

MONITORING URBAN FOREST HEALTH

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Abstract. Renewed interest in urban forestry has resulted in significant public investment in trees during the past few years, yet comprehensive urban forest monitoring programs are uncommon. Monitoring is an integral component of a program to sustain healthy community forests and long term flows of net benefits. Volunteer-based monitoring will promote continued public involvement and support in community forestry. To overcome constraints to monitoring in urban environments, programs must be personally relevant, socially desirable, scientifically credible, and economically feasible. A three-tiered monitoring approach is presented. Canopy cover analysis documents net gains and losses in regional urban forest cover. Simplified detection monitoring uses trained volunteers to better understand tree population dynamics, while intensive monitoring characterizes urban forest functions and stressors. Implementation of an urban forest health initiative to develop, place, and evaluate monitoring programs is advocated.

1. Introduction

Comprehensive monitoring programs have been developed for forest health, water quality, air quality, and other natural resources. However, little of this attention has been directed towards monitoring urban tree health, despite the fact that increasing numbers of people are joining community forestry programs and planting trees. This paper addresses three questions related to monitoring urban forest change. Why monitor urban forests? What should be the goals of urban forest monitoring? What monitoring approaches are likely to work? A national initiative to implement urban forest monitoring is suggested.

2. Why Monitor Urban Forests?

Monitoring is an early and essential activity to planning and accomplishment of management activities. There are at least three reasons why we must begin monitoring to improve management of our urban forests: (1) we already invest considerable amounts of money in greenspace management; (2) significant tangible and intangible urban forest benefits can be returned; and (3) increasing environmental awareness is influencing attitudes towards urban trees, forests, and global health.

Urban forest lands, defined as areas that are vegetated and bare soil within the urban and built-up area, occupy about 25 million acres (10 million ha) in the United States. There are 50 million acres (20 million ha) of urban lands (Sampson *et al.*, 1991), and about half of these lands are vegetated and bare soil (Rowntree, 1984). In contrast, exurban forest land, defined as timberland using the USDA Forest Service definition (i.e., at least 10% stocked, capable of producing 20 cu. ft. of

wood per acre, not withdrawn from production by statute) covered 483 million acres (195 million ha) in 1986/87 (MacCleery, 1992). Thus, exurban forest lands cover 95 percent more area than urban forest lands. Similarly, 99 percent more carbon is stored in exurban forests than in urban forests. Birdsey (1990) estimates that 52.5 billion metric tons (47.6×10^{12} kg) of carbon are stored in all U.S. forests, while Nowak (in press) estimates that 350–750 million metric tons ($318\text{--}680 \times 10^9$ kg) of carbon are sequestered in all U.S. urban forests.

Despite their diminutive stature, urban forests are intensively used and managed. An informal survey of several public agencies found that annual expenditures for planning and management of parks, street trees, and other public greenspace resources averaged \$1203 per acre (\$2975/ha). Assuming an average annual management cost of all greenspace is \$600 per acre (\$1483/ha) (reduced from \$1203/acre to account for lower expenditures on private lands), approximately \$15 billion is spent annually managing urban forest lands. In contrast, \$1.3 billion was appropriated by the USDA Forest Service for management of 191 million acres (77 million ha) of National Forest System land during fiscal year 1992. Assuming this average cost of \$6.80 per acre (\$16.80/ha) applies to exurban forest lands owned by other public and private parties, a total national expenditure of \$3.3 billion is estimated for all exurban forest lands. Hence, dollars invested in forest management are nearly five times greater for urban compared to exurban forest lands.

