Chapter 4

David Nowak

Urban Forests

Urban forests (and trees) constitute the second forest resource considered in this report. We specifically emphasize the fact that agricultural and urban forests exist on a continuum defined by their relationship (and interrelationship) with a given landscape. These two forest types generally serve different purposes, however. Whereas agricultural forests are considered primarily in terms of their contribution to biodiversity conservation or, as in the case of agroforestry, to agricultural production, urban forests are assessed primarily in terms of the range of environmental services and values they provide to urban and suburban residents. The potential list of services is extensive and will vary according to different individuals, organizations, and locations, with many services being difficult to precisely quantify. Trees affect numerous environmental processes, such as water cycling; sound propagation; and pollution formation, dispersion, and removal. Trees also directly affect human populations by altering the social, economic, health, and aesthetic aspects of urban environments. These effects exist in all treed landscapes but are more prominent in urban areas because of the higher concentration of people.

As in the previous chapter, this chapter begins with a general description of the resource, including formal definitions. This first section also includes a brief listing of environmental services associated with urban forests and the specific threats they face. The second section presents currently available data for understanding urban forests at the national scale. These data rely heavily on satellite imagery and are focused on describing the extent of forest cover in urban areas. The chapter concludes with a discussion of the adequacy of the current information base and strategies for improving it.

Definitions and Characteristics of Urban Forest Ecosystems

Urban forests are defined by their proximity to human populations and include numerous physical elements that constitute urban development. The characteristics of these forests are determined by both their natural components and the anthropogenic elements in the landscapes in which they occur.

Definitions

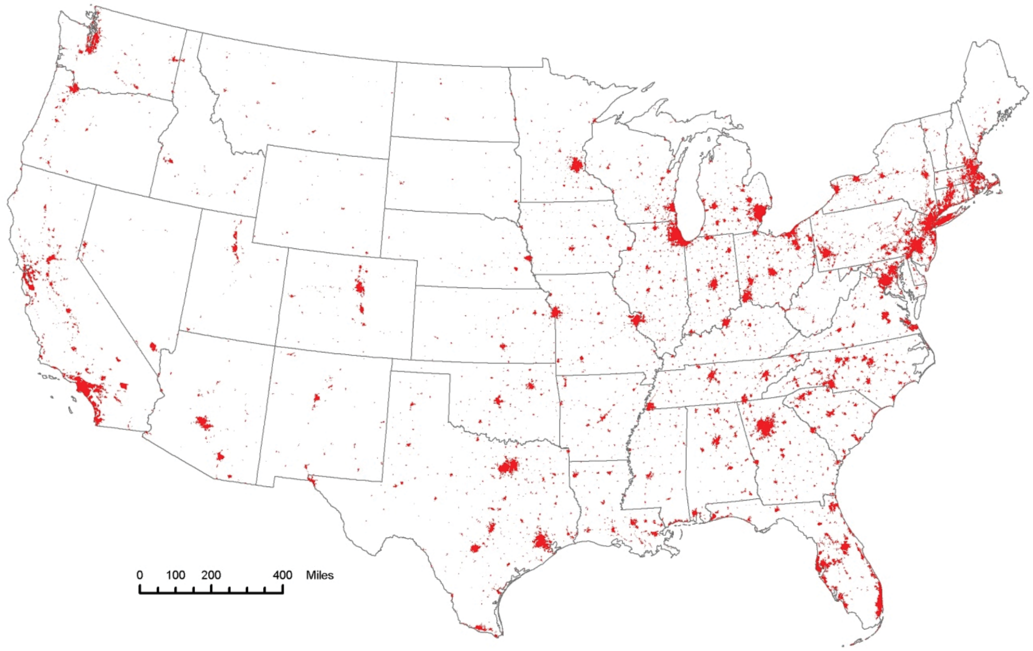
For purposes of this report, *urban forests* are composed of all the trees within our urban lands. The definition conceptually extends to include the various ecosystem components that accompany these trees (e.g., soils or understory flora), although we do not explicitly identify all these components. Urban forests can contain forested stands, like in rural areas, but they also contain trees found along streets, in residential lots, in parks, and in other land uses. The forests are a mix of planted and naturally regenerated trees. For data gathering and reporting purposes, the key to defining urban forests lies in the definition of what precisely constitutes urban land. Using the Census Bureau's definition, *urban land* consists of all territory, population, and housing units located within either urbanized areas or urban clusters (Census Bureau 2014).

Urbanized areas consist of densely settled territories that contain 50,000 or more people; urban clusters consist of densely settled territories that have at least 2,500 people but fewer than 50,000 people (fig. 4.1). Urbanized area and urban cluster boundaries encompass densely settled territories and are defined by—

- A cluster of one or more block groups or census blocks with a population density of at least 1,000 people per square mile.
- Surrounding block groups and census blocks with a population density of 500 people per square mile.
- Less densely settled blocks that form enclaves or indentations or that are used to connect discontinuous areas (Census Bureau 2014).

This definition of urban lands is based solely on census blocks and their population density. Census blocks, in turn, are determined in part by physical features on the land, both constructed, such as roads and rail lines, and natural, such as rivers and

Figure 4.1. Urban areas in the contiguous United States, 2000, based on the Census Bureau definition of urban land (Nowak and Dwyer 2007).



ridgelines. (Additional information is available at the Census Bureau's Web site—http://www.census.gov/ [August 2015].) The resulting definitions of urban lands will not always match the jurisdictional boundaries of cities and towns. Urban forests, however, are most commonly managed at the municipal level. A uniform definition that can consistently span different jurisdictional boundaries is essential for developing consistent national and regional inventories, especially if the inventories are to be combined with inventories from other land use classes, but jurisdictional boundaries will often be crucial in determining how, and if, forest resources will be managed. Assessments conducted within jurisdictional boundaries (community forests) and urban boundaries (urban forests) can be found within State reports at http://www.nrs.fs.fed.us/data/urban (August 2015). Information about wildland-urban interfaces, or WUIs, is available at http://www.nrs.fs.fed.us/disturbance/fire/wui/ (August 2015).

Characteristics of Urban Forests

Urban forest ecosystems have many special characteristics that, in combination, distinguish them from other forest types. These characteristics include (1) close proximity to large or dense human populations, (2) relatively high diversity of species and forest patch structures, (3) multiple public and private ownership types, and (4) management often geared toward sustaining tree health and ecosystem services. More than 80 percent of the U.S. population lives in urban areas; thus, urban forests greatly influence the day-to-day lives of most Americans.

