Understanding and Quantifying Urban Forest Structure, Functions, and Value

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ABSTRACT

Trees in urban areas can have a significant impact on human health and the environment. Unfortunately, there is relatively little data about the structure, health, functions, and long-term changes in this important resource. In the United States, a number of efforts are underway to assess urban forest attributes at the local to national scales. In addition, tools are being developed to facilitate urban forest quantification by managers. These assessments and tools can be used in Canada and other counties to aid in planning and improving urban forest management.

INTRODUCTION

Urbanization and urban forests are likely to be the greatest forest influence and influential forest of the 21st Century. Urban areas in the contiguous United States have doubled in area between 1969 and 1994, and continue to expand through urban sprawl. Urban areas currently occupy 3.5% of the coterminous U.S. land base with an average tree cover of 27.1% (Dwyer et al. 2000; Nowak et al. 2001a). Although urban areas continue to expand and urban forests (all trees within urban areas) play a significant role in environment quality and human health, little is known about this important resource or its value to society. Understanding the value of an urban forest can give managers and planners a basis with which to develop and evaluate programs for managing urban trees.

To help quantify the structure of this significant resource (e.g., species composition, number of trees, tree sizes, tree locations) and what functions and values this resource provides (e.g., air pollution removal, carbon storage), various resource assessments and tools are being developed and used. In the U.S., national assessments of the urban forest resource are being conducted using new satellite imagery, national urban forest ground-based inventory procedures are being field tested, local city analyses are

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being completed, and a number of new urban forest assessment tools are being developed to aid in urban forest analysis, management, and design. This paper briefly overviews these new assessment procedures and/or findings to outline how some of these procedures could be used to help aid in urban forest management in Canada. In addition, some urban forest data are presented from Calgary, Alberta and Toronto, Ontario.

NATIONAL URBAN FOREST ASSESSMENTS IN THE UNITED STATES

As part of the Renewable Resources Planning Act (RPA) process, the first national urban forest assessment recently was completed (Dwyer et al. 2000; Nowak et al. 2001a). This assessment used 1991 Advanced Very High Resolution Radiometer (AVHRR) data (Zhu 1994) and 1990 census data to estimate that urban areas in the lower 48 United States:

- Cover 3.5 percent of the total area
- Have doubled in size between 1969 and 1994
- Contain more than 75 percent of the U.S. population
- Average 27.1 percent tree canopy cover

Data from this national assessment were combined with field data from individual cities analyzed using the Urban Forest Effects (UFORE) model (Nowak and Crane, 2000) to estimate that urban forests in the lower 48 United States have:

- Approximately 3.8 billion trees (Dwyer et al. 2000; Nowak et al. 2001a).
- A compensatory or structural value of around $2.4 trillion, with values from a limited number of individual city tree populations (entire city) ranging from $101 million in Jersey City, New Jersey to $5.2 billion in New York, New York (Nowak et al., 2002).
- A potential risk to infestation from an Asian longhorned beetle (*Anoplophora glabripennis*) of approximately 35% of the urban tree cover nationally, with a potential loss of 1.2 billion trees and $669 billion in structural value (Nowak et al., 2001b).
- 700 million metric tons of carbon stored ($14.3 billion value), with a gross annual carbon sequestration rate of 22.8 million metric tons of carbon/year ($460 million / year) (Nowak and Crane, 2002).

New national urban forest assessments are underway investigating the value and amount of air pollution removed annually by urban forests, as well as the urban forest's national impact on building energy use. New Landsat data (c. 2000) are being analyzed in cooperation with the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center and others to develop new national tree and impervious surface cover maps for the United States. These data will provide more recent and higher resolution data to assess urban forests and will be combined with 2000 U.S. Census and new field data to update estimates of national urban forest structure and functions.

