FINAL REPORT

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Project Name: Identifying Environmental Constraints Affecting Tree Survival and Growth in Rural, Suburban, and Urban Public Settings

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Please provide an abstract on your project and its results (approximately 200 words or less):

This project was done to assess relationships between tree growth and environmental parameters known to vary across the rural-suburban-urban continuum. For this study, 320 established, healthy, open-crown trees were sampled according to gradients in community population level (0 (rural parks), 500, 5,000 and 50,000) and land use (city parks, residential, and commercial sites) in 5 Midwestern states. According to population levels, trees in rural parks were older (69 years) and had lower mean growth rates (3.5 mm/yr) than trees in small (51 yrs, 4.6 mm/yr), medium (40 yrs, 4.7 mm/yr), and large towns (39 yrs, 4.6 mm/yr). Across the land use gradient, both mean age and growth rate were lower for trees on commercial sites (24 years and 4.1mm/yr) than for those in city parks (54 yrs, and 5.2 mm/yr). The relationships between tree growth rates and several biotic and abiotic variables were also examined. For individual biotic variables, number of other trees within 9 m, and presence of disease, insects, and human-induced injuries were strongly related to tree growth rates. Individual abiotic variables that affected tree growth included bulk density and presence of pavement in proximity to the trees. Values for measured soil properties that increased significantly going from rural to urban and from park to commercial sites included pH. coarse fragment content. and metal content (Pb, Cd, Cu, and Zn). Bulk density increased significantly going from urban to rural sites, and from commercial to park sites, although very few samples had values that are considered limiting to tree growth.

Project objectives:

1. Develop historical information database on trees/soils for 50 to 60 sites in the Midwest.
2. Use this data for selection of smaller number of sites for field study.
3. Perform detailed field study to collect tree and soil samples as well as data on other environmental parameters.
4. Perform gradient analysis and develop environmental indices using data collected above.

Objectives met successfully:

A mailed survey was used to collect historical information for potential study sites. The information gathered was used to develop a stratified random sampling design, which included 6 "clusters" (rural parks. small towns. medium-sized towns, and large towns) of sites located in 5 states (Illinois. Iowa, Minnesota, Missouri, and Wisconsin, see attached figure). Within each town, different land use areas were selected for study. including park, residential. and commercial sites where trees were found. Tree increment cores and associated surface soil samples (15 cm deep) were collected for each of 320 trees located on 42 study sites. In addition, for a single cluster 1-m deep soil cores were collected to more fully describe urban soil characteristics.

Analyses completed to date include evaluation of tree characteristics across the human population gradient and the land use gradient, and regression analyses of tree growth rates in relation to a number of biotic and abiotic factors. In addition, analyses of soil properties across the two gradients have been completed.

Objectives not yet met:

Historical analyses of tree growth rates over time are not complete. Relationships between some soil properties and tree growth rates have not been examined. Comparisons of growth rates for the different species included in the study have not been completed. The results have not yet been combined to develop environmental indices to enable prediction of tree performance in different settings. We anticipate completion of these objectives within 6 months when Rebecca Mack completes her MS thesis. Ms. Mack is one of two graduate students who will earn MS degrees from this project. The other was Valasia Iakovoglou, who successfully defended her thesis in November, 2000.

List the major research or policy findings of your project. If not apparent in the above, or if your project did not involve research, how did the project increase the knowledge we have about urban forestry? How did (will) the public benefit?

Characteristics of the sample tree population

These findings are based on a stratified random sample of 320 trees, partitioned among 4 community population levels (0, 500, 5,000 and 50,000) and 3 land uses (park, residential and commercial) within each community population level. Our proxy for the rural-urban continuum was the selection of towns with these population levels within 45-krn radius areas that we refer to as - clusters". Two clusters were studied in Iowa, and one each in Illinois, Minnesota, Missouri, and Wisconsin (see attached Figure 1). Along the rural-urban continuum, trees on rural sites were older (average age was 67 years) than trees in small towns, medium-sized towns, and large towns (51, 40, and 39 years, respectively). Age ranges encountered across the entire rural-urban gradient were similar, from about 10 years to about 140 years. This indicates that the potential for longevity exists even in relatively large cities. For trees sampled according to land use, average age was greatest for trees in city parks (54 years), intermediate for trees in residential areas (41 years) and lowest for commercial sites (24 years). Age ranges for trees in parks and residential sites were similar. from about 10 to about 140 years. The age range for trees in commercial sites was less, from 9 to 69 years. However, this still indicates greater potential longevity than has been previously reported in the literature for intensively altered (commercial) urban settings.

Most of the trees sampled had relatively high incremental diameter growth rates. The typical annual increment growth averaged over the last 10 years was between 3 and 6 mm/year, with lower average growth occurring on rural sites for the rural-urban gradient, and lower growth rates on commercial sites for the land use gradient. These growth rates are more rapid than the literature led us to expect, although they seem reasonable given our sampling criteria for trees, which included open canopies and overall good health.

Our analyses indicate that tree-tree competition is related to urban tree growth rates even though trees with open or nearly open crowns were selected for this study. Levels of competition are relatively high on rural sites and decrease as community population levels increase (see attached Figure 2). Competition is also greater on park and residential sites compared to commercial sites. Competition level was statistically related to decreased tree growth rates for rural parks, but not for other sites. In fact, on commercial sites, increasing numbers of nearby trees were related to increased growth rates. We are doing further investigation of other factors that may affect tree growth rates in commercial settings. Even though competition was statistically related to growth rates of the sampled trees, it did not seem to be limiting growth from a pragmatic standpoint, since tree growth rates of all sampled trees were relatively high.

Relationship between edaphic factors and tree growth rates

Regression analyses were performed for three scenarios: All species sampled in all clusters. a single species in all clusters, and all species in a single cluster. Six biotic variables and seven abiotic variables were tested for all clusters. Eleven abiotic variables were included in the analysis of a single cluster. Biotic factors that were strongly related to tree growth rates included number of competing trees within 9 m, presence of disease or insects, and human-induced injuries. Abiotic factors that were strongly related to tree growth included soil core bulk density and presence of pavement near the tree. The amount of variability explained using regression techniques was small (between 5 and 11%, depending on the scenario examined). albeit statistically significant.

In general the soil properties observed in this study don't appear to be limiting tree growth. For example, the mean core bulk density of the top 15 cm of soil was 1.1 g cm', which is ideal for growth. Maximum core bulk density was 1.6 g cm', which is only slightly limiting for plant growth. The lowest core bulk densities were found on commercial sites. This reflects the high proportion of peat, bark, wood fragments and other organic debris incorporated into tree planters/pits, which were common in commercial settings. The range in pH for the top 15 cm of soil was 5.3 to 8.0, which suggests that no soil was extremely acidic nor extremely alkaline or sodium-enriched. In analyses completed to date, soil pH has not been found to be an important limiting factor for tree growth. Additional soil analyses that have been completed indicate increasing levels of metals (Pb, Cd. Cu, and Zn) with increasing community population levels and with increasing intensity of land use. Particle size analyses indicate very few textural differences along the urban-rural gradient, for the land use gradient coarser soil textures (more sand and less clay) were observed in commercial settings than in park settings. Additional statistical analyses of soil properties and their relationship to tree growth are ongoing. Analyses of deep soil cores are also ongoing (see Figure 3).

What recommendations might you make for community foresters or others who might benefit from your project?

(1) Characteristics of this sample population suggest that trees can thrive in all of the settings we examined. Thus while good management practices are a must, no particular locale should be "written off' as unsuitable for trees without thorough site investigation.

(2) Urban environments are extremely heterogeneous, both above- and below- ground. Factors that may limit growth in one setting may enhance growth in another setting (e.g. number of neighboring trees has a negative effect on growth rates for park trees, but it has a positive effect for trees in commercial settings). Thus, while generalizations may help somewhat for the purpose of organizing information, they may not apply well to urban tree management from a pragmatic standpoint.

(3) Previously reported urban tree demographics, based on average ages and sizes, may "undersell" the potential of some sites to support long-term tree growth. Based on our study, trees can thrive under the proper conditions even in large cities and in intensive land use settings for up to 70 or 100 years. Since benefits that accrue from these trees increase dramatically as the trees' canopies expand, community foresters should be encouraged to judiciously plant long-lived species and maintain them to achieve maximum benefits in the long run.

Attach copies of reports, publications, or videos. If your work has been published (journals, popular press, etc.), provide where they have been published or reported and how copies can be obtained.

Attached: Iakovoglou. V. 2000. Trees examined along a rural-urban gradient and by local land use in the Midwestern US: An investgation of factors related to tree growth. Unpubl. MS thesis, Iowa State University, Ames, 129 pages.

Other publications are not yet available. We will provide copies to NUCFAC and Midwest area coordinators as soon as they are completed.

How were your results disseminated to the public?

Abstracts based on this project have been submitted for presentations at the International Society of Arboriculture's Midwest Chapter meeting in February, 2001 and for the National Urban Forestry Conference in September. 2001. Four manuscripts are in preparation and will be submitted for peer review early in 2001. Journals to which these will be submitted include Journal of Arboriculture, Journal of Environmental Quality, and the Soil Science Society of America Journal. Those manuscripts as well as a more popular audience "fact sheet" will be distributed to State Urban Forestry Coordinators and their advisory councils throughout the Midwest, as well as to contacts at all field sites included in the study.

List the active partners (key individuals or organizations) involved in the project:

Jan Thompson, Lee Burras, Phil Dixon, John Smith (Faculty/staff, Iowa State University)
Valasia Iakovoglou. Rebecca Mack (Graduate Research Assistants, Iowa State University)
Peggy Sand. Dick Rideout, Robert Krepps, John Walkowiak, Reinee Hildebrandt (current or former State Urban Forestry Coordinators in 5-state study area)
Local contacts (city foresters, city clerks, local tree volunteers, or public works personnel at 42 sites)

Photo or Illustration:

See attached figures. Citations are given on each.

If a no-cost time extension was granted for this project, why was it needed?

One no-cost time extension was granted to allow completion of data analyses. The extra time was needed for the two graduate students working on the project adequate time to process the data and write draft manuscripts to be submitted for publication.

How would you evaluate the grant process? What changes, if any, would you recommend?

The grant process was excellent. Preparation of a less detailed pre-proposal before submittal of the full proposal was very helpful to us. We enjoyed excellent communication with Ms. del Villar, who addressed all of our questions in a, very timely manner as the project went forward. We appreciated the mail reminders for submittal of progress reports, and it was helpful that preparation of those reports satisfied both NUCFAC and our Federal reporting requirements. We recommend no changes.

Comments considered of importance but not covered above:

We thank NUCFAC for their support of this project. It offered the principle investigators the opportunity to more closely examine factors affecting urban tree growth in a variety of settings. It offered the opportunity and provided monetary support for two graduate students to focus on a significant research problem for a two-year period. We look forward to publication of the results in the very near future.

