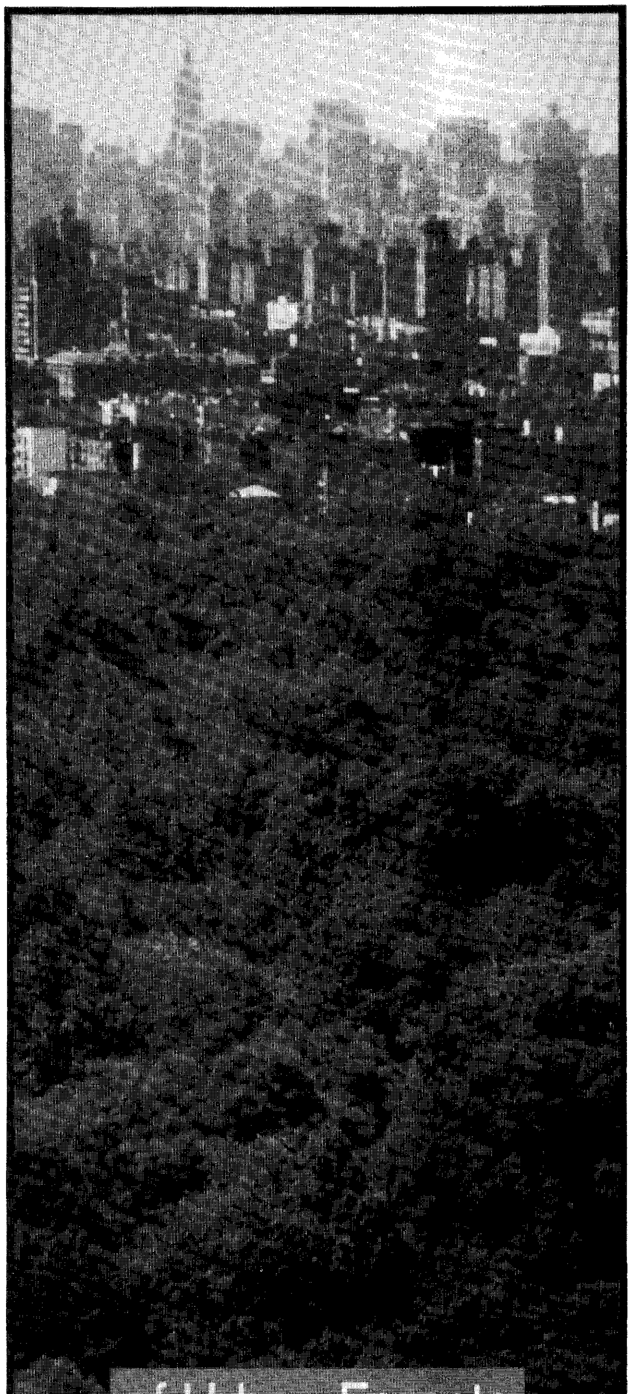
Understanding the Structure of Urban Forests



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By David J. Nowak

Urban forests are complex ecosystems created by the interaction of anthropogenic and natural processes. One key to better management of these systems is to understand urban forest structure and its relationship to forest functions. Through sampling and inventories, urban foresters often obtain structural information (e.g., numbers, location, size, and condition) on street- and/or park-tree populations to aid management. However, these public trees compose only a small portion of the urban forest.

Management of the entire urban forest ecosystem requires information on all vegetation and other attributes of the system across the urban landscape. This type of structural information establishes a basis for comprehensive management that recognizes linkages among the multiple land uses and owners of the urban forest. Forest structure also provides a means to estimate the actual and potential physical, biological, social, and economic functions of the urban forest. Urban foresters can then develop plans and programs that provide for these functions across the urban landscape.

Urban Forest Structure

Urban forest structure is the spatial arrangement of vegetation in relation to other objects, such as buildings, within urban areas (Rowntree 1984a). Three broad factors determine urban forest structure: urban morphology, which creates the spaces available for vegetation; natural factors, which influence the amount and type of vegetation likely to be found within cities; and human management systems, which modify vegetation configurations across land-use types (e.g., Whitney and Adams 1980, Sanders 1984). Morphology, natural factors, and management systems interact to create diverse forest structures across urban landscapes. Despite this diversity, there are some broad similarities in urban vegetation patterns. A number of studies have examined urban forest structure from the gross structural characterizations of tree canopy and land use to detailed investigations of individual trees.

