IOWA, U.S., COMMUNITIES BENEFIT FROM A TREE-PLANTING PROGRAM: CHARACTERISTICS OF RECENTLY PLANTED TREES

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Abstract. Since 1990, externally funded tree-planting activities have taken place in more than 350 Iowa, U.S., communities. The species diversity, survival, size, growth, carbon uptake, carbon storage, and pollution removal of 932 trees planted in 21 communities of different sizes and in different parts of Iowa were assessed by repeated measurements over a 4-year period. The sample included 40 taxa and was dominated by crabapples (*Malus* spp.) and green ash (*Fraxinus pennsylvanica* Marsh.). Species diversity was described using the reciprocal of Simpson's index for the overall population (10.92), by community size, and by location in the state. No differences in species diversity were detected according to community size or location in the state. Overall survival rate for the trees was 91%; no significant differences in survival rate related to community size or location were detected. Estimated carbon stored by all trees was 2,252 kg (4,954 lb), and carbon uptake was estimated to be 568 kg yr^{-1} (1,250 lb). Total pollution removal by all trees was estimated at 2 kg yr^{-1} (4.4 lb).

Key Words. Community forestry; tree survival; urban tree diversity; Simpson's index; carbon sequestration; urban forest sustainability.

Legislation enacted in 1989 by the state of Iowa, U.S., required investor-owned utilities to spend 1.5% to 2% of their revenues on cost-effective energy efficiency incentive programs. The legislation outlined several types of programs, including tree planting. The six existing electric and natural gas companies with service areas in Iowa all became involved in tree-planting programs for energy efficiency. From 1990 through 1997 (in 1997, the legislation was amended to remove the funding formula), several utilities participated in tree planting through a community challenge grant program administered by the nonprofit organization Trees Forever.

As McPherson and Simpson (1999) have indicated, many municipal shade tree programs have been supported by partnerships among utilities, nonprofit organizations, and local municipalities. Most of these programs operate at the level of a single municipality. A well-known example is Sacramento's Cool Community Program (described by Sarkovich 2003). However, in Iowa, utility-supported tree planting was coordinated at the state level by a single nonprofit organization.

By 1995, more than 350 communities throughout Iowa were involved in tree-planting programs funded by utilities in partnership with Trees Forever (Trees Forever 1995). Tree-planting activities were conducted by volunteers in most communities, and Trees Forever staff provided technical assistance and volunteer coordination in participating communities. Community volunteers were encouraged to obtain landscape-sized trees from local nurseries and were provided information on stock selection from a variety of sources (Vitosh and Thompson 2000). Participating communities were required to provide a 50:50 match for grant funds.

Benefits to communities from tree-planting programs include both social and ecological/environmental components. Social benefits include volunteer involvement, sense of community, and development of support for environmental programs such as tree planting. Ecological and environmental benefits of trees in urban and community landscapes depend on a number of factors, including their placement with respect to other structures, site conditions and tree adaptability to those conditions, rate of survivorship, age/size of trees, tree life span, growth rate, and canopy characteristics. For example, in view of global climate change, the potential for direct benefits from carbon storage by urban trees and landscapes has been examined (Minnesota Department of Natural Resources 1991; Sampson et al. 1992; Nowak 1993, 1994; Jo and McPherson 1995; McPherson and Simpson 1999; Nowak and Crane 2002; Nowak et al. 2002), as has the potential for indirect benefits from decreased energy use made possible by proper placement of trees (Heisler 1986; Akbari et al. 1990; McPherson 1994; McPherson and Simpson 1995). These ecological functions depend heavily on the factors listed above and have gone largely unstudied in terms of benefits accruing to small towns through community forestry activities. In addition, given external support for tree planting from utility sponsors, it is important to document the contribution of new trees with respect to benefits provided (in this case, carbon storage and pollution absorption).

Community forestry in Iowa must necessarily focus on programs that will work for small communities, since 97% of the state's incorporated places have populations of fewer than 10,000 people (Iowa League of Municipalities 1995;

Vitosh 1998). Numerous small communities present unique difficulties and opportunities for community tree management efforts across the state and have led to a focus on leveraging resources and involving volunteers in many aspects of community forestry (as recommended for Illinois communities by Groninger et al. 2002). When volunteers are a significant component of community forestry activities, requiring a local "investment" (e.g., 50:50 match) and incorporating sound management goals (including appropriate species diversity, developing uneven-aged stands of long-lived species, providing follow-up care for newly planted trees), constant encouragement, education, and collaborative efforts among resource professionals, communities, and volunteers are necessary.

