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Strategic National Urban Forest Inventory for the United States

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Abstract

In response to the strategic plan required by the Agricultural Act of 2014, the USDA Forest Service Forest Inventory and Analysis (FIA) program is initiating a strategic inventory of the nation's urban forests. The inventory is designed to provide timely and credible data on urban forests, thereby meeting an expanding need for information on trees located in communities where more than 80% of people live. The program monitors the status and trends of trees in urban settings (i.e., urban forests), enabling assessment of their composition and structure, ecosystem services and values, health, and risk from pests and disease. At full implementation with funding, resources, and partnerships in place, the program as designed would provide annual updates of urban forest conditions on approximately 68 million acres of land and for 100 of the most populous cities in the United States. The traditional forestland inventory of FIA continues and is complemented by the new urban inventory providing the means for a more complete assessment of the tree and forest resources across the United States.

Study Implications: Urban forests provide many benefits that improve the quality of life for people residing in urban settings. By initiating an urban inventory, the FIA program seeks to provide consistent, timely, and credible data about urban forests across the United States and thereby meet the needs of users and partners as expressed in its strategic plan. In addition to baseline information, the urban inventory will provide information on urban forest change for managers to help guide or mitigate forest and environmental changes to desirable outcomes. State, regional, and national urban forest assessments useful to setting policy will be strengthened by the standardized data collection procedures. The urban inventory is a significant step toward more seamless rural-urban monitoring and "all tree" assessments that will be necessary to address the challenges that urban expansion presents to adjacent rural and forestlands.

Keywords: monitoring, urban settings, FIA, i-Tree, sampling frame, estimation

Interactions between people and urban forests are more relevant now than at any other time in the nation's history. More people are living in urban areas, which are defined as densely developed residential, commercial, and other nonresidential areas (US Census Bureau 2012a). From 2000 to 2010, the percentage of the US population living in urban areas increased from 79.0% to 80.7%, with the urban population growing from 222.4 million to 249.3 million, an increase of 12.1% (US Census Bureau 2012a, 2017). By 2050, 340 million people (87.4% of the US population) are projected to live in urban areas (Duffin 2019, Vespa et al. 2020).

Urban forests, which include all trees in urban settings, affect the livability of cities and the quality of life in urban areas. US urban forests conservatively produce more than $18 billion annually in benefits related to air pollution removal, carbon sequestration, and reduced energy use (Nowak and Greenfield 2018b). However, urban tree cover has been on the decline in recent years, decreasing by 690,000 acres from 40.4% (ca. 2009) to 39.4% (ca. 2014) (Nowak and Greenfield 2018a). This loss equates to 138,000 acres of tree cover per year or about 28.5 million trees per year. Given the magnitude of the resource value and rates of change, there is an increasing need for credible, consistent, and timely information on the urban forest resource to support management, planning, and policy (Cumming et al. 2008, Corona 2016).

Urban lands are expanding with important implications for adjacent rural areas and forestlands. From 2000 to 2010, urban land in the conterminous United States grew from 57.5 million acres (3.0% of land area) to 67.6 million acres (3.6%), an increase of 17.5%. Urban land is projected to increase to 8.6% by 2060, an increase of 95.5 million acres, which is greater than the area of Montana (Nowak and Greenfield 2018b). Expanding urban areas directly transform land and can result in the loss of forestland. Invasive species, unmanaged recreation, fragmentation, and wildfire connected to urbanization can be threats to forest sustainability (Nowak et al. 2005). This rural-urban continuum is increasingly recognized as an important area in need of monitoring, although one that presents a unique set of challenges (Westfall et al. 2018).

The Forest Inventory and Analysis (FIA) program of the US Department of Agriculture (USDA) Forest Service collects and disseminates data and information on the nation's forests. Estimates of the extent and condition of forestland, including both the stock and change in numbers of trees, volume, biomass, and carbon, are primary FIA products. Information produced by FIA helps improve forest management and planning, policymaking, carbon accounting, forest health evaluations, sustainability assessments, and investment decisions by industry (USDA Forest Service 2016).