Urban forest cover. There are significant variations in urban forest cover both within and among cities. Past studies indicate that urban tree cover ranges from a high of 55 percent in Baton Rouge, Louisiana, to a low of 1 percent in Lancaster, California, with a US average of 26 percent (Nowak et al., in review). Tree cover in the United States tends to be highest in cities developed in naturally forested areas (32%), followed by grassland cities (18%) and desert cities (10%) (Nowak et al., in review). Within a city, the highest percentage of canopy cover is generally found on vacant, park, and residential land *(table 1).* Tree cover analyses across an entire city reveal tree distribution and interconnections among land use types (Rowntree 1984b). However, more detailed investigations of structure are necessary for improved understanding and management of specific areas within the city to enhance particular functions.

Tree composition and structure. A number of studies have evaluated street-tree populations or limited portions of non-street-tree populations, but there have been few ground-based urban forest structural analyses of an entire urban area. Various typologies have been developed to

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classify urban vegetation across a city (Brady et al. 1979, Sukopp and Werner 1983), but land-use type is probably the most common classification used.

Overall, urban trees are relatively small in stature, with the majority of them less than 6 inches dbh (Dorney et al. 1984, Nowak 1993a, Nowak 1994a). The distribution of tree sizes usually varies depending on the history and intensity of vegetation management. Less-managed or naturally managed land tends to have the highest proportion of small trees—due in part to natural regeneration in these areas.

Tree species composition varies by land-use type, but overall, the urban forest composition is generally dominated by a few species. In Oakland, four species make up 49 percent of the tree population (Nowak 1993a); in Chicago, six species or genera constitute more than half of the population (Nowak 1994a); and in Athens, Greece, five species groups compose much more than half of the tree population (Profous et al. 1988).

Exotic species can also play an important role in the urban forest ecosystem. In Oakland, 69 percent of the existing trees are not native, and these exotic species contribute to high species diversity. Urbanization has increased Oakland's tree species diversity index from 1.9 (Shannon-Weiner diversity index) to 5.1 (Nowak 1993b). Although citywide diversity can be increased by the introduction of exotics, diversity in natural forest stands in urban areas can decrease as a result of human activity. For example, air pollution has increased tree mortality (Iizumi 1983).

Data from Chicago and Oakland reveal that most urban trees are located on institutional and vacant land. Such land is often the most natural and exhibits typical forest stand structures. But in some instances, human activities that lead to changes such as reduction in fire frequency and introduction of exotic species have altered stand structure.

In Oakland, California, bay is dominating reproduction in many stand types. In the absence of fire, bay woodlands will likely replace oak/bay woodlands in the Oakland area (McBride 1974). In the Chicago area (Cook and DuPage Counties), the exotic and highly invasive buckthorn is the most common tree species, composing a significant proportion of trees on institutional, vacant, and residential lands. Although this species will not likely dominate the urban forest overstory canopy because of its relatively small size, its abundance and invasive characteristics pose problems for vegetation managers.

Four of the eight most common species/genera in the Chicago area are native pioneer species: green/white ash, boxelder, willow, and cottonwood, which account for 25 percent of the population of trees below 3 inches dbh. Canopy dominance in the urban forest of the Chicago area will likely shift more toward these native pioneer species. Although silver maple, white oak, and bur oak account for one-third of the trees above 18 inches dbh, they account for only 3 percent of small trees and are not likely to increase in significance in the future. Another successful pioneer species regenerating in many urban areas across the United States is the exotic ailanthus.

