- Standard 1 – Campus Tree Advisory Committee
- Standard 2 – Campus Tree Care Plan
- Standard 3 – Campus Tree Program with Dedicated Annual Expenditures
- Standard 4 – Arbor Day Observance
- Standard 5 – Service Learning Project

Sound management plans have been implemented and documented on other university campuses and have proven to be a valuable resource for grounds maintenance and campus safety (Huyler et al. 2010; Martin et al. 2011) and are vital to an ever-growing campus environment (Zipperer et al. 1997).

6. CONCLUSION

The importance of understanding the stresses affecting urban trees is vital. These forests store and sequester mT of C and CO_2, respectively, and provide environmental benefits to towns and cities. As urban trees are lost, they must be replaced. If these trees are not replaced, then these dead/removed trees will indirectly and directly affect atmospheric C pools.

The data and results provided here will enable Landscape Services to analyze species health, size, and diversity of the trees throughout campus. Additionally, an actively updated GIS database will aid Landscape Services in managing hazardous trees. In the past, Landscape Services has had a reactive approach to tree maintenance by removing trees after they became problematic. An accurate GIS database allows a proactive approach to managing trees, reducing costs and risks to personnel and infrastructure.

An active, thorough, and current data set insures up-to-date management plans. These management plans aid in maximizing ecosystem services provided as well as reduced hazard risks within ASU's urban forests. Ultimately, when suitable tree species are planted in appropriate locations, there is a significant decrease in long term up-keep cost and little maintenance is required (USDA 2006).

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TABLES

Table 2.1 Summary of hazard data collected for the managed campus.

	No. Trees	% of Campus
Accessibility	2812	87.1
Targets	1979	61.3
Crown Cleaning	822	25.5
Girdling Roots	294	9.1
Wounds	277	8.6
Included Bark	200	6.2
Roots Compromised	171	5.3
Column of Decay	92	2.9
Cavity Present	58	1.8
Exfoliating Bark	38	1.2
Hangers	37	1.1

FIGURES

Figure 2.01. Proportion of the population on the managed campus that were noted as having between 1-10 targets.

Figure 2.02. Proportion of population for each health category (1-5) assigned on the managed campus. Health rating was a progressive scale from 1 indicating a dead/dying tree, to 5, indicating a very healthy tree. Heath categories were assigned based on a collective tree assessment described by ASU's Physical Plant.

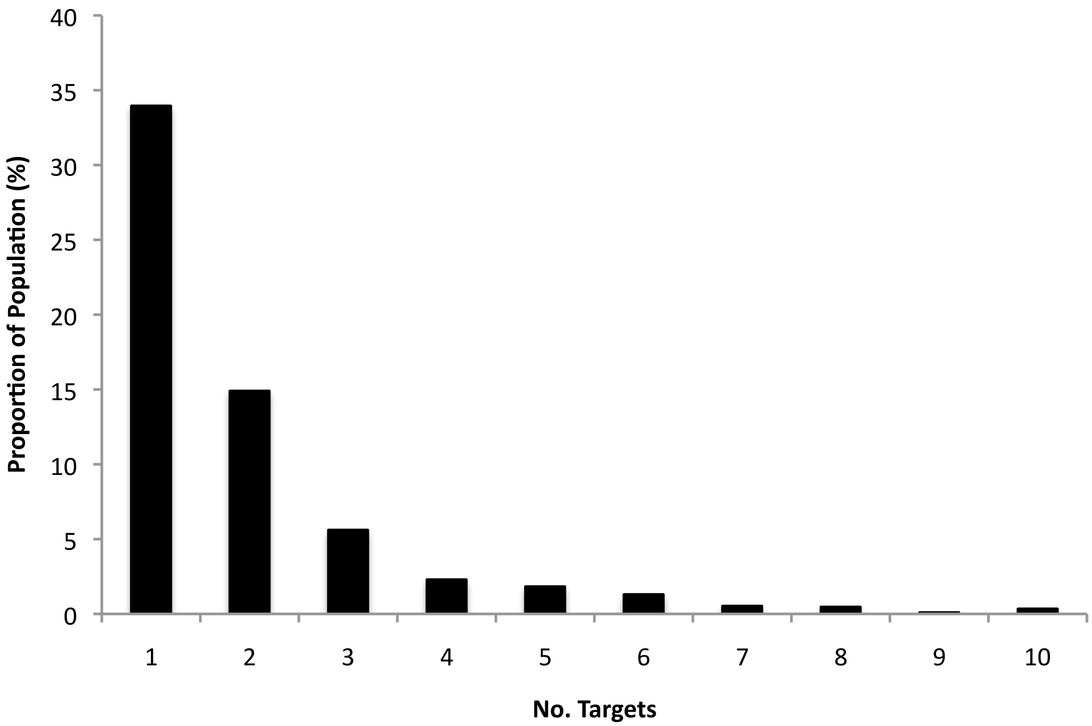
Figure 2.03. Proportion of the population for each of the 10 most abundant species in each health category (1-5) for the managed campus.

