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Urban Forest Sustainability in the United States

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Abstract
Urban forests in the United States provide numerous ecosystem services that vary in magnitude across the country and are valued in the billions of dollars per year. Urban tree cover has been on the decline in recent years. Numerous forces for change will continue to alter urban forests in the coming years (i.e., development, climate change, insects and diseases, invasive plants, wildfires). These forces can both decrease (e.g., via enhanced tree loss) and increase (e.g., via enhanced tree planting and/or natural regeneration) tree cover. On average, about one in three trees are planted in U.S. cities; this proportion varies by land use, ecoregion, and population density. Monitoring the magnitude and characteristics of these natural and human-caused tree gains and losses is important for creating and managing sustainable and healthy urban forests. Such forests often require knowledge of the local forest resource and benefits and the development of long-term urban forest management goals, plans, and monitoring programs. Sustainable and healthy urban forests can help ensure improvements in urban environmental quality, human health, and well-being for current and future generations.

Key words: urban tree cover, ecosystem services, development, climate change, forest pests, invasive species.

Introduction

Urban forests in the United States provide numerous services and values, especially to the more than 80% of the population who live within the nation's urban areas. Urban areas occupy about 3.6% of the total land area in conterminous United States, and their extent is increasing (Nowak et al. 2014). Urban forests include street trees, backyard trees, trees in forested stands, and all other trees on urban lands. The ecosystem services and benefits of these trees include moderating climate, reducing building energy use and atmospheric carbon dioxide, improving air quality, mitigating rainfall runoff and flooding, enhancing human health and social well-being, and lowering noise levels (Nowak and Dwyer 2007). Urban forests also have costs associated with tree planting, maintenance and removal, and other indirect costs such as allergies from tree

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pollen, increases in winter building energy use caused by tree shade, invasive plants that alter local biodiversity, and higher taxes from increased property values.

Trees and forests in these urban areas are constantly changing but are facing many new threats that may accelerate forest change. By sustaining desired levels of tree cover with proper species and in appropriate locations, cities can sustain forest ecosystem services and values. This paper gives a brief overview of urban tree cover and urban forest ecosystem services in the United States, discusses current and potential changes to tree cover, and outlines steps that cities can take to sustain desired or optimal levels of urban forests.

U.S. Urban Tree Cover

Forest attributes such as species, tree size, health, and location are important for designing optimal ecosystems services at the site scale; however, one of the simplest metrics of urban forests that can be easily measured and understood is tree cover. In the conterminous United States, overall tree cover averages 34.2%; in urban areas it averages 35%, and in rural areas it averages 34.1% (Nowak and Greenfield 2012a). Urban tree cover is highest in Connecticut (66.5%), Massachusetts (64.5%), and New Hampshire (64%); it is lowest in Wyoming (9%), Montana (9%), Nevada (12%), and New Mexico (12%). Urban tree cover varies by ecoregion. In forested regions, it averages 38%, in grasslands 23%, and in deserts 15%. Percent tree cover in urban areas is also negatively correlated with urban population density.

About 75% of the tree cover in cities is found on residential and vacant lands, but the distribution varies by ecoregion (Nowak et al. 1996). In forested regions, residential areas account for 43% of total tree cover; vacant areas account for 37%. In grasslands, the distribution shifts to 54% on residential lands and 20% on vacant lands. In deserts it shifts even more toward residential: 72% of the total city tree cover is on residential lands and 2% on vacant lands. This distribution illustrates the role of ample precipitation and natural regeneration on urban tree cover in forested regions. Tree cover from natural regeneration on vacant lands has a more substantial influence on overall tree cover as water availability increases from desert to grassland to forest regions. Similarly, the overall influence of residential areas on total tree cover increases as water availability decreases from forest to desert regions, because people often need to supply water to sustain tree cover in desert and grassland regions. In all ecoregions, parklands contribute about 10% of total city tree cover.

Urban Forest Ecosystem Services and Values

Urban forests in the United States deliver numerous ecosystem services to society. They bring costs as well. Only a few of these services and costs, however, have been assessed at the national scale. Pollution removal by urban trees in the United States has been estimated at 711,000 metric tons (t) per year; average percent air quality improvement in cities during the daytime in the vegetation in-leaf season is typically lower than 1% (Nowak et al. 2006). A more recent assessment of pollution removal by trees across the conterminous United States estimated national pollution removal by forests at 17.4 million t in 2010 (range: 9.0–23.2 million t), 651,000 t of which is removed by urban forests (4% of the national total) (Nowak et al. 2014). The human health value of the air pollution removal was estimated at $6.8 billion nationally; 68% ($4.7 billion) of this value occurs in urban areas. Health impacts nationally included the avoidance of more than 850 incidences of human mortality and 670,000 incidences of acute respiratory symptoms.