URBAN FOREST HEALTH MONITORING

As there is currently only limited tree and forest field data from urban areas, a pilot program was developed to test the feasibility of implementing a national urban forest health monitoring program. This program would provide field data from urban areas throughout the United States to yield information on the status of this resource, how it is changing, and factors that might lead to changes in urban forest structure, function, and health. This integrated national program has three stages:

Stage 1. National Urban Forest Health Monitoring

In this stage, Forest Inventory and Analysis (FIA) data and Forest Health Monitoring (FHM) data are collected on an annualized basis at a rate of one plot every 6,000 acres within Census-defined urban areas. Approximately 11,735 plots (each 1/6 acre in size) would fall within U.S. urban areas based on the 1990 census definition (Nowak et al., 2001c). This stage would fill in the urban "data-gap" within the FIA and FHM national data collection program. A pilot test for this stage was implemented in Indiana in 2001 and in Wisconsin in 2002. Future testing in New Jersey is planned for 2003.

Stage 2. National Street Tree Health Monitoring

This stage focuses on the street tree resource at the state level. Street tree monitoring is done only for trees in the public right of way along highways, streets, and roads, and only in Census-defined urban areas. Street tree plots consist of linear samples similar in size to the stage 1 plots and are based on protocols that have been developed over several years of testing. A pilot test for this stage was implemented in Maryland in 2001 and in Maryland (repeat measures), Wisconsin, and Massachusetts in 2002.

Stage 3. Local Urban Forest Health Monitoring

This stage is the development of protocols, field manuals, and data analysis packages to allow municipalities to intensify field sampling for local situations. The sampling protocols and manuals will be specifically designed to provide users with flexible and easy to follow instructions that enable municipalities, urban foresters, or volunteers to gather and analyze local information in a comparable fashion to stages 1 and 2. A pilot of this stage has been proposed for New England in 2003.

One goal of this urban forest health monitoring program is to develop an annual report at the state level on the status and condition of the urban forest and street tree resource. In addition, local entities will have tools and protocols that will facilitate local scale assessments to aid in urban forest planning, design, and management.

URBAN FOREST EFFECTS (UFORE) MODEL

The Urban Forest Effects (UFORE) computer model was developed to help managers and researchers quantify urban forest structure and its functions (Nowak and Crane, 2000). UFORE is designed to use standardized field data from randomly located plots, and local hourly air pollution and meteorological data to quantify urban forest structure and numerous urban forest effects for cities across the world. The model currently quantifies:

- Urban forest structure by land use type (e.g., species composition, tree density, tree health, leaf area, leaf biomass, species diversity, etc.).
- Hourly amount of pollution removed by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Hourly urban forest volatile organic compound emissions and the relative impact of tree species on net ozone and carbon monoxide formation throughout the year.
- Total carbon stored and carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration.

- Tree pollen allergenicity index.
- Potential impact of gypsy moth and Asian longhorned beetle infestation.
- Tree transpiration.

To date, cities that have been analyzed using UFORE include: Atlanta, GA; Baltimore, MD; Boston, MA; Brooklyn, NY; Calgary, Alberta; Hefei, China; Jersey City, NJ; Freehold, NJ; Moorestown, NJ; New York, NY; Ningbo, China; Philadelphia, PA; Syracuse, NY; Toronto, Ontario; and Woodbridge, NJ. Cities currently being analyzed include: Baton Rouge, LA; Fuenlabrada, Spain; Houston, TX; Morgantown, WV; Phoenix, AZ; San Juan, PR; and Santiago, Chile. Many of these analyses are being conducted in cooperation with local institutions.

In cooperation with the Davey Resource Group, the UFORE model is currently being converted to a Windows® platform to facilitate its use through easy operation. To assist local users, a field data collection manual is being developed along with handheld data collection programs for personal data assistants (PDAs) (e.g., Palm Pilots) to facilitate local data collection. Plot selection programs for ArcView® v3.x have also been developed for easy selection of plot locations within cities or neighborhoods.

New UFORE components currently in development include: Human Comfort; Ultraviolet Radiation Reduction; Water Quality and Quantity Effects; and more Insect and Disease Potentials. New UFORE management decision programs are also in development, which include:

- <u>UFORE Planting Locator</u>: This program will use digital cover maps and other GIS layers to map the best locations to plant trees.
- <u>UFORE Species Selector</u>: Based on user inputs of planting location attributes (e.g., city, overhead restrictions) and ranking numerous tree factors (e.g., air pollution removal, low pollen emission, fall color) on scale of 0 (unimportant) to 10 (highly important), this Windows® program will rank hundreds of tree species to determine the best tree to plant given the user's preferences.
- <u>UFORE Future Effects:</u> This program projects future canopy cover and benefits of an urban forest over a 100-year period based on estimated forest growth and mortality. The program

also estimates the number of trees that need to be established annually to sustain or increase tree cover.