Figure 2.04. Health rating (1-5) for each zone on the managed campus.

Figure 2.05. Pedestrian use intensity for the managed campus.

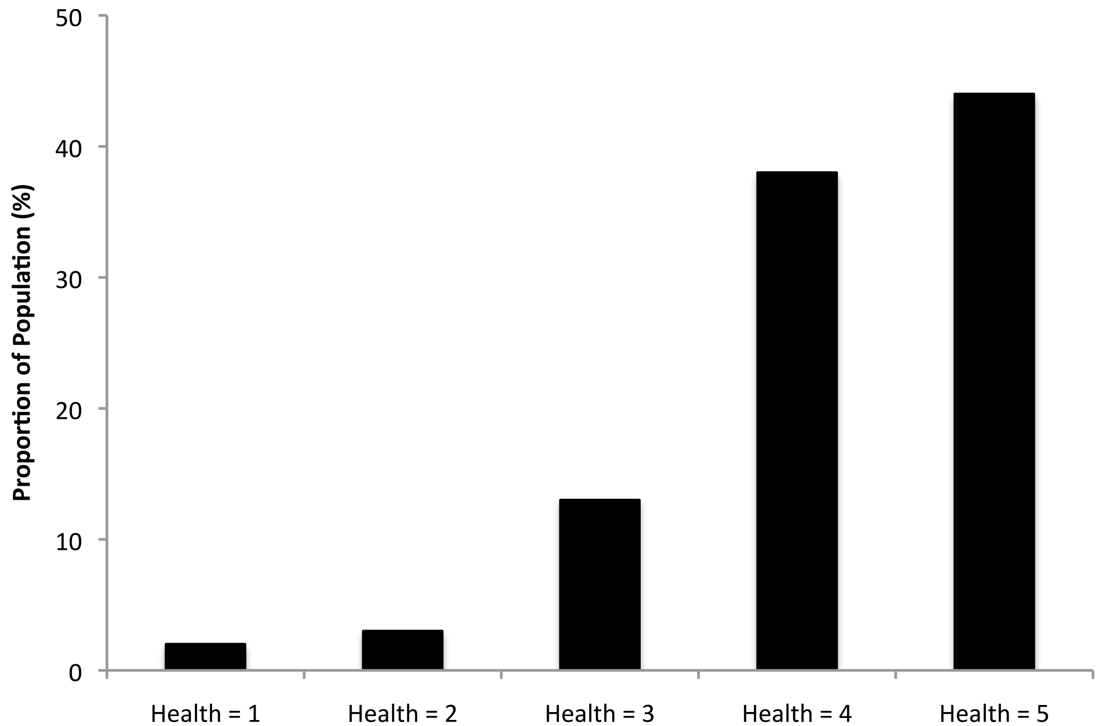
Figure 2.06. Proportion of trees inventoried in each pedestrian use intensity class on the managed campus.