The Agricultural Act of 2014 (Public Law 113–79 Sec 8301), commonly known as the 2014 Farm Bill, called for an FIA strategic plan describing in detail the organization, procedures, and funding needed to achieve several elements set forth in the act. In 2016, FIA published a strategic plan that included the Farm Bill element "implement an annualized inventory of trees in urban settings, including the status and trends of trees and forests, and assessment of their ecosystem services, values, health, and risk to pests and diseases" in FIA Strategic Plan Option C—National Core Program (USDA Forest Service 2016, p.14).

It can take years to ramp up to an operational nationwide inventory with a capable and fully staffed workforce implementing fully vetted and widely accepted protocols. Here we describe the envisioned major features of an annualized inventory of trees in urban settings, including general information on sample design, estimation, data acquisition, information management, and reporting. We discuss similarities and dissimilarities between the urban inventory and the national forestland inventory and citywide i-Tree Eco inventories. Accomplishments in advancing the strategic vision are presented along with goals assuming eventual full implementation.

Background

The first ground-based inventories of vegetation conducted for an entire city occurred in the late 1980s and early 1990s (Nowak 1994). The first national assessment of urban forest resources in the United States was published in 2000 (Dwyer et al. 2000, Nowak et al. 2001). In the 2000s, urban inventories increasingly became recognized as a source of information that could support natural resource management and policy decisions by state and local officials. The computation of urban forest benefits and services was becoming increasingly accessible through development and maturation of software tools that incorporated the latest research findings relevant to urban forest. For example, the Urban Forest Effects (UFORE) model was created to estimate urban forest structure and function values using forest inventory, tree cover, meteorological, and pollution concentration data (Nowak and Crane 2000). In 2006, UFORE was incorporated within i-Tree (www.itreetools.org), a suite of software tools that assesses urban forest structure and benefits, with UFORE being renamed i-Tree Eco. As of 2019, more than 410,000 users worldwide have used i-Tree tools, including academic institutions, forestry consultants, government officials, and nonprofit groups. Through the collaborative efforts of the Forest Service, Davey Tree Expert Company, Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, and Casey Trees, the capabilities of the suite of software tools continues to develop and expand (i-Tree 2020).

The FIA program dates to the 1930s when periodic timber resource surveys were conducted on a state-by-state basis. In 1999, FIA began a transition to an annual inventory of forestland conducted simultaneously across the nation (Gillespie 1999, USDA Forest Service 2016). The transition from a timber inventory to a forest inventory extended the applications of FIA data and information beyond a commodity focus to environmental and forest ecosystem health interests (McRoberts et al. 2005). Even with the expanded focus, most trees in urban settings remained outside the program's monitoring efforts. In the forestland inventory, data are collected from trees on lands meeting the FIA definition of forest; thus many trees in urban settings are not included (Riemann 2003, Nowak et al. 2006, 2013, Cumming et al. 2008).

FIA efforts in urban settings expanded as urban forest managers, nonprofit groups, citizens, and state officials communicated a need for such information and as knowledge of the significance of urban forest values increased and the capacity to quantify and monetize benefits advanced. Hershey and Birch (1996) combined existing FIA data with US Census Bureau geospatial layers to estimate the extent of urban forest in New York. In a study of a five-county area in Maryland, Riemann (2003) demonstrated that trees on nonforest conditions were present in sufficient numbers to substantially add to the estimates of tree attributes (e.g., number, basal area, carbon) typically computed from only forest conditions. In the conterminous United States, only 13.7% of urban land, or about 38.6% of all urban tree cover, is measured by FIA forestland inventory plots (Nowak et al. 2013). Urban tree cover in the United States is substantial, averaging 39.4% nationally and covering about 26.8 million acres (Nowak and Greenfield 2018b).

Cumming et al. (2008) reported on efforts to pilot the FIA urban inventory and the UFORE model in Indiana (Nowak et al. 2007), Wisconsin (Cumming et al. 2007), New Jersey, Tennessee (Nowak et al. 2012a), and Colorado. Results included statewide estimates of urban forest structure (e.g., number and basal area of trees by species and diameter class) and estimates on structural value, pollution removal, building energy conservation, avoided runoff, carbon storage, and carbon sequestration. Structural value, pollution removal, building energy conservation, and avoided runoff represented new areas for FIA with no counterpart in rural forest monitoring and reporting. Efforts in other states followed, including the Great Plains (Kansas, Nebraska, North Dakota, South Dakota; Nowak et al. 2012b), Washington, Oregon, and California. These early efforts demonstrated that the FIA sampling frame and protocols, with some modification, could successfully monitor urban forests at large scales (Nowak et al. 2006, Cumming et al. 2008).

