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ECOLOGICAL CHANGES IN THE URBAN FOREST OF SIX,
MIDWEST USA CITIES OVER TWENTY-FIVE YEARS

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ECOLOGICAL CHANGE IN THE URBAN FOREST OF SIX MIDWEST, USA CITIES OVER TWENTY-FIVE YEARS

By

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ABSTRACT

ECOLOGICAL CHANGE IN THE URBAN FOREST OF SIX MIDWEST, USA CITIES OVER TWENTY-FIVE YEARS

By

Charles Anthony Wade

This is one of the first long term studies that takes into consideration the entire urban forest, both public and private trees, over time. In 1980, an inventory of the urban forest in 10 cities was established to monitor the spread of Dutch elm disease. Shortly after the original study was concluded, the entire study ended. In 2003/2005, Bowling Green, Bucyrus, Delaware and Wooster, OH, Hutchinson, MN and Lincoln, NE were resurveyed to document the changes that have occurred over the years in the urban forest structure.

Between 1980 and 2003/2005, the urban tree density, species richness, and diversity did not change significantly. The public to private tree ratio also did not change significantly over the years, 8.5 and 7.9 to 1, respectively. The species richness of the urban forest is significantly greater than the natural forest. In 1980, 27%, and in 2003/2005, 42% of the tree taxa were considered overplanted. There were even more public trees that were overplanted; in 1980 and 2003/2005 there were 74% and 73%, respectively, deemed to be overplanted. The percentage of private trees that were regarded as overplanted is very similar to the total percentages. In 1980, 27% and in 2003/2005, 41% were considered overplanted. Of these overplanted taxa, many of them are native to North America, which creates an awkward situation for any emphasis to be further placed on the planting of "native species".

The size and condition of the trees were also measured. The average dbh of the urban forest trees change significantly over the years. One peculiarity that was noted was the significant loss of small trees between the years. This is due in part to in-growth between size categories, and fewer small trees are being planted. Also, over the years, the percent of trees in the different size classes of the urban forest begin to resemble what is found in a natural forest. The condition of the trees has gotten significantly worse between 1980 and 2003/2005. However, there are significantly more trees in the best condition category in both 1980 and 2003/2005.

As a result of the damage by an unusually large snowstorm that hit Lincoln, NE, in October 1997, when the trees still had leaves, there was a loss of 48.2% of the trees in the city. More than 90% of the smallest trees were lost, which produced a significant change in the average tree size, and the cleanup of the storm produced a significant change in the condition of the trees, for the better. The diversity of the trees did not change. But, there was a significant change in the number of the trees present in the urban forest. Finally, no correlation was found in the relationship between any of the wood properties (wood density, specific gravity, modulus of rupture or modulus of elasticity) and the percent lost of any of the species of trees.

For Melissa, Charles and Branden

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Chapter 1

Introduction

Urban Ecosystems

The ecology of the Earth's surface has been altered and manipulated in many ways. One of the greatest land-cover changes is the effect that humans have had on natural ecosystems, especially in urban areas (Vitousek, 1994; Zipperer et al., 2000; Grove et al., 2003). Local culture, behavior, social organization and economy affect the urban ecosystem (Nowak et al., 2001). Traditionally, urban areas have not been considered ecosystems that can function properly because they are continuously manipulated and therefore not considered "natural" (McDonnell and Pickett, 1991; Kendle and Forbes, 1997; McDonnell et al., 1997; Lundholm and Marlin, 2006). As examples of this manipulation, waterways are channeled, areas that naturally received full sun are now in the shade of a building or other structure, or a wetland may be filled in for a new housing development. The construction of a highway eliminates hills from the rolling countryside to ensure that the grade of the road is maneuverable and safe for vehicles, and wind breaks are constructed to protect houses and other buildings.

Some ecologists once considered urban areas to be "biological deserts" (Brady et al., 1979). They had the misconception that urban areas have little diversity, relative to the surrounding rural and natural areas. In actuality, reports have shown that the urban forest is very diverse, in some cases more so than rural areas, because of planting activities of home owners and the introduction of exotic species (Miller, 1997). Urban forests have also been perceived as not very productive. However, when lawn, shrub and tree aboveground biomass are included along with the belowground biomass, primary productivity is comparable to that of a natural forested ecosystem. This being said, most of the biomass is found in the trees (Dorney et al., 1984).

Over the last decade, a major research project has been leading the way for urban ecosystem studies. The project is the Baltimore Ecosystem Study (BES). It is one of the National Science Foundation's Long Term Ecological Research Network and the project is trying to identify and understand how the ecosystem is changing in Baltimore over time. The one major difference between this current study and the BES is the current study was established in 1980 and has 25 years of documented growth and change in the urban forest structure. Another difference is that the BES is looking at the entire urban ecosystem and not just the urban forest structure. The BES is looking at the Baltimore watershed, soils, urban design, etc.

Urban Forests

The urban forest is "the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan regions" (Miller, 1996). The study of urban forestry deals with tree growth characteristics, ecology and management in cities (Bradshaw et al., 1995; Grey, 1996; Dwyer et al., 2000; Kielbaso, 2008). Cities have the potential to accommodate more species than natural areas in the surrounding rural countryside (Gilbert, 1989; Jim, 2002). This is due to the wide variety of different habitats that can accommodate both natural and exotic tree species. Cities and urban areas in the United States generally represent very young successional habitats, in comparison to surrounding natural, more mature habitats (Wittig, 2004).

Much has been written about the urban forest, particularly street tree inventories (Impens and Delcaret, 1979; Dawson and Khawaja, 1985; Jim, 1986; Steven and Richard, 1986; Smiley and Baker, 1988; Jaenson et al., 1992; Chacalo et al., 1994; Poracsky and Scott, 1999; Sanders, 1981; Wray and Prestemon, 1983; McPherson and Rowntree, 1989; Lesser, 1996; Gartner et al., 2002; Maco and McPherson, 2003). Street trees are not the only trees that contribute to the urban forests (Schroeder and Cannon, 1987), in fact, street trees account for only about 10% of the urban forest (Kielbaso, 1988). Unfortunately, there have been few studies of the structure of the entire urban forest (Nowak, 1994). The study of the trees that make up the entire urban forest is important because people are responsible for the creation of new plant communities with artificial tree compositions comprised of natural, cultivated and exotic species (Whitney and Adams, 1980; Rebele, 1994; Vitousek et al., 1997; Zipperer et al., 1997). Some urban forests occur as remnants of natural forests that have survived the process of urbanization. Other urban forests were developed by deliberate planning, which in many cases included the introduction of many non-native, or exotic, species (Kowarik, 2005; Turner et al., 2005).

Urbanization

Urban area can be defined broadly as an area of high human population density, and/or significant commercial or industrial structures (Mills and Hamilton, 1984; Kinzig and

Grove, 2001). "Urban areas" have also been precisely defined as a region that has a density greater than 620 individuals per km^2 (Rowntree, 1984; McDonnell and Pickett, 1990). In the United States, population trends confirm that urban areas are getting larger; humans are becoming an urban species (Carreiro, 2008; Wu, 2008). In 1989, 74% of the United States population resided within urban areas. By 2025, the population that lives in urban areas is expected to increase to more than 80% (McDonnell and Pickett, 1990; Parlange, 1998; Pickett, 2001). Along with the increase in the number of people living in urban areas, there is also an increase in the size of the urban areas (Pickett et al., 2001). In 1970 urban areas encompassed nearly 13 million acres. In the late 1980's, the urban areas had reached 22 million acres, an increase of 9 million acres, or 41% in nearly twenty years (McDonnell and Pickett, 1990; Parlange, 1998). By 2000, the urban area in the United States had grown to more than 69 million acres (Dwyer et al., 2000). With this seemingly endless expansion of urban areas, it is hard to draw a distinct line between the boundaries that separate urban from suburban areas and suburban from rural areas (Kinzig and Grove, 2001).

With the expansion of urban areas comes an alteration of nature by the construction of residential, commercial and industrial structures (Solotaroff, 1911; White and Pickett, 1985; Broshot, 2007). Urbanization causes many individual plants, or even entire populations, to be lost because of the urban conditions (Dorney et al., 1984). This leaves open areas that can be colonized by other adapted species, some of which may be exotic and/or weedy species. Urbanization also brings the inevitable introduction of ornamentals to the native vegetation. All of this will cause competition, resulting in a reassortment of the species composition (Clemens et al., 1984; Sharpe et al., 1986). An example of this is the introduction of the non-woody species, purple loosestrife (*Lythrum salicaria*) or the woody species, European buckthorn (*Rhamnus cathartica*) and autumn-olive (*Elaeagnus umbellata*).

Brady et al. (1979) provided a nomenclature for these re-assortments in urban areas. This typology was based on the community structure and ecological dynamics within the city (Brady et al., 1979; Dorney et al., 1984). Specifically, urban land types are named for the physical/manmade, and the biological components. As an example, the term "Cliff/Organic Detritus" refers to the vertical aspects of very tall buildings. Such vertical buildings produce a number of different physical and biological phenomena, i.e. microclimate differences. The detritus is organic material produced from the waste of common urban animals and plants, as well as the products brought in by humans.

McDonnell and Pickett (1990) proposed a conceptual model of the effects of urbanization on ecological phenomena. Their model takes into consideration the three main realms of the urban ecosystem; physical structures, biotic components, and human culture. This model accounts for the aspects that constitute urbanization, the effects of urbanization on the biota and the environment and the ecosystem effects. McDonnell and Pickett (1990) state that the study of the aspects that constitute urbanization, and the effects on the ecosystem, which are still understudied, are becoming important because of the "magnitude of anthropogenic effects of today." They also suggest that studying the urban-rural gradient will "provide a new context in which to integrate humans as critical components of ecological systems" because it was not long ago that ecologists excluded humans from ecology.

Urban to Rural Gradient

It has been long recognized that there is an urban to rural gradient in the vegetation when one starts at a city core and moves out towards the rural areas (Register, 2006). However, there have not been many studies based on these urban to rural gradients (Iakovoglou et al., 2001). McDonnell and Pickett (1990) and Baxter et al. (1999) did two such studies. They found that urban areas generally appear as highly developed, densely populated cores in the center of the cities, surrounded by irregular rings of diminishing development. These studies and future urban to rural gradient studies will provide an opportunity to explicitly examine the role that people have on the formation and regulation of the urban ecosystem. These investigations can also be used to study the effects of urbanization upon natural areas (Blair, 1996; Porter et al., 2001).

Pre-Settlement Forests and Natural Vegetation

When considering the effects of urbanization on pre-settlement vegetation, it is easy to assume that there was an uninterrupted forest and that there has been total removal of that original forest. Many ecologists have studied the destruction of the native vegetation by urbanization. Some of these studies have shown that there has not been a complete devastation of the native forest. Instead, the surviving individuals serve as the foundation from which much of the current vegetation was derived (McBride and Jacobs, 1976; Brady et al., 1979; Sharpe et al., 1986).

McBride and Jacobs (1986) concluded that pre-settlement forests influence the early development of the urban ecosystem. These original forests, along with the species that are introduced with urbanization, either accidentally or purposely, cause the creation of a new vegetation complex. The original species that made up the ancestral forest are normally represented only when the original vegetation had long-lived species. An example of an exception to this would be *Fagus gandifolia*, American beech, which can be long-lived in natural areas but dies off soon after urbanization begins which is probably a result of soil microclimate disturbances (Wyman, 1965; Pirone, 1978; Partyka et al., 1980). Short-lived species die off before a new vegetation composition can be formed. Due to the influence of humans in this process of vegetation change, ecologists are reluctant to use the term "succession" except in the development from pre-settlement vegetation (Rowntree, 1988).

Study Hypotheses

The main questions that I was interested in were dealing with the succession and dynamics of the urban forest. Little is known about the entire urban forest. The street trees have been studied, but not the entire urban forest. Are there any trends in the urban forest structure that can be identified? How dynamic are the urban forests over time? Do the urban forests, at anytime, resemble a natural forest?

The overriding null hypothesis for this study is that there have been no changes in the urban forest over the past twenty-five years in six Midwestern cities. The alternative hypothesis is that there have been changes in the urban forest over the past twenty-five years. Chapter 2 specifically addresses six separate, but related hypotheses:

1) H_1 – urban tree density, trees per acre, has remained the same over the years of this study.
2) H_2 – urban tree species richness, number of different species, has remained the same over the years of this study.
3) H_3 – urban tree public to private ratio has remained the same over the years of this study.
4) H_4 – urban tree diversity, as measured with the Shannon index, has remained the same over the years of this study.
5) H_5 – urban tree species composition has remained the same over the years of this study.
6) H_6 – there is no difference in the species richness between the urban forests of this study and of natural forest in surrounding woodlots.

Chapter 3 addresses three hypotheses concerning the urban trees:

1) H_7 – the average diameter at breast height, DBH, of the urban forest trees has not changed over time.
2) H_8 – the average urban forest tree condition has not changed over time.

3) H_9 – there is no correlation in tree size and condition, or tree size and condition are independent of one another.

Chapter 4 focuses on an unusually large and early snowstorm that affected Lincoln, NE in 1997. The five hypotheses that are addressed in this chapter are:

1) H_{10} – the snowstorm did not change the average size of the urban forest trees.
2) H_{11} – the snowstorm did not change the average condition of the urban forest trees.
3) H_{12} – the snowstorm did not change the diversity, Shannon index, of the urban forest trees.
4) H_{13} – the snowstorm did not change the number of trees in the urban forest.
5) H_{14} – the physical and mechanical wood properties, per species, did not influence the percentage lost.

Before I began this study, I expected there to be enormous changes in the urban forest between the sampling years. In chapter 2, I expected there to be changes in the density, species richness, diversity, species composition and private to public ratio of the urban trees. In chapter 3, I also expected that the size (dbh) and condition of the trees changed. Additionally, I expected that there was going to be a correlation between the tree size and condition. In chapter 4, I expected that the snowstorm would have a negative effect on most of the measures of the urban forest in Lincoln, NE

Study History

In 1980, an unpublished urban forest inventory was conducted by Drs. W.M. Cannon, Jr. and D.P. Worley at the USDA - Forest Service, to evaluate the spread of Dutch elm disease in ten different cities. The cities were: Bowling Green, OH; Bucyrus, OH; Charlottesville, VA; Delaware, OH; Grand Junction, CO; Hutchinson, MN; Jamestown, NY; Lincoln, NE; West Springfield, MA; and Wooster, OH. The original study identified all of the trees in nine study plots per city. Species, on both public and private land, the diameter at breast height (dbh) and condition of each tree in each plot was documented. Tree condition was based on specific plant parts: crown, main stem and branches, base and roots. Each tree was assigned to a condition category based on the total number of decline or defect indicators found per tree. Trees were also placed into three age categories based on the age of the homes in these neighborhoods; the neighborhoods were under ten years old in 1980, 10 to 40 years old in 1980 and older than 40 years in 1980. In 1992, Kielbaso et al. resurveyed the same plots in Bowling Green, OH and Lincoln, NE to document changes that had taken place in the 13 years since the original inventories in those two cities.

Six of the ten cities were resurveyed in 2003 and 2005: Bowling Green, OH; Bucyrus, OH; Delaware, OH; Hutchinson, MN; Lincoln, NE; and Wooster, OH. The pre-settlement vegetation for these six cities falls into two basic vegetational categories; prairie and forest. Lincoln, NE, is in the prairie region of North America and when the city was originally established as Lancaster in 1856, there were only six trees within the city limits. In 2003, the Lincoln City Arborist, Steve Schwab, estimated that there were between 300,000 and 400,000 trees within the city limits (Laukaitis, 2003). The other five cities are located in forested regions of North America. Hutchinson, MN, is found in the "Big Woods" section of the "Maple-Basswood Region" where the pre-settlement vegetation was dominated by *Acer sp.* (maple) and *Tilia americana* (basswood) (Braun, 1950). The four Ohio cities, Bowling Green, Bucyrus, Delaware and Wooster, are all in the "Beech-Maple Region", where the pre-settlement vegetation was dominated by *F. grandifolia* (American beech) and *Acer saccharum* (sugar maple) (Braun, 1950).

Methods

In 2003, I inventoried Bowling Green, OH, Lincoln, NE, and Hutchinson, MN and in 2005, I resurveyed Bucyrus, Delaware and Wooster, OH. In all of the cities that were resurveyed the same criteria and methods that Cannon and Worley (1980) used in their original study were followed with two differences. The first was an addition that occurred in 1992, when Kielbaso et al. (1993) added three city blocks to each of the three surveys for Bowling Green, OH, and Lincoln, NE; one city block to each of the age categories. The second difference was the replacement of all nine city blocks in 1980 with 15 city blocks in 2005, in the surveys for Bucyrus, Wooster, and Delaware, OH, to generate a larger sample, and more importantly, the need to reestablish these blocks since the original data was fugitive. City officials in Delaware then requested another sample group to be added. This new group was also based on the age of the city blocks, but is comprised of relatively new blocks because the city is growing rapidly. Thus, five city blocks that were less than ten years old were added in 2005, resulting in a total of 11 additional blocks to the survey for Delaware, as compared to six additional blocks for

Bucyrus and Wooster. This new category of blocks, less than 10 years old in 2005, was not included in calculations because there was no other city with which they could be compared to.

Of the original cities, Bowling Green, OH, Lincoln, NE, and Hutchinson, MN, were the only locations where the original blocks and trees could be relocated. In Bucyrus, Delaware and Wooster, OH, the original data were available, but the actual city block locations were not known nor were they able to be reconstructed. Therefore, blocks were newly established in 2005 following the procedures and criteria that were set forth by Cannon and Worley (unpublished). Even though the data from these last three cities are not from the exact addresses as those in 1980, the pooled data averages are still similar between 1980 and 2003/2005. The criteria divided the cities into three categories based on the age of the houses present on the city blocks. Since the original blocks could not be relocated in Bucyrus, Delaware, and Wooster, OH, I compared overall trends based on different samples in the overall tree data for these three cities.

In the original study, as stated, nine city blocks were surveyed in each city. These nine blocks were divided into three age categories based on the age of the homes in these neighborhoods: less than 10 years; 10 to 40 years; and older than 40 years in 1980. These age categories assured diversity and it generated a data set that was more typical or representative of the entire urban forest. The trees were also divided by land ownership, public or private. "Private ownership" refers to trees located in the front, side and back yards and "public ownership" refers to trees located in the public right–of–way, which is usually between the sidewalk and the street. If there was no sidewalk, then the trees within 15 feet of the street were considered public. The dbh (diameter at breast height) for every tree was measured and the trees placed into size classes: (1) – 5.1 to 10.2 cm (2 to 4 inches), (2) – 10.2 to 25.4 cm (4 to 10 inches), (3) – 25.4 to 40.6 cm (10 to 16 inches), and (4) – greater than 40.6 cm (16 inches).

For the purpose of calculating tree density, city plat maps were used to compute the area of each block. To determine the public tree density, the entire street right-of-way was used, from the center of the street to the inside of the sidewalk. Much of the right-of-way area is covered by the street, leaving only the tree lawn, the small grassy area between the street and sidewalk, for tree growth. Using the complete right-of-way area is appropriate because the total private area was used and private areas are also partially covered by impermeable surfaces such as houses and other structures, driveways, pools, etc.

Tree health conditions were assessed by identifying signs of decline; the fewer signs of decline, the better the health condition of the tree. Specific decline signs were evaluated by looking at the crown, trunk and branches, and base of the trees. Examples of decline signs include: decay symptoms, girdling roots, broken branches/limbs, included bark, etc. Once the tree was evaluated, then the decline signs were summed. If the tree had zero or one sign of decline, then it was rated a (1), if the tree had two decline signs, it was rated a (2), if it had three or four decline signs, it was rated a (3), if it had five or more decline signs it was rated a (4), and if it was dead or was obviously in the process of dying it was rated a (5). This system was unique to the original study and has produced reasonably consistent comparisons with current ISA/CTLA evaluations guide procedures.

To evaluate species diversity that was found in each of the cities, the Shannon diversity index was used. The Shannon index (H'):

$$H' = -\Sigma p_i \ln p_i$$

takes into account species richness and incorporates species abundance (evenness). A *t*-test was used to identify any significant differences in diversity over the sampling times (Magurran, 1988, 2004).

For the purpose of looking at overall trends in the urban forest of the Midwest, all six of the cities' data were pooled. In this way any tendencies in the data can be compared between 1980 and 2003/2005. Individual cities were looked at, but are generally not reported on in chapters 2 and 3. For individual city data, please see the appendix.

Demographics of each city

Bowling Green, Ohio – According to the 2000 census there were 29,636 people, with a median annual household income of $30,599. The city measures 10.2 square miles and had a density of 2,905 people per square mile. Bowling Green has been recognized as an Arbor Day Foundation's *Tree City USA* since 1980, employs a city arborist and has a tree commission. There are approximately 8,000 street trees and the city has an urban forestry budget of $454,000. This is $56.75 per tree (Table 1.1).

Bucyrus, Ohio – In the 2000 census there were 13,224 people with a median annual household income of $32,394. The city is 7.49 square miles, with a population density of 1,766 people per square mile. The city does not have an arborist/forester or tree commission/board and is not a *Tree City USA*. There are 1,790 street trees in the city and there is a budget of less than $20,000 for trees and tree maintenance. This is $11.17 per tree (Table 1.1).

Delaware, Ohio – The 2000 census reported 25,246 people and a median annual household income of $39,030. The city is 15.1 square miles in size with a population density of 1,672 people per square mile. The city has been a *Tree City USA* since 1981, with a tree commission and a city forester. Delaware has roughly 14,000 street trees and an annual budget of $140,000 for trees. This is $10.00 per tree (Table 1.1).

Hutchinson, Minnesota – In the 2000 census, Hutchinson had 13,560 people with a median annual income of $42,278, and is 7.8 square miles in size, with a population density of 1,739 people per square mile. Hutchinson has been a *Tree City USA* since 1979 and has an urban forester and Shade Tree board. There are 4,336 boulevard/alley trees and an annual budget of $130,000. This is $29.98 per tree (Table 1.1).

Lincoln, Nebraska – The 2000 census showed that there were 225,581 people with a median annual household income of $40,605. There are 81.2 square miles, with a population density of 2,779 people per square mile. The city has an urban forester with a tree commission and Lincoln has been a *Tree City USA* since 1977. Lincoln has 62,559 street trees and a tree budget of $1,133,110. This is $18.11 per tree (Table 1.1).

Wooster, Ohio – In the 2000 census, there were 24,811 people with a median annual household income of $37,400. There are 14.4 square miles with a population density of 1,722 people per square mile. The city is a *Tree City USA* since 1976, has a tree commission and a city forester/arborist. There are approximately 15,000 street trees in the city and an annual budget of about $155,000 for tree maintenance and upkeep. This is $10.33 per tree (Table 1.1).

One major question that has arisen in this study is concerning Lincoln, NE: should Lincoln be added into the overall averages? Or should Lincoln be removed from the overall average because it is so different? The answer is solidly no, Lincoln should not be removed from the overall averages. Lincoln, NE is not in a forested region; it is, instead, in the Great Plains or prairie region of North America. When Lincoln was established as the city of Lancaster in 1856, there were only 6 trees in the city limits (Laukaitis, 2003). Also, did the snowstorm (chapter 4) have an effect on the 2003 data? After comparing the data, with or without Lincoln's data included, it was found that there are no significant differences (Table 1.3).

Appendices

Several tables containing important information not reported on in the chapters are included as appendices which are organized by city. The first table in each city's appendix is a summary of the total number of trees in the plots present during each year an inventory took place. The number of the tables in each appendix depends on how many times that city was inventoried. For each year that an inventory was performed, there is a table showing the total number of trees, both public and private. There are separate tables showing only the public trees and others showing only the private trees. Each of the tables of species also ranks the trees by the percentage of each species present.

Table 1.1. City Demographics Based on Street Trees.

	Cities Bowling Green	Bucyrus	Delaware	Hutchinson	Lincoln	Wooster	Six City Average	United States Mean 1988 (Kielbaso et al.)
City size (sq. mi)	10.2 ($26.4\ km^2$)	7.49 ($19.4\ km^2$)	15.1 ($39.1\ km^2$)	7.8 ($20.2\ km^2$)	81.2 ($210.3\ km^2$)	14.4 ($14.4\ km^2$)	22.7 ($55.0\ km^2$)	34 ($88.1\ km^2$)
Sample area size (acre)[1]	82.63 (33.45 ha)	53.78 (21.77 ha)	97.97 (39.66 ha)	32.73 (13.25 ha)	56.03 (22.68 ha)	71.65 (29.01 ha)	65.8 (26.64 ha)	——
Number of street trees[2]	8,000	1,790	14,000	4,336	62,559	15,000	17,614	29,677
Total number of trees[3]	61,040	15,358	97,720	13,268	275,885	246,150	138,271[4]	232,964[4]
City population	29,636	13,224	25,246	13,560	225,581	24,811	55,343	——
Total tree care budget[5]	$454,000	$20,000	$140,000	$130,000	$1,133,110	$155,000	$338,685	$163,349
Total trees/capita	2.12	1.06	4.35	2.51	2.18	4.75	2.83	——
Street trees/capita	0.27	0.16	0.55	0.32	0.28	0.60	0.36	0.47
Dollars/street tree	$56.75	$11.17	$10.00	$29.98	$18.11	$10.33	$22.72	$10.62
Dollars/capita	$15.32	$1.51	$9.68	$9.59	$5.02	$6.25	$7.90	$2.60

1 Sample size in 2003/2005
2 Reported by individual cities
3 Calculated using the findings of the current 2003/2005 data for each individual city for private trees to 1 public tree
4 Calculated using the findings of the current 2003/2005 data of 7.85 private trees to 1 public tree
5 2007 budget

Table 1.2. Compared selected urban forest descriptor data from the six Midwest cities, 1980 to 2003/2005.

	Cities Bowling Green		Bucyrus		Delaware		Hutchinson		Lincoln		Wooster		Overall Average
	1980	2003/2005	1980	2003/2005	1980	2003/2005	1980	2003/2005	1980	2003/2005	1980	2003/2005	2003/2005
Number of Lots surveyed	214	237	143	228	231	442	155	118	146	220	204	289	256
Number of Trees	2280	2279	876	1111	2486	3515	704	654	953	1049	1682	2316	1821
Diversity[1]	3.60	3.57	3.24	2.39	3.22	3.20	2.96	2.96	3.47	3.36	3.27	3.27	3
Species Richness	75	82	54	58	66	80	43	47	62	63	62	67	66
Density[2]	36.9	28.9	19.2	20.7	30.6	35.9	36.2	32.5	24.2	20.4	26.5	32	28
Avg. Tree Condition	1.32	1.66	1.65	1.59	1.44	1.51	1.74	1.8	1.73	1.69	1.32	2	2
Avg. Tree Size[3]	5.73	9.61	7.48	11.02	6.34	9.33	9.17	10.34	9.11	11.56	6.80	8.89	10
Private to Public Ratio	6.89 to 1	7.63 to 1	4.92 to 1	8.58 to 1	14.54 to 1	6.98 to 1	3.57 to 1	3.06 to 1	6.27 to 1	4.41 to 1	14.72 to 1	16.41 to 1	7.85 to 1

1 Shannon diversity index value
2 Trees per acre
3 DBH in inches

Table 1.3. Comparison of urban forest descriptor averages with and without Lincoln, NE data in 1980 and 2003/2005.

	1980 With Lincoln's Data	1980 Without Lincoln's Data	2003/2005 With Lincoln's Data	2003/2005 Without Lincoln's Data
Basal area (sq. feet per acre)	6.49	6.25	13.95	14.02
Denstiy (trees per acre)	28.93	29.88	28.45	30.06
Average size (inches)	7.44	7.10	10.13	9.83
Average condition	1.53	1.49	1.65	1.64
Diversity (Shannon index)	3.29	3.26	3.13	3.10
Private to public ratio	8.49 to 1	8.93 to 1	7.85 to 1	8.53 to 1
Average number of lots	182.2	189.4	261.8	270.2
Average Species Richness	60.3	60.0	66.2	66.8

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Chapter 2

Changes in Urban Forest Structure in Six Cities in the Midwest Region of the United States

Abstract

Urban forest structure and dynamics are largely driven by both public and private tree planting and removal processes as trees interact with site limitations, insects, diseases, and competition, yet joint consideration of forests on both public and private property is rare. This report summarizes changes in forest structure in six Midwestern cities (Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN) based on surveys conducted on public and private land in 1980, then again in 2003/2005. The public to private ratio of trees in all six cities was 8.5 private trees to1 public tree in 1980 and 7.9 to 1 in 2003/2005. Species richness, in all six of the cities, combined, increased from 97 in 1980 to 100 in 2003/2005, while species diversity (Shannon index) basically remained the same over time in both studies. When species richness in urban forests was compared to natural forests in the vicinity, urban forests contained many more species (47 to 82) than the natural forests in the vicinity of the cities (18 to 23). In the urban forests of this study, the most common tree genus in both surveys, 1980 and 2003/2005, was *Acer,* which comprised 22% in 1980 of all tree species and 24% in 2003/2005. The genus *Acer* accounted for nearly 40% of the public trees and about 20% of the private trees in both 1980 and 2003/2005. In 1980, 27% and in 2003/2005, 42% of the tree taxa were considered overplanted. Many of the most common species in the urban forest may be considered overplanted, consisting of more than 5% of the total species richness. Intriguingly, 89% and 75% of the overplanted trees in the urban forests surveyed in 1980 and 2003/2005, respectively, are considered native to North America. This study also shows the importance of including the private trees in these studies because nearly 90% of the urban forest is private trees.

Key Words: urban forest density; species richness; diversity; urban succession

Introduction

Most studies examining the structure of the urban forests include only public street tree data (Sanders, 1981; Wray and Prestemon, 1983; McPherson and Rowntree, 1989; Lesser, 1996; Maco and McPherson, 2003). While useful for many purposes, these studies ignore approximately 90% of the trees in the urban ecosystem that are on private land (Kielbaso et al., 1988; Miller, 1988; Moll, 1989; Kielbaso and Cotrone, 1990; Kielbaso et al., 1993; Moll and Kollin, 1993; Maco and McPherson, 2002; Kielbaso, 2008).

It is generally accepted that tree species diversity in the city should be maintained and is important in order to reduce the chance of a catastrophic, species specific disease or pest outbreak (Raupp et al., 2006). In 1975, Barker recommended that no single species should make up more than 5% of the total species richness. Moll (1989) suggested a guideline for maximum diversity in urban forests at no more than 5% of any one species and no more than 10% of any one genus. In 1991, Miller and Miller proposed that Barker's recommendation be modified to no more than one species comprising more than 10% of total species richness. A more encompassing approach was proposed by Santamour (1990), with no more than 10% of any one species, no more than 20% in any one genus and no more than 30% from any one family should be planted. A different approach was taken when Richards (1983, 1993) proposed that a species may be considered overused if it is often planted where other proven species are likely to be better suited. All of these guidelines are based on street trees and do not take into consideration the trees in private yards that make up the majority of urban forests (Moll and Kollin, 1993; Clark et al., 1997).

Urban forests, like natural forests, can be defined by species composition. Likewise, urban forest development to some extent follows natural forest succession. However, urban forest succession is greatly influenced by people living within these forest communities. Successional development starts with a distinct tree species composition and is characterized by an extended period of time of "slow, subtle, but continuous and irreversible change" (Oliver and Larson, 1996). Urban forest development can be altered by sporadic, unexpected, and extraordinary destructive disturbances (Botkin, 1990; Frelich, 2002). When one lives in an urban area, it is hard to observe these subtle changes, but sudden destructive changes are easily noticed. In the absence of destructive changes, one may think that the urban forest is stable and not changing. But, when comparative surveys are performed over times, the changes are discernible and can be documented. When these manifestations are compared, the urban forest is quite dynamic.

Species richness in urban forests is considerably higher than in surrounding natural forest (Gilbert, 1989; Zipperer et al., 1997; Pickett et al. 2001; Nowak, 2007). Similarly, post-settlement urban forests are also more diverse when compared to pre-settlement natural forests (McBride and Jacobs, 1986; Zipperer et al., 1991; Nowak, 1993). The increase is generally attributable to the introduction of exotic plant species. However, the influx of aliens only accounts for a portion of the large species richness in cities. The increase in species richness does not peak as it does in a natural forest (Nowak, 1993), but continually increases as new species are planted. Another component that increases the species diversity in a city is the heterogeneity of the small-scale habitats that are created by individual developments within the city (Brady et. al., 1979; Gilbert, 1989; Zipperer, 2000).

Because of urbanization, the tree density, trees per acre, of the urban forest tends to be lower than similar natural forest. This is generally true because of the removal of the understory and shrub layer for the establishment of lawns and other open areas in private yards. The only real exception to this are stands growing where large estates once were and where there are remnants of large stands in very large urban parks (Lawrence, 1995; Pickett et al., 2001).

I hypothesized that there were no changes in density, species richness, and the public to private ratio of the urban trees of the six cities that were examined over the years of this study. Also, I hypothesized that there were no changes in the urban tree diversity and the composition of the trees over the study period.

The six specific null hypotheses that were tested in this study are:

H_1 There has been no change in density of the trees in the urban forest in the six cities examined over the years of this study;

H_2 There has been no change in tree species richness in the urban forest in the six cities examined over the years of this study;

H_3 There has been no change in the public to private ratio of trees in the urban forest in the six cities examined over the years of this study;

H_4 There has been no change in the urban tree diversity of the trees in the urban forest in the six cities examined over the years of this study;

H_5 There has been no change in the urban tree species composition in the urban forest in the six cities examined over the years of this study; and

H_6 There is no difference in the species richness between the urban forest in the urban forest in the six cities examined over the years of this study.

Methods

I quantified the urban forest structure, richness, composition and changes in these attributes over time based on repeated surveys (1980 and 2003/2005) of both public and private property in six Midwestern cities (Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN). This study follows the procedures that were established in the original study by W.M. Cannon, Jr. and D.P. Worley at the USDA-Forest Service in 1980, and replicated in part by Kielbaso, et al. in 1993. In 2003/2005 I surveyed these cities again. I revisited each of the cities and inventoried the blocks again. I documented every tree on public and private land in the study areas as to species, size (diameter at breast height, dbh) and tree category (e.g. large deciduous, intermediate deciduous, etc.). In this study, I defined a tree as being a woody perennial plant with a dbh greater than 2 in. (5.1 cm). Shrubs were not considered in this study with the exception of a few *Taxus sp.* (yews) that were included because they had a dbh greater than 2 in. and a height greater than 12 feet. The trees in this study were also classified as being: large deciduous, intermediate deciduous, small deciduous, large evergreen, intermediate evergreen, and small evergreen. This classification is based on tree descriptions from Dirr, 1998.

In Cannon and Worley's study, nine city blocks were randomly selected and inventoried in each of ten different cities, Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN, West Springfield, MA, Jamestown, NY, Grand Junction, CO and Charlottesville, VA . These nine blocks were sampled from three age categories: less than 10 years; 10 to 40 years; and older than 40 years in 1980. The blocks that were older than 40 years in 1980 may be as old as the cities. The reason for these age categories was to insure diversity in the trees based on cultural and planting practices. The goal was to generate a data set that was typical or representative of the entire urban forest. The trees were also categorized by land ownership, public or private. Private ownership refers to trees located in the front, side and back yards of private residences and public ownership refers to trees located in the public right–of–way which is usually between the sidewalk and the street in front of private residences. If there was no sidewalk, then the trees within the street right-of-way, per plat maps, typically 15 feet off the street, were considered public. Each tree was surveyed by gaining prior permission from the owners of all 1571 properties and visiting every single tree on each of the properties.

Of the original study in 1980, only 6 of those cities were resurveyed. This was due to committee decision based on time and accessibility to the cities. In the original surveys, 9 city blocks were studied in each of the cities. In 1992, one additional block was added to each of the age categories in Lincoln and Bowling Green, making a total of 12 blocks surveyed (Kielbaso et al. 1993). In 2003; Lincoln, NE, Bowling Green, OH and Hutchinson MN were resurveyed. In Lincoln and Bowling Green the same 12 blocks were surveyed as in 1992. Only seven of the original blocks could be resurveyed due to redevelopment of the city in Hutchinson. In 2005, I resurveyed Bucyrus, Delaware and Wooster, OH. However, none of the actual blocks could be relocated due to fugitive data. So, the blocks were reestablished using the same criteria for picking the blocks that were employed by Cannon and Worthy in 1980. In each of these cities, 5 city blocks for each of the different age categories were chosen, making a total of 15 blocks in each city. In Delaware, a new age category, less than 5 years old in 2005, with 5 city blocks was added. This was prompted by the large amount of newly constructed neighborhoods and subdivisions in the city since 2000, and a specific city request.

For the purpose of calculating tree density (trees per acre), city plat maps were used to compute the areas of different city blocks. To determine the public tree density, the entire street right-of-way was used, from the center of the street to the inside of the sidewalk. Much of the right-of-way area is covered by the street, leaving only the tree lawn for tree growth. Using the complete right-of-way area is justified because the total private area was used and it is also partially covered by impermeable surfaces; houses and other structures, driveways, pools, etc.

Basal area is a measurement of stand density developed by foresters. It is a way of measuring the total cross-sectional area of the trees in a stand. The basal area is expressed as square feet per acre and was calculated with the formula:

Basal Area = $(((0.005454)\ (\text{avg. dbh})^2)\ (\text{number of trees}))$ / total acres, where 0.005454 is a constant calculated for the area of a one foot diameter dbh tree.

To predict species richness throughout the six cities, a nonparametric estimate of the original data was derived by jackknifing, a re-sampling technique without replacement (Heltshe and Forrester, 1983; Smith and Belle, 1984; Heltshe, 1985; Palmer, 1991; Gimaret-Carpentier et al., 1998; Cao et al., 2004; Magurran, 2004). By re-sampling the collected data multiple times and taking an average value based on the acres surveyed, I predicted the number of species that may be found when randomly surveying acres in the city.

I used the Shannon index ($H' = -\Sigma p_i \ln p_i$) to measure tree diversity where the quantity p_i is the proportion of individuals found in the *i*th species. The Shannon index is an expression of a community's diversity which is calculated by taking into account species richness or abundance and evenness among species (Elliott, 1989). A *t*-test was conducted to determine if there were any differences in Shannon index values between 1980 and 2003/2005 (Magurran, 1988). Other statistical comparisons were also performed using ANOVA with a Tukey's HSD (honestly significant difference) Post Hoc test to determine differences in the categories of species richness. Chi-square was also used to test 1980 to 2003/2005 data.