Figure 2.01



40
35
30
25
20
15
10
5
0
Proportion of Population (%)
1
2
3
4
5
6
7
8
9
10
No. Targets

Figure 2.02



50
40
30
20
10
0
Proportion of Population (%)
Health = 1
Health = 2
Health = 3
Health = 4
Health = 5

Figure 2.03

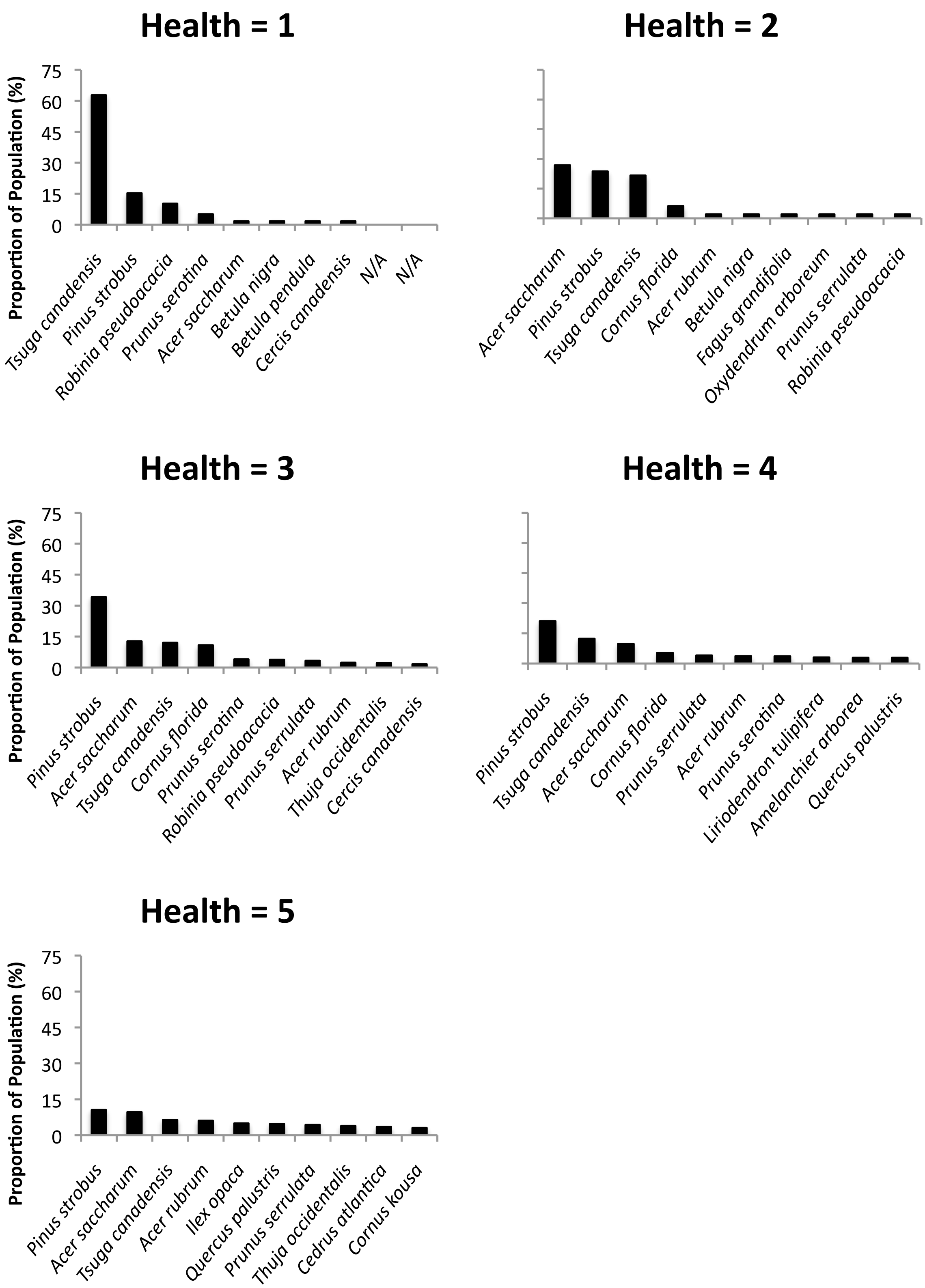

Health = 1
Proportion of Population (%)
75
60
45
30
15
0
Tsuga canadensis
Pinus strobus
Robinia pseudoacacia
Prunus serotina
Acer saccharum
Betula nigra
Betula pendula
Cercis canadensis
N/A
N/A
Health = 2
Acer saccharum
Pinus strobus
Tsuga canadensis
Cornus florida
Acer rubrum
Betula nigra
Fagus grandifolia
Oxydendrum arboreum
Prunus serrulata
Robinia pseudoacacia
Health = 3
Proportion of Population (%)
75
60
45
30
15
0
Pinus strobus
Acer saccharum
Tsuga canadensis
Cornus florida
Prunus serotina
Robinia pseudoacacia
Prunus serrulata
Acer rubrum
Thuja occidentalis
Cercis canadensis
Health = 4
Pinus strobus
Tsuga canadensis
Acer saccharum
Cornus florida
Prunus serrulata
Acer rubrum
Prunus serotina
Liriodendron tulipifera
Amelanchier arborea
Quercus palustris
Health = 5
Proportion of Population (%)
75
60
45
30
15
0
Pinus strobus
Acer saccharum
Tsuga canadensis
Acer rubrum
Ilex opaca
Quercus palustris
Prunus serrulata
Thuja occidentalis
Cedrus atlantica
Cornus kousa

