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GREEN INFRASTRUCTURE: FROM GLOBAL TO LOCAL

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Picture on the front cover. Photo: Gunnar Britse

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GREEN INFRASTRUCTURE: CONDITION CHANGES IN SIX USA URBAN FORESTS

CHARLES A. WADE AND J. JAMES KIELBASO

Abstract

This study is one of the first to consider both public and private trees in an urban forest in the United States of America. 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. Tree size was measured by dbh (diameter at breast height, which is measured at a height of 1.4 meters in the United States) and tree health conditions were calculated by a point system. Tree health was assessed by identifying signs of decline or hazards on the crown, trunk, branches, base and roots. Then, the decline signs were counted and a value was assigned based on the number of decline signs. Our data indicates that there is a general tendency for the smallest trees to have the best health condition. When considering the relationship between the size of the trees and overall tree health conditions, we can state with certainty, that there is a strong negative correlation between the size of urban trees and the health condition of urban trees; conditions decrease or worsen as size increase.

Key words:
Urban forest ecology; 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 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, 1983; Lakovoglou, et al., 2001).

Factors 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 leading to the death of the tree. Competition is always for resources/limiting factors (i.e. sunlight, nutrients, and water) (Close, et al., 1996a; 1996b; Fox, Bi and Ades, 2007) and space. 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. Trees 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, Clark and Matheny, 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, 1997; Peper, Mcpherson and Mori, 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, Favorite and Lorenzo, 1998; Scott, Simpson and McPherson, 1999; Beckett, Freer-Smith and Taylor, 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 in the United States (Kielbaso, et al., 1993; Wade, 2010).

The concept of urban and urbanization is defined by population density as determined by the U.S. Census Bureau (2007). An urban area is described as a densely populated settlement which has a population in excess of 386 people/km^2. Another urban category that the U.S. Census Bureau recognizes is the urban cluster (suburban or peri-urban areas) which has a population between 193 and 386 people/km^2. This study takes place in the Midwestern United States. It is the region of the USA which includes the Great Plains and the Great Lakes area of the country. The Midwest is made up of twelve states having a population of approximately 65 million inhabitants.

The rationale for this study was to look at twenty-five years of changes in a human dominated ecosystem, which had never been done before. The purpose of this study is to give researchers, arborists and planners an understanding of the conditions and sizes of the urban trees in the Midwestern United States. It is meant to give assistance to someone considering what trees should be planted. It is also intended to give an appreciation of what can be expected in the tree health condition and size, over the lifetime of an urban tree.

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 1993. 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 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 5.1 cmdbh 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 Bowling Green and Lincoln and three were added from the downtown area, so that there were 12 total blocks. Hutchinson was not re-surveyed in 1992. In 2003, all three cities were re-surveyed. 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 assistance 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 sites.

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) 5.1 to 10.2 cm, (2) 10.3 to 25.4 cm, (3) 25.5 to 40.6 cm, and (4) greater than 40.7.

Evaluating urban tree condition can be highly subjective (Webster, 1978). To eliminate subjectivity between years, we 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).

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, there were many differences. See table 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 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 1).

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 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	2 280	2 279
	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	1 111
	Lots Surveyed		228
	Average Tree Condition Rating	1.65	1.59
	Average Tree Size (inches)	7.48	11.02
Delaware, OH	Number of Trees	2 486	3 515
	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	1 049
	Lots Surveyed		220
	Average Tree Condition Rating	1.73	1.69
	Average Tree Size (inches)	9.11	11.56
Wooster, OH	Number of Trees	1 682	2 316
	Lots Surveyed		289
	Average Tree Condition Rating	1.32	1.66
	Average Tree Size (inches)	17.3	22.6
Summary of the urban forrest discriptors	Number of Trees	24.86	10 924
	Lots Surveyed		1 579
	Average Tree Condition Rating	1.53	1.68
	Average Tree Size (inches)	18.9	25.7