Results

The six cities of this study are all found in the Midwest region of the United States. However, that does not mean the cities are similar. See Table 2.1 for a comparison of the six cities.

Total Density and Number of Trees – In 1980, there were 409.77 acres in the sample area and 8,980 trees. This is a density of 21.9 trees per acre. In 2003/2005, there were 493.04 acres sampled with 10,924 total trees. This is a density of 22.2 trees per acre, an increase of 0.25 trees per acre, or 1.13%.

On public land, in 1980, the density was 12.6 trees per acre and in 2003/2005 it was 13.3 trees per acre, a gain of 5.7%. The private trees had a density of 24.1 trees per acre in 1980 and 24.4 trees per acre in 2003/2005, a small gain of roughly 0.9%.

The basal area in 1980 for all of the trees was 35.36 square feet per acre while in 2003/2005 the basal area was more than double, at 76.78 square feet per acre. The basal area for the public area in 1980 was 43.19 and in 2003/2005 it was 58.23 and the private tree basal area was 33.01 in 1980 and it was almost tripled in 2003/2005, at 82.90.

The ratio of private trees to public trees in the urban forest was 8.49 private trees to 1 public tree in 1980 meaning that the private trees made up 89.5% of the urban forest. In 2003/2005 the ratio had decreased to 7.85 private trees to 1 public tree, signifying that the private trees make up 88.7% of the urban forest. During this time period, the land area ratio remained basically the same at 5.10 and 5.01 private acres to 1 public acre in 1980 and 2003/2005 respectively.

Species Richness and Diversity – The total number of tree species counted in the six cities was 97 in 1980 and was 100 in 2003/2005. There were 40 species on public land and 95 species on private land in 1980 compared to 51 and 97, respectively, in 2003/2005 (Table 2.2).

When comparing species per acre, there were 0.236 species per acre in the 409.8 acres in 1980 and 0.211 species per acre in the 493.0 acres in 2003/2005 for all trees in all cities. Neither of these are statistically different from one another ($\chi^2 = 2.74$, $p > 0.05$).

The genus *Acer* accounted for the most individual trees in 1980 and 2003/2005 (Figure 2.1). There were eight different species in the genus *Acer* in 1980, with *Acer saccharinum* L, silver maple, being the most common. In 2003/2005 there were eight different *Acer* species with *A. saccharinum* L, being the most common also. In both surveys, 13 genera made up at least 2% of the total tree species, which accounted for approximately 80% of all trees (Figure 2.1).

The public (Figure 2.2) and private (Figure 2.3) trees follow the same trend with *Acer* being the most common genus. *Acer* made up 39.7% of the public trees in 1980 and 22.1% of the private trees. In 2003/2005 the genus *Acer* made up 40.0% of the public trees and 21.1% of the private trees.

In 1980, the most abundant tree in all six cities was silver maple, with 10.4% of the total, followed by blue spruce (*Picea pungens* Engelm.), with 6.9% and crabapple (*Malus sp.*), with 5.1%. In the latest survey of all six cities, 2003 and 2005, the two most abundant trees were arborvitae (*Thuja occidentalis* L.) with 9.0% and silver maple with 8.6%, respectively. The third most abundant tree species in the latest survey was Norway maple (*Acer platanoides* L.) with 6.4% (Table 2.3). One species of note that has been disappearing consistently from all of the cities since 1980 is the American elm (*Ulmus americana* L.). In 1980, the American elm was the fourth most abundant tree species in all of the cities, making up 4.7% of the total composition. In the 2003/2005 survey the American elm had fallen to the 31st most abundant tree species making up only 0.8% of the total species composition.

The estimation of the total species richness per acre was similar in 1980 and 2003/2005, even though many more acres were surveyed in 2003/2005 (Figure 2.4). The species richness estimation for the public and private trees is also similar between the years, and private trees estimation is similar between the years. The private species richness is comparable to the values of the total trees species richness, which is not surprising, since this survey shows that about 90% of the total tree species richness is private.

Trees were divided into categories based on their size and leaf type (e.g. evergreen vs. deciduous). An analysis of the differences in species richness among the categories of trees (e.g. large deciduous, large evergreen, etc.) in 1980 and 2003/2005 indicates that the large deciduous and intermediate deciduous trees were essentially the same (Table 2.4). All of the other comparisons of the species richness in the different categories of trees were significantly different from one another ($F_{5,6} = 198.24$, $p < 0.01$). However, there were no differences between 1980 and 2003/2005.

The Shannon index for the entire urban forest decreased, insignificantly ($t = 0.31$, $p > 0.05$), from 3.69 in 1980 to 3.62 in 2003/2005. However, the public trees had a significant increase ($t = 1.39$, $p < 0.05$) in the value of the Shannon index. In 1980 the value was 2.92 and in 2003/2005 the value was 3.59. The private tree Shannon index values were similar to the total values; 1980 was 3.67 and in 2003/2005 it was 3.61 ($t = 0.32$, $p > 0.05$).

This study also shows that not every acre in a city needs to be surveyed in order to account for the majority of the species richness. In 1980, 21.7 acres of the average 55.7 acres per city, accounted for 83.6% of all the species richness. In order to account for 90.2% of the species richness, 35.9 acres needs to be surveyed. In 2003/2005, 27.3 acres of the average 63.8 acres per city, accounted for 80.3% of the species richness. To account for 90.1% of the species richness, 45.5 acres needs to be surveyed. Surveying more acres will probably only detect unique and novelty species. This demonstrates that the entire city does not need to be inventoried in order to reveal the majority of the species richness.

Urban Forests Compared to Natural Forests – By comparing the average species richness of all six cities, in 2003/2005 the urban forest has approximately 3 times more tree species than the natural forest. The species richness between the urban forest in 1980 and 2003/2005, and the natural forest is statistically different, ($F_{2, 18} = 45.89$, $p < 0.01$), and a Tukey's comparison of the tree groups indicate that the natural forest species richness is significantly less ($p < 0.05$) than the urban forest in both 1980 and 2003/2005. However, the urban forest data are essentially the same between 1980 and 2003/2005.

Discussion

Tree Distribution - Many authors (Kielbaso et al., 1988; Miller, 1988; Moll, 1989; Kielbaso et al., 1993; Moll and Kollin, 1993) have reported that about 90% of the urban forest consists of private trees and the remaining 10% are public trees or street trees. This study found similar percentages. In 1980 the private to public tree ratio for all six of the cities in this study was 8.49 to 1, which means 89.5% of the trees are private trees, in 2003/2005 the ratio was 7.85 to 1, which denotes that 88.7% of the trees are private. Dwyer et al. (2000) stated that the national average ratio is about 62 non-street trees for every one street tree in urban areas across the United States. This current study does not support this liberal estimate. The probable explanation for this great difference is in how the data were derived. Dwyer et al. (2000) used "data on percentage of the tree cover for the conterminous United States ... derived through geographical information systems

(GIS) analysis of forest cover maps and maps of census-designated entities". These estimates were then compared with aerial photographs. These GIS/aerial photographs combined urban residential areas, parks, cemeteries, riparian and suburban areas that may still have been forested in order to calculate the ratio of public to private trees. The current study is limited to urban residential areas only, and the data was collected on the ground.

Tree Density - The total tree density increased slightly due primarily to an increase in the private trees. During this time, homeowners were buying trees to enhance their properties. At the same time, more warehouse franchises and discount stores were offering inexpensive trees. This is one of the reasons for the substantial increase in the number of arborvitae that was seen in this study.

In general, the basal area increased from 1980 to 2003/2005. The total tree basal area basically doubled while the public tree basal area increased by 34.8% and the private tree basal area increased by 151.8%. A natural woodlot under harvest management is usually maintained at a basal area of around 80-100 square feet per acre (Mr. Bob Cool, personal communication). The total tree basal area is approaching this, at 76.8 square feet per acre and the private tree basal area in within this range, at 82.9 square feet per acre. This indicates that, with time, the urban forest basal area approaches the basal area found in managed natural forests with essentially a closed canopy, which would leave few places to plant new trees.

Species Richness/Diversity – When species richness was compared, there was basically no difference between 1980 and 2003/2005. This was true when comparing the public, private and total species richness for both years. There was also no substantial difference in species richness among the different age groups in 1980 and 2003/2005.

If the recommended species planting rules proposed by Miller and Miller, (1991) and Santamour, (1990) are followed, some species and genera are overplanted, *Acer* in particular. According to these rules, no one species should comprise more than 10% of the total population species richness. When considering total species richness in all cities in 1980, only silver maple was overplanted. In 2003/2005, no species made up more than 10% of the total species. If, instead, the species composition rules proposed by Barker, (1975) and Moll, (1989) are followed, then no single species should be more than 5% of the total composition. With their suggested rules for the composition of the total urban forest, in 1980 silver maple, blue spruce (*Picea pungens* Engelm.), crabapple and ash (*Fraxinus spp.*) were overplanted. In 2003/2005, arborvitae, silver maple, Norway maple, blue spruce, ash and Norway spruce (*Picea abies* (L.) Karst.) are all overplanted (Table 2.4). The implication is that more tree species are being overplanted and this is being driven by individual property owners because they control approximately 90% of the urban trees, not city arborists or foresters. The only real solution to this is education. Property owners need to be provided an expanded list of trees to rely on, and growers need to alter their production to meet these needs.

In 1980, 27%, and in 2003/2005, 42% of the tree taxa were considered overplanted (Table 2.5). This indicates that we are relying on fewer tree species today than we were in 1980. In 1980, silver maple, blue spruce, crabapple and ash made up more than 5% of the total trees in the urban forest. In 2003/2005, Arborvitae, silver maple, Norway maple, blue spruce, ash and Norway spruce made up more than 5% or the total urban forest.

When considering which trees were overplanted in 1980, in the public trees there were four species that each accounted for 10% or more of the species; sugar maple, silver maple, ash and crabapple. In 2003/2005 there were three species where each comprised more than 10% of the public species; ash, Norway maple and sugar maple. In total, there were eight species on public land that comprised more than 5% of the tree composition in both 1980 and in 2003/2005 (Table 2.5).

The private trees in 1980, only silver maple accounted for more than 10% of the species, and in 2003/2005 only arborvitae was overrepresented in the private species. One reason the arborvitae is growing in popularity with homeowners is the availability of the species at low prices at such places as large discount warehouses and nurseries (Kielbaso and Kennedy, 1983). Another reason for arborvitae to be over planted in recent years is the fact that they are often planted in rows for screening and homeowners like a "living fence". In 1980, four species comprised more than 5% of the total private tree composition, and in 2003/2005, six species made up more than 5% of the private tree composition (Table 2.5).

When comparing the genera, it is apparent that *Acer* is overrepresented. In 1980, *Acer* made up over 22% of the total urban forest and in 2003/2005 it was 24% of the total. Of the public trees, the genus *Acer* is even more overrepresented. In both years, 1980 and 2003/2005 *Acer* represents nearly 40% of the public trees. The amount of *Acer* in private trees is similar to the amounts in the total trees. In 1980 the percentage of *Acer* was almost 20% and in 2003/2005, *Acer* was just over 21% of the private trees. These percentages indicate that the genus *Acer* is over planted. Other authors have also observed this (Kielbaso and Kennedy, 1983).

There are very good reasons for avoiding mass plantings of the same species and genera; e.g. American elm (*Ulmus americana* L.) with Dutch elm disease and ash (*Fraxinus sp.*) with emerald ash borer (*Agrilus planipennis* Fairemaire) are two examples. It seems that the genus *Acer* has replaced the American elm as being overplanted and may now be waiting for a calamity to happen, e.g. Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky), an exotic insect believed to be from China that primarily attacks and kills the genus *Acer* (Becker, 2000). If it becomes established in these Midwest cities, it would dramatically change the urban forest by decimating 24% of the trees.

One speculation as to why *Acer* is overplanted is that it is a proven genus for surviving the extreme environment of the urban forest: temperature extremes, root space, compacted soils, etc. The genus has also not had many known pests that destroy the trees. *Acer* is known as a hardy genus with a variety of different species that can tolerate the urban forest conditions. It is also widely grown and available at local nurseries. One species, Norway maple (Acer platanoides L.), may be questioned about its appropriateness as a species for planting in urban areas because it is invasive (Wyckoff and Webb, 1996; Webb et al., 2001; Webster et al, 2004). This is acknowledged, but not addressed here.

Instead of planting more *Acer* species, I suggest the planting of other species that can be added to the urban forest palate that have been proven to do well in the overall urban forest. For example large trees: pin oak, *Quercus palustris* Muenchh.; saw-tooth oak, *Quercus acutissima* Carruth.; northern hackberry, *Celtis occidentalis* L.; and hardy rubber trees, *Eucommia ulmoides* Oliv. For medium trees: linden or basswood, *Tilia americana* L.; Hop-hornbeam, *Ostrya virginiana* (Mill.) Koch; American yellow-wood, *Cladrastis kentuckea* (Dum.-Cours.) Rudd ; and Japanese Zelkova, *Zelkova serrata* (Thunb.) Mak. For small or ornamental trees: Cornelian cherry, *Cornus mas* L.; serviceberry, A*melanchier spp.*; Japanese tree lilac, *Syringa reticulate* (Bl.) Hara; and redbud, *Cercis Canadensis* L.

There is a question, or concern, about native versus exotic tree species. Some advocate that only native species of trees should be planted in urban forests. However, many native tree species simply do not do well in urban situations. Clinging to the few proven native species may have already led to certain species and genera being overplanted. This can lead to devastation by uncontrolled pests or diseases, not necessarily of native origin. American elm and ash are both native species that were overplanted in many cities and today both are being or have been destroyed by exotics. Interestingly, in 1980, 89% of the public and private species of trees that are considered overplanted in this study are native, with the exception of the Norway maple. In 2003/2005, most (75%) of the public and private species of trees that are considered overplanted in this study are native, with the exceptions of the Norway maple; Norway spruce; and linden (*Tilia sp.* most of which were little-leaf linden, *Tilia cordata* Mill.) (Table 2.5).

The total diversity as measured by the Shannon index has not changed. This is true for the entire urban forest as well as the public and private trees. This simply means that the diversity of the urban forest is being maintained and should not be used as a measure for maintaining the overplanting of the species that already account for more than five percent of the urban forest.

Urban Forests Compared to Natural Forests - Urban forests generally have greater species richness than existing natural forest (Zipperer et al., 1997; Pickett et al., 2001). In a natural forest, less competitive species begin to die off over time and are replaced by more competitive, shade tolerant species. Eventually, as succession approaches a climax community, species richness approaches to a steady-state. In the urban forest, there is initially a loss of species richness due to site construction. When construction or development is completed, species richness increases. This increase in species richness is due to the planting of new species by home owners and property developers. Zipperer et al. (1997) hypothesizes that the urban forest species richness does not peak as it would in a natural forest. Instead, the species richness continues to increase as new species are planted. The continual planting of new species in urban forests will generally offset any species richness lost over time, although the species composition may change over time. This phenomenon was true in these cities studied.

In North America, species richness of the natural forests is quite varied when comparing forests in the north to the forests in the south. In Northern Canada, as few as five species make up the composition of these distinct forests (Raup and Argus, 1982). As one moves south to the warm, humid, floodplain forests of the southeastern United States as many as 70 different tree species can be found (Putnam et al., 1960). A comparison of the species richness in the urban forest to the natural forests growing in the vicinity of the six cities in 1980 and 2003/2005 (Table 2.6) revealed that urban forest species richness was greater than in natural forest. All four of the Ohio cities, Bowling Green, Bucyrus, Delaware and Wooster are in the "beech-maple forest region" (Braun, 1950), Hutchinson, MN is in the "big woods" area of the "maple-basswood forest region" and Lincoln, NE is in the "tall-grass prairie region" (Barbour and Christensen, 1993). When the average species richness of all six cities in 2003/2005, the urban forest has approximately three times more tree species than the natural forest. This supports Zipperer et al. (1997) in their proposition that the species richness of the urban forest is greater than the natural forest. Table 2.5 also generally supports Nowak (1993) in his speculation that species richness or diversity does not peak as it does in the natural forest, but gradually increases as new species are planted. This is true for the different aged blocks. All of the cities increased slightly in species richness between 1980 and 2003/2005 except Hutchinson, MN, which actually lost one species.

Conclusion

Interestingly, it was the demise of the American elm (*Ulmus americana* L.) that precipitated the original study back in 1980 until that study was abandoned. The majority of trees in the urban forest are privately owned and most of the data in recent studies have been collected from public trees only. This study demonstrates that both public and private trees must be surveyed and studied in order to understand the true structure and dynamics of the entire urban forest. Examining only public trees would have resulted in missing 89.5% of the trees in 1980 and 88.7% in 2003/2005, which means many of the overall trends would not be evident.

Over time, the urban tree species composition has also changed. Most of the common trees have remained dominant with one exception, arborvitae. Arborvitae has become the most common tree in the cities studied. The perplexing issue is that it is not necessarily a proven tree that is known for its good growth habit. Arborvitae is also being used as a living fence in many private yards.

The diversity, species richness, and density in the urban forest were not very dynamic over the years of this study. However, comparing individual cities does reveal some changes. As noted, these differences can be produced by a variety of factors; latitude, original forest condition, dedicated forest professional, availability of trees, etc. Density, species richness and diversity (Shannon index) of the total trees all remained moderately constant over the years. The private trees also followed this tendency with the forest structure remaining basically steady. This is not surprising, because the private trees account for such a preponderance of the total trees. Differences in species richness and diversity are seen in the public trees. This may be because some individual cities have tree professionals making decisions about their trees regardless of what is happening on private property.

The difference between the urban forest and natural forest species richness is notable. Those that work with the urban forest have suspected for years that this was true, but lacked data on the private trees. With this study, it is very apparent that the urban forest has a species richness that exceeds the natural forest many times over. The reason for this varies, but one revelation is personal choice and the variety of trees that are available to the private land owner. Personal choice is also one of the driving forces behind the introduction of many exotics and unproven species to the urban forest.

This study suggests that, in these six cities, an adequate number of acres were surveyed in order to explain the species richness. When analyzing the tree species richness per acre, only about 35 acres, of the average 65.8 acres per city, needed to be surveyed in order to account for at least 90% of the species richness. More acreage surveyed only turns up rarities and unique species that were not represented by more than a single tree or two.

One change that is going to continue to take place in the urban forests of North America is the elimination of the ash due to the devastation by the emerald ash borer (EAB) (*Agrilus planipennis* Fairemaire). The EAB was discovered in Michigan in 2002 and by

2004 was found in Bowling Green, Ohio. By the end of 2008, the EAB had spread to all of the cities that were studied in Ohio. Thus far, as of the summer of 2009, the EAB has not been identified in Hutchinson, Minnesota or Lincoln, Nebraska. The eastern United States urban forests were at one time dominated by the American elm and Dutch elm disease wiped them out. Ash replaced many of the elms and became one of the primary urban forest trees, and the EAB is currently wiping them out. If the diversity of the urban forest is not maintained, in some cases enhanced, other species may be in jeopardy. The genus *Acer* could be the next.

Table 2.1. A comparison of selected urban forest descriptor data of the six Midwestern, USA cities in 1980 and 2003/2005.

		1980	2003/2005
Bowling Green, OH	Number of Trees	2280	2279
	Lots Surveyed	-----	237
	Diversity[1]	3.6	3.57
	Species Richness	75	82
	Density[2]	36.9	28.9
	Private to Public Ratio	6.89 to 1	7.63 to 1
	Money Spent on Trees per capita	-----	$15.32
Bucyrus, OH	Number of Trees	876	1111
	Lots Surveyed	-----	228
	Diversity[1]	3.24	2.39
	Species Richness	54	58
	Density[2]	19.2	20.7
	Private to Public Ratio	4.92 to 1	8.58 to 1
	Money Spent on Trees per capita	-----	$1.51
Delaware, OH	Number of Trees	2486	3515
	Lots Surveyed	-----	442
	Diversity[1]	3.22	3.2
	Species Richness	66	80
	Density[2]	30.6	35.9
	Private to Public Ratio	14.54 to 1	6.98 to 1
	Money Spent on Trees per capita	-----	$9.59
Hutchinson, MN	Number of Trees	704	654
	Lots Surveyed	-----	155
	Diversity[1]	2.96	2.96
	Species Richness	43	47
	Density[2]	36.2	32.5
	Private to Public Ratio	3.57 to 1	3.06 to 1
	Money Spent on Trees per capita	-----	$9.59
Lincoln, NE	Number of Trees	953	1049
	Lots Surveyed	-----	220
	Diversity[1]	3.47	3.36
	Species Richness	62	63
	Density[2]	24.2	20.4
	Private to Public Ratio	6.27 to 1	4.41 to 1
	Money Spent on Trees per capita	-----	$7.90

Table 2.1. Cont'd.

		1980	2003/2005
Wooster, OH	Number of Trees	1682	2316
	Lots Surveyed	-----	289
	Diversity[1]	3.27	3.27
	Species Richness	62	67
	Density[2]	26.5	32.3
	Private to Public Ratio	14.72 to 1	16.41 to 1
	Money Spent on Trees per capita	-----	$2.60
Summary of the urban forest discriptors	Average Number of Trees	1497	1821
	Total Number of Trees	8981	10924
	Average Lots Surveyed	-----	262
	Total Lots Surveyed	-----	1571
	Diversity[1]	3.29	3.13
	Species Richness	60	66
	Density[2]	28.9	28.5
	Private to Public Ratio	8.49 to 1	7.85 to 1
	Money Spent on Trees per capita	-----	$7.75

1 Diversity as calculated with the Shannon index

2 Trees Per Acre

Table 2.2. Species richness per acre in different-aged urban forests of six Midwestern, USA cities in 1980 and 2003/2005

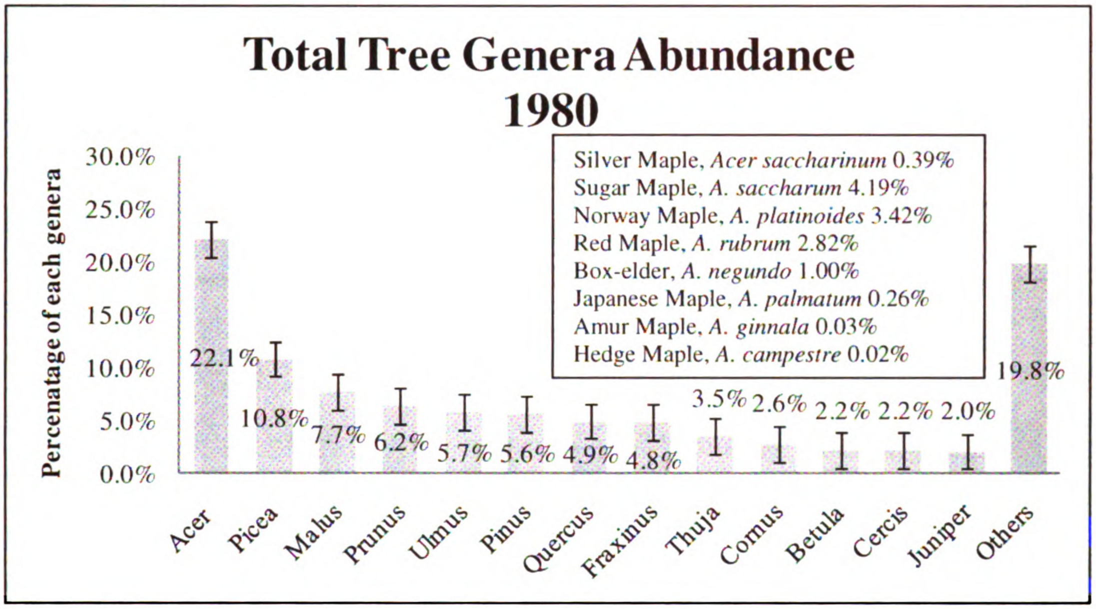
	Species Richness per Acre					
City	Public Trees		Private Trees		All Trees[2]	
Block Age[1]	1980	2003/2005	1980	2003/2005	1980	2003/2005
<10 years old	0.626	0.670	0.601	0.605	0.491	0.492
10 to 40 years old	0.871	0.784	0.805	0.643	0.646	0.520
>40 years old	1.180	1.299	0.603	0.576	0.501	0.475
Total[3]	0.496	0.544	0.287	0.256	0.236	0.211

[1] Age of houses in neighborhood blocks surveyed

[2] Species richness per acre for All Trees is not the sum of the public and private trees species richness; it is the species richness in public and private areas combined on all of the acres surveyed.

[3] Species richness per acre total is not the sum of the individual column; it is the total number of different species per acre in that column

Figure 2.1. Abundance by genus in the urban forest of six Midwest, USA cities in 1980 and 2003/2005. In 1980, "others" represented 83 different species and in 2003/2005 it represented 92 different species.



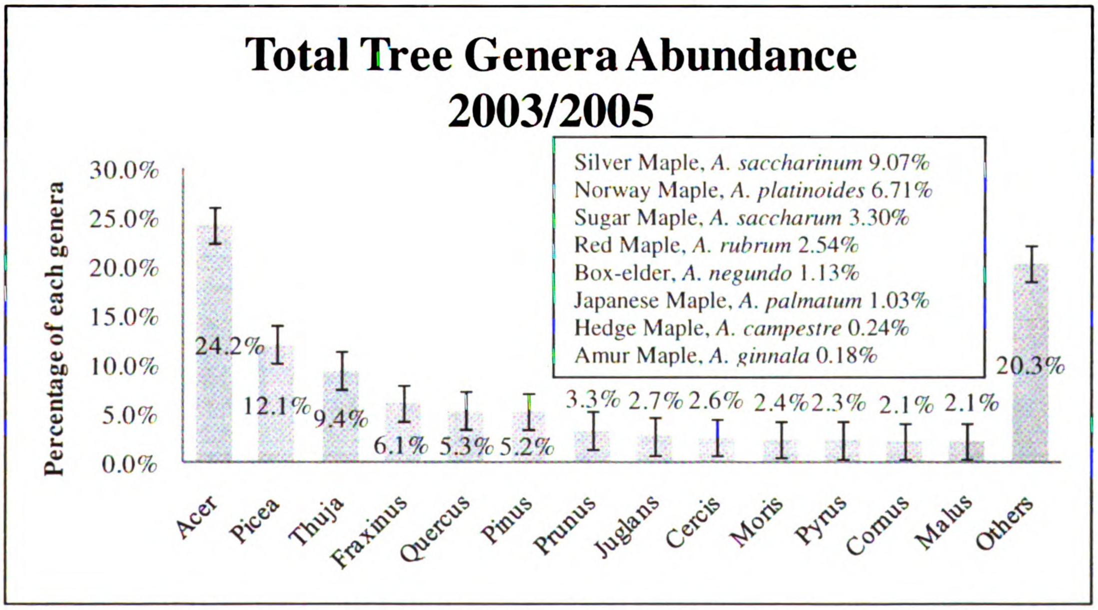
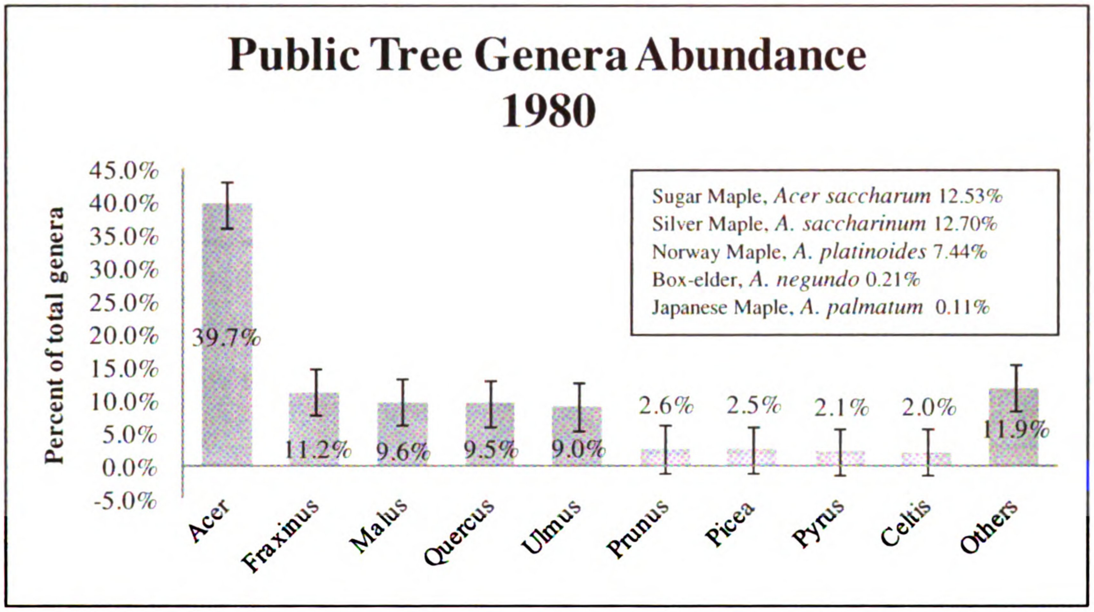


Figure 2.2. Abundance by genus in the public trees of six Midwest, USA cities in 1980 and 2003/2005. In 1980, "others" represented 34 different species and in 2003/2005 it represented 43 different species.



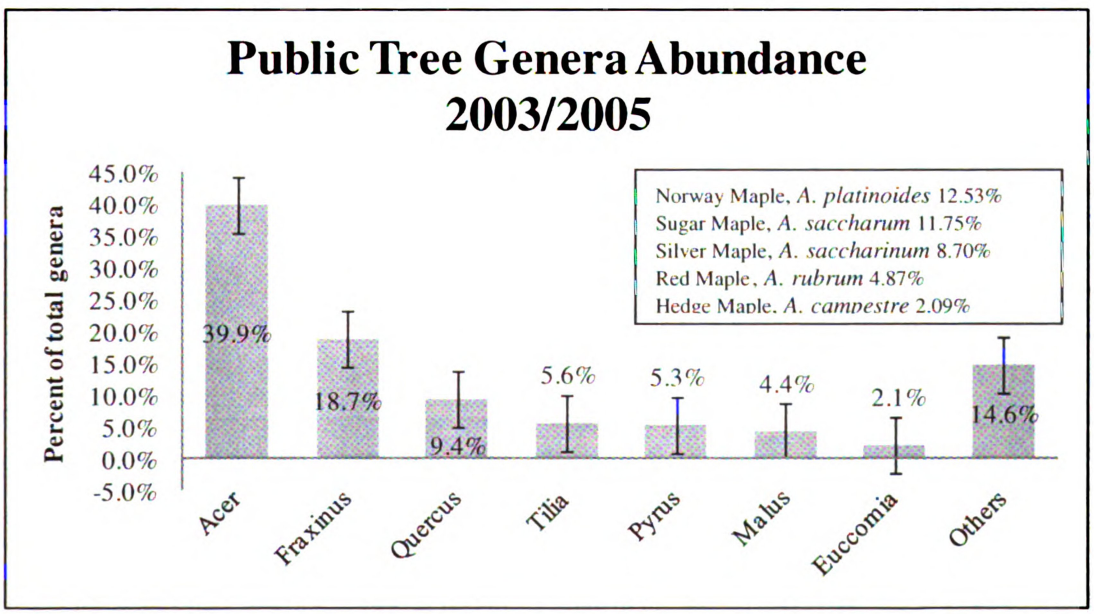
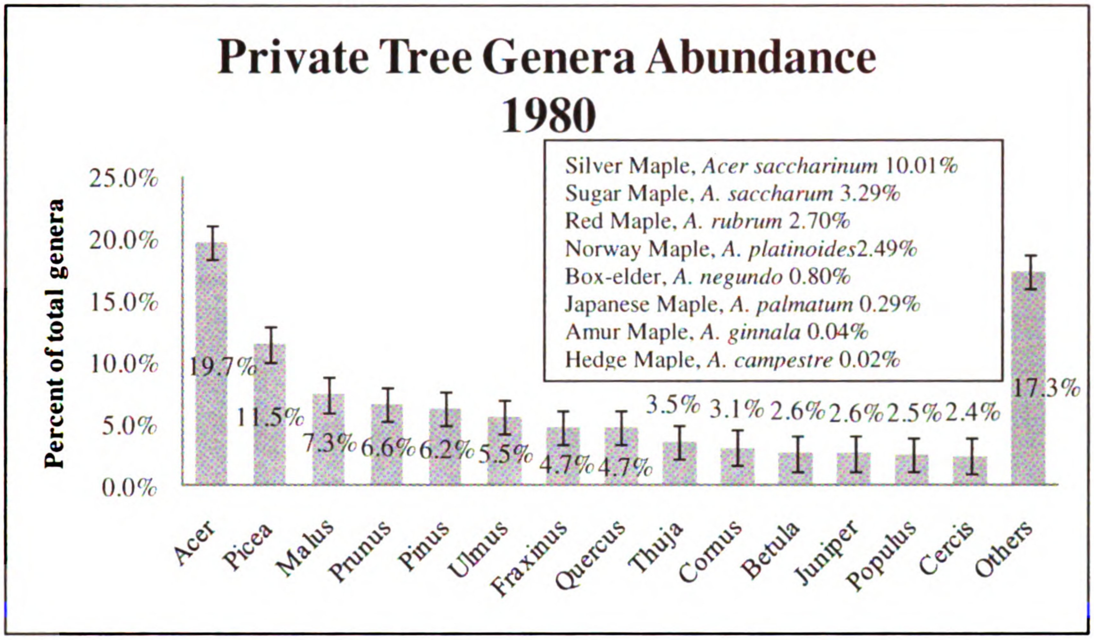


Figure 2.3. Abundance by genus in the private trees of six Midwest, USA cities in 1980 and 2003/2005. In 1980, "others" represented 79 different species and in 2003/2005 it represented 88 different species.



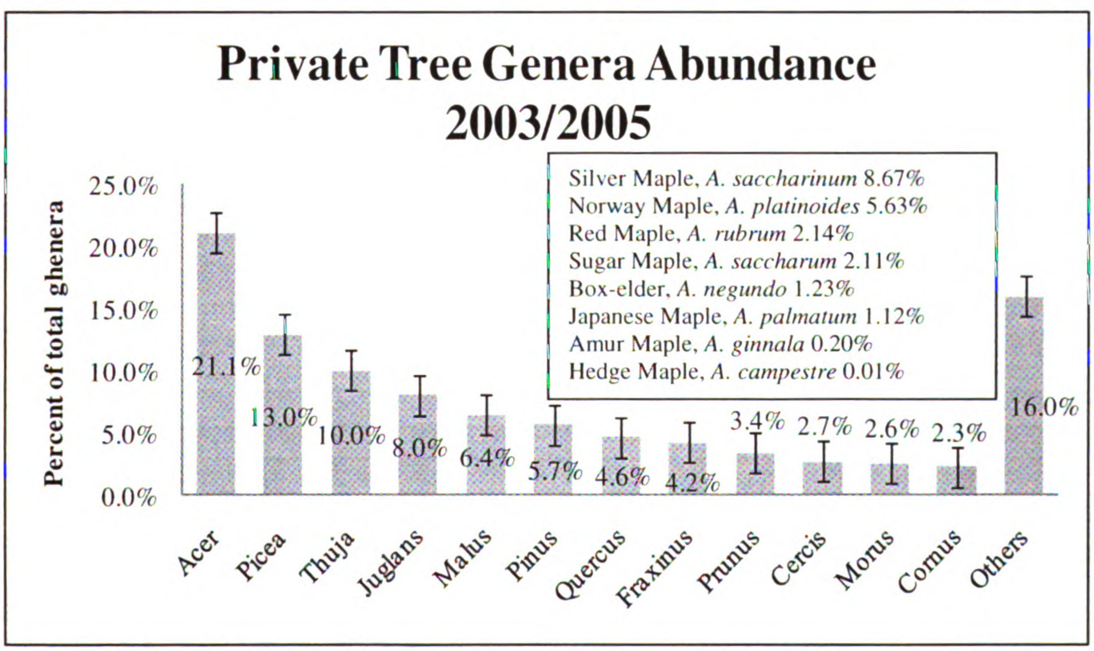
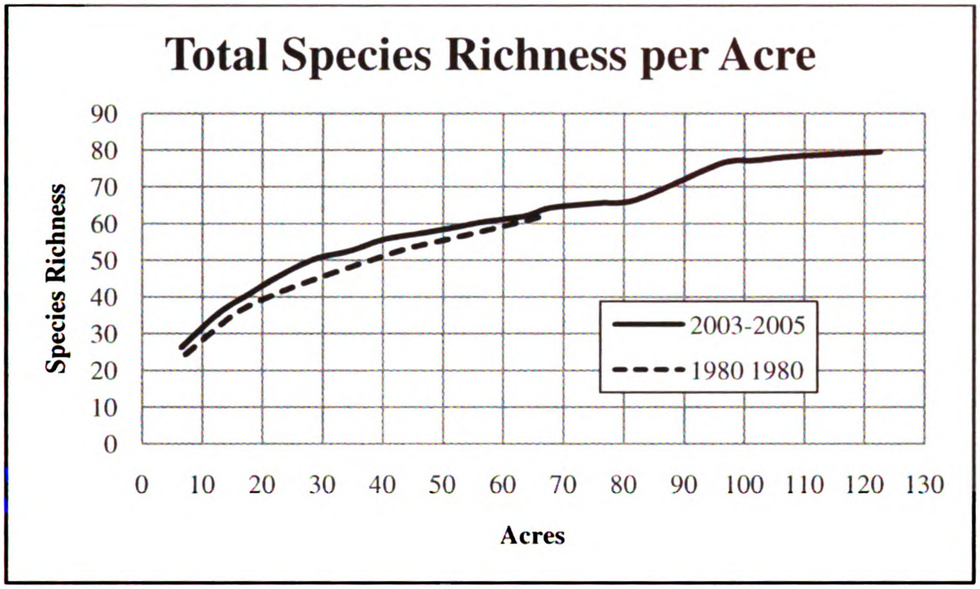
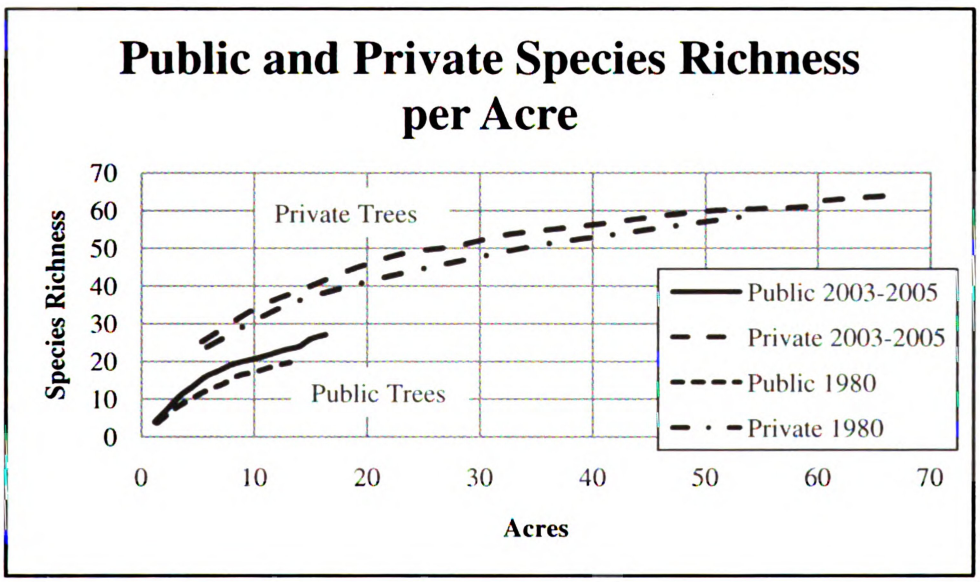


Table 2.3. The twenty-five most common tree taxa in the two surveys (1980 and 2003/2005) in six Midwest, USA cities.