Figure 2.04

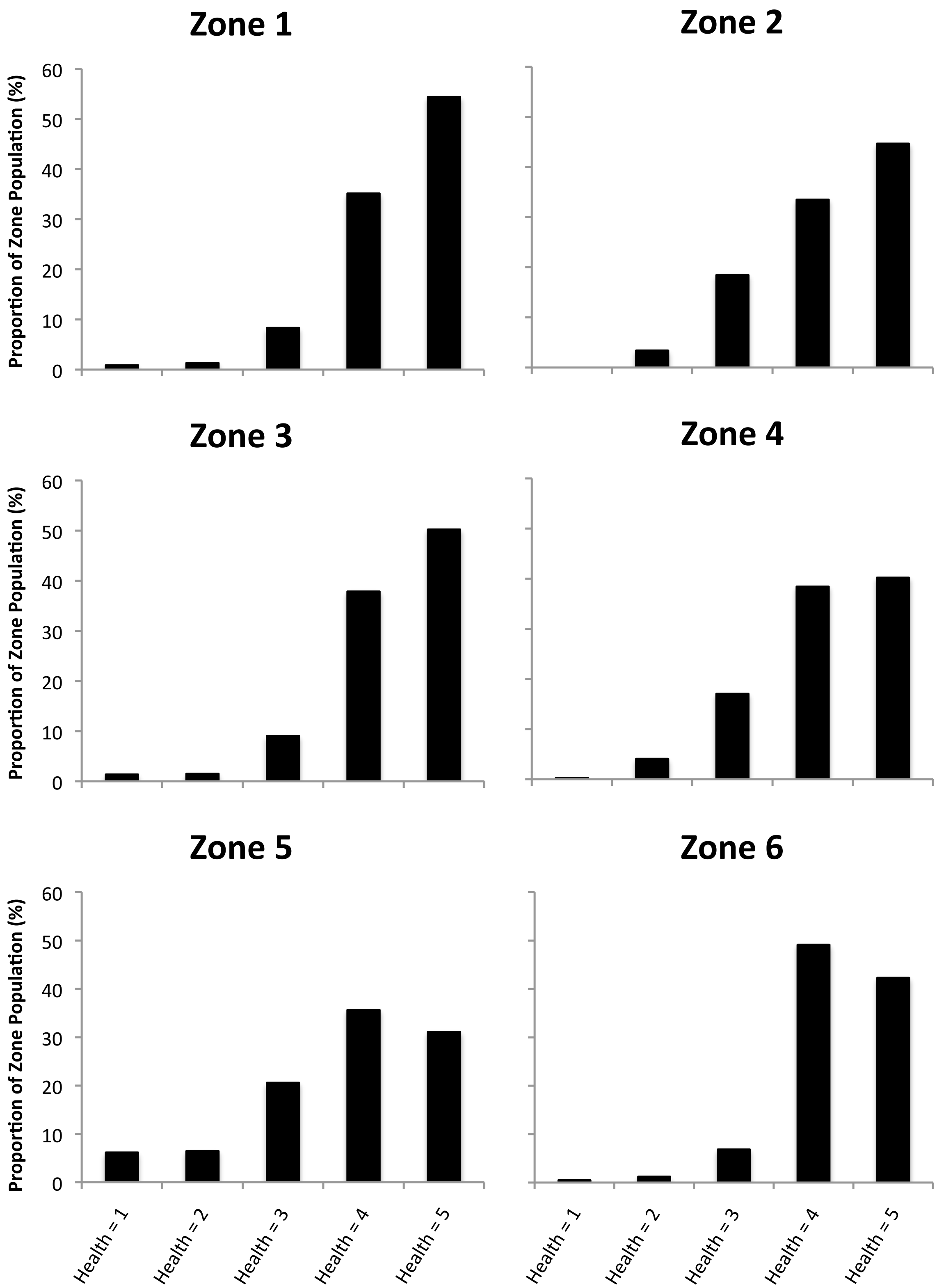

Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Proportion of Zone Population (%)
0
10
20
30
40
50
60
Health = 1
Health = 2
Health = 3
Health = 4
Health = 5

