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Institutionalizing urban forestry as a "biotechnology" to improve environmental quality

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Abstract

Urban forests can provide multiple environmental benefits. As urban areas expand, the role of urban vegetation in improving environmental quality will increase in importance. Quantification of these benefits has revealed that urban forests can significantly improve air quality. As a result, national air quality regulations are now willing to potentially credit tree planting as means to improve air quality. Similarly, quantification of other environmental benefits of urban trees (e.g., water quality improvement, carbon sequestration) could provide for urban vegetation to be incorporated in other programs/regulations designed to improve environmental quality.

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Keywords: Urban forests; Air quality; Environmental regulations

Introduction

Urbanization concentrates people, materials, and energy into relatively small geographical areas to facilitate the functioning of society. Urbanization often degrades local and regional environmental quality as natural landscapes are replaced with anthropogenic materials. Byproducts of urbanization (e.g., heat, combustion, and chemical emissions) affect the health of the local and regional landscapes, as well as the health of people who reside, visit, and/or work in and around urban areas.

In the lower 48 United States, percent of land classified as urban increased from 2.5% in 1990 to 3.1% in 2000 (44,834 km^2), an area about the size of Vermont and New Hampshire combined. Patterns of urban expansion reveal that increased growth rates are likely in the future (Nowak et al., 2005a, b). Urban land is projected to increase from 3.1% in 2000 to 8.1% in 2050, an area (392,000 km^2) greater than the size of Montana. By 2050, four states (Rhode Island, New Jersey, Massachusetts, and Connecticut) are projected to be more than half urban land (Nowak and Walton, 2005).

Urban vegetation, through its natural functioning, can improve environmental quality and human health in and around urban areas. These benefits include improvements in air and water quality, building energy conservation, cooler air temperatures, reduction in ultraviolet radiation, and many other environmental and social benefits (Nowak and Dwyer, 2000). Properly designed and managed, urban vegetation can be used as a natural "biotechnology" to reduce some of the adverse environmental and health effects associated with urbanization. With the extent of urbanization expanding across the landscape, there is an urgent need to incorporate the effects of urban vegetation on reducing the adverse effects of urbanization into long-term planning, policies, and regulations to improve environmental quality.

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The purpose of this paper is to detail effects of urban forests on air quality and streams flows in particular cities and discuss the role of urban forests within national programs/regulations related to environmental quality and human health.

Methods

To incorporate the effects of urban trees in meeting environmental standards, the impacts of trees on the environment need to be quantified. The urban forest functions that appear to be most critical to environmental quality and associated regulations are tree effects on air and water quality, and carbon sequestration. To quantify these urban forest effects in various cities, the Urban Forest Effects (UFORE) model was used. The UFORE model uses standardized field data from randomly located urban forest plots and local hourly air pollution and meteorological data to quantify urban forest structure, functions, and values (e.g., Nowak et al., 2000, 2001, 2002a, b, 2005a, b; Nowak and Crane, 2000, 2002). The model currently quantifies: (a) urban forest structure by land use type (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.); (b) hourly amount of pollution removed by the urban forest, its value, 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 ($<10\,\mu$m); (c) hourly urban forest volatile organic compound (VOC) emissions and the relative impact of tree species on net ozone and carbon monoxide formation throughout the year; (d) total carbon stored and net carbon annually sequestered by the urban forest, including its value to society; and (e) effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.

To date, urban forest structural data (e.g., tree species composition, number of trees, trees size, health) have been or are being collected and analyzed with the UFORE model for about 30 cities, with about one-third of the analyses occurring in cities outside of the United States – e.g., Beijing, China (Yang et al., 2005); Fuenlabrada, Spain (Lozano, 2004); Santiago, Chile (Escobedo et al., 2006); and Toronto, Ontario, Canada (Kenney et al., 2001). From this basic field data, leaf area and leaf biomass estimates are made and combined with local meteorological and pollution data to estimate hourly air pollution removal, total carbon storage, and annual carbon sequestration.

Hourly pollution removal is based on the downward pollutant flux (F; in g/m^2 s) calculated as the product of the deposition velocity (V_d; in m/s) and the pollutant concentration (C; in g/m^3) ($F = V_d C$). Deposition velocity was calculated as the inverse of the sum of the aerodynamic (R_a), quasi-laminar boundary layer (R_b), and canopy (R_c) resistances. Hourly estimates of R_a and R_b were calculated using standard resistance formulas and local hourly weather data. Hourly canopy resistance values for O_3, SO_2, and NO_2 were calculated based on a modified hybrid of big-leaf and multilayer canopy deposition models (Baldocchi et al., 1987; Baldocchi, 1988). As removal of CO and particulate matter by vegetation are not directly related to photosynthesis/transpiration, R_c for CO was set to a constant for in-leaf season (50,000 s/m) and leaf-off season (1,000,000 s/m) (Bidwell and Fraser, 1972). For particles, the median deposition velocity (Lovett, 1994) was set to 0.064 m/s based on 50% resuspension rate (Zinke, 1967). The base V_d was adjusted according to in-leaf vs. leaf-off season parameters. To limit deposition estimates to periods of dry deposition, deposition velocities were set to zero during periods of precipitation. Detailed methods of pollution removal are given in Nowak et al. (1998, 2002b, 2006).

To calculate current carbon storage and annual carbon sequestration, biomass for each measured tree is calculated using allometric equations from the literature (Nowak, 1994; Nowak et al., 2002b). Equations that predict above-ground biomass were converted to whole tree biomass based on root-to-shoot ratio of 0.26 (Cairns et al., 1997). Equations that compute fresh-weight biomass were multiplied by species- or genus-specific conversion factors to yield dry-weight biomass. Open-grown, maintained trees tend to have less above-ground biomass than predicted by forest-derived biomass equations for trees of the same diameter at breast height (Nowak, 1994). To adjust for this difference, biomass results for urban trees were multiplied by a factor 0.8 (Nowak, 1994). No adjustment was made for trees found in more natural stand conditions (e.g., on vacant lands or in forest preserves). Total tree dry-weight biomass was converted to total stored carbon by multiplying by 0.5 (Forest Products Lab, 1952; Chow and Rolfe, 1989).

The multiple equations used for individual species were combined together to produce one predictive equation for a wide range of diameters for individual species. The process of combining the individual formulas (with limited diameter ranges) into one, more general species formula, produced results that were typically within 2% of the original estimates for total carbon storage of the urban forest (i.e., the estimates using the multiple equations). Formulas were combined to prevent disjointed sequestration estimates that can occur when calculations switch between individual biomass equations. If no allometric equation could be found for an individual species, the average of results from equations of the same genus were used. If no genus equations were found, the average of results from all