1980 Taxa	Number of Trees	Percent	2003/2005 Taxa	Number of Trees	Percent
Silver Maple (*Acer saccharinum*)	957	10.66	Arborvitae (*Thuja occidentalis*)	980	8.97
Blue Spruce (*Picea pungens*)	621	6.92	Silver Maple (*Acer saccharinum*)	942	8.62
Crabapple (*Malus sp.*)	458	5.1	Norway Maple (*Acer platanoides*)	701	6.42
American Elm (*Ulmus americana*)	418	4.65	Blue Spruce (*Picea pungens*)	676	6.19
Ash (*Fraxinus sp.*)	389	4.33	Ash (*Fraxinus sp.*)	634	5.8
Sugar Maple (*Acer saccharum*)	355	3.95	Crabapple (*Malus sp.*)	523	4.79
Arborvitae (*Thuja occidentalis*)	327	3.64	Norway Spruce (*Picea abies*)	506	4.63
Norway Spruce (*Picea abies*)	323	3.6	Sugar Maple (*Acer saccharum*)	334	3.06
Norway Maple (*Acer platanoides*)	305	3.4	White Pine (*Pinus strobus*)	321	2.94
Cherry (*Prunus sp.*)	276	3.07	Pin Oak (*Quercus palustris*)	292	2.67
Red Maple (*Acer rubrum*)	262	2.92	Redbud (*Cercis canadensis*)	268	2.45
Pin Oak (*Quercus palustris*)	254	2.83	Red Maple (*Acer rubrum*)	265	2.43
Dogwood (*Cornus florida*)	246	2.74	Mulberry (*Morus sp.*)	248	2.27
Apple (*Malus sp.*)	237	2.64	Pear (*Pyrus sp.*)	238	2.18
White Pine (*Pinus strobus*)	233	2.59	Dogwood (*Cornus florida*)	224	2.05
Redbud (*Cercis canadensis*)	207	2.31	Cherry (*Prunus sp.*)	200	1.83
Plum (*Prunus sp.*)	203	2.26	Black Walnut (*Juglans nigra*)	200	1.83
Birch (*Betula sp.*)	195	2.17	Honeylocust (*Gliditia tricanthus*)	193	1.77
Scotch Pine (*Pinus sylvestris*)	187	2.08	Apple (*Malus sp.*)	171	1.57
Juniper (*Juniperus sp.*)	171	1.9	Hackberry (*Celtis occidentalis*)	164	1.5
Honeylocust (*Gliditia tricanthus*)	161	1.79	Juniper (*Juniperus sp.*)	161	1.47
Black Walnut (*Juglans nigra*)	149	1.66	Linden (Tilia sp.)	147	1.35
Lombardy Poplar (*Populus nigra* 'Italica')	136	1.51	Hemlock (*Tsuga canadensis*)	145	1.3
Mulberry (*Morus sp.*)	117	1.3	Birch (*Betula sp.*)	139	1.27
Hawthorn (*Crataegus sp.*)	112	1.25	Magnolia (*Magnolia sp.*)	130	1.19

Figure 2.4. Non-parametric estimate* of species richness per acre in the urban forest of six Midwest, USA cities in 1980 and 2005.





*Values that were used to generate these graphs were calculated by jackknife; i.e. re-sampling without replacement.

Table 2.4. Comparison of the species richness of the different categories[1] of trees found in the urban forest in six Midwest cities in two measurement times[2].

	1980[3]	2003/2005[3]
Large Deciduous	29[a]	30[a]
Intermediate Deciduous	28[a]	31[a]
Small Ornamental	22[b]	20[b]
Large Evergreen	15[c]	14[c]
Intermediate Evergreen	3[d]	3[d]
Small Evergreen	0[d]	2[d]
Total	97	100

[1]Tree categories as described by Dirr, 1998.

[2]Values labeled with the same letter in a column are not significantly different from each other following the Tukey's HSD post hoc test for multiple comparisons. All other comparisons are significantly different from one another ($p < 0.01$) except for the small ornamental and large evergreen comparison ($p < 0.05$).

[3]There is no significant difference between the different years.

Table 2.5. List of species that may be considered overplanted by being more than 5% of the total species composition in select Midwest cities in 1980 and 2003/2005.

Total Urban Trees			
1980		2003/2005	
Silver Maple	10%	Arborvitae	9%
Blue Spruce	7%	Silver Maple	9%
Crabapple[2]	5%	Norway Maple[1]	7%
Ash	5%	Blue Spruce	6%
		Ash	6%
		Norway Spruce	5%
Total	27%		42%

Public Urban Trees			
1980		2003/2005	
Sugar Maple	14%	Ash	19%
Silver Maple	13%	Norway Maple[1]	13%
Ash	11%	Sugar Maple	12%
Crabapple[2]	10%	Silver Maple	9%
Norway Maple[1]	7%	Pin Oak	6%
Pin Oak	7%	Linden[2,3]	6%
Elm[2]	7%	Pear[1]	5%
Red Maple	5%	Red Maple	5%
Total	74%		73%

Private Urban Trees			
1980		2003/2005	
Silver Maple	10%	Arborvitae	10%
Blue Spruce	7%	Silver Maple	9%
Elm	5%	Blue Spruce	7%
Ash	5%	Norway Maple[1]	6%
		Norway Spruce[1]	5%
		Crabapple[2]	5%
Total	27%		41%
Total number of trees	8,980		10,924

1 Not a native to the USA

2 Some species may not be native

3 Most trees were *Tilia cordata*

Table 2.6. Comparison of the Natural Forest Tree Species Richness to Urban Forest Tree Species Richness.

	Natural Forest Species Richness[1]	1980 Urban Forest Species Richness	2003/2005 Urban Forest Species Richness
Bowling Green	21 - 25	75	82
Bucyrus	21 - 25	54	58
Delaware	26 - 30	67	80
Hutchinson	16 - 20	48	47
Lincoln	< 10	62	63
Wooster	26 - 30	62	67
Average	18.3 - 23.3	61.3	66.2

[1]Iverson and Prasad, 2001; values are reported per county for the natural forest.

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Chapter 3

Changes in Size and Condition of Urban Trees in Six Cities in the Midwestern Region of the United States

Abstract

This study is one of the first to consider both public and private trees in an urban forest. The size and health conditions of urban forest trees are determined by many factors ranging from the genetics of the individual trees to environmental factors and anthropogenic issues. My data indicates that there is a general tendency for the smallest trees to have the best health condition. This is evident in the six Midwest, USA cities (Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN) in 1980 and 2003/2005, for trees on both public and private land. However, as time goes on, a 50 year old urban forest begins to resemble the size (dbh) distribution found in a natural forest. Considering both tree size and health conditions, there has been a perception that larger trees, in general, are in worse health condition. This correlation or measure of association is true for the 2003/2005 trees in this study.

Key Words: urban forest ecosystem; urban trees; tree condition; tree size

Introduction

The size and health condition of urban trees are the result of many interacting factors, often classified as being either abiotic or biotic. The abiotic factors that influence the growth of the urban trees include: soil properties (physical and chemical), soil moisture availability, soil compaction and soil volume (Ware, 1990; Day et al., 2001). The biotic factors that influence the growth of urban trees are competition with other trees, competition with other plants, pathogens, and insects (Kielbaso and Kennedy, 1993; Iakovoglou et al. 2001; Metzger and Oren, 2001).

Environmental stresses that can impede growth include restricted root zones, soil compaction, competition and sometimes allelopathies. Restricted root zones will produce stunted trees relative to the same species and the same age growing in more favorable situations. Soil compaction may create situations that are similar to restricted root zones and trees may be stunted sufficiently to lead to the death of the tree. Competition is always for resources/limiting factors (i.e. sunlight, nutrients, and water) (Close et al., 1996; Fox et al., 2007). This competition is generally with other trees in natural areas, and with turf in urban areas, which can take in enormous amounts of these resources before the trees can access them. As trees grow, the competition and retention of resources may become restrictive. The effects of allelopathy from certain trees in urban areas can range from abnormally slow growth, e.g. black cherry, sugar maples, and black spruce, to death, e.g. white pine, red pine and white birch (Chick and Kielbaso, 1998).

The size and health conditions of trees are an integral part of the analysis of the urban forest. It is generally thought among arborists and urban foresters that as trees get older and larger, there is an increasing chance that the trees will become damaged or diseased. This may lead to tree conditions that are dangerous or hazardous. Healthy, vigorous trees are more likely to withstand such impacts as root injury, minor wind damage, and other physical damages to the tree structure. Tree that have extensive wood rot, broken branches, weak branch attachments, and other structural damages which may lead to failure will need attention in order to prevent damage to people and property (Matheny and Clark, 1991; Shigo,1991; Harris, 1999).

The size of trees is generally expressed as height, crown spread, or as in this study, the diameter of the trunk (dbh). Inventories, such as this one, rely primarily on the tree diameter. The other size measurements, height and crown spread, are usually made in order to address particular management problems (Miller, 1996; Peper et al., 2001). Tree size can be related to problems that may persist in trees. Small trees, depending on the species, may be weak and less able to withstand ice, snow and wind storms. Larger trees, depending on the species, may be more prone to decay and breakage.

Tree health directly affects the ecosystem services and functions of the urban forest (McPherson, 1990; Rowntree and Nowak, 1991; McPherson, 1993; McPherson, 1994; Nowak, 1994; Qi et al., 1998; Scott et al., 1999; Beckett et al., 2000; Cumming et al., 2001; Xiao and McPherson, 2002). The urban forests not only provide aesthetic and recreational benefits, they also reduce air pollution and storm runoff, conserve energy, store carbon, provide protection from ultraviolet radiation, create habitat for wildlife, and moderate temperatures (Xiao and McPherson, 2005).

This is a unique study where all of the urban trees, on both public and private land, were surveyed in certain city blocks. This comprehensive study is the first to take a complete picture of the urban forest instead of relying on just the city street trees to represent the entire urban forest. City street trees make up only 10% of the entire urban forest (Kielbaso, 1993).

The question has arisen, how similar are the trees in the urban forest to a natural forest? Well, the health condition of the natural forest is largely missing from the literature. There is some literature pertaining to individual tree species (Close et al., 1993), but by and large, the conditions of the natural forest as a whole are missing. So, no comparison was made. However, there is literature pertaining to the size of the trees in natural forests (Boyce and Cost, 1978).

It is hypothesized that the size and health condition of the six urban forests' trees considered in this study have not changed over the years. Also, the average individual tree size and health condition have not changed over the years. A second hypothesis is that tree size and conditions are statistically independent from one another.

H_1 – The average size of the urban trees did not change over the study years.

H_2 – The average condition of the urban trees did not change over the study years.

H_3 – The average tree species size did not change over the study years.

H_4 – The average tree species condition did not change over the study years.

H_5 – There is no correlation between the average size and average condition of the urban trees over the study years.

Methods

This study follows the procedures that were established by Cannon and Worley at the USDA-Forest Service in 1980 and repeated by Kielbaso, et al. in 1992. Six cities (Bowling Green, Bucyrus, Delaware, and Wooster, OH; Lincoln, NE and Hutchinson, MN) were inventoried. The city blocks were sampled in age categories, which were established by the age of the homes on the different blocks in 1980. The age categories were: younger than 10 years old in 1980, 10 to 40 years old in 1980, and more than 40 years old in 1980. In 1980, three city blocks were inventoried from within each of the age categories. All of the blocks were residential.

In Bowling Green and Lincoln, three city blocks were surveyed from each of the age categories; a total of nine blocks in each city. The number of blocks was a little different in Hutchinson, where there were four blocks that were younger than 10 years, three blocks that were 10 to 40 years, and four blocks that were older than 40 years. All trees over two inches dbh were measured. Then in 1992, Bowling Green and Lincoln were re-surveyed by Kielbaso (1993). At that time, another block was added to each of the age categories in Lincoln and three were added from the downtown area, so that there were 12 total blocks. Hutchinson was not resurveyed in 1992. In 2003, all three cities were resurveyed. However, only seven blocks from the original study in 1980 could be relocated in Hutchinson because the original data addresses were not available. The seven blocks were located with the assistances of the city forester, Mark Schnobrich. The blocks that were missing are due to re-development (e.g. new supermarket).

In 2005, five city blocks were inventoried in each city from each age category for a total of 15 city blocks for each of the cities. These new city blocks were chosen with the help of the city foresters, cooperative extension agents, and county mapping offices. All of the new city blocks were chosen randomly, without first seeing the blocks. This was done to minimize any bias that might have developed after seeing the blocks.

The most common signs of decline in 2003/2005 were broken branches and lawnmower damage to the base of tree and/or surface roots. There were also many trees with improper pruning which was causing abnormal callus growth and the wounds were not closing very efficiently.

The unique and important aspect of this study is that both public street trees and private property trees were inventoried. Variables collected for each tree were: ownership (public/private), species, dbh, and the overall tree health or condition. The ownership of the trees was defined by the sidewalk. If the tree was growing between the street and the sidewalk, then it was considered a public tree. If there was no sidewalk, then trees growing within the right a way from the center of the street were considered public trees. All of the other trees in the front, side, and back yards were considered private trees. The dbh for every tree was measured and the trees were placed into size classes: (1) 5.08 to 10.16 cm (2 to 4 inches), (2) 10.16 to 25.40 cm (4 to 10 inches), (3) 25.40 to 40.64 cm (10 to 16 inches), and (4) greater than 40.64 cm (16 inches).

Evaluating urban tree condition can be highly subjective (Webster, 1978). To eliminate subjectivity between years, I used a point system that was used in the original study in 1980 which was based on the number of visible decline signs that could be easily identified. Tree health was assessed by identifying signs of decline on the crown, trunk, branches, base and roots. Examples of decline included: decay, girdling roots, broken branches, included bark, etc. Decline signs were summed. If the tree had zero or one sign it was rated a (1), if the tree had two decline signs, it was rated a (2), if it had three or four decline signs, it was rated a (3), if it had five or more decline signs it was rated a (4), and if it was dead or was obviously in the process of dying it was rated a (5). This system was used in the original study and has produced reasonably consistent comparison with current ISA/CTLA evaluations guide procedures (Kielbaso et al., 1993).

A comparison of the distribution of tree sizes, by percentage, in a natural forest to the urban forests in this study was generated. The age classes for the natural forest came from an inventory of 6,396 acres in Buncombe County, North Carolina (Boyce, 1984). The time "zero" for the natural forest on the graph is not the beginning of succession, but a mid-successional step in the process. This is why old-growth trees are present at time zero. The particular mode of management for this natural forest is one of no timber being ha

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harvested and "the forest changes with forces unaffected by man" (Boyce and Cost, 1978).

ANOVA with a Tukey's HSD (honestly significant difference) post hoc test was used to establish differences between categories ($p < 0.05$). The ANOVA was used to establish any differences, and then Tukey's HSD was used to find where the differences were between the categories. Correlations between tree size and condition were analyzed using chi-square ($p < 0.05$). Then Cramer's V was calculated as a measure of association to verify if there was a correlation in the categorical variables. The Cramer's V test takes the square root of the Chi-square value, divided by (N) the number of trees, then divided by three, which is the degrees of freedom for the rows in the contingency table. Cramer's V values are between zero and 1.0. The magnitude and strength of the relationship between the size and condition of the urban trees were then described (Cohen, 1988; Gravetter and Wallnau, 2007). Cohen (1988) proposed that, after adjusting for the degrees of freedom, if the Cramer's V value is between 0.0 and 0.06, there is no relationship; 0.06 to 0.17, there is a small relationship; 0.17 to 0.29, there is a moderate relationship; and if the value is greater than 0.29, there is a strong or large relationship.

Results

The six cities of this study are all found in the Midwest region of the United States. However, that does not mean the cities are not similar. See Table 3.1 for a comparison of the six cities.

Tree Condition – None of the tree conditions changed significantly during the study period. Overall tree condition averaged in 1980 was 1.4 ±0.009 and it was 1.6 ±0.008 in 2003/2005 (Figure 3.1). The average public tree condition remained the same over the years at 1.7 with a standard error of ±0.03 and ±0.02 in 1980 and 2003/2005, respectively. The average private tree condition over the six cities was basically the same as the overall trees averages, in 1980 it was 1.4 ±0.009 and in 2003/2005 it was 1.6 ±0.008 (Figure 3.1).

When comparing the data from 1980 to 2003/2005, no notable differences were detected. However, when comparing conditions from the years 1980 and 2003/2005, there was a large difference in the number of trees in each of the condition categories, $F_{4,5} = 33.91$, $p < 0.001$. Further tests indicated that the number of trees in the condition category 1 (excellent rating) was significantly greater than in all of the other condition categories, (Tukey = $p < 0.01$) and the other four condition categories were not different from one another. The private trees showed the same trend as was seen in the total trees conditions. The public trees in 1980 and 2003/2005 were significantly different from one another, $F_{4,5} = 22.02$, $p < 0.01$ and, $F_{4,5} = 34.53$, $p < 0.001$, respectively (Table 3.3). The average health condition between the 25 most common tree species in 1980 and 2003/2005 shows that the trees are getting significantly worse with time, $F_{1,48} = 5.08$, $p < 0.05$ (Table 3.3). The public trees showed no real difference while the private trees fared significantly worse in 2003/2005 than in 1980, ($F_{1,48} = 7.57$, $p < 0.01$).

In 1980, considering all cities combined, there were a significant number of trees in excellent condition with a rating of 1, (Figure 3.3). When the ages of the blocks were considered, there were still a significant number of trees in the best condition classes in each of the age categories. The public and private trees showed the same trend as was observed in the total trees, with an overwhelming number of trees being in excellent condition. In 1980, in the blocks that were less than 10 years old, more than 80% of the trees had a condition of 1 and each of the other four conditions each had a rating less than 10%. The blocks that were 10 to 40 years old followed the same trend as the trees that were on the blocks that were less than 10 years old. In the blocks that were more than 40 years old, condition 1 accounted for only 60.5% and the other four conditions had percentages that tended to be slightly higher than the other two block ages.

In 2003/2005 the trend was the same, but the number of trees in condition 1 was fewer than in 1980 (Figure 3.4). The other condition values were generally greater. In blocks that were younger than 10 years old, 61% were in condition 1, while in the blocks that were 10 to 40 years old, condition 1 had 52% of the trees; and in the blocks that were greater than 40 years old, condition 1 had 57% of the trees.

Tree Size – The average size class for the top 25 species in 1980 and 2003/2005 is shown on Table 3.2. A comparison of the average size classes for all of the trees was 1.2 and 2.2 in 1980 and 2003/2005, respectively, which is a highly significant growth in dbh over the years, $F_{1,48} = 20.26$, $p < 0.0001$. The average size class for the public trees in 1980 was 1.7 and in 2003/2005 were 2.6, which is also a highly significant increase in the dbh size class, $F_{1,43} = 14.59, p < 0.001$. The average size class for the private trees was similar to all the trees. The 1980 average size class was 1.2 and in 2003/2005 it was 2.2. Again, this is a highly significant increase in the dbh size class, $F_{1,48} = 19.11, p < 0.0001$.

The average dbh in 1980 was 17.2 cm (6.8 in.), and in 2003/2005 it was 25.2 cm (9.9 in.) an increase of 8.0 cm (20.3 in.) (Figure 3.2). The average public tree dbh in 1980 was 24.3 cm (9.6 in.), and it was 29.1 cm (11.5 in.) in 2003/2005, an increase of 4.8 cm (1.9 in). The average private tree dbh in 1980 was 15.9 cm (6.2 in.), and in 2003/2005 the average dbh was 24.7 cm (9.7 in.), an increase of 8.8 cm (3.5 in.) which was a significant increase.

A comparison of average overall size (dbh) of the 25 most common tree species in 1980 to 2003/2005 showed that the 2003/2005 trees are significantly larger than the 1980 trees, $F_{1,48} = 20.26, p < 0.0001$ (Table 3.2). A comparison of the public trees between the years showed highly significant growth in the tree size over the years, $F_{1,43} = 14.59, p < 0.001$. The private trees showed the same highly significant growth as the public trees, $F_{1,48} = 19.11, p < 0.0001$.

When comparing the public trees to the private trees within the different years, there was no significant difference between the public and private average tree size in 1980. However, there was a significant difference between the public and private average tree size in 2003/2005, $F_{1,46} = 4.38, p < 0.05$.

There was no significant difference between the size of the trees in the less than10 years old and 10 to 40 years old blocks in 1980. However, the trees that were greater than 40 years old, public and private showed a significant difference, $F_{1,6} = 12.52, p < 0.05$. In 2003/2005, there was significant difference in all three of the age categories between public and private trees; < 10 years old, $F_{1,6} = 6.79, p < 0.05$, 10 to 40 years old, $F_{1,6} = 21.5, p < 0.01$, and >40 years old, $F_{1,6} = 11.64, p < 0.05$.

When comparing the tree size categories per block age, in 1980 the smallest trees, less than 4 inches dbh, were the most common at almost every block age (Figure 3.5) However, in 2003/2005 the 4 to 10 inch trees were the most common (Figure 3.6).

In the comparison of the urban forest to a natural forest, there is a sizeable difference between the percentages of each size category in the urban forest for the early years compared to the natural forest (Figure 3.7). As time goes on, though, the percentage value of each size category in the urban forest begins to approach the percentage of values seen in a natural forest.

Tree Size and Condition Relationship – The Cramer's V value was 0.338 ($p < 0.05$) for the 2003/2005 data. There was a strong negative relationship between size and condition, as the trees get larger, the health condition gets worse.

Discussion

Tree Condition – The tree condition was a measure of categories and it was not a measure of continuous data for the condition of the trees. Therefore, the average conditions are not precise, but approximate values. When comparing the average values for condition for each species, it is hard to discern any differences. However, if the average total condition is compared for all trees over the years, then differences can be observed.

When comparing the six cities to one another in 1980, there were three cities where the mean values for the condition were different from one another, the tree condition was worse: Delaware, Hutchinson, and Lincoln. In the other three cities, Bowling Green, Bucyrus, and Wooster, there was no real difference. Delaware, Hutchinson, and Lincoln have had urban tree ordinances since the beginning of this study and have had an urban forester or arborist to oversee the care of each city's trees. These differences may also simply be the result of geography, Nebraska vs. Minnesota vs. Ohio. Or, it may be the dissimilarities involving the particular ecosystems that these cities are situated in, Lincoln is in the prairie; Hutchinson is found in the "Big Woods" section of the "Maple-Basswood Region" (Braun, 1950) and Delaware "Beech-Maple Region" (Braun, 1950).

Then in 2003/2005, mean conditions were identified in Bowling Green and Delaware. One explanation is that Delaware is where the USDA-Forest Service Northeastern Forest Experiment Station is located and is the hometown of the original researchers for this study, each of whom was, and still is, active in the planning and oversight of the urban forest. Bowling Green has had a few different urban foresters or arborists and at times has had no one to help and counsel about tree issues. Next, the mean condition in Wooster is different from Bucyrus, Bowling Green, Delaware and Hutchison. Wooster's mean condition is similar to the mean condition in Lincoln. No explanation for this is evident.

The reasons for the decline in percentage of condition 1 in the greater than 40 year old blocks trees are not apparent, but one suggestion is that the older the blocks, the older and larger the trees, and the more the chance the trees will have decline signs and/or be damaged.

The reason for the differences in percentages between 1980 and 2003/2005 may be bias by the data collectors or the inexperience of the students who did the survey in 1980, or the trees may simply be in a worse condition today. Another explanation may be that in 1980 huge numbers of trees were in the smallest dbh class which indicates that they were relatively new, young, vigorous trees. In 2003/2005 the greatest percentage of tree size shifted, and the largest size category was the 4 to 10 inch dbh. This means there are fewer small trees.

Tree Size – It should not be surprising to see that as time goes on, the average tree size gets larger. In a comparison between the tree sizes in the different years that data were collected, Delaware, Bucyrus, Hutchinson and Wooster were statistically different in the size between years, which generally indicates that the trees are growing. It can alternatively be interpreted that not as many small trees were being added to the urban forest. If trees were continuously being planted or volunteer trees were becoming established, there would not be that significant of an increase in tree size over the years.

In 1980, the trees in Wooster and Hutchinson were notably larger than in all of the other cities. The tree sizes in the other four cities were basically the same. In 2003/2005 there were no real recognizable differences in the tree sizes in any of the cities or geographical areas.

The reasons why it was so hard to detect any specific reason why a city's tree sizes are similar or different are numerous. First, the environment must be taken into consideration. Lincoln, NE is situated in a prairie where the trees are subjected to strong seasonal droughts and relentless competition from perennial herbs and graminoids; Hutchinson, MN is in the "Big Woods" section of the "Maple-Basswood Region" of the eastern deciduous forest (Braun, 1950) where the winters are relatively long and severe; and the other four cities, Bowling Green, Bucyrus, Delaware and Wooster, Ohio are in the "Beech-Maple Region" of the eastern deciduous forest (Braun, 1950) which has relatively mild summers and winters compared to the other two cities. So the individual cities' environments are varied and some conditions are more conducive for tree growth than other conditions.

Second, urban trees are under tremendous amounts of stress, and some microclimates are simply more favorable for tree growth than others. These stresses stem from manmade conditions such as soil compaction, improper pruning, soil pH irregularities, etc., to natural phenomena like competition, diseases, and parasites (Close et al., 1996a; Close et al., 1996b).

Third, are new trees being planted? Some cities have comprehensive plans and budgets for the planting of new trees and the replacement of dead or hazardous trees. If the city is not planting new trees, then the average size will continue to get larger. If new trees are being added to the urban forest, usually trees with a relatively small dbh, then the average size of the city's trees will remain roughly the same or even decrease. All of the cities in this study have a comprehensive tree planting plan except for Bucyrus, OH.

Finally, does the public value trees? If so, then trees are going to be cared for and their growth will be valued. It has recently been shown that the presences of trees in urban settings generate many psycho-social benefits, including: lower levels of fear, less violent behaviors, and better neighbor relationships (Kuo, 2003). When people understand this, they will be more apt to value the trees that are currently growing in cities and to spend money to plant and care for more trees. With this, it is hard to quantify how the public values trees (Kuo, 2003).

The main difference in the size categories, when comparing the age of blocks between 1980 and 2003/2005 was that the 4 to 10 inch dbh size category was the largest category in 2003/2005, where in 1980 the less than 4 inch category was the largest. This was due in part to in-growth; the trees in the smallest size category have grown. Another explanation is that this may indicate that fewer trees were being planted since 1980, so there were fewer small trees. This trend was evident in all of the block ages, and in both the public and private trees.

In the comparison of the percentage of the tree sizes of the urban forest to the natural forest, there is a large difference in the beginning of the urban forest with many more small trees than are in the natural forest. Remember that the natural forest is in the midst of a later successional stage and the urban forest is in the beginning or early stage of development. The complex of the urban forest trees percentage at 60 years of development is beginning to resemble the percentage of the tree sizes at the first measurement of the mature forest of the natural forest. This phenomenon is an example of succession, and over time the urban forest is increasingly more similar to the natural forest.

Tree Size and Condition Relationship – Intuitively, many think that as trees get larger, they become hazards because their health conditions worsen. This mindset has been brought about because as the trees get larger, there is more chance that they will become damaged or diseased. Testing the association between tree size and tree condition tells us if the variables are dependent or independent of each other. It was found that the association between the tree size and tree condition is a moderately strong relationship. Therefore, we can state with certainty, that there is a strong negative correlation between the size and health condition of urban trees. Conditions decrease or worsen as size increases. This may simply be, not surprising, as the trees age there are more chances of damage or pests.

Conclusion

The importance of this research is to assess the entire urban forest, not just the street trees. The trees growing on privately owned property make up a preponderance of the trees in the urban forest and need to be included in any summaries and conclusions that are made about the urban forest.

This study has shown statistically that over time, the condition of the trees is worsening and not surprisingly, the tree dbh has increased, but if trees were being planted at the same earlier rates this would not likely be the case. What is surprising is the number of trees in each of the size categories. In 2003/2005 there were many more trees in the 4 to 10 inch category than in the less than 4 inch category, as opposed to in 1980, when most of the trees were in the less than 4 inch size category. This indicates that fewer trees were being planted; even if the urban forester or arborist has increased the public tree planting, the private property owners have not.

The initial percentages of the size categories were not very similar when a natural forest was compared to an urban forest. This was because so much of the urban area was altered and so many of the trees have been removed due to the development of the urban area. As time goes on, the percentage of trees in the different size categories of the urban forest began to approximate the percentage of trees in the different size categories in a natural forest through succession.

Table 3.1. A comparison of selected urban forest descriptor data of the six Midwestern, USA cities in 1980 and 2003.2005.

		1980	2003/2005
Bowling Green, OH	Number of Trees	2280	2279
	Lots Surveyed	-----	237
	Average Tree Condition Rating	1.32	1.66
	Average Tree Size (inches)	5.73	9.61
Bucyrus, OH	Number of Trees	876	1111
	Lots Surveyed	-----	228
	Average Tree Condition Rating	1.65	1.59
	Average Tree Size (inches)	7.48	11.02
Delaware, OH	Number of Trees	2486	3515
	Lots Surveyed	-----	442
	Average Tree Condition Rating	1.44	1.51
	Average Tree Size (inches)	6.334	9.33
Hutchinson, MN	Number of Trees	704	654
	Lots Surveyed	-----	155
	Average Tree Condition Rating	1.74	1.80
	Average Tree Size (inches)	9.17	10.34
Lincoln, NE	Number of Trees	953	1049
	Lots Surveyed	-----	220
	Average Tree Condition Rating	1.73	1.69
	Average Tree Size (inches)	9.11	11.56
Wooster, OH	Number of Trees	1682	2316
	Lots Surveyed	-----	289
	Average Tree Condition Rating	1.32	1.66
	Average Tree Size (inches)	6.80	8.89
Summary of the urban forest discriptors	Number of Trees	2486	796
	Lots Surveyed	-----	567
	Average Tree Condition Rating	1.53	1.65
	Average Tree Size (inches)	7.44	10.13

Figure 3.1. Tree condition rating in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

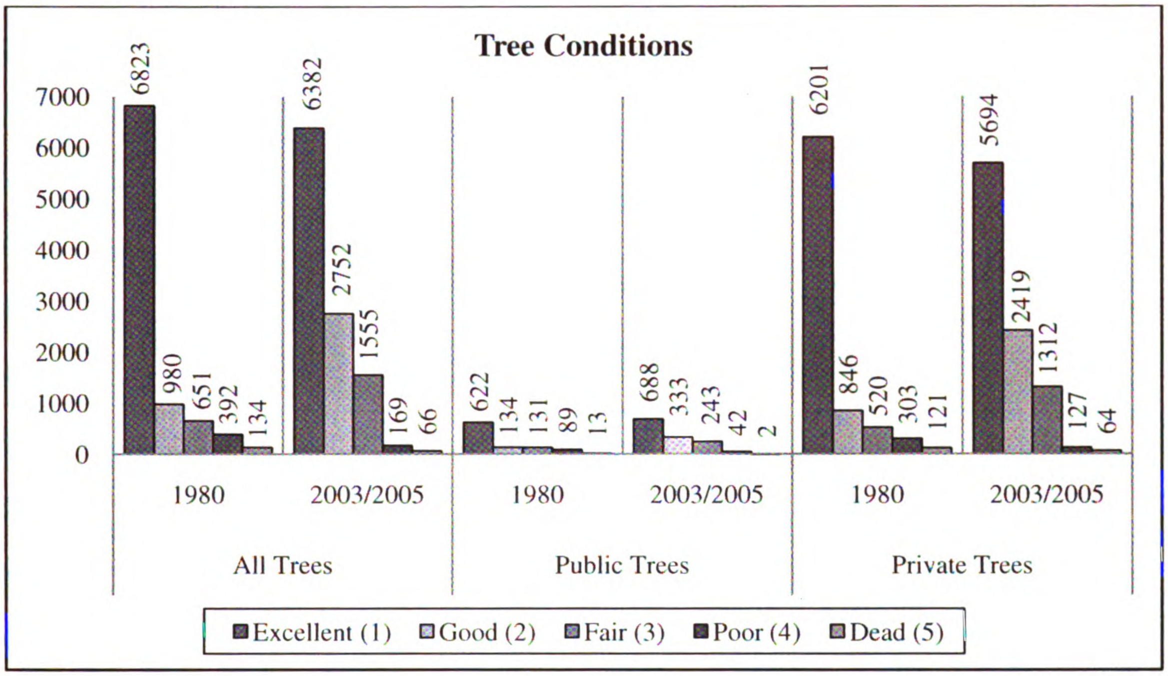


Figure 3.2. Tree size distribution in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

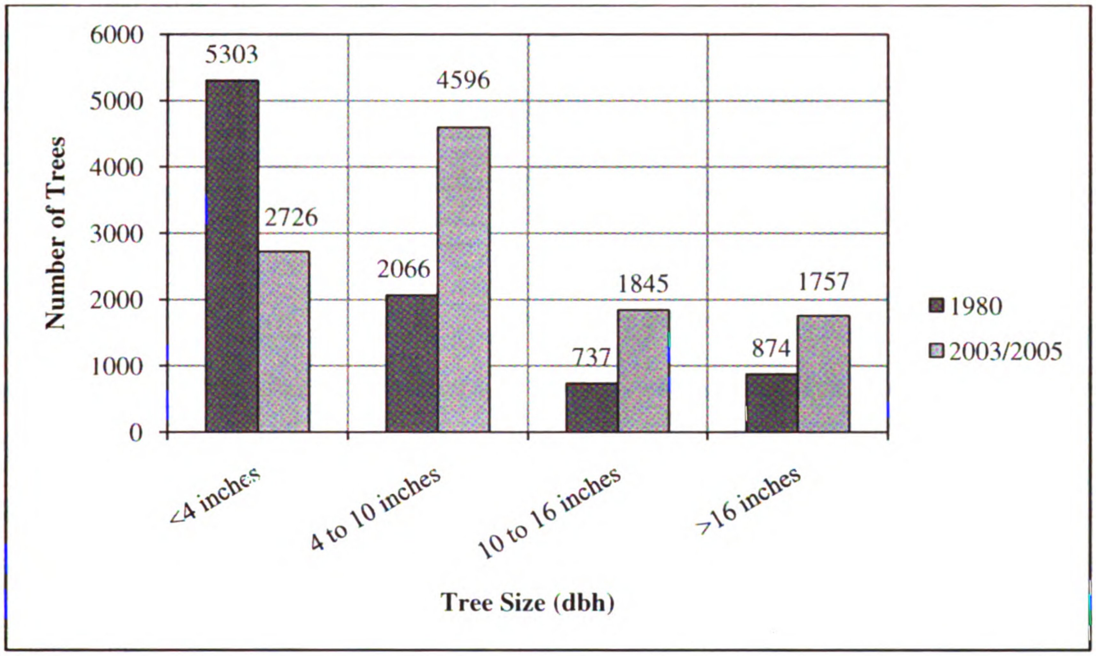


Figure 3.3. 1980 tree health condition in the six Midwestern, USA cities by location and age of blocks (All, Public and Private Trees).

