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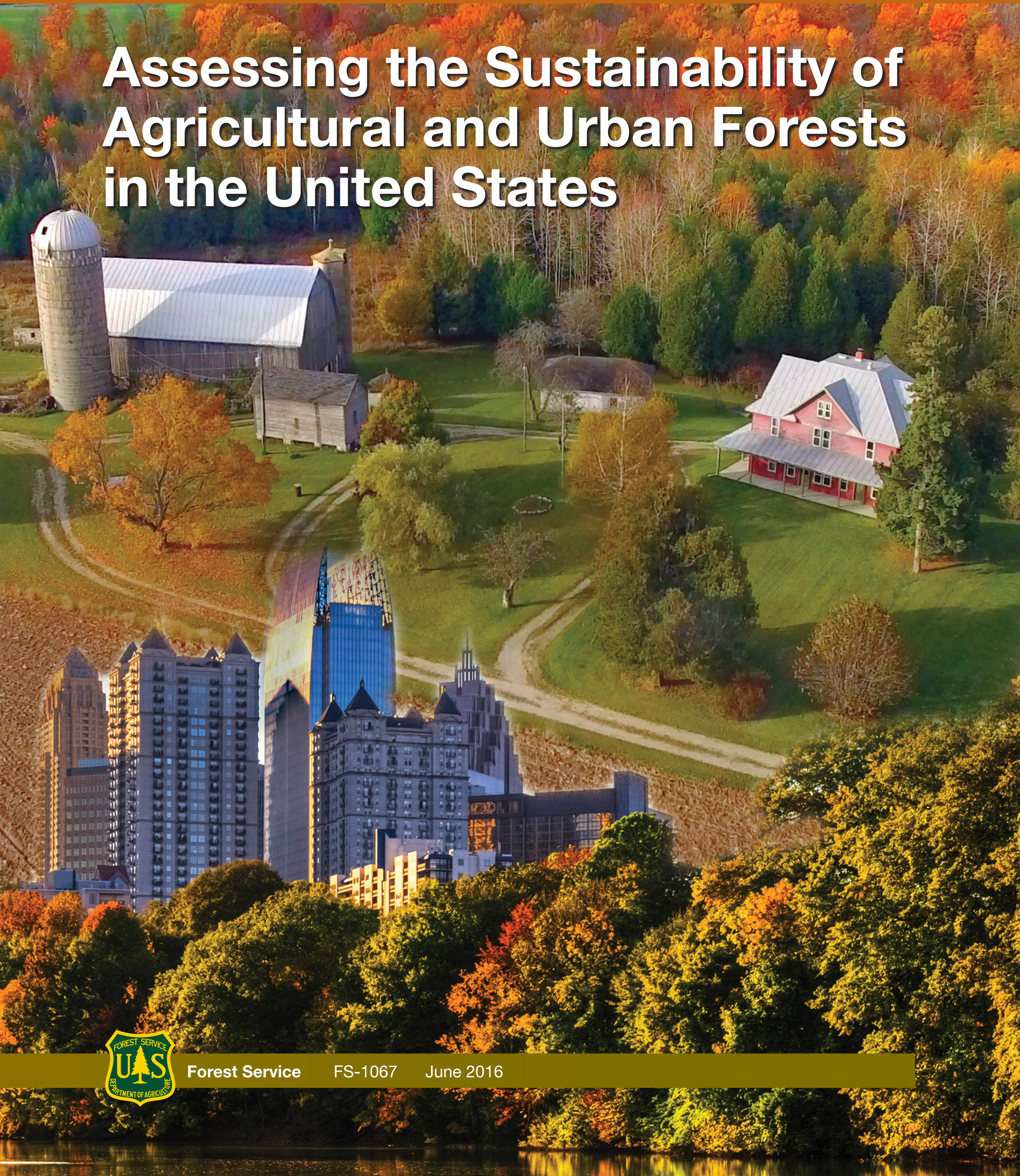
Assessing the Sustainability of Agricultural and Urban Forests in the United States



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Abstract

The Forest Service, an agency of the U.S. Department of Agriculture (USDA), published the *National Report on Sustainable Forests—2010* (USDA Forest Service 2011) (hereafter, *National Report*) several years ago and will be releasing a subsequent version of the report in 2017. Based on the Montréal Process Criteria and Indicators for Forest Sustainability, the *National Report* provides information on a comprehensive range of measures related to forest conditions and sustainability in the United States. Two important categories of forest resources—agricultural and urban forests—are not treated directly in the *National Report*, however.

The current report is designed to augment the *National Report* by focusing on agricultural and urban forest resources within the context of national forest sustainability reporting. The report provides (1) a brief description of the benefits accruing from these resources; (2) displays and analyses of currently available data describing them, particularly at the national level; and (3) a discussion of potential strategies for developing consistent national datasets and ongoing reporting procedures. The ultimate aim is to lay the foundation for reporting information about agricultural and urban forests that is roughly comparable with the information presented for conventional forests in the *National Report* and that can be incorporated into the Forest Service's ongoing forest sustainability reporting activities.

Editors:

Guy Robertson
Andy Mason

Contributing Authors:

Greg Liknes
Andy Lister
David Nowak
Charles Perry
Steve Rasmussen
Michele Schoeneberger
Chris Woodall

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Numerous individuals substantially contributed to the production of this report either through extensive review or the provision of important information.

Andy Mason and Richard Straight, both working at the U.S. Department of Agriculture (USDA), National Agroforestry Center in Lincoln, NE, at the time, deserve credit for coming up with the original idea for this report and its application of forest sustainability concepts to agricultural and urban forests.

Michele Schoeneberger of the National Agroforestry Center led the work on agricultural forests, with Andy Lister of the Forest Service and Steve Rasmussen of the Nebraska Forest Service contributing writeups on the Great Plains Tree and Forest Invasives Initiative, a forest inventory effort with which they are intimately familiar. David Nowak, an expert in urban forestry who works at the Forest Service, Northern Research Station, wrote the chapter on urban forests. Charles Perry, Greg Liknes, and Chris Woodall, research scientists affiliated with the Forest Service, Forest Inventory and Analysis program, provided the final chapter on potential forest inventory approaches.

The Forest Service's Sonja Beavers and Louise Wilde provided essential help in editing, formatting, and publishing the final version of this report, and former Forest Service intern Yooni Choi produced many of the graphics used in chapter 2.

Numerous people provided comments and advice on the different chapters contained in this report. Of these individuals, Fred Cubbage of North Carolina State University deserves special thanks for his insightful comments on the initial chapters describing the application of sustainability measures and for his ongoing support of the Forest Service's sustainability reporting efforts overall. Richard Pouyat and Beth Larry, Forest Service research scientists at the Washington Office, each commented on the entire document, and their perspectives on the report as a whole were invaluable.

Executive Summary

Society is increasingly realizing the value of individual trees and forested areas found on urban, suburban, and agricultural lands. Termed *agricultural and urban forests* in this report, these resources directly enhance our lives and, if managed correctly, can increase the efficiency and productivity of agricultural and urban systems. A short list of benefits includes aesthetic amenities, water and soil retention, biodiversity conservation, recreational opportunities, and the sequestration of greenhouse gases, but many other values have also been identified. Moreover, research continues to reveal new and sometimes surprising ways in which trees in the places where we live and work provide tangible benefits for people.

Wise management is essential to sustain and enhance the values associated with agricultural and urban forests, and wise management, in turn, requires good information. The central purpose of this report is to assess the current state of information for agricultural and urban forests and lay the foundation for its improvement in the future. As scientists from the U.S. Department of Agriculture (USDA), Forest Service, we use the Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability, a comprehensive framework for forest assessment across the ecological, social, and economic dimensions of sustainability, as a starting point and frame of reference. Other scientists also used the MP C&I to assess the sustainability of the Nation's conventional forest lands in the *National Report on Sustainable Forests—2010* (USDA Forest Service 2011), a periodic Forest Service report with which the current report is closely associated. Ideally, our aim is to replicate the type of information base available for conventional forests for agricultural and urban forests. This information will enable us to better manage these resources, in their own right, and better integrate them with other land cover and land use types to facilitate policy formulation and landscape-scale management. Moreover, an agricultural and urban forest inventory will provide the data needed for comprehensive forest carbon estimates for inclusion in a national Greenhouse Gas Inventory. Owing primarily to the lack of a comprehensive inventory of agricultural and urban forest resources, however, we are a long way from this goal.

Key Findings

Agricultural and urban forests represent a vast topic area, and the information in this report only touches the surface. Nonetheless, we are able to glean a number of summary conclusions from the data and analysis presented here.

Agricultural and urban forests are important. This point is obvious but deserves to be emphasized. The various and specific ways in which these resources benefit (and sometimes cost) human society are discussed in detail throughout this report.

Agricultural and urban forests represent a vast and varied resource. Urban lands in the United States total more than 60 million acres (24 million hectares) (138 million acres [56 million hectares] if community lands are included). If current trends continue, this number will more than double by 2050. Croplands, grasslands, and rangelands total slightly more than 1 billion acres (400 million hectares). Tree cover on urban lands is currently estimated at 35 percent. Quantitative measures of forest cover on agricultural lands are not available, but the percent of forest cover on these lands is likely less than the tree cover on urban lands. Nevertheless, the sheer extent of agricultural lands ensures that the total amount of forests in this category is immense. These resources span the various ecoregions existing across the United States and play an essential role in all the landscapes in which they are found.

Data on agricultural and urban forests are relatively scarce. Forest inventory activities have long been applied coast to coast for conventional forests, and the resulting information forms the backbone of forest assessment and sustainability reporting in the United States. Similar inventory and reporting activities are sorely lacking for agricultural and urban forests at the national level.

Data availability, however, is improving. Satellite imagery and related remote sensing techniques have allowed for forest cover estimates for urban forests; tools facilitating the digital collection and consolidation of urban forest data are being developed and used; and pilot inventory projects, including a wall-to-wall inventory in the upper Midwest, are building experience in inventorying agricultural and urban forests in an integrated fashion.

A national urban forest inventory under FIA is in its initial stages of implementation. The 2014 Farm Bill (formally the Agricultural Act of 2014, Public Law 113-79) directs the Forest Service's Forest Inventory and Analysis (FIA) program to revise its strategic plan and describe the "organization, procedures, and funding needed" to implement an annualized urban forest inventory. This effort builds on years of preparatory work performed by FIA. Sampling protocols and related details for the program have been established and will further evolve as FIA and its collaborators gain more experience in inventorying urban trees and forests at the national scale.

A comprehensive inventory of agricultural and urban forests is feasible at a relatively modest cost. Based on lessons learned from the newly instituted urban forest inventory and using a combination of remote-sensing and plot-sampling strategies, a wall-to-wall inventory measuring the physical characteristics of trees and forests on agricultural and urban lands could be developed, likely at a fraction of the annual cost currently devoted to inventorying conventional forests. Building the institutional arrangements and devising a consistent sampling protocol spanning these different land use types, however, will require considerable effort.

Addressing the social and economic aspects of forest sustainability in agricultural and urban settings will still be problematic. A comprehensive physical inventory will go a long way in helping us understand the dimensions of this resource, but many important data gaps will remain, especially in regard to quantifying the benefits, uses, and values these forests supply to U.S. citizens.

Policy Recommendations

The principal policy recommendation of this report is that the Federal Government should seriously consider the development and implementation of a comprehensive inventory of trees and forests on both agricultural and urban lands, thus enabling a broader forest inventory covering all lands in the United States. Such an inventory should—

1. Incorporate an efficient combination of remote sensing and on-the-ground plot survey techniques.
2. Be consistent with the Forest Service FIA inventory program for conventional forests (and the newly instituted program for urban trees and forests) so that the resulting data can be consolidated and compared across different land use and land cover types.
3. Include explicit mechanisms for ongoing input from stakeholders across all levels of government and all sectors of society.
4. Be flexible and adaptive, while simultaneously maintaining consistency across space and time.

The Forest Service FIA program has already completed a number of pilot inventories and is instituting a national program in urban areas, and the USDA National Resources Inventory (NRI) program has experience inventorying forests on agricultural lands. These two programs—FIA and NRI—would likely lead the initial development of an agricultural inventory designed to complement FIA inventories for conventional and urban forests, and it is not too early to explicitly consider an expansion of urban FIA sampling activities into agricultural areas. Other Federal agencies, such as the U.S. Geological Survey and the National Aeronautics and Space Administration, should be involved at an early stage in the planning process. More important to the success of the project will be the cooperation from various municipalities and other local government entities and also from private-sector and nongovernmental organizations. Building these relationships will require time and effort, and the stakeholder engagement model, already established by FIA for conventional forests, provides a good starting point. The institutional foundation that results will be a valuable resource for improving the management of America's forests wherever they are found.

The end result ideally will be a wall-to-wall inventory of forest resources spanning forest, agricultural, and urban lands—an inventory that draws on plot-sampling and remote-sensing data sources, meets the needs of the diverse user communities, and enables us to assess the sustainability of these resources. This report is designed to lay the foundation for the dialogue and decisions needed to achieve this goal.

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Chapter 1

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Introduction

Measurement is a prerequisite for effective management. This fact has long been recognized in the area of forest resources, as evidenced by the effort the U.S. Government has devoted to surveying the Nation's forests for more than a century now. Charles Sargent produced one of the first inventories of U.S. forest resources in 1884 in conjunction with the 1880 census. Totaling more than 600 pages, the 1884 survey was close to a decade in the making and stands as a monument to the belief that quantitative information describing natural resources is important, even in an age when such information was extremely difficult to acquire (Sargent 1884). Since that time, the U.S. Department of Agriculture (USDA), Forest Service has undertaken increasingly frequent forest surveys, augmenting them with periodic assessments such as the Resources Planning Act (RPA) Assessment and, more recently, the *National Report on Sustainable Forests—2010* (USDA Forest Service 2011), hereafter, the *National Report*.[1]

The Forest Service, Forest Inventory and Analysis (FIA) program currently samples numerous measures describing forest resources on a rolling basis across all 50 States. The FIA program employs close to 600 scientists and technicians and is funded at more than $75 million per year (http://www.fia.fs.fed.us/ [August 2015]). The FIA and related Forest Service assessment efforts, however, are directed primarily at measuring forest land as traditionally defined; these efforts largely omit the forest resources occurring on agricultural and developed urban lands. In a similar way, the National Resources Inventory (NRI), under-taken by the USDA Natural Resources Conservation Service, or NRCS, provides information on forests using slightly different forest land definitions than FIA uses, but the NRI generally does not cover agricultural and urban forests either (USDA/NRCS 2009). These nonconventional forests are the topic of this report.

As our understanding of the complexity of forest ecosystems has grown and our relationship with them evolved, the scope and nature of our reporting efforts have changed. Whereas early surveys tended to focus on merchantable tree species, their stocking, and the productivity of underlying lands, current reporting efforts treat a much broader range of variables, covering ecological conditions and also social and economic factors that describe the human systems that rely on and affect forests. This tendency is epitomized by the recent growth of forest sustainability reporting efforts and their use of criteria and indicators (C&I) for information organization and display. At the national level, this trend is embodied in the *National Report*, the first edition of which was produced in 2003, with a subsequent version published in 2011. The next edition of the *National Report* is due for release in 2017.

These reports rely on a comprehensive set of measures for forest sustainability designed through an international collaboration known as the Montréal Process (http://www.montrealprocess.org/ [August 2015]). The resulting Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability[2] include 54 indicators arranged under 7 major criteria spanning ecological, social, and economic dimensions. Many of the indicators in the MP C&I are pertinent to the description of agricultural and

[1] The 1974 Forest and Rangeland Renewable Resources Planning Act mandates a periodic assessment of conditions and trends for the Nation's renewable resources. The most recent assessment, *Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment*, was published in 2012 (USDA Forest Service 2012), and an interim update is slated for release in 2016. In contrast to the *National Report on Sustainable Forests*, the RPA Assessment provides information on a broader range of natural resources than just forests, and it does so in an integrated modeling framework with forward-looking (50-year) projections. The *National Report* treats a broader range of measures, each in a more concise fashion, but it does not provide future projections. Taken together, the RPA Assessment and the *National Report*, supported by FIA survey activities, comprise the backbone of Forest Service national assessment activities. A digital version of the RPA Assessment and related project information are available at http://www.fs.fed.us/research/rpa/ (August 2015). The *National Report* is further described in the following sections. See http://www.fs.fed.us/research/sustain/ (August 2015) for digital copies and related information.

[2] The full title is *Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests*.

urban forest resources, but the overwhelming focus of the effort at the international level and here in the United States has been on conventional forest lands; agricultural and urban forests are not explicitly addressed in the MP C&I.[3]

The consideration of agricultural and urban forests within the context of forest sustainability reporting is important for several reasons. First, we are increasingly recognizing the numerous public benefits provided by the trees in our cities, suburbs, and farms, many of which will be outlined further in this report. With this recognition have come myriad programs at local, regional, and national levels aimed at using trees and forestry to enhance the livability of our communities in general and to provide valuable services through their role as "green infrastructure" in particular. Second, we have come to see the challenge of sustaining natural and human environments as one of managing landscapes that span different ecosystem types, ownership classes, and land uses. Wildlands, agricultural lands, and developed areas are all seen as being integrated in a broader landscape in which changes in one category inevitably result in changes in the others. The status and management options for agricultural and urban forests are an essential component in this "all lands" approach to sustainable resource management. Finally, a more immediate and specific goal for developing statistics on agricultural and urban forest resources is that it will provide the data needed for a comprehensive estimate of forest carbon sequestration and thereby aid in the development of a national greenhouse gas inventory.

So developing an increased understanding of these resources is important; however, it also entails significant challenges. The study of conventional forests and their management has developed over a number of centuries, involving dedicated schools and institutions, professional designations (e.g., forester), and subdisciplines. Along with this professional development has come an established stream of data sampling and reporting activities (through programs such as the FIA) and also standardized industry and product designations for tracking the production and trade of wood products. Agricultural and urban forests have received no such longstanding attention. Certainly agroforestry and urban forestry have been increasingly recognized as important areas for research and development in their own right, but their knowledge base, statistical development, and institutional support are not yet commensurate with that of forestry proper.

Most importantly for the purposes of this report, neither agricultural nor urban forests enjoy anything like the same type of data coverage as has been established for conventional forests. The reasons for this lack of coverage are outlined in the following chapters, but, in general, they can be attributed, in part, to a lack of effort and, in large part, to the simple fact that agricultural and urban forest resources are difficult to define, delineate, and measure, occurring, as they do, interspersed with other land uses and across multiple ownerships and jurisdictions. The situation, however, is not hopeless. Urban forestry techniques and applications are being developed and refined by municipalities across the country, and the FIA program is embarking on a new effort to inventory urban forest resources, the details of which will be evolving during the coming years. In the realm of agroforestry, with the release of the *USDA Agroforestry Strategic Framework, Fiscal Year 2011–2016* (USDA 2011), the Secretary of Agriculture has provided a first-of-its-kind roadmap for Federal agencies and other government bodies to use to advance the science, practice, and application of agroforestry as a means of enhancing America's agricultural landscapes, watersheds, and rural communities.[4]

Along with an increased realization of the value of these nonconventional forest resources has come a willingness to direct attention and expend resources for their measurement. FIA, for example, has temporarily extended its sampling activities to a number of urban areas for the purposes of experiment (see figure 2.3 in chapter 2) and will be expanding this activity in the future. New technologies, notably those in the area of remote sensing and Geographic Information Systems, or GISs, are increasingly being harnessed to develop information about forest cover and extent in developed and rural areas. More collaborative and participatory forms of research, sampling, and information sharing promise to yield better data if we can successfully bring people together. One promising example of such an effort is in the Great Plains States, where four State forestry agencies partnered with FIA to develop and conduct a first-ever 2008-to-2009 inventory of "nonforest" areas in Kansas, Nebraska, North Dakota, and South Dakota. Another, in the realm of urban forestry, is the expanding use of the "i-Tree Eco Model," a tool that enables local citizens and professionals to inventory their local tree resources in a fashion that is flexible enough to meet their needs but can also produce information that is consistent across time and space so that it can be compared with inventories produced elsewhere.

Still, readers who are hoping that this report will provide comprehensive and accurate information about even basic forest inventory measures for agricultural and urban forests at the national level will be disappointed. Those data simply do not exist, and the information we do have is often the product of

[3] Definitions and terminology associated with conventional forests and agricultural and urban forests are addressed more fully in chapter 2.

[4] In relation to the core focus of this report, the *Agroforestry Strategic Framework* specifically addresses the issue of resource monitoring and measurement in Objective 3.2 ("ASSESS PERFORMANCE: Account for and monitor agroforestry impacts and applications") and in more detail in Strategy #2 ("Work within USDA to establish a comprehensive continuous national inventory of on-the-ground applications of agroforestry practices/systems or include in existing inventory structures [e.g., Forest Inventory and Analysis or the National Resources Inventory"]).

one-time studies limited in coverage to a specific place, time, or management question. It is essential for us to determine what we do know and explore ways to build a more complete base of knowledge and data for the future.

The purpose of this report is to lay the groundwork for better integrating agricultural and urban forest resources in national-level forest sustainability reporting efforts. Simply describing what we currently know about these resources will be a major part of the report, but we also want to consciously address questions about data and how they can be developed, organized, and reported now and in the future. Using the MP C&I as a starting point, we will assess the current availability of quantifiable data describing agricultural and urban forest resources at broad spatial scales and explore potential avenues for enhancing this information, either through expanded sampling and inventory efforts or through better use of already existing information sources.

The report is divided into five chapters. Following this introductory chapter, chapter 2 introduces key issues and concepts associated with agricultural and urban forest resources, and it provides a broad summary of the MP C&I as they potentially relate to reporting on these resources, particularly at the criterion level. The aim here is twofold: (1) explore ways in which agricultural and urban forests can be integrated with current sustainability reporting efforts applied to conventional forests; and (2) use the MP C&I and their comprehensive coverage of social, ecological, and economic aspects as a starting point for identifying the key information pieces we need to know about these resources.

Chapters 3 and 4 address agricultural and urban forests, respectively. Each chapter presents (1) a current description of the state of the resource to the extent that existing data allow, (2) a brief summary of the various ecosystem services and related benefits these forests provide, (3) a discussion of the ways in which these forests are affected through their close proximity to human systems, (4) an assessment of current data adequacy in describing these resources at national and regional scales, and (5) a discussion of potential strategies to enhance these data in the future. Chapter 5, the final chapter of the report, discusses potential approaches to enhancing data. The primary avenue considered here is expanded forest inventory and sampling techniques augmented with remote-sensing data. As a result, the primary focus in the chapter is on biophysical measures more than on social or economic measures, although the development of socioeconomic measures is considered when possible.

References

Sargent, C.S. 1884. Report on the forests of North America. Washington, DC: Government Printing Office. 612 p.

U.S. Department of Agriculture (USDA). 2011. USDA agroforestry strategic framework, fiscal year 2011–2016. Washington, DC: U.S. Department of Agriculture. 35 p. http://www.usda.gov/documents/AFStratFrame_FINAL-lr_6-3-11.pdf. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2011. National report on sustainable forests—2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 p. http://www.fs.fed.us/research/sustain/. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2012. Future of America's forest and rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC: U.S. Department of Agriculture, Forest Service. 198 p. http://www.fs.fed.us/research/rpa/assessment/. (August 2015).

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2009. Summary report: 2007 national resources inventory. Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service; Ames, IA: Iowa State University, Center for Survey Statistics and Methodology. 123 p. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041379.pdf. (August 2015).

Chapter 2

Guy Robertson

Agricultural and Urban Forests and Their Relation to the Montréal Process Criteria and Indicators

In this chapter, we lay the groundwork for understanding agricultural and urban forest resources within the context of this report and the goal of better integrating these resources in forest sustainability reporting efforts. The chapter begins with a discussion of definitions and concepts related to agricultural and urban forests, followed by a brief description of the overall extent of these types of lands in the United States. The chapter concludes with a description of the Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability[5] and their potential relation to the forests and trees that are found in our farms, suburbs, and cities.

Definitions

By *agricultural and urban forests*, we mean trees and woodlands that occur on or adjacent to farmland and developed areas and that would not normally be classified as forests under current forest inventory definitions. This grouping is essentially a subset of *trees outside forests*, or TOF, a term common in the scientific and governmental literature (see Long and Ramachandran 1999, for a listing of the various types of TOF found throughout the world). The *agricultural and urban* terminology used in this report, however, stresses the relationship of these trees to human occupation and land use patterns, an emphasis we want to maintain. The term *forests* emphasizes the broader ecosystem components and functions associated with agricultural and urban trees, including flora, fauna, and forest soils. This broad definition is used throughout the report.

What we have termed "conventional forests" refers to (relatively) large, contiguous tracts of natural or managed forests that contain (relatively) little human habitation or agricultural development within their boundaries. These forests are tallied in conventional forest inventory efforts. For example, the Forest Inventory and Analysis (FIA) inventory of the U.S. Department of Agriculture (USDA), Forest Service, defines forests as areas more than 120 feet (37 meters) wide and more than 1 acre (.4 hectares) in total extent with at least 10 percent forest stocking. As they actually occur, however, the "forests" considered in this report span a continuum between developed lands and wildlands, where different types of land uses and natural vegetation cover tend to blend together in a mosaic that may be easily characterized at its extremes but that entails substantial gray areas when it involves mixtures of uses and cover types.

Precise definitions often appear to be somewhat arbitrary and, sometimes, even counterproductive. The challenge in applying definitions sometimes occurs when attempting to delineate "conventional forests," and it is more common when trying to distinguish agricultural and urban forests, because they often occur at the interface of developed, agricultural, and natural landscapes. Definitions and distinctions are nonetheless essential for measurement and analysis and for the various programs, laws, and regulations with which we pursue sustainable resource management. We should remember, however, that these definitions divide what is essentially a unified landscape, and this division affects our statistics and the understandings that flow from them.

Characteristics and Underlying Concepts

To varying degrees, agricultural and urban forests share many of the attributes that characterize conventional forests, but they also differ in several fundamental ways from the types of forests covered in the *National Report on Sustainable Forests—2010* (USDA Forest Service 2011a), hereafter the *National Report*; the RPA Assessment; or FIA periodic reporting documents. The main difference, of course, is that agricultural and urban forests each occur in developed landscapes in close proximity to human activities. As a result, the functions they serve and the benefits they provide to society are quite different from those that conventional forest provide, and the influences, positive and negative,

[5] The full title is *Montréal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests*.

they are subject to also differ. Next, their spatial configuration is different from that of conventional forests, being characterized by a higher degree of fragmentation, attenuation (i.e., occurring in lines or narrow lengths filling in the interstices between buildings, roads, and fields), and smaller areas with greater edge effects. Agricultural and urban forests are usually owned by a diverse set of individuals and entities whose primary concern is not forest management, whether it be for timber production, environmental conservation, or the provision of ecosystem services. This parcelization, or fragmentation of ownership, means that the management of these resources is considered amid other competing objectives, if it is considered at all.[6]

For clarity, these characteristics can be abbreviated as follows: (1) proximity to human activities, (2) spatial configuration and fragmentation, and (3) fragmented ownership and lack of forest management focus. In combination, these characteristics result in novel and often radically modified environments requiring different management strategies tailored to their specific situations. An example of how forest and trees can be integrated in an urban-rural continuum is provided in figure 2.1.[7] Here, some of the potential functions (and benefits) of agricultural and urban forests are clear as are the various spatial forms these forests may take.

Figure 2.1. Idealized depiction of forests in an urban-rural landscape.

[6] The growing awareness and inclusion of forest management concerns in local planning efforts provide numerous exceptions to this observation, but, even for cases in which local forest management is active, forest management concerns must compete with a variety of other objectives for land use and planning.

[7] Unfortunately, street trees and their functions are omitted from the diagram—a point noted by several of our reviewers.

Proximity to Human Activities

Agricultural and urban forest resources generally occur in areas dominated by human activity—areas where we live, work, and produce most of the food that sustains us. Although we may not be aware of the role forests play in the landscape, seeing them as simply greenery by the roadside, trees and forests interact in numerous complex and subtle ways with people and their activities. In recent years, the benefits trees bring to us have increasingly been recognized, and the science underlying this recognition advanced. Trees in agricultural and urban settings certainly overlap in terms of the benefits they provide, but the benefits most commonly recognized on farms are that trees protect valuable top soil, livestock, crops, and wildlife (through, for example, windbreaks and shelterbelts) and improve local water quality (through, for example, riparian forest buffers). In urban areas, on the other hand, trees help abate pollution, mitigate temperatures, and provide healthier, more pleasing places to work and live. These benefits, however, comprise only a small sample of an ever-growing list of values and services we have come to associate with these resources. The following chapters will describe these benefits and services in greater detail for agricultural and urban settings, respectively. The purpose of this report, however, is not to analyze forest benefits in detail or use them as a reason to argue that trees are important; such an analysis could easily take up several books. The importance (although perhaps not the full extent) of these benefits is fully evidenced by the effort and expense individuals devote to planting and caring for trees in agricultural and urban environments. Rather, the crucial question for this report is to what extent these benefits can actually be measured.

The nature of the interaction between people and trees is not all positive. Trees can have negative impacts in various ways—by falling on houses or encroaching on fields, for example. The pollen of certain trees can be a serious allergy trigger, and leaves and other detritus are a nuisance and a source of considerable expense for residents and municipalities. Under certain conditions, the volatile gases emitted by some tree species can interact with ambient urban pollution to exacerbate smog (Benjamin and Winer 1998), although some studies indicate that these effects, in general, are less than the ameliorating effect of trees on ambient air pollution (Nowak et al. 2000). The negative interactions resulting from proximity, however, by and large, move in the opposite direction, with trees being negatively affected by human actions, including such factors as pollution, soil compaction, the introduction of invasive plants and animals, and, of course, fragmentation and destruction to make way for development. Again, the interactions are often complex and difficult to identify; positive effects on trees from carbon dioxide (CO_2) and nitrogen (N) deposition (e.g., Lovett et al. 2000) and longer growing seasons (because urban environments are warmer, in general) have also been noted (Zhang et al. 2004). In an ideal situation, we would be able to measure the changing health of our agricultural and urban forests at multiple spatial scales, including the national level, where we could then discern the overall trend in forest health with respect to these resources. These types of comprehensive statistics, however, are not currently available, and a concerted effort to gather them is needed.

Spatial Configuration and Fragmentation

The spatial configuration of agricultural and urban forests differs from that of conventional forests, being characterized by a high degree of fragmentation and novel configurations, such as the “linear forests” found in windrows between fields or the green spaces separating housing developments. This characteristic is not always apparent when seen from the ground, but, when seen from the air, the fragmentation and attenuation of these forests are often strikingly obvious, particularly in agricultural areas. Conversely, the individual trees lining streets or planted in urban parks and gardens can comprise a substantial urban tree canopy (once again, this pattern is most evident when seen from the air), which, in general, is more sparse and varied than conventional forest canopies.

Common measures of forest area, such as those provided by the FIA and included in the *National Report*, are expressed in terms of extent of area, such as acres, square miles, or, in the interntional arena, hectares. These types of measures are difficult to apply to agricultural or urban configurations. Agricultural windbreaks, for example, occur in long narrow lines (hence the term *linear forests*), where the use of acres or similar measures can hardly capture the full extent or importance of the resource. At the extreme, individual trees on a street provide an example in which neither two-dimensional units (acres) nor one-dimensional units (miles or yards) suffice. In these cases, density measures such as trees per acre may be the best way to describe the resource. In any case, these different configurations entail significant challenges in sampling and reporting statistics to adequately describe the resource in question.

Forest fragmentation is also an important issue here. It includes the effects from proximity to the human activities identified previously but also involves a number of dynamics specific to forest ecosystems regardless of human influences. These dynamics include habitat connectivity, edge effects, and the ratio of core or interior forest to forest edge (Murcia 1995). The influence of these and associated factors will vary according to the forest type in question. Depending on their degree of fragmentation, forests may include a very different set of species and growth characteristics than outwardly similar and more intact forests occurring nearby. To adequately capture fragmentation and its trends over time, measures need to characterize the spatial configuration of the resource and not only its extent. This requirement is true for conventional forests as well, but the challenge is all the more pronounced in the case of agricultural and urban forest resources.

Fragmented Ownership and Lack of Forest Management Focus

A large proportion of conventional forests in the United States is composed of relatively large parcels managed by public and private landowners who view natural resource management as a core aspect of their ownership objectives. This ownership pattern is certainly evident for the vast public lands managed by the Forest Service and the U.S. Department of the Interior, Bureau of Land Management. In the private sector, despite the ongoing shift away from large holdings by forest management and wood products firms, most conventional forest land is still held in relatively large ownerships in which the character and potential value of the forest as a resource is recognized. The same cannot be said for agricultural and urban forests, where forest resources usually exist as a small portion of a broader land area dedicated to a variety of purposes with little or nothing to do with either traditional wood products production or forest-based ecosystem services. Moreover, resource ownership is seldom consolidated in the hands of an individual holder because of the mosaic of different ownerships that characterize agricultural and, especially, urban or suburban landscapes. In this setting, effective management demands significant collaboration among different owners and other stakeholders in the community. The dedication of urban foresters, municipal parks and recreation staff, and others notwithstanding, the management of forests and individual trees in these settings is often something of an afterthought or exists as a necessary but unwanted expense entailed in the production of intangible benefits that accrue to the community at large but that individual landowners cannot easily capture or profit from.

At the same time, many of the trees and forests occurring in agricultural and urban settings require a higher degree of management than conventional forests need. As noted previously, these forests are often subject to higher levels of stress originating from a more diverse set of stressors. Because of their close proximity to human activity and habitation, their growth, health, and survival patterns will often directly and significantly affect people. Moreover, many of these trees were purposefully planted and have been nurtured throughout their lives. Hands-off management is often not a viable option and tree replacement through the process of natural regeneration cannot be assumed.

From the standpoint of gathering and reporting statistics to describe agricultural and urban forests, ownership fragmentation and lack of forest management focus present major challenges. To be specific, there is no national-level inventory activity for agricultural and urban forests that is comparable with the inventory the FIA provides for conventional forests. Many municipalities devote significant resources to planting and maintaining urban trees, and various programs promote tree planting and management on agricultural lands, but these activities often do not include inventory sampling, especially consistent sampling across time, space, and ownership or administrative boundaries. Agricultural and urban forest resource information consequently is disconnected, being composed of data from different counties and municipalities often produced in the course of one-time studies without regular updating and reporting functions. So, although we know these resources are important, we have little information on their status and extent at either the national or regional levels. As will be described later in the chapter on urban forests, this situation is improving through the use of satellite imagery.

Landscape-Scale Management and Conservation

Although we have aimed in this chapter to distinguish agricultural and urban forest resources from more conventional forests, it is important to emphasize the fact that, in actuality, landscapes exist on a continuum between developed and natural settings. This continuum involves not only the biophysical configuration of the landscape but also its social configuration, ranging from small and diverse ownerships focused on various goals to more homogenous ownerships focused on natural resource management. The breakpoints we have identified in this continuum help us to describe the resource, but we must remember that society's objective should be to manage the continuum in its entirety. In recognition of this goal, the idea of landscape-scale conservation and management has been gaining increasing attention among public officials, natural resource managers, agriculturalists, urban planners, and interested members of the public. The focus on agricultural and urban forests in this report helps reinforce this concept, because we are taking what traditionally has been a subject for foresters and resource managers and extending it to the more complex mosaic of land uses that is found in the landscapes where most of us live and work. Although the distinctions we have drawn between conventional forests on the one hand and agricultural and urban forests on the other hand serve to aid in their measurement and analysis, understanding the underlying linkages between these resource categories is essential in their effective management.

The recognition of the need for integrated landscape-scale management is growing at all levels of government. At the national level, USDA Secretary Tom Vilsack has stressed the need for an all-lands approach to forest management that spans ecological and social boundaries (Vilsack 2009). The Forest Service has elaborated this approach in detail in a number of documents (e.g., USDA Forest Service 2009 and 2011b), as has the National Association of State Foresters (NASF 2009). It is at the local and regional levels, however, where the types of innovative projects, programs, and activities that best exemplify landscape-scale conservation take place. Baltimore (MD) County's Forest Sustainability Strategy is a notable example of this work, one that has received considerable attention at local and national levels (Baltimore County, MD 2005), but numerous other examples can be found throughout the country.

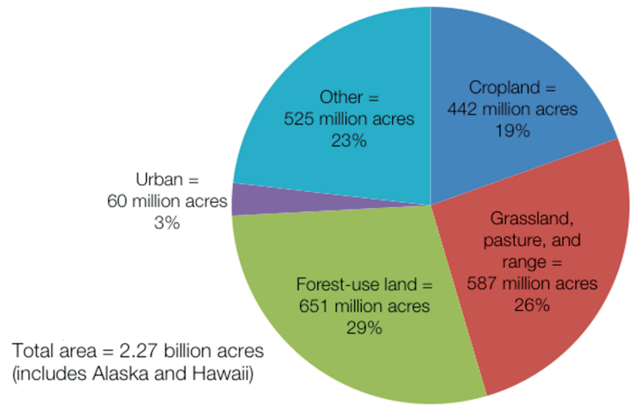
The growth of suburban and exurban development in forested areas has spawned a new term, the *wildland-urban interface* (WUI), and a new area of research. Throughout the country, and particularly in regions prone to forest fires, the WUI and its management are driving innovative forms of collaboration among private citizens, municipalities, forest landowners, and public land management agencies, and they are providing a focus for multidisciplinary research combining social and ecological dimensions with the aim of modifying landscapes and landowner behavior.[8]

Landscapes managed under an all-lands approach involve social, economic, and political dimensions every bit as much as they involve the ecological aspects of a landscape. The MP C&I, with their comprehensive treatment of social, economic, and ecological elements of the forest, is well suited as a foundation for developing the information base needed for this style of management. Most of the focus of this report, however, is simply on measuring and reporting the biophysical dimensions of agricultural and urban forest resources; the type of information that can be developed using forest inventory and remote-sensing activities. At the same time, opportunities for developing a more robust social and economic database are considered to a limited degree.

Agricultural and Urban Land Area in the United States

To begin to understand the potential scope of agricultural and urban forest resources in the United States, figure 2.2 provides a summary display of major land uses at the national level. This information relies on specific definitions (Lubowski et al. 2005), and it is not precisely comparable with the similar statistics found in the various other reports and data streams covering land use in the United States. (For example, forest-use land referenced here excludes lands managed by the U.S. Department of Defense, wildlife refuges, and similar other areas, resulting in a somewhat smaller number than the 751 million acres [304

Figure 2.2. Land use in the United States, 2002 (USDA Economic Research Service, http://www.ers.usda.gov/publications/EIB14/eib14.pdf [August 2015]).



million hectares] of forest land reported in the 2010 *National Report.*) The chart, however, is sufficient to give us a general picture of the lay of the land without being distracted by the details of definition and precision, questions which will be addressed in greater depth in subsequent chapters of this report.

Comprising 442 million acres (179 million hectares), cropland constitutes 19 percent of total land area, and the various windbreaks and shelter belts, riparian forest buffers, and woodlots found on lands in this category are most directly relevant in our consideration of agricultural forest resources. A considerable amount of pastureland is also forested, but a large proportion of this area is classified as forest land in the FIA inventories. Where forest canopy cover is not sufficient to meet FIA definitions for forest land, however, the trees on those lands, and the ecosystem services they provide, will not be accounted for in FIA inventories and would fall under the agricultural forest category considered in this report.

Urban areas were estimated to cover approximately 60 million acres (24 million hectares) in 2002, or 3 percent of total land area, but this number too is an artifact of definition, and the total area of land that is devoted to human habitation is much larger.[9] More recent estimates place the total urban land area at 68 million acres (28 million hectares), and if community lands are included, the total more than doubles to 138 million acres (56 million hectares). This figure also underestimates the importance of urban and suburban forests because urban and suburban areas are where most people live (close to 85 percent of total U.S. population by current estimates—table 2.1) and the direct benefits to citizens are commensurately larger. These

[8] The Forest Service's "Forests on the Edge" project specifically targets the wildland-urban interface for the development of research and management tools. Relevant publications and project information are available at http://www.fs.fed.us/openspace/fote/ (August 2015).

[9] Theobald (2005), for example, estimated that 31 million acres (13 million hectares) of land existed in urban and suburban designations (less than 1.68 acres [.68 hectares] per housing unit) in 2000 but that an additional 226 million acres (91 million hectares) existed in the exurban category (1.68 to 39.98 acres per housing unit—the decimals are due to metric conversion).

Table 2.1. U.S. population by land category (in millions).

	1980	1990	2000	2008	Change 1980–2008
Rural	46	45	49	50	4 (10%)
Urban	181	204	233	254	73 (40%)
Total	227	249	281	304	77 (34%)

Source: USDA Economic Research Service (http://www.ers.usda.gov/StateFacts/US.htm [August 2015]).

areas and the exurban housing development that immediately surrounds them are expanding, with associated losses in other land use categories.

The area statistics presented here help give us an idea of the potential scope of the resource. Their relative land areas, however, should not be used to gauge the relative value of agricultural and urban forests to our society. Urban forests, for example, account for a very small share of total forest area in the United States, but their value is proportionately quite large. A 1994 study estimated the total value of street trees alone to be in excess of $30 billion (Schoeneman and Ries 1994), and Nowak et al. (2002) estimated a total value for all urban trees of $2.4 trillion. Each estimate is based roughly on how much it would cost to replace these trees, and the linkage of these numbers to the actual benefits derived from urban trees is loose, at best. Other studies (e.g., Donovan and Butry 2011) have analyzed real estate markets to show that urban trees have significant positive effects on real estate sale and rental values, demonstrating a direct linkage between urban trees and consumer willingness to pay.

Similar value estimates for agricultural forests were not available for this report, but, given the ecosystem services associated with these trees, the values are likely quite large. In any case, economic valuations of this type are, by necessity, quite imprecise. In practice, it is virtually impossible to develop a single measure that summarizes the contribution of these resources to society (note that the same can be said for forest resources in general).

Data Sources Specific to Forests in Agricultural and Urban Settings

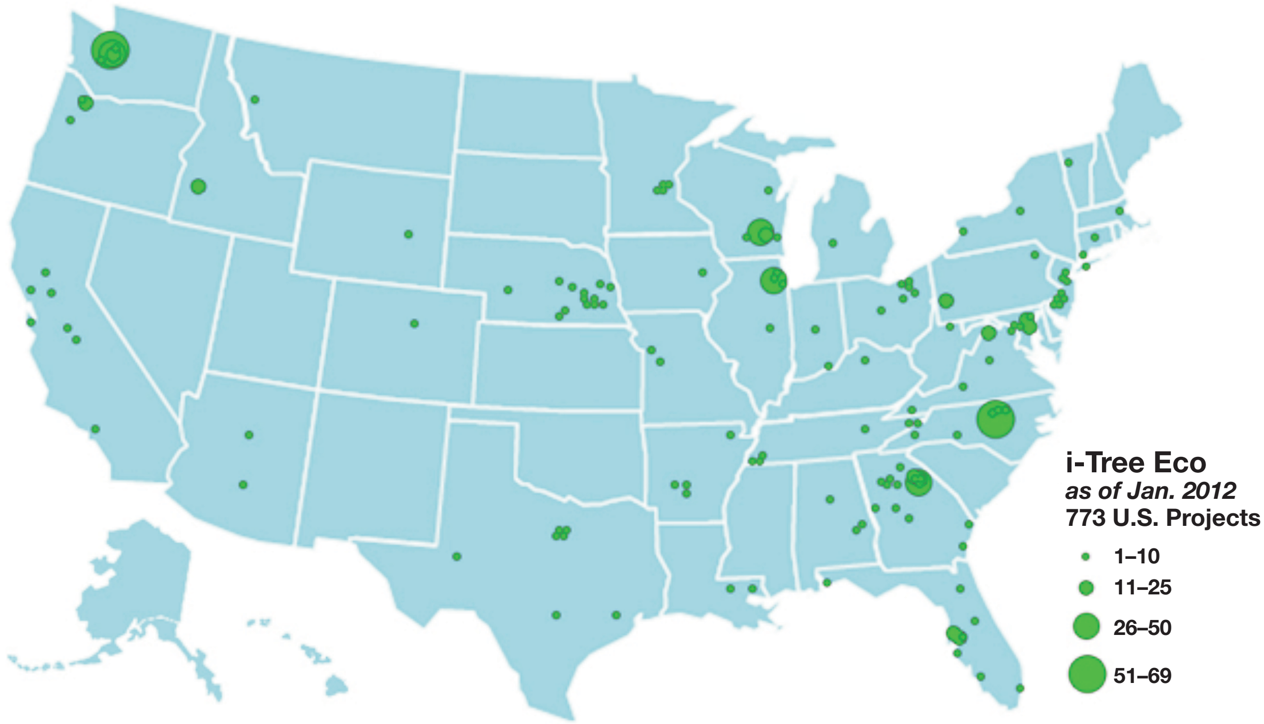
A central focus throughout this report is the data sources available for understanding and measuring agricultural and urban forests. The FIA program and the National Resources Inventory, carried out by the USDA Natural Resources Conservation Service, constitute the backbone of national sampling of forest resources, but these inventories have not yet[10] been consistently extended to the forests and trees considered in this report. What remains is a piecemeal collection of discreet studies and pilot projects, some of which are shown in figure 2.3. In the area of urban forestry, the FIA has extended forest sampling to urban areas on a pilot project basis in a number of States, in its Urban Pilot Plot projects and in the Pacific Rim Urban Inventory. On a more local level, a growing number of municipalities are using the Forest Service "i-Tree Eco" model to sample local urban forest resources in a consistent fashion, and, more generally, a growing number of municipalities, counties, and regional bodies are using remote-sensing and Geographic Information System, or GIS, technology to inventory and analyze their local forests and trees. These approaches are discussed further in the chapter 4, but the important point to remember is that these efforts are not integrated into a nationally consistent survey of urban forests. The Great Plains Tree and Forest Invasives Initiative (GPI), on the other hand, provides a consistent, wall-to-wall survey of agricultural and urban forests for Kansas, Nebraska, North Dakota, and South Dakota. The GPI constitutes the best data source we have to date on agricultural forests, but it is (of course) limited to a specific region. The GPI is a central focus in chapter 3, which addresses agricultural forests.

In addition to the ground-sampling activities listed previously, satellite imagery and related remote-sensing applications provide a source of increasingly sophisticated information on forests that is uniformly consistent and available wall-to-wall for the entire Nation. For certain measures, notably forest cover, remote sensing constitutes an extremely valuable source of information, but it will never fully take the place of ground-based sampling for understanding many of the aspects of forests that are considered important.

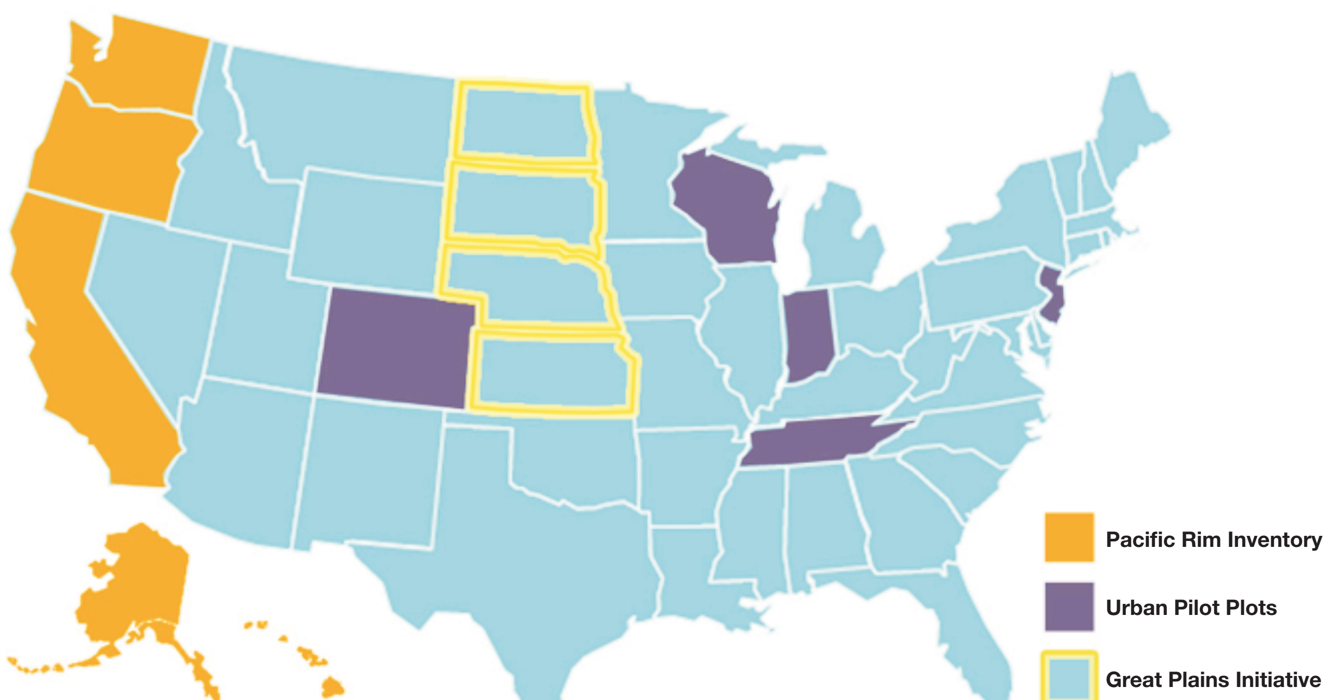
The Long Term Ecological Research Network (LTER) maintains research sites in the contiguous United States, Puerto Rico, Alaska, and Antarctica with the aim of tracking ecological change at specific locations over the span of decades or longer (see http://www.lternet.edu/ [August 2015] for project information and publications). Of particular interest for the purposes of this study, LTER sites in Baltimore County, MD, and Phoenix, AZ, focus on ecosystems in urban settings, and the Kellogg Biological Station LTER in Michigan focuses on agricultural environments. Given their site-specific nature, the LTERs are excellent for studying biological processes and exploring specific research questions in depth, but they do not deliver the type of broad-scale monitoring statistics that are the primary focus of this report.

[10] A National Urban Forest Inventory under FIA is in its initial stages of implementation. This effort builds on years of preparatory work on the part of FIA. Sampling protocols and related details for the program have been established and will further evolve as FIA and its collaborators gain more experience in inventorying urban trees and forests at the national scale. Nationally consistent inventory data from this effort, however, will not be available for at least several years.

Figure 2.3. Forest Service and related data sampling activities for agricultural and urban forests.



i-Tree Eco Assessments (1996–2012).



Pacific Rim Urban Forest Inventory (2010–2012); Urban Forest Inventory and Analysis Pilots (as of 2013); Great Plains Tree and Forest Invasives Initiative Inventory (2008–2009).

The foregoing discussion shows that a large and growing set of information is available to help us understand forests in agricultural and urban settings, but this information is not well integrated at the national level. As a result, one the most important steps we can take in developing a national assessment of agricultural and urban forests, and the database to support this assessment, is to simply make better use of the data we are already collecting. This theme is central in chapter 5, which considers ways to improve our data collection and sustainability reporting efforts in regard to these forest resources.

The Montréal Process Criteria and Indicators and Agricultural and Urban Forests

A central tenant of forest sustainability reporting efforts is that decisions about how society manages its forests must be guided by accurate and sufficient information. This idea is not new, but the degree to which managers have recently tried to institutionalize and standardize the process is. To aid in this effort, analysts and managers have increasingly turned to criteria and indicators as fundamental tools to rationalize their reporting processes, explicitly identifying the specific pieces of information they will be tracking and refining over time.

The MP C&I are one such approach. Initiated in the mid-1990s and applied in the United States first in 2003 and more recently in 2010 (USDA Forest Service 2011a), the MP C&I codify a set of measures needed to manage temperate and boreal forests sustainably. Since it is the product of an international collaborative process involving 12 signatory countries, the content of the MP C&I represents, in effect, a broad compromise between widely different perspectives reflecting equally different conditions within their respective countries. It also reflects the individual perspectives of the many people who participated. Data availability was purposefully omitted as a requirement when choosing indicators for the MP C&I (Montréal Process 2007). The resulting C&I set should thus be seen as a comprehensive list that a broad range of individuals has chosen and further refined, which identifies factors that should be considered when attempting to ascertain the sustainability of forest ecosystems, whether or not all of those factors can readily be measured. The MP C&I are subject to periodic review and adjustment to incorporate the experiences of reporting countries.

The strengths of the MP C&I include their comprehensive coverage of ecological, social, and economic dimensions of forest sustainability and their flexible nature, in which many indicators are loosely defined and left to country analysts to address as they see fit. Weaknesses include a lack of systematic consistency across reporting countries, large information requirements, and the practical impossibility of adequately addressing certain indicators.

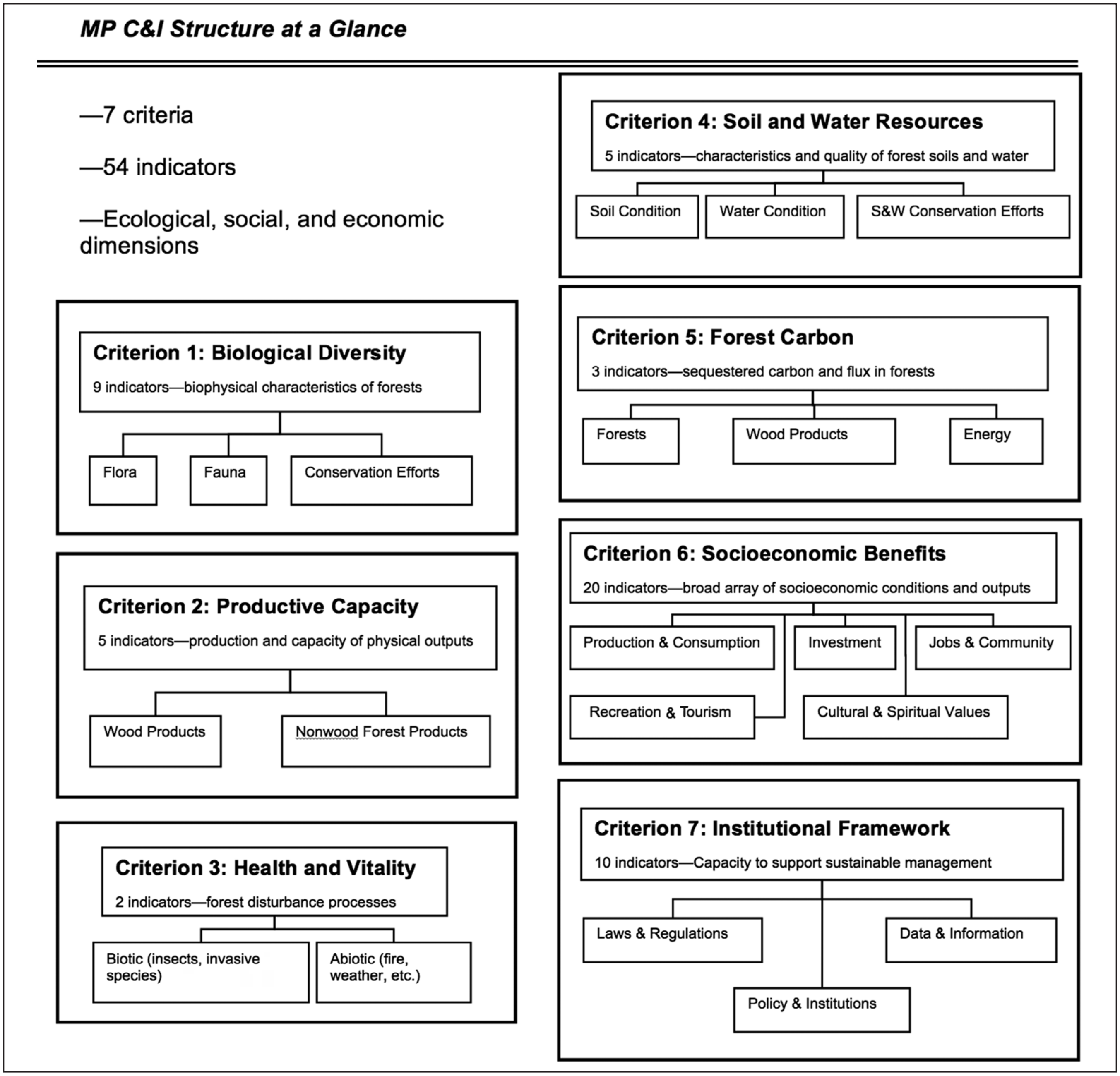
With 54 different indicators arranged under 7 criteria spanning ecological, social, and economic dimensions, the types of variables, their degree of accuracy and specificity, and the availability of information to treat them differ greatly between the indicators and their respective criteria.[11] Although certain indicators are easily addressed with available datasets, many others involve considerable information gathering and analysis, and still others can be reported only in an anecdotal or qualitative fashion, if at all. When applied to agricultural and urban forest resources, the data gaps and associated challenges become even more apparent, but these problems are as much the result of our lack of baseline data and analysis tools as they are the result of an inherent deficiency in the MP C&I or potential mismatch between conventional forest resources and the resources that are the subject of this report. More to the point, the MP C&I provides an excellent starting point (but only a starting point) for determining the current status of and potential future needs for information in assessing the sustainability of agricultural and urban forests, the challenges and data gaps inherent in the system notwithstanding.

The Seven Criteria in Relation to Agricultural and Urban Forest Resources

The basic structure of the MP C&I is displayed in figure 2.4. The figure shows the seven criteria along with the general areas they cover. The remainder of this chapter will be devoted to addressing these criteria one by one as they relate to agricultural and urban forest resources. In this fashion, we hope to use the MP C&I to highlight the various aspects of agricultural and urban forests as they relate to the general concerns of sustainability and the specific challenges of measurement and reporting. Although we have omitted a discussion of each of the individual indicators, we do reference certain key indicators if they are particularly important. A more detailed mapping of the MP C&I into specific indicators, tailored to agricultural and urban forests, is provided on a provisional basis in chapter 5.

[11] The number of indicators was reduced to 54 in 2009 (too late for inclusion in the 2010 *National Report*). A current listing of the criteria and indicators comprising the MP C&I is available in the Montréal Process Booklet, 4th edition (Montréal Process 2009). http://www.montrealprocess.org/documents/publications/general/2009/2009p_4.pdf (August 2015).

Figure 2.4. Montréal Process Criteria and Indicators for Forest Sustainability.*



MP C&I = Montréal Process Criteria and Indicators.
*The full title is *Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests*.
Note: The criteria titles and descriptive information are abbreviations.

Criterion 1: Conservation of Biological Diversity. The nine indicators in Criterion 1 provide information on the extent and character of forests as they relate to ecosystem, species, and genetic diversity. These indicators comprise the core variables of a biophysical inventory and include the amount of forests of different types (as measured in acres), the number and status of different species of flora and fauna contained within them, and the genetic resources they represent. Measuring the extent of agricultural and urban forest resources is a central concern in this report, and, in an ideal world, we would be able to replicate the simple area measures for these resources that are already available for conventional forests in the first two indicators displayed for this criteria in the *National Report*. The primary FIA data used for conventional forests, however, are not available for agricultural and urban forest resources, and, owing to the fragmentation of these resources, the type of area measures may not always be appropriate (as was discussed previously). Much of the rest of this report is devoted to issues involved in developing this type of baseline inventory data.

To the extent that agricultural and urban forests serve as an important reservoir for biodiversity, the species and genetic diversity measures found in Criterion 1 will also be important, particularly if these resources harbor species not found on conventional forest lands. Moreover, recent studies have found that scattered trees, a configuration common to urban and some agricultural landscapes, have a disproportionately large positive effect on animal diversity, at least for birds and bats (Fischer et al. 2010, Manning et al. 2006). Add to this effect the high number of introduced species (intentionally and accidentally), and it is not surprising that agricultural and, especially, urban landscapes can exhibit a high degree of biological diversity, although this diversity should not be seen as a substitute for intact natural ecosystems (Kowarik 2011). By extending FIA sampling activities to agricultural and urban forests, some of this information may be developed using the sampling process, but the Criterion 1 biodiversity indicators in the main *National Report* also rely on a number of data sources that will likely not be easily replicated in agricultural and urban settings. This data challenge is even more pronounced for genetic diversity, an area that presented challenges for the *National Report* as well.

Criterion 2: Maintenance of Productive Capacity of Forest Ecosystems. Criterion 2 contains five indicators providing information on growth, harvests, and inventory of valued forest outputs. These outputs include conventional wood products, such as lumber or wood fiber for paper or other uses, and "non-wood" forest products, a category covering an array of other outputs ranging from mushrooms and herbs to Christmas trees. Owing to their status as a major industry with long-established accounting and tracking procedures, the wood products indicators in Criterion 2 enjoy fairly good coverage through the FIA program and regular reporting of harvest activity. The nonwood forest products category, on the other hand, includes a large number of products for which little or no information is readily available. Regarding agricultural and urban forests, a central question will be the degree to which these types of outputs, either wood or nonwood, are important. These forests most likely are not the source of substantial volumes of wood products, and the same type of growth and yield measures that are applied to conventional forests would not be useful. Urban forests generate significant amounts of woody biomass in the form of yard wastes and debris, a small proportion of which is recovered through mulching, recycling, and other uses (including a growing amount of bioenergy generation). In addition, substantial amounts of nonwood products may be harvested from agricultural and urban forests, although these products may not always enter the cash economy through sale or exchange (Poe et al. 2013). Agroforestry, for example, purposefully integrates nonwood forest products (and wood products in some cases) with agricultural production (see Gold et. al. 2000 for an overview of agroforestry in the United States). In addition, if energy from woody-biomass becomes more common in the future, trees in urban, and, particularly, in agricultural settings, may come to constitute an important source of energy (Ruark et al. 2006). How trees grown expressly for energy production will be classified—as forests or as crops—remains an open question, however. In any case, the data streams available to cover these outputs are not well established, and initial reporting efforts will be incomplete if undertaken at all.

Although the commodity outputs flowing from agricultural and urban forests may at present be relatively insubstantial, the ecosystem services associated with these resources are generally well recognized—they are the reason these trees were established or preserved in the first place. The actual definition of what constitutes an ecosystem service can include a variety of beneficial aspects, some of which have been enumerated in the previous chapter, but, in general, these services are not directly associated with easily quantified measures (although our capacity in this area is increasing).

The MP C&I do not explicitly treat ecosystem services in Criterion 2,[12] reserving that topic for Indicator 28 in Criterion 6 ("payments for ecosystem services"),[13] but given the importance of ecosystem services as a primary output and justification for agricultural and urban forest resources, the services associated with these resources should perhaps be specifically considered within Criterion 2. This inclusion would entail first identifying key services on which we wish to concentrate and then working to devise, where possible, quantitative measures of the capacity of forest resources to actually supply them.

Criterion 3: Maintenance of Forest Ecosystem Health and Vitality. Criterion 3 contains two indicators, focused on biotic disturbances (insects, diseases, and invasive species) and abiotic disturbances (fire, drought, storms, pollution, and development). Although biotic and abiotic disturbances are treated separately, they are often closely related. Drought-stricken forests, for example, are more susceptible to insect infestation and then, in turn, to fire. Numerous similar associations between biotic and abiotic disturbance agents can be found in the various paths through which forest ecosystems evolve over time. The Forest Service, Forest Health Protection, or FHP, program supplied the major data sources used to populate this indicator in the 2010 *National Report*.

[12] Criterion 4, which addresses soil and water conservation is closely linked to the concept of ecosystem services, particularly those related to the provision and flow regulation of water. Carbon sequestration, addressed in Criterion 5, also constitutes an important ecosystem service, and several other indicators are closely associated with ecosystem services, but none treat them explicitly.

[13] Note that "payments for ecosystem services" is not the same as a physical measurement of outputs nor is it a measure of the total value to society provided by these services.

As evidenced by the progression of Dutch elm disease through the tree lined streets of our towns and cities in the past century and by the wildfires that have afflicted our western towns in more recent years, forest health and disturbance are crucial considerations for agricultural and urban forests. The adverse effects of disturbance are often obvious and direct because these resources are interspersed with human settlement and activity, ranging from the loss of benefits trees provide to, in the case of fire, loss of property and even lives.

Owing to their different spatial configuration and proximity to human disturbance agents (such as pollution and ignition sources), and to their often artificial species distribution, agricultural and urban forests may be more susceptible to certain disturbance events. The tendency to rely on a limited set of species in urban forestry, for example, has led to concerns about enhanced vulnerability to species-specific pathogens (Lacan and McBride 2008). The species selected for agricultural lands too have been limited in regions, as evidenced by predominance of ash trees found in the Great Plains, trees which are now at considerable risk to emerald ash borer (*Agrilus planipennis;* EAB) infestation (Rasmussen 2009). All these factors point to the importance of understanding and monitoring the health of agricultural and urban forests, but, as is true with the provision of basic inventory data, no mechanisms are in place to develop these data for agricultural and urban forests in a consistent fashion, at either the national or regional level.

The 2010 edition of the *National Report* identified rising levels of forest disturbance, particularly that associated with insects, as one of its keys findings and a leading indicator of potential threats to the sustainability of conventional forests in the near future, particularly in relation to impending climate change. This same issue likely applies in the case of agricultural and urban forests (indeed, the GPI inventory, discussed in the next chapter, was largely motivated by concern for potential damage from the EAB).

Criterion 4: Conservation and Maintenance of Soil and Water Resources. The five indicators in Criterion 4 are designed to measure the current status of water and soil resources in forested ecosystems and our efforts to conserve them. The data sources used to populate these indicators range from information on protective land use designations to State-level data on water quality impairment and FIA sampling of soil conditions.

Soils are a foundational element for forested ecosystems, and water quality enhancement and flow retention are recognized as essential outputs associated with these ecosystems. Soils and water are likewise important in the case of agricultural and urban forests. Soil conservation was the prime motivation behind the establishment of the windbreaks and shelterbelts and related forested areas that comprise a large proportion of our agricultural forest resources.[14] In a similar way, the importance of forests in the provision of water for urban populations has long been recognized, resulting in explicit management prescriptions to enhance and conserve water resources in forested watersheds serving municipal entities (e.g., the Bull Run Watershed serving Portland, OR), and, more recently, innovative policies that incentivize and motivate private landowners to preserve forest cover and water quality (the New York City (NYC) Long-Term Watershed Protection Program,[15] for example). Another recent example is the Executive Order[16] signed on May 12, 2009, by President Obama that is aimed at protecting and restoring the Chesapeake Bay Watershed, which has led to the establishment of a goal to establish 14,400 miles of riparian forest buffers by 2025. Moreover, by providing permeable surfaces and water retention, forested green spaces within municipal boundaries are now being increasingly proposed as an alternative to physical water control infrastructure (i.e., drainage pipes) in urban areas (Booth et al. 2002).

Although soil and water conservation are recognized as a key aspect of agricultural and urban forests, their measurement within the context of Criterion 4 will likely remain challenging. Soil sampling through an expanded FIA program or similar activity could provide some data on soils at least, but developing information on water quality would be hampered by the unique spatial configurations and lack of management focus associated with agricultural and urban forests identified in the previous section. Most of the data will depend on reporting by State or local agencies, and the data streams associated with these reporting mechanisms are often inconsistent or otherwise difficult to aggregate and compare—a problem that hampered reporting for Criterion 4 for conventional forests in the *National Report* as well.

Criterion 5: Maintenance of Forest Contribution to Global Carbon Cycles. The role of forest ecosystems (including forest soils) in absorbing, storing, and emitting carbon is the key focus

[14] The most visible example of this effort is the creation of the Soil Conservation Service and the Prairie States Forestry Project by the Roosevelt administration to combat loss of topsoil in the Dust Bowl States during the Great Depression. See Munns and Stoeckeler (1946) for a description of the project and its relative success.

[15] The NYC Long-Term Watershed Protection Program has received a great deal of attention during the past decade for providing an innovative solution to the complex problem of supplying clean drinking water to one of the world's largest cities and for its explicit recognition of the value of forest-based ecosystem services. See Pires (2004) for a description of the project. Program information is available on the project's Web site. http://www.nyc.gov/html/dep/html/watershed_protection/index.shtml. (August 2015).

[16] http://www.executiveorder.chesapeakebay.net/default.aspx. (August 2015).

of Criterion 5. In addition to forest ecosystem carbon accounts, Criterion 5 indicators track the amount of carbon stored in long-lived forest products, and fossil fuel carbon emissions avoided through the use of wood to generate energy. In the *National Report*, the indicators in Criterion 5 are populated using forest inventory data or information tracking wood products and energy production that is then converted to carbon equivalents using conversion factors. These conversion factors, which estimate such aspects as the tons of carbon per acre of a given type of forest with a given stocking level or the amount of carbon in different wood products along with their rate of decay, are subject to substantial error bounds, but they are getting more accurate at a rapid pace as researchers gain more knowledge in this relatively new research area. The overarching goal of Criterion 5 is, of course, to better understand the influence of forests and forestry on global climate change via their contribution to atmospheric carbon balances.

Developing comparable information on carbon for agricultural and urban forest resources will involve two steps. First, baseline inventory and production data must be obtained. Basic inventory data could be developed by expanding FIA or similar sampling activities, but sampling would have to include information sufficient to develop estimates of forest volume (which FIA certainly does at present for conventional forest ecosystems) and not just forest cover. Forest soils also constitute significant carbon sinks (Pouyat et al. 2006), and soil carbon estimates specific to agricultural and urban forest soil types will need to be developed. Measuring forest outputs from agricultural and urban forests in the form of wood products and energy would likely be more difficult, owing to reasons noted in the previous discussion of Criterion 2, and a first step would be to ascertain whether these outputs are sufficiently large to justify a major data-gathering effort in the first place. The second challenge will be to develop appropriate carbon conversion factors to transform inventory and output measures into carbon equivalents. For forest carbon, conversions may simply entail using factors already in use for forested ecosystems, but agricultural and urban forests will often differ considerably in terms of spatial configuration and species composition, and we cannot simply assume that the conversion factors currently in use will be appropriate in this new setting. Nonetheless, substantial progress has already been made in estimating carbon volumes, at least for urban forests (Nowak et al. 2002). Assuming that the base data for wood products and energy outputs are available, conversion factors will probably be quite similar to those used to estimate carbon for these outputs in the case of conventional forests, but whether the amounts of carbon involved actually justify the effort needed to estimate them remains a question.

In the case of agricultural forests, and agroforestry systems in particular, payments for carbon sequestration may present a growing opportunity (Schoeneberger 2008) as could the production of woody biomass for energy production. Once again, however, the question remains as to whether the resulting plantings would be classified as forests or crops. In any case, the possible advent of these kinds of activities bears watching. The activities would be directly related to the indicators in Criterion 5 and to other indicators covering the production of forest products and ecosystem services, and the economic activities that accompany them.

Criterion 6: Maintenance and Enhancement of Socioeconomic Benefits. Containing 20 of the 54 indicators that comprise the MP C&I in total, Criterion 6 addresses a range of socioeconomic dimensions associated with forests and the goods and services they provide. This criterion is further divided into five subcriteria: (1) production and consumption; (2) investment in the forest sector; (3) employment and community needs; (4) recreation and tourism; and (5) cultural, social, and spiritual needs and values. Each subcriterion and its respective indicators obviously will relate to agricultural and urban forest resources in different ways, and many will likely not be appropriate or feasible in this context at all. Moreover, the primary focus of the current report is to explore options for developing baseline inventory information, and many of the indicators in Criterion 6 fall outside this objective and are perhaps best viewed as candidates for future