Frequently urban trees are regarded as ornamentals. However, research findings show that urban forests have environmental, social, and economic value (ISA, 1991; Rodbell, 1992). For example, computer studies for seven U.S. cities show annual energy cost savings from three additional mature trees to be \$75–\$175 per household (Akbari *et al.*, 1992). Chicago Urban Forest Climate Project scientists estimated that during a July day trees on 525 acres (212 ha) of lakefront Lincoln Park intercept up to 370 pounds (168 kg) of particulates, and absorb up to 163 pounds (74 kg) of carbon monoxide, 144 pounds (65 kg) of nitrogen oxides, and 2573 pounds (1167 kg) of sulfur dioxide. Using current air pollution control costs for those pollutants, the daily pollution abatement value of Lincoln Park's trees totaled \$3343 (McPherson *et al.*, 1992). Projected average annual environment benefits (i.e., energy savings, carbon dioxide conserved, improved air quality, and reduced stormwater runoff) associated with proposed planting of 500000 trees in Tucson, Arizona were \$25.09 per tree versus costs (i.e., planting, pruning, removal, water) of \$9.61 per tree (McPherson, 1991). The value of recreation experiences provided by U.S. urban forests could exceed \$2 billion, and the contribution of trees and forests to residential real estate values could be two to three times this amount (Dwyer *et al.*, 1992). Studies have shown that landscapes with trees and vegetation produce more relaxed physiological states in humans than landscapes that lack these natural features (Schroeder, 1989). The benefits to public health of urban forests have not been translated into monetary terms, but are potentially very significant (Ulrich, 1984). Also significant are the many other intangible benefits urban forests provide such as wildlife habitat, esthetic surroundings, meaningful

connections between people and the natural environment, settings for important emotional and spiritual experiences, stronger sense of community, and the personal empowerment of residents. Although research continues to reveal the significance of urban forests, it has provided little information for managers regarding the influence of species composition, diversity, age structure, and location on the flow of these benefits.

The call to 'think globally and act locally' has been heard by residents of almost every community, large and small. A concern for the long term health of our planet has led many citizens to environmental stewardship activities, including participation in local tree planting programs. Grass-roots urban forestry has been spurred on by President Bush's America the Beautiful program, the American Forest's Global ReLeaf program, and programs such as Tree City, USA sponsored by the National Arbor Day Foundation. Not since the City Beautiful movement during the early twentieth century has public interest in community tree planting been this great. Urban forest health may take on added significance to the extent that urbanites' attitudes towards forests and the environment are influenced by their interactions with urban trees.

3. What Should be the Goals of Urban Forest Monitoring?

I adopt Shafer's (1991) view that before forest health can be defined, one's set of values used to measure forest health must be defined. I define a healthy urban forest as one that sustains production of goods and services over the long term. Healthy urban forests maintain a steady flow of net benefits and ideally, they are managed to be profit-maximizing. Goods and services produced by healthy urban forests could include high levels of biodiversity, increased sense of place, and cost-effective environmental control (McPherson, 1990).

Although increasing species diversity of our urban forests is important to their long-term ecological stability, healthy urban forests are managed to enhance other types of diversity as well. Four other types of diversity should be considered, two are above the species level (structural and functional diversity) and two are below the species level (life-cycle and genetic diversity) (Odum, 1989). The 'clean and green' look of many horticultural landscapes can mask the cultural history, ecology, and unique character of sites, neighborhoods, and communities. Urban dwellers' sense of identity and belonging can be enhanced when landscapes are managed to promote sense of place (Hull and Ulrich, 1991). Trees can be cost-effective substitutes or complements to traditional fossil fuel-based technologies used for environmental improvement. For example, shade from trees was found to be 20% more cost-effective over a 40-year period than shade from metal bus shelters at hot, unshaded bus stops in Tucson (McPherson and Biedenbender, 1991).

3.1. MONITORING GOALS

I propose two goals for urban forest monitoring. First, monitoring should increase public involvement in environmental stewardship. I believe that to monitor urban forests we will need trained and motivated volunteers. Some of the current enthusiasm for tree planting must be shifted to stewardship. We must find new ways to link the health of our community trees with the health of our planet, and to bring the science of urban ecology into the minds and hearts of urban America. More people must become involved in the continuous experiment of monitoring their own environments.