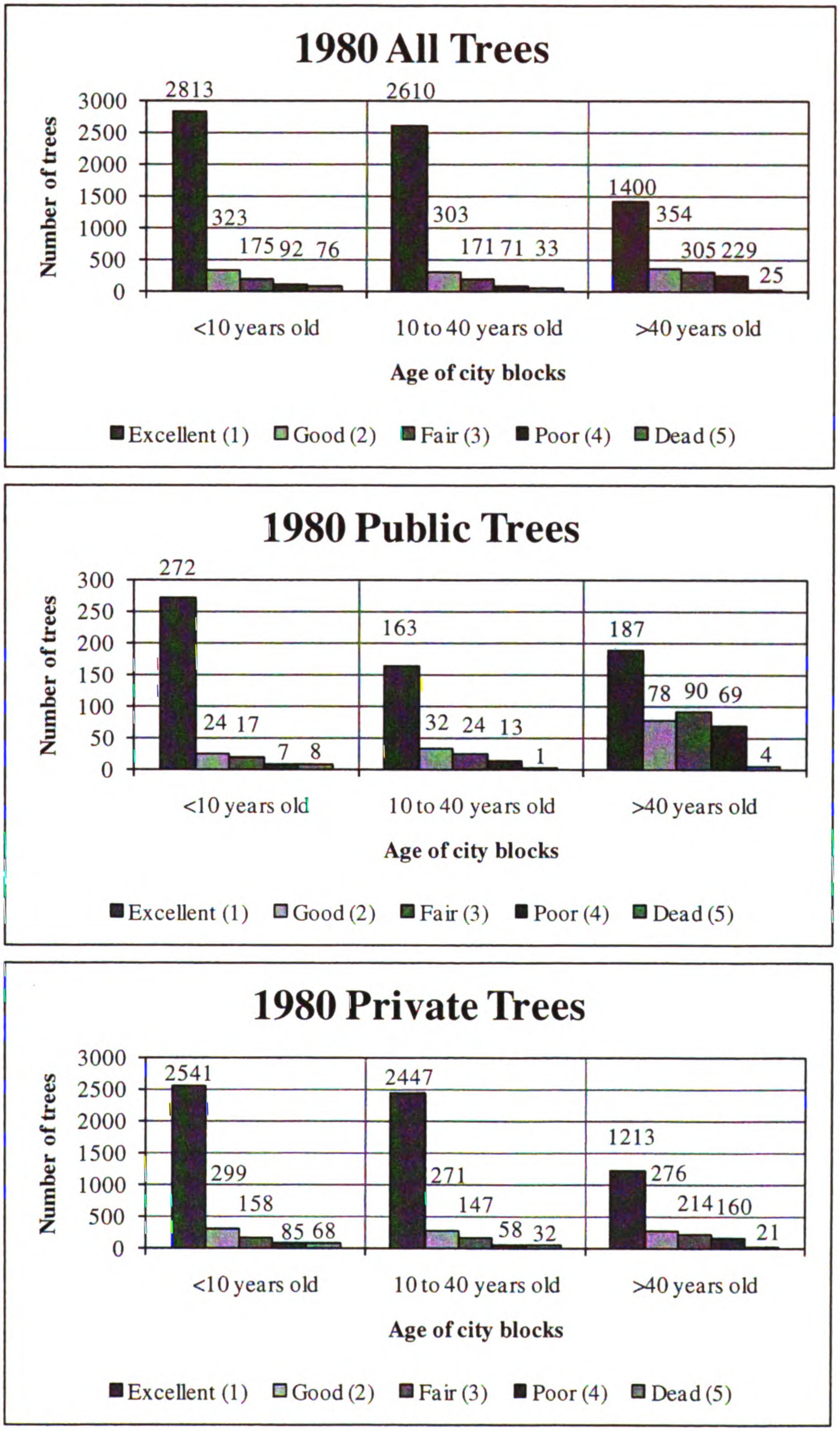
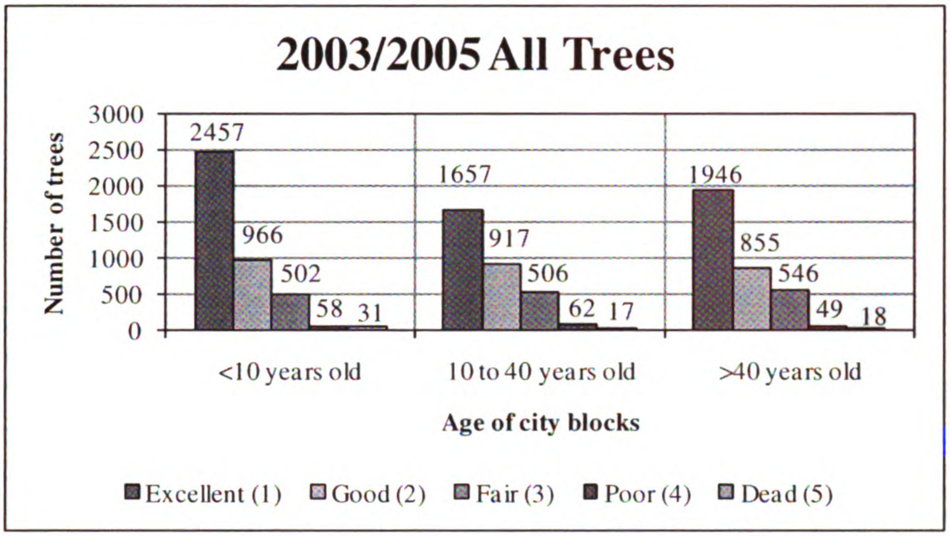
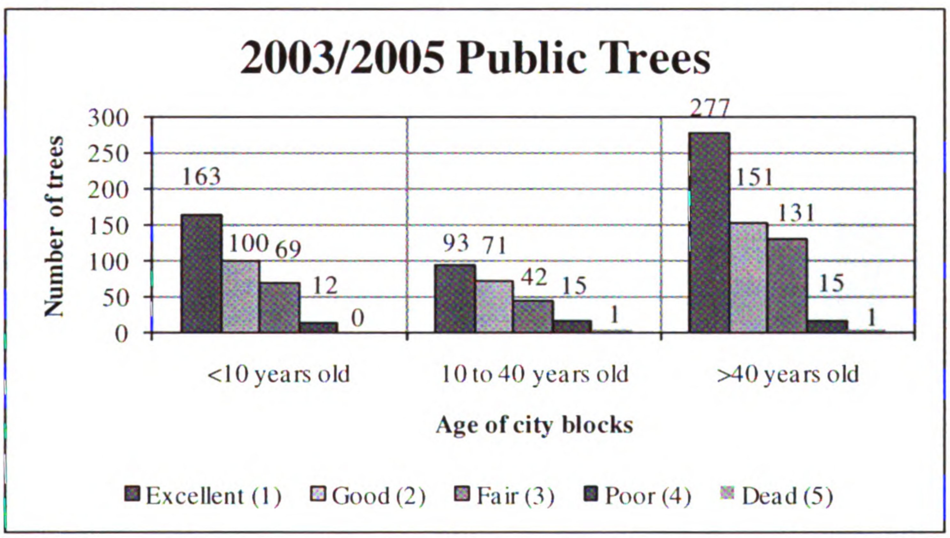


Figure 3.4. 2003/2005 tree health condition in the six Midwestern, USA cities by location and age of blocks (All, Public and Private Trees).





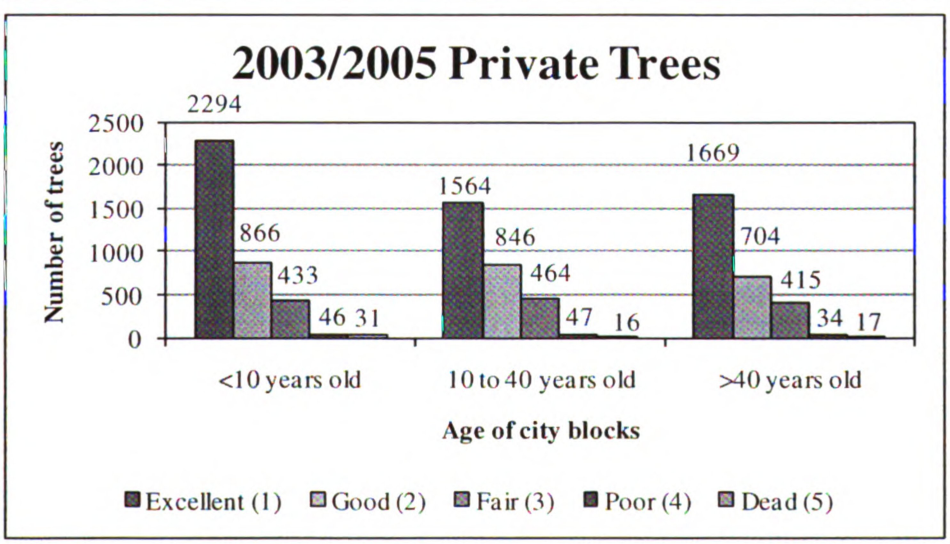
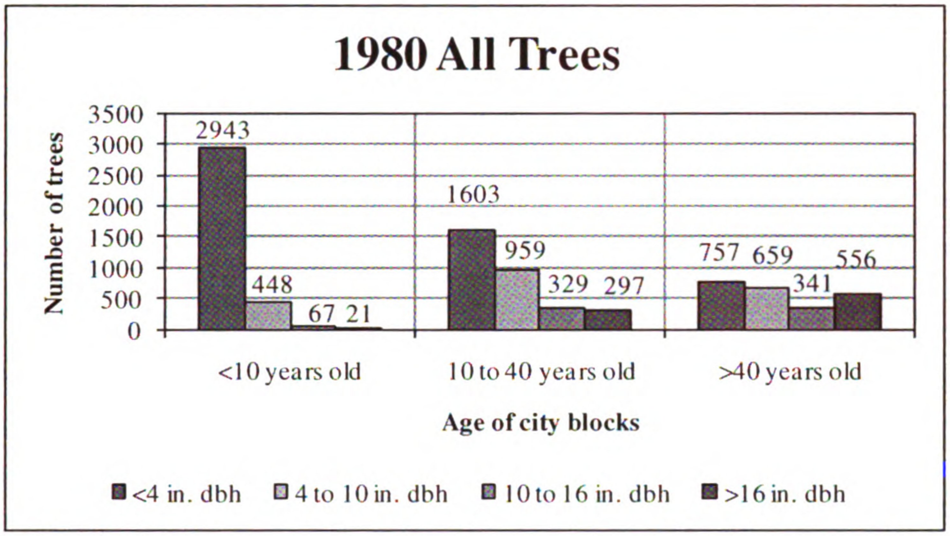
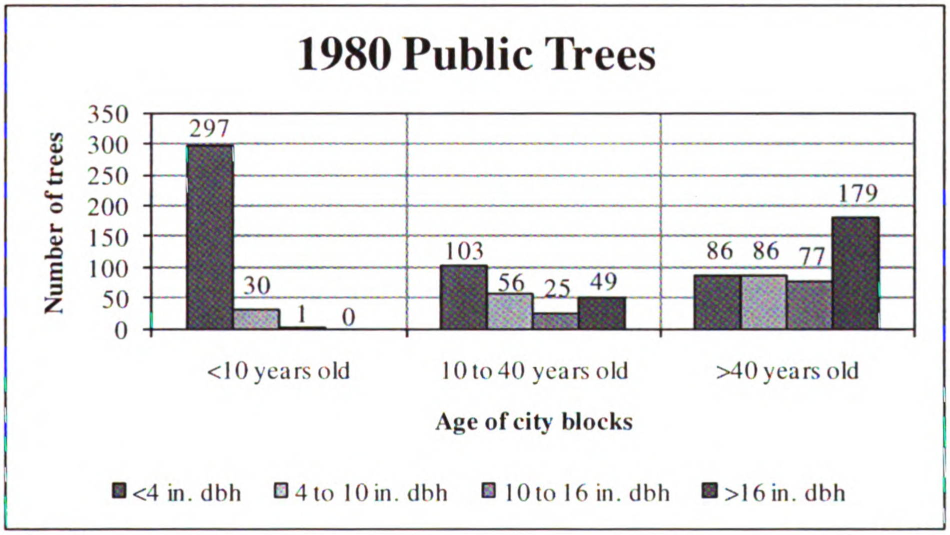


Figure 3.5. 1980 tree size distribution in the six Midwestern, USA cities (All, Public and Private Trees).





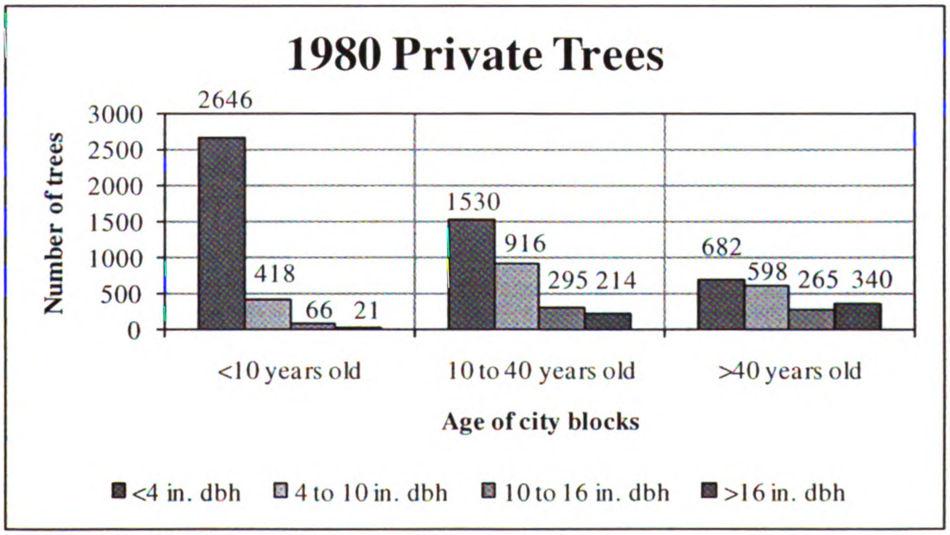


Figure 3.6. 2003/2005 tree size distribution in the six Midwestern, USA cities (All, Public and Private Trees).

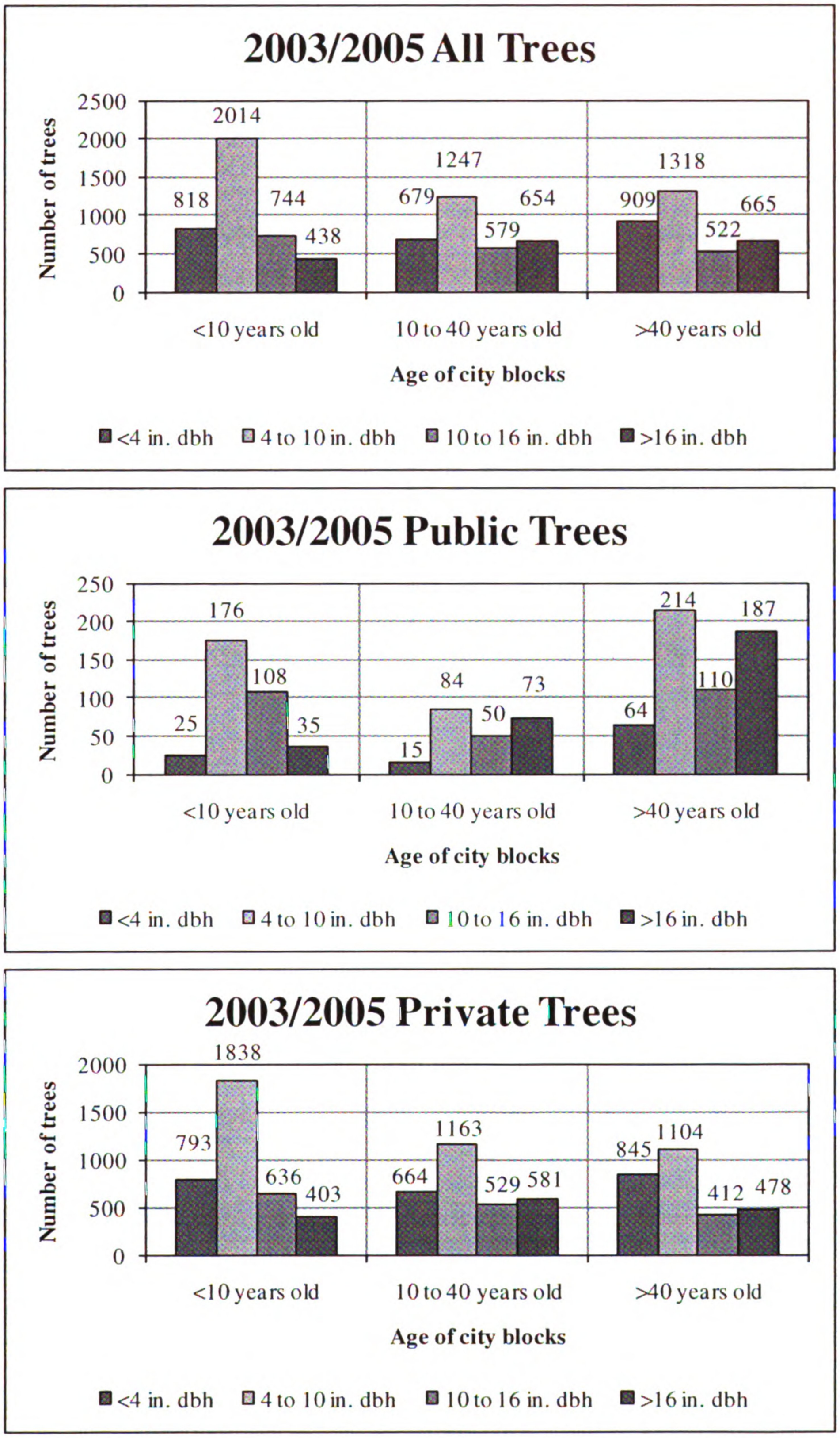
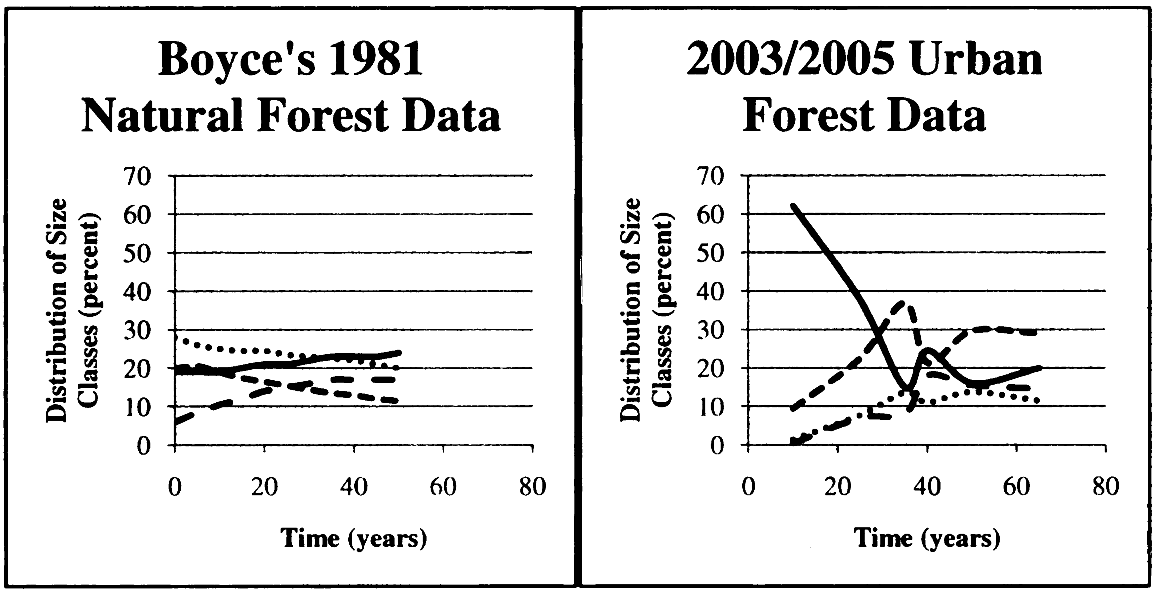


Figure 3.7. Comparison of urban forest and natural forest tree size succession over time. Adapted from Boyce, 1981, in Wenger, 1984.



Solid line is dbh less than 4 inches
Small dashed line is dbh 4 to 10 inches
Large dashed line is dbh 10 to 16 inches
Dotted line is dbh greater than 16 inches

Note: As time goes on, the percentage of tree sizes in urban forests approaches that of tree sizes in Boyce's natural forest. Also note that Boyce begins with a mature forest.

Table 3.2. The 25 most common tree taxa in 1980 and 2003/2005 and their overall average condition** in the six Midwestern, USA cities; reported by public, private and total trees.

1980		Average Condition			2003/2005		Average Condition		
Taxa	Number of Trees	Public	Private[1]	Total[2]	Taxa	Number of Trees	Public	Private[1]	Total[2]
Silver Maple (Acer saccharinum)	957	2.7	1.4	1.6	Arborvitae (Thuja occidentalis)	980	1.8	1.5	1.5
Blue Spruce (Picea pungus)	621	1.0	1.1	1.1	Silver Maple (Acer saccharinum)	942	1.9	1.8	1.8
Crabapple (Malus sp.)	458	1.1	1.2	1.2	Norway Maple (A. plataniodes)	701	1.9	1.6	1.7
American Elm (Ulmus americana)	418	2.6	1.5	1.8	Blue Spruce (Picea pungus)	676	1.1	1.3	1.3
Ash (Fraxinus sp.)	389	1.5	1.4	1.4	Ash (Fraxinus sp.)	634	1.5	1.6	1.5
Sugar Maple (A. saccharum)	355	1.7	1.6	1.6	Crabapple (Malus sp.)	523	1.7	1.7	1.7
Arborvitae (Thuja occidentalis)	327	1.0	1.1	1.1	Norway Spruce (P. abies)	506	1.0	1.7	1.7
Norway Spruce (P. abies)	323	1.6	1.1	1.2	Sugar Maple (A. saccharum)	334	2.2	1.8	2.0
Norway Maple (A. plataniodes)	305	1.6	1.4	1.5	White Pine (Pinus strobus)	321	1.0	1.6	1.6
Cherry (Prunus sp.)	276	1.7	1.8	1.8	Pin Oak (Quercus palustris)	292	1.9	1.6	1.6
Red Maple (A. rubrum)	262	2.0	1.5	1.6	Redbud (Cercis canadensis)	280	1.9	1.6	1.6
Pin Oak (Quercus palustris)	254	1.4	1.4	1.4	Red Maple (A. rubrum)	268	1.9	1.6	1.7
Dogwood (Cornus florida)	246	2.0	1.5	1.5	Mulberry (Moris sp.)	265	1.0	1.7	1.7
Apple (Malus sp.)	237		1.5	1.5	Pear (Pyrus sp.)	248	1.7	1.5	1.5

(Table 3.2 cont'd)

White Pine (Pinus strobus)	233	1.5	1.1	1.1	Dogwood (Cornus florida)	238	1.0	1.3	1.3
Redbud (Cercis canadensis)	207	1.0	1.5	1.5	Cherry (Prunus sp.)	224	2.3	1.7	1.7
Plum (Prunus sp.)	203	1.7	1.5	1.5	Black Walnut (Juglans nigra)	200	1.5	1.4	1.4
Birch (*Betula sp.*) (Betula sp.)	195	2.2	1.5	1.5	Honeylocust (Gliditsia triacanthus)	193	1.5	1.7	1.7
Scotch Pine (P. sylvestris)	187	1.0	1.3	1.3	Apple (Malus sp.)	171	2.0	1.8	1.8
Juniper (Juniperus sp.)	171		1.5	1.5	Hackberry (Celtis occidentalis)	164	2.4	1.6	1.7
Honeylocust (Gliditsia triacanthus)	161	1.1	1.4	1.3	Juniper (Juniperus sp.)	161	2.3	1.4	1.4
Black Walnut (Juglans nigra)	149	2.5	1.4	1.6	Linden (Tilia sp.)	147	1.7	1.5	1.6
Lombardy Poplar (Populus nigra 'Italica')	136	1.0	1.8	1.8	Hemlock (Tsuga canadensis)	145		1.6	1.6
Mulberry (Moris sp.)	117		1.9	1.9	Birch (Betula sp.)	139	2.0	1.5	1.5
Hawthorn (Crataegus sp.)	112	1.1	1.2	1.2	Magnolia (Magnolia sp.)	130		1.2	1.2
Total trees	7299	1.6	1.4	1.5	Total trees	8882	1.7	1.6	1.6
Sum of all trees	8,980				Sum of all trees	10,924			

[1]Private tree conditions are highly significantly worse between 1980 and 2003/2005, $p < 0.01$

[2]Total tree conditions are significantly worsebetween 1980 and 2003/2005, $p < 0.05$

**Conditions: 1 = excellent, 2 = good, 3 = fair, 4 = poor, and 5 = dead

Table 3.3. The six Midwestern, USA cities 25 most common tree species in 1980 and 2003/2005 and the overall average size**; public, private and total trees.

1980					2003/2005				
		Average Size					Average Size		
Taxa	Number of Trees	Public[1]	Private[2]	Total[3]	Taxa	Number of Trees	Public[1]	Private[2]	Total[3]
Silver Maple (Acer saccharinum)	957	3.2	2.1	2.2	Arborvitae (Thuja occidentalis)	980	1.9	1.6	1.6
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(Table 3.3 cont'd)

White Pine (Pinus strobus)	233	1.0	1.3	1.3	Dogwood (Cornus florida)	238	1.3	1.5	1.5
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Juniper (Juniperus sp.)	171		1.6	1.6	Hackberry (Celtis occidentalis)	164	4.0	2.0	2.1
Honeylocust (Gliditsia triacanthus)	161	1.5	2.1	2.0	Juniper (Juniperus sp.)	161	2.0	1.6	1.6
Black Walnut (Juglans nigra)	149	2.0	2.3	1.3	Linden (Tilia sp.)	147	2.5	2.4	2.5
Lombardy Poplar (Populus nigra 'Italica')	136	2.0	1.5	1.5	Hemlock (Tsuga canadensis)	145		1.6	1.6
Mulberry (Moris sp.)	117		1.9	1.9	Birch (Betula sp.)	139	3.0	2.1	2.1
Hawthorn (Crataegus sp.)	112	1.1	1.2	1.2	Magnolia (Magnolia sp.)	130		1.6	1.6
Total trees	7299	1.7	1.6	1.6	Total trees	8882	2.6	2.2	2.2
Sum of all trees	8,980				Sum of all trees	10,924			

[1] Public tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.001$

[2] Private tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.0001$

[3] Total tree sizes were highly significantly bigger between 1980 and 2003/2005, $p < 0.0001$

**Sizes: 1 = <4 in. dbh, 2 = 4 to 10 in. dbh, 3 = 10 to 16 in. dbh, and 4 = >16 in. dbh

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Chapter 4

Effects of an Early Snowstorm on the Urban Forest Ecosystem in Lincoln, NE

Abstract

On October 24, 1997, before leaf senescence, a severe snowstorm swept through Lincoln, NE resulting in 33.5 cm (13.2 inches) of accumulation over roughly two days. The weight of the snow caused devastating damage to trees. It was reported that 90 to 95 percent of trees in southeastern Nebraska were damaged (IANR News Service 2001). This snowstorm cause dramatic changes in the urban forest. A survey in 2003 found that 48% of the trees recorded in a 1992 survey were lost. A comparison of trees by sizes revealed that the smallest trees were devastated while larger trees were not, and a comparison of trees by condition showed substantial losses in all condition classes. Losses varied among species. Species such as mugo pine (*Pinus mugo*), mulberry (*Morus sp.*) and plum (*Prunus sp.*) had losses greater than 80%, while some others, white pine (*P. strobus*) and pin oak (*Quercus palustris*), had losses of 20% or less. Using the Shannon diversity index, there was a loss of approximately 6% of the total diversity of trees. Species richness decreased by nearly 10%. There were no correlations between specific tree species' vulnerability to snow damage and tree physical properties: wood density, specific gravity, modulus of rupture or modulus of elasticity.

Key Words: Lincoln, NE; snowstorm; urban forest ecosystem; urban trees; wood density; specific gravity; modulus of rupture; modulus of elasticity.

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Introduction

The effect of snowstorms on the urban forest has not been well documented, unlike the effects of ice storms. Ice storms resulting in accumulations of several centimeters of ice on trees happen periodically throughout the Midwest and northeast United States and much has been written about ice damage to forest trees in these areas: Abell 1934; Croxton 1939; Lemon 1961; Bruederle 1985; Hauer et al. 1993; Sisinni et al. 1995; Rebertus 1997; Rhoads et al. 2002; Hauer et al. 2006. Individual tree species vary in response to snow and ice loading on branches, with some species being more susceptible to breakage under the weight of the snow and ice buildup (Croxton 1939; Cannell and Morgan 1989; Lilly and Sydnor 1995; Valinger and Fridman 1997; Warrillow and Mou 1999). Many past reports on ice and snow damage to trees have reported a comparison of the damaged forest area to an adjacent area that was not disturbed by the storm (Rogers, 1923; Croxton, 1939; Dueber, 1940; Whitney, 1984). However, nothing has been reported about snowstorm damage to the urban forest and none of these papers address the ice or snow loading on trees that still have their leaves present.

This paper addresses the effects of a late October 1997 snowstorm on the urban forest in Lincoln, NE and started with data that had been collected in an earlier study of the same sample areas. This is also the first study to deal with the effects of a snowstorm on an urban forest. Another unique feature of this study is that it takes into account all trees in the urban forest, both public and private trees, not just street trees.

The size of a tree is usually expressed as height, crown spread, or diameter of trunk (dbh). This study utilizes the dbh as the size of the tree. Small trees, depending on the species, may be weak and less able to withstand snow load and wind while larger trees, depending on the species, may be more prone to decay and breakage.

Tree health conditions directly affect the ecosystem services of the urban forest (McPherson, 1990; Rowntree and Nowak, 1991; McPherson, 1993; McPherson, 1994; Nowak, 1994; Qi et al., 1998; Scott et al., 1999; Beckett et al., 2000; Cumming et al., 2001; Xiao and McPherson, 2002). The urban forest provides aesthetics that can increase property values and recreational benefits, and it reduces air pollution and storm runoff, conserves energy, stores carbon, provides protection from ultraviolet radiation, creates habitat for wildlife, and moderates temperatures (Xiao and McPherson, 2005). The diversity of the urban forest should be maintained and it is important to maintain the diversity as high as possible to reduce the chance of a catastrophic event destroying the forest.

Wood properties vary between the different tree species. The wood density is the dry weight per unit volume of wood. It is an important parameter that can be used to indicate strength. Specific gravity can be thought of as the relative hardness of different wood. It is the wood density divided by the density of water. The modulus of rupture is the measure of the force necessary to cause failure in a given beam or it is the maximum load of a carrying capacity of a beam which is a measurement of strength. The modulus of elasticity is the measurement of a force that can be applied to bend an object and the object can return to its former position (Green et al., 1999).

I hypothesized that the snowstorm, in October 1997, had no effect on the size and condition of the urban trees. I also hypothesized that the diversity and number of trees did not change because of the snowstorm and that the physical and mechanical wood properties of trees did not play a role in the survival of the individual tree species.

H_1 – The average size of the urban forest trees did not change because of the snowstorm.

H_2 – The average condition of the urban forest trees did not change because of the snowstorm.

H_3 – The Shannon diversity index of the urban forest trees did not change because of the snowstorm.

H_4 – The number of trees in the urban forest did not change because of the snowstorm.

H_5 – The physical and mechanical wood properties, per species, determined percentage lost of trees due to the snowstorm.

History

From October 24 to October 26, 1997, it snowed in Lincoln, NE, as it did in many other locations ranging from Colorado to Michigan. The storm left 33.5 cm (13.2 inches) of snow in Lincoln, NE. Snow build up on trees was unusually heavy because most of the leaves were still present and this caused devastating damage to the trees. It was estimated that 90 to 95 percent of the trees in southeastern Nebraska were damaged (IANR News Service, 2001). When the snow started falling the temperature was hovering around 0°C (32°F) and three days later, the temperature had dropped to -13.3°C (8°F). This is the earliest single digit temperature ever recorded in Lincoln, NE. It took until the summer of 1998 to completely clean up the debris from this storm in Lincoln. This storm did not lose much of its strength as it moved across the plains states. The storm stretched all the way to Lansing, MI and as an example of this snowstorm's size and strength, it did so much "natural pruning" that it took until February to clean up, according to the city of Lansing Forester Mr. Paul Dykema (2004). When the clean up was completed, the city of Lansing had six million pounds of wood chips and the city of Lincoln had many more.

Methods

Twelve sample blocks in Lincoln, NE, that were chosen during an original survey in 1980, were divided into age categories based on the age of the homes according to an earlier survey (Kielbaso, 1993) which in turn was based on an original survey by William Cannon in 1980. The age categories were: younger than 10 years; 10 to 40 years; and older than 40 years in 1980. Four entire city blocks were surveyed from each of the age categories; a total of 12 blocks. All trees, on both public and private land, over 5.1 cm (2 inches) dbh were measured and placed into a size class.

The design of this study follows the criteria established in 1980. So, in 1992, the identification of all trees in each of these blocks, by house was possible. Also, in 2003, I could precisely determine which trees had been added, or lost, between studies. The data collected for each tree were: ownership (public/private); species or genus; diameter category; and overall tree health condition. Trees between the street and the sidewalk were considered public. If there was no sidewalk, then the trees that were within 15 feet of the street were considered public. All other trees in the yards, front, back and sides, were private. The diameter at breast height (dbh) for each tree was measured and each tree was put into a size class: 1 - 5.1 to 10.2 cm (2 to 4 inches); 2 - 10.2 to 25.4 cm (4 to 10 inches); 3 - 25.4 to 40.6 cm (10 to 16 inches); and 4 - greater than 40.6 cm (16 inches). The health conditions were assessed by looking for signs of decline; the fewer signs of decline, the better the health of the tree. The specific decline signs were evaluated by looking at the crown, trunk and branches, and the base and roots. Some examples of decline signs are: decay, girdling roots, broken branches/limbs, included bark, etc. Once the tree was evaluated, the decline signs were added up. If the tree had zero or one sign of decline, it was rated a 1; if the tree had two decline signs, it was rated a 2, if it had three or four decline signs, it was rated a 3, if it had five or more decline signs it was rated a 4, and if it was dead or was in the process of dying, it was rated a 5. This system was unique to the original study by Cannon and has produced reasonably consistent comparison with current ISA/CTLA evaluation guide procedures. Chi-square statistical analyses were used to test for significant differences in the data between 1992 and 2003 ($p < 0.05$). In the case of the species diversity, a t-test was used to compare differences in the Shannon index values.

A multiple regression was performed to see if there was any correlation between the percent of tree species lost and the reported wood property. The specific wood property values that were used were from published data and a multiple regressions was performed to illustrate any relationships. The focus of a multiple regression is to illustrate any relationship between several independent variables, in this case the wood density, specific gravity, modulus of rupture, modulus of elasticity, and size (dbh). The dependent variable was the percent loss of the specific tree species.

Results

Numbers of Trees – Individual species were recorded and the twenty-five most common tree species are shown in Table 4.1. In 1992 there were 1346 trees in the 12 block sample while in 2003 there were 697. Overall there was a loss of 48.2% of the original 1992 trees ($\chi^2 = 9.04$ (df = 1) $p < 0.05$). The 2003 count does not include the number of new trees that were planted following the snowstorm. 352 new trees were detected in 2003. These were identifiable as they did not appear in the 1992 study.

In 1992 there were 212 public trees and in 2003 there were 147 public trees, which is a loss of 30.7% of the public trees. The private trees did not fare as well as the public trees. In 1992 there were 1134 private trees and in 2003 there were 550 private trees (Figure 4.1), a loss of 51.5%.

Newer neighborhoods, based on plat map dates, lost more trees than older neighborhoods. The newest neighborhoods (less than 10 years old in 1980) lost 69%, and the ne

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the next oldest aged neighborhoods (10 to 40 years old in 1980) lost 45%, whereas the oldest neighborhoods lost only 19.0% (Figure 4.2), which is a significantly smaller loss for all of the age groups, ($\chi^2 = 64.77$ (df = 2) $p < 0.0001$).

Mr. Steve Schwab, the City Arborist of Lincoln, reported that when the city was established in the 1800's, there were only 6 trees within the city (Laukaitis, 2003). The density was 24.0 trees per acre in 1992 and in 2003, there were only 12.2 trees per acre. This is a loss of 49.1% of the trees. In 2003, that loss had been lessened by an active tree planting program. In these 12 city blocks, 404 trees have been planted since the snowstorm. As a result, there were 18.7 trees per acre in 2003, improving the tree population losses to 22.1% of that of 1992.

Size of Trees – The losses between 1992 and 2003 were greatest in the small trees (Figure 4.3). In 1992 there were 381 trees in the size 1 class and in 2003 there were 25 trees, a loss of 93.4%. Size class 2, had 477 trees in 1992 while in 2003 there were 251 trees, which is a loss of 47.4%. Size class 3, had 222 trees in 1992 and 160 trees in 2003, which is a loss of 27.9%. The largest trees, size class 4, had 266 trees while in 2003 there were 262, which is a loss of 1.9%. During this time period, 288 trees that were lost from the three smaller trunk sizes actually grew and are now accounted for in the next larger trunk size class. There was 139 tree that grew from the size category 1 to 2, 101 trees grew from size category 2 to 3, and 48 trees grew from size category 3 to 4.

There was a correlation between dbh and the percentage of trees lost, as the dbh increased, the percentage of tree lost decreased. So many small trees died in the snowstorm that the average dbh of the surviving trees changed dramatically. The average dbh of all the trees present in 1992 was 24.4 cm (9.6 inches). After the snowstorm in 2003, the average dbh of all of the trees remaining from 1992 was 39.4 cm (15.5 inches). However, when you take into account the 352 new trees planted since the snowstorm, the average dbh of all of the trees in 2003 is 27.7 cm (10.9 inches). With the addition of the new trees, the average dbh is now more similar to what the dbh was before the storm. The tree size data for the different years, 1992 and 2003, shows there was a significant loss of trees in all of the size categories ($\chi^2 = 207.17$ (df = 3) $p < 0.0001$).

There is a direct correlation with age of city block and size of the trees. In general, the youngest city blocks have the youngest trees which are also the smallest trees. The older city blocks have the oldest and the largest trees. When considering just age, the youngest blocks experienced a 69% loss of trees, while the middle-aged blocks lost 45% of the trees and the oldest blocks lost only 19% of their trees. This is a highly significant loss of trees in all of the age categories ($\chi^2 = 64.77$ (df = 2) $p < 0.0001$). The size of the trees shows the same trend as did the age. In the case of this snowstorm, the size and the age of the trees mattered, statistically. The larger the trees and the older the trees, as measured by block age, the better the chance of surviving this snowstorm.

Condition of Trees – In 1992 there were 587 trees that were rated a 1, the best health condition (Figure 4.5) and in 2003 there were 345, a loss of 41.2% of the trees. There wer

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were 508 trees rated as a 2 in 1992, and 219 trees in 2003, a reduction of 56.9%. In 1992, 170 trees received a rating of 3, and in 2003 there were 117, a loss of 31.2%. There were 58 trees rated as a 4 in 1992, and in 2003 there were 14, a reduction of 75.9%. In 1992 there were 23 trees with a health condition rating of 5; this means the trees were dead or nearly so, in 2003, there were only two dead trees standing which is a reduction of 91.3%. All of the condition categories show significant losses, ($\chi^2 = 28.77$ (df = 4) $p < 0.0001$).