These influences include positive and negative experiences (see Associated Benefits and Costs in the following section). Often, the only "nature" some urbanites experience in their lives is from contact with urban forests. These trees and forests provide an array of species and structural diversity that is not typically found in other forests. Species richness and diversity in urban forests are typically greater than what is found in surrounding native stands, with urban forests containing varying proportions of nonnative tree species (Nowak 2010). Not only are species diverse, but the tree configurations in urban areas also can be diverse, crossing many land use types and including single tree specimens, linear rows of street trees or trees along fence rows, and large patches of intact forest stands. The diversity of trees is often dwarfed by the diversity of landowners in urban areas. The ownership of trees ranges from numerous small parcels of family homes, to private commercial tracts, to varying-sized public properties with varying densities of trees. Urban trees include a mix of planted and naturally regenerated species (Nowak 2012) and often are managed to sustain tree health and benefits and to minimize risk to or conflict with human populations. They typically are not managed as a crop to be harvested; rather, they are a landscape element to be enhanced or sustained.

Urban Forest Sustainability

One main objective of urban forest management is to provide for optimal and sustainable benefits from trees for current and future generations. To promote optimum sustainability, managers need to understand the current resource and how it is changing so they can properly guide the resource to a desired future state. Tree cover in urban areas has been declining in recent years (Nowak and Greenfield 2012b) and tree cover is constantly changing due to various natural and anthropogenic forces.

Natural forces for change include natural regeneration, tree growth and tree mortality from insects and diseases, storms, fire, old age, etc. Anthropogenic factors that influence tree cover include tree planting and tree mortality or removal from either direct or indirect human actions such as development and pollution. The combination of these factors through time determines existing and future forest structure, species composition, and tree-cover levels.

Sustaining desired levels of services or benefits is most easily related to sustaining a certain level and distribution of tree cover. Sustaining a desired level of canopy cover requires ensuring an adequate establishment of new trees (via planting or natural regeneration) to offset loss in tree canopy due to tree mortality. Determining the exact tree establishment rate is difficult because trees grow (increasing canopy through time), trees are different sizes (canopy loss from the removal of one large tree cannot be replaced by planting one small tree), and the system is constantly changing due to human (e.g., development) and natural (e.g., storms) factors that can create drastic cover changes in a short period of time. Although *sustaining* canopy cover is important, it is different from *optimizing* canopy cover, which requires additional information on species and locations to ensure the optimal distribution of benefits at minimal cost over time.

Monitoring urban forests is critical to ensure sustainable, optimal, and healthy urban forests. Monitoring data can be used to detect changes and determine if management plans are meeting their desired goals. By monitoring, managers can better understand how the resource is changing and management plans can be adjusted to ensure healthy urban forests that meet the desired goals of the local residents and sustain forest benefits for future generations.

Benefits and Costs Associated With Urban Forests

Urban trees provide innumerable annual ecosystem services that affect the local physical environment (such as air and water quality) and the social environment (such as individual and community well-being). These services can positively influence urban quality of life but also have various costs (Nowak and Dwyer 2007). Urban forest services (benefits) and disservices (costs) include, but are not limited to, the following.

Energy conservation and carbon dioxide sequestration. Trees reduce energy needs for heating or cooling buildings by shading buildings in the summer, reducing summer air temperatures (primarily through transpirational cooling), and by blocking winter winds. Trees also can increase heating needs, however, by shading buildings in the winter if planted in improper locations close to structures. The energy effects of trees vary with regional climate and their location around the building (Heisler 1986).

Urban trees reduce carbon dioxide (CO_2), a major greenhouse gas, by directly removing it from the atmosphere and storing ("sequestering") the carbon in the trees as biomass. By reducing building energy use, trees can also reduce the emission of CO_2 from power plants. Tree-maintenance activities often require the use of fossil fuels that emit CO_2, however, and improperly located trees around buildings can increase energy demands and consequent emissions of CO_2 (e.g., Nowak 2000; Nowak et al. 2002b).

Air quality. Trees influence air quality in a number of ways. Trees remove pollution from the air by intercepting airborne particles on their leaves and branches, and absorbing gaseous pollutants into their leaves via stomata. Pollution removal by trees within a city can be on the order of thousands of tons annually, with air-quality improvement typically less than 1 percent (Nowak et al. 2006a). Trees also emit various volatile organic compounds that can contribute to the formation of ozone (O_3). By lowering air temperatures via transpirational cooling and shading, however, trees lower the emission of volatile organic compounds from vegetation and numerous anthropogenic sources (e.g., gasoline), thus reducing the potential for ozone formation. In addition, trees can produce pollen that can exacerbate allergies. Finally, by reducing building energy requirements, trees reduce pollutant emissions from power plants, thereby improving air quality (Nowak 1994; Nowak et al. 2006a; Nowak and Dwyer 2007).

Urban hydrology. By intercepting and retaining or slowing the flow of precipitation reaching the ground, urban forests can play an important role in urban hydrologic processes. They can reduce the rate and volume of stormwater runoff, flooding damage, and stormwater treatment costs, and they can enhance water quality. Estimates of runoff for an intense storm in Dayton, OH, for example, showed that the existing tree canopy reduced potential runoff by 7 percent; a modest increase in the canopy would have reduced runoff by nearly 12 percent (Sanders 1986). The greatest percent of rainfall interception occurs during the more common small storm events. During large rain events, the percent of rainfall interception can drop to a very small percent as most of the rain reaches the ground. During these large storm events, trees exert a relatively small effect from rainfall interception. To better manage storm runoff, a number of U.S. cities are moving forward with the use of enhanced tree plantings in combination with other "green infrastructure" in lieu of expanded pipe and culvert networks, or "grey infrastructure" (Philadelphia's Green Infrastructure Plan is a notable example).

Noise reduction. Properly designed plantings of trees and shrubs can significantly reduce noise levels (Anderson et al. 1984). Wide belts (approximately 100 feet [30 meters]) of tall dense trees combined with soft ground surfaces can reduce apparent loudness by 50 percent or more (6 to 10 decibels) (Cook 1978). Although noise reduction from plantings along roadsides in urbanized areas often is limited due to narrow roadside planting space (less than 10 feet [3 meters] in width), reductions in noise of 3 to 5 decibels can be achieved with narrow dense vegetation belts with one row of shrubs roadside and one row of trees behind (Reethof and McDaniel 1978).

Quality of life. The presence of urban trees can make the urban environment a more aesthetic, pleasant, and emotionally satisfying place in which to live, work, and spend leisure time (Dwyer et al. 1991; Taylor et al. 2001a, 2001b; Ulrich 1984). Studies of urbanites' preferences and behavior have confirmed the strong contribution of trees and forests to the quality of life in urban areas. Urban forests also provide significant outdoor leisure and recreation opportunities for urbanites (e.g., Dwyer 1991, Dwyer et al. 1989).