Second, monitoring should help us better define, detect, and predict urban forest health. To begin, monitoring should enhance our understanding of urban forest population dynamics by telling us whether numbers are rising or falling, and depicting changes in species composition, age structure, and biomass. These data will permit initial characterization of normal and abnormal population trends. Appropriate management prescriptions could follow. Additional monitoring information could be collected to characterize major stressors such as drought, nutrient deficiency, vandalism, soil compaction, mechanical injury, ice/wind storm, pest/disease, salt, air pollution, and soil toxicity. Monitoring and computer modeling should be integrated with the goal of creating user-friendly urban forest management systems.

3.2. CONSTRAINTS ON MONITORING URBAN FORESTS

Managing and also monitoring activities for greenspace are limited by factors unique to urban environments. More than half of the urban forest typically occurs on residential land. Access to this private property is difficult and levels of management skill vary among residents. About 10 to 30% of the urban forest resource occurs on public property (e.g., along streets, parks, schools) and receives more uniform levels of care from fewer managers than does residential greenspace. Most of the remaining urban greenspace (5–20%) occurs on commercial, industrial, and institutional properties and is managed by landscape contractors. Moreover, a variety of organizations and governmental agencies can exert control over urban forest management on private and public lands. Some examples include departments of planning (landscape ordinances), transportation/public works (rights-of-way), flood control (streams and channels), air quality (pollen, dust, biogenic emissions), water resources (landscape water use), solid waste (green waste and landfills), and energy utilities (power line clearance, energy savings). Therefore, a myriad of masters and their social, legal, political, bureaucratic, and economic boundaries can obstruct efforts aimed at comprehensive urban forest management and monitoring.

Other potential constraints to monitoring urban forests must be recognized prior to developing realistic goals. The urban environment is heterogeneous and 'representative' monitoring sites can be hard to find. Unique sampling approaches are required. Once desirable sites are located it may be difficult to obtain access and secure monitoring equipment from vandalism and theft. Urban land uses are

constantly changing, making the concept of 'permanent plots' impractical in some areas. Changing environmental conditions in cities can be confounding, and seriously complicate interpretation of base lines. Finally, local resources will be needed to conduct urban forest monitoring.

4. What Monitoring Approaches are Likely to Work?

Traditional monitoring approaches applied in exurban areas focus on detecting ecosystem change, but do not promote environmental stewardship amongst the public through direct participation in monitoring. To monitor tree health and promote stewardship, urban forest monitoring must be:

- personally relevant – meaningful to participants,
- socially desirable – the right thing to do for the land and people,
- scientifically credible – good quality assurance and quality control,
- economically feasible – volunteer-based (Salwasser, 1991).

4.1. VOLUNTEER-BASED MONITORING

I propose a three-tiered monitoring approach that is accomplished by trained volunteers and local technical experts. Limited resources will make it impossible to hire professionals for urban forest monitoring. However, volunteer cadres could be trained to provide credible information. It should be recognized that the motivation, length of commitment, and required training for a volunteer usually differ from that of a paid employee (Wilson, 1976). Volunteers are typically motivated to participate by power (influence and creativity), achievement (new knowledge and experience), and affiliation (contact with people and groups). Most volunteers length of commitment is one or two days, but some will make a long term commitment. It is important that the latter group be involved in all phases of program development. Volunteers will require special training for most urban forest monitoring tasks. Moreover, training will need to be repeated on a regular basis. Volunteer participation is usually related to volunteers' perception of the value of their task. If the task is highly valued and likely to have an impact, they will usually participate.

Non-profit community forestry programs have been established in over 300 cities across the U.S. Most of these programs have educational sessions and training workshops for tree planting and tree care activities. Before granting trees for planting, some programs require that applicants agree to monitor the transplants for several years following installation. Urban forestry training and education materials are passed down to community groups through a network of state urban forest councils, state foresters, and regional Forest Service specialists. Implementing urban forest monitoring through existing volunteer-based community forestry

programs appears feasible. The joint EPA Environmental Monitoring Assessment Program (EMAP) and USDA Forest Service's Forest Health Monitoring (FHM) offer workable approaches for urban forests if simplified to account for volunteer participation. A three-tiered approach for monitoring urban tree health is proposed.