This report was prepared by:
Name: Jan Thompson
Title: Assistant Professor, Forest Biology and Urban & Community **Forestry**
Phone Number: 515-294-0024
Date: December 19, 2000

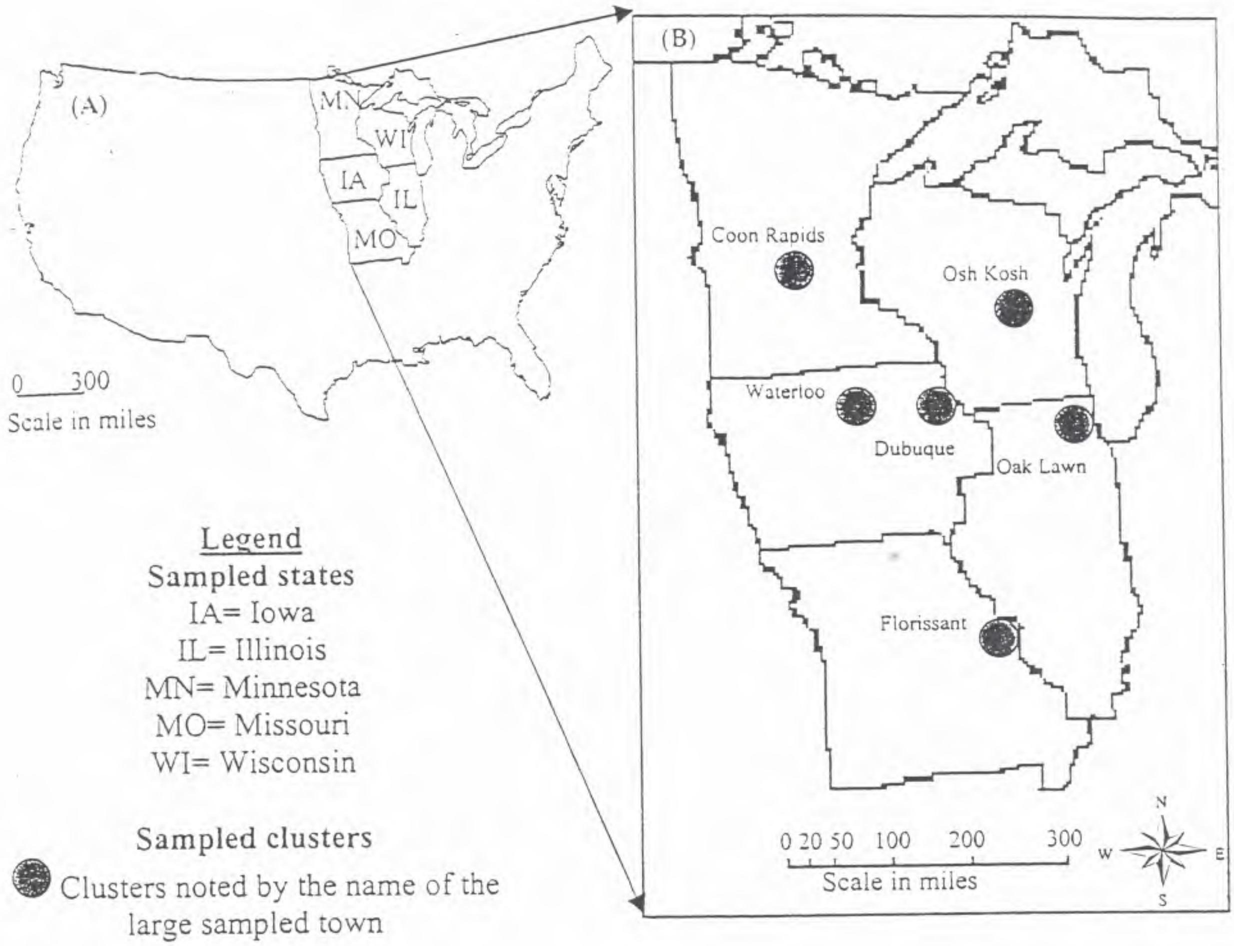


Figure 1. A) Presentation of the study area. Five states representing the Midwest (IA-1, IA-2, IL, MN, MO, WI) were included in the study. B) Map indicates the approximate location of clusters according to the largest sampled town.

From Iakovoglou, V. 2001. Trees examined along a rural-urban gradient and by land use in the Midwestern U.S.: An investigation of factors related to tree growth. Unpublished M.S. Thesis, Iowa State Univ. Ames, IA.

Figure 2. Photo A shows a typical rural park, photo B shows a typical commercial site, Photo C and photo D show a city park and residential site, respectively.

From Iakovoglou, V. 2001. Trees examined along a rural-urban gradient and by land use in the Midwestern U.S.: An investigation of factors related to tree growth. Unpublished M.S. Thesis, Iowa State Univ. Ames, IA.

sentation of large trees than did other land-use types. Kjelgren and Clark (1992) included an analysis of the effect of land use on radial growth rates for juvenile sweetgum trees in Seattle, Washington; they found higher growth rates for trees growing on park sites compared to downtown street trees and trees on a traffic island site.

The relative performance of several different species in urban settings has also been examined. Average ages vary according to historical availability of different types of plant material. For example, for residential sites in New Jersey and New York, average ages for London planetrees (39 years) and Norway maples (48 years) were much lower than that reported for silver maples (73 years) (Richards 1979: Polanin 1991). Rhoads et al. (1981) evaluated 15 different species in street tree plantings in Philadelphia, finding most rapid radial growth for American elm (*Ulmus americana* cv Augustine, "Augustine ascending elm"), Chinese elm, Japanese scholar tree, and willow oak. Diameter growth rates ranging from 2.8 mm/yr for Alaskan white cedar to 13.4 mm/yr for northern red oak were reported by Rhodes and Stipes (1999) for trees growing on a university campus in Virginia.

One key limitation of previous research is that it does not clearly and systematically distinguish how community population level and land use were related to tree performance. In addition, few studies analyzed the performance of common midwestern urban forest species. Our study was conducted to systematically examine how four different community population levels and three different land uses are related to tree growth and condition for five midwestern species. Population levels included rural parks, small towns (~ 500 people), medium towns (~ 5,000 people), and large towns (~ 50,000 people). Land uses were city park, residential, and commercial. Species were silver maple (*Acer saccharinum* L.), honeylocust (*Gleditsia triacanthos* L.), hackberry (*Celtis occidentalis* L.), black maple (*Acer nigrum* Michx. F.), and basswood (*Tilia americana* L.). We hypothesized that tree growth rate would decrease as population increased due to stress induced by deviation from natural ecosystem characteristics. Among land uses, we hypothesized that there would be a relationship between the level of human impact on a site and tree performance—that intense land uses would be associated with decreased tree growth compared to more natural city park sites. We also hypothesized that species adapted to disturbance (e.g., silver maple) would perform better on a variety of different site types.

MATERIALS AND METHODS

Study Area and Site Selection

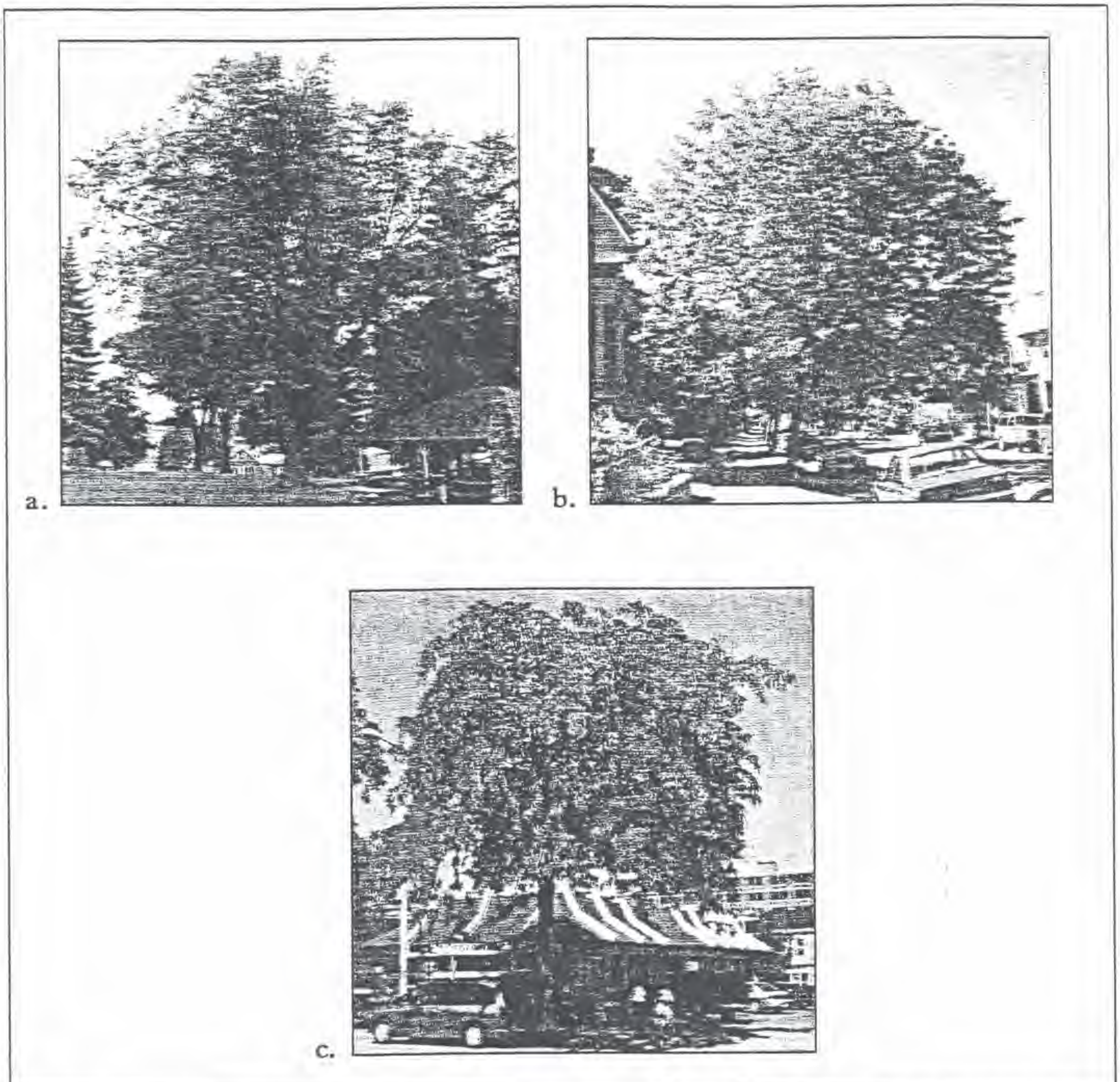
The study area included Illinois, Iowa, Minnesota, Missouri, and Wisconsin. Sites were between 45° 34' N and 38° 42' N latitude, and between 8745' W and 94° 02' W longitude. The sampling protocol used "clusters" of towns, each composed of two rural parks, two small towns (approximate population of 500), two medium towns (population of 5,000), and one large town (population of 50,000). One cluster was sampled in Illinois, Minnesota, Missouri, and Wisconsin, and two clusters were sampled in Iowa. The large town in each cluster was randomly selected from a list of towns in each state with an approximate population of 50,000. In order to minimize geographic and climatic variability within each cluster, other sampled locations were randomly selected from lists of towns with appropriate population levels within a 45-km (28-mi) radius of the largest town. Each municipality was contacted by letter and by telephone in advance of fieldwork, and permission was obtained to collect samples. All samples were collected between May and September 1999.