Urban forest environments provide aesthetically pleasing surroundings, increased enjoyment of everyday life, and a greater sense of connection between people and the natural environment. Trees are among the most important features that contribute to the aesthetic quality of residential streets and community parks (Schroeder 1989). Perceptions, such as aesthetic quality and personal safety, are highly sensitive to features of the urban forest such as number of trees per acre and viewing distance (Schroeder and Anderson 1984).

Community well-being. Urban forests make important contributions to the vitality and character of a city, neighborhood, or subdivision. Furthermore, the act of planting and caring for trees, when undertaken by residents, yields important social benefits and a stronger sense of community. In addition, empowerment to improve neighborhood conditions in inner cities has been attributed to involvement in urban forestry efforts (Kuo and Sullivan 2001a, 2001b; Sommer et al. 1994a, 1994b; Westphal 1999, 2003).

Physical and mental health. Reduced stress and improved physical health for urban residents have been associated with the presence of urban trees and forests. Landscapes with trees and other vegetation have produced more relaxed physiological states in humans than landscapes without these natural features. Hospital patients with window views of trees recovered significantly faster and with fewer complications than comparable patients without such views (Ulrich 1984).

Local economic development. Urban forest resources contribute to the economic vitality of a city, neighborhood, or subdivision. By improving the environment, trees contribute to increased property values, sales by businesses, and employment (e.g., Anderson and Cordell 1988; Corrill et al. 1978; Donovan and Butry 2008; Dwyer et al. 1992; Wolf 2003, 2004). Urban forest maintenance and management activities also create jobs to help the local economy, and wood from removed trees and limbs can be used to produce various wood products or fuels (e.g., fire wood or ethanol) that can be used by residents, while creating additional jobs in the process.

Management costs. Although natural regeneration is a powerful force in shaping the urban forest (Nowak 2012), tree planting and various maintenance activities (e.g., watering, raking, pruning, tree removals) incur economic costs while helping to provide for safe and healthy urban forests. Enhancing tree cover in environments that tend to be precipitation limited involves additional economic and environmental costs. Planting trees in these environments can produce substantial benefits for the urban population, but such plantings often require water or economic resources that may be scarce. In addition to management costs, various risks associated with urban forests related to falling trees and limbs may pose additional costs through personal injury, property damage, and power outages. Proper management and maintenance can minimize risks and costs, while enhancing numerous benefits for current and future generations. Disposal of leaves and other detritus can incur significant cost but also represents a potentially valuable supply of wood or organic matter (e.g., for mulch, wood products or bioenergy applications).

Major Threats and Influences Affecting the Urban Forest

Numerous potential threats can significantly alter urban forests and their associated benefits. These threats (Nowak et al. 2010) include the following.

Insects and diseases. Urban forests can be, and are, severely affected by numerous insects and diseases, many of them introduced from other geographic regions into urban centers. Some insects and diseases—such as the gypsy moth, Asian longhorned beetle, emerald ash borer, and Dutch elm disease—have caused significant tree mortality that has virtually eliminated dominant tree species in some places (e.g., Dozier 2012, Liebhold et al. 1995).

Wildfire. Uncontrolled fires can cause significant damage to trees and forests and dramatically alter the urban landscape, especially in urban areas adjacent to wildlands (Nowak 1993, 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). In addition, the intermingling of trees with manufactured structures in these areas significantly complicates and limits the options available for fire suppression activities and vegetation management practices used to reduce fire risk.

Storms. Urban forests can be altered and have been significantly damaged by wind, ice, and snow storms that result in broken branches and toppled trees (e.g., Greenberg and McNab 1998, Irland 2000, Proulx and Greene 2001, Valinger and Fridman

1997). As in the case of fire, the proximity of trees to buildings, roads, and power lines complicates forest management in this regard, while elevating the potential damage that can result.

Invasive plants. Invasive plants such as kudzu (*Pueraria lobata*), English ivy (*Hederal helix*), European buckthorn (*Rhamnus cathartica*), and Norway maple (*Acer plantanoides*) can degrade or alter urban forests by removing and replacing native plants and altering ecosystem structure. English ivy and kudzu have been known to cover acres of canopy trees (Dozier 2012, Webb et al. 2001). The introduction of nonnative species in gardens and parks enhances this risk.

Development. Land development significantly alters the urban landscape, affecting plant and wildlife populations and forest biodiversity and health (Nowak et al. 2005). Development can lead to rapid reductions in tree populations (clearing of forest stands), can alter species composition (e.g., tree planting after development), can increase tree populations (e.g., tree planting in formerly cleared areas), and can alter the urban environment (e.g., increase or decrease in air temperatures). Development associated with urban expansion into rural areas can also significantly alter the regional landscape, particularly in forested regions where forest area is reduced, fragmented, or parcelized (i.e., forest stands remain intact but have multiple landowners). In timber-producing regions, when development alters the rural forest landscape, it will likewise affect the available timber supply and forest management practices (Zhang et al. 2005).

Pollution. Air and water pollution can affect tree health in urban areas if pollutant concentrations reach damaging levels. Forests have been shown to be affected by air pollution, especially from regional deposition of ozone, nitrogen, sulfur, and hydrogen (Stolte 1996). Ozone has been documented to reduce tree growth (Pye 1988), reduce resistance to bark beetle, and increase susceptibility to drought (Stolte 1996). Air pollution can also enhance tree growth through increased levels of carbon dioxide or by providing essential plant nutrients such as sulfur and nitrogen (e.g., NAPAP 1991).

Climate change. Climate change is expected to produce warmer air temperatures, altered precipitation patterns, and more extreme temperature and precipitation events (EPA 2009, IPCC 2007). These climate changes can cause changes in urban forest composition (Iverson and Prasad 2001, Johnston 2004) and have the potential to exacerbate other urban forest threats (e.g., invasive species and pests). Climate change has the potential to alter urban forests, not only through species changes, but also through direct effects from storms, floods, etc., that may kill large portions of the forest in relative short time periods. Urban forest managers will need to understand and adapt to potential species shifts and changes to the environment to produce sustainable and healthy urban forests under future climatic conditions.

Improper management. Because numerous people directly manage most of the urban forest, the decisions and actions of the managers significantly affect urban forest composition and health. Improper decisions related to species selection, tree locations, and maintenance can lead to conflicts with the urban population and infrastructure, tree damage, and poor tree health that can lead to premature tree mortality. Actions or inactions taken by the multitude of urban landowners can pose a threat to urban forests, but they can also help bolster urban forest health and sustainability if proper tree care and management are conducted.