Defining Urban Forests

The urban inventory initiative is an expansion with modification of FIA's monitoring efforts that aims to produce information about urban forests, which are defined as all trees in urban settings. Different program goals result in urban settings being constructed using one of two models (Figure 1). For the first program goal, that of providing strategic-level coverage of urban forests across the nation, FIA uses US Census Bureau–defined urban areas. The US Census Bureau identifies two types of urban areas, both of which are included in FIA's strategic inventory goals: urbanized areas (UA) and urban clusters (UC). UAs are densely developed territory containing 50,000 or more people. UCs are densely developed territory with at least 2,500 people but fewer than 50,000 people. As of the 2010 US Census, there were 486 UAs and 3,087 UCs across the nation covering approximately 68 million acres (US Census Bureau 2012a, 2012b, 2017). A second program goal is to provide strategic urban inventories for the US cities with the largest populations. FIA is targeting cities with populations of at least 200,000 people as of the 2010 US Census and delimits city area using US Census Bureau Place boundaries. A few cities with populations below 200,000 are included to ensure that every state has at least one target city in the program. Where two or more large cities occur in the same general vicinity (i.e., in the same Core-Based Statistical Area), plans are to assess the most populated city. With these criteria in place, approximately 100 cities would be included once funding, resources, and partnerships are fully in place.