Within each community, sites were randomly selected within specific land uses using city maps. For large and medium towns, trees in commercial and residential districts as well as from city parks were sampled. In small towns, only trees in residential and city park sites were sampled, due to absence of trees in commercial districts.

City park sites were city-designated park/recreation areas (Figure la). Mowed lawn (evidence of maintenance) was the primary criterion for site selection within city parks. Residential sites were areas of single-family housing with yards (Figure lb). Commercial sites were areas surrounded by sidewalks, parking lots, or other commercial amenities with businesses extending at least one city block in each direction (Figure lc).

Selection of Sample Trees

To control biological variability, only five species—silver maple, honeylocust, hackberry, black maple, and basswood—were sampled. These species were chosen because of their broad geographical ranges. abundance in the study area (Preston 1989), representation in the urban forests of the area (Schoon 1993), and general good health. Species exhibiting decline symptoms (the ashes) or susceptible to disease transmission using the increment borer (the oaks) were avoided. Although sites were randomly chosen, the largest, healthiest, and most open-grown trees on those sites were preferen-



a. b. c.

Figure 1. Representative sites for a large town (Dubuque) in Iowa. (a) City park, (b) residential area, and (c) commercial site.

tially sampled, and among species silver maple was preferentially sampled (up to 50% representation). These criteria were imposed to minimize extraneous factors (other than site) that might influence growth and to provide data for in-depth analysis of a single species across all sites. Four to six trees per land use within each town were selected.

Measurements of Sample Trees and Tree Core Collection

Tree height and diameter at 1.37 m (4.5 ft dbh) were recorded for each tree. Height and dbh were measured using a clinometer and a diameter tape, respectively.

Tree cores were extracted from each tree at dbh using a handheld 5-mm (0.2-in.) diameter increment borer following the method described by Phipps (1985). Cores up to 61 cm (24 in.) long were collected. Cores were stored in 5-mm plastic straws in a chilled cooler (field) or freezer (laboratory). Cores were air-dried, glued in wooden trays, and smoothed with fine-grade sandpaper. Ring width measurements were done manually using a magnifying lamp and digital calipers. When rings were difficult to distinguish. a photo-microscope was used and cores were moistened to increase visibility of annual rings.

Tree age was determined for cores reaching the pith. When cores did not reach the pith, an estimate of age was made by dividing the tree diameter by the mean ring width of all measured years. Ring width data for the last ten years were used to compare growth rates between community population levels and different land uses.

Data Analysis

This study used a stratified sampling design. Each cluster represented a stratum, and class variables were the selected community population levels and land uses. Ring width measurements were log-transformed to reduce the effect of age on ring width (Cook 1987). The general linear models (GLM) procedure of the Statistical Analysis System (SAS Institute Inc. 1996) was used to describe and compare mean values of all tree characteristics that were adjusted to accommodate an unbalanced sample size between clusters. For example, the descriptive mean age of 60 years for silver maple in rural settings was adjusted to 62 years to allow comparison in the model for age according to population level, a change of 3%. The types of adjustment required for all models are indicated where marginal means are presented (Littell et al. 1991). Multiple comparisons were done by evaluating p values for all pairs of means for both population level (trees sampled in rural parks, and small, medium, and large towns) and by land use (commercial, residential, and park) (Bowerman and O'Connell 1990). Separate species analyses (resulting in different marginal mean values according to necessary adjustment in the models) were also done using pairwise comparisons. Statistical significance was determined for comparisons with $p < 0.05$.

RES U LTS

Three hundred twenty-eight trees were sampled (Table 1). Silver maple was the most common species sampled (43%), although predominant species varied somewhat according to community. population level and land use (Table 1). Trees over 30 cm (12 in.) diameter constituted 80% of the sample population. Detailed results for tree performance across the two gradients are presented first, followed by a comparison of performance for three of the sampled species.

Characteristics of Trees Sampled According to Community Population Level

The age range across the community population gradient for trees sampled in rural park sites was 16 to 148 years; for trees in small and medium towns it was 9 to 144 years and 7 to 130 years, respectively; for trees in large towns it was 10 to 144 years.

As community population level increased, sampled trees were younger, shorter, and had smaller diameters (Figure 2). Application of the statistical model to examine the population level gradient to two individual species (silver maple and honeylocust), however, indicated that silver maple deviated from the general pattern observed, with no significant differences in age or diameter along the population gradient (Figure 2).

Table 1. Number of sampled trees by species across the community population gradient and land use. Row totals indicate the total number of trees sampled in each community and land use, and column totals indicate the total number of sampled trees for each species. For land use, parks include only city parks.

Gradient		Number of trees of each species					
Community population	Total # of sites	Silver maple	Honeylocust	Hackberry	Black maple	Basswood	Total # of trees
Rural park	12	9	7	12	8	8	44
Small town	11	42	6	10	15	3	76
Medium town	12	57	27	15	14	12	125
Large town	6	32	34	8	2	7	83
Total	**4**	**140**	**74**	**45**	**39**	**30**	**328**
Land use	Total # of site types						
City park	26	55	23	20	7	6	111
Residential	29	63	12	13	16	12	116
Commercial	15	13	32	0	8	4	57
Total	**70**	**131**	**67**	**33**	**31**	**22**	**284**

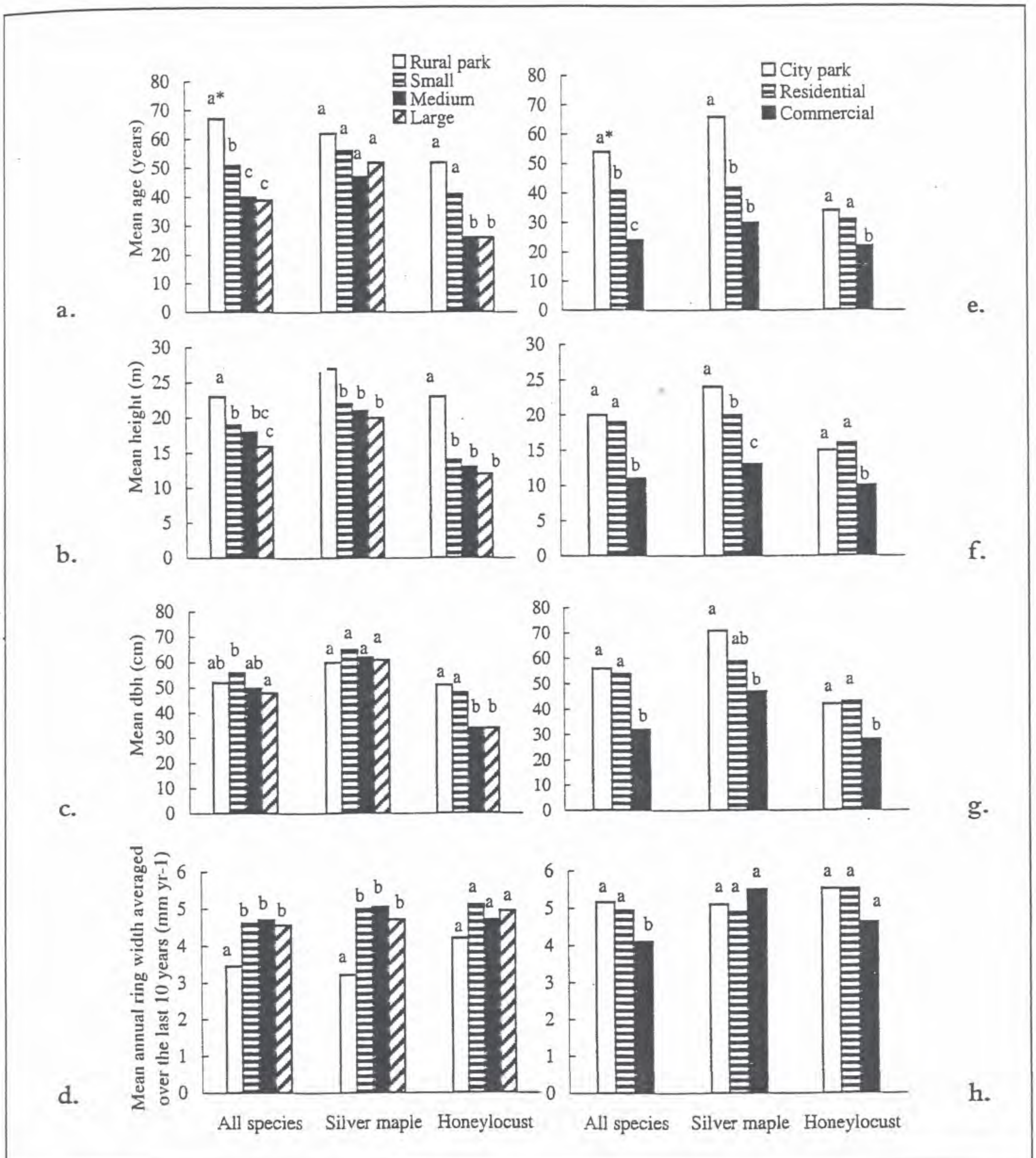


Figure 2. (a) Mean age, (b) height, and (c) diameter (adjusted for cluster) and (d) mean annual ring width over the past 10 years (also adjusted for age) for all species, silver maple, and honeylocust for community population levels; and (e) mean age, (f) height, and (g) diameter (adjusted for cluster) and (h) mean annual ring width over the past 10 years (also adjusted for age) for all species, silver maple, and honeylocust for land use. *Means with the same letter are not significantly different at $p < 0.05$.

Adjusted mean annual ring width, averaged over the past 10 years for all species, was smaller for trees in rural parks than those in small, medium. and large towns (Figure 2). There were no differences between small, medium, and large towns. Application of the statistical model for population level in this case indicated that silver maple also had lower growth rates in rural parks compared to all town sizes. Honeylocust showed no differences in ring width along the population gradient. The effect of age on mean annual ring width averaged over the past 10 years for the overall analysis was significant, even though the ring width data were log-transformed for data analysis; greater ring widths were consistently associated with younger trees: $\ln(rw) = —0.0108x + 1.9967; r2=0.38$.

Characteristics of Trees by Land Use

The age range for trees sampled in city parks was 7 to 144 years, for trees on residential sites it was 9 to 144 years, and for trees on commercial sites it was 9 to 69 years.

As land use changed from park and residential to commercial, sampled trees were younger, shorter, and had smaller diameters (Figure 2). When the statistical model for the land-use gradient was applied to all species and to a single species (honeylocust), height and diameter of trees on residential sites were not different from those in city parks.

Adjusted mean annual ring width averaged over the last 10 years for all species was greater for trees in city parks and in residential sites compared to commercial sites (Figure 2). When the land-use model was applied to single species, there were no significant differences in growth rates for silver maple or honeylocust (Figure 2). Again, the effect of age was significant, even though the ring width data were log-transformed for data analysis; greater ring widths were associated with younger trees.

Comparison of Species

Overall adjusted mean age was greater for black maple than for honeylocust. basswood, or hackberry (Table 2). Adjusted mean height and diameter of silver maple were greater than those of all other species. Adjusted mean ring width over the past 10 years for silver maple was also greater than that of black maple and honeylocust.

Table 2. Overall comparison of species based on means (adjusted for cluster, town, size, and land use) for age, height, diameter, and ring width (also adjusted for age).