Between 1990 and 1997, a large number of young trees were added to Iowa's communities through the utility-sponsored challenge grant tree-planting program. Based on detailed project planting records, communities involved in this program planted 38 to 63 mm (1.5 to 2.5 in.) diameter balled and burlapped (44% of trees included in the study) or 1.8 to 3.6 m (6 to 12 ft) containerized stock (54% of trees) readily available at local nurseries. Three communities included in the study had access to a tree spade and planted some larger stock (2% of trees). Community volunteers received training in tree selection, proper tree planting, and young tree maintenance from a Trees Forever community coordinator, and/or through other programs in the state (e.g., the Community Tree Steward program offered through Iowa State University Cooperative Extension). Communities were required to indicate parties responsible for performing routine maintenance at the time of planting and to provide evidence of tree maintenance for at least 3 years following planting, in order to receive subsequent grants.

Based on a community volunteer survey conducted in 1996, a conservative estimate is that approximately 18,320 trees per year were planted with support from this program in participating communities over the 3-year period 1994–1996 (Vitosh and Thompson 2000). The survey conducted in 1996 also documented changes in community programs in response to the availability of external funding and program administration by Trees Forever (Vitosh and Thompson 2000).

The 1996 survey provided the backdrop for an analysis of the biological impact of tree planting in Iowa across a wide range of community sizes and soil conditions. To help provide information to sustain Iowa's urban forest resource (e.g., Clark et al. 1997; Dwyer et al. 2003), an assessment of the newly planted trees was conducted. The objectives of this study were to measure survival, diversity, and growth rates of trees planted using external funding and to determine if community size and/or location in the state had a significant effect on tree success. An additional objective was to assess benefits provided to communities in terms of new tree functions (carbon sequestration, storage, and pollution removal).

METHODS

To obtain a representative sample of communities with newly planted trees in Iowa, a stratified random sampling scheme was used to identify 20 communities of differing sizes that had participated in utility-funded tree planting. Community selection was evenly distributed among four quadrants of the state (Table 1). Each quadrant differed in factors that influence woody plant survival and growth, primarily mean annual temperature and precipitation. The communities sampled in each quadrant included one large community (population > 10,000), two medium (population 2,000–10,000), and two small communities (population < 2,000). One additional large community that participated in a Small Business Association–supported planting program was also selected in the second year of the study.

A random cluster sampling technique was used to identify project sites and trees within sites, based on planting records provided by community volunteers or by Trees Forever personnel. Varying proportions of trees planted on project sites in public settings (10% to 20%) were selected based on the total number of project sites and on the total number of trees that had been planted in each community.

Table 1. Communities in Iowa where trees were sampled by location (quadrant) and by community population level. The total number of sample trees in each community is indicated parenthetically following the community name. In all communities, trees sampled were located in public spaces, except for West Okoboji, where residential trees were evaluated.

Community population category	Quadrant			
	Northeast	Northwest	Southeast	Southwest
>10,000	Waterloo (58)	Sioux City (57)	Iowa City (36)	Ankeny (46) Des Moines (141)
2,000–10,000	Maquoketa (35)	Webster City (57)	Pella (46)	Johnston (48)
	Eldora (70)	Rock Valley (50)	North Liberty (57)	Clarinda (61)
<2,000	Calmar (25) Colesburg (32)	West Okoboji (27) Holstein (34)	Delta (14) Baxter (6)	Lenox (22) Treynor (10)

The most recent planting projects within communities were chosen—those planted during or after fall 1995. Most trees included in the sample had thus been through only the first growing season before their first measurement (an exception is described later). Repeated measurements of the same individual trees were made each year, from spring 1997 through spring 2000. Presence (survival since record or previous year), species, height, diameter [dbh, measured at 1.4 m (4.5 ft)], canopy width, and canopy shape were recorded in 1997. In addition to these parameters, foliage condition ratings and percentage of foliage retained within the measured crown volume were recorded in 1998–2000. Additional planting projects that occurred in the selected communities in spring 1997 were added to the sample in 1998. Sample tree location within the community (street, park, or school planting) was also recorded. Planting projects in the 21st community, added in 1998, had been undertaken in 1994. Although these plantings were 4 years old at first measurement, detailed planting records were available that allowed our first measurement to include mortality since planting.