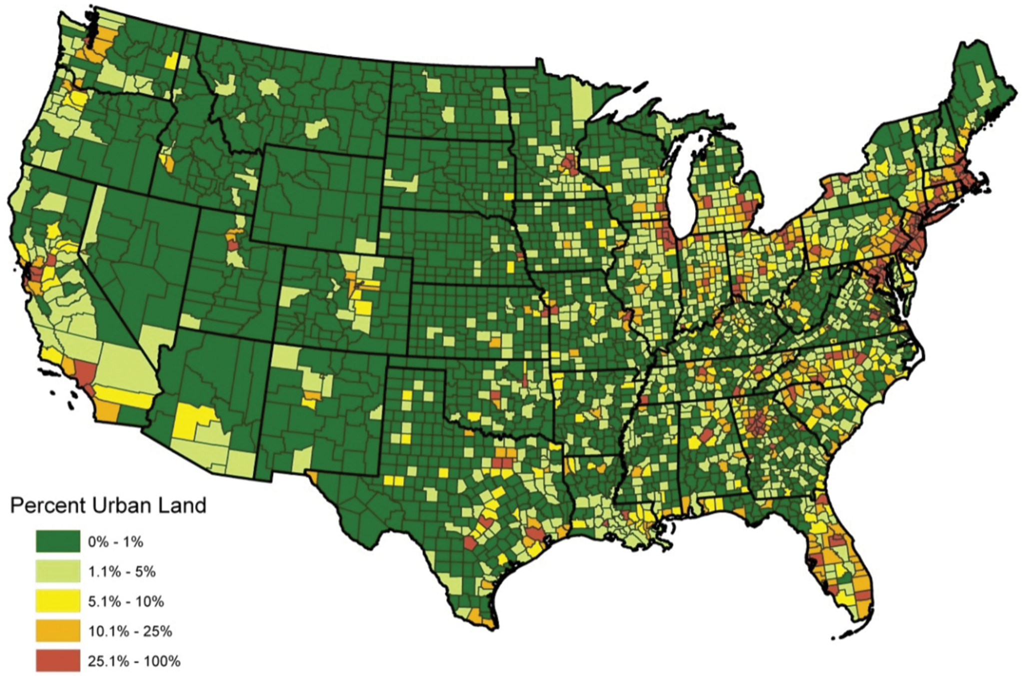
Currently Available Data on U.S. Urban Forests

Although far from complete for national assessment needs, the data describing urban forests in the United States is improving. Remote-sensing techniques are being used to construct urban forest cover estimates at the local and regional level across the country. In addition, new urban forest field data are continually being collected by local groups and cities, and through the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service in select metropolitan areas. Tools are being designed and improved to help municipalities inventory their forests in a consistent fashion while fostering the participation of interested citizens.

Extent of Urban Land in the United States

The importance of urban forests and their benefits in the United States is increasing because of the expansion of urban land. The percent of the coterminous United States classified as urban increased from 2.5 percent in 1990 to 3.1 percent in 2000, an area about the size of Vermont and New Hampshire combined. The States with the highest percent urban land are New Jersey (36.2 percent), Rhode Island (35.9 percent), Connecticut (35.5 percent), and Massachusetts (34.2 percent), and 7 of the top 10 most urbanized States are located in the Northeastern United States (fig. 4.2). Urban land in the coterminous United States in 2010 increased to 3.6 percent (U.S. Census 2014). Most of the 1990-to-2000 urban expansion occurred in previously forested areas (33.4 percent of the expansion) or agricultural lands (32.7 percent). The dominant type of land uses or cover classes occurring in a given State largely determines the type of land being converted to development. States where more than 60 percent of urban land expansion occurred in forests were Rhode Island (64.8 percent of urban expansion), Connecticut (64.1 percent), Georgia (64.0 percent), Massachusetts (62.9 percent), West Virginia (62.2 percent), and New Hampshire (61.3 percent). States where more than 60 percent of urban land expansion

Figure 4.2. Percent of U.S. counties classified as urban, 2000 (Nowak et al. 2010).



occurred in agricultural lands were Nebraska (68.9 percent), Indiana (66.8 percent), Illinois (64.8 percent), and Wisconsin (62.0 percent) (Nowak et al. 2005). These estimates of urban land and urban land expansion within land cover types are based on Census Bureau maps of urban land and National Land Cover Database (NLCD) maps of land cover types. Although these maps may have some inaccuracies, the urban land maps are fairly accurate because they are based on extensive census data.

The most urbanized regions of the United States are the Northeast (9.7 percent of total land area) and Southeast (7.5 percent), with these regions also exhibiting the greatest increase in percent urban land between 1990 and 2000 (1.5 and 1.8 percent, respectively). States with the greatest increase in percent urban land between 1990 and 2000 were Rhode Island (5.7 percent), New Jersey (5.1 percent), Connecticut (5.0 percent), Massachusetts (5.0 percent), Delaware (4.1 percent), Maryland (3.0 percent), and Florida (2.5 percent). States with the greatest absolute increase in urban land are Florida (925,000 acres; 374,000 hectares), Texas (871,000 acres; 352,000 hectares) and California (737,000 acres; 298,000 hectares) (Nowak et al. 2005).

Given the urban growth patterns of the 1990s, urban land is projected to expand from 3.1 percent of conterminous United States in 2000, to 8.1 percent in 2050, an increase in area greater than the size of Montana (fig. 4.3). The total projected amount of U.S. forest land projected to be subsumed by urbanization between 2000 and 2050 is about 29.2 million acres (11.8 million hectares), an area approximately the size of Pennsylvania (Nowak and Walton 2005) (fig. 4.4).

Figure 4.3. Percent of land classified as urban in 2000 (a) and projected percent of land classified as urban in 2050 (b), by county (Nowak and Walton 2005).