The number of trees in each of the health conditions showed a similar trend as above. The trees in the best health condition had the smallest percentage of losses, while each consecutive lower health condition category had a greater percentage of loss than the previous health condition. The average health condition of all the trees in 1992 was 1.88. After all of the dead and damaged trees from the snowstorm were removed, the average health condition of the trees that were present in 1992 and still alive in 2003, was 1.99. This means that the surviving trees from 1992 have a slightly worse average health condition. In 2003, the average health condition of all the trees (surviving 1992 trees plus trees planted since the snowstorm) is 1.59, slightly better than in 1992.

Diversity of Trees – Species richness was also affected by the snowstorm, but not significantly. Species richness went from 62 in 1992 to 56 in 2003, a loss of 9.7%. Table 4.1 shows results for individual species. The Shannon index for diversity (Magurran, 1988; Marurran, 2004) based on species richness and evenness, was 3.5 in 1992 and 3.25

in 2003. This is a loss of 6.1%, which indicates that between 1992 and 2003 the loss in species diversity was nonsignificant.

Individual tree species were analyzed in the study. Table 4.1 shows the twenty-five most common tree species in the city blocks that were studied. Some trees; mugo pine (*Pinus mugo*), plum (*Prunus sp.*) and mulberry (*Morus sp.*) show a loss of more than 80% from 1992. Also on this list, are ten additional species that lost more than 50% of their population: redbud (*Cercis canadensis*), birch (*Betula sp.*), arborvitae (*Thuja occidentalis*), cherry (*Prunus sp.*), Siberian elm (*Ulmus pumila*), apple (*Malus sp.*), crabapple (*Malus sp.*), juniper (*Juniperus sp.*), pear (*Pyrus sp.*), and hackberry (*Celtus occidentalis*). The species and/or genera that fared the best were: pin oak (*Quercus palustris*), white pine (*Pinus strobes*) and ash (*Fraxinus sp.*). Ash was mostly green ash (*F. pennsylvanica* Marsh.), but white ash (*F. Americana*) and Hessei European ash (*F. excelsior 'hessei'*) were also noted.

Physical and Mechanical Properties of Wood – The relationship of wood properties to the percentage lost of individual tree species (Table 4.1) was analyzed by multiple regression. The percentage loss of each species was the dependent variable and the wood density, specific gravity, modulus of rupture and the modulus of elasticity were the independent variables. The relationship between the dependent variable and the independent variables was not significant. None of the independent variables helps to explain the value of the dependent variable, namely the percentage of trees lost owing to the snowstorm (wood density – $F_{1, 19} = 0.798$, $p > 0.05$; specific gravity – $F_{1, 20} = 0.0015$,

$p > 0.05$; modulus of elasticity – $F_{1, 15} = 0.0034$, $p > 0.05$; modulus of rupture – $F_{1, 16} = 0.1965$, $p > 0.05$).

Discussion

Number of Trees –The urban forest of Lincoln, NE lost nearly half of the trees during this snowstorm. This left large areas of the city without much tree cover. When comparing the percent of tree loss by the age of the city blocks, the older the block, the better the chance of tree survival, the younger the block the better the chance of tree failure. This may be because of resilience. Only the most resilient trees survive to old age and the rest, less resilient trees died earlier in life.

Presumably after the snowstorm and before 2003, 352 new trees were planted in order to replace the dead and removed trees. The urban forest will continue to recover in number and density, as the trees that were lost in the snowstorm are replaced.

Size of Trees – During the snowstorm, 93% of the smallest trees were damaged to the point where they were removed during the cleanup after the snowstorm. The city forester of Lincoln was questioned about these high losses. He stated that there was a conscious effort to save as many of the public trees as possible and it was up to each property owner to decide what happened to the private trees. So, small public trees were not simply removed, but instead, when possible, the small trees were pruned and maintained in a manner that would help guarantee their survival.

So many small trees died in the snowstorm that the average dbh of the surviving trees changed dramatically. However, because of all of the replanting that has taken place, the average dbh of all of the trees including the 352 new ones is getting close to what it was in 1992. The reason for the substantial increase in the average dbh in the trees that survived the snowstorm, 24.4 cm in 1992 to 39.4 cm in 2003, was that more than 90% of the smallest trees died and 288 of the surviving trees grew into the next larger size class. Given this, we can predict snowstorm damage based on the size of the trees with some certainty, the smaller trees do not fare as well as larger trees in this situation.

Condition of Trees – All conditions categories lost many trees. In general, as the condition of the trees gets decreased, the percent of trees lost increased. This was not surprising, since I expected that trees with disease or defects would be more susceptible to the heavy snow load.

Diversity of Trees – In general, species richness and species diversity did not change much. However, Hauer et al. (1993) summarized 12 studies along with their own research to produce a list of 11 storm susceptible trees from urban and natural forests. Of the trees that were considered “susceptible” to damage in Hauer’s report, only cherry (*Prunus sp.*), Siberian elm (*Ulmus pumila* L.) and pear (*Pyrus sp.*) lost more than 50% of their population in this study. One difference in the current study from Hauer et al. is that they considered arborvitae to be “resistant” to damage, whereas in this study, arborvitae lost over 67% of its population in the snowstorm. These trees were one hundred percent private trees and were probably cut down due to the snow load causing disfigurement to the trees. Many of these arborvitae were small and in hedges.

Physical and Mechanical Properties of Wood – The susceptibility of snowstorm damage appears to be a product of the size and age of the trees rather than the physical and mechanical properties of the wood. This concurs with the findings of Hauer et al. (1993) where they compared wood properties to the susceptibility to ice storm damage in Urbana, Illinois.

Conclusion

The severe snowstorm that hit Lincoln, NE and many other parts of the Midwest was devastating to trees. Some trees fared better than others, but the entire urban forest was affected, particularly the small trees. Physical signs of the storm can still be seen today, but with time, these wounds are healing and replacement trees are being planted by both the city and individual home-owners. A diverse urban forest, that includes tree species that are more resistant to snow and ice loads, that are maintained on a regular basis so that the tree architecture is sound, and where any structural weaknesses in the trees are removed, will minimize the dangers from these types of storms (Hauer et. al. 2006).

Table 4.1. The 25 most common tree taxa in the study area of Lincoln, NE and their percent loss, in decreasing order, due to the October 24, 1997 snowstorm along with the physical and mechanical wood properties related to strength (Does not include trees planted after 1997).

Species	1992 trees	Percentage of total	2003 trees	Percentage of total	Wood Density (Kg/m^3)	Specific[1] Gravity (g/cm^3)	Modulus[1] of Rupture (kPa)	Modulus[1] of Elasticity (MPa)	Percent Lost
American elm (Ulmus americana)*	17	1.3%	1	0.1%	560	0.46	50000	7700	-94.1%
Mulberry (*Morus sp.*)	42	3.1%	3	0.4%	670-850[6]	0.59[3]			-92.9%
Plum (*Prunus sp.*)	37	2.7%	5	0.7%	630	0.47	55000	9000	-86.5%
Mugo Pine (*Pinus mugo*)	18	1.3%	3	0.4%					-83.3%
Redbud (*Cercis canadensis*)	44	3.3%	13	1.9%	720-839[6]	0.58[4]			-70.5%
Birch (*Betula sp.*)**	16	1.2%	5	0.7%	610	0.54	55333	9933	-68.8%
Arborvitae (*Thuja occidentalis*)	101	7.5%	33	4.7%	310	0.29	29000	4400	-67.3%
Cherry (*Prunus sp.*)	15	1.1%	5	0.7%	630	0.47	55000	9000	-66.7%
Siberian Elm (*Ulmus pumila*)	33	2.5%	11	1.6%		0.46[4]			-66.7%
Apple (*Malus sp.*)	28	2.1%	10	1.4%	640	0.61	51016	7239	-64.3%
Crabapple (*Malus sp.*)	80	5.9%	30	4.3%	640	0.61	51016	7239	-62.5%
Juniper (*Juniperus sp.*)	92	6.8%	36	5.2%	430	0.44	48000	4500	-60.9%
Pear (*Pyrus sp.*)	35	2.6%	15	2.2%	600-839[6]				-57.1%
Hackberry (*Celtus occidentalis*)	30	2.2%	15	2.2%	530	0.49	45000	6600	-50.0%
Austrian Pine (*Pinus nigra*)	33	2.5%	19	2.7%	360-839[6]	0.41[4]			-42.4%
Blue Spruce (*Picea pungens*)[2]	44	3.3%	26	3.7%	433	0.38[4]	39000	8600	-40.9%
Red Maple (*Acer rubrum*)	17	1.3%	11	1.6%	490-540	0.49	53000	9600	-35.3%

Table 4.1. Continued

Silver Maple (*Acer saccharinum*)	99	7.4%	67	9.6%	470	0.44	40000	6500	-32.3%
Linden (*Tilia sp.*)	44	3.3%	30	4.3%	417	0.32	34000	7200	-31.8%
Scotch Pine (*Pinus sylvestris*)	29	2.2%	20	2.9%	513	0.42	46000	7300	-31.0%
Norway Maple (*Acer platanoides*)	45	3.3%	33	4.7%		0.92 [5]		7000 [5]	-26.7%
Honeylocust (*Gliditsia triacanthus*)	42	3.1%	32	4.6%	630	0.6	70000	8900	-23.8%
Ash (*Fraxinus sp.*)**	115	8.5%	89	12.8%	670	0.51	58200	8620	-22.6%
White Pine (*Pinus strobus*)	15	1.1%	12	1.7%	400	0.34	34000	6800	-20.0%
Pin Oak (*Quercus palustris*)	93	6.9%	82	11.8%	815	0.58	57000	9100	-11.8%
Other	182	13.5%	91	13.1%					-50.0%
Total	1346	100.0%	697	100.0%					

1 Green et.al., 1999

2 Englemann Spruce data

3 Hidayat and Simpson, 1994

4 Jenkin et. al., 2004

5 Horácek, 2000

6 Wood Density Database

*Decline may have been caused by disease and not storm

**Average values calculated from several species from the genus

Figure 4.1. Comparison of tree counts in Lincoln, NE by ownership (1992 and 2003).

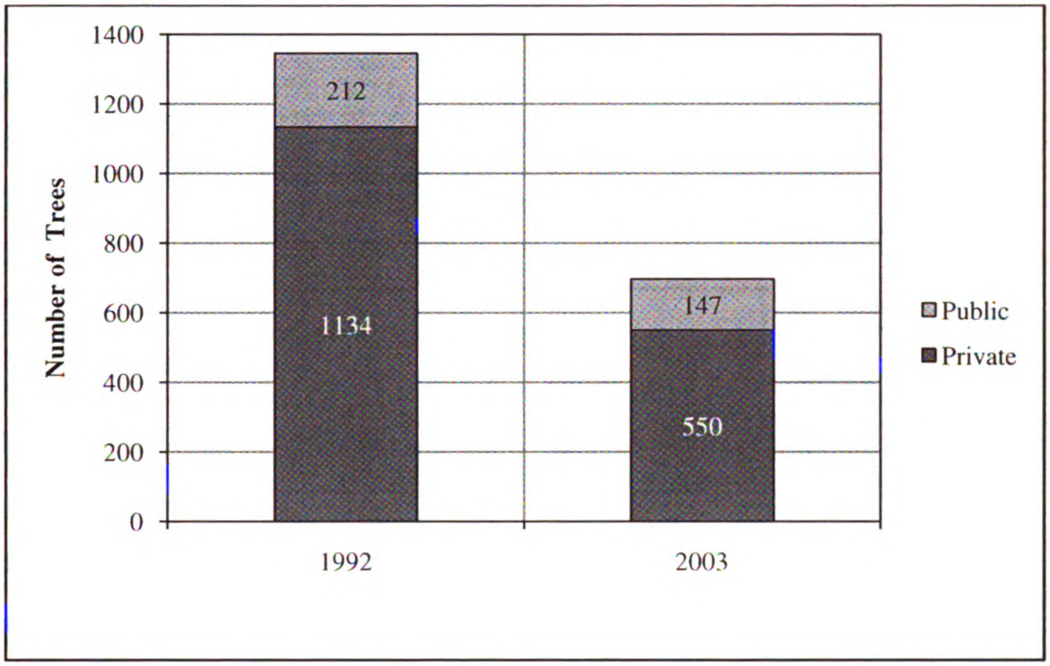


Figure 4.2. Age categories of homes and the number of trees compared by blocks in Lincoln, NE in 1992 and 2003.

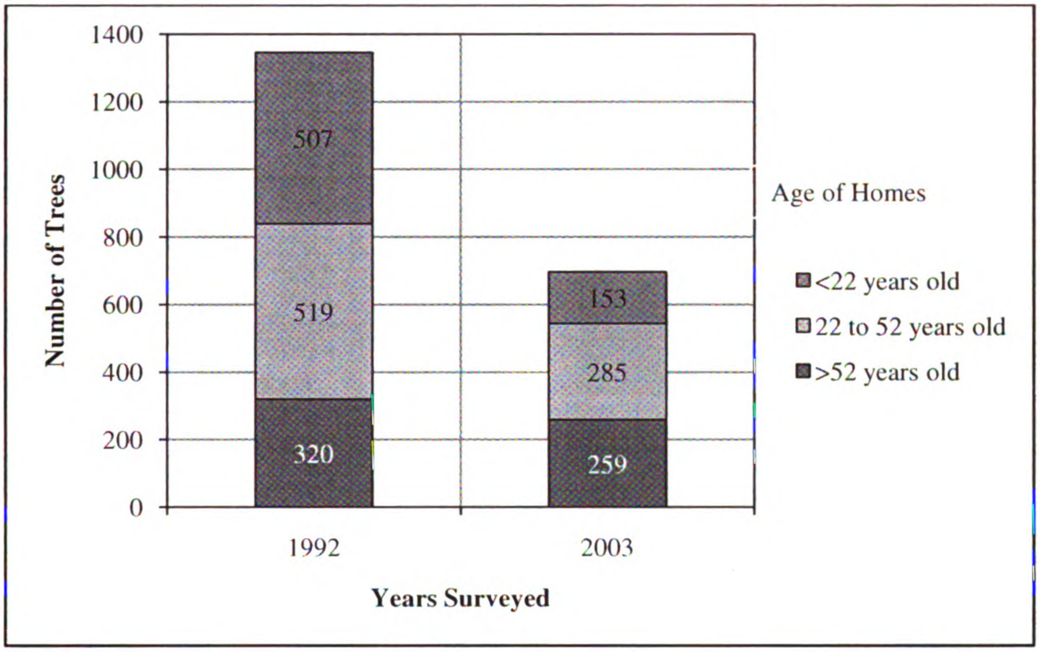
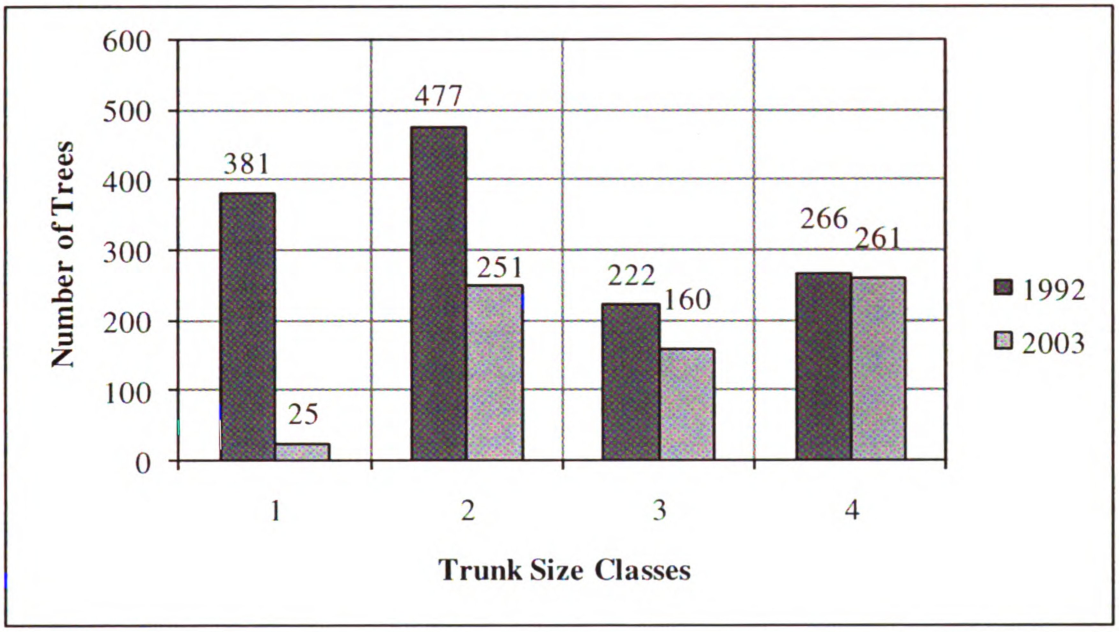
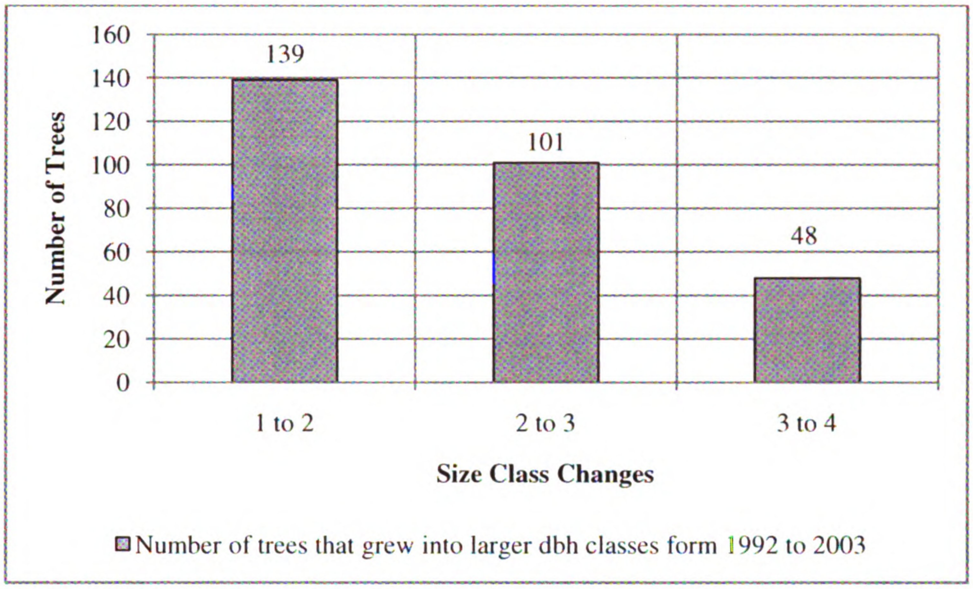


Figure 4.3. Comparison of the number of trees in each trunk size class in 1992 and 2003 in Lincoln, NE.



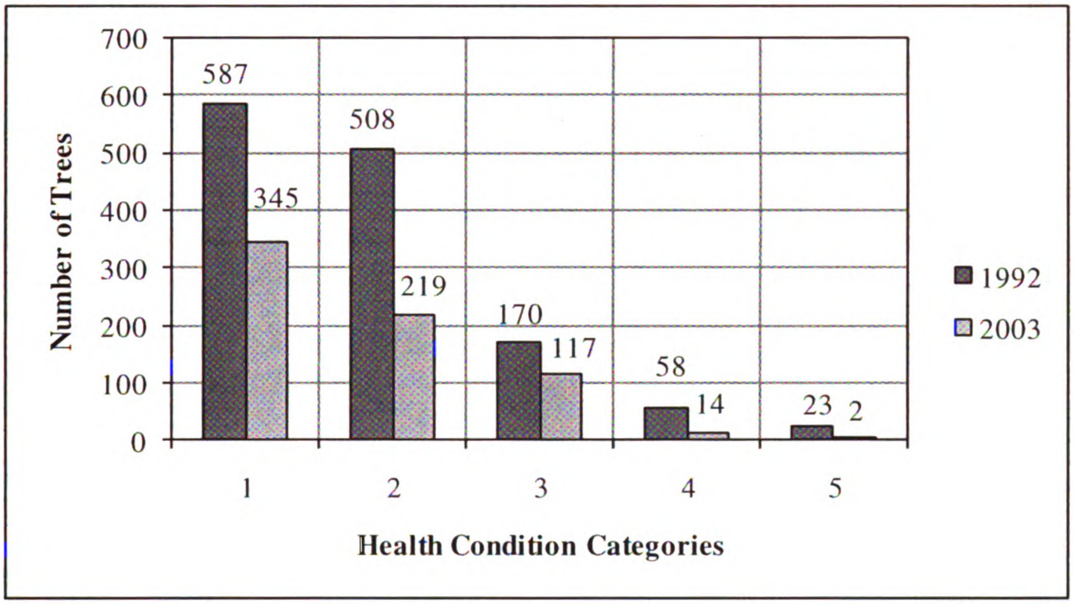
Size class 1 = less than 10.2 cm (4 inches)
Size class 2 = 10.7 to 25.4 cm (4 to 10 inches)
Size class 3 = 25.4 to 40.6 cm (10 to 16 inches)
Size class 4 = more than 40.6 cm (16 inches)

Figure 4.4. Comparison of the number of trees in each dbh category that grew into the next larger size category from 1992 to 2003 in Lincoln, NE.



Size class 1 = less than 10.2 cm (4 inches)
Size class 2 = 10.7 to 25.4 cm (4 to 10 inches)
Size class 3 = 25.4 to 40.6 cm (10 to 16 inches)
Size class 4 = more than 40.6 cm (16 inches)

Figure 4.5. Comparison of the number of trees in each health condition category in 1992 and 2003 in Lincoln, NE.



Condition 1 = zero or one signs of decline
Condition 2 = two signs of decline
Condition 3 = three or four signs of decline
Condition 4 = five or more signs of decline
Condition 5 = dead

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Chapter 5

Summary

Diversity

Total diversity of the urban forests studied here, as measured by Shannon index and species richness, basically remained the same over the years. The Shannon index values for the total and private trees changed very little. However, the public tree Shannon index value indicates that there was a significant increase in the Shannon index values. This increase is probably due to the efforts of the city trying to increase diversity in the public trees. Greater diversity must be maintained in order to insure urban forest vitality.

Species richness also did not change much over the years. In 1980 there were 97 species of trees, while in 2003/2005 there were 100 species. One very interesting fact was how similar the species richness was in the different tree categories (i.e. large deciduous, intermediate deciduous, small deciduous, large evergreen, intermediate evergreen and small evergreen) between 1980 and 2003/2005. Only when the individual tree categories, such as large deciduous versus large evergreen, compared within the years, do we find significant differences.

Overplanted Species

The most conservative percentage for being considered an overplanted species is 5% of the total urban forest. Of the species in this study that would be considered overplanted, many of them, 89% are native to North America. Organizations (Native Plant Society of America), State Departments of Natural Resources (North Carolina, Texas, Maryland, etc.) and State Cooperative Extension Services (Ohio, Hawaii, Florida, etc.) suggest planting native trees. The main reason given for the "go native" agenda is to help control the spread of invasive plants that may alter or impact the native environment in an adverse way. I recommend that these organizations should suggest planting proven native trees in the urban forest before using exotics. There is an assumption that native species are best because they have evolved in or acclimated to that area. The pool of proven native trees has been narrowed over the years, and there is a reliance on fewer native tree species which are now becoming overplanted. The selection of proven native trees should be broadened so that native species are not overplanted. Another consideration that needs to be explained is what exactly is a native species? To most, native means it grows naturally in North America or in the United States. Some would say it is native if it is found in the Midwest. But a more conservative definition for being a native tree would be one that grows in the vicinity or region of the city.

Tree Size and Condition

I have shown that when trees are larger, there is a negative relationship with the condition or tree health. Larger trees are generally in worst condition. However, larger trees have a better chance to survive storms. So, trees need to be maintained in a manner which promotes faster growth in order for the trees to get past the vulnerable small sized stage. By promoting fertilization, good tree structure by proper pruning and selecting good plant material for the specific sites, urban foresters can more quickly get the tree larger in order to for them able to resist storm damage.

Recommendations

It is recommended that the urban forest be maintained as an integral part of the infrastructure of all cities and treated as an ecosystem. A vigorous, healthy urban forest provides many ecological services that are necessary for urbanites to enjoy a standard of living and a sense of community that is better than what it would be if the trees were not there. As people become educated about these benefits of trees, public and private, more trees will be planted and the existing trees may be valued and better taken care of.

If this study was started today, several things should be done differently. First, ALL trees should be identified, leaving no trees identified as "unknown", as was the case in several instances in 1980. Second, classifying all trees to the precise species is important and just classifying to the genus (e.g. *Fraxinus* or *Pinus*) should not be allowed. These genera are too diverse, and species can be identified with a little work or with the help of other professionals. Finally, the tree sizes should not be measured on broad dbh size categories in order to calculate more precise averages. Each and every tree's dbh should be measured to the inch or centimeter. Additionally, it may be desirable to measure the height and/or possibly crown spread of each tree in order to calculate carbon sequestration and other ecosystem services that are provided by the trees.

Since this study is unique in tracking the trends and patterns in succession, and provides insight into the dynamics of the entire urban forest, this study should be continued in the future. It is one of the first, if not the first, long term studies on the entire urban forest. Several authors have studied street trees over the years (Kielbaso, 1989; Sun, 1991;

Goodwin, 1996; Lesser, 1996; Poracsky and Scott, 1999) but there is a lack of reports on the total urban forest (all trees, not just street trees). All-inclusive inventories and monitoring of the urban forest is necessary if the diverse urban landscape ecosystem is to be understood and these inventories can be used to encourage management techniques (Dwyer, 2002).

There are four other cities that were surveyed in 1980 and the data from these cities should be reported along with the current cities that are reported on here. This study should continue in order to capitalize on this unique long term study; all of these cities should be resurveyed every 12 to 15 years in order to monitor the dynamics of the urban forests. Once trends are established in each of the cities, then comprehensive management programs can be developed. It will also be very interesting to see what the effects have been on the urban forest structure because of the introduction of the emerald ash borer and the Asian longhorned beetle. None of these cities had been invaded by either insect as of 2005, but in 2010, only Lincoln, NE had not been plagued by the emerald ash borer. The Asian longhorned beetle is still not known from any of the six cities.

Since this study began, a new tool has been developed that can be used to help manage urban tree data. This tool is a computer program for ecosystem analysis from the USDA-Forest Service called i-Tree. It was developed to provide urban forestry analysis and tree benefit assessments. This tool is beginning to be used by many urban foresters, arborist and researchers. One such example that was published on-line in 2008 is the i-Tree

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Ecosystem Analysis: Milwaukee Urban Forest Effects and Values. I recommend that i-Tree be considered to aid in the analysis of the tree data if this study is continued. In this way we can calculate not only urban forest structure, but also urban ecosystem services.

Conclusion

Technically, only the public trees are managed. Private trees, which make up the largest segment of the urban forest, are in essence unmanaged. This unmanaged forest is controlled by individual property owners, which represents a "tyranny of small decisions". The property owners are making individual decisions for their lands, usually without any regard for what is happening in the rest of the neighborhood or city. These individual decisions are partially driving the increased diversity in species that is seen in the urban forest. This also includes the introductions of exotic or weedy species such as: Siberian elm (*Ulmus pumila*), buckthorn (*Rhmnus sp.*), Tree-of-heaven (*Ailanthus altissima*) and Amur maple (*Acer ginnala*). It falls on the urban forester/arborist or other public officials to educate the property owners as to what trees are appropriate and how to properly maintain them.

Many of the cities have a species richness that is weighted to one or two species (silver maple, *Acer saccharinum* L. and arborvitae, *Thuja occidentalis* L.). It is the suggestion here that more diversity of species should be the goal. Many of the species with only a few individuals may actually become proven species that grow and thrive in urban settings, making them good candidates for being planted more often (e.g. hardy rubber tree, *Eucommia ulmoides* Oliv.; saw-toothed oak, *Quercus acutissima* Carruth.; or

Japanese Zelkova, *Zelkova serrata* (Thunb.) Mak.), but for some reason have not yet become popular. By adding individuals of these, and other proven species, their presence can add diversity to the urban forest and can help to alleviate the threat and damage from devastating, invasive pests and diseases.

In general, the biggest, healthiest trees seem to have an advantage in surviving catastrophic events. This was the case in Lincoln, NE after the 1997 snowstorm, where larger, healthier trees fared better than smaller trees or those in worse health conditions. This particular snowstorm produced enough snow to push the tolerance of these big, healthy trees to their limits, but they still survived and continue to thrive.

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Appendix A

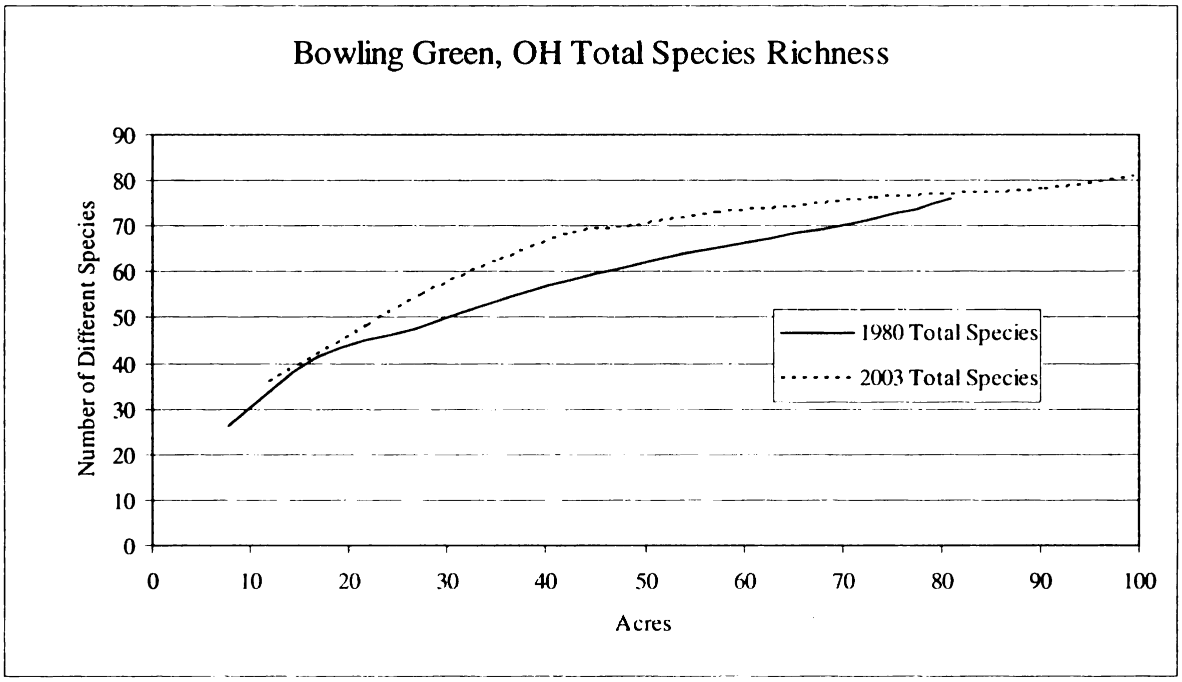
Bowling Green, Ohio

Table A-1. Selected data of the urban forest in Bowling Green, OH.

	1980 Total	1980 Public	1980 Private	1992 Total	1992 Public	1992 Private	2003 Total	2003 Public	2003 Private
Number of trees	2280	289	1991	2965	332	2633	2279	264	2015
Number of acres sampled	67.2			82.6			82.6		
Density (trees per acre)	36.85	4.18	32.64	37.52	3.94	33.64	28.92	3.21	25.70
Public to private tree ratio	6.89/1			7.39/1			7.63/1		
Diversity (Shannon index)	3.60			3.64			3.57		
Species richness per block age									
<10 yrs old	56	28	56	63	26	61	64	23	62
10 - 40 yrs old	57	18	56	64	26	63	62	19	61
>40 yrs old	51	14	50	63	18	62	58	17	58
Total *	75	35	74	82	42	80	82	37	80

* Totals are not the sum of the columns, they are the total number of different species in that column

Figure A-1. Species richness per acre in the urban forest of Bowling Green, OH, in 1980 and 2003.



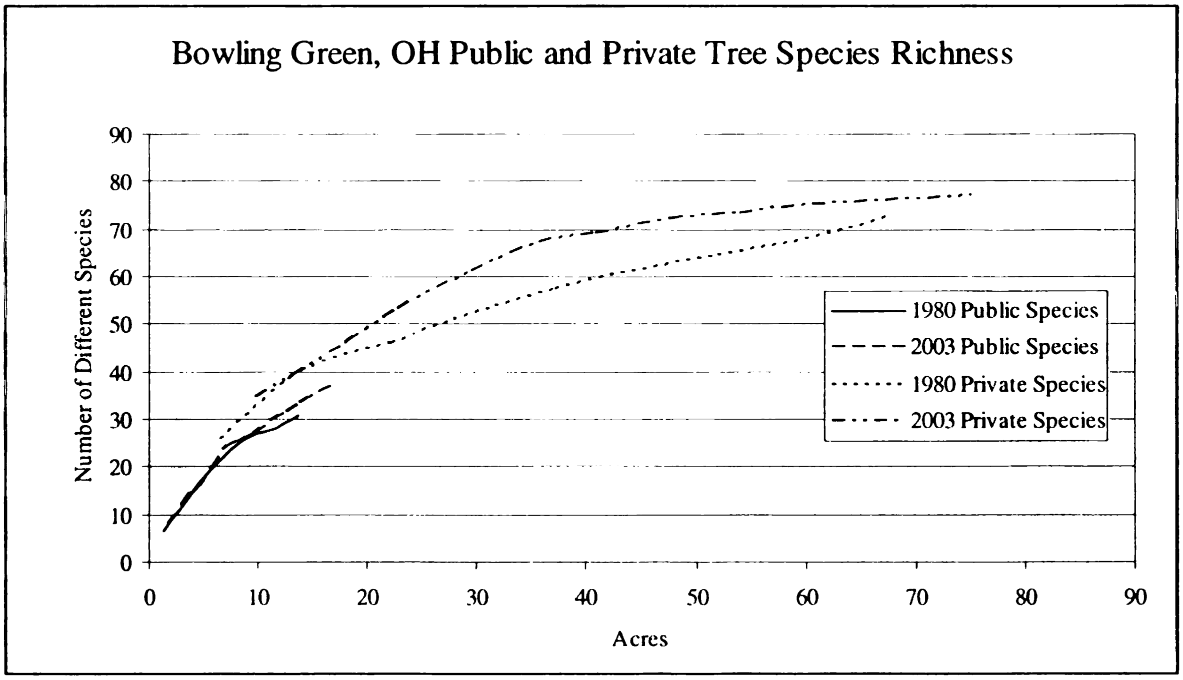
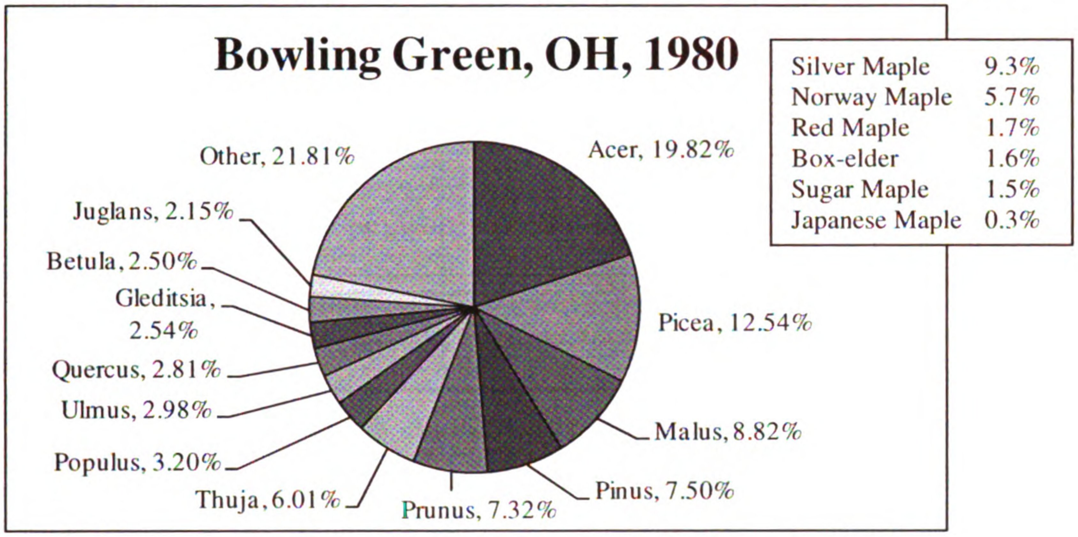


Figure A-2. Richness by genus in Bowling Green, OH in 1980, 1992 and 2003.



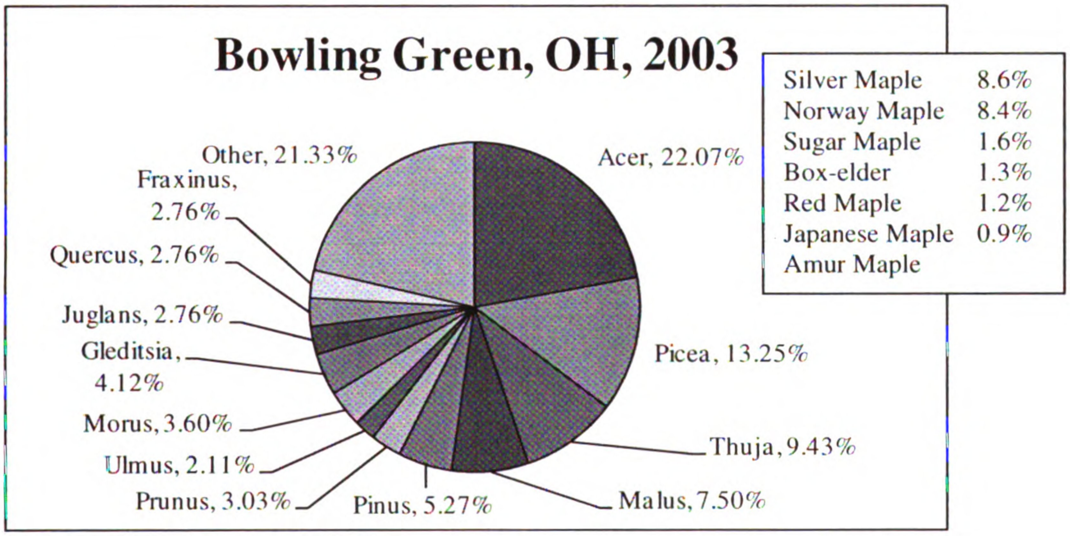


Table A-2. Ownership of all Trees, Bowling Green, OH: 1980 - 1992 - 2003.