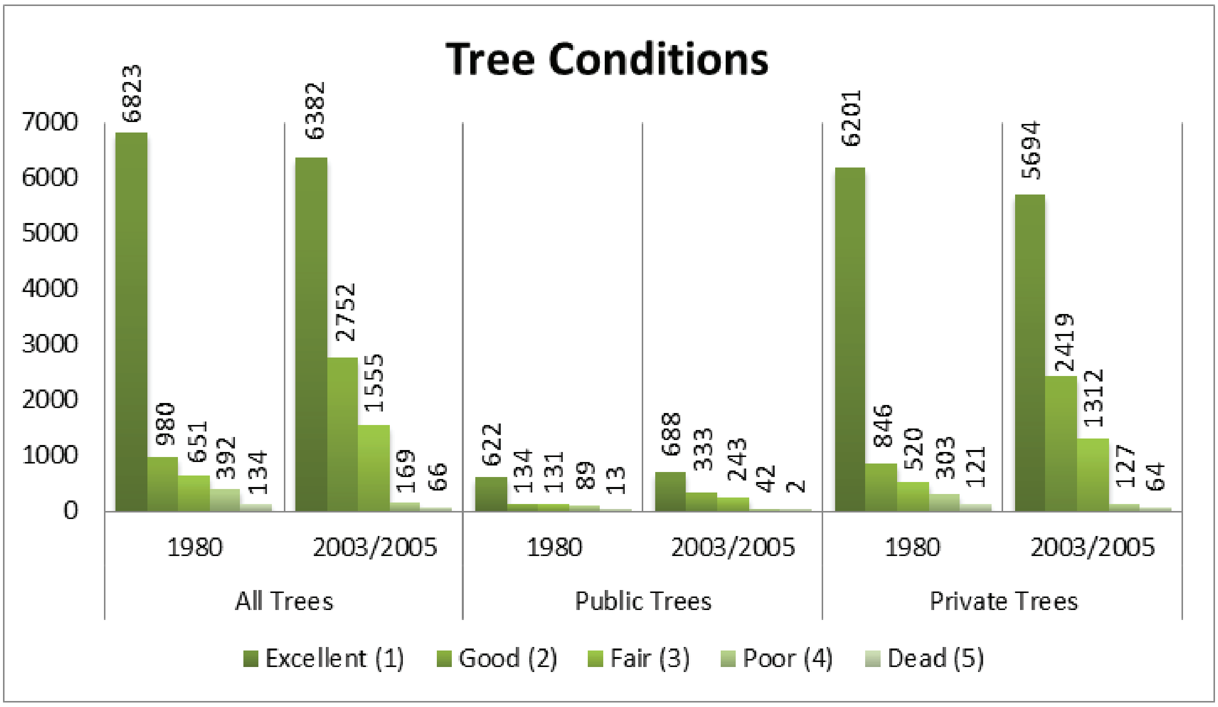

Figure 1
Tree condition rating in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

The average health condition of the 25 most common tree species between 1980 and 2003/2005 shows that the trees were getting significantly worse with time, $F_{1,48} = 5.08$, $p < 0.05$ (table 2). 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. 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. 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.

Table 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.

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Condition				Number of Trees	Average Condition		
		Public	Private[1]	Total[2]			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 pungens)*	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. platanoides)*	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
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.)*	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

(Table 2 cont'd)

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Condition				Number of Trees	Average Condition		
		Public	Private[1]	Total[2]			Public	Private[1]	Total[2]
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	7 299	1.6	1.4	1.5	Total trees	8 882	1.7	1.6	1.6
Sum of all trees	8 980				Sum of all trees	10 924			

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

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

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

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.

Tree Size – The average size class for the top 25 species in 1980 and 2003/2005 is shown on table 3. 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, and in 2003/2005 it was 25.2 cm an increase of 8.0 cm (figure 2). The average public tree dbh in 1980 was 24.3 cm, and it was 29.1 cm in 2003/2005, an increase of 4.8 cm. The average private tree dbh in 1980 was 15.9 cm, and in 2003/2005 the average dbh was 24.7 cm, an increase of 8.8 cm which was a significant increase.