Species	N	Age	Height	Diameter	Ring width
Silver maple	140	53 ac*	21.1 a	60.4 a	4.8 a
Honeylocust	74	36 b	15.8 b	40.4 b	3.9 b
Hackberry	45	44 cb	16.7 b	44.1 b	4.2 ab
Black maple	39	58 a	16.1 b	43.2 b	3.6 b
Basswood	30	41 b	14.8 b	41.3 b	4.3 ab

*Means within a column with the same letter are not statistically different at $p < 0.05$.

Table 3. Radial growth rates (mm/yr) reported in the literature (sources noted as footnotes below table) and documented during this study in different settings for five species common in the midwestern United States. Some published diameter growth rates were converted to radial growth for ease of comparison.

	Published growth rates (mm/yr)				Measured growth rates (mm/yr)			
Species	Rural areas	Urban small	Urban medium	Urban large	Rural parks	Urban small	Urban medium	Urban large
Silver maple	7–12[z]				1.3–4.7	1.1–14.4	0.7–16.5	1.7–7.0
Basswood	1.5–2.4[z] 2.2[y]				0.8–3.9	5.7–11.0	3.3–9.7	2.8–7.2
Hackberry	2.5–4.0[z]				1.1–9.4	2.0–9.7	1.7–13.3	2.6–7.4
Honeylocust	4–6.5[z]			7.9[w]	1.1–7.4	2.9–6.7	2.3–11.8	2.3–9.0
Black maple	3.2[z]				1.0–4.5	1.0–7.9	1.6–7.8	5.2–5.4
Other species	4.0[t]	1.9[x]		4.0–8.0[v] 2.1-7.9[u] 5.5[s]				

[z]Burns and Honkala 1990.
[y]Hix and Lorimer 1996.
[x]Rhoades and Stipes 1999 (nine different species, Virginia Tech campus site).
[w]Rhoads et al. 1981.
[v]Neal and Whitlow 1997 (willow oak).
[u]Kjelgren and Clark 1992 (sweetgum).
[t]Jo and McPherson 1995 (average for young (< 30cm dbh) hardwood species including maple, elm, honeylocust, mulberry, crabapple, ash).
[s]Smith and Shifley 1984 (mean diameter growth for hardwood species in Illinois and Indiana forests).

Both the range of measured ring widths and the greatest values for ring widths of trees sampled in towns in this study were greater than those we measured in rural parks or found reported in the literature for trees growing in natural stands (Table 3). However, measured ring-width values are consistent with those previously reported for urban trees (Table 3).

Characteristics of Species According to the Two Gradients

A statistical model for species comparison was applied for each community size and land use including all species, but only the three most common species sampled are reported here: silver maple, honeylocust, and hackberry (Table 4). When tree ages were compared according to population level, silver maple and hackberry were older than honeylocust sampled in medium and large towns (Table 4). Silver maple sampled in city parks were also older than honeylocust. For all town sites sampled along both gradients, silver maple had consistently greater height and diameter than did honeylocust. There were no differences between species in adjusted mean ring width for the last 10 years in rural parks or large towns (Table 4). Silver maple had greater adjusted mean ring widths than did honeylocust in small and medium towns and in city parks and commercial areas. In residential areas, silver maple had greater mean ring widths than did hackberry (Table 4).

Table 4. Comparison of three species by community population and land use based on means (adjusted for cluster) for age, height, diameter, and ring width over the past 10 years (also adjusted for age). Analysis included five species, but only three are presented due to small sizes.

	Community population				Land use		
Species	Rural parks	Small town	Medium town	Large town	City park	Residential	Commercial
			Age (years)				
Silver maple	46 a*	54 a	47 a	51 a	64 a	42 a	30 a
Honey locust	48 a	50 a	27 b	29 b	34 b	34 a	22 a
Hackberry	45 a	33 a	53 a	54 a	54 ab	40 a	
			Height (m)				
Silver maple	26.4 a	21.2 a	21.4 a	19.4 a	23.4 a	20.0 a	14.9 a
Honey locust	24.2 a	15.0 b	13.2 b	12.8 b	15.1 b	16.6 b	10.0 b
Hackberry	17.9 b	14.8 b	20.2 a	22.3 a	19.5 b	19.2 ab	
			Diameter (cm)				
Silver maple	59.6 a	63.5 a	62.0 a	60.0 a	69.4 a	58.5 a	49.6 a
Honey locust	46.4 ab	52.5 ab	34.4 b	36.1 b	41.6 b	45.9 b	28.5 b
Hackberry	37.4 b	39.0 b	56.7 a	57.1 a	50.2 b	55.5 ab	
			Ring width of past 10 years (mm/yr)				
Silver maple	2.5 a	5.1 a	5.8 a	5.4 a	4.9 a	5.5 a	8.1 a
Honey locust	2.6 a	3.6 b	4.4 b	4.5 a	3.7 b	4.6 ab	5.0 b
Hackberry	3.0 a	3.8 ab	5.2 ab	6.4 a	4.8 ab	4.5 b	

*Means within a column with the same letter are not statistically different at $p < 0.05$.

DISCUSSION

Community population levels and land uses were each related to tree growth, although our initial hypotheses were not all validated. Our hypothesis that higher community population levels would be associated with reduced growth rates of trees was not supported. In fact, we found the opposite to be true—as community population level increased, mean radial growth rates also increased. Our hypothesis that city park sites would be associated with greater growth rates compared to commercial sites was validated. Lastly, our hypothesis that disturbance-adapted species such as silver maple would perform better on a variety of site types was found to be true.

Although site selection was done randomly for this study, individual tree selection criteria were such that the sample population reported on here is composed of larger, older trees (80% were > 30 cm diameter) compared to earlier reports for urban tree populations (60% to 80% of trees < 30 cm; e.g., Kielbaso and Cotrone 1989, Jo and McPherson 1995). Although this precludes some analyses, our objective of sampling the healthiest specimens at any given site was met. Our results and interpretation are limited to site comparisons, and the sample population reported here should not considered representative of actual urban forests.

The adjusted mean age of trees sampled was youngest in large towns, intermediate in small towns, and oldest in rural parks. These data for the Midwest corroborate trends reported earlier by Moll (1989) and Kielbaso and Cotrone (1989). Our interpretation is that the predominance of younger trees in large towns is largely due to relatively recent tree planting associated with urban redevelopment and/or expansion. For example, according to census data. Coon Rapids (the large town sampled in Minnesota) has experienced a 420% increase in population over the past 40 years (from 14,931 residents in 1960 to 62,790 residents in 1996). Alternatively, the lower average age of trees in more highly populated communities could indicate reduced lifespan, although our study did not include examination of mortality.

Adjusted growth rates averaged over the past 10 years clearly indicate that trees in rural parks have been growing more slowly than trees on city sites. These results corroborate at a regional scale the earlier findings of Rhoades and Stipes (1999), who found reduced radial growth rates for trees in rural areas compared to urban settings in and near Blacksburg, Virginia. Reduced growth rates in our study are partly attributable to greater mean age of rural trees, even though the data were log-transformed to reduce that effect. Although an attempt was made to sample open-crown trees, there were a greater number of potentially competitive trees in the rural parks, which may be related to radial tree growth in those settings (lakovoglou 2001).

For trees sampled according to land use, those in city parks were oldest, residential areas were intermediate, and those in commercial sites were youngest. These trends were consistent with previous reports for street trees (Moll 1989; Foster and Blaine 1978), although previously reported age values for downtown sites were considerably less (7 years and 10 years, respectively). The mean age of these trees reflects relatively recent planting. However, our data also indicate that early mortality on downtown sites may be avoidable. The range in age for trees in commercial settings in our study was from 9 to 69 years, indicating the potential for much greater longevity than is typically believed to be true for downtown environments. Continued investment in seeking better ways to install and manage trees for potentially long lives in commercial districts is worthwhile.

Even though commercial trees were young, they had lower mean growth rates compared to residential and city park trees (Figure 2). Kjelgren and Clark (1992) reported similar findings for juvenile sweetgum trees in Seattle, Washington. Since age was not the cause for reduced growth rates on commercial sites, other site-related factors appear to cause unfavorable conditions for tree growth. This provides evidence that downtown settings are limiting long-term tree growth compared to other land-use types in the Midwest.

The relative performance of the three species most thoroughly evaluated on different site types in this study could be summarized by generally examining the age—growth rate relationships for each species along both of the gradients analyzed. This interpretation is based on fewer available data points (Table 3). Overall, mean tree age decreased with increasing community population and increasing intensity of land use (Figure 2). A concomitant increase in radial growth rate could be expected if growth rate for each species was due simply to age, which was a significant factor in the overall analysis (an expected scenario is shown in Figure 3a). For the town size gradient, silver maple and honeylocust generally follow this pattern (Figure 3b). Although less data are available, hackberry differs from the expected relationship since it has significantly greater growth rates in large towns even though there is not a consistent trend in age along the population gradient for this species (Figure 3b). Considering land-use types, silver maple exhibits an expected increase in growth rate (although not statistically significant) with average age decreasing from park sites to commercial sites (Figure 3c). Differences in growth rate along the land-use gradient were not significant for honeylocust or hackberry, although growth rates for these species were generally lowest on commercial sites in spite of the relative youth of the trees (Figure 3c). This analysis suggests that silver maple, honeylocust, and hackberry could be expected to grow well in urban settings regardless of city size. In addition, it is evident that silver maple grows rapidly even under relatively intense land-use situations where the other species examined in this study do not.

PRACTICAL APPLICATIONS

Characteristics of this sample population suggest that trees can perform well in all of the settings we examined. Thus, while good management practices are a must, no particular locale should be deemed unsuitable for trees without a thorough site investigation. In addition, previously reported urban tree demographics, based on average ages and sizes. may undersell the potential of some sites to support long-term tree growth. Based on our study, trees can thrive under the proper conditions even in large cities and with intensive land uses for 70 to 100 years. Since benefits that accrue from these trees increase dramatically as the trees' canopies