Simpson's index was calculated for the whole sample population and within each community to evaluate species diversity (Magurran 1988). The Simpson's index (D) was used because of its sensitivity to dominance (in this application, to the number of individuals of particular species or genus groups) within a test population, based on the following equation:

$$D = \Sigma\, [n_i(n_i-1)]/[N(N-1)] \qquad (1)$$

where n_i = the number of specimens of the ith species, and N = the total number of specimens in the population. The reciprocal form of Simpson's index, 1/D, increases with increasing diversity and is the value reported and used in statistical analyses. Simpson's index was selected to describe species diversity due to the known preponderance of two species in the sample.

To compare diversity, the general linear models procedure of the Statistical Analysis System was used for analysis of variance using quadrant and community size as main effects in the model (SAS Institute, Inc. 1996). Statistical significance was determined for comparisons with $p < 0.05$.

Survival was determined based on presence or absence of each tree based on planting records, presence in 1997, and presence in subsequent years. A logistic regression procedure of SAS was used to evaluate overall survival and survival for two species represented in all communities by location (quadrant) and community size. Williams' method was used to account for overdispersion in the analysis of overall survival. The Wald chi-square test was used in the logistic regressions to test significance at $p < 0.05$ (SAS Institute, Inc. 1996).

The Urban Forest Effects (UFORE) model was used to estimate carbon sequestration and pollution removal for the measured trees based on 1998 field data and 2000 hourly pollution and weather data (e.g., Nowak et al. 1998; Nowak and Crane 2000, 2002; Nowak et al. 2002). Estimates of carbon storage per tree were calculated from species and genera-specific allometric equations based on measured tree dbh and height, along with a measured adjustment factor to compensate for differences in biomass between forest and street trees (Nowak 1994). Annual sequestration estimates were based on estimated annual growth using dbh-specific growth rates from street trees (Nowak 1994) in conjunction with the allometric equations.

Hourly pollution removal was calculated using data from visual assessments of canopy density, canopy shape, and tree leaf area estimates (Nowak 1996) in conjunction with hourly weather data (for year 2000) from Des Moines and pollution concentration data (also year 2000) from throughout Iowa. These data were combined in the UFORE deposition model, which is a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi et al. 1987; Baldocchi 1988) to calculate hourly and annual pollution removal by trees.

RESULTS

In 1997, 650 trees were measured in 20 communities (Table 1). In 1998–2000, a total of 932 trees (including the previous 650) in 21 communities were evaluated [8% of the 268 communities that maintained volunteer tree organization records with Trees Forever as of 1996 (Vitosh and Thompson 2000)]. Based on an estimate of 18,320 trees planted per year in Iowa communities (as reported by community volunteers) between 1994 and 1996 (Vitosh and Thompson 2000), the 932 trees represent 0.7% of the approximately 130,000 trees planted between 1990 and 1997. Based on 1998 data, 39% of trees measured were on public school properties, 23% were street trees, and 38% were park trees.

The number of sample trees from each community was related to community size, with means of 21, 53, and 68 trees for small, medium, and large communities, respectively. (Table 1). These numbers were proportional to the number of projects and the number of trees planted within projects according to community planting records. Number of sample trees per community ranged from 6 trees in the smallest community to 140 trees in the largest. Sampled trees were relatively evenly distributed across the four quadrants of the state, with 24% in each of the northern quadrants, 17% in the southeast, and 35% in the southwest quadrant.

Species Diversity

Sample trees included a total of 40 taxa, with trees being identified only to genus for *Malus*, *Prunus*, and *Pyrus* (Table 2). The value of the reciprocal of Simpson's index for the

overall population was 10.92. The average value of the reciprocal of Simpson's index for the quadrants ranged from 4.93 for the southeast to 7.12 for the southwest, although there were no significant differences among quadrants (Table 3). The values of the reciprocal of Simpson's index for individual communities ranged from 1.50 to 13.48, although no significant differences were detected among means calculated for community size (Table 3).

The 10 most commonly planted taxa, which represented approximately 70% of the sample, were crabapple (*Malus* spp.), green ash (*Fraxinus pennsylvanica* Marsh.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), basswood (*Tilia americana* L.), Norway maple (*A. platanoides* L.), honeylocust (*Gleditsia triacanthos* L. var *inermis* Willd.), northern red oak (*Quercus rubra* L.), Japanese tree lilac (*Syringa reticulata*), and ornamental pear (*Pyrus calleryana*).