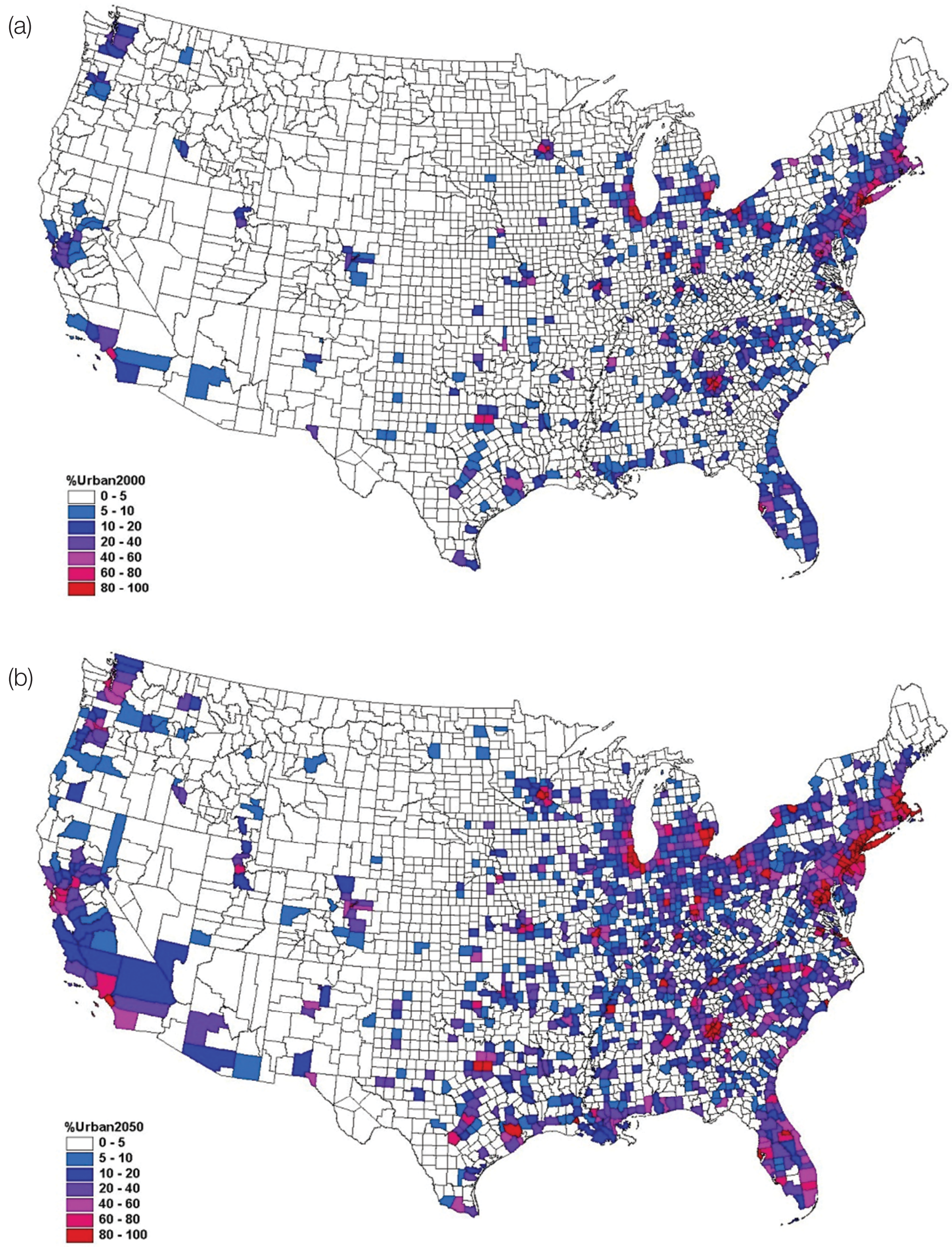
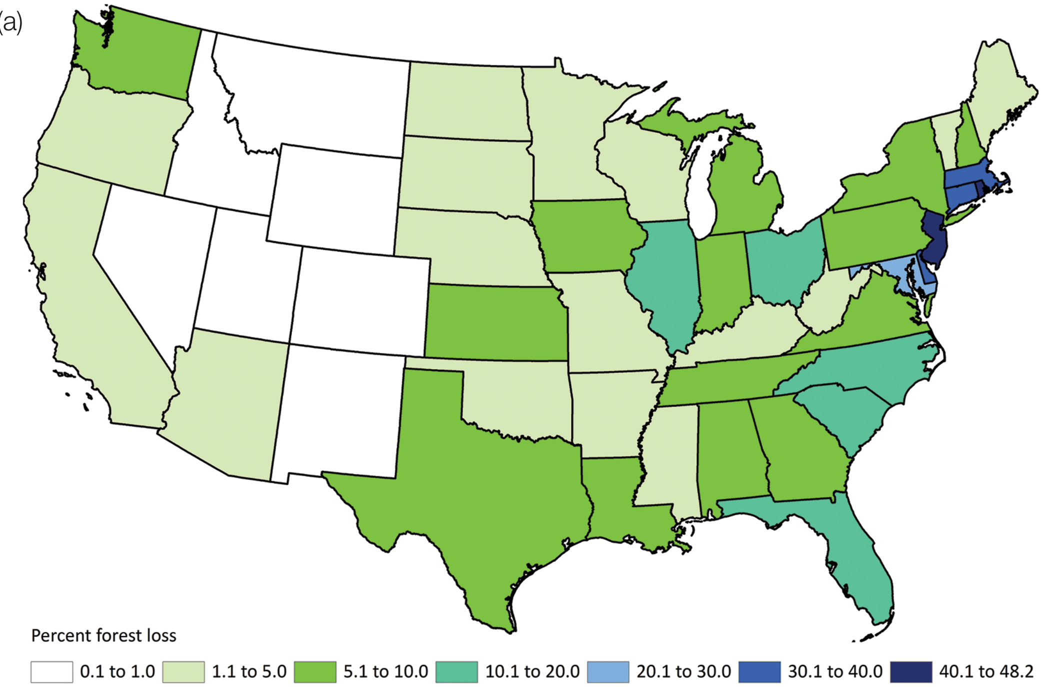
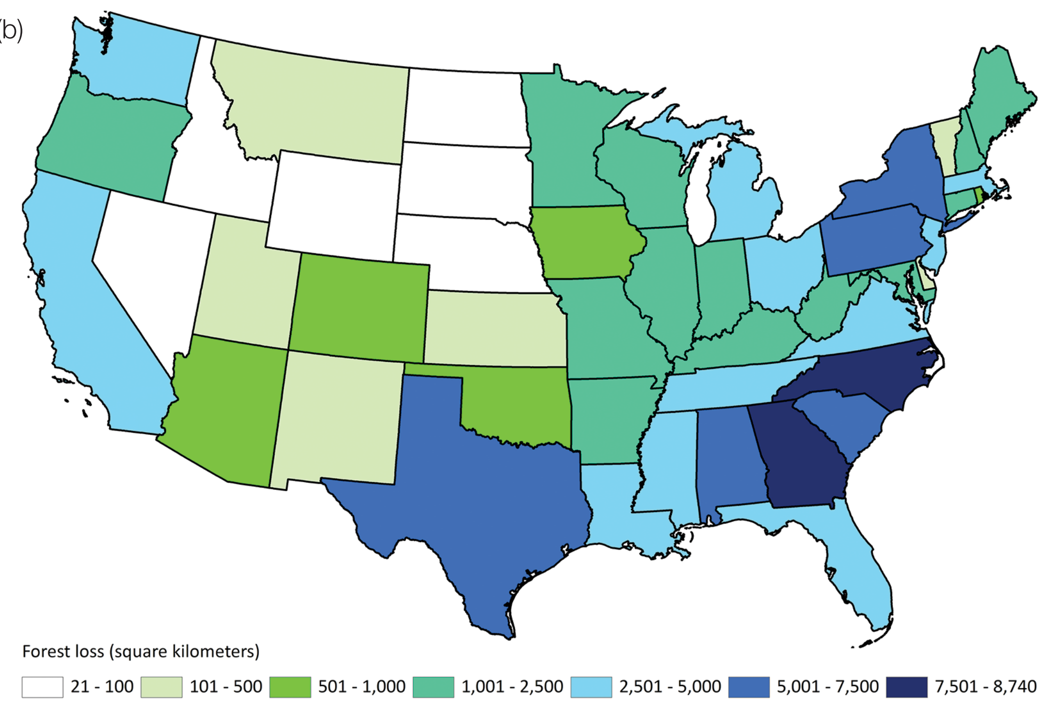


Figure 4.4. Percent (a) and square kilometers (b) of nonurban forest subsumed by projected urban growth, 2000 through 2050, by State (Nowak and Walton 2005).