Ownership	1980* Number of Trees	Percent	1993 Number of Trees	Percent	2003 Number of Trees	Percent
Private	1991	87.32	2633	88.80	2015	88.42
Public	289	12.68	332	11.20	264	11.58
Total	2280	100.00	2965	100.00	2279	100.00

*Does not include blocks J, K and L because they were not part of the study in 1980

Table A-3. Species (Public and Private) of trees, Bowling Green, OH: 1980.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	209	9.30	Magnolia	8	0.36
Blue Spruce	196	8.72	Hackberry	7	0.31
Crabapple	141	6.28	American Chestnut	6	0.27
Arborvitae	137	6.10	Apricot	6	0.27
Norway Maple	129	5.74	Japanese Maple	6	0.27
Norway Spruce	88	3.92	White Oak	6	0.27
White Pine	73	3.25	Aspen	5	0.22
Cherry	66	2.94	Juniper	5	0.22
Plum	66	2.94	Catalpa	4	0.18
Scotch Pine	63	2.80	Serviceberry	4	0.18
Apple	60	2.67	White Popular	4	0.18
Honeylocust	58	2.58	Dawn Redwood	3	0.13
Birch	57	2.54	Mugo Pine	3	0.13
American Elm	55	2.45	Unknown	3	0.13
Lombardy Popular	52	2.31	White Fir	3	0.13
Black Walnut	49	2.18	Almond	2	0.09
Mulberry	45	2.00	Bald Cypress	2	0.09
Pin Oak	42	1.87	Blue Beech	2	0.09
Redbud	41	1.82	Butternut	2	0.09
Red Maple	39	1.74	Fir	2	0.09
Pear	38	1.69	Holly	2	0.09
Box-elder	35	1.56	Horsechestnut	2	0.09
Mountain Ash	34	1.51	Tamarack	2	0.09
Sugar Maple	34	1.51	White Spruce	2	0.09
Sweetgum	34	1.51	Beech	1	0.04
Dogwood	33	1.47	Bur Oak	1	0.04
Austrian Pine	32	1.42	Golden-chain Tree	1	0.04
Ash	30	1.34	Hemlock	1	0.04
Peach	29	1.29	Hickory	1	0.04
Sycamore	28	1.25	Persimmon	1	0.04
Hawthorn	26	1.16	Sassafras	1	0.04
Russian Olive	22	0.98	Staghorn Sumac	1	0.04
Linden	20	0.89	Yellow-wood	1	0.04
Willow	19	0.85			
Tree-of-heaven	16	0.71			
Red Oak	15	0.67	Total	2247	100.00
Douglas Fir	13	0.58			
Siberian Elm	13	0.58			
Cottonwood	12	0.53			
Tulip Tree	11	0.49			
Black Locust	10	0.45			
Ginkgo	10	0.45			

Table A-4. Public Tree Species, Bowling Green, OH: 1980.

Species	Number of Trees	Percent
Crabapple	25	17.73
Norway Maple	25	17.73
Pear	13	9.22
Blue Spruce	12	8.51
Honeylocust	11	7.80
Red Maple	9	6.38
Pin Oak	7	4.96
Linden	6	4.26
American Elm	4	2.84
Sycamore	4	2.84
Scotch Pine	3	2.13
Birch	2	1.42
Cherry	2	1.42
Dogwood	2	1.42
Sugar Maple	2	1.42
White Pine	2	1.42
Ash	1	0.71
Austrian Pine	1	0.71
Hawthorn	1	0.71
Japanese Maple	1	0.71
Lombardy Popular	1	0.71
Norway Spruce	1	0.71
Plum	1	0.71
Red Oak	1	0.71
Redbud	1	0.71
Silver Maple	1	0.71
Sweetgum	1	0.71
White Oak	1	0.71
Total	141	100.00

Table A-5. Private Tree Species, Bowling Green, OH: 1980.

Species	Number of Trees	Percent
Blue Spruce	77	9.28
Silver Maple	69	8.31
Arborvitae	64	7.71
Crabapple	50	6.02
White Pine	41	4.94
Birch	40	4.82
Scotch Pine	39	4.70
Lombardy Popular	38	4.58
Plum	36	4.34
Norway Spruce	30	3.61
Norway Maple	29	3.49
Apple	24	2.89
Cherry	24	2.89
Mountain Ash	24	2.89
Honeylocust	21	2.53
Ash	18	2.17
Sweetgum	18	2.17
Austrian Pine	17	2.05
Russian Olive	16	1.93
Redbud	15	1.81
Peach	14	1.69
Pin Oak	14	1.69
Douglas Fir	13	1.57
Pear	11	1.33
Sycamore	11	1.33
Red Maple	10	1.20
Dogwood	9	1.08
Hawthorn	9	1.08
Willow	7	0.84
Magnolia	5	0.60
Red Oak	5	0.60
Sugar Maple	5	0.60
Tulip Tree	5	0.60
American Elm	4	0.48
Linden	4	0.48
Mugo Pine	3	0.36
Siberian Elm	3	0.36
Apricot	2	0.24
Bald Cypress	2	0.24
Black Locust	2	0.24
Black Walnut	2	0.24

Species	Number of Trees	Percent
Blue Beech	2	0.24
Fir	2	0.24
Japanese Maple	2	0.24
Mulberry	2	0.24
Unknown	2	0.24
White Oak	2	0.24
Box-elder	1	0.12
Cottonwood	1	0.12
Ginkgo	1	0.12
Hemlock	1	0.12
Horsechestnut	1	0.12
Juniper	1	0.12
White Fir	1	0.12
White Spruce	1	0.12
Yellow-wood	1	0.12
Total	830	100.00

Table A-6. Species (Public and Private) of trees, Bowling Green, OH: 1992.

Species	Number of Trees	Percent
Arborvitae	285	9.61
Blue Spruce	217	7.32
Crabapple	199	6.71
Silver Maple	192	6.48
Norway Maple	176	5.94
Mulberry	107	3.61
Honeylocust	93	3.14
Norway Spruce	88	2.97
Black Walnut	77	2.60
Cherry	77	2.60
White Pine	77	2.60
Apple	76	2.56
American Elm	64	2.16
Redbud	62	2.09
Ash	61	2.06
Red Maple	60	2.02
Box-elder	57	1.92
Plum	57	1.92
Tree-of-heaven	55	1.85
Austrian Pine	53	1.79
Hawthorn	49	1.65
Siberian Elm	49	1.65
Birch	47	1.59
Pear	46	1.55
Pin Oak	46	1.55
Dogwood	44	1.48
Sugar Maple	43	1.45
Willow	37	1.25
Sweetgum	36	1.21
Scotch Pine	30	1.01
Mountain Ash	26	0.88
Russian Olive	26	0.88
Lombardy Popular	24	0.81
Linden	23	0.78
Hemlock	20	0.67
Sycamore	20	0.67
Ginkgo	18	0.61
Mugo Pine	17	0.57
White Spruce	17	0.57
Magnolia	16	0.54
Aspen	14	0.47
Juniper	12	0.40
Red Oak	12	0.40
Autumn Olive	11	0.37
Japanese Maple	11	0.37
Peach	11	0.37
Douglas Fir	10	0.34
Serviceberry	10	0.34
Tulip Tree	9	0.30
Cottonwood	8	0.27
Hackberry	8	0.27
White Oak	8	0.27
Chinese Elm	7	0.24
Smoke-tree	5	0.17
Black Locust	4	0.13
Catalpa	4	0.13
Horsechestnut	4	0.13
Staghorn Sumac	4	0.13
Unknown	4	0.13
White Popular	4	0.13
Black Oak	3	0.10
Fraser Fir	3	0.10
Kentucky Coffee Tree	3	0.10
American Chestnut	2	0.07
Black Maple	2	0.07
Butternut	2	0.07
Chestnut Oak	2	0.07
Hickory	2	0.07
Sassafras	2	0.07
Slippery Elm	2	0.07
Tamarack	2	0.07
White Fir	2	0.07
Yellow-wood	2	0.07
Bald Cypress	1	0.03
Blue Beech	1	0.03
Dawn Redwood	1	0.03
Fir	1	0.03
Holly	1	0.03
Hop-Hornbeam	1	0.03
Japanese Zelkova	1	0.03
Red Pine	1	0.03
Yellow Buckeye	1	0.03
Total	2965	100.00

Table A-7. Public Tree Species, Bowling Green, OH: 1992.

Species	Number of Trees	Percent
Norway Maple	28	21.05
Crabapple	21	15.79
Pear	13	9.77
Blue Spruce	10	7.52
Honeylocust	10	7.52
Red Maple	10	7.52
Linden	6	4.51
Pin Oak	6	4.51
Sycamore	4	3.01
American Elm	3	2.26
Cherry	3	2.26
Birch	2	1.50
Cottonwood	2	1.50
Silver Maple	2	1.50
White Pine	2	1.50
Ash	1	0.75
Austrian Pine	1	0.75
Catalpa	1	0.75
Hawthorn	1	0.75
Japanese Maple	1	0.75
Mountain Ash	1	0.75
Peach	1	0.75
Red Oak	1	0.75
Redbud	1	0.75
Scotch Pine	1	0.75
White Oak	1	0.75
Total	133	100.00

Table A-8. Private Tree Species, Bowling Green, OH: 1992.

Species	Number of Trees	Percent
Arborvitae	138	13.62
Blue Spruce	99	9.77
Crabapple	71	7.01
Silver Maple	64	6.32
Apple	42	4.15
Plum	39	3.85
Norway Maple	37	3.65
White Pine	35	3.46
Austrian Pine	30	2.96
Birch	30	2.96
Honeylocust	29	2.86
Ash	28	2.76
Norway Spruce	28	2.76
Willow	28	2.76
Red Maple	27	2.67
Siberian Elm	19	1.88
Cherry	18	1.78
Scotch Pine	18	1.78
Pin Oak	17	1.68
Russian Olive	17	1.68
Mountain Ash	16	1.58
Pear	16	1.58
Sweetgum	16	1.58
Hawthorn	15	1.48
Mugo Pine	13	1.28
Redbud	12	1.18
Mulberry	11	1.09
Aspen	9	0.89
Linden	9	0.89
Lombardy Popular	9	0.89
Magnolia	9	0.89
White Spruce	9	0.89
Peach	8	0.79
Sycamore	8	0.79
Autumn Olive	7	0.69
Dogwood	7	0.69
Sugar Maple	7	0.69
Douglas Fir	6	0.59
Box-elder	3	0.30
Hemlock	3	0.30
Japanese Maple	3	0.30
Tulip Tree	3	0.30
White Oak	3	0.30
Black Locust	2	0.20
Black Maple	2	0.20
Black Oak	2	0.20
Black Walnut	2	0.20
Ginkgo	2	0.20
Juniper	2	0.20
Smoke-tree	2	0.20
White Popular	2	0.20
American Elm	1	0.10
Bald Cypress	1	0.10
Blue Beech	1	0.10
Cottonwood	1	0.10
Dawn Redwood	1	0.10
Fir	1	0.10
Horsechestnut	1	0.10
Tree-of-heaven	1	0.10
Unknown	1	0.10
Yellow-wood	1	0.10
Total	1013	100.00

Table A-9. Species (Public and Private) of trees, Bowling Green, OH: 2003.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Arborvitae	215	9.43	Juniper	9	0.39
Blue Spruce	196	8.60	Mountain Ash	9	0.39
Silver Maple	196	8.60	Taxus	9	0.39
Norway Maple	191	8.38	Cherry	8	0.35
Crabapple	135	5.92	Douglas Fir	8	0.35
Honeylocust	94	4.12	Peach	8	0.35
Mulberry	82	3.60	White Oak	8	0.35
Norway Spruce	80	3.51	Cottonwood	7	0.31
Ash	63	2.76	Willow	7	0.31
Black Walnut	63	2.76	Russian Olive	6	0.26
White Pine	58	2.54	Black Locust	5	0.22
Redbud	42	1.84	Horsechestnut	5	0.22
Pear	38	1.67	Smoke-tree	5	0.22
Apple	36	1.58	Aspen	4	0.18
Sugar Maple	36	1.58	Japanese Zelkova	4	0.18
Pin Oak	35	1.54	White Fir	4	0.18
Birch	34	1.49	Catalpa	3	0.13
Hawthorn	34	1.49	Kentucky Coffee Tree	3	0.13
Tree-of-heaven	33	1.45	Lombardy Popular	3	0.13
Austrian Pine	32	1.40	Sassafras	3	0.13
Box-elder	30	1.32	White Popular	3	0.13
Dogwood	29	1.27	Butternut	2	0.09
Plum	27	1.18	Golden-rain Tree	2	0.09
Red Maple	27	1.18	Holly	2	0.09
Sweetgum	27	1.18	Hop-Hornbeam	2	0.09
Siberian Elm	26	1.14	Tamarack	2	0.09
Cherry	25	1.10	Yellow-wood	2	0.09
Linden	22	0.97	American Chestnut	1	0.04
American Elm	21	0.92	Apricot	1	0.04
Hemlock	21	0.92	Amur Maple	1	0.04
Japanese Maple	21	0.92	Autumn Olive	1	0.04
Red Oak	19	0.83	Bald Cypress	1	0.04
Ginkgo	18	0.79	Balsam Fir	1	0.04
Magnolia	17	0.75	Beech	1	0.04
Scotch Pine	17	0.75	Black Maple	1	0.04
White Spruce	16	0.70	Blue Beech	1	0.04
Serviceberry	15	0.66	Chestnut Oak	1	0.04
Sycamore	15	0.66	Hickory	1	0.04
Hackberry	13	0.57	Noble Fir	1	0.04
Mugo Pine	13	0.57	Slippery Elm	1	0.04
Tulip Tree	11	0.48			
Alberta Spruce	10	0.44			
			Total	2279	100.00

Table A-10. Public Tree Species, Bowling Green, OH: 2003.

Species	Number of Trees	Percent
Norway Maple	29	27.88
Crabapple	14	13.46
Honeylocust	12	11.54
Pear	10	9.62
Red Maple	7	6.73
Linden	6	5.77
Pin Oak	5	4.81
Silver Maple	4	3.85
American Elm	2	1.92
Cottonwood	2	1.92
Ash	1	0.96
Blue Spruce	1	0.96
Catalpa	1	0.96
Cherry	1	0.96
Hawthorn	1	0.96
Hop-Hornbeam	1	0.96
Mountain Ash	1	0.96
Mugo Pine	1	0.96
Plum	1	0.96
Red Oak	1	0.96
Sugar Maple	1	0.96
White Oak	1	0.96
White Pine	1	0.96
Total	104	100.00

Table A-11. Private Tree Species, Bowling Green, OH: 2003.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Arborvitae	202	10.73	Taxus	9	0.48
Blue Spruce	194	10.31	Ginkgo	8	0.43
Silver Maple	178	9.46	Mountain Ash	8	0.43
Norway Maple	146	7.76	Peach	8	0.43
Crabapple	97	5.15	Douglas Fir	7	0.37
Mulberry	82	4.36	Juniper	7	0.37
Norway Spruce	79	4.20	White Oak	7	0.37
Honeylocust	72	3.83	Willow	7	0.37
Black Walnut	60	3.19	Russian Olive	6	0.32
White Pine	57	3.03	Black Locust	5	0.27
Ash	49	2.60	Cottonwood	5	0.27
Redbud	41	2.18	Horsechestnut	5	0.27
Apple	36	1.91	Smoke-tree	5	0.27
Birch	33	1.75	Aspen	4	0.21
Tree-of-heaven	33	1.75	White Fir	4	0.21
Austrian Pine	32	1.70	Kentucky Coffee Tree	3	0.16
Box-elder	30	1.59	Lombardy Popular	3	0.16
Pin Oak	30	1.59	White Popular	3	0.16
Dogwood	29	1.54	Butternut	2	0.11
Pear	28	1.49	Catalpa	2	0.11
Sugar Maple	28	1.49	Golden-rain Tree	2	0.11
Hawthorn	27	1.43	Holly	2	0.11
Plum	26	1.38	Japanese Zelkova	2	0.11
Cherry	25	1.33	Sassafras	2	0.11
Siberian Elm	25	1.33	Tamarack	2	0.11
Hemlock	21	1.12	Yellow-wood	2	0.11
Japanese Maple	21	1.12	American Chestnut	1	0.05
Red Oak	18	0.96	Apricot	1	0.05
Magnolia	17	0.90	Amur Maple	1	0.05
Red Maple	17	0.90	Autumn Olive	1	0.05
Scotch Pine	17	0.90	Bald Cypress	1	0.05
American Elm	16	0.85	Balsam Fir	1	0.05
Sweetgum	16	0.85	Beech	1	0.05
White Spruce	16	0.85	Black Maple	1	0.05
Sycamore	15	0.80	Blue Beech	1	0.05
Hackberry	13	0.69	Chestnut Oak	1	0.05
Serviceberry	13	0.69	Hickory	1	0.05
Mugo Pine	12	0.64	Noble Fir	1	0.05
Linden	11	0.58	Slippery Elm	1	0.05
Alberta Spruce	10	0.53			
Tulip Tree	10	0.53			
			Total	1882	100.00

Appendix B

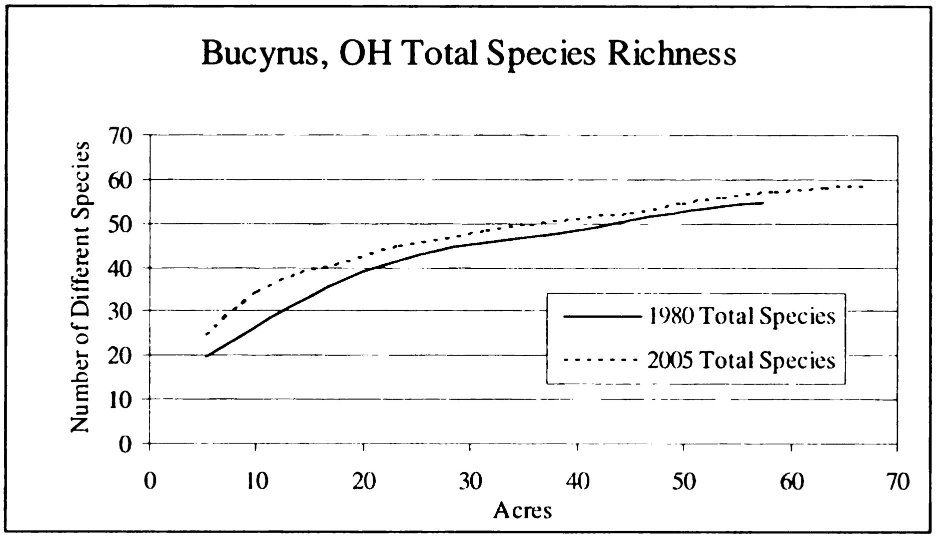
Bucyrus, Ohio

Table B-1. Selected data of the urban forest in Bucyrus, OH.

	1980 Total	1980 Public	1980 Private	2005 Total	2005 Public	2005 Private
Number of trees	876	148	728	1111	116	995
Number of acres sampled	45.71			53.78		
Density of trees (per acre)	19.16	3.24	15.93	20.66	2.16	18.50
Public to private tree ratio	4.92/1			8.58/1		
Diversity (Shannon index)	3.24			3.39		
Species richness per block age						
<10 yrs old	34	6	34	46	2	45
10 - 40 yrs old	45	9	44	45	6	44
>40 yrs old	41	13	40	48	14	45
Total *	54	19	54	58	16	58

* Totals are not the sum of the columns, they are the total number of different species in that column

Figure B-1. Species richness per acre in the urban forest of Bucyrus, OH, in 1980 and 2005.



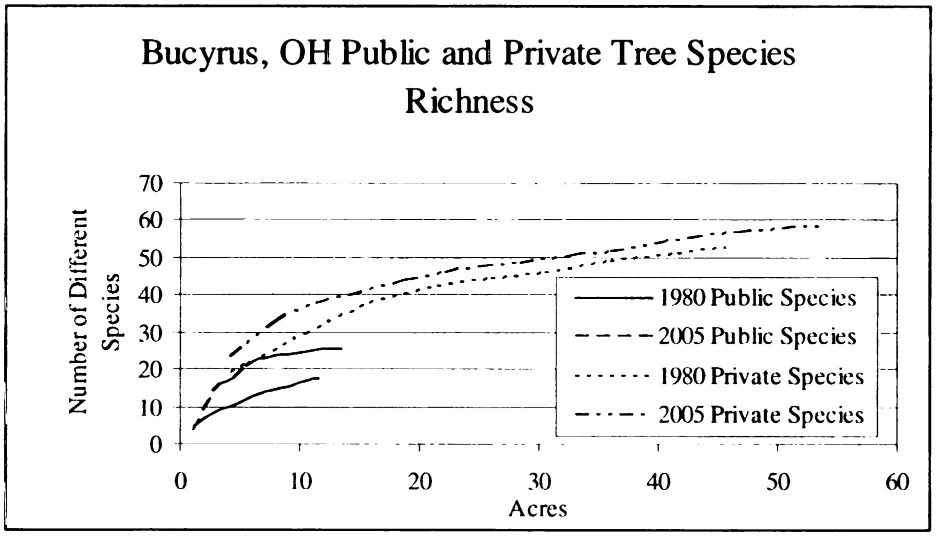


Figure B-2. Richness by genus in Bucyrus OH in 1980 and 2005.

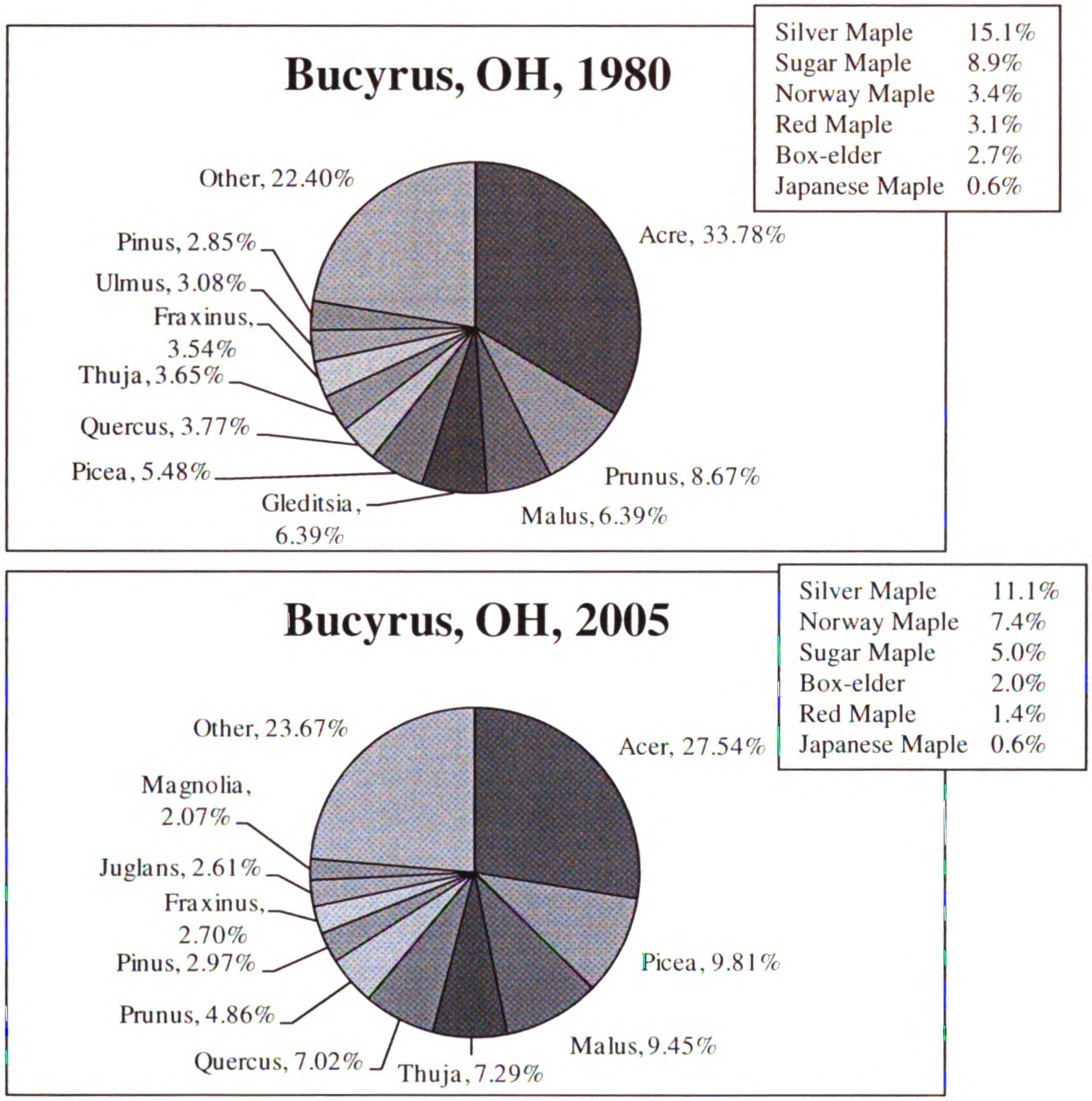


Table B-2. Ownership of all Trees, Bucyrus, OH: 1980 – 2005.

Ownership	1980* Number of Trees	Percent	2005** Number of Trees	Percent
Private	728	83.11	995	89.56
Public	148	16.89	116	10.44
Total	876	100.00	1111	100.00

*9 City Blocks

**15 City Blocks

Table B-3. Species (Public and Private) of trees, Bucyrus, OH: 1980.

Species	Number of Trees	Percent
Silver Maple	132	15.07
Sugar Maple	78	8.90
Arborvitae	56	6.39
Crabapple	48	5.48
Norway Spruce	42	4.79
Honeylocust	32	3.65
Blue Spruce	31	3.54
Norway Maple	30	3.42
Plum	27	3.08
Red Maple	27	3.08
Pin Oak	25	2.85
Apple	24	2.74
Box-elder	24	2.74
Elm	24	2.74
Ash	22	2.51
Cherry	22	2.51
Redbud	17	1.94
Walnut	17	1.94
Dogwood	16	1.83
Pear	16	1.83
Birch	15	1.71
Russian Olive	14	1.60
Mountain Ash	13	1.48
Peach	10	1.14
White Pine	10	1.14
Austrian Pine	9	1.03
Fir	8	0.91
Juniper	8	0.91
Black Locust	7	0.80
Red Oak	6	0.68
Japanese Maple	5	0.57
Scotch Pine	5	0.57
Sumac	5	0.57
Lombardy Popular	4	0.46
Magnolia	4	0.46
Willow	4	0.46
Catalpa	3	0.34
Cottonwood	3	0.34
Hickory	3	0.34
Horsechestnut	3	0.34
Linden	3	0.34
Mulberry	3	0.34
Serviceberry	3	0.34
Tree-of-heaven	3	0.34
Buckeye	2	0.23
Hawthorn	2	0.23
Hemlock	2	0.23
Sycamore	2	0.23
Tulip Tree	2	0.23
Hackberry	1	0.11
Sassafras	1	0.11
Shingle Oak	1	0.11
Sweetgum	1	0.11
White Oak	1	0.11
Total	876	100.00

Table B-4. Public Tree Species, Bucyrus, OH: 1980.

Species	Number of Trees	Percent
Silver Maple	60	40.54
Sugar Maple	44	29.73
Norway Maple	13	8.78
Honeylocust	6	4.05
Red Maple	4	2.70
Ash	3	2.03
Crabapple	3	2.03
Blue Spruce	2	1.35
Mountain Ash	2	1.35
Norway Spruce	2	1.35
Austrian Pine	1	0.68
Cherry	1	0.68
Elm	1	0.68
Hickory	1	0.68
Pear	1	0.68
Pin Oak	1	0.68
Russian Olive	1	0.68
Scotch Pine	1	0.68
Tulip Tree	1	0.68
Total	148	100.00

Table B-5. Private Tree Species, Bucyrus, OH: 1980.

Species	Number of Trees	Percent
Silver Maple	72	9.89
Arborvitae	56	7.69
Crabapple	45	6.18
Norway Spruce	40	5.49
Sugar Maple	34	4.67
Blue Spruce	29	3.98
Plum	27	3.71
Honeylocust	26	3.57
Apple	24	3.30
Box-elder	24	3.30
Pin Oak	24	3.30
Elm	23	3.16
Red Maple	23	3.16
Cherry	21	2.88
Ash	19	2.61
Norway Maple	17	2.34
Redbud	17	2.34
Walnut	17	2.34
Dogwood	16	2.20
Birch	15	2.06
Pear	15	2.06
Russian Olive	13	1.79
Mountain Ash	11	1.51
Peach	10	1.37
White Pine	10	1.37
Austrian Pine	8	1.10
Fir	8	1.10
Juniper	8	1.10
Black Locust	7	0.96
Red Oak	6	0.82
Japanese Maple	5	0.69
Sumac	5	0.69
Lombardy Popular	4	0.55
Magnolia	4	0.55
Scotch Pine	4	0.55
Willow	4	0.55
Catalpa	3	0.41
Cottonwood	3	0.41
Horsechestnut	3	0.41
Linden	3	0.41
Mulberry	3	0.41
Serviceberry	3	0.41
Tree-of-heaven	3	0.41
Buckeye	2	0.27
Hawthorn	2	0.27
Hemlock	2	0.27
Hickory	2	0.27
Sycamore	2	0.27
Hackberry	1	0.14
Sassafras	1	0.14
Shingle Oak	1	0.14
Sweetgum	1	0.14
Tulip Tree	1	0.14
White Oak	1	0.14
Total	728	100.00

Table B-6. Species (Public and Private) of trees, Bucyrus, OH: 2005.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	123	11.07	Ailanthus	4	0.36
Norway Maple	82	7.38	Mugo Pine	4	0.36
Arborvitae	81	7.29	Willow	4	0.36
Blue Spruce	64	5.76	Beech	3	0.27
Crabapple	64	5.76	Ginkgo	3	0.27
Sugar Maple	56	5.04	Hawthorn	3	0.27
Norway Spruce	43	3.87	Tulip Tree	3	0.27
Apple	41	3.69	Buckeye	2	0.18
Pin Oak	33	2.97	Bur Oak	2	0.18
Cherry	32	2.88	Smoke-tree	2	0.18
Ash	30	2.70	White Spruce	2	0.18
Walnut	29	2.61	Japanese Zelcova	1	0.09
Red Oak	28	2.52	Peach	1	0.09
Magnolia	23	2.07	Sassafras	1	0.09
Box-elder	22	1.98	Swamp White Oak	1	0.09
Pear	22	1.98	White Fir	1	0.09
Redbud	22	1.98			
Plum	21	1.89			
Mulberry	18	1.62	Total	1111	100.00
Honeylocust	16	1.44			
Juniper	16	1.44			
Red Maple	16	1.44			
Dogwood	15	1.35			
Hemlock	15	1.35			
Hickory	15	1.35			
Birch	14	1.26			
White Oak	14	1.26			
White Pine	13	1.17			
American Elm	12	1.08			
Austrian Pine	9	0.81			
Cottonwood	9	0.81			
Linden	8	0.72			
Mountain Ash	8	0.72			
Siberian Elm	8	0.72			
Catalpa	7	0.63			
Douglas Fir	7	0.63			
Hackberry	7	0.63			
Japanese Maple	7	0.63			
Scotch Pine	7	0.63			
Serviceberry	7	0.63			
Ironwood	5	0.45			
Sweetgum	5	0.45			

Table B-7. Public Tree Species, Bucyrus, OH: 2005.

Species	Number of Trees	Percent
Norway Maple	29	25.00
Red Oak	1	0.86
Silver Maple	27	23.28
Sugar Maple	29	25.00
Linden	3	2.59
Red Maple	1	0.86
Blue Spruce	2	1.72
Plum	4	3.45
Dogwood	2	1.72
Mountain Ash	2	1.72
Crabapple	3	2.59
Pear	4	3.45
Pin Oak	6	5.17
Ginkgo	1	0.86
Honeylocust	1	0.86
Sweetgum	1	0.86
Total	116	100.00

Table B-8. Private Tree Species, Bucyrus, OH: 2005.

Species	Number of Trees	Percent
Silver Maple	96	9.65
Arborvitae	81	8.14
Blue Spruce	62	6.23
Crabapple	61	6.13
Norway Maple	53	5.33
Norway Spruce	43	4.32
Apple	41	4.12
Cherry	32	3.22
Ash	30	3.02
Walnut	29	2.91
Pin Oak	27	2.71
Red Oak	27	2.71
Sugar Maple	27	2.71
Magnolia	23	2.31
Box-elder	22	2.21
Redbud	22	2.21
Mulberry	18	1.81
Pear	18	1.81
Plum	17	1.71
Juniper	16	1.61
Hemlock	15	1.51
Hickory	15	1.51
Honeylocust	15	1.51
Red Maple	15	1.51
Birch	14	1.41
White Oak	14	1.41
Dogwood	13	1.31
White Pine	13	1.31
American Elm	12	1.21
Austrian Pine	9	0.90
Cottonwood	9	0.90
Siberian Elm	8	0.80
Catalpa	7	0.70
Douglas Fir	7	0.70
Hackberry	7	0.70
Japanese Maple	7	0.70
Scotch Pine	7	0.70
Serviceberry	7	0.70
Mountain Ash	6	0.60
Ironwood	5	0.50
Linden	5	0.50
Ailanthus	4	0.40
Mugo Pine	4	0.40
Sweetgum	4	0.40
Willow	4	0.40
Beech	3	0.30
Hawthorn	3	0.30
Tulip Tree	3	0.30
Buckeye	2	0.20
Bur Oak	2	0.20
Ginkgo	2	0.20
Smoke-tree	2	0.20
White Spruce	2	0.20
Japanese Zelcova	1	0.10
Peach	1	0.10
Sassafras	1	0.10
Swamp White Oak	1	0.10
White Fir	1	0.10
Total	995	100.00

Appendix C

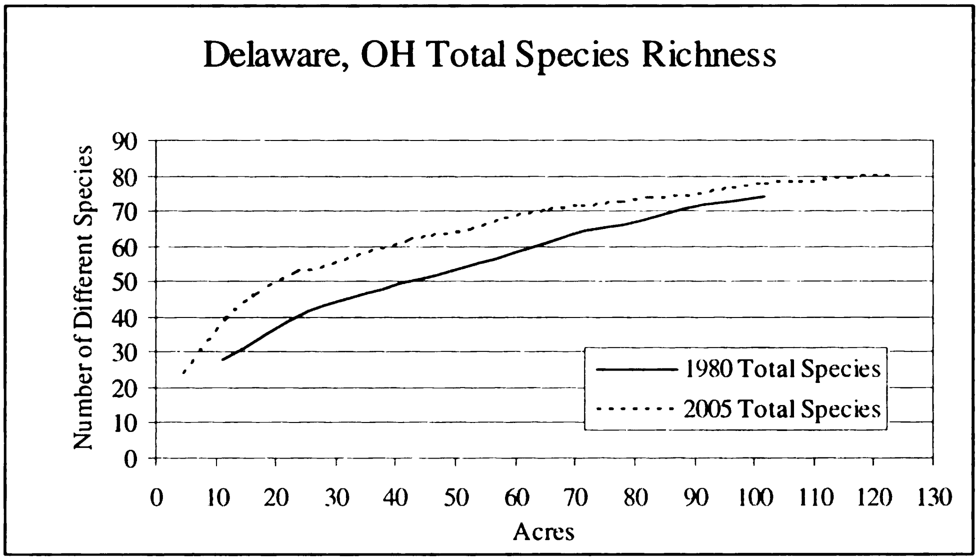
Delaware, Ohio

Table C-1. Selected data of the urban forest in Delaware, OH.

	1980 Total	1980 Public	1980 Private	2005 Total	2005 Public	2005 Private
Number of trees	2486	160	2326	3515	440	3075
Number of acres sampled	81.37			97.97		
Density of trees (per acre)	30.55	1.97	28.59	35.88	4.49	31.39
Public to private tree ratio	14.54/1			6.98/1		
Diversity (Shannon index)	3.22			3.30		
Species richness						
<10 years old in 2005				32	11	26
<10 yrs old	48	7		52	11	50
10 - 40 yrs old	47	9		57	12	56
>40 yrs old	54	15		68	29	62
Total *	66	22		80	37	75

* Totals are not the sum of the columns, they are the total number of different species in that column

Figure C-1. Species richness per acre in the urban forest of Delaware, OH, in 1980 and 2005.