Figure 2.05

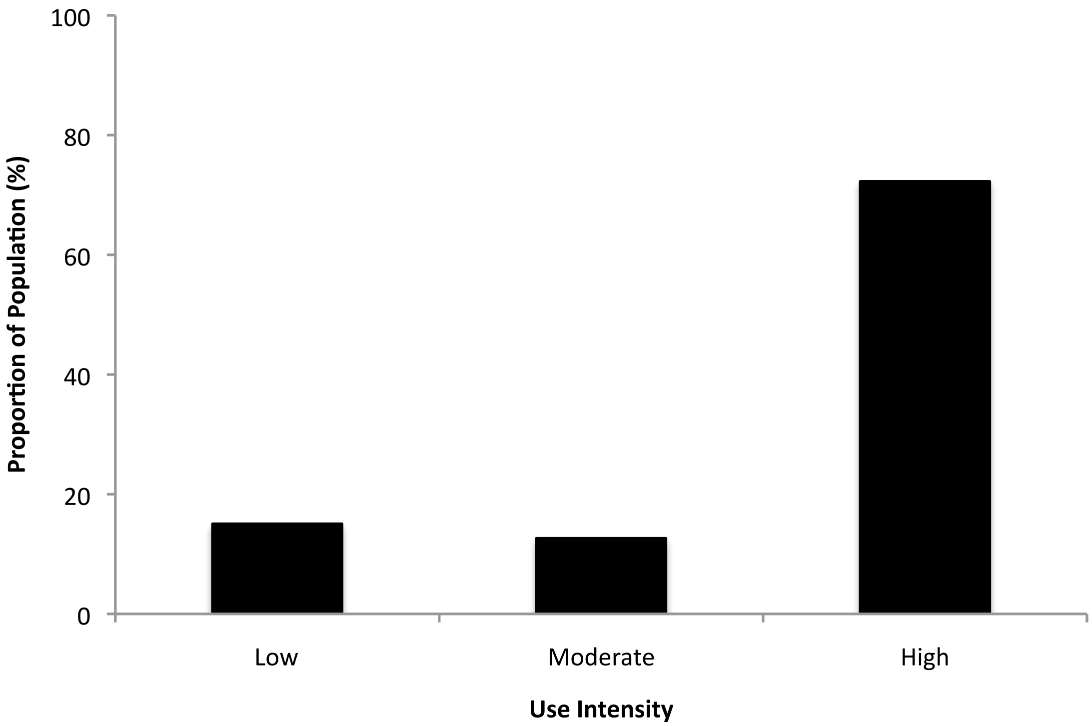
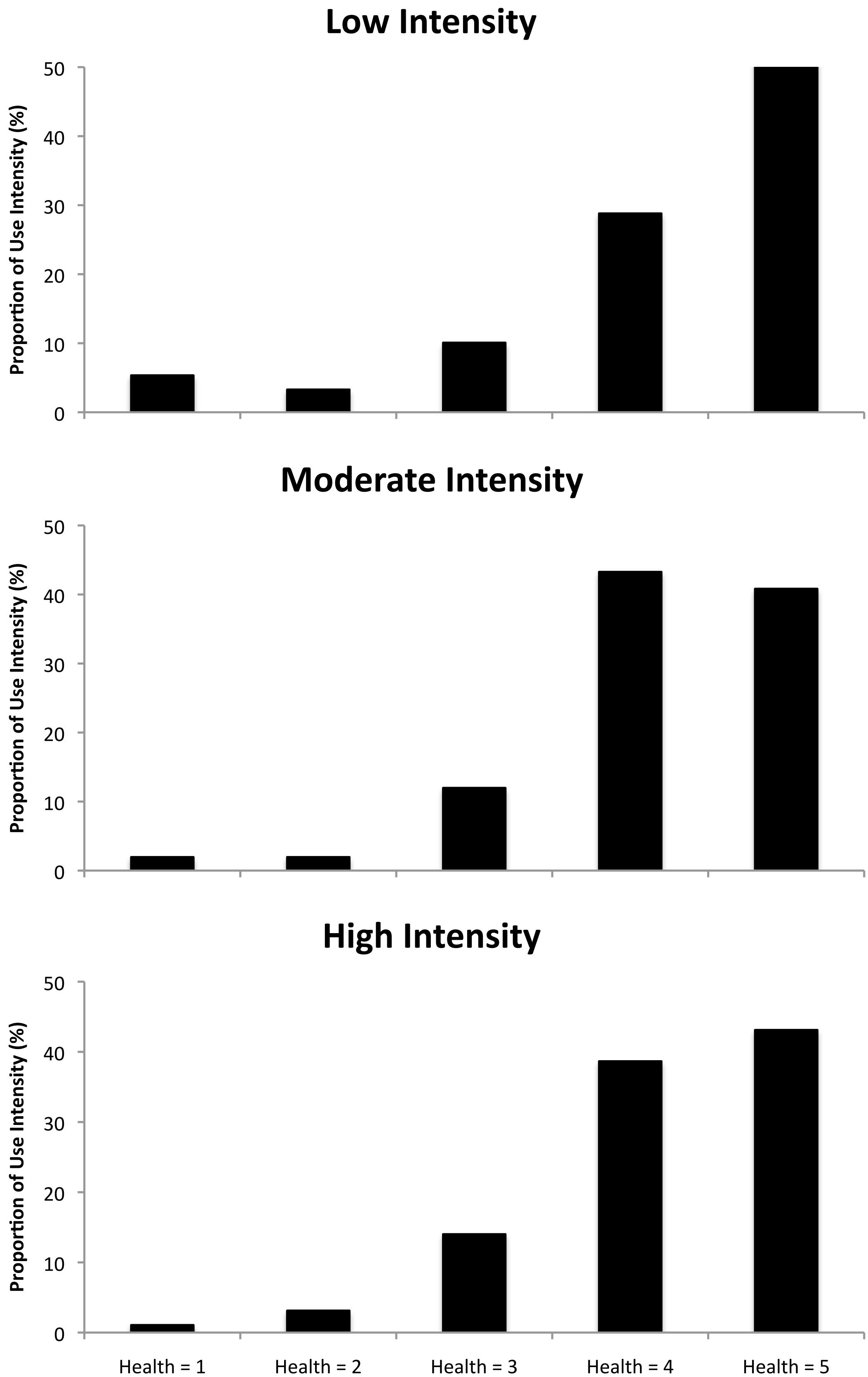

100
80
60
40
20
0
Proportion of Population (%)
Low
Moderate
High
Use Intensity

Figure 2.06



Low Intensity
Moderate Intensity
High Intensity
Proportion of Use Intensity (%)
0
10
20
30
40
50
Health = 1
Health = 2
Health = 3
Health = 4
Health = 5