4.2. CANOPY COVER ANALYSIS

Tree cover analyses usually involve interpretation of aerial photographs to provide information about the amount and distribution of tree cover throughout a community. Findings can be used to gauge the amount of influence trees have on the environment. As the first-tier in monitoring urban forest changes, periodic analysis of canopy cover can indicate whether there is a net loss or gain in greenspace over time. Policies and management can then focus on relative needs for new plantings, preservation of existing forest cover, and routine care of existing urban forest resources.

Urban forest cover data also indicate the potential for new tree plantings in different areas. Analyses show the amount of area occupied by other urban surfaces that impede or facilitate planting, such as buildings, pavement, water, grass, and bare soils (Nowak, 1991). Relations between existing tree cover and planting potential among different land use types (e.g., residential, commercial, industrial) are also helpful in prioritizing future plantings (Rowntree, 1984).

Canopy cover analysis usually involves dividing regions into smaller areas with permanent boundaries. Dots are randomly located on aerial photographs (scale about 1 : 4800) and classified according to land use and cover type. Cover proportions are calculated by dividing the number of dots in the category of cover type by the total number of dots in that area. Aerial photo interpretation is tedious and time consuming. It is best conducted by a limited number of trained volunteers with long term commitments to the program. Biased results can be reduced by initially checking for differences between interpreters and using only a few individuals for the task.

4.3. SIMPLIFIED DETECTION MONITORING

In the FHM program, detection monitoring occurs at a national network of permanent plots to establish baselines, detect change, and trigger more in-depth evaluation if problems are discovered (Radloff *et al.*, 1991). Data are collected on a wide variety of health indicators (e.g., soils, foliage, lichens). This approach could be simplified for urban forests by focusing on indicators of population dynamics in 'representative' locations.

For example, on one or two days each year teams of trained volunteers might collect information regarding plant species, size, and condition at selected locations along streets (residential and arterial), park-type areas (e.g., parks, campuses, golf courses, schools), commercial/industrial areas (professionally maintained), residential areas (high and low density), and in plots on unmanaged lands (e.g., riparian, wooded, and wetlands). Trained homeowners could collect similar data

on all trees at their residences, thereby supplementing information for residential locations. These 'permanent plots' would be revisited annually to track long term change in urban forest structure. Data collected by the volunteers would be used to assess rates of planting, mortality, and growth by both species and locations. In some circumstances, it may be feasible to collect additional information related to symptoms and causes of tree mortality and decline. Photographs of each plot from permanent camera stations could be taken annually to visually illustrate urban forest change. Some volunteers may be interested in analyzing tree rings from sections of removed trees to explore relations between tree species, locations, climates, and growth rates.

If field data collection is perceived as having little value, active participation by volunteers is unlikely. Several ways to increase the perceived value of monitoring are to: (1) provide tools that volunteers can use to easily analyze the data, assess the health of their urban forest, and estimate the benefits it provides; (2) illustrate how to use monitoring results to make better management decisions; and (3) link participation in monitoring to grants for tree planting. Awards that recognize exemplary monitoring programs could also elevate the importance of monitoring in the public's mind.

4.4. INTENSIVE MONITORING

The purpose of intensive urban forest monitoring differs from detection monitoring because the focus expands to include urban forest function, as well as structure. Intensive monitoring should measure long term effects of large-scale tree plantings or ecological restoration projects on urban forest structure and function. Neighborhood-scale permanent plots could be established in relatively stable areas. Research scientists, local greenspace managers, and trained volunteers could work together to identify relevant issues, locate desirable sites, and establish protocols for intensive monitoring. In addition to tracking changes in plant populations, monitoring could assess changes in: (1) meteorological variables that influence energy use, air quality, and human comfort; (2) deposition rates of particulate and gaseous pollutants, nutrients, and metals; (3) water relations such as rainfall interception, runoff, and evapotranspiration rates; (4) root growth, soil conditions, and soil microbial activity; (5) cycling rates for nutrients, carbon, and heavy metals; (6) visual qualities that influence scenic beauty estimates; (7) abundance and diversity of selected wildlife species; and (8) the demographics, preferences, use patterns, and physiological/psychological responses of those consuming goods and services produced by the greenspace in question. Short term intensive measurements could supplement continuous extensive measurements to capture more detailed data at appropriate time intervals.