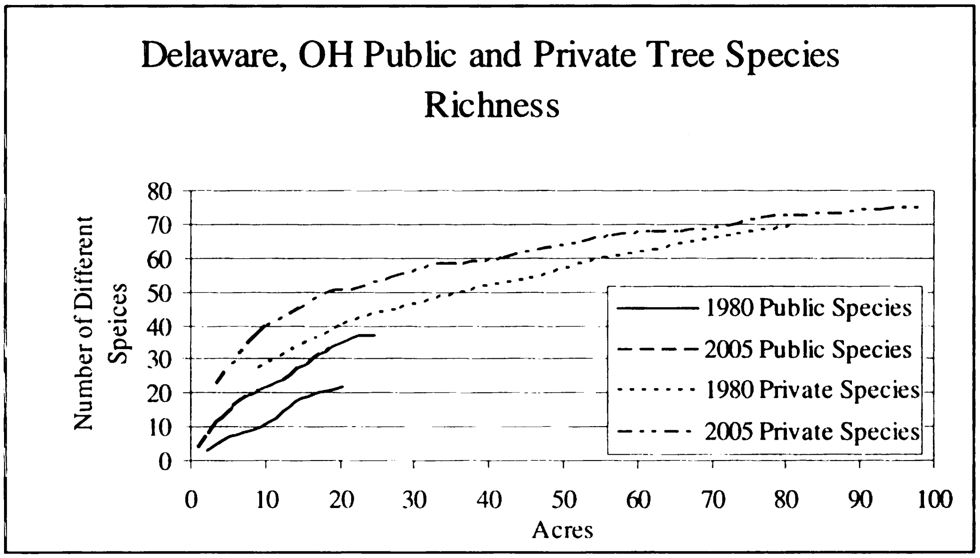
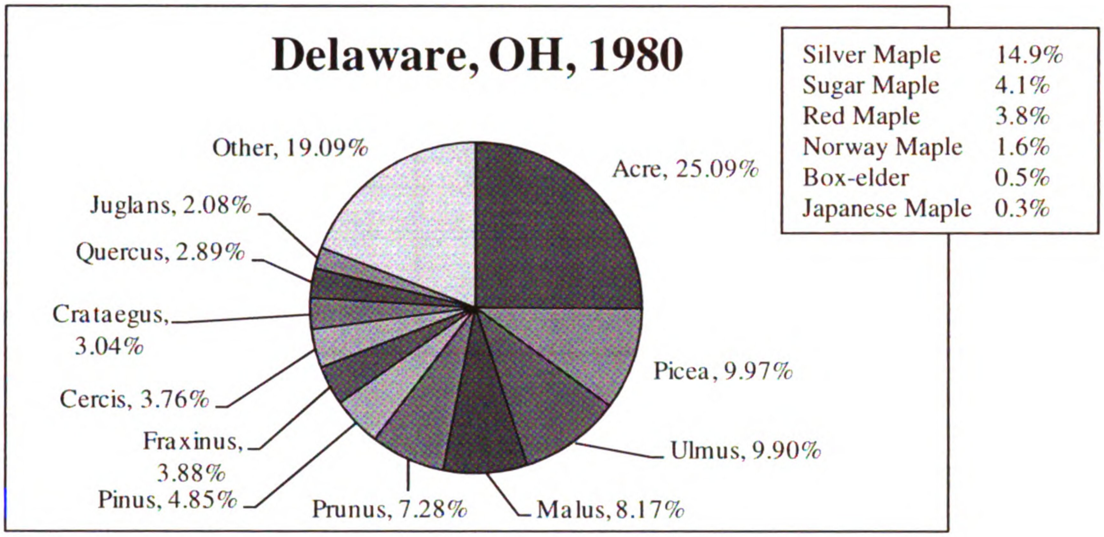


Figure C-2. Richness by genus in Delaware, OH in 1980 and 2005.



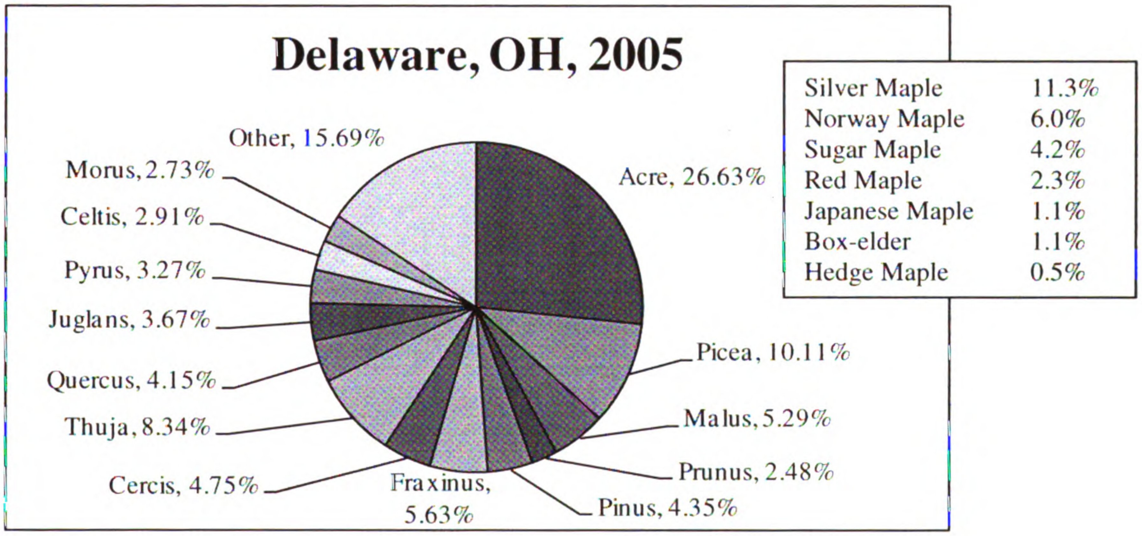


Table C-2. Ownership of all Trees, Delaware, OH: 1980 – 2005.

Ownership	1980* Number of Trees	Percent	2005** Number of Trees	Percent
Private	2326	93.56	3075	87.48
Public	160	6.44	440	12.52
Total	2486	100.00	3515	100.00

*9 City Blocks
**20 City Blocks

Table C-3. Species (Public and Private) of trees, Delaware, OH: 1980.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	371	14.92	Tree-of-heaven	10	0.40
Elm	235	9.45	Linden	8	0.32
Blue Spruce	153	6.15	Japanese Maple	7	0.28
Crabapple	123	4.95	Buckeye	5	0.20
Cherry	103	4.14	Austrian Pine	4	0.16
Sugar Maple	102	4.10	Chestnut	4	0.16
Ash	97	3.90	Fir	4	0.16
Red Maple	94	3.78	Golden-rain Tree	3	0.12
Redbud	94	3.78	Horsechestnut	3	0.12
Norway Spruce	93	3.74	Persimmon	3	0.12
Apple	81	3.26	White Spruce	3	0.12
Hawthorn	76	3.06	Beech	2	0.08
Scotch Pine	60	2.41	Bur Oak	2	0.08
White Pine	57	2.29	Holly	2	0.08
Walnut	52	2.09	Hop-hornbeam	2	0.08
Dogwood	49	1.97	Hornbeam	2	0.08
Plum	45	1.81	Paw Paw	2	0.08
Mulberry	42	1.69	Shingle Oak	2	0.08
Norway Maple	40	1.61	Bald Cypress	1	0.04
Sweetgum	40	1.61	Black Locust	1	0.04
Arborvitae	38	1.53	Ginkgo	1	0.04
Peach	34	1.37	Tamarack	1	0.04
Pin Oak	25	1.01	White Popular	1	0.04
Birch	24	0.97	Yellow-wood	1	0.04
White Oak	23	0.93			
Hemlock	21	0.84			
Juniper	21	0.84	Total	2486	100.00
Lombardy Popular	21	0.84			
Hickory	20	0.80			
Red Oak	20	0.80			
Cottonwood	19	0.76			
Hackberry	17	0.68			
Honeylocust	16	0.64			
Mountain Ash	14	0.56			
Box-elder	13	0.52			
Magnolia	13	0.52			
Pear	12	0.48			
Russian Olive	12	0.48			
Tulip Tree	11	0.44			
Willow	11	0.44			
Catalpa	10	0.40			
Sycamore	10	0.40			

Table C-4. Public Tree Species, Delaware, OH: 1980.

Species	Number of Trees	Percent
Silver Maple	38	23.75
Crabapple	35	21.88
Red Maple	18	11.25
Sugar Maple	11	6.88
Ash	9	5.63
Peach	7	4.38
Sweetgum	7	4.38
Plum	6	3.75
Redbud	6	3.75
Norway Maple	4	2.50
Cherry	3	1.88
Linden	3	1.88
Red Oak	2	1.25
Russian Olive	2	1.25
White Oak	2	1.25
Box-elder	1	0.63
Catalpa	1	0.63
Cottonwood	1	0.63
Dogwood	1	0.63
Elm	1	0.63
Mountain Ash	1	0.63
Walnut	1	0.63
Total	160	100.00

Table C-5. Private Tree Species, Delaware, OH: 1980.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	333	14.32	Catalpa	9	0.39
Elm	234	10.06	Japanese Maple	7	0.30
Blue Spruce	153	6.58	Buckeye	5	0.21
Cherry	100	4.30	Linden	5	0.21
Norway Spruce	93	4.00	Austrian Pine	4	0.17
Sugar Maple	91	3.91	Chestnut	4	0.17
Ash	88	3.78	Fir	4	0.17
Crabapple	88	3.78	Golden-rain Tree	3	0.13
Redbud	88	3.78	Horsechestnut	3	0.13
Apple	81	3.48	Persimmon	3	0.13
Hawthorn	76	3.27	White Spruce	3	0.13
Red Maple	76	3.27	Beech	2	0.09
Scotch Pine	60	2.58	Bur Oak	2	0.09
White Pine	57	2.45	Holly	2	0.09
Walnut	51	2.19	Hop-hornbeam	2	0.09
Dogwood	48	2.06	Hornbeam	2	0.09
Mulberry	42	1.81	Paw Paw	2	0.09
Plum	39	1.68	Shingle Oak	2	0.09
Arborvitae	38	1.63	Bald Cypress	1	0.04
Norway Maple	36	1.55	Black Locust	1	0.04
Sweetgum	33	1.42	Ginkgo	1	0.04
Peach	27	1.16	Tamarack	1	0.04
Pin Oak	25	1.07	White Popular	1	0.04
Birch	24	1.03	Yellow-wood	1	0.04
Hemlock	21	0.90			
Juniper	21	0.90			
Lombardy Popular	21	0.90	Total	2326	100.00
White Oak	21	0.90			
Hickory	20	0.86			
Cottonwood	18	0.77			
Red Oak	18	0.77			
Hackberry	17	0.73			
Honeylocust	16	0.69			
Magnolia	13	0.56			
Mountain Ash	13	0.56			
Box-elder	12	0.52			
Pear	12	0.52			
Tulip Tree	11	0.47			
Willow	11	0.47			
Russian Olive	10	0.43			
Sycamore	10	0.43			
Tree-of-heaven	10	0.43			

Table C-6. Species (Public and Private) of trees, Delaware, OH: 2005.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	391	11.12	Austrian Pine	12	0.34
Arborvitae	293	8.34	Smoke-tree	12	0.34
Norway Maple	210	5.97	Japanese Lilac Tree	11	0.31
Ash	198	5.63	Cottonwood	10	0.28
Blue Spruce	169	4.81	Green Mountain Maple	10	0.28
Redbud	167	4.75	Hawthorn	10	0.28
Sugar Maple	138	3.93	Siberian Elm	10	0.28
White Pine	133	3.78	Beech	9	0.26
Crabapple	130	3.70	Bur Oak	9	0.26
Walnut	129	3.67	Ginkgo	8	0.23
Pear	115	3.27	White Spruce	8	0.23
Norway Spruce	112	3.19	Willow	8	0.23
Hackberry	102	2.90	Scotch Pine	7	0.20
Mulberry	96	2.73	Shingle Oak	7	0.20
Red Maple	82	2.33	Celebration Maple	6	0.17
Dogwood	70	1.99	Peach	5	0.14
Cherry	57	1.62	Buckeye	4	0.11
Apple	56	1.59	Black Gum	3	0.09
Catalpa	54	1.54	Hop-hornbeam	3	0.09
Juniper	52	1.48	Horsechestnut	3	0.09
Pin Oak	52	1.48	Black Locust	2	0.06
Magnolia	47	1.34	Butternut	2	0.06
Hemlock	44	1.25	Douglas Fir	2	0.06
Japanese Maple	40	1.14	Katsura	2	0.06
Box-elder	39	1.11	Russian Olive	2	0.06
Sweetgum	39	1.11	Arum Maple	1	0.03
Birch	29	0.83	Autumn Olive	1	0.03
Tree-of-heaven	29	0.83	Bald Cypress	1	0.03
Red Oak	28	0.80	Black Spruce	1	0.03
Plum	25	0.71	Blue Beech	1	0.03
Hardy Rubber Tree	24	0.68	Dawn Redwood	1	0.03
Linden	21	0.60	English Holly	1	0.03
White Oak	21	0.60	Golden-rain Tree	1	0.03
Hedge Maple	19	0.54	Japanese Zelcova	1	0.03
Serviceberry	19	0.54	Mountain Ash	1	0.03
Honeylocust	18	0.51	Mugo Pine	1	0.03
American Elm	17	0.48	Sassafras	1	0.03
Saw-toothed Oak	16	0.46	Tamarack	1	0.03
Tulip Tree	16	0.46			
Hickory	14	0.40			
Swamp White Oak	13	0.37	Total	3515	100.00
Sycamore	13	0.37			

Table C-7. Public Tree Species, Delaware, OH: 2005.

Species	Number of Trees	Percent
Ash	74	16.82
Silver Maple	56	12.73
Sugar Maple	51	11.59
Norway Maple	39	8.86
Pear	32	7.27
Hardy Rubber Tree	24	5.45
Red Maple	20	4.55
Hedge Maple	18	4.09
Saw-toothed Oak	16	3.64
Crabapple	13	2.95
Linden	12	2.73
Green Mountain Maple	10	2.27
Japanese Lilac Tree	10	2.27
Sweetgum	9	2.05
Serviceberry	8	1.82
Celebration Maple	6	1.36
Red Oak	5	1.14
Ginkgo	4	0.91
Tulip Tree	4	0.91
Catalpa	3	0.68
Pin Oak	3	0.68
Redbud	3	0.68
Walnut	3	0.68
Black Gum	2	0.45
Mulberry	2	0.45
Siberian Elm	2	0.45
Apple	1	0.23
Arborvitae	1	0.23
Black Locust	1	0.23
Cherry	1	0.23
Dawn Redwood	1	0.23
Honeylocust	1	0.23
Horsechestnut	1	0.23
Juniper	1	0.23
Katsura	1	0.23
Shingle Oak	1	0.23
Smoke-tree	1	0.23
Total	440	100.00

Table C-8. Private Tree Species, Delaware, OH: 2005.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Silver Maple	335	10.89	Beech	9	0.29
Arborvitae	292	9.50	Bur Oak	9	0.29
Norway Maple	171	5.56	Linden	9	0.29
Blue Spruce	169	5.50	Siberian Elm	8	0.26
Redbud	164	5.33	White Spruce	8	0.26
White Pine	133	4.33	Willow	8	0.26
Walnut	126	4.10	Scotch Pine	7	0.23
Ash	124	4.03	Shingle Oak	6	0.20
Crabapple	117	3.80	Peach	5	0.16
Norway Spruce	112	3.64	Buckeye	4	0.13
Hackberry	102	3.32	Ginkgo	4	0.13
Mulberry	94	3.06	Hop-hornbeam	3	0.10
Sugar Maple	87	2.83	Butternut	2	0.07
Pear	83	2.70	Douglas Fir	2	0.07
Dogwood	70	2.28	Horsechestnut	2	0.07
Red Maple	62	2.02	Russian Olive	2	0.07
Cherry	56	1.82	Arum Maple	1	0.03
Apple	55	1.79	Autumn Olive	1	0.03
Catalpa	51	1.66	Bald Cypress	1	0.03
Juniper	51	1.66	Black Gum	1	0.03
Pin Oak	49	1.59	Black Locust	1	0.03
Magnolia	47	1.53	Black Spruce	1	0.03
Hemlock	44	1.43	Blue Beech	1	0.03
Japanese Maple	40	1.30	English Holly	1	0.03
Box-elder	39	1.27	Golden-rain Tree	1	0.03
Sweetgum	30	0.98	Hedge Maple	1	0.03
Birch	29	0.94	Japanese Lilac Tree	1	0.03
Tree-of-heaven	29	0.94	Japanese Zelcova	1	0.03
Plum	25	0.81	Katsura	1	0.03
Red Oak	23	0.75	Mountain Ash	1	0.03
White Oak	21	0.68	Mugo Pine	1	0.03
American Elm	17	0.55	Sassafras	1	0.03
Honeylocust	17	0.55	Tamarack	1	0.03
Hickory	14	0.46			
Swamp White Oak	13	0.42			
Sycamore	13	0.42	Total	3075	100.00
Austrian Pine	12	0.39			
Tulip Tree	12	0.39			
Serviceberry	11	0.36			
Smoke-tree	11	0.36			
Cottonwood	10	0.33			
Hawthorn	10	0.33			

Appendix D

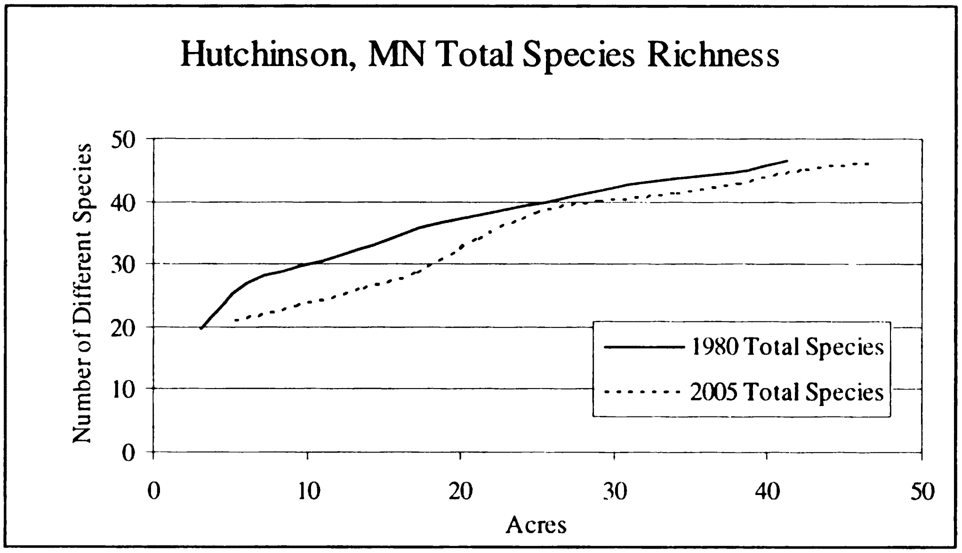
Hutchinson, Minnesota

Table D-1. Selected data of the urban forest in Hutchinson, MN.

	1980 Total	1980 Public	1980 Private	2003 Total	2003 Public	2003 Private
Number of trees	704	154	550	654	161	493
Number of acres sampled	32.73			32.73		
Density (trees per acre)	36.16	8.81	27.45	32.52	9.02	23.50
Public to private tree ratio	3.57/1			3.06/1		
Diversity (Shannon index)	2.96			2.96		
Species richness						
<10 yrs old	36	9	36	36	8	35
10 - 40 yrs old	23	6	23	23	6	21
>40 yrs old	22	8	21	27	13	23
Total *	43	15	43	47	15	44

* Totals are not the sum of the columns, they are the total number of different species in that column

Figure D-1. Species richness per acre in the urban forest of Hutchinson, MN, in 1980 and 2003.



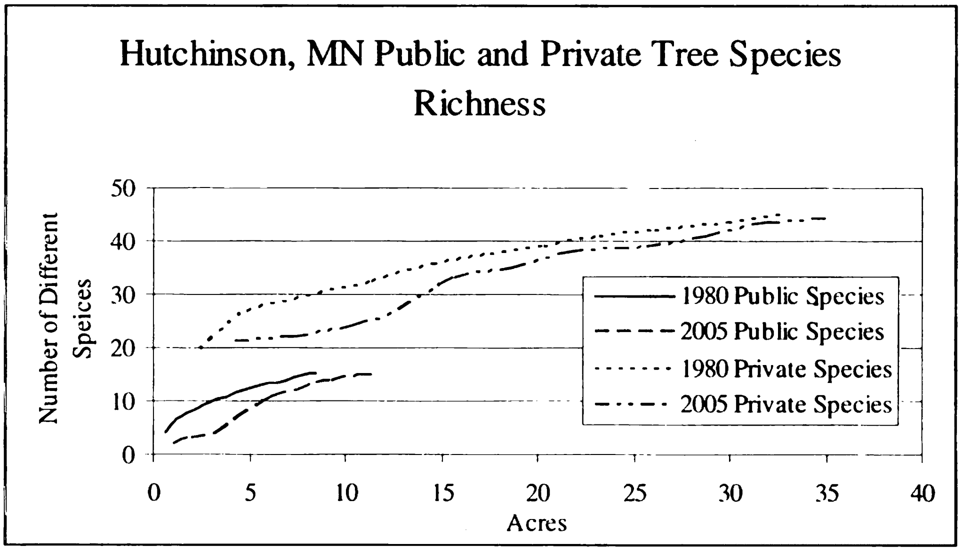


Figure D-2. Richness by genus in Hutchinson, MN in 1980 and 2003.

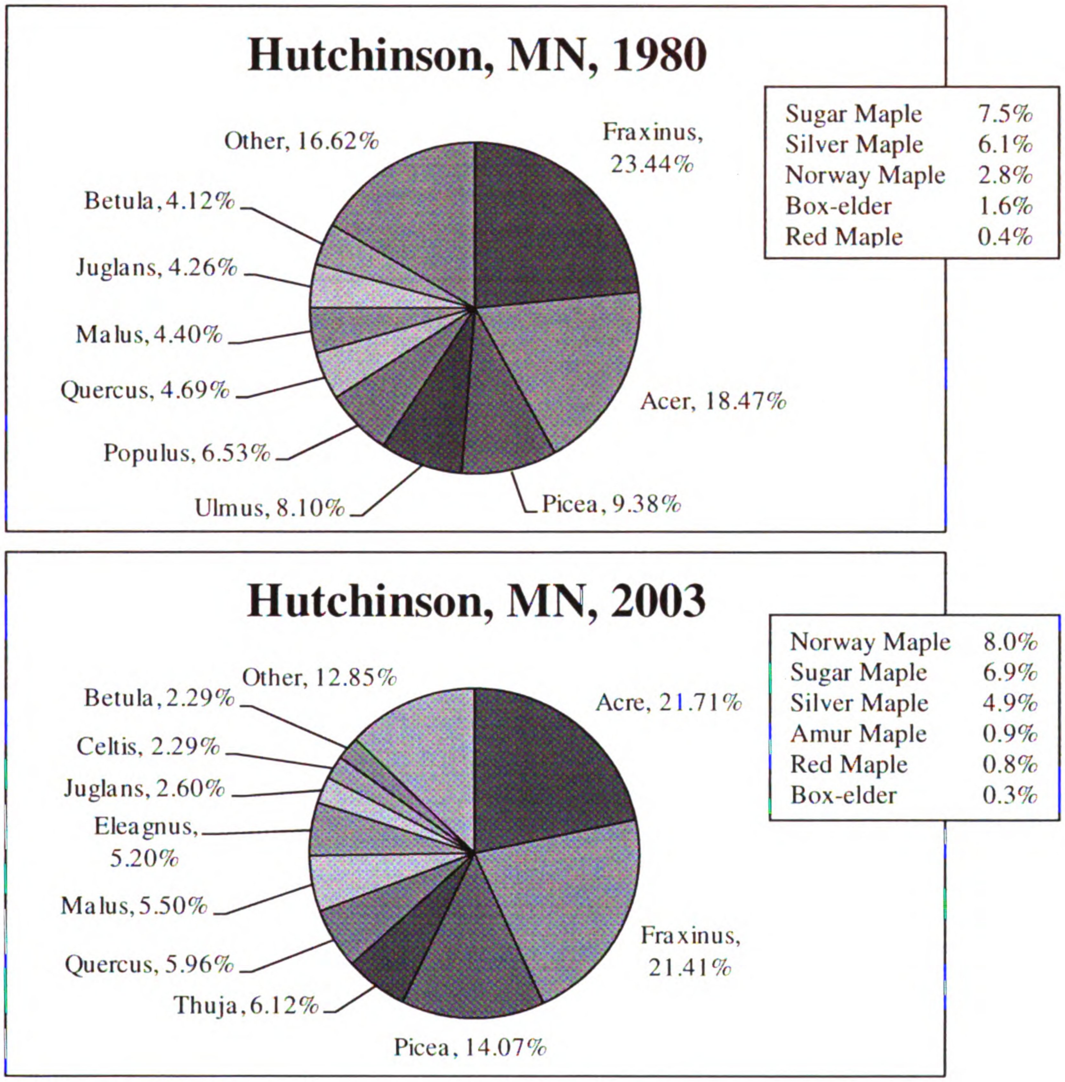


Table D-2. Ownership of all Trees, Hutchinson, MN: 1980 – 2005.

Ownership	1980 Number of Trees	Percent	1980* Number of Trees	Percent	2003* Number of Trees	Percent
Private	923	78.55	550	78.13	493	75.38
Public	252	21.45	154	21.88	161	24.62
Total	1175	100.00	704	100.00	654	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003

Table D-3. Species (Public and Private) of trees (all blocks), Hutchinson, MN: 1980.

Species	Number of Trees	Percent
Ash	231	19.66
Elm	137	11.66
Sugar Maple	94	8.00
Blue Spruce	82	6.98
Bur Oak	77	6.55
Silver Maple	67	5.70
Lombardy Popular	56	4.77
Juniper	50	4.26
Birch	41	3.49
Norway Maple	38	3.23
Crabapple	32	2.72
Apple	26	2.21
Walnut	26	2.21
Norway Spruce	20	1.70
Hackberry	16	1.36
Mountain Ash	13	1.11
Box-elder	12	1.02
Honeylocust	12	1.02
Plum	12	1.02
Scotch Pine	12	1.02
Willow	12	1.02
Russian Olive	11	0.94
Fir	10	0.85
Buckeye	9	0.77
Cherry	8	0.68
Linden	8	0.68
Red Maple	7	0.60
Butternut	6	0.51
Populus sp.	6	0.51
White Spruce	6	0.51
Catalpa	5	0.43
Dogwood	5	0.43
Pinus sp.	5	0.43
Mulberry	3	0.26
Arborvitae	2	0.17
Cottonwood	2	0.17
Hemlock	2	0.17
Kentucky Coffee Tree	2	0.17
Picea sp.	2	0.17
Viburnum	2	0.17
Acer sp.	1	0.09
Peach	1	0.09
Pear	1	0.09
Ponderosa Pine	1	0.09
Red Oak	1	0.09
White Oak	1	0.09
White Pine	1	0.09
White Popular	1	0.09
Total	1175	100.00

Table D-4. Public Tree Species, Hutchinson, MN: 1980.

Species	Number of Trees	Percent
Ash	81	32.14
Sugar Maple	59	23.41
Elm	57	22.62
Silver Maple	8	3.17
Hackberry	8	3.17
Bur Oak	7	2.78
Norway Maple	6	2.38
Blue Spruce	5	1.98
Lombardy Popular	4	1.59
Birch	3	1.19
Norway Spruce	3	1.19
Red Maple	3	1.19
Walnut	3	1.19
Linden	2	0.79
Box-elder	1	0.40
Juniper	1	0.40
Catalpa	1	0.40
Total	252	100.00

Table D-5. Private Tree Species, Hutchinson, MN: 1980.

Species	Number of Trees	Percent
Ash	150	16.25
Elm	80	8.67
Blue Spruce	77	8.34
Bur Oak	70	7.58
Silver Maple	59	6.39
Lombardy Popular	52	5.63
Juniper	49	5.31
Birch	38	4.12
Sugar Maple	35	3.79
Crabapple	32	3.47
Norway Maple	32	3.47
Apple	26	2.82
Walnut	23	2.49
Norway Spruce	17	1.84
Mountain Ash	13	1.41
Honeylocust	12	1.30
Plum	12	1.30
Scotch Pine	12	1.30
Willow	12	1.30
Box-elder	11	1.19
Russian Olive	11	1.19
Fir	10	1.08
Buckeye	9	0.98
Cherry	8	0.87
Hackberry	8	0.87
Butternut	6	0.65
Linden	6	0.65
Populus sp.	6	0.65
White Spruce	6	0.65
Dogwood	5	0.54
Pinus sp.	5	0.54
Catalpa	4	0.43
Red Maple	4	0.43
Mulberry	3	0.33
Arborvitae	2	0.22
Cottonwood	2	0.22
Hemlock	2	0.22
Kentucky Coffee Tree	2	0.22
Picea sp.	2	0.22
Viburnum	2	0.22
Acer sp.	1	0.11
Peach	1	0.11
Pear	1	0.11
Ponderosa Pine	1	0.11
Red Oak	1	0.11
White Oak	1	0.11
White Pine	1	0.11
White Popular	1	0.11
Total	923	100.00

Table D-6. Species (Public and Private) of trees, Hutchinson, MN: 1980.

Species*	Number of Trees	Percent
Ash	165	23.44
Elm	57	8.10
Sugar Maple	53	7.53
Blue Spruce	46	6.53
Silver Maple	43	6.11
Lombardy Popular	42	5.97
Bur Oak	32	4.55
Juniper	30	4.26
Birch	29	4.12
Crabapple	22	3.13
Norway Maple	20	2.84
Walnut	14	1.99
Norway Spruce	13	1.85
Box-elder	11	1.56
Scotch Pine	10	1.42
Hackberry	10	1.42
Willow	9	1.28
Plum	9	1.28
Mountain Ash	9	1.28
Apple	9	1.28
Russian Olive	8	1.14
Buckeye	7	0.99
Honeylocust	6	0.85
White Spruce	5	0.71
Linden	4	0.57
Fir	4	0.57
Dogwood	4	0.57
Cherry	4	0.57
Red Maple	3	0.43
Populus sp.	3	0.43
Pinus sp.	3	0.43
Catalpa	3	0.43
Viburnum	2	0.28
Picea sp.	2	0.28
Kentucky Coffee Tree	2	0.28
Cottonwood	2	0.28
Butternut	2	0.28
Arborvitae	2	0.28
White Popular	1	0.14
Red Oak	1	0.14
Ponderosa Pine	1	0.14
Pear	1	0.14
Mulberry	1	0.14
Total	704	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Table D-7. Public Tree Species, Hutchinson, MN: 1980.

Species*	Number of Trees	Percent
Ash	64	41.56
Sugar Maple	31	20.13
Elm	27	17.53
Silver Maple	6	3.90
Hackberry	5	3.25
Bur Oak	2	1.30
Norway Maple	3	1.95
Blue Spruce	5	3.25
Lombardy Popular	4	2.60
Birch	2	1.30
Norway Spruce	1	0.65
Walnut	1	0.65
Linden	1	0.65
Juniper	1	0.65
Catalpa	1	0.65
Total	154	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Table D-8. Private Tree Species, Hutchinson, MN: 1980.

Species*	Number of Trees	Percent
Ash	101	18.36
Blue Spruce	41	7.45
Lombardy Popular	38	6.91
Silver Maple	37	6.73
Bur Oak	30	5.45
Elm	30	5.45
Juniper	29	5.27
Birch	27	4.91
Crabapple	22	4.00
Sugar Maple	22	4.00
Norway Maple	17	3.09
Walnut	13	2.36
Norway Spruce	12	2.18
Box-elder	11	2.00
Scotch Pine	10	1.82
Apple	9	1.64
Mountain Ash	9	1.64
Plum	9	1.64
Willow	9	1.64
Russian Olive	8	1.45
Buckeye	7	1.27
Honeylocust	6	1.09
Hackberry	5	0.91
White Spruce	5	0.91
Cherry	4	0.73
Dogwood	4	0.73
Fir	4	0.73
Linden	3	0.55
Pinus sp.	3	0.55
Populus sp.	3	0.55
Red Maple	3	0.55
Arborvitae	2	0.36
Butternut	2	0.36
Catalpa	2	0.36
Cottonwood	2	0.36
Kentucky Coffee Tree	2	0.36
Picea sp.	2	0.36
Viburnum	2	0.36
Mulberry	1	0.18
Pear	1	0.18
Ponderosa Pine	1	0.18
Red Oak	1	0.18
White Popular	1	0.18
Total	550	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Table D-9. Species (Public and Private) of trees, Hutchinson, MN: 2003.

Species	Number of Trees	Percent
Ash	140	21.41
Norway Spruce	65	9.94
Norway Maple	52	7.95
Sugar Maple	45	6.88
Arborvitae	40	6.12
Bur Oak	36	5.50
Russian Olive	34	5.20
Silver Maple	32	4.89
Crabapple	29	4.43
Blue Spruce	18	2.75
Black Walnut	17	2.60
Hackberry	15	2.29
Birch	15	2.29
Linden	13	1.99
Elm	12	1.83
Apple	7	1.07
Juniper	6	0.92
Amur Maple	6	0.92
Red Maple	5	0.76
Plum	5	0.76
Mugo Pine	5	0.76
White Spruce	4	0.61
Serviceberry	4	0.61
Pear	4	0.61
Mulberry	4	0.61
Honeylocust	4	0.61
Blue Spruce	4	0.61
White Oak	3	0.46
Tree-of-heaven	3	0.46
Mountain Ash	3	0.46
Willow	2	0.31
Kentucky Coffee Tree	2	0.31
Catalpa	2	0.31
Buckeye	2	0.31
Box-elder	2	0.31
Balsam Fir	2	0.31
Aspen	2	0.31
Yew	1	0.15
White Pine	1	0.15
Ponderosa Pine	1	0.15
Hop-Hornbeam	1	0.15
Hemlock	1	0.15
Golden-rain Tree	1	0.15
Cottonwood	1	0.15
Buckthorn	1	0.15
Black Gum	1	0.15
Alberta Spruce	1	0.15
Total	654	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Table D-10. Public Tree Species, Hutchinson, MN: 2003.

Species*	Number of Trees	Percent
Ash	77	47.83
Sugar Maple	33	20.50
Norway Maple	18	11.18
Linden	6	3.73
Elm	4	2.48
Blue Spruce	4	2.48
White Oak	3	1.86
Silver Maple	2	1.24
Black Walnut	2	1.24
Serviceberry	1	0.62
Hop-Hornbeam	1	0.62
Catalpa	1	0.62
Hackberry	2	1.24
Bur Oak	6	3.73
White Spruce	1	0.62
Total	161	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Table D-11. Private Tree Species, Hutchinson, MN: 2003.

Species*	Number of Trees	Percent
Norway Spruce	65	13.18
Ash	63	12.78
Arborvitae	40	8.11
Norway Maple	34	6.90
Russian Olive	34	6.90
Bur Oak	30	6.09
Silver Maple	30	6.09
Crabapple	29	5.88
Blue Spruce	18	3.65
Birch	15	3.04
Black Walnut	15	3.04
Hackberry	13	2.64
Sugar Maple	12	2.43
Elm	8	1.62
Apple	7	1.42
Linden	7	1.42
Amur Maple	6	1.22
Juniper	6	1.22
Mugo Pine	5	1.01
Plum	5	1.01
Red Maple	5	1.01
Honeylocust	4	0.81
Mulberry	4	0.81
Pear	4	0.81
Mountain Ash	3	0.61
Serviceberry	3	0.61
Tree-of-heaven	3	0.61
White Spruce	3	0.61
Aspen	2	0.41
Balsam Fir	2	0.41
Box-elder	2	0.41
Kentucky Coffee Tree	2	0.41
Willow	2	0.41
Buckeye	2	0.41
Alberta Spruce	1	0.20
Black Gum	1	0.20
Buckthorn	1	0.20
Catalpa	1	0.20
Cottonwood	1	0.20
Golden-rain Tree	1	0.20
Hemlock	1	0.20
Ponderosa Pine	1	0.20
White Pine	1	0.20
Yew	1	0.20
Total	493	100.00

*Does not include blocks D, E, G and J because they could not be relocated in 2003.

Appendix E

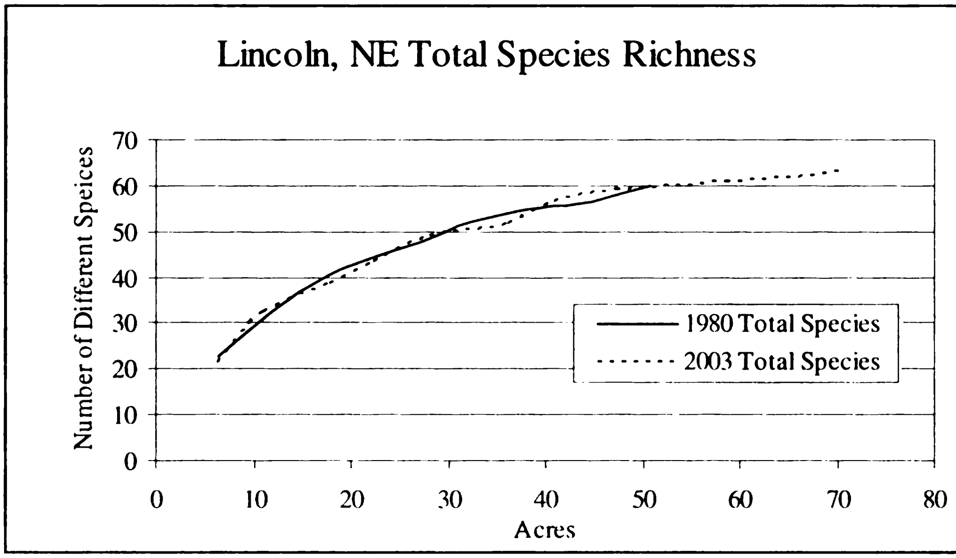
Lincoln, Nebraska

Table E-1. Selected data of the urban forest in Lincoln, NE.

	1980			1992			2003		
	Total	Public	Private	Total	Public	Private	Total	Public	Private
Number of trees	952	131	821	1346	212	1132	1049	194	855
Number of acres sampled	40.47			56.03			56.03		
Density (trees per acre)	24.23	3.76	20.47	24.79	3.97	20.82	20.4	3.89	16.51
Diversity (Shannon index)	3.47			3.46			3.36		
Public to private tree ratio	6.27/1			5.34/1			4.41/1		
Species richness									
<10 yrs old	39	5	38	43	7	43	42	6	42
10 - 40 yrs old	54	5	53	54	10	53	47	9	45
>40 yrs old	40	16	37	46	17	42	42	14	38
Total *	62	20	62	62	23	62	63	15	62

* Totals are not the sum of the columns, they are the total number of different species in that column

Figure E-1. Species richness per acre in the urban forest of Lincoln, NE in 1980 and 2003.