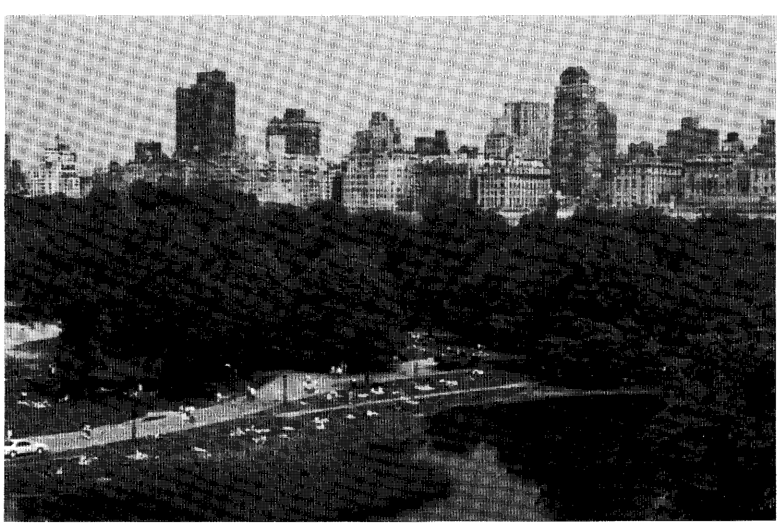
Street trees. Street trees account for 1 of every 10 trees in Chicago, and 1 of every 4 trees in Chicago's 1- to 3-family residential areas. Due to their relatively large size, Chicago's street trees contribute 24 percent of the total city leaf-surface area, and 44 percent of total leaf area on 1- to 3-family residential land. Street trees play an important role in heavily urbanized areas where artificial surfaces and land-use activities limit their space, but are a less significant component of the forest in suburban areas. In suburban Cook County, street trees constitute 1 of every 37 trees, and 1 of every 77 trees in DuPage County. Although only a minor component of the urban forest as a whole, street trees are a significant component of the street-corridor and human environment (Schroeder and Cannon 1987).

Individual tree attributes. Individual tree attributes, such as leaf surface area and transpiration, are critical to many urban forest functions, such as reductions in air temperature and air pollution removal. Typical leaf area indices (LAI) are 10 to 11 for tropical rain forests, 5 to 8 for deciduous forests, and 9 to 11 for boreal coniferous forests (Barbour et al. 1980). The average LAI (exclusive of grass) for tree-covered areas in Chicago is 6.0, which is at the low end of the normal range of LAIs exhibited for deciduous forests. This relatively low LAI is attributable to the lack of understory trees in some urban areas, where the understory is occupied only by grass or impervious materials.

Other individual tree attributes, such as in-leaf and out-of-leaf shading densities (McPherson 1984) and growth rates (Fleming 1988), are important for estimating current and potential urban forest functions such as energy conservation and carbon dioxide sequestration.

Urban Forest Functions and Management

Urban forest structure is a key determinant of function. To enhance forest functions across the urban landscape, managers and planners strive for appropriate forest designs and linkages, healthy trees, and long-term tree survival. By understanding urban forest structure, how it relates to



Wayne Zipperer

Opposite: Urban ecosystems are a combination of interactive anthropogenic and natural systems. Understanding the structure of these systems can lead to better planning and management of urban vegetation.

Left: Benefits of urban forests such as New York City's Central Park include not only beauty and recreational opportunities but improved air quality and reduced energy consumption.

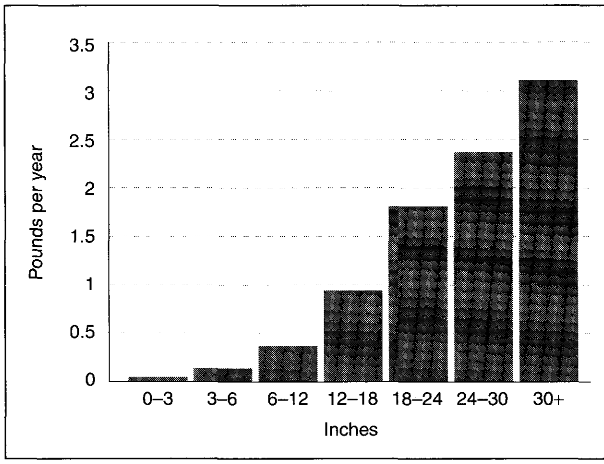


Figure 1. Estimated pollution removal of individual urban trees, by diameter class, in Chicago, 1991 (Nowak 1994b).

specific functions, and how structure and functions link not only within the urban area but between the urban area and surrounding forest environments, managers can better direct forest structure to enhance particular functions.