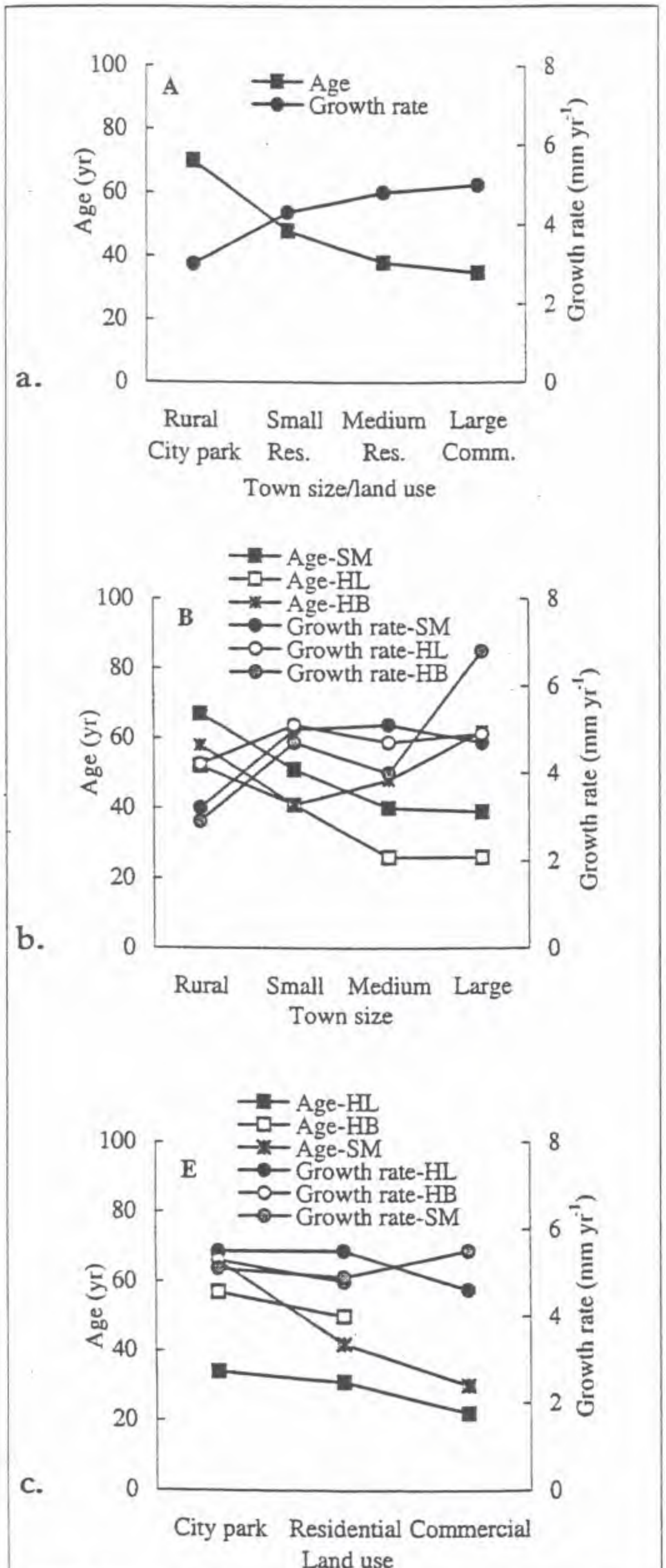


Figure 3. (a) Expected and (b, c) actual age versus growth rates for all species by community population levels (b) and by land uses (c). SM = silver maple, HL = honeylocust, HB = hackberry.

expand, community foresters are encouraged to plant long-lived species and maintain them to achieve maximum benefits in the long run. Finally, although structural integrity in silver maple can be problematic, this species appears to be adapted to environments with significant human disturbance. Thus, silver maple may merit serious consideration for impacted sites where rapid tree growth and canopy development are desired and adequate maintenance will be provided.

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Résumé. À long terme, la croissance des arbres est cruciale en raison des besoins par rapport aux bénéfices procurés par les arbres ainsi que des frais d'investissement élevés. Cette étude a été menée dans cinq états du Midwest américain afin d'examiner comment les caractéristiques des arbres sont reliées au niveau de population ainsi qu'au type d'utilisation du territoire. L'âge, la hauteur, le diamètre et le taux de croissance moyen pour la dernière décennie ont été mesurés sur 328 arbres. Lorsque évalué en terme de type de communauté, les arbres dans les parcs ruraux étaient plus grands que ceux des villes, petites ou grandes. Le taux ajusté de croissance moyenne était plus faible dans les parcs ruraux que dans les petites, moyennes ou grandes villes. Lorsque évalué en terme d'utilisation du territoire, à la fois l'âge moyen et le taux de croissance moyen étaient plus élevés pour les arbres dans les parcs urbains que sur les sites commerciaux. Les arbres dans les secteurs résidentiels avaient des caractéristiques intermédiaires d'âge, de dimensions et de taux de croissance. Des cinq espèces étudiées, l'érable argenté, le févier inerme et le micocoulier occidental étaient celles qui avaient une bonne performance dans les divers types de sites.

Zusammenfassung. Langfristige Baumpflanzungen in Städten sind unter dem Aspekt des daraus resultierenden Nutzens und der Standortkosten kritisch zu beurteilen. Diese Studie wurde in 5 US-Bundesstaaten des mittleren Westens durchgeführt, um die Baumcharakteristika in Bezug mit der Bevölkerung und der Landnutzung zu setzen. Alter, Höhe, Durchmesser und durchschnittliche Wachstumsraten wurden über die Jahre an 328 Bäumen gemessen. Bei Messungen in Bezug auf die Bevölkerungsdichte wurde festgestellt, dass die Bäume in großen Stadtparkanlagen älter waren als in kleinen, mittleren und größeren Städten. Die angepasste mittlere Wachstumsrate war in diesen Anlagen aber geringer. In Bezug auf Landnutzung waren sowohl Durchschnittsalter als auch Durchschnittswachstumsrate bei Stadtbäumen größer als in Gewerbeanlagen. Die Bäume in Wohngegenden hatten durchschnittliche Alter-, Größen-, und Wachstumscharakteristika. Von den 5 untersuchten Spezies zeigten Silberahorn, Gleditschie und Hackberry an allen Standorten gute Ergebnisse.

Resumen. El crecimiento a largo plazo de los árboles urbanos es crucial debido a los altos costos de emplazamiento y por los beneficios derivados de los mismos. Este estudio fue realizado en cinco estados del medio-oeste de los Estados Unidos, con el fin de examinar de qué manera las características del árbol están relacionadas con el nivel de población de la comunidad y el tipo de uso del suelo. Para 328 árboles se midió la edad, altura, diámetro, tasas de crecimiento promedio para los últimos 10 años. Cuando fueron evaluados en términos de la población de la comunidad, los árboles en parques rurales fueron más viejos que los árboles en pueblos pequeños, medios y grandes. Cuando se evaluaron en términos del uso del suelo, tanto la edad media como la tasa de crecimiento fueron mayores para los árboles en parques urbanos que en sitios comerciales. Los árboles en áreas residenciales tuvieron edad intermedia, tamaño y tasa de crecimiento característicos. De las cinco especies estudiadas, silver maple, honeylocust y hackberry trabajaron bien en una amplia variedad de ambientes.

CHARACTERISTICS OF TREES ACCORDING TO COMMUNITY POPULATION LEVEL AND BY LAND USE IN THE U.S. MIDWEST

by Valasia Iakovoglou 1, Jan Thompson 1, and Lee Burras 2

Abstract. Long-term urban tree growth is crucial because of the need for tree-derived benefits and high placement costs. This study was conducted in five U.S. midwestern states to examine how tree characteristics are related to community population leyel and land-use type. Age, height, diameter, and average growth rates for the last decade were measured on 328 trees. When evaluated in terms of community population, trees in rural parks were older than trees in small, medium, and large towns. Adjusted mean growth rate was lower in rural parks than in small, medium, and large towns. When evaluated in terms of land use, both mean age and mean growth rate were higher for trees in city parks than in commercial sites. Trees in residential areas had intermediate age, size, and growth rate characteristics. Of the five species studied, silver maple, honeylocust, and hackberry performed well in a variety of settings.

Key Words. Growth rate; age—growth rate relationships; tree performance; increment core analysis.

It is often suggested that urban environments are stressful for trees because they differ from forest environments with respect to a number of factors. As Whitlow and Bassuk (1987) and Nowak and McBride (1991) have pointed out, the types of stress imposed in urban settings differ from those of forest environments, although the magnitude of stress has not been shown to be different. Owing to the complexity and interrelated nature of different environmental stress factors that may affect urban trees, previous researchers have suggested the use of tree performance to evaluate the impact of site on urban trees (e.g., Whitlow and Bassuk 1987; Neal and Whitlow 1997). Easily identified urban characteristics, such as population level and different types of land use, may be related to environmental stress and could be used to extend this approach beyond specific site analyses.

There has been little research done to systematically compare tree performance according to human population levels and land use, although some work has analyzed tree age, size, and growth rate. Moll (1989) reported differences in tree populations between rural and urban settings, with much higher average ages for trees in rural settings (150 years) compared to city trees (32 years) using data gathered during a nationwide survey from more than 300 cities in 21 U.S. states. Based on the same data, Kielbaso and Cotrone (1989) described the diameter distribution of sampled trees, with 66% less than 30 cm (12 in.) in diameter and only 8% more than 60 cm (24 in.) in diameter. In an analysis of the urban forest structure of Chicago, Illinois, Nowak (1994) reported that only 7.5% of trees were greater than 46 cm (18 in.). Jo and McPherson (1985) also found that 80% to 90% of residential trees in two neighborhoods in Chicago were less than 30 cm (12 in.) diameter. Radial growth rates of urban trees also appeared to vary according to city size. In general, radial growth rates reported for rural forest areas ranged from 1.5 mm/yr to 12 mm/yr for species that are common in both forested and urban areas of the Midwest (Smith and Shifley 1984; Burns and Honkala 1990; Hix and Lorimer 1996). Radial growth rates for urban areas ranged from 1.9 mm/yr in small towns to 8 mm/yr in large towns (Rhoads et al. 1981; Jo and McPherson 1985; Kjelgren and Clark 1992; Neal and Whitlow 1997; Rhoades and Stipes 1999). In one study that directly compared the radial growth rates of rural and urban trees, Rhoades and Stipes (1999) found greater growth rates for urban trees, which they attributed to fertilization and lack of competition on the urban sites.

Within urban settings, there is limited information available on the potential effect of land use on tree performance. Moll (1989) reported lower average age (7 years) for trees in downtown areas compared to the average age of trees on residential sites (32 years). Slightly greater ages (median age of 17 years) were reported by Urban (1989) for trees growing in downtown areas in 13 eastern U.S. cities. Nowak (1994) reported that institutional land dominated by buildings and residential areas in Chicago had greater proportional representation of large trees than did other land-use types. Kjelgren and Clark (1992) included an analysis of the effect of land use on radial growth rates for juvenile sweetgum trees in Seattle, Washington; they found higher growth rates for trees growing on park sites compared to downtown street trees and trees on a traffic island site.

The relative performance of several different species in urban settings has also been examined. Average ages vary according to historical availability of different types of plant material. For example, for residential sites in New Jersey and New York, average ages for London planetrees (39 years) and Norway maples (48 years) were much lower than that reported for silver maples (73 years) (Richards 1979; Polanin 1991). Rhoads et al. (1981) evaluated 15 different species in street tree plantings in Philadelphia, finding most rapid radial growth for American elm (*Ulmus americana* cv Augustine, "Augustine ascending elm"), Chinese elm, Japanese scholar tree, and willow oak. Diameter growth rates ranging from 2.8 mm/yr for Alaskan white cedar to 13.4 mm/yr for northern red oak were reported by Rhodes and Stipes (1999) for trees growing on a university campus in Virginia.

One key limitation of previous research is that it does not clearly and systematically distinguish how community population level and land use were related to tree performance. In addition, few studies analyzed the performance of common midwestern urban forest species. Our study was conducted to systematically examine how four different community population levels and three different land uses are related to tree growth and condition for five midwestern species. Population levels included rural parks, small towns 500 people), medium towns 5,000 people), and large towns 50,000 people). Land uses were city park, residential, and commercial. Species were silver maple (*Acer saccharinum* L.), honeylocust (*Gleditsia triacanthos* L.), hackberry (*Celtis occidentalis* L.), black maple (*Acer nigrum* Michx. E), and basswood (*Tilia americana* L.). We hypothesized that tree growth rate would decrease as population increased due to stress induced by deviation from natural ecosystem characteristics. Among land uses, we hypothesized that there would be a relationship between the level of human impact on a site and tree performance—that intense land uses would be associated with decreased tree growth compared to more natural city park sites. We also hypothesized that species adapted to disturbance (e.g., silver maple) would perform better on a variety of different site types.