Table 2. Taxa represented in the sample of new community trees in Iowa, number of specimens of each, and communities in which they were part of the sample. *Malus* spp. and *Fraxinus pennsylvanica* were the only taxa sampled in all communities.

Species (group)	Number of trees in 1998	Number of communities species was sampled in
Abies concolor Lindl.	10	1
Acer × freemannii	12	4
Acer tataricum L. subsp. *ginnala* Maxim.	8	2
Acer nigrum Michx.	7	3
Acer platanoides L.	36	10
Acer rubrum L.	47	10
Acer saccharinum L.	9	7
Acer saccharum Marsh.	46	11
Amelanchier arborea Michx.	7	2
Betula nigra L.	20	5
Celtis occidentalis L.	22	5
Cercis canadensis L.	8	2
Craetagus phaenopyrum L.	17	5
Cornus florida L.	3	1
Fraxinus americana L.	17	4
Fraxinus pennsylvanica Marsh.	107	21
Gingko biloba L.	2	2
Gleditsia triacanthos L. var *inermis* Willd.	33	7
Gymnocladus dioicus L.	1	1
Koelreuteria paniculata	1	1
Malus spp.	215	21
Picea glauca Moench	16	5
Picea mariana Mill.	12	1
Picea pungens Englm.	2	2
Pinus strobus L.	5	1
Pinus sylvestris L.	24	2
Populus alba × *P. grandidentata*	8	1
Prunus spp.	12	5
Pyrus spp.	25	5
Quercus alba L.	2	2
Quercus bicolor Willd.	8	3
Quercus macrocarpa Michx.	11	9
Quercus palustris Muenchh.	8	4
Quercus rubra L.	30	10
Salix babylonica L.	1	1
Syringa reticulata	27	5
Thuja occidentalis L.	9	2
Tilia americana L.	49	10
Tilia cordata Mill.	4	3
Ulmus americana cv. Liberty	1	1

Survival

Based on final field assessments in spring 2000, 847 of 932 trees were still alive, for an overall survival rate of 91% (for most trees, this was over the first 3 or 4 years after planting). Average annual mortality rates, based on tree presence/absence in each year subsequent to first measurement, were 6%. Survival rates for all species combined ranged from 88% to 94% among quadrants, from 88% to 92% by community size (Table 3) and from 87% to 93% by project site (street, park, or school). Based on logistic regressions using Wald's chi-square test, there were no significant differences in overall survival due to quadrant, community size, or project site location.

Survival rates for the 10 most common species ranged from 73% for red maple and basswood to 100% for tree lilac (Table 4). No significant differences were found for crabapple or green ash survival rates when compared by quadrant and community size using the logistic regression procedure. Other than crabapple and green ash, survival rates for individual taxa were not compared statistically due to incomplete representation among communities and quadrants.

Tree Size

Individual tree measurements of the 847 living trees in spring 2000 were used to calculate average tree height, diameter (dbh), and canopy width for the entire population of trees, and by species for the 10 most common species in the population (Table 4). Average height for all trees was 4 m (13.1 ft), average dbh was 69 mm (2.7 in.), and average crown width was 2.7 m (8.9 ft). Tree size varied by species, according to size of available planting stock, and depended

Table 3. Values of the reciprocal of Simpson's Diversity Index (SDI) and tree survival, for each community (one large, two medium, and two small communities) and by quadrant. Standard errors for marginal means of Simpson's index are included. No significant differences were detected for either diversity or survival between quadrants or by community size.

Community population category		Quadrant NE	NW	SE	SW	Average for community size	Standard error of marginal mean (SDI)
>10,000	Diversity	7.06	8.14	2.68	3.81		
					6.94*	5.81	1.53
	Survival (%)	84	84	94	89		
					98*	92	
2,000–10,000	Diversity	12.42	2.69	6.75	6.79		
		5.16	3.83	6.84	13.48	7.24	1.16
	Survival (%)	91	91	100	98		
		87	90	87	92	92	
<2,000	Diversity	4.08	4.76	9.10	7.70		
		6.88	2.46	1.50	4.00	5.06	1.16
	Survival (%)	92	89	100	59		
		94	85	100	90	88	
Average for quadrant	Diversity	7.11	5.00	4.93	7.12		
	Survival (%)	89	88	94	93		
Standard error of SDI marginal mean		1.54	1.54	1.54	1.34		

*Two large communities were sampled in the southwest quadrant.