U.S. urban forests store 643 million t of carbon and annually sequester 25.6 million t of carbon (Nowak et al. 2013). Based on the most recent social cost of carbon for the United States ($143 per t of carbon) (EPA 2013; IWG 2015), carbon storage is valued at $91.9 billion and annual carbon sequestration at $3.7 billion per year. Urban forests in the United States also reduce residential building energy use by 7.2%, which equates to $4.7 billion per year in reduced energy costs and an additional $2.3 billion per year in savings from reduced emissions from power plants (Nowak et al. 2016a). The total annual national value for the pollution, carbon, and energy effects is $15.4 billion. This value is conservative because it includes only a limited selection of ecosystem services and values provided by the urban forest.

Changes in Urban Tree Cover

Urban forests are constantly changing through time due numerous factors such as land development, tree growth and mortality, natural regeneration, tree planting, and tree maintenance and management activities. Tree planting, growth, and natural regeneration increase tree cover; tree removal, decline, and mortality decrease it. What then is the net change in tree cover caused by these competing forces? The ecosystem service values that the forest structure yields will change as the structure itself changes.

Analysis of tree and impervious cover change in 20 U.S. cities circa 2004 to 2008 revealed that 17 of these cities had statistically significant declines in tree cover, and 16 cities had statistically significant increases in impervious cover. National results indicate that tree cover in urban areas of the United States is declining at a rate of about 7,900 hectares per year or 4 million trees per year (Nowak and Greenfield 2012b).

Tree cover in the early 2000s was generally on the decline; however, it will not necessarily continue to decline. Tree cover tends to cycle with patterns of growth and decline through time. If development and other factors that lead to tree removal increase, tree cover could continue to decrease. More research is needed to determine if this tree cover decline pattern is continuing. To this end, a new national assessment of urban tree cover change (c. 2009–2014) is being completed to help monitor changes in urban tree cover.

The rates of tree mortality versus the rate of tree influx, in conjunction with tree canopy growth and decline of existing trees affect the amount of tree cover. When mortality and canopy decline exceed tree influx and canopy growth, tree cover tends to decline. Conversely, when tree influx and canopy growth exceed canopy losses from mortality and decline, tree cover tends to increase. As a result, the influx rate of new trees via tree planting and natural regeneration is an important factor in establishing a sustainable tree cover. If influx rates are too low, canopy cover could decline; if they are too high, canopy cover could increase, but not necessarily in a sustainable fashion. The key to a sustainable canopy cover is to strike the right balance between influx and mortality losses such that overall tree cover remains relatively constant at the desired level.

Drastic changes in tree cover can occur through natural events such as storms, pest outbreaks, or wildfires, when a large proportion of canopy could be lost in a short time. It can also occur through human actions such as deforestation from land development. Overplanting of trees can lead to a less sustainable cover. Too many trees planted over a relatively short time could create a "bubble" in the population structure where this cohort of trees will grow old together and create a large influx of new tree canopy. The increase in canopy may be desirable, but too much canopy within a small age class can lead to a tree cover crash when the trees all grow old and die within a relative short time. For sustainable tree cover, it is important to avoid relying on one small age class for most of the tree cover. It is better to distribute the cover effects among all age classes so cover can be sustained more evenly through time.

A key to sustaining tree cover is monitoring tree losses and gains to balance planting rates that help ensure sustainable tree cover. Tree gains come from both planting and natural regeneration, so it is important to know regeneration rates to determine desired planting rates. In the United States and Canada, about one in three trees are planted in cities. Land uses with the highest proportion of trees planted were residential (74.8% of trees planted) and commercial/industrial (61.2%). The percentage of the tree population planted is higher in cities in grassland areas than in those in forests and tends to increase with increased population density and percent impervious cover in cities. New tree influx rates ranged from four trees per hectare per year in Baltimore, MD, to 8.6 trees per hectare per year in Syracuse, NY; with more than 90% of the new tree influx coming natural regeneration (Nowak 2012).

In addition to tree cover change in established urban areas, urban tree cover tends to increase in magnitude nationally as urban areas expand into surrounding rural areas. Urban land is projected to increase from 3.1% of the conterminous United States in 2000 to 8.1% in 2050, an increase in area greater than the size of Montana (Nowak and Walton 2005). The increasingly urban landscape will have significant impacts on land management and efforts to sustain environmental quality in urban and urbanizing areas.

Forces for Urban Forest Change

In addition to natural forces for change such as tree growth, regeneration, and mortality, other forces have altered—and will continue to alter—urban forest composition and consequently ecosystem services and values. The forces that are most likely to alter urban forests in the coming years are development and urbanization, climate change, insects and diseases, invasive species, and wildfires.

Development and Urbanization

Development can alter forest structure within and around urban areas. Development within established urban areas can either decrease (tree removal) or increase (tree planting) tree cover within urban areas. As urban areas expand outward, the total urban forest area will grow at the expense of rural areas, which often are in either forested or agricultural lands (Nowak et al. 2005). Urban expansion tends to reduce overall tree cover in forested regions but increase tree cover in grassland areas (Nowak and Greenfield 2002a). In forested regions, development can lead to decreases in forest area and fragmentation of forest stands, which can significantly affect plant and wildlife populations, forest biodiversity, and health (Nowak et al. 2005). In addition, forested areas that are parceled (where stands remain intact but have multiple landowners) can affect the available timber supply and forest management (Zhang et al. 2005).