Enhancement of various functions may require different urban forest structures. For example, improving air quality calls for a forest structure that includes maximum leaf-surface area of pollution-tolerant species in the most polluted areas. Trees in Chicago were estimated to remove 651 tons of air pollution in 1991, with large trees removing 60 to 70 times more air pollution than small trees *(fig. 1)*. To reduce building energy use, trees need to be selected and located around buildings to maximize building shade in summer, minimize winter shade, block winter winds, and provide transpirational cooling. The maximum potential annual effect of trees on reducing conventional house energy use is about 20 to 25 percent, but energy costs can increase with improper tree configurations (Heisler 1986). Esthetic improvement plans need to consider people's preferences for tree density and arrangement (Schroeder and Green 1985). These and other improvements in the urban landscape can generate millions of dollars in enhanced real estate values, local economic development, and other benefits (Dwyer et al. 1992).

All urban forest designs and plans need to consider the specific morphology, natural factors, and human influences. By understanding land-use vegetation structure in context with local conditions, managers can identify potential opportunities and limitations to enhancing urban forest functions.

Many urban areas offer potential space for trees, but the natural environment (such as lack of water), current land uses (such as baseball fields), management practices (such as mowing), and/or limited management/maintenance budgets may preclude tree planting and maintenance. Some of these limitations can be overcome with education and/or increased funding. However, increased tree cover is not appropriate in all urban areas. Some management objectives, such as prairie restoration or active recreation fields, call for minimizing trees. Other areas, such as low-income multifamily residential areas, commercial-industrial areas, freeways, schools, and passive recreational parks, could be greatly enhanced with more trees.

Conclusion

Urban vegetation has many different functions that provide a wide range of services (Dwyer et al. 1992). Urban forest managers should decide which functions are important—for example, local air quality improvement, reduced energy usage, or improved esthetics—and develop plans and programs that will provide a vegetative structure for these functions. However, efforts to enhance one function may impair others. Designs to improve air quality, for example, may not be the most esthetic or conducive to recreational activities. In many instances, the forest resources over widespread areas within and around cities interact to provide particular functions such as wildlife habitat. Thus, urban forestry plans and programs need to consider the wide spectrum of forest functions and how various management units in the urban forest can be linked to enhance overall functions.

By understanding forest structure across the entire urban area, managers can better evaluate the differences among the multiple owners of the urban forest and

Table 1. Percentages of total tree cover, impervious cover (e.g., buildings, roads), and tree cover by various land-use types for cities in the United States.

City	City tree cover	Impervious cover	Tree cover by land-use type: Residential	Comm/ind[a]	Institutional	Park	Vacant	Other
Atherton, CA	47	31	50	19	29	21	39	8
Waterbury, CT	44	34	36	15	18	40	74	12
Birmingham, AL	37	34	37	10	28	54	72	12
Cincinnati, OH	36	36	34	5	24	59	81	6
Syracuse, NY	24	45	27	8	18	22	42	12
Oakland, CA	21	49	21	2	17	24	46	4
Sioux Falls, SD	19	32	31	3	14	11	20	7
Yakima, WA	18	42	23	10	12	14	10	14
Modesto, CA	17	47	21	7	12	24	1	18
Sacramento, CA	14	39	23	9	11	27	2	3
Chicago, IL	11	62	13	3	7	33	20	2
Logan, UT	11	39	12	3	5	9	23	6
Merced, CA	6	34	9	3	2	25	3	4
Palm Springs, CA	4	12	19	6	3	7	1	1
Lancaster, CA	1	12	5	1	0	0	0	0

[a] *Commercial/industrial*

how these land ownerships affect management and ecosystem functions, both within and outside the urban area. Managers can also assess potential changes in urban forest structure (e.g., species shifts), appraise opportunities and limitations to enhancing urban forest functions, and direct management efforts to enhance these functions. JOF

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