MATERIALS AND METHODS

Study Area and Site Selection

The study area included Illinois, Iowa, Minnesota, Missouri, and Wisconsin. Sites were between 45° 34' N and 38° 42' N latitude, and between 87°45' W and 94° 02' W longitude. The sampling protocol used "clusters" of towns, each composed of two rural parks, two small towns (approximate population of 500), two medium towns (population of 5,000), and one large town (population of 50,000). One cluster was sampled in Illinois, Minnesota, Missouri, and Wisconsin, and two clusters were sampled in Iowa. The large town in each cluster was randomly selected from a list of towns in each state with an approximate population of 50,000. In order to minimize geographic and climatic variability within each cluster, other sampled locations were randomly selected from lists of towns with appropriate population levels within a 45-km (28-mi) radius of the largest town. Each municipality was contacted by letter and by telephone in advance of fieldwork, and permission was obtained to collect samples. All samples were collected between May and September 1999.

Within each community, sites were randomly selected within specific land uses using city maps. For large and medium towns, trees in commercial and residential districts as well as from city parks were sampled. In small towns, only trees in residential and city park sites were sampled, due to absence of trees in commercial districts.

City park sites were city-designated park/recreation areas (Figure la). Mowed lawn (evidence of maintenance) was the primary criterion for site selection within city parks. Residential sites were areas of single-family housing with yards (Figure lb). Commercial sites were areas surrounded by sidewalks, parking lots, or other commercial amenities with businesses extending at least one city block in each direction (Figure 1c).

Selection of Sample Trees

To control biological variability, only five species—silver maple, honeylocust, hackberry, black maple, and basswood—were sampled. These species were chosen because of their broad geographical ranges, abundance in the study area (Preston 1989), representation in the urban forests of the area (Schoon 1993), and general good health. Species exhibiting decline symptoms (the ashes) or susceptible to disease transmission using the increment borer (the oaks) were avoided. Although sites were randomly chosen, the largest, healthiest, and most open-grown trees on those sites were preferen-

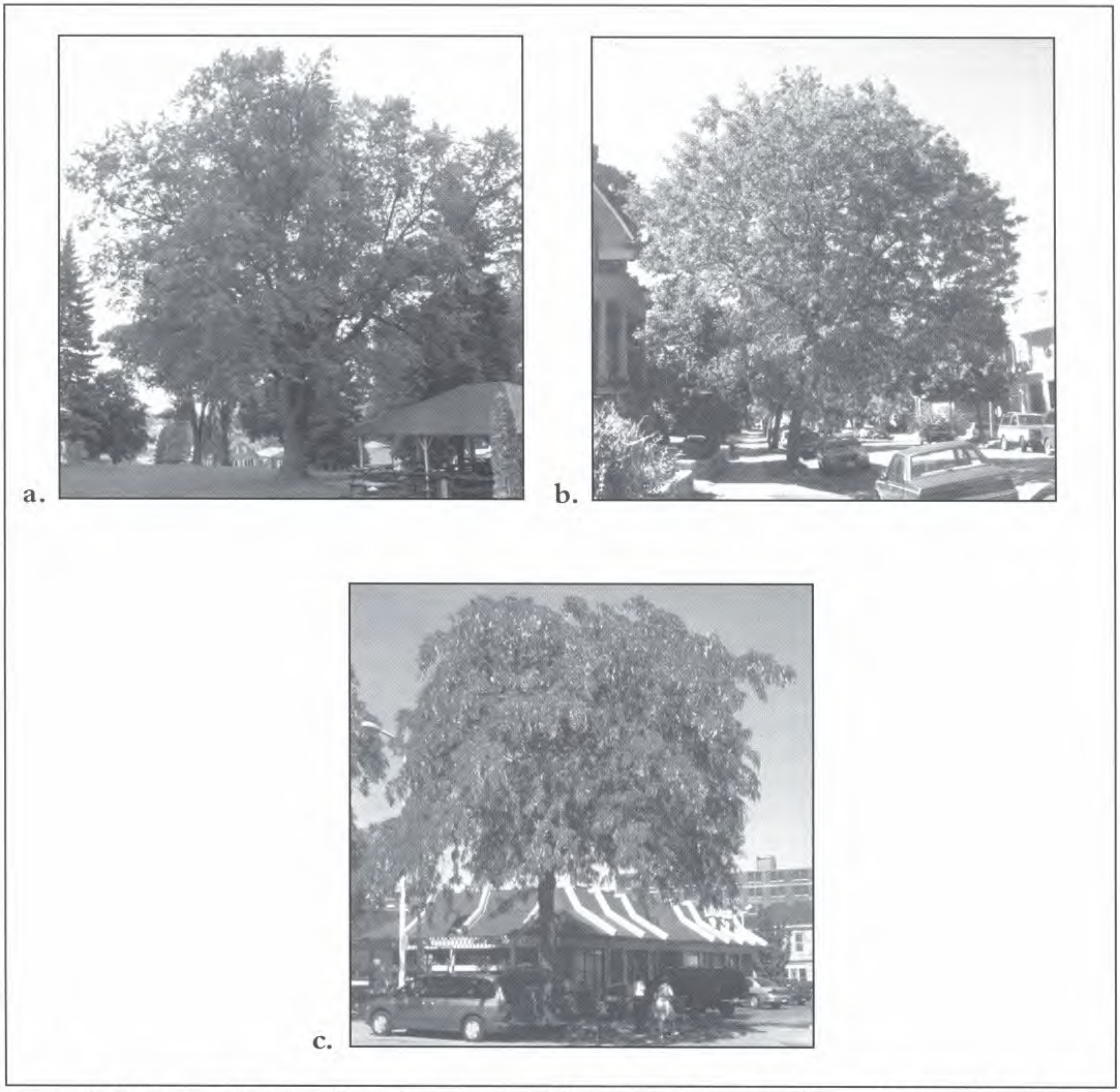

Figure 1. Representative sites for a large town (Dubuque) in Iowa. (a) City park, (b) residential area, and (c) commercial site.

tially sampled, and among species silver maple was preferentially sampled (up to 50% representation). These criteria were imposed to minimize extraneous factors (other than site) that might influence growth and to provide data for in-depth analysis of a single species across all sites. Four to six trees per land use within each town were selected.

Measurements of Sample Trees and Tree Core Collection

Tree height and diameter at 1.37 m (4.5 ft dbh) were recorded for each tree. Height and dbh were measured using a clinometer and a diameter tape, respectively

Tree cores were extracted from each tree at dbh using a handheld 5-mm (0.2-in.) diameter increment borer following the method described by Phipps (1985). Cores up to 61 cm (24 in.) long were collected. Cores were stored in 5-mm plastic straws in a chilled cooler (field) or freezer (laboratory). Cores were air-dried, glued in wooden trays, and smoothed with fine-grade sandpaper. Ring width measurements were done manually using a magnifying lamp and digital calipers. When rings were difficult to distinguish, a photo-microscope was used and cores were moistened to increase visibility of annual rings.

Tree age was determined for cores reaching the pith. When cores did not reach the pith, an estimate of age was made by dividing the tree diameter by the mean ring width of all measured years. Ring width data for the last ten years were used to compare growth rates between community population levels and different land uses.

Data Analysis

This study used a stratified sampling design. Each cluster represented a stratum, and class variables were the selected community population levels and land uses. Ring width measurements were log-transformed to reduce the effect of age on ring width (Cook 1987). The general linear models (GLM) procedure of the Statistical Analysis System (SAS Institute Inc. 1996) was used to describe and compare mean values of all tree characteristics that were adjusted to accommodate an unbalanced sample size between clusters. For example, the descriptive mean age of 60 years for silver maple in rural settings was adjusted to 62 years to allow comparison in the model for age according to population level, a change of 3%. The types of adjustment required for all models are indicated where marginal means are presented (Littell et al. 1991). Multiple comparisons were done by evaluating p values for all pairs of means for both population level (trees sampled in rural parks, and small, medium, and large towns) and by land use (commercial, residential, and park) (Bowerman and O'Connell 1990). Separate species analyses (resulting in different marginal mean values according to necessary adjustment in the models) were also done using pairwise comparisons. Statistical significance was determined for comparisons with $p < 0.05$.

RES U LTS

Three hundred twenty-eight trees were sampled (Table 1). Silver maple was the most common species sampled (43%), although predominant species varied somewhat according to community population level and land use (Table 1). Trees over 30 cm (12 in.) diameter constituted 80% of the sample population. Detailed results for tree performance across the two gradients are presented first, followed by a comparison of performance for three of the sampled species.

Characteristics of Trees Sampled According to Community Population Level

The age range across the community population gradient for trees sampled in rural park sites was 16 to 148 years; for trees in small and medium towns it was 9 to 144 years and 7 to 130 years, respectively; for trees in large towns it was 10 to 144 years.

As community population level increased, sampled trees were younger, shorter, and had smaller diameters (Figure 2). Application of the statistical model to examine the population level gradient to two individual species (silver maple and honeylocust), however, indicated that silver maple deviated from the general pattern observed, with no significant differences in age or diameter along the population gradient (Figure 2).

Table 1. Number of sampled trees by species across the community population gradient and land use. Row totals indicate the total number of trees sampled in each community and land use, and column totals indicate the total number of sampled trees for each species. For land use, parks include only city parks.