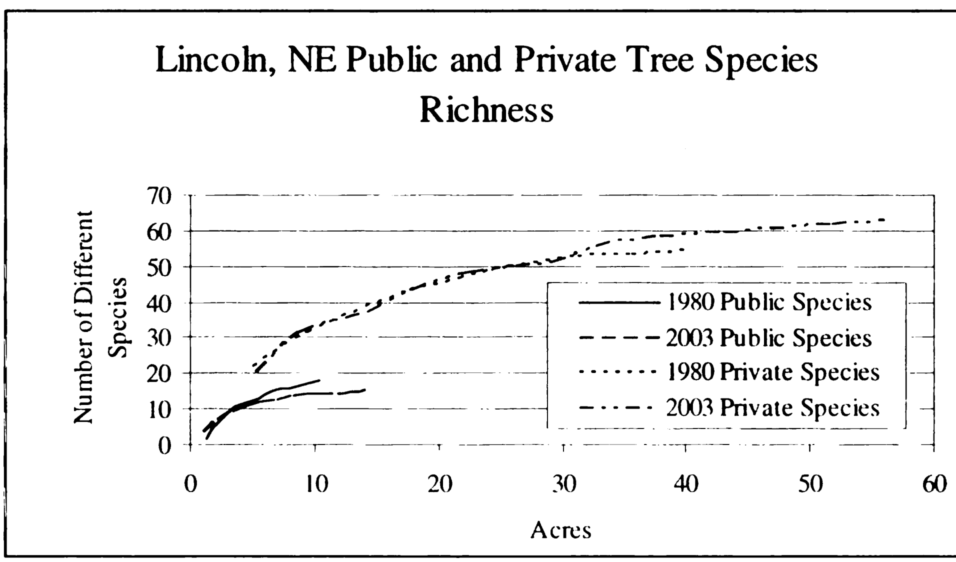
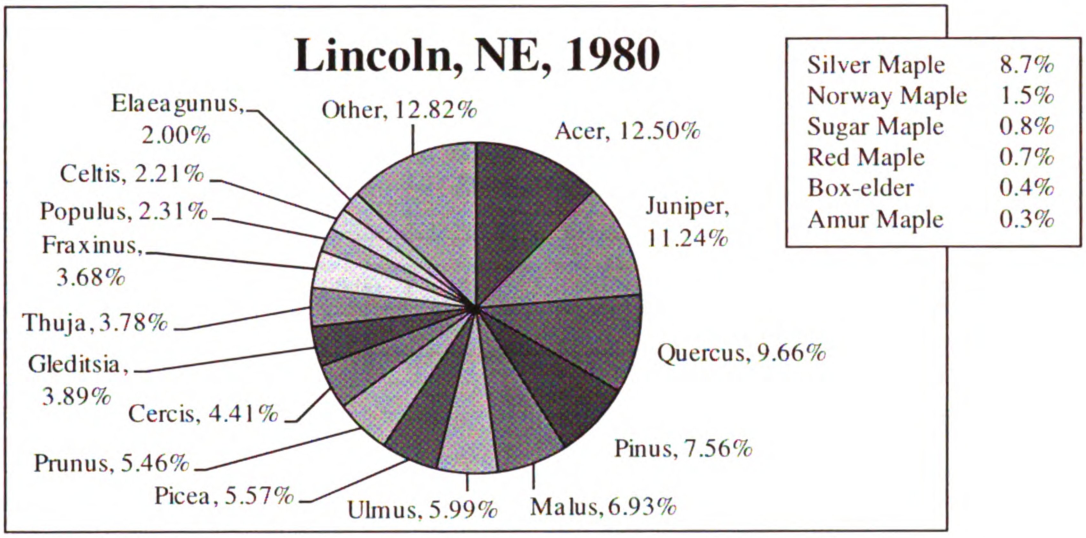


Figure E-2. Richness by genus in Lincoln, NE in 1980 and 2003.



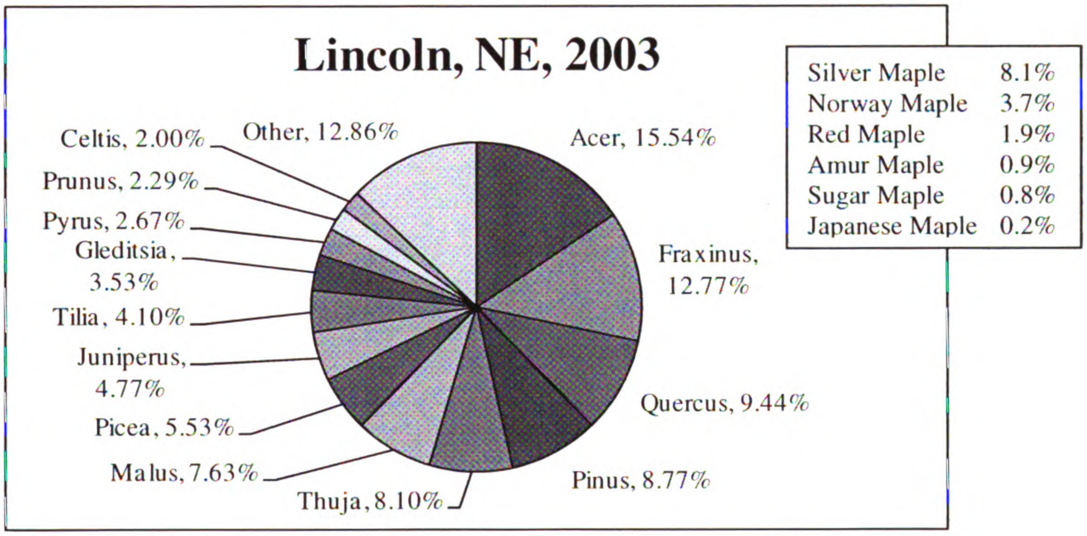


Table E-2. Ownership of all Trees, Lincoln, NE: 1980 - 1992 - 2003.

Ownership	1980* Number of Trees	Percent	1993 Number of Trees	Percent	2003 Number of Trees	Percent
Private	821	86.24	1134	84.25	855	81.51
Public	131	13.76	212	15.75	194	18.49
Total	952	100.00	1346	100.00	1049	100.00

*Does not include blocks J, K and L because they were not part of the study in 1980

Table E-3. Species (Public and Private) of trees, Lincoln, NE: 1980.

Species*	Number of Trees	Percent
Red Cedar	107	11.24
Pin Oak	83	8.72
Silver Maple	83	8.72
Redbud	42	4.41
Crabapple	39	4.10
Honeylocust	37	3.89
Arborvitae	36	3.78
Blue Spruce	36	3.78
Ash	35	3.68
Scotch Pine	33	3.47
Siberian Elm	29	3.05
American Elm	28	2.94
Apple	27	2.84
Hackberry	21	2.21
Plum	21	2.21
Russian Olive	19	2.00
Cherry	18	1.89
Mulberry	18	1.89
Austrian Pine	17	1.79
Pear	17	1.79
Norway Maple	14	1.47
Aspen	13	1.37
Birch	13	1.37
Peach	13	1.37
White Spruce	13	1.37
Linden	11	1.16
Willow	10	1.05
Walnut	9	0.95
White Pine	9	0.95
Ponderosa Pine	8	0.84
Red Oak	8	0.84
Sugar Maple	8	0.84
Mountain Ash	7	0.74
Red Maple	7	0.74
Cottonwood	6	0.63
Box-elder	4	0.42
Douglas Fir	4	0.42
Norway Spruce	4	0.42
Sycamore	4	0.42
Ailanthus	3	0.32
Amur Maple	3	0.32
Balsam Fir	3	0.32
Dogwood	3	0.32
Mugo Pine	3	0.32
Sweetgum	3	0.32
Unknown	3	0.32
Catalpa	2	0.21
Hawthorn	2	0.21
Sumac	2	0.21
White Popular	2	0.21
Beech	1	0.11
Black Oak	1	0.11
Hop-hornbeam	1	0.11
Hornbeam	1	0.11
Kentucky Coffee Tree	1	0.11
Limber Pine	1	0.11
Lombardy Popular	1	0.11
Magnolia	1	0.11
Red Pine	1	0.11
Tulip Popular	1	0.11
White Fir	1	0.11
Witch Hazel	1	0.11
Total	952	100.00

*Does not include data from plots J, K, and L, they were not part of the study in 1980.

Table E-4. Public Tree Species, Lincoln, NE: 1980.

Species*	Number of Trees	Percent
Pin Oak	59	45.04
American Elm	12	9.16
Hackberry	11	8.40
Ash	9	6.87
Siberian Elm	7	5.34
Norway Maple	4	3.05
Red Maple	4	3.05
Red Oak	4	3.05
Aspen	3	2.29
Pear	3	2.29
Silver Maple	3	2.29
Walnut	3	2.29
Redbud	2	1.53
Catalpa	1	0.76
Cherry	1	0.76
Crabapple	1	0.76
Honeylocust	1	0.76
Linden	1	0.76
Mountain Ash	1	0.76
Sugar Maple	1	0.76
Total	131	100.00

*Does not include data from plots J, K, and L, they were not part of the study in 1980.

Table E-5. Private Tree Species, Lincoln, NE: 1980.

Species	Number of Trees	Percent
Red Cedar	107	13.03
Silver Maple	80	9.74
Redbud	40	4.87
Crabapple	38	4.63
Arborvitae	36	4.38
Blue Spruce	36	4.38
Honeylocust	36	4.38
Scotch Pine	33	4.02
Apple	27	3.29
Ash	26	3.17
Pin Oak	24	2.92
Siberian Elm	22	2.68
Plum	21	2.56
Russian Olive	19	2.31
Mulberry	18	2.19
Austrian Pine	17	2.07
Cherry	17	2.07
American Elm	16	1.95
Pear	14	1.71
Birch	13	1.58
Peach	13	1.58
White Spruce	13	1.58
Aspen	10	1.22
Hackberry	10	1.22
Linden	10	1.22
Norway Maple	10	1.22
Willow	10	1.22
White Pine	9	1.10
Ponderosa Pine	8	0.97
Sugar Maple	7	0.85
Cottonwood	6	0.73
Mountain Ash	6	0.73
Walnut	6	0.73
Box-elder	4	0.49
Douglas Fir	4	0.49
Norway Spruce	4	0.49
Red Oak	4	0.49
Sycamore	4	0.49
Ailanthus	3	0.37
Amur Maple	3	0.37
Balsam Fir	3	0.37
Dogwood	3	0.37
Mugo Pine	3	0.37
Red Maple	3	0.37
Sweetgum	3	0.37
Unknown	3	0.37
Hawthorn	2	0.24
Sumac	2	0.24
White Popular	2	0.24
Beech	1	0.12
Black Oak	1	0.12
Catalpa	1	0.12
Hop-hornbeam	1	0.12
Hornbeam	1	0.12
Kentucky Coffee Tree	1	0.12
Limber Pine	1	0.12
Lombardy Popular	1	0.12
Magnolia	1	0.12
Red Pine	1	0.12
Tulip Popular	1	0.12
White Fir	1	0.12
Witch Hazel	1	0.12
Total	821	100.00

*Does not include data from plots J, K, and L, they were not part of the study in 1980.

Table E-6. Species (Public and Private) of trees, Lincoln, NE: 1992.

Species	Number of Trees	Percent
Ash	115	8.54
Arborvitae	101	7.50
Silver Maple	99	7.36
Pin Oak	93	6.91
Red Cedar	92	6.84
Crabapple	80	5.94
Norway Maple	45	3.34
Blue Spruce	44	3.27
Linden	44	3.27
Redbud	44	3.27
Honeylocust	42	3.12
Mulberry	42	3.12
Plum	37	2.75
Pear	35	2.60
Austrian Pine	33	2.45
Siberian Elm	33	2.45
Hackberry	30	2.23
Scotch Pine	29	2.15
Apple	28	2.08
Mugo Pine	18	1.34
American Elm	17	1.26
Red Maple	17	1.26
Birch	16	1.19
Cherry	15	1.11
White Pine	15	1.11
Amur Maple	14	1.04
White Spruce	14	1.04
Ponderosa Pine	12	0.89
Sugar Maple	12	0.89
Willow	12	0.89
Cottonwood	10	0.74
Hawthorn	10	0.74
Red Oak	10	0.74
Russian Olive	9	0.67
Walnut	9	0.67
Norway Spruce	7	0.52
Ailanthus	6	0.45
Black Oak	4	0.30
Dogwood	4	0.30
Mountain Ash	4	0.30
Peach	4	0.30
Smoke-tree	4	0.30
Unknown	4	0.30
Black Locust	3	0.22
Douglas Fir	3	0.22
Magnolia	3	0.22
Aspen	2	0.15
Bald Cypress	2	0.15
Box-elder	2	0.15
Kentucky Coffee Tree	2	0.15
Sweetgum	2	0.15
Sycamore	2	0.15
White Fir	2	0.15
White Popular	2	0.15
Balsam Fir	1	0.07
Butternut	1	0.07
Catalpa	1	0.07
Gingko	1	0.07
Horse Chestnut	1	0.07
Limber Pine	1	0.07
Red Pine	1	0.07
White Oak	1	0.07
Total	1346	100.00

Table E-7. Public Tree Species, Lincoln, NE: 1992.

Species	Number of Trees	Percent
Pin Oak	62	29.25
Ash	38	17.92
Norway Maple	27	12.74
Linden	21	9.91
Hackberry	13	6.13
Pear	12	5.66
Siberian Elm	7	3.30
Red Oak	5	2.36
American Elm	4	1.89
Red Maple	3	1.42
Silver Maple	3	1.42
Walnut	3	1.42
Honeylocust	2	0.94
Redbud	2	0.94
Sugar Maple	2	0.94
Apple	1	0.47
Aspen	1	0.47
Cherry	1	0.47
Cottonwood	1	0.47
Crabapple	1	0.47
Kentucky Coffee Tree	1	0.47
Mountain Ash	1	0.47
Unknown	1	0.47
Total	212	100.00

Table E-8. Private Tree Species, Lincoln, NE: 1992.

Species	Number of Trees	Percent
Arborvitae	101	8.91
Silver Maple	96	8.47
Red Cedar	92	8.11
Crabapple	79	6.97
Ash	77	6.79
Blue Spruce	44	3.88
Mulberry	42	3.70
Redbud	42	3.70
Honeylocust	40	3.53
Plum	37	3.26
Austrian Pine	33	2.91
Pin Oak	31	2.73
Scotch Pine	29	2.56
Apple	27	2.38
Siberian Elm	26	2.29
Linden	23	2.03
Pear	23	2.03
Mugo Pine	18	1.59
Norway Maple	18	1.59
Hackberry	17	1.50
Birch	16	1.41
White Pine	15	1.32
Amur Maple	14	1.23
Cherry	14	1.23
Red Maple	14	1.23
White Spruce	14	1.23
American Elm	13	1.15
Ponderosa Pine	12	1.06
Willow	12	1.06
Hawthorn	10	0.88
Sugar Maple	10	0.88
Cottonwood	9	0.79
Russian Olive	9	0.79
Norway Spruce	7	0.62
Ailanthus	6	0.53
Walnut	6	0.53
Red Oak	5	0.44
Black Oak	4	0.35
Dogwood	4	0.35
Peach	4	0.35
Smoke-tree	4	0.35
Black Locust	3	0.26
Douglas Fir	3	0.26
Magnolia	3	0.26
Mountain Ash	3	0.26
Unknown	3	0.26
Bald Cypress	2	0.18
Box-elder	2	0.18
Sweetgum	2	0.18
Sycamore	2	0.18
White Fir	2	0.18
White Popular	2	0.18
Aspen	1	0.09
Balsam Fir	1	0.09
Butternut	1	0.09
Catalpa	1	0.09
Gingko	1	0.09
Horse Chestnut	1	0.09
Kentucky Coffee Tree	1	0.09
Limber Pine	1	0.09
Red Pine	1	0.09
White Oak	1	0.09
Total	1134	100.00

Table E-9. Species (Public and Private) of trees, Lincoln, NE: 2003.

Species	Number of Trees	Percent
Ash	134	12.77
Arborvitae	85	8.10
Pin Oak	85	8.10
Silver Maple	85	8.10
Crabapple	68	6.48
Red Cedar	50	4.77
Linden	42	4.00
Norway Maple	39	3.72
Honeylocust	37	3.53
Blue Spruce	31	2.96
Scotch Pine	29	2.76
Pear	28	2.67
Hackberry	21	2.00
Mugo Pine	20	1.91
Red Maple	20	1.91
Austrian Pine	19	1.81
Redbud	17	1.62
White Pine	15	1.43
Alberta Spruce	14	1.33
Birch	14	1.33
Taxus	14	1.33
Plum	13	1.24
Apple	12	1.14
Mulberry	12	1.14
Red Oak	11	1.05
Siberian Elm	11	1.05
White Spruce	10	0.95
Amur Maple	9	0.86
American Elm	8	0.76
Ponderosa Pine	8	0.76
Sugar Maple	8	0.76
Cherry	7	0.67
Smoke-tree	6	0.57
Walnut	6	0.57
Cottonwood	5	0.48
Ailanthus	4	0.38
Hawthorn	4	0.38
Magnolia	4	0.38
Black Oak	3	0.29
Norway Spruce	3	0.29
Willow	3	0.29
Balsam Fir	2	0.19
Black Locust	2	0.19
Douglas Fir	2	0.19
Japanese Maple	2	0.19
Kentucky Coffee Tree	2	0.19
Lombardy Popular	2	0.19
Mountain Ash	2	0.19
Peach	2	0.19
Russian Olive	2	0.19
Sweetgum	2	0.19
Sycamore	2	0.19
Weeping Cherry	2	0.19
White Popular	2	0.19
Bald Cypress	1	0.10
Catalpa	1	0.10
Dogwood	1	0.10
Gingko	1	0.10
Hemlock	1	0.10
Horse Chestnut	1	0.10
Red Pine	1	0.10
Silver Linden	1	0.10
White Fir	1	0.10
Total	1049	100.00

Table E-10. Public Tree Species, Lincoln, NE: 2003.

Species	Number of Trees	Percent
Ash	54	27.84
Pin Oak	52	26.80
Linden	27	13.92
Norway Maple	19	9.79
Pear	9	4.64
Hackberry	8	4.12
Crabapple	5	2.58
Red Maple	5	2.58
Red Oak	5	2.58
Redbud	3	1.55
Walnut	3	1.55
American Elm	1	0.52
Honeylocust	1	0.52
Kentucky Coffee Tree	1	0.52
Sugar Maple	1	0.52
Total	194	100.00

Table E-11. Private Tree Species, Lincoln, NE: 2003.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Arborvitae	85	9.94	Black Locust	2	0.23
Silver Maple	85	9.94	Douglas Fir	2	0.23
Ash	80	9.36	Japanese Maple	2	0.23
Crabapple	63	7.37	Lombardy Popular	2	0.23
Red Cedar	50	5.85	Mountain Ash	2	0.23
Honeylocust	36	4.21	Peach	2	0.23
Pin Oak	33	3.86	Russian Olive	2	0.23
Blue Spruce	31	3.63	Sweetgum	2	0.23
Scotch Pine	29	3.39	Sycamore	2	0.23
Mugo Pine	20	2.34	Weeping Cherry	2	0.23
Norway Maple	20	2.34	White Popular	2	0.23
Austrian Pine	19	2.22	Bald Cypress	1	0.12
Pear	19	2.22	Catalpa	1	0.12
Linden	16	1.87	Dogwood	1	0.12
Red Maple	15	1.75	Gingko	1	0.12
White Pine	15	1.75	Hemlock	1	0.12
Alberta Spruce	14	1.64	Horse Chestnut	1	0.12
Birch	14	1.64	Kentucky Coffee Tree	1	0.12
Redbud	14	1.64	Red Pine	1	0.12
Taxus	14	1.64	White Fir	1	0.12
Hackberry	13	1.52			
Plum	13	1.52	Total	855	100.00
Apple	12	1.40			
Mulberry	12	1.40			
Siberian Elm	11	1.29			
White Spruce	10	1.17			
Amur Maple	9	1.05			
Ponderosa Pine	8	0.94			
American Elm	7	0.82			
Cherry	7	0.82			
Sugar Maple	7	0.82			
Red Oak	6	0.70			
Smoke-tree	6	0.70			
Cottonwood	5	0.58			
Ailanthus	4	0.47			
Hawthorn	4	0.47			
Magnolia	4	0.47			
Black Oak	3	0.35			
Norway Spruce	3	0.35			
Walnut	3	0.35			
Willow	3	0.35			
Balsam Fir	2	0.23			

Appendix F

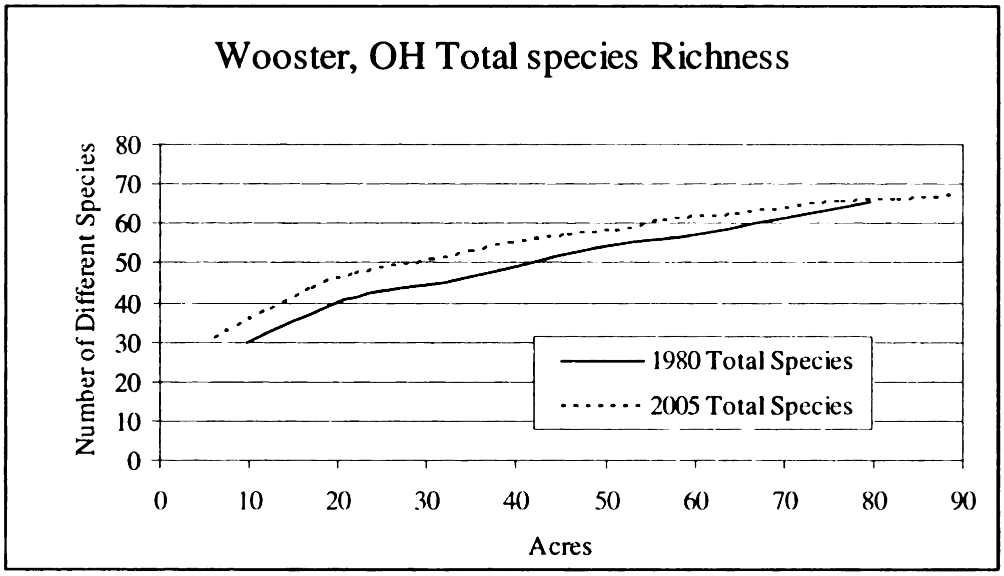
Wooster, Ohio

Table F-1. Selected data of the urban forest in Wooster, OH.

	1980 Total	1980 Public	1980 Private	2003 Total	2003 Public	2003 Private
Number of trees	1682	107	133	2316	1575	2183
Number of acres sampled	63.42			71.65		
Density (trees per acre)	26.52	1.69	1.86	32.32	24.83	30.47
Public to private tree ratio	14.72/1			16.41/1		
Diversity (Shannon index)	3.27			3.27		
Species richness						
<10 yrs old	47	8	47	49	15	48
10 - 40 yrs old	54	3	54	46	2	46
>40 yrs old	39	13	36	51	20	45
Total *	62	17	61	67	25	64

* Totals are not the sum of the columns, They are the total number of different species in that column

Figure F-1. Species richness per acre in the urban forest of Wooster, OH in 1980 and 2005.



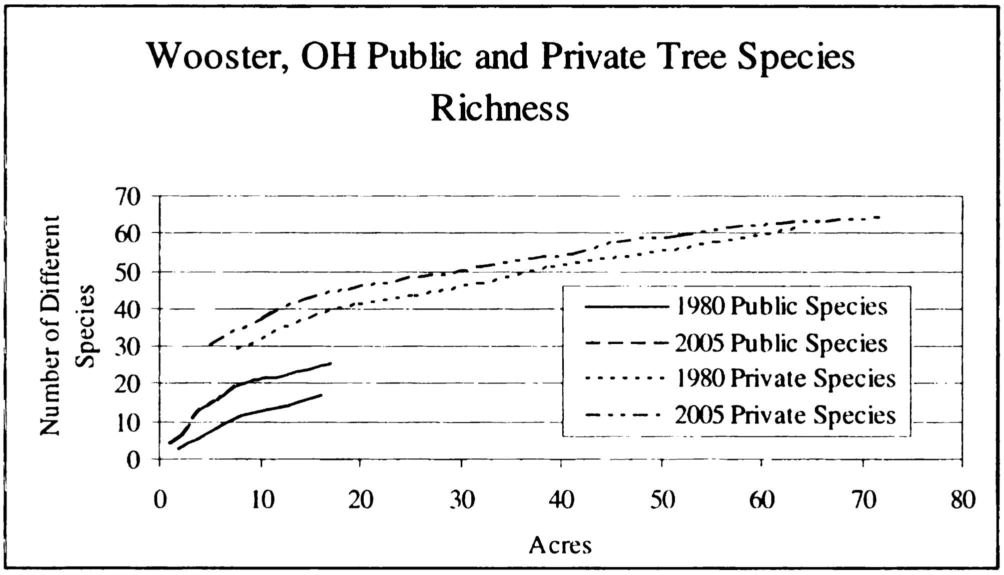


Figure F-2. Richness by genus in Wooster, OH in 1980 and 2005.

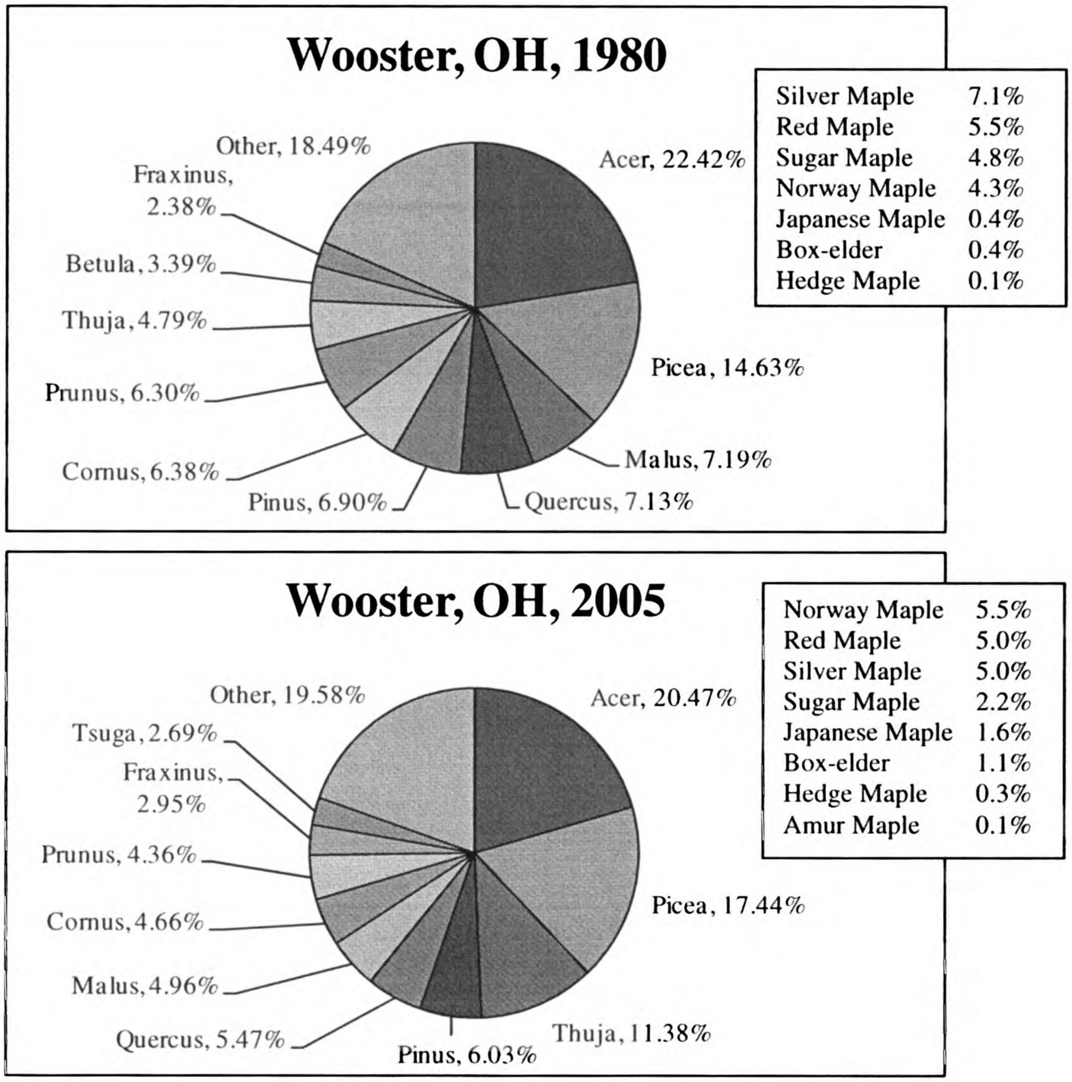


Table F-2. Ownership of all Trees, Wooster, OH: 1980 – 2005.

Ownership	1980* Number of Trees	Percent	2005** Number of Trees	Percent
Private	1575	93.64	2183	94.26
Public	107	6.36	133	5.74
Total	1682	100	2316	100

*9 City Blocks
**15 City Blocks

Table F-3. Species (Public and Private) of trees, Wooster, OH: 1980.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Blue Spruce	159	9.45	Hickory	4	0.24
Dogwood	141	8.38	Serviceberry	4	0.24
Silver Maple	119	7.07	Spruce	4	0.24
Red Maple	92	5.47	Black Gum	3	0.18
Crabapple	85	5.05	White Oak	3	0.18
White Pine	84	4.99	Black Locust	2	0.12
Norway Spruce	83	4.93	Holly	2	0.12
Sugar Maple	80	4.76	Sycamore	2	0.12
Pin Oak	79	4.70	Apricot	1	0.06
Norway Maple	72	4.28	Bald Cypress	1	0.06
Cherry	63	3.75	Beech	1	0.06
Arborvitae	58	3.45	Big-tooth Aspen	1	0.06
Birch	57	3.39	Buckeye	1	0.06
Ash	40	2.38	Ginkgo	1	0.06
Red Oak	38	2.26	Golden-chain Tree	1	0.06
Apple	36	2.14	Golden-rain Tree	1	0.06
Plum	35	2.08	Hackberry	1	0.06
Hemlock	31	1.84	Hedge Maple	1	0.06
Sweetgum	26	1.55	Japanese Zelkova	1	0.06
Pear	22	1.31	Tree-of-heaven	1	0.06
Elm	19	1.13			
Mountain Ash	18	1.07			
Tulip Tree	17	1.01	Total	1682	100.00
Austrian Pine	16	0.95			
Lombardy Popular	16	0.95			
Scotch Pine	16	0.95			
Chestnut	15	0.89			
Russian Olive	14	0.83			
Redbud	13	0.77			
Honeylocust	12	0.71			
Catalpa	10	0.59			
Magnolia	9	0.54			
Fir	8	0.48			
Linden	8	0.48			
Mulberry	8	0.48			
Walnut	8	0.48			
Willow	8	0.48			
Japanese Maple	7	0.42			
Peach	7	0.42			
Box-elder	6	0.36			
Hawthorn	6	0.36			
White Popular	5	0.30			

Table F-4. Public Tree Species, Wooster, OH: 1980.

Species	Number of Trees	Percent
Crabapple	26	24.30
Norway Maple	16	14.95
Sugar Maple	14	13.08
Red Maple	13	12.15
Silver Maple	9	8.41
Linden	6	5.61
Red Oak	5	4.67
Pear	3	2.80
Plum	3	2.80
Ash	2	1.87
Dogwood	2	1.87
Elm	2	1.87
Redbud	2	1.87
Birch	1	0.93
Hawthorn	1	0.93
Japanese Zelkova	1	0.93
Sweetgum	1	0.93
Total	107	100.00

Table F-5. Private Tree Species, Wooster, OH: 1980.

Species	Number of Trees	Percent
Blue Spruce	159	10.10
Dogwood	139	8.83
Silver Maple	110	6.98
White Pine	84	5.33
Norway Spruce	83	5.27
Pin Oak	79	5.02
Red Maple	79	5.02
Sugar Maple	66	4.19
Cherry	63	4.00
Crabapple	59	3.75
Arborvitae	58	3.68
Birch	56	3.56
Norway Maple	56	3.56
Ash	38	2.41
Apple	36	2.29
Red Oak	33	2.10
Plum	32	2.03
Hemlock	31	1.97
Sweetgum	25	1.59
Pear	19	1.21
Mountain Ash	18	1.14
Elm	17	1.08
Tulip Tree	17	1.08
Austrian Pine	16	1.02
Lombardy Popular	16	1.02
Scotch Pine	16	1.02
Chestnut	15	0.95
Russian Olive	14	0.89
Honeylocust	12	0.76
Redbud	11	0.70
Catalpa	10	0.63
Magnolia	9	0.57
Fir	8	0.51
Mulberry	8	0.51
Walnut	8	0.51
Willow	8	0.51
Japanese Maple	7	0.44
Peach	7	0.44
Box-elder	6	0.38
Hawthorn	5	0.32
White Popular	5	0.32
Hickory	4	0.25
Serviceberry	4	0.25
Spruce	4	0.25
Black Gum	3	0.19
White Oak	3	0.19
Black Locust	2	0.13
Holly	2	0.13
Linden	2	0.13
Sycamore	2	0.13
Apricot	1	0.06
Bald Cypress	1	0.06
Beech	1	0.06
Big-tooth Aspen	1	0.06
Buckeye	1	0.06
Ginkgo	1	0.06
Golden-chain Tree	1	0.06
Golden-rain Tree	1	0.06
Hackberry	1	0.06
Hedge Maple	1	0.06
Tree-of-heaven	1	0.06
Total	1575	100.00

Table F-6. Species (Public and Private) of trees, Wooster, OH: 2005.

Species	Number of Trees	Percent	Species	Number of Trees	Percent
Arborvitae	266	11.49	White Oak	5	0.22
Norway Spruce	203	8.77	Blackgum	4	0.17
Blue Spruce	194	8.38	Tree-of-heaven	4	0.17
Norway Maple	127	5.48	Beech	3	0.13
Red Maple	115	4.97	Golden-rain Tree	3	0.13
Silver Maple	115	4.97	Japanese Lilac Tree	3	0.13
Dogwood	109	4.71	Kentucky Coffee Tree	3	0.13
White Pine	101	4.36	Smoke-tree	3	0.13
Crabapple	97	4.19	Amur Maple	2	0.09
Pin Oak	87	3.76	Black Spruce	2	0.09
Cherry	71	3.07	Dawn Redwood	2	0.09
Ash	69	2.98	Japanese Yew	2	0.09
Hemlock	63	2.72	Paw Paw	2	0.09
Sugar Maple	51	2.20	Quaking Aspen	2	0.09
Linden	41	1.77	White Fir	2	0.09
Magnolia	39	1.68	Balsam Fir	1	0.04
Japanese Maple	38	1.64	Black Oak	1	0.04
Mulberry	36	1.55	Buckthorn	1	0.04
Walnut	36	1.55	English Holly	1	0.04
Red Oak	34	1.47	Hop-Hornbeam	1	0.04
Birch	33	1.42	Horsechestnut	1	0.04
Pear	31	1.34	Mountain Ash	1	0.04
Plum	31	1.34	Shingle Oak	1	0.04
Austrian Pine	30	1.30	Sycamore	1	0.04
Juniper	28	1.21	Willow	1	0.04
Box-elder	25	1.08			
Honeylocust	24	1.04			
American Elm	21	0.91	Total	2316	100.00
Redbud	20	0.86			
Apple	19	0.82			
Sweetgum	18	0.78			
Black Locust	17	0.73			
Serviceberry	16	0.69			
Tulip Tree	11	0.47			
White Spruce	9	0.39			
Amur Cork Tree	6	0.26			
Hackberry	6	0.26			
Hedge Maple	6	0.26			
Siberian Elm	6	0.26			
Hawthorn	5	0.22			
Mugo Pine	5	0.22			
Scotch Pine	5	0.22			

Table F-7. Public Tree Species, Wooster, OH: 2005.

Species	Number of Trees	Percent
Red Maple	23	17.29
Crabapple	15	11.28
Linden	10	7.52
Norway Maple	10	7.52
Sugar Maple	10	7.52
Ash	9	6.77
Amur Cork Tree	6	4.51
Hedge Maple	6	4.51
Pear	6	4.51
Silver Maple	5	3.76
Sweetgum	5	3.76
Blackgum	3	2.26
Honeylocust	3	2.26
Red Oak	3	2.26
Serviceberry	3	2.26
Arborvitae	2	1.50
Blue Spruce	2	1.50
Dogwood	2	1.50
Hawthorn	2	1.50
Kentucky Coffee Tree	2	1.50
Norway Spruce	2	1.50
American Elm	1	0.75
Hop-Hornbeam	1	0.75
Japanese Lilac Tree	1	0.75
Tulip Tree	1	0.75
Total	133	100.00

Table F-8. Private Tree Species, Wooster, OH: 2005.

Species	Number of Trees	Percent
Arborvitae	264	12.09
Norway Spruce	201	9.21
Blue Spruce	192	8.80
Norway Maple	117	5.36
Silver Maple	110	5.04
Dogwood	107	4.90
White Pine	101	4.63
Red Maple	92	4.21
Pin Oak	87	3.99
Crabapple	82	3.76
Cherry	71	3.25
Hemlock	63	2.89
Ash	60	2.75
Sugar Maple	41	1.88
Magnolia	39	1.79
Japanese Maple	38	1.74
Mulberry	36	1.65
Walnut	36	1.65
Birch	33	1.51
Linden	31	1.42
Plum	31	1.42
Red Oak	31	1.42
Austrian Pine	30	1.37
Juniper	28	1.28
Box-elder	25	1.15
Pear	25	1.15
Honeylocust	21	0.96
American Elm	20	0.92
Redbud	20	0.92
Apple	19	0.87
Black Locust	17	0.78
Serviceberry	13	0.60
Sweetgum	13	0.60
Tulip Tree	10	0.46
White Spruce	9	0.41
Hackberry	6	0.27
Siberian Elm	6	0.27
Mugo Pine	5	0.23
Scotch Pine	5	0.23
White Oak	5	0.23
Tree-of-heaven	4	0.18
Beech	3	0.14
Golden-rain Tree	3	0.14
Hawthorn	3	0.14
Smoke-tree	3	0.14
Amur Maple	2	0.09
Black Spruce	2	0.09
Dawn Redwood	2	0.09
Japanese Lilac Tree	2	0.09
Japanese Yew	2	0.09
Paw Paw	2	0.09
Quaking Aspen	2	0.09
White Fir	2	0.09
Balsam Fir	1	0.05
Black Oak	1	0.05
Blackgum	1	0.05
Buckthorn	1	0.05
English Holly	1	0.05
Horsechestnut	1	0.05
Kentucky Coffee Tree	1	0.05
Mountain Ash	1	0.05
Shingle Oak	1	0.05
Sycamore	1	0.05
Willow	1	0.05
Total	2183	100.00