Table 4. Percentage of sample population represented by the ten most common taxa, their individual survival rates, and mean height, diameter, and crown width with related standard errors as measured in spring 2000. Together these taxa make up approximately 70% of the sample population.

Taxa	% of population	% survival	Height, m (S.E.)	Diameter, mm (S.E.)	Crown, m (S.E.)
Crabapple	24	91	3.6 (0.6)	56 (19)	2.8 (0.7)
Green ash	12	88	5.6 (1.2)	83 (31)	3.2 (0.9)
Red maple	5	73	4.8 (1.3)	60 (14)	2.3 (0.6)
Sugar maple	5	78	5.1 (1.4)	65 (32)	2.4 (0.9)
Basswood	5	73	4.8 (0.9)	80 (15)	2.8 (0.6)
Norway maple	4	89	5.1 (1.0)	78 (24)	2.9 (0.9)
Honeylocust	4	88	5.3 (0.6)	79 (9)	4.1 (0.8)
Red oak	3	88	4.5 (1.2)	60 (17)	2.7 (0.6)
Japanese tree lilac	3	100	2.8 (0.5)	41 (15)	1.5 (0.2)
Ornamental pear	3	78	5.0 (1.1)	78 (18)	2.9 (0.9)

on variation in post-transplant growth rates. The average size of trees in spring 2000 compared to the year of first measurements indicated overall annual growth rates of 8 mm yr^{-1} (0.31 in) in diameter, 0.29 m yr^{-1} height (0.95 ft), and 0.30 m yr^{-1} (0.98 ft) in canopy spread (Table 5).

Carbon Storage

Tree size and condition data collected in 1998 for 857 trees [out of 879 surviving trees, 22 trees that were less than 1.3 cm (0.5 in.) diameter were not included in the analysis because the model is designed for trees with a minimum dbh of 1.3 cm] were used in the UFORE model to estimate carbon (C) storage and annual sequestration on an individual tree basis. Total C stored by the population of trees was estimated at 2,252 kg (4,954 lb), or about 2.7 kg (5.9 lb) per tree. Total C sequestration was estimated at 568 kg yr^{-1} (1,250 lb) or about 0.68 kg yr^{-1} (1.5 lb) per tree. C storage and sequestration rates varied according to tree size and species.

Table 5. Ranges and averages for incremental height and diameter growth rates for recently planted trees measured in Iowa and growth rates reported in the literature (sources noted as footnotes below table) for young trees.

	Height (cm yr^{-1})		Diameter (mm yr^{-1})	
	Range	Average	Range	Average
Measured in Iowa	17–53	29	5.0–13.0	8.0
Published	5–60[z]	27	3.8–16.0[y]	7.9

[z]Includes data for shoot extension from Kjelgren and Clark 1992 (sweetgum trees in Seattle); Rhoads et al. 1981 (several species in Philadelphia); and Buckstrup and Bassuk 2000 (hackberry, hophornbeam, and swamp white oak in Ithaca, New York), and estimates for height growth of young trees from Frelich 1992 (12 species, Minneapolis).

[y]Includes data from Neal and Whitlow 1997 (willow oak in Washington, D.C.); Rhoades and Stipes 1999 (nine different species in Virginia); Kjelgren and Clark 1992 (as above); Frelich 1992 (as above), Jo and McPherson 1995 (several young hardwood species in Chicago); and Nowak et al. 1990 (black locust, southern magnolia, and London plane tree in California).

Air Pollution Removal

Air pollution removal by the 879 surviving trees in 1998 was estimated at 21.2 kg yr^{-1} (46.6 lb), with an annual value of US$117.30 per year (Table 5). The greatest removal was for ozone and particulate matter less than 10 microns.

DISCUSSION

The results of this assessment indicate the success of this externally funded program in planting and sustaining new trees as a part of community forestry, implemented largely by volunteers, and effective even for small towns. Earlier research also indicated that the methods used in utility grant administration by Trees Forever contributed to broad community support for tree-related activities and a more comprehensive approach to vegetation management (Vitosh and Thompson 2000), also essential to community forest sustainability (Clark et al. 1997; Dwyer et al. 2003).