Although the role of experts will be more important in intensive monitoring than in simplified detection monitoring, significant opportunities for public involvement and education could still exist. Trained volunteers with long term commitments to the program could assist with routine measurements and data analysis, similar to

'weather watchers' who regularly report to television news stations. Local Extension scientists and university researchers could use intensive monitoring sites as outdoor laboratories for hands-on training of students. Public participation in tracking success and failure and quantifying the flow of benefits and costs will strengthen support and involvement in community forestry programs. It will also increase the likelihood of integrating monitoring results with the management process.

5. Summary and Conclusions

The small size of urban forests belie their importance unless one considers that large sums of money are dedicated to their management and that the value of environmental, social, and economic benefits they provide is substantial. Renewed interest in urban forestry has resulted in significant public investment in trees during the past few years. A long term commitment to monitoring urban forest change will help insure that this investment provides large returns to future generations, as well as continued public involvement and support in community forestry. Healthy urban forests maximize and sustain long term flows of net benefits. They are also sources of pride within communities. Urban forest monitoring should ultimately enhance the health of our community forests by increasing public involvement in their stewardship and helping managers better define, detect, and predict urban forest health.

A three-tiered approach to urban forest monitoring is presented. Canopy cover analysis uses trained volunteers to determine existing canopy cover by geographic areas and land uses within the community. Net gain or loss of forest cover can be detected through periodic analysis of aerial photographs. Simplified detection monitoring assesses plant population changes in representative field locations. Several ways to make sometimes tedious monitoring tasks meaningful to volunteers are discussed. Intensive monitoring relies on experts as well as volunteers to assess the impacts of large scale planting or ecological restoration projects on urban forest structure and functions. Although surveys are now tracking numbers of new plantings associated with America the Beautiful, and new methods and technologies for inventorying the urban forest resource are being investigated, this paper is one of the first to scrutinize the topic of urban forest monitoring. Clearly, there is need for more viewpoints, study, and refinement.

If urban forest monitoring is important, how do we go about developing and implementing workable programs? I suggest that an urban forest health initiative be established with the goal of developing, placing, and evaluating the success of monitoring programs in a dozen U.S. cities by 1996. A steering committee with representatives of volunteer groups, professional urban forest managers, landscape industry organizations, and urban forest researchers should help set the agenda and direct the program. Urban forest managers, volunteers, and researchers can work in concert to determine the who, what, when, where, and hows of urban forest monitoring. An extensive network of national, regional, state, and local urban

forestry groups can be used to identify communities where the prototype program can be implemented and evaluated. Once evaluated and revised, the program can be delivered to communities throughout the U.S. The future costs of ailing urban forests may far outweigh the present costs of investing in monitoring programs aimed at checking the vital signs of this increasingly important natural resource.