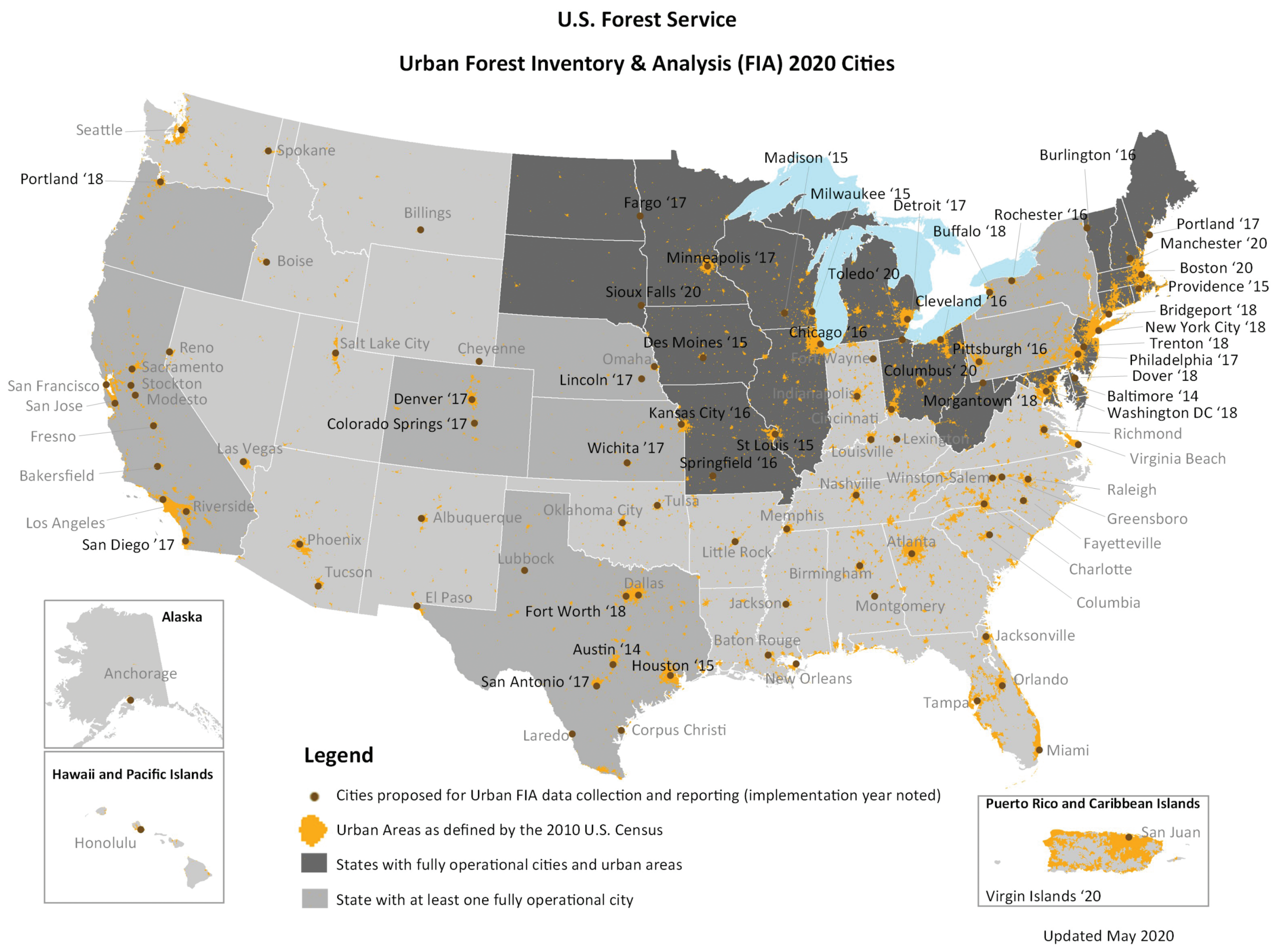

Figure 1. Urban areas and cities included in the urban inventory.

In defining a tree, FIA drew from extensive experience in the forestland inventory, pilot urban inventories, and i-Tree inventories. As a starting point, all tree species tallied in the forestland inventory were included in the urban inventory. A supplemental species list for urban settings included tree species primarily encountered in urban settings. Separate species lists are a complicating factor when forestland and urban inventory data are combined for assessment (e.g., Staudhammer et al. 2018, Westfall et al. 2018). In 2019, FIA conducted an extensive review of species inclusion, culminating in the adoption of one species list that is being applied to both the forestland and urban inventories moving forward.

Sampling Frame, Plot Configuration, and Measurements

The hexagonal sampling frame developed for the forestland inventory is used in the urban inventory. The base spatial sampling intensity for urban areas is one plot per approximately 6,000 acres, the same base spatial intensity as used in the forestland inventory. The spatial sampling intensity is increased in targeted cities to produce numbers of plots sufficient to produce estimates deemed suitable for strategic planning efforts. To meet this objective, FIA seeks at least 200 plots in each of the targeted cities, a number adapted from i-Tree inventories (Nowak et al. 2008a).

A portion of the plots are measured every year in the annual inventory. The selection of plots to measure is based on a panel system, where each panel provides approximately uniform spatial coverage of the population. One panel of plots is measured every year and then remeasured only after all the other panels of plots have been measured. Cycle length is the term commonly applied to denote the number of years to measure all the panels of plots. The cycle length applied in an urban area or target city is set equal to the cycle length of the forestland inventory of the same region. Cycle lengths of five or seven years are used in the eastern United States, and 10 years is used in the western United States.

Reams et al. (2005) provides a detailed description of the FIA sampling frame, and readers seeking more information are referred to that resource.

The urban inventory uses a national standard plot configuration that consists of one 48.0 ft radius circular plot and four 6.8 ft radius circular microplots offset 12.0 ft in each of the cardinal directions from plot center (Figure 2). The urban inventory plot differs in design but not area from the forestland inventory plot, which consists of four 24.0 ft radius circular subplots arranged in a cluster fashion (Bechtold and Scott 2005). Pilot studies demonstrated that the forestland inventory plot applied to urban settings resulted in a much higher number of contacts with owners than occurred in rural settings (Nowak et al. 2008b). For example, an average of five owner contacts were made per plot in the 2002 Wisconsin pilot (Nowak et al. 2006). The urban inventory forgoes the four subplots in favor of one plot to reduce the number of owner contacts. The size of the urban inventory plot was set to a 48.0 ft radius (1/6 ac) to equal the area of forestland inventory subplots. A common plot configuration in i-Tree Eco inventories is a circular plot of 37.2 ft radius (1/10 ac).