Gradient		Number of trees of each species					
Community population	Total # of sites	Silver maple	Honeylocust	Hackberry	Black maple	Basswood	Total # of trees
Rural park	12	9	7	12	8	8	44
Small town	11	42	6	10	15	3	76
Medium town	12	57	27	15	14	12	125
Large town	6	32	34	8	2	7	83
Total	**4**	**140**	**74**	**45**	**39**	**30**	**328**
Land use	Total # of site types						
City park	26	55	23	20	7	6	111
Residential	29	63	12	13	16	12	116
Commercial	15	13	32	0	8	4	57
Total	**70**	**131**	**67**	**33**	**31**	**22**	**284**

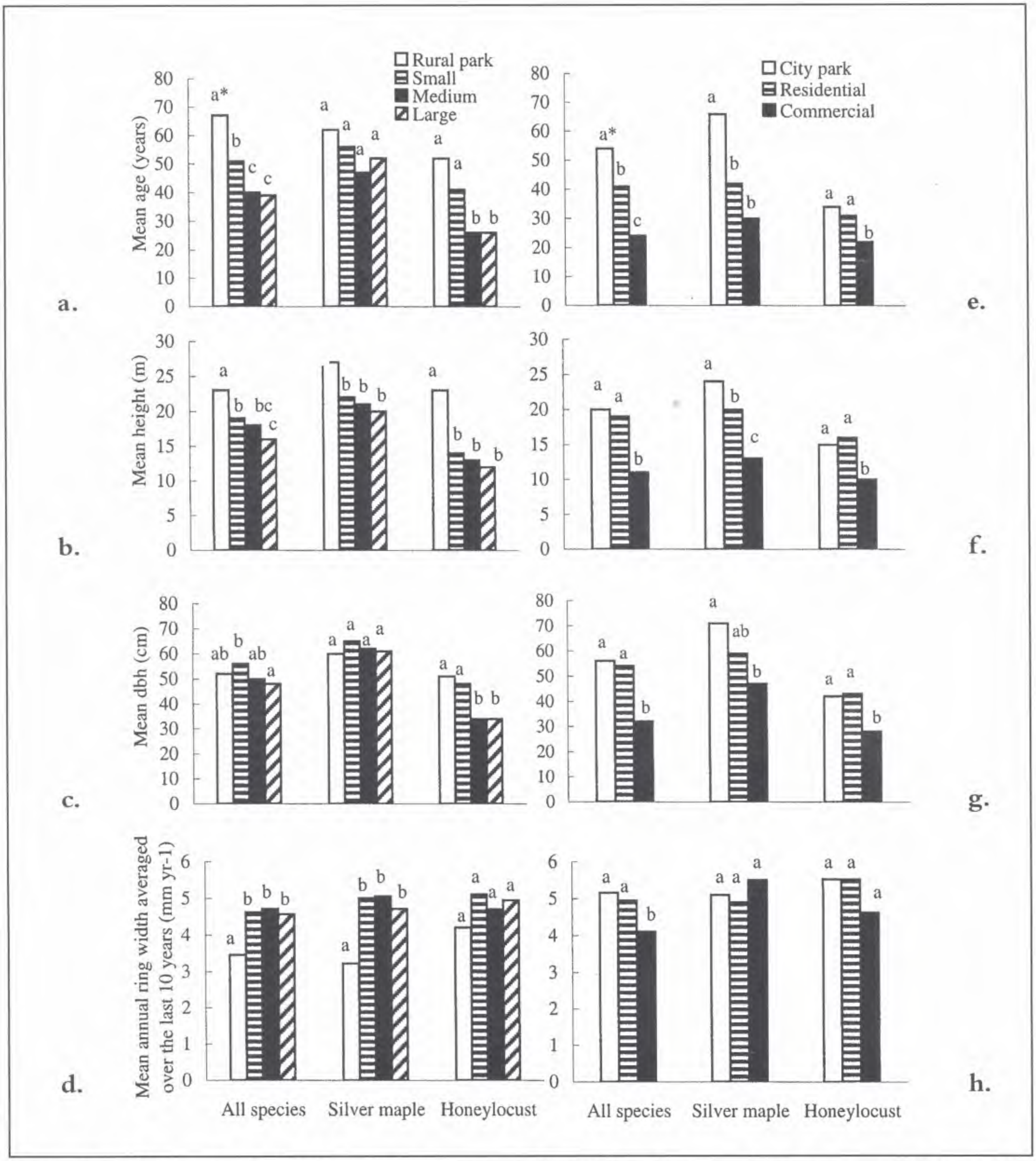

Figure 2. (a) Mean age, (b) height, and (c) diameter (adjusted for cluster) and (d) mean annual ring width over the past 10 years (also adjusted for age) for all species, silver maple, and honeylocust for community population levels; and (e) mean age, (f) height, and (g) diameter (adjusted for cluster) and (h) mean annual ring width over the past 10 years (also adjusted for age) for all species, silver maple, and honeylocust for land use. *Means with the same letter are not significantly different at $p < 0.05$.

Adjusted mean annual ring width, averaged over the past 10 years for all species, was smaller for trees in rural parks than those in small, medium, and large towns (Figure 2). There were no differences between small, medium, and large towns. Application of the statistical model for population level in this case indicated that silver maple also had lower growth rates in rural parks compared to all town sizes. Honeylocust showed no differences in ring width along the population gradient. The effect of age on mean annual ring width averaged over the past 10 years for the overall analysis was significant, even though the ring width data were log-transformed for data analysis; greater ring widths were consistently associated with younger trees: in (rw) = —0.0108x + 1.9967; r^2 =0.38.

Characteristics of Trees by Land Use

The age range for trees sampled in city parks was 7 to 144 years, for trees on residential sites it was 9 to 144 years, and for trees on commercial sites it was 9 to 69 years.

As land use changed from park and residential to commercial, sampled trees were younger, shorter, and had smaller diameters (Figure 2). When the statistical model for the land-use gradient was applied to all species and to a single species (honeylocust), height and diameter of trees on residential sites were not different from those in city parks.

Adjusted mean annual ring width averaged over the last 10 years for all species was greater for trees in city parks and in residential sites compared to commercial sites (Figure 2). When the land-use model was applied to single species, there were no significant differences in growth rates for silver maple or honeylocust (Figure 2). Again, the effect of age was significant, even though the ring width data were log-transformed for data analysis; greater ring widths were associated with younger trees.

Comparison of Species

Overall adjusted mean age was greater for black maple than for honeylocust, basswood, or hackberry (Table 2). Adjusted mean height and diameter of silver maple were greater than those of all other species. Adjusted mean ring width over the past 10 years for silver maple was also greater than that of black maple and honeylocust.

Table 2. Overall comparison of species based on means (adjusted for cluster, town, size, and land use) for age, height, diameter, and ring width (also adjusted for age).

Species	N	Age	Height	Diameter	Ring width
Silver maple	140	53 ac[z]	21.1 a	60.4 a	4.8 a
Honeylocust	74	36 b	15.8 b	40.4 b	3.9 b
Hackberry	45	44 cb	16.7 b	44.1 b	4.2 ab
Black maple	39	58 a	16.1 b	43.2 b	3.6 b
Basswood	30	41 b	14.8 b	41.3 b	4.3 ab

[z]Means within a column with the same letter are not statistically different at $p < 0.05$.

Table 3. Radial growth rates (mm/yr) reported in the literature (sources noted as footnotes below table) and documented during this study in different settings for five species common in the midwestern United States. Some published diameter growth rates were converted to radial growth for ease of comparison.

	Published growth rates (mm/yr)				Measured growth rates (mm/yr)			
Species	Rural areas	Urban small	Urban medium	Urban large	Rural parks	Urban small	Urban medium	Urban large
Silver maple	7–12[z]				1.3–4.7	1.1–14.4	0.7–16.5	1.7–7.0
Basswood	1.5–2.4[z] 2.2[y]				0.8–3.9	5.7–11.0	3.3–9.7	2.8–7.2
Hackberry	2.5–4.0[z]				1.1–9.4	2.0–9.7	1.7–13.3	2.6–7.4
Honeylocust	4–6.5[z]			7.9[w]	1.1–7.4	2.9–6.7	2.3–11.8	2.3–9.0
Black maple	3.2[z]				1.0–4.5	1.0–7.9	1.6–7.8	5.2–5.4
Other species	4.0[s]	1.9[x]		4.0–8.0[v] 2.1-7.9[u] 5.5[t]				

[z]Burns and Honkala 1990.
[y]Hix and Lorimer 1996.
[x]Rhoades and Stipes 1999 (nine different species, Virginia Tech campus site).
[w]Rhoads et al. 1981.
[v]Neal and Whitlow 1997 (willow oak).
[u]Kjelgren and Clark 1992 (sweetgum).
[t]Jo and McPherson 1995 (average for young (< 30cm dbh) hardwood species including maple, elm, honeylocust, mulberry, crabapple, ash).
[s]Smith and Shifley 1984 (mean diameter growth for hardwood species in Illinois and Indiana forests).

Both the range of measured ring widths and the greatest values for ring widths of trees sampled in towns in this study were greater than those we measured in rural parks or found reported in the literature for trees growing in natural stands (Table 3). However, measured ring-width values are consistent with those previously reported for urban trees (Table 3).

Characteristics of Species According to the Two Gradients

A statistical model for species comparison was applied for each community size and land use including all species, but only the three most common species sampled are reported here: silver maple, honeylocust, and hackberry (Table 4). When tree ages were compared according to population level, silver maple and hackberry were older than honeylocust sampled in medium and large towns (Table 4). Silver maple sampled in city parks were also older than honeylocust. For all town sites sampled along both gradients, silver maple had consistently greater height and diameter than did honeylocust. There were no differences between species in adjusted mean ring width for the last 10 years in rural parks or large towns (Table 4). Silver maple had greater adjusted mean ring widths than did honeylocust in small and medium towns and in city parks and commercial areas. In residential areas, silver maple had greater mean ring widths than did hackberry (Table 4).

Table 4. Comparison of three species by community population and land use based on means (adjusted for cluster) for age, height, diameter, and ring width over the past 10 years (also adjusted for age). Analysis included five species, but only three are presented due to small sizes.

Species	Community population: Rural parks	Small town	Medium town	Large town	Land use: City park	Residential	Commercial
			Age (years)				
Silver maple	46 a[z]	54 a	47 a	51 a	64 a	42 a	30 a
Honey locust	48 a	50 a	27 b	29 b	34 b	34 a	22 a
Hackberry	45 a	33 a	53 a	54 a	54 ab	40 a	
			Height (m)				
Silver maple	26.4 a	21.2 a	21.4 a	19.4 a	23.4 a	20.0 a	14.9 a
Honey locust	24.2 a	15.0 b	13.2 b	12.8 b	15.1 b	16.6 b	10.0 b
Hackberry	17.9 b	14.8 b	20.2 a	22.3 a	19.5 b	19.2 ab	
			Diameter (cm)				
Silver maple	59.6 a	63.5 a	62.0 a	60.0 a	69.4 a	58.5 a	49.6 a
Honey locust	46.4 ab	52.5 ab	34.4 b	36.1 b	41.6 b	45.9 b	28.5 b
Hackberry	37.4 b	39.0 b	56.7 a	57.1 a	50.2 b	55.5 ab	
			Ring width of past 10 years (mm/yr)				
Silver maple	2.5 a	5.1 a	5.8 a	5.4 a	4.9 a	5.5 a	8.1 a
Honey locust	2.6 a	3.6 b	4.4 b	4.5 a	3.7 b	4.6 ab	5.0 b
Hackberry	3.0 a	3.8 ab	5.2 ab	6.4 a	4.8 ab	4.5 b	

[z]Means within a column with the same letter are not statistically different at $p < 0.05$.

DISCUSSION

Community population levels and land uses were each related to tree growth, although our initial hypotheses were not all validated. Our hypothesis that higher community population levels would be associated with reduced growth rates of trees was not supported. In fact, we found the opposite to be true—as community population level increased, mean radial growth rates also increased. Our hypothesis that city park sites would be associated with greater growth rates compared to commercial sites was validated. Lastly, our hypothesis that disturbance-adapted species such as silver maple would perform better on a variety of site types was found to be true.

Although site selection was done randomly for this study, individual tree selection criteria were such that the sample population reported on here is composed of larger, older trees (80% were > 30 cm diameter) compared to earlier reports for urban tree populations (60% to 80% of trees < 30 cm; e.g., Kielbaso and Cotrone 1989, Jo and McPherson 1995). Although this precludes some analyses, our objective of sampling the healthiest specimens at any given site was met. Our results and interpretation are limited to site comparisons, and the sample population reported here should not considered representative of actual urban forests.