Diversity indices have not frequently been used in urban tree analyses; more often, results have been described and recommendations have been made based on proportional representation of different species in a population (e.g., Barker 1975; Miller and Miller 1991). For this study, examining species diversity for the whole population of trees added to Iowa communities, as well as comparison of diversity in populations according to community size and quadrant, was facilitated by the use of Simpson's index. Our estimates of diversity are conservative, due to inclusion of *Malus*, *Prunus*, and *Pyrus* as genus groups (this decision was made to simplify field operations and other data analyses, because species and cultivars within these groups are functionally similar). In most communities, a single species from these groups was most readily available at the local nursery, and plantings within these genera were very uniform.

For a hypothetical population of 1,000 trees, with 100 each of 10 species (following the recommendation of no more than 10% representation by individual species proposed by Miller and Miller 1991), the reciprocal of Simpson's index would be 10.10. For a population of 1,000 trees with 400 individuals of a single species, 100 each of 5 species, and 25 each of 4 additional species, the reciprocal of Simpson's index would be 4.72 (same total number of species with unequal representation). For a natural forest area in the central hardwoods region (Missouri), Magurran (1988) calculated a value of 5.36. Most of the values calculated for new trees in the communities assessed were between the hypothetical values offered above, and many were greater than that for the natural forest (indicative of range of diversity of native and therefore well-adapted species in the area). Although there appeared to be heavy reliance on a few taxa (particularly the crabapples and green ash), species diversity for the population as a whole (10.92) was greater than the hypothetical value for balanced representation of 10 species.

Although we expected diversity to be greater in the southeastern portion of the state (due to a greater variety of well-adapted indigenous species) and in larger communities (due to likelihood of a greater selection in local nurseries), no significant differences in diversity were detected according to community size or location (Table 3). Anecdotally, volunteer contacts in the two communities with relatively high diversity indices (12.42 and 13.48) identified species diversity as a priority in their planting program. Although green ash is already a significant component of Iowa's community forests, most other species that were relatively common in planting projects examined in this study are not over-represented among mature tree populations (Iowa Department of Natural Resources 1996). It is important to balance the priority of having diversity in species representation with the need to select species that are well adapted to the site and growing conditions (e.g., Richards 1993). The data indicate that overall diversity of this new population of trees is greater than that of local forests, and also greater than what would be expected following the 10% rule, but long-term observations will be necessary to adequately assess each species' performance, especially for species that are not already well represented in mature community tree populations.

Overall survival (91%) for this population of new trees was higher than indicated in many previous reports for other community tree-planting projects and programs, although rates that have been reported are extremely variable depending on the nature of the setting and the species of trees. For example, Nowak et al. (1990) reported first-year survival of 82% and second-year survival of 66% for newly planted street trees in California. Mortality rates in the California study differed significantly by adjacent land

use type. Based on their survey of the literature, an average first-year mortality rate of 16% could be expected, although the range was from 3% to 99%. Again, average annual mortality over 3 or 4 years for the trees in this study was only 6% and did not vary significantly by setting (community size, location in the state, or site type).

In a study of street trees in three Wisconsin cities, Miller and Miller (1991) reported survival rates from 52% to 76% over 4 years. In our study, we anticipated higher survival rates in larger communities (often with professional tree care staff) and in the southern portion of the state (milder climatic conditions). However, survival rates in this study were uniformly high and no significant differences were detected according to community size or location. One community with a small number of trees had a relatively low survival rate (59%), probably due to poor site conditions at a single planting project where most of the trees were located. Post-mortem observations, although not recorded in every instance, indicated that street trees and park trees often had been damaged by mowers or occasionally had been planted too deep. School trees and street trees were damaged by construction activities and subsequently died in a few cases. In parks located on the periphery of small towns, deer rub appeared to have been an important factor in tree mortality.

Average incremental height and diameter growth rates for trees in this study compare favorably with those reported in the literature for recently transplanted trees (Table 5). Comparison data are taken from a variety of studies that focused on only one or a few sites, and in locations from throughout the United States. We were unable to find documentation for similar externally supported tree-planting programs coordinated at the scale of an entire state for comparison. Survival rates for individual taxa also varied in this study, although statistical analysis was precluded by the limited number of trees (for most species) and their uneven distribution across the state.