References

- Akbari, H., Davis, S., Dorsano, S., Huang, J. and Winnett, S. (Eds.): 1992, *Cooling Our Communities: A Guidebook On Tree Planting and Light-Colored Surfacing*. U.S. Environmental Protection Agency, Washington, D.C.
- Birdsey, R.A.: 1990, 'Inventory of Carbon Storage and Accumulation in U.S. Forest Ecosystems', in: H.E. Burkhart, G.M. Bonnor and J.J. Lowe (Eds.), *Research in Forest Inventory, Monitoring, Growth and Yield*, (Report No. FWS-3-90). School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA, pp. 24-31.
- Dwyer, J., McPherson, G., Schroeder, H. and Rowntree, R.: 1992, 'Assessing the Benefits and Costs of the Urban Forest', *J. Arbor.* **18**, 227-234.
- Hull, R.B. and Ulrich, R.S.: 1992, 'Health Benefits and Costs of Urban Trees', in: P.D. Rodbell (Ed.), *Proceedings of the Fifth National Urban Forest Conference*. American Forestry Association, Washington, D.C., pp. 69-72.
- International Society of Arboriculture (Ed.): 1991, *A National Research Agenda for Urban Forestry in the 1990's*. International Society of Arboriculture, Urbana, IL.
- MacCleery, D.W.: 1992, 'Timber Growth, Removals, Standing Timber Volume, and Timberland Area in the United States, By Ownership', Unpublished technical report. USDA, Forest Service, Washington, D.C.
- McPherson, E.G.: 1990, 'Creating an Ecological Landscape', in: P. Rodbell (Ed.), *Proceedings of the Fourth Urban Forestry Conference*. American Forestry Association, Washington, D.C., pp. 63-67.
- McPherson, E.G., 1991, 'Economic Modeling for Large-Scale Tree Plantings', in: E. Vine, D. Crawley and P. Centolella (Ed.), *Energy Efficiency and the Environment: Forging the Link*. American Council for an Energy-Efficient Economy, Washington, D.C., pp. 349-369.
- McPherson, E.G. and Biedenbender, S.: 1991, 'The Cost of Shade: Cost-Effectiveness of Trees Versus Bus Shelters', *J. Arbor.* **17**, 233-241.
- McPherson, E.G., Nowak, D.J., Sacamano, P.L., Makra, E. and Prichard, S.E.: 1992, *Chicago's Evolving Urban Forest*. USDA Forest Service, Northeastern Forest Experiment Station, Chicago Urban Forest Climate Project, Chicago, IL.
- Nowak, D.J.: 1991, 'Urban Forest Development and Structure: Analysis of Oakland, California', Ph.D. Dissertation, University of California, Berkeley, CA.
- Nowak, D.J.: in press, 'Atmospheric Carbon Reduction by Urban Trees', *J. Environ. Manag.*
- Odum, E.P.: 1989, 'Diversity in the Landscape: The Multilevel Approach', *Georgia Landscape*. Spring, 4.
- Radloff, D., Loomis, B., Barnard, J. and Birdsey, R.: 1991, 'Forest Health Monitoring: Taking the Pulse of America's Forests', in: *Agriculture and the Environment: The 1991 Yearbook of Agriculture*. U.S. Government Printing Office, Washington, D.C., pp. 41-47.
- Rodbell, P.D. (Ed.): 1992, *Proceedings of the 5th National Urban Forestry Conference, Alliances for Community Trees*. American Forestry Association, Washington, D.C.
- Rowntree, R.A.: 1984, 'Forest Canopy Cover and Land Use in Four Eastern United States Cities', *Urb. Ecol.* **8**, 55-67.
- Salwasser, H.: 1991, 'Biological Diversity and Sustaining Ecological Systems', Keynote remarks and unpublished paper from the *Symposium On Biodiversity of Northwestern California*, Santa Rosa, CA, 11 pp.
- Sampson, R.N., Moll, G.A. and Kielbaso, J.J.: 1991, *Urban Forests, Carbon Storage, and Energy Conservation*. American Forestry Association, Washington, D.C. Schroeder, H.W.: 1989, 'En-

- vironment, Behavior, and Design Research on Urban Forests', in: E.H. Zube and G.T. Moore (Eds.), *Advances in Environment, Behavior, and Design*. Plenum, New York, pp. 87–117.
- Shafer, J.D.: 1991, 'A Silviculturalist's Creed', in: *Proceedings of the Symposium On Management of Forest Pests Through Silviculture*, pp. 1–5.
- Ulrich, R.S.: 1984, 'View Through a Window May Influence Recovery from Surgery', *Science* **224**, 420–421.
- Wilson, M.: 1976, *The Effective Management of Volunteer Programs*. Johnson Publishing, Boulder, CO.