The adjusted mean age of trees sampled was youngest in large towns, intermediate in small towns, and oldest in rural parks. These data for the Midwest corroborate trends reported earlier by Moll (1989) and Kielbaso and Cotrone (1989). Our interpretation is that the predominance of younger trees in large towns is largely due to relatively recent tree planting associated with urban redevelopment and/or expansion. For example, according to census data, Coon Rapids (the large town sampled in Minnesota) has experienced a 420% increase in population over the past 40 years (from 14,931 residents in 1960 to 62,790 residents in 1996). Alternatively, the lower average age of trees in more highly populated communities could indicate reduced lifespan, although our study did not include examination of mortality.

Adjusted growth rates averaged over the past 10 years clearly indicate that trees in rural parks have been growing more slowly than trees on city sites. These results corroborate at a regional scale the earlier findings of Rhoades and Stipes (1999), who found reduced radial growth rates for trees in rural areas compared to urban settings in and near Blacksburg, Virginia. Reduced growth rates in our study are partly attributable to greater mean age of rural trees, even though the data were log-transformed to reduce that effect. Although an attempt was made to sample open-crown trees, there were a greater number of potentially competitive trees in the rural parks, which may be related to radial tree growth in those settings (Iakovoglou 2001).

For trees sampled according to land use, those in city parks were oldest, residential areas were intermediate, and those in commercial sites were youngest. These trends were consistent with previous reports for street trees (Moll 1989; Foster and Blaine 1978), although previously reported age values for downtown sites were considerably less (7 years and 10 years, respectively). The mean age of these trees reflects relatively recent planting. However, our data also indicate that early mortality on downtown sites may be avoidable. The range in age for trees in commercial settings in our study was from 9 to 69 years, indicating the potential for much greater longevity than is typically believed to be true for downtown environments. Continued investment in seeking better ways to install and manage trees for potentially long lives in commercial districts is worthwhile.

Even though commercial trees were young, they had lower mean growth rates compared to residential and city park trees (Figure 2). Kjelgren and Clark (1992) reported similar findings for juvenile sweetgum trees in Seattle, Washington. Since age was not the cause for reduced growth rates on commercial sites, other site-related factors appear to cause unfavorable conditions for tree growth. This provides evidence that downtown settings are limiting long-term tree growth compared to other land-use types in the Midwest.

The relative performance of the three species most thoroughly evaluated on different site types in this study could be summarized by generally examining the age—growth rate relationships for each species along both of the gradients analyzed. This interpretation is based on fewer available data points (Table 3). Overall, mean tree age decreased with increasing community population and increasing intensity of land use (Figure 2). A concomitant increase in radial growth rate could be expected if growth rate for each species was due simply to age, which was a significant factor in the overall analysis (an expected scenario is shown in Figure 3a). For the town size gradient, silver maple and honeylocust generally follow this pattern (Figure 3b). Although less data are available, hackberry differs from the expected relationship since it has significantly greater growth rates in large towns even though there is not a consistent trend in age along the population gradient for this species (Figure 3b). Considering land-use types, silver maple exhibits an expected increase in growth rate (although not statistically significant) with average age decreasing from park sites to commercial sites (Figure 3c). Differences in growth rate along the land-use gradient were not significant for honeylocust or hackberry, although growth rates for these species were generally lowest on commercial sites in spite of the relative youth of the trees (Figure 3c). This analysis suggests that silver maple, honeylocust, and hackberry could be expected to grow well in urban settings regardless of city size. In addition, it is evident that silver maple grows rapidly even under relatively intense land-use situations where the other species examined in this study do not.

PRACTICAL APPLICATIONS

Characteristics of this sample population suggest that trees can perform well in all of the settings we examined. Thus, while good management practices are a must, no particular locale should be deemed unsuitable for trees without a thorough site investigation. In addition, previously reported urban tree demographics, based on average ages and sizes, may undersell the potential of some sites to support long-term tree growth. Based on our study, trees can thrive under the proper conditions even in large cities and with intensive land uses for 70 to 100 years. Since benefits that accrue from these trees increase dramatically as the trees' canopies

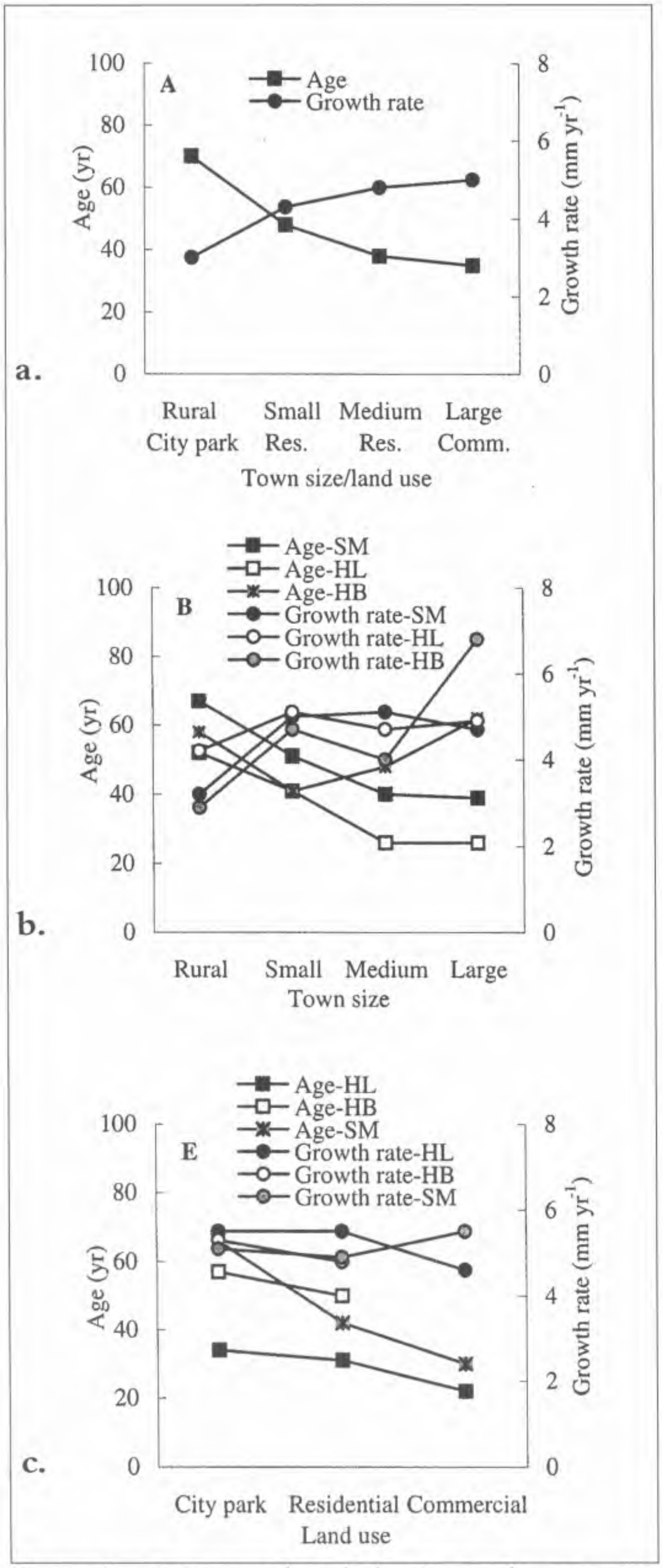

Figure 3. (a) Expected and (b, c) actual age versus growth rates for all species by community population levels (b) and by land uses (c). SM = silver maple, HL = honeylocust, HB = hackberry.

expand, community foresters are encouraged to plant long-lived species and maintain them to achieve maximum benefits in the long run. Finally, although structural integrity in silver maple can be problematic, this species appears to be adapted to environments with significant human disturbance. Thus, silver maple may merit serious consideration for impacted sites where rapid tree growth and canopy development are desired and adequate maintenance will be provided.

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Résumé. À long terme, la croissance des arbres est cruciale en raison des besoins par rapport aux bénéfices procurés par les arbres ainsi que des frais d'investissement élevés. Cette étude a été menée dans cinq états du Midwest américain afin d'examiner comment les caractéristiques des arbres sont reliées au niveau de population ainsi qu'au type d'utilisation du territoire. L'âge, la hauteur, le diamètre et le taux de croissance moyen pour la dernière décennie ont été mesurés sur 328 arbres. Lorsque évalué en terme de type de communauté, les arbres dans les parcs ruraux étaient plus grands que ceux des villes, petites ou grandes. Le taux ajusté de croissance moyenne était plus faible dans les parcs ruraux que dans les petites, moyennes ou grandes villes. Lorsque évalué en terme d'utilisation du territoire, à la fois l'âge moyen et le taux de croissance moyen étaient plus élevés pour les arbres dans les parcs urbains que sur les sites commerciaux. Les arbres dans les secteurs résidentiels avaient des caractéristiques intermédiaires d'âge, de dimensions et de taux de croissance. Des cinq espèces étudiées, l'érable argenté, le févier inerme et le micocoulier occidental étaient celles qui avaient une bonne performance dans les divers types de sites.

Zusammenfassung. Langfristige Baumpflanzungen in Städten sind unter dem Aspekt des daraus resultierenden Nutzens und der Standortkosten kritisch zu beurteilen. Diese Studie wurde in 5 US-Bundesstaaten des mittleren Westens durchgeführt, um die Baumcharakteristika in Bezug mit der Bevölkerung und der Landnutzung zu setzen. Alter, Höhe, Durchmesser und durchschnittliche Wachstumsraten wurden über die Jahre an 328 Bäumen gemessen. Bei Messungen in Bezug auf die Bevölkerungsdichte wurde festgestellt, dass die Bäume in großen Stadtparkanlagen älter waren als in kleinen, mittleren und größeren Städten. Die angepasste mittlere Wachstumsrate war in diesen Anlagen aber geringer. In Bezug auf Landnutzung waren sowohl Durchschnittsalter als auch Durchschnittswachstumsrate bei Stadtbäumen größer als in Gewerbeanlagen. Die Bäume in Wohngegenden hatten durchschnittliche Alter-, Größen-, und Wachstumscharakteristika. Von den 5 untersuchten Spezies zeigten Silberahorn, Gleditschie und Hackberry an allen Standorten gute Ergebnisse.

Resumen. El crecimiento a largo plazo de los árboles urbanos es crucial debido a los altos costos de emplazamiento y por los beneficios derivados de los mismos. Este estudio fue realizado en cinco estados del medio-oeste de los Estados Unidos, con el fin de examinar de qué manera las características del árbol están relacionadas con el nivel de población de la comunidad y el tipo de uso del suelo. Para 328 árboles se midió la edad, altura, diámetro, tasas de crecimiento promedio para los últimos 10 años. Cuando fueron evaluados en términos de la población de la comunidad, los árboles en parques rurales fueron más viejos que los árboles en pueblos pequeños, medios y grandes. Cuando se evaluaron en términos del uso del suelo, tanto la edad media como la tasa de crecimiento fueron mayores para los árboles en parques urbanos que en sitios comerciales. Los árboles en áreas residenciales tuvieron edad intermedia, tamaño y tasa de crecimiento características. De las cinco especies estudiadas, silver maple, honeylocust y hackberry trabajaron bien en una amplia variedad de ambientes.