(a)



(b)



Urban Tree-Cover Estimates

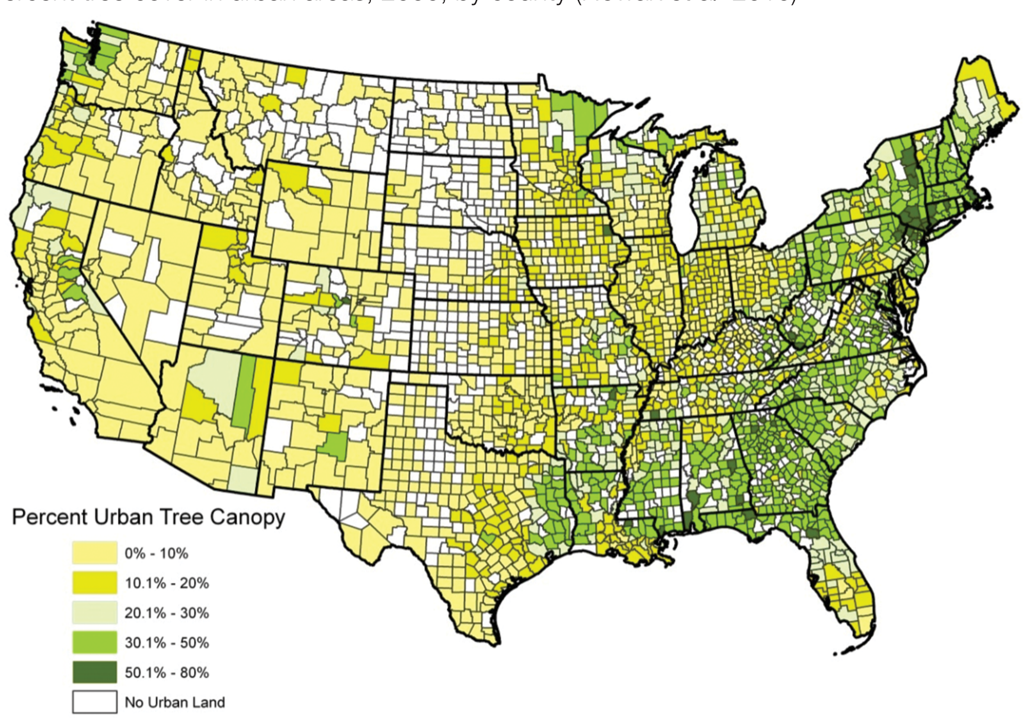
Tree cover in urban lands in the United States (circa [ca.] 2005) is currently estimated at 35.0 percent (Nowak and Greenfield 2012a). Urban tree cover has declined slightly in recent years (ca. 2002 to 2009) with a loss of about 4 million urban trees per year (Nowak and Greenfield 2012b). These estimates are based on photo interpretation of tree cover nationally. Urban tree cover varies across the United States, with urban tree cover tending to be highest in forested regions, followed by grasslands and deserts (Nowak et al. 2001). In addition to photo-interpretation estimates, tree-cover maps for the United States have been produced based on 30-meter resolution satellite data (ca. 2001) as part of the NLCD (USGS 2008) (fig. 4.5). These tree-cover maps underestimate tree cover on average by 9.7 percent, with underestimation varying across the conterminous United States (Greenfield et al. 2009, Nowak and Greenfield 2010).

Based on field data sampled from several cities combined with national urban tree-cover estimates, an estimated 3.8 billion urban trees are growing in the conterminous United States (the actual range of the national estimate is between 2.4 and 5.7 billion trees, based on minimum and maximum city tree-cover density estimates) (Nowak et al. 2001). These trees have an estimated structural asset value of $2.4 trillion (Nowak et al. 2002a). The structural value averages about $600 per tree and is based on a formula from the Council of Tree and Landscape Appraisers that estimates the replacement or compensatory (if a tree is too large to be directly replaced) value of a tree. Structural values vary by location, tree size, species, and condition of the tree. The urban forest nationally stores about 709 million tons (643 million metric tons) of carbon (Nowak et al. 2013), which is valued at $94.3 billion, or $146.7 per metric ton of carbon (Interagency Working Group 2015, U.S. EPA 2015). Soils in urban areas also store about 2.1 billion tons of carbon in the United States (Pouyat et al. 2006). These values are current asset values that would be lost through the loss of existing urban forests nationally.

In addition to these structural values, urban forests annually provide substantial functional values or benefits based on the ecosystem services they provide. Some of these functional benefits accrue in the tree (e.g., carbon storage) and can be partially or completely lost when the trees die (e.g., tree decomposition can release carbon back to the atmosphere). Other functional values do not accrue within a tree, however, and thus are continuously gained as long as the forest is healthy and functioning and will not be lost when the forest dies (e.g., accrued energy savings from temperature moderation and shade during a tree's lifetime are not lost when the tree dies).

Urban trees in the conterminous United States remove approximately 651,000 metric tons (717,000 tons) of air pollution annually, with a value of $4.7 billion (Nowak et al. 2014). These trees also annually sequester about 25.6 million metric tons of carbon (28.2 million tons of carbon) (Nowak et al. 2013), or $3.8 billion per year based on 2015 estimates of the total cost of a unit of carbon emissions to a society (Interagency Working Group 2015, U.S. EPA 2015). In addition, the total annual contribution of trees in urban parks and recreation areas to the value of recreation experiences provided in the United States could exceed $2 billion (Dwyer 1991).

Figure 4.5. Percent tree cover in urban areas, 2000, by county (Nowak et al. 2010).



Local Inventory Activities and Related Tools

The foregoing text has stressed information available at the national scale, relying primarily on remote-sensing data of urban tree cover combined with various one-time analyses of city tree populations to derive estimates of national urban tree totals and economic values. Urban forests, however, are managed at the local level and, in recent years, local citizens and interest groups have become increasingly engaged in assessing urban forest resources and improving their condition through management. New tools have emerged to facilitate this activity. The i-Tree Eco model is one example, in which local residents are encouraged to use standard sampling protocols in their local area to ensure the collection of consistent data that measure important aspects of urban forests (Nowak et al. 2008).[19] Since i-Tree's introduction in 2006, there have been more than 60,000 users in more than 120 countries, with user downloads increasing at a rate of about 25 percent per year. This growth reflects the desire by citizens and managers to better understand the ecosystem services that urban forests provide. The i-Tree provides a foundation for a growing database on local forest conditions, but it does not constitute a consistent national survey of urban forest resources in the United States.