Measurement of urban inventory plots is accomplished through the efforts of the Forest Service, state forestry agencies, city forestry departments, universities, and contracting personnel. Individuals responsible for urban inventory measurements receive extensive annual training and must successfully complete certification training. FIA requires landowner permission to access all plots and does not visit plot locations that contain hazardous conditions. Trees on land defined by FIA as forest are the focus of the forestland inventory, whereas all trees regardless of stand size, width, canopy cover,

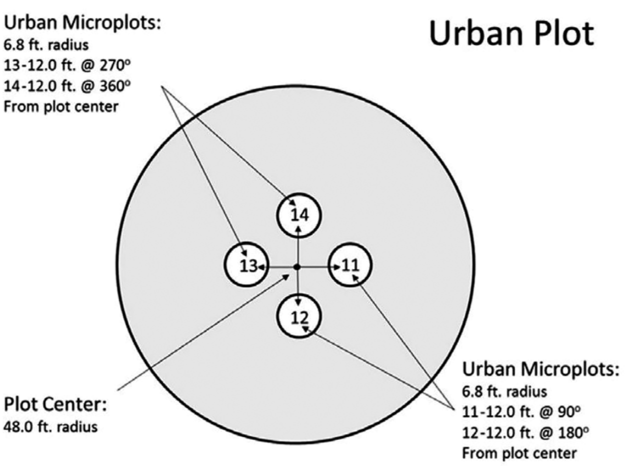

Figure 2. Urban inventory plot configuration.

or land use are the focus of the urban inventory. In this regard, the urban inventory is like the i-Tree Eco inventory approach where all trees are measured regardless of land use. On the plot, trees 5.0 inches and larger in diameter at breast height (DBH) or diameter at root collar (DRC) are measured. FIA classifies all tree species into either woodland or timber categories. Woodland species are typically small trees characterized by a multistemmed growth form, and diameter measurements for these species are taken as DRC. Timber species are generally characterized by the growth of a central stem, and diameter is taken as DBH. On each microplot, trees at least 1.0 inch but less than 5.0 inches DBH or DRC are measured. Specifics on measurements are too numerous to list here, but in general the urban inventory incorporates the variables from both the forestland inventory and the i-Tree Eco protocol. For example, the urban inventory combines forestland inventory data variables that track merchantability standards such as percent rotten and missing cull. i-Tree Eco's measurements of proximity to residential buildings, which is used to estimate energy cost savings, are included in the urban inventory.

FIA regularly reviews and updates field procedures and publishes a field manual with the complete listing of measurements and details at https://www.fia.fs.fed.us/library/field-guides-methods-proc/index.php. Measurement of multistemmed trees provides an example of the regular review and adjustment process. The FIA forestland inventory and i-Tree methods differ in the way data are collected and recorded for forked trees. The urban inventory now includes both stem-level and whole tree measurements, and many variables, including the number of trees, can be estimated using either approach. Field manuals for previous years' inventories are available, permitting tracking of any changes in procedures and protocols over time.

Estimation, Analysis, and Reporting

FIA compilations provide many of the attributes that characterize the composition and structure of the urban forest, such as number of trees, basal area, volume, biomass, and carbon. The i-Tree Eco tools provide some structural characteristics (e.g., compensatory value) and ecosystem services estimates (e.g., air pollution removal, avoided precipitation runoff, energy use reduction) (Nowak and Crane 2000, Nowak et al. 2008b). FIA and i-Tree Eco compilations are included in the publicly available database. Some information produced by i-Tree Eco is reported directly as a population estimate rather than on a per tree basis. For example, surface water runoff avoided is derived from processes of a water balance model (Wang et al. 2008) applied at the population level. Implementation of the model in i-Tree Eco is detailed by Hirabayashi (2012). The i-Tree website (itreetools.org) contains current information on the modeled population estimates in i-Tree Eco. Pollution removal and health impacts, rainfall interception and avoided runoff, and volatile organic compound emissions are i-Tree Eco outputs reported at the population level.

Where compilations produce a tree-level value, the sample-based estimators of Scott et al. (2005) are used to produce population estimates. Precision of an estimate can be assessed with a confidence interval. Using a 95% confidence interval as an example, we would expect if the inventory were independently repeated over and over again on the same population using the same procedures that 95% of the intervals would include the true population value. This process also means we would expect 5% of the intervals would not include the true population value. Because the true value is not known, it cannot be stated with certainty whether a specific interval includes the true value or not.