Analyses of data from various cities reveal that urban forests are a significant resource (Table 1) and can have significant impacts on environmental quality (Table 2). To more accurately estimate the functional values of urban forests, research is needed on how urban-forest structure affects functions (e.g., how different numbers, sizes, species, and locations of trees affect air pollution) and the value placed on these functions by society. Certain functional benefits and values of urban forests are being assessed (air pollution removal, energy conservation), but other values need to be quantified with respect to urban-forest structure (e.g., esthetic, social and community, and wildlife values).

CONCLUSION

Research tools are being developed and assessments conducted to provide better data for urban forest management decisions and policies, and to increase access to urban forest data at the local scale. Better urban forest information at the local to national scale can lead to improved urban forest management decisions to enhance environmental quality and improve human health and well-being in urban and urbanizing areas. Assessment information and tools may be helpful in Canada and other countries to aid in improving urban forest management.

Table 1. Estimates of number of trees and tree density (trees ha^{-1}) for cities analyzed with the UFORE model. Estimates of percent tree cover are based on satellite images or sampling of aerial photographs. Data from Oakland, CA (Nowak, 1993a,b) and Chicago, IL (Nowak, 1994) were not analyzed with UFORE (SE = standard error).

	Number of Trees		Tree Density		Tree Cover (%)	
City	Total	SE	Mean	SE	Mean	SE
Calgary, Alberta	11,890,000	2,777,000	165	39	7.2[1]	0.9
Atlanta, GA	9,420,000	749,000	276	22	32.9	na
Toronto, Ontario[2]	7,540,000	889,000	119	14	20.5[1]	1.5
New York, NY	5,220,000	719,000	65	9	16.6	0.3
Chicago, IL	4,130,000	634,000	68	10	11.0	0.2
Baltimore, MD	2,600,000	406,000	109	17	18.9	na
Philadelphia, PA	2,110,000	211,000	62	6	21.6	0.4
Oakland, CA	1,590,000	51,000	120	4	21.0	0.2
Boston, MA	1,180,000	109,000	83	8	21.2	0.4

[1] Cover analysis based in cover estimates from field plots
[2] Kenney et al., (2001)
na = not analyzed; base data for Atlanta from American Forests; base data for Baltimore from Grove (1996).

Table 2. Total estimated pollution removal (metric tons) by trees during nonprecipitation periods (dry deposition) and associated monetary value (thousand dollars) for New York (799 km^2; 1994 pollution conditions), Toronto (632 km^2; 1998), and Calgary (721 km^2; 1998) based on UFORE field data collection. Estimates are for ozone (O_3), particulate matter less than 10 microns (PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). Numbers in parentheses represent expected range of values (no range determined for CO). Monetary value of pollution removal by trees was estimated using the median externality values for United States for each pollutant (Murray et al., 1994). Externality values for O_3 were set to equal the value for NO_2.

	New York, New York		Toronto, Ontario		Calgary, Alberta	
Pollutant	Removal	Value	Removal	Value	Removal	Value
O_3	569	3,843	405	2,733	102	687
	(140-769)	(943-5,192)	(104-530)	(704-3,581)	(32-124)	(213-836)
PM10[1]	518	2,336	284	1,282	119	536
	(202-810)	(913-3,650)	(111-444)	(501-2,003)	(46-186)	(209-838)
NO_2	535	3,611	199	1,343	57	387
	(226-697)	(1,524-4,708)	(97-262)	(653-1,771)	(31-68)	(211-459)
SO_2	270	446	77	209	17	29
	(131-435)	(217-718)	(38-126)	(62-127)	(10-26)	(16-43)
CO	122	117	33	32	7	6
Total	2,014	10,353	998	5,599	302	1,645
	(821-2,833)	(3,714-14,385)	(383-1,395)	(1,952-7,514)	(126-411)	(655-2,182)

[1] Assumes 50% resuspension of particles.

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