Building a National Inventory

In an effort to better understand the urban forest resource at the national scale, urban forest inventory methods were pilot-tested in five States (Colorado, Indiana, New Jersey, Tennessee, and Wisconsin; Cumming et al. 2008). Statewide urban forest inventories have also been conducted more recently in Alaska, California, Hawaii, Oregon, and Washington. Data from these State assessments are run through the i-Tree model to provide estimates of ecosystem services and values. This activity is the foundation for the full implementation of a national urban forest inventory and monitoring program of major metropolitan areas that started in 2014 with the FIA program staff measuring field plots in Baltimore, MD, and Austin, TX.

Assessing Data Adequacy and Identifying Major Data Gaps

Although i-Tree Eco assessments and urban forest assessments by FIA are increasing, major gaps still exist in basic urban forest field data. Local city assessments provide urban forest data that are useful at the local scale, but local-scale assessments, in general, are piecemeal in nature and are not always consistent with efforts undertaken elsewhere. Alone, these local inventories cannot be readily used as building blocks for a national assessment. The State urban forest assessments are geared to providing consistent urban forest data at the State scale, but they are currently of limited usefulness at the national scale due to the small number of State assessments so far completed.

The planned implementation of an FIA urban forest inventory and monitoring program at the national level will fill a major information gap in the effort to improve urban natural resource stewardship (Cumming et al. 2008). The starting of FIA measurement and monitoring in Baltimore, Austin, and other cities will facilitate better linking and consistency among FIA urban and conventional forest inventories and also inclusion within i-Tree. This new national FIA urban program is expanding to other cities and will provide more useful data at the local scale due to increased sample sizes within the cities. These data will provide critical baseline information and monitoring data from local to regional scales. These local-scale analyses will provide limited information, however, for a national assessment. Until all metropolitan areas are assessed, development of a national urban forest assessment will be challenging.

Local-scale urban forest information can be, and is being, analyzed using i-Tree, but these data are collected by various groups with varying degrees of quality control and are not an adequate substitute for field data gathered through a national inventory in a consistent fashion across space and time. This critical information gap needs to be filled to fully assess and understand our Nation's urban forest resources. Information from a national survey can be used to better understand the magnitude of this resource, and how it is changing through time, so that better management plans and policies can be developed to sustain and enhance urban forest benefits for future generations. This understanding, in turn, will enable us to disseminate improved best practices, identify emergent threats, and devise national and regional policies and partnerships aimed at improving stewardship of these valuable resources. If integrated with conventional forest inventory activity through the FIA program, along with similar surveys of agricultural forests resources, a national urban forest inventory would constitute an essential piece of the information base needed to successfully engage in landscape-scale resource conservation that bridges jurisdictional boundaries, ownership classes, and land use types.

Efforts to assess current urban forests at the national scale have several limitations due to the gaps in urban forest data. To produce national or regional estimates of urban forests and their

[19] The i-Tree Eco model is a new iteration of the UFORE (Urban Forest Effects) model and is one of several urban forest tools found within the i-Tree modeling suite. i-Tree is developed, maintained, and supported by a consortium of partners, including the Forest Service, Davey Tree, National Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees. Information on the model and other i-Tree applications is available at http://www.itreetools.org.

effects, national or regional tree-cover data are combined with averages from various local urban forest assessments, and these localities may not truly represent the overall region of analysis. National and regional averages, from limited amounts and limited spatial distribution of urban forest field samples, present challenges in providing truly accurate regional or national estimates.

Another challenge faced by national and regional urban forest estimates is the accuracy of the tree-cover data at these scales. Tree-cover maps based on 30-meter resolution images from the early 2000s are limited in their ability to accurately estimate tree cover, particularly in urban areas. Recent photo-interpretations of tree cover nationally demonstrate that these tree-cover maps underestimate tree cover, on average, by 9.7 percent with underestimation varying across the conterminous United States (Greenfield et al. 2009; Nowak and Greenfield 2010). Improved tree-cover estimates will provide a basis for better estimates of urban forest structure, functions, and values from local to broader scales, but these estimates will still be limited by the absence of information from field data assessments (e.g., number of trees, species composition, diameter distribution, tree health). This field derived information on urban forests is lacking for most cities and regions of the United States. Most data from field assessments are derived from individual efforts on the part of municipalities or regional collaborations. As a result, although the quantity and quality of urban forest data are increasing, these data are not sufficient to adequately monitor or assess urban forests at the regional or national scale.

Data adequacy relative to the Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability. As described previously, the information we currently have about urban forest resources *at the national level* is largely restricted to urban forest cover estimates derived from the analyses of satellite images or photo-interpretation, along with some estimates of tree counts and economic values modeled or otherwise derived from the cover estimates and various field data assessments. This information is much less than the database that was assembled to address the 54 MP indicators covered in the *National Report on Sustainable Forests—2010*, hereafter the *National Report* (USDA Forest Service 2011). Nonetheless, the data on urban forests that we currently do have will go a long way in addressing some of the key indicators on forest extent found in MP Criterion 1, and these data constitute an important foundation for developing a more comprehensive inventory. Knowledge of local or regional tree species distributions can be cross-referenced with cover data to develop estimates of total regional or national species counts and thereby potential susceptibility to pest epidemics and other pathogens. This example is only one illustration of how the forest cover data can be used in conjunction with other data to address MP indicators or other concerns at different spatial scales. Numerous other possibilities exist. The MP indicators on carbon balances in Criterion 5 can likewise be addressed in this fashion and could be improved with the addition of soil sampling and soils information. Most of this type of information, however, will be the result of one-time analyses, which may provide useful information but will not result in the consistency across time and space that is the ultimate goal of the MP C&I and similar reporting efforts. For that, a more comprehensive data gathering and reporting effort combining remote-sensing capabilities with on-the-ground inventory sampling will be needed.

As it currently stands, the nationally consistent data we have on urban forests enable us to partially address the following MP criteria:

- **Criterion 1: Conservation of biological diversity.** Tree-cover data only, giving us an idea of the extent of forests but not their species structure or diversity. Fragmentation may be measured and described using available data, but analysis techniques will have to be developed. Tree counts can be extrapolated from existing data (although these counts are not considered in the MP C&I).
- **Criterion 2: Maintenance of productive capacity.** Rough estimates of standing volume and volume growth can be derived from forest cover information, but on-the-ground sampling is needed for greater precision. MP indicators on timber and wood fiber production are not very applicable in this context, but other output measures specific to urban forests may be devised.
- **Criterion 5: Maintenance of forest contribution to global carbon cycles.** Carbon stocks and net sequestration on urban forests can be estimated using forest cover and volume stocking estimates developed for Criteria 1 and 2. On-the-ground sampling is needed for greater precision, and overall carbon estimates for urban areas could be improved with the addition of soil sampling.