Tree size information also was included in this report to establish a frame of reference for the carbon uptake and carbon sequestration performance of the trees. As of yet, these trees do not store a significant amount of carbon (an estimated total of 2,252 kg). McPherson and Simpson (1999) and Nowak et al. (2002) have noted that performance of community trees as carbon sinks increases as trees mature and net carbon effects are greater for long-lived, low-maintenance trees that are large at maturity. In fact, net carbon storage by community trees can be diminished by the carbon emissions that are required for maintenance (Jo and McPherson 1995; Nowak et al. 2002). The ornamental species (crabapple, pear, and tree lilac) that were abundant in this study probably will not contribute significantly to carbon storage due to their relatively small stature at maturity. However, a number of the other species (approximately 40% of the taxa) that were also commonly planted will mature to be medium- to large-sized trees, and are medium- to long-lived; for example, green ash, red maple, basswood, honeylocust, and red oak (McPherson and Simpson 1999; Nowak et al. 2002). The potential certainly exists for these trees to sequester and store significant quantities of carbon over their life spans. In Chicago, Illinois, and Brooklyn, New York, average carbon storage of trees greater than 75 cm (30 in.) dbh were respectively 1,000 and 530 times greater than trees less than 7.5 cm (3 in.) dbh (Nowak 1994; Nowak et al. 2002). The relatively large difference for carbon storage between Chicago and Brooklyn was related to the difference in diameter distribution of trees greater than 75 cm dbh.

The trees in Iowa currently remove about 21 kg (46.2 lb) of air pollution annually (Table 6). This amount equates to about 24 g (0.84 oz) per tree per year. This removal rate is comparable to small trees in Chicago and Brooklyn (Nowak 1994; Nowak et al. 2002). The standardized removal rate for these trees (grams of pollution removed per meter square of canopy) was about 6.2. This removal rate is relatively low compared to other cities (e.g., Brooklyn, 10.2 g/m^2; Chicago, 8.9 g/m^2) likely due to the relatively low leaf area index of these small trees, differences in local meteorology, and the relatively clean air in Iowa compared to some other areas. The amount of pollution removed by these trees will increase annually as the trees grow. Large trees greater than 75 cm dbh in the previously cited studies removed 67 and 65 times more pollution, respectively, than trees less than 7.5 cm dbh, with removal rates reaching about 2 kg (4.4 lb) per tree per year for large trees (Nowak 1994; Nowak et al. 2002).

Table 6. Total estimated pollution removal (kg yr^{-1}) and associated monetary value (dollars yr^{-1}) for 879 street trees in Iowa during nonprecipitation periods (dry deposition) in 2000. Monetary value of pollution removal by trees was estimated using the median externality values for the United States for each pollutant (Murray et al. 1994). Externality values for ozone were set to equal the value for NO_2.

Pollutant	Removal (kg yr^{-1})	Value (US$ yr^{-1})
Ozone	10.2	68.6
Particulate matter < 10 μ[z]	6.4	28.8
Nitrogen dioxide[y]	2.5	16.7
Sulfur dioxide	1.7	2.8
Carbon monoxide	0.4	0.4
Total	**21.2**	**117.3**

[z]Assumes 50% re-suspension of particles.

[y]Because there was no complete data set on nitrogen dioxide (NO_2) concentrations in Iowa, estimates of NO_2 removal by trees in Iowa were based on removal rates for trees in Omaha, Nebraska in 1994 (0.73 g/m^2 of canopy cover). This estimate is reasonable due to geographical proximity of Omaha to Iowa; also, removal rates in Omaha were relatively low compared to data from other cities in the United States.

CONCLUSIONS

Results of the survey conducted in 1996 indicated that the guidance provided to communities along with utility grant funding that supported tree-planting efforts in Iowa communities were effective in developing social support for community tree-related activities (Vitosh and Thompson 2000). Findings of this study point also to the effectiveness of the program in terms of the diversity of trees added to Iowa communities, excellent survival, and favorable growth rates of the newly planted trees, and the potential for future growth and environmental benefits that will accrue. Planting and maintenance efforts directed toward this new population of trees have been largely in the hands of volunteers who received assistance and education from Trees Forever staff, as well as the Iowa Urban and Community Forestry Council, Iowa State University Cooperative Extension personnel, Iowa Department of Natural Resources staff, and local nurseries (Vitosh and Thompson 2000). Volunteer activities have contributed to an enhanced vegetation resource in communities throughout Iowa. Quantification of the ecological and environmental functions of these trees provides important information to utility sponsors about current and anticipated benefits of large-scale tree-planting programs.

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