Appendix A. Species List – Managed Campus

Species Name	Number of Trees	Percent
Pinus strobus L.	585	18.12
Tsuga canadensis (L.) Carrière	351	10.87
Acer saccharum Marshall	338	10.47
Cornus florida L.	146	4.52
Acer rubrum L.	144	4.46
Prunus serrulata Lindl.	127	3.93
Quercus palustris Münchh.	108	3.35
Ilex opaca Aiton	91	2.82
Prunus serotina Ehrh.	75	2.32
Amelanchier arborea (F. Michx.) Fernald	71	2.20
Betula nigra L.	70	2.17
Liriodendron tulipifera L.	67	2.08
Cedrus atlantica Endl.	64	1.98
Quercus phellos L.	63	1.95
Carpinus betulus L.	60	1.86
Thuja species L.	58	1.80
Cornus kousa Hance	57	1.77
Acer palmatum Thunb.	55	1.70
Ginkgo biloba L.	44	1.36
Robinia pseudoacacia L.	41	1.27
Cercis canadensis L.	38	1.18
Picea abies (L.) H. Karst.	35	1.08
Quercus rubra L.	34	1.05
Picea glauca (Moench) Voss	32	0.99
Nyssa sylvatica Marshall	29	0.90
Acer platanoides L.	26	0.81
Fagus grandifolia Ehrh.	24	0.74
Taxodium distichum (L.) Rich.	23	0.71
Platycladus orientalis (L.) Franco	21	0.65
Quercus alba L.	21	0.65
Picea pungens Engelm.	21	0.65
Pyrus communis L.	20	0.62
Betula pendula Roth	17	0.53
Chionanthus retusus Lindley & Paxton	15	0.46
Liquidambar styraciflua L.	14	0.43

Malus spp.	14	0.43
Acer griseum (Franch.) Pax	14	0.43
Betula lenta L.	13	0.40
Crataegus phaenopyrum Borkh.	13	0.40
Oxydendrum arboreum (L.) DC.	11	0.34
Celtis laevigata (Willdenow)	11	0.34
Carpinus caroliniana Walter	11	0.34
Thuja occidentalis L.	10	0.31
Chionanthus virginicus L.	9	0.28
Catalpa bignonioides Walter	8	0.25
Fraxinus excelsior L.	8	0.25
Acer buergerianum Miq.	8	0.25
Carya tomentosa Sarg.	8	0.25
Betula alleghaniensis Britt.	7	0.22
Metasequoia glyptostroboides Hu and W.C.Cheng,	7	0.22
Platanus hybrida (Aiton) Willd.	6	0.19
Fraxinus americana L.	6	0.19
Fagus sylvatica L.	6	0.19
Ulmus parvifolia Jacq.	6	0.19
Juniperus chinensis L.	5	0.15
Gleditsia triacanthos L.	5	0.15
Acer saccharinum L.	5	0.15
Salix x sepulcralis simonk	5	0.15
Chamaecyparis obtusa (Siebold & Zucc.) Endl.	3	0.09
Chamaecyparis pisifera (Siebold & Zucc.) Endl.	3	0.09
Styrax japonicus L.	3	0.09
Quercus texana Buckley	3	0.09
Acer negundo L.	2	0.06
Carya aquatica (Michx. f.) Nutt.	2	0.06
Koelreuteria paniculata Laxm.	2	0.06
Cotinus coggygria Scop.	2	0.06
Halesia carolina L.	2	0.06
Hamamelis virginiana L.	2	0.06
Viburnum rhytidophyllum Hemsl.	2	0.06
Hamamelis species L.	2	0.06
Magnolia x soulangiana	2	0.06
Tsuga caroliniana Engelm.	1	0.03
Tilia americana L.	1	0.03
Salix species L.	1	0.03
Quercus prinus L.	1	0.03
Prunus cerasifera Ehrh.	1	0.03
Morus alba L.	1	0.03
Aesculus hippocastanum L.	1	0.03
Lagerstroemia indica L.	1	0.03
Catalpa speciosa (Warder) Warder ex Engelm.	1	0.03
Juglans nigra L.	1	0.03

Fraxinus pennsylvanica Marshall	1	0.03
Castanea dentata (Marshall) Borkh.	1	0.03
Cornus racemosa Lam.	1	0.03
Magnolia acuminata (L.) L.	1	0.03