The other MP criteria and many of the indicators in the three criteria listed above currently cannot be adequately addressed at the national level with available data. Although a number of these indicators are not very applicable in the realm of urban forestry, others, such as those covering forest health, are essential to understanding and managing urban forests.

Strategies for Improving Urban Forest Data

Improvement in urban forest data gathering and reporting activities can be accomplished by (1) synthesizing existing data and standardizing data collection and formatting and (2) gathering more data from local to national scales.

Standardizing and Synthesizing Available Data

As increasing amounts of urban tree and forest data become available, the ability to synthesize and report these data in a fashion useful to managers, planners, or policymakers working at local, regional, and national scales becomes paramount. Data collection efforts are currently not systematic, but rather opportunistic, being based on local managers' desires and efforts to collect and analyze urban forest data. A key challenge of this effort is developing ways by which these local efforts can contribute to, and benefit from, data collection efforts elsewhere. This integration can best be accomplished by developing consistent data collection protocols that can be used in different settings and then by providing consistent data reporting and analysis tools so that information can be easily shared. The i-Tree model, discussed previously, is an example of how this type of consolidation can be achieved on a voluntary basis. By providing local practitioners with tools that make their jobs easier, i-Tree facilitates consistent data generation and reporting, allowing for comparability and (to a limited extent) aggregation across space and time. Local reports are produced (e.g., Nowak et al. 2006b) and data can be combined with aerial cover analyses to estimate regional- to national-scale characteristics of urban forests. Although this activity does not take the place of an integrated national inventory, it does provide a wealth of data for understanding local conditions and for developing studies at broader scales. It can also provide an important source of information for validating and augmenting broader inventory efforts. Regarding data standardization, efforts are also currently underway to develop international urban forest data-collection standards.

In addition to the information developed by i-Tree, a great deal of disparate information is available from a wide variety of sources, ranging from municipal reports to academic studies and broader natural resource sampling efforts, such as the yearly North American Breeding Bird Survey. With these various sources of data, the challenge becomes how to combine information to better understand urban forests in a broader spatial and social context. In most cases, this kind of work takes the form of one-time analyses that can contribute background information supporting the type of consistent and repeated data-reporting efforts that are called for by the MP C&I. For those cases in which data collection efforts are ongoing, it may be possible to institute analysis protocols to develop measures that can be reported consistently across space and time. This type of analysis, combining available data in an opportunistic fashion from multiple sources, is, in fact, a key strategy in addressing a number of the MP indicators on conventional forests in the *National Report*, but it requires a sustained effort and an explicit commitment to consistency, which is not easy. Nonetheless, until a national urban forest inventory is fully implemented, this approach is the most likely strategy for addressing the data needs of the MP C&I. Moreover, even with a fully implemented inventory, this kind of synthetic approach will be essential for addressing many of the social, economic, and institutional indicators that are found in Criteria 6 and 7 of the MP C&I.

New Data Gathering Opportunities and Challenges

The most obvious means for attaining long-term and consistent data for urban forest analysis from the regional to national scale is to integrate urban tree data collection within existing forest inventory work under the FIA program, which currently collects data for conventional forests across the entire United States. In preparation for a national urban inventory, pilot testing of FIA plots and data collection techniques in urban areas (Cumming et al. 2008) has been conducted in Indiana (Nowak et al. 2007), Wisconsin (Cumming et al. 2007), New Jersey, Tennessee (Nowak et al. 2012), Alaska, California, Colorado, Hawaii, Oregon, and Washington. A more recent action, the 2014 Farm Bill (formally the Agricultural Act of 2014, Public Law 113-79), laid the legislative foundation for a national urban inventory by directing FIA to revise its strategic plan and describe the "organization, procedures, and funding needed" to implement an annualized urban forest inventory. To this end, FIA has implemented a monitoring program that focuses on metropolitan regions and began data collection in the Baltimore, MD, and Austin, TX, metropolitan areas in 2014 and additional areas in 2015 (i.e., Houston, TX; Madison, WI; Milwaukee, WI; Providence, RI; St. Louis, MO, and Des Moines, IA). FIA intends to sample and monitor more metropolitan areas in the coming years. Through the inclusion of additional metropolitan areas, a better national picture of urban areas can be obtained over time.

A central question in institutionalizing a national inventory of urban forests is exactly what variables to measure. The i-Tree Eco urban variables have been developed and tested within the State urban pilot projects (Cumming et al. 2008) and provide a starting point for considering this question (see box 1). i-Tree Eco is designed to be consistent with many standard FIA variables while simultaneously being responsive to the needs of urban foresters, and both professionals and volunteers can use it. A nationally instituted inventory of urban forests would differ somewhat from a typical i-Tree Eco local analysis in terms of variables and protocols for measurement, but the general analyses involving plot-level, tree-level, and environmental variables would be consistent. The new urban FIA monitoring program is integrating data collection with i-Tree variables so that both i-Tree and FIA analysis programs can analyze the data. Should this inventory be expanded to agricultural forests, the degree to which these protocols would be adjusted to allow for consistency across agricultural and urban forests will need

Box 1. i-Tree Eco Sampling Variables*

Plot-Level Information

Tree cover: The amount of the plot covered by tree canopy (in percent)

Shrub cover: The amount of the plot covered by shrub canopy (in percent)

Plantable space: Estimate of the amount of the plot area that is plantable for trees (in percent)

Land Use
- Actual land use(s): Required (e.g., residential, golf course, park, commercial)
- Percent of area in each land use

Ground Cover
- Ground cover types present (e.g., bare soil, cement, grass)
- Percent of area under each ground cover type

Shrub Information
- Shrub species: Identify the shrub species
- Shrub height
- Percent of total shrubs area
- Percent of the shrub mass that is missing

Tree Information (for individual tree measurements)

Land use (specific to tree)

Species

Status (records presence or removal of tree relative to past inventory)

Tree Characteristics
- Total tree height
- Height to live top
- Height to crown base
- Crown width
- Percent canopy missing
- Crown dieback
- Crown light exposure
- Percent impervious surface under the tree
- Percent shrub cover under the tree
- DBH (diameter at breast height)

Direction to building

Shortest distance to building

*Abbreviated version. For more detail on included variables and sampling protocols see: www.itreetools.org.

to be addressed, as will be the potential inclusion of additional variables (e.g., soils) targeted at specific MP indicators or related information needs.

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