Annual measurement of a portion of the plots means new estimates can be produced every year. Estimates are computed using all the panels of plots. Using an inventory with a five-year cycle as an example, the estimate in year 7 of the inventory is computed by combining panels measured in years 3, 4, 5, 6, and 7 (Figure 3). In year 8 a new estimate is computed by combining panels measured in years 4, 5, 6, 7, and 8. Thus, approximately 80% of the plot observations are the same in consecutive year estimates (e.g., year 7 and year 8). Although estimates combine observations from a number of years, common practice is to refer to an estimate by the latest year of the data used in the estimate, although other conventions have been used (i.e., the middle year). The combining of panels reduces the variance of estimates and is therefore generally the preferred approach in most estimation situations. An exception occurs if a widespread catastrophic event happens during the measurement periods, which is fairly uncommon. In these situations, combining panels may dampen trends and obscure annual fluctuations (Patterson and Reams 2005). Panel systems can be highly responsive in these situations, but approaches that differ from the standard approach (e.g., combining of all panels) need to be applied (Edgar et al. 2019). Users might consider contacting FIA customer support (www.fia.fs.fed.us/tools-data/customer-service/) for guidance in these situations.

It is common in forest assessments to divide the population into classes and then seek information specific to one or more classes. For example, urban trees are strongly influenced by land use, and, therefore, estimates for land-use classes may be desired. This subdivision is an example of domain estimation. FIA's domain estimation methods are documented by Scott et al. (2005). Besides division by area (e.g., land use, type of ownership), domains can also form by divisions of trees (e.g., species, diameter class). Normally, the finer the division in forming the domain, the lower the precision of the resulting estimate.

Urban inventory results are being disseminated in a number of different ways to reach as broad an audience as possible. Field measurements and processed data are incorporated in a publicly available Urban Data Mart at www.fia.fs.fed.us/tools-data/. A user guide for the urban database is available at https://www.fia.fs.fed.us/library/database-documentation/index.php, and a population estimation guide is forthcoming. Reports

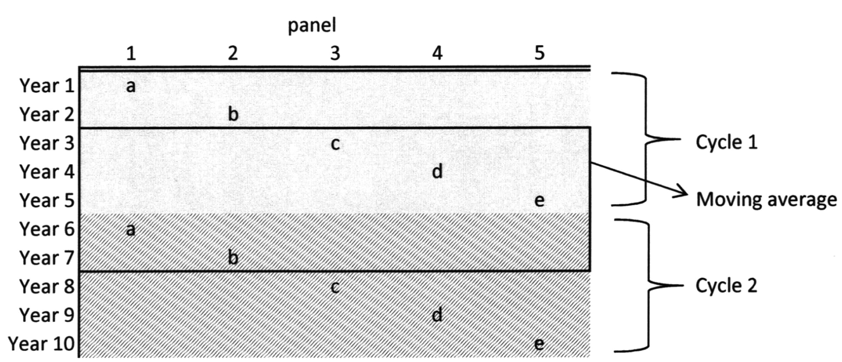

Figure 3. Schematic of an inventory design consisting of five panels (a, b, c, d, and e) and the measurement sequence over two five-year cycles. (Figure adapted from Westfall et al. 2013.)

summarizing key results from the first two city assessments have been published (Nowak et al. 2016, 2017). Reports include sections on urban forest structure, composition, health, and ecosystem service values. Management implications are also discussed, with sections devoted to information on nonnative invasive species, insects and disease impacts, and population growth, for example. Reports are made available at the program website www.fia.fs.fed.us/program-features/urban/.

Online applications are increasingly being used to disseminate inventory results. The application My City's Trees (mycitystrees.com) was developed by Texas A&M Forest Service with support from the Forest Service for the purpose of providing easy access to urban inventory data. Users can explore results for cities and produce custom analyses and reports. My City's Trees is designed to work with smart phones, tablets, and desktop computers. The Forest Service is developing an online analytical tool for the urban inventory patterned on the existing forestland inventory analysis tool EVALIDator. This tool provides the means to conduct highly customizable queries and produce estimates of population attributes including measures of precision.