Appendix B. Species List – Nature Preserve

Species Name	No. Trees	Percent
Acer rubrum L.	4152	22.07
Liriodendron tulipifera L.	3728	19.82
Prunus serotina Ehrh.	2288	12.16
Quercus rubra L.	1779	9.46
Hamamelis virginiana L.	1356	7.21
Robinia pseudoacacia L.	1017	5.41
Acer pensylvanicum L.	847	4.50
Halesia carolina L.	678	3.60
Quercus prinus L.	508	2.70
Fraxinus pennsylvanica Marshall	424	2.25
Carya tomentosa (L.) Nutt.	339	1.80
Pinus strobus L.	339	1.80
Cornus florida L.	254	1.35
Fagus grandifolia Ehrh.	254	1.35
Oxydendrum arboreum (L.) DC.	254	1.35
Acer leucoderme Small	85	0.45
Crataegus crus-galli L.	85	0.45
Magnolia fraseri Walter	85	0.45
Malus spp.	85	0.45
Quercus alba L.	85	0.45
Quercus phellos L.	85	0.45
Tsuga canadensis (L.) Carrière	85	0.45

Appendix C. Glossary – Hazard Assessment Data

Data	Definition
Tree Location	GPS location
Pedestrian Use Intensity	Visually estimated via observed foot traffic within close proximity to each tree. Intensity was classified as high, moderate, or low.
Health	Determined through visual inspection of all tree attributes. Tree health was rated from 1-5 (1 = dead; 5 = very healthy).
Girdling Roots	Determined by the lack of root flare at the base of the trunk or visible girdling roots.
Excavation	This was noted if girdling roots were suspected but not obvious. Future management would require unearthing the root ball to remove potential girdling roots.
Root Zone	Notes were collected if the root zone was compromised by sidewalks, roads, or underground structures, such as water lines, power lines, and steam lines.
Pest/Pathogen	Data were collected if obvious pest or pathogen presence was seen.
Wounds	Included wounds inflicted via ice, wind, freeze-thaw, lawn mower/weed eater, and vehicle collisions.
Cracks	Presence of torsion or stress cracks.

Cavities	Data were collected on visible cavities, as well as suspected cavities located in the interior of the trunk.
Column of Decay	Column of decay is “death in the trunk” and signifies an irreversible health decline.
Codominate	When more than one main stem is present.
Lean	Degree of lean was noted for each tree.
Ground Heaving	Typically caused by severely leaning trees, is the mound of earth that is potentially lifted up on the opposite side of lean.
Included Bark	Defined as bark touching bark and usually found between codominate stems. Areas of included bark are prone to failure during wind and ice events.
Exfoliating Bark	Where bark is peeling away from either limbs or the main trunk. Exfoliating bark signifies death.
Crown Cleaning	When dead limbs were noted in the canopy, data were collected for crown cleaning in order to facilitate the removal of possible hazards.
Hangers	This refers to limbs that have broken off the main stem in the canopy and are now "hanging" (Widowmaker).
Targets	Buildings, sidewalks, and pedestrians that were located within the fall zone of trees were noted.
Accessibility	Data were recorded if trees were accessible by a bucket truck or required a climbing arborist.

Vita

Mr. Jason Coit Harkey was born in Iron Station, North Carolina on June 6, 1986 to Bobby and Cecilia Harkey. He has a younger brother, Justin Lee Harkey, and is married to Mrs. Sara Margaret Harkey. He attended elementary through high school in Lincoln County, North Carolina and graduated from East Lincoln High School in June 2004. In August 2004 he attended Appalachian State University in Boone, North Carolina to pursue a degree in biology with a concentration in ecology and environmental biology. In May 2008, he graduated with a Bachelor of Science degree in Biology, as well as a Bachelor of Science degree in Secondary Education for General Science. From August 2008 through June 2010, he taught high school science at West Lincoln High School in Lincoln County, North Carolina. In the fall of 2010, he returned to Appalachian State University to work toward a Master of Science degree. In May 2013, he was awarded his Master of Science degree in Biology with a concentration in Ecology and Evolutionary Biology.

Currently, he works with the Landscape Services branch of Appalachian State's Physical Plant managing their urban forest. He hopes to work for a prestigious company, or organization that would allow him to better enhance, manage, and protect our natural resources.