Climate Change

In the United States, climate change is expected to produce warmer air temperatures, altered precipitation patterns, and more extreme temperature and precipitation events (IPCC 2007), all of which can cause changes in urban forests via damage from storms or other extreme events (e.g., drought) and changes in tree species habitat suitability (see, for example, Iverson and Prasad 2001). Climate change also has the potential to exacerbate other urban forest threats, discussed in the following sections.

Insects and Diseases

U.S. urban forests are affected by numerous insects and diseases that have caused—or have the potential to cause—significant damage. Some invasive species—such as the gypsy moth, emerald ash borer, and the fungi that cause Dutch elm disease and chestnut blight—have caused catastrophic tree mortality that has virtually eliminated dominant tree species in some places (Liebhold et al. 1995; Dozier 2000). These changes by various pests are altering urban forest structure and associated ecosystem services and values.

Invasive Species

Kudzu (*Pueraria lobata*), English ivy (*Hedera helix*), European buckthorn (*Rhamnus cathartica*), and, in some areas, Norway maple (*Acer platanoides*), are some of the numerous invasive plants that can degrade or modify urban forests, in part by removing and replacing native plants and altering ecosystem structure (Dozier 2000; Webb et al. 2001). The invasive characteristics of some these species also pose problems associated with their spread into surrounding landscapes, because they can displace native species and alter local ecosystems (e.g., Pimentel et al. 2000).

Wildfire

Uncontrolled fires, or wildfires, can cause substantial damage to urban forests and dramatically alter the urban landscape, especially in urban areas adjacent to wildlands (Spyratos et al. 2007). High population growth and urban expansion in California, for example, have led to a substantial increase in fire ignitions in wildland–urban interface areas (Syphard et al. 2007).

Urban Forest Sustainability

To sustain urban tree cover and ecosystem services and values at the national level, it is important to sustain urban tree cover at the local level. Decisions on the desired or optimal amount of tree cover depend on local environmental (e.g., precipitation) and social (e.g., land use distribution, desires of the local population) conditions. Regardless of location, five key steps can help create healthy, sustainable and functioning urban forests.

1) Assess the Urban Forest Resource. Determine forest resources and assess the potential space for additional tree cover. Urban forests can be assessed through aerial-based approaches (e.g., mapping or interpretation of aerial images) or ground-based assessments (e.g., tree inventories or samples) (Nowak 2013). These types of assessments provide a baseline of information to help create sustainable future forests.

2) Understand the Actual and Potential Services and Values of the Forest Resource. Along with understanding the forest resource (e.g., tree locations, species composition, number of trees), it is important to know what types of ecosystem services and values the forest resource delivers. To this end, there is a series of freely available tools to aid in assessing urban forests and their ecosystem services and values (i-Tree: www.itreetools.org, Nowak et al. 2008). By understanding the actual and potential values, along with the most important local environmental or social issues (e.g., air pollution, water quality, high temperatures, crime), management plans can be developed that use urban forests to help improve environmental quality and human health and well-being.

3) Develop a Management Plan. Steps 1 and 2 provide essential information for developing an urban forest management plan to create sustainable forest services for future generations. By combining forest information with local needs through a public participation process, desirable and attainable forest plans can be developed. These plans can detail specific goals and time frames (e.g., canopy cover or tree planting goals) along with information about items such as budgets; public versus private tree planting incentives; projected maintenance costs; and tree species, locations, and planting rates needed to create healthy and sustainable urban forests.

4) Implement the Plan. Once the plan is developed, put it into action.

5) Monitor the Changes. Monitoring is a critical element in sustainability, because it helps determine urban forest change and whether the goals of the management plans are being met. One of the best ways to monitor is to remeasure the data collected in step 1 using the same methods and locations. Once the data are remeasured (e.g., every 5 years), steps 1–5 can be redone and management plans adjusted based on the new data to ensure that management plan goals and objectives continue to be met.

In the United States, the U.S. Forest Service Forest Inventory and Analysis program has started to implement, in partnership with cities, long-term urban forest monitoring programs. This program measures urban forest data annually to assess urban forest structure; ecosystem services and values; and changes in structure, services, and values. The first city to complete a baseline inventory was Austin, Texas (Nowak et al. 2016b), but numerous other cities are being monitored and new cities will be added to the monitoring program in the next few years (Forest Service 2016).

By measuring and monitoring urban forests, society can better understand the magnitude of the resource, the values supplied by urban forests, and how urban forests and associated values are changing. The development of management plans to create desirable, healthy, and sustainable urban forests can help ensure that these forests continue to improve environmental quality and human health and well-being for current and future generations.

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