Implementation and Status

Initial efforts in program delivery have focused on areas where state and local partners have expressed a willingness to collaborate and support the program. The inventory is fully operational in the targeted cities and urban areas of 19 states, Washington, DC, and the US Virgin Islands (Figure 1). The inventory is also operational in at least one targeted city in eight additional states. At current program funding levels, FIA anticipates continuing with the partnership model and will strive to efficiently implement the program to the extent permitted by available resources. When fully implemented, the inventory seeks to provide annual updates of urban forest conditions on approximately 68 million acres and for the 100 most populated US cities.

FIA programs National Woodland Owner Survey (NWOS) and Timber Product Output (TPO) are also expanding into urban settings. NWOS is examining the social dimensions of the urban forest by surveying the private residential landowners who manage the urban forest and other green space. Initial efforts have focused on Austin, TX; Madison, WI; Wausau, WI; Milwaukee, WI; Green Bay, WI; and Baltimore, MD. These efforts are currently being expanded across the country in Houston, TX; Portland, OR; St. Louis, MO; and Denver, CO. TPO surveys estimate production and movement of roundwood. In urban settings, trees are removed for a variety of reasons often associated with death, damage, or development. Information on urban tree removals and disposal or use of that material is desired, and TPO expertise is being applied to development of urban wood assessments. Initial efforts have focused on Baltimore, MD, and plans are being explored to expand to other cities.

The extension of the FIA sampling frame to include the measurement of trees and other attributes within urban settings provides an opportunity to survey forests and trees without duplication and without gaps between forestland and urban inventories. Historically, forestland inventories and urban inventories were conducted independently. Different traditions led to differences in practical implementation (e.g., species included, variables measured, plot configuration, sampling intensity) with the potential to limit integrated assessment and analysis (Staudhammer et al. 2018, Westfall et al. 2018). The integration of the FIA sampling frame into the urban inventory provides a foundation for more seamless rural-urban monitoring than previously possible.

The urban inventory will meet many of the needs participating cities have for strategic urban forest data used to enhance urban forest planning and management to sustain forest health and benefits for future generations. Communities with interest in subpopulation estimates (i.e., domains) should consider whether the precision of FIA urban inventory meets their needs. For example, a city primarily interested in park trees may find estimates for that subpopulation insufficiently precise for their purposes. In cases where better precision is desired, it is advantageous to define these areas separately and tailor the sampling independently. This intensification may be achieved through more flexible programs like i-Tree Eco, where it is possible to design a project specially to address a subpopulation of interest.

Standardized data collection in the urban inventory will address a shortcoming that has limited earlier efforts at state, regional, and national urban forest assessments. Cities with inventories have conducted those inventories independently, and different data collection practices have been applied. For example, some cities may have collected data on all ownerships or land uses, whereas other focused on select ownerships or land uses (Cumming et al. 2008). The standardization that FIA is applying in the urban inventory will strengthen state, regional, and national urban forest assessments in support of informed urban natural resource management, strategic planning, and policymaking. For example, states prepare Forest Action Plans that inform application for federal funding through the Forest Service State and Private Forestry Program. In preparing their Forest Action Plan for 2020, Texas A&M Forest Service used results from the recently completed urban inventories of Austin and Houston as a source of urban forest condition information. The use of urban inventory data with high-resolution imagery was identified as a strategy to meet the objective of monitoring the impact of land-use change on urban forests and achieve the goal of strengthening urban and community forest health and biodiversity for long term resilience (Texas A&M Forest Service 2020).

Conclusions

The FIA program is expanding to meet the need for more information on the growing and important US urban forest population. Although still being refined, the program has been tested and shown to provide important information regarding urban forest populations and their values. Currently, 40 cities are being monitored as part of the urban FIA program with more cities being added each year. Although the baseline information regarding each city's urban forest is important, a more important value will be realized when plot remeasurement data are analyzed. These data on urban forest change will provide important information for managers to help guide or mitigate forest and environmental changes to desirable outcomes. As urban areas expand and environmental conditions change (e.g., weather, insects and diseases, fire regimes, invasive plants), monitoring urban forest change will be essential to sustaining both forest health and the health and well-being of a growing and vastly urban US population.

Acknowledgments

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