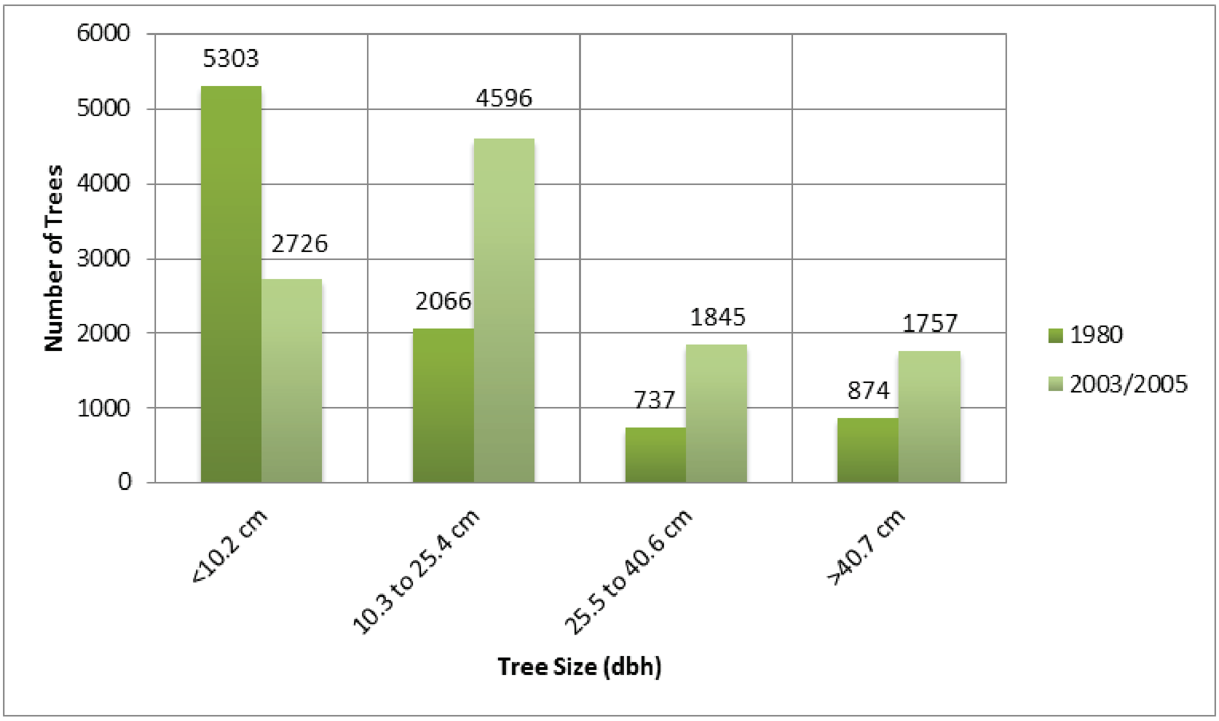

Figure 2
Tree size distribution in the six Midwestern, USA cities' urban forests that were surveyed in 1980 and in 2003/2005.

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 blocks 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 10.2 cmdbh, were the most common at almost every block age. However, in 2003/2005 the 10.3 to 25.4 cm trees were the most common.

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.

Table 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.

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Size				Number of Trees	Average Size		
		Public[1]	Private[2]	Total[3]			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
Blue Spruce *(Picea pungens)*	621	1.1	1.3	1.3	Silver Maple *(Acer saccharinum)*	942	3.2	3.3	3.2
Crabapple *(Malus sp.)*	458	1.1	1.3	1.3	Norway Maple *(A. platanoides)*	701	2.2	2.2	2.2
American Elm *(Ulmus americana)*	418	3.3	2.0	2.4	Blue Spruce *(Picea pungens)*	676	2.7	2.1	2.1
Ash *(Fraxinus sp.)*	389	1.5	1.8	1.7	Ash *(Fraxinus sp.)*	634	2.3	2.5	2.4
Sugar Maple *(A. saccharum)*	355	2.5	1.7	2.0	Crabapple *(Malus sp.)*	523	1.9	1.9	1.9
Arborvitae *(Thuja occidentalis)*	327	1.0	1.2	1.2	Norway Spruce *(P. abies)*	506	4.0	2.5	2.5
Norway Spruce *(P. abies)*	323	2.0	1.7	1.7	Sugar Maple *(A. saccharum)*	334	2.9	2.9	2.9
Norway Maple *(A. platanoides)*	305	1.6	1.7	1.7	White Pine *(Pinus strobus)*	321	3.0	2.2	2.2
Cherry *(Prunus sp.)*	276	1.7	1.5	1.5	Pin Oak *(Quercus palustris)*	292	3.7	3.4	3.5
Red Maple *(A. rubrum)*	262	1.5	1.8	1.7	Redbud *(Cercis canadensis)*	280	2.1	1.6	1.7
Pin Oak *(Quercus palustris)*	254	3.3	2.3	2.5	Red Maple *(A. rubrum)*	268	2.1	2.2	2.2
Dogwood *(Cornus florida)*	246	1.0	1.0	1.0	Mulberry *(Moris sp.)*	265	1.0	1.8	1.8
Apple *(Malus sp.)*	237		1.6	1.6	Pear *(Pyrus sp.)*	248	2.2	1.8	1.9
White Pine *(Pinus strobus)*	233	1.0	1.3	1.3	Dogwood *(Cornus florida)*	238	1.3	1.5	1.5
Redbud *(Cercis canadensis)*	207	1.2	1.3	1.3	Cherry *(Prunus sp.)*	224	2.6	2.1	2.1
Plum *(Prunus sp.)*	203	1.0	1.2	1.2	Black Walnut *(Juglans nigra)*	200	3.7	2.3	2.4
Birch *(Betula sp.)*	195	1.2	1.3	1.3	Honeylocust *(Gliditsia triacanthus)*	193	2.7	2.9	2.9
Scotch Pine *(P. sylvestris)*	187	1.0	1.2		Apple *(Malus sp.)*	171	2.0	1.9	1.9

(Table 3 cont'd)

Taxa	1980				Taxa	2003/2005			
	Number of Trees	Average Size				Number of Trees	Average Size		
		Public[1]	Private[2]	Total[3]			Public[1]	Private[2]	Total[3]
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	7 299	1.7	1.6	1.6	Total trees	8 882	2.6	2.2	2.2
Sum of all trees	8 980				Sum of all trees	10 924			

** Sizes: 1 = <10.2 cmdbh, 2 = 10.3 to 25.4 cmdbh, 3 = 25.5 to 40.6 cmdbh, and 4 = >40.7 cmdbh

[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, $p < 0.0001$

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, three of the cities are very different from the rest, the tree condition was worse in Delaware, Hutchinson, and Lincoln. In the other three cities, Bowling Green, Bucyrus, and Wooster, there was no real difference in the condition of the trees. 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 North eastern 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 of 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 10.3 to 25.4 cmdbh. 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; 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.

Tree Size and Condition Relationship – Intuitively, many think that as trees get larger, they become hazardous 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 10.3 to 25.4 cm category than in the less than 10.2 cm category, as opposed to 1980, when most of the trees were in the less than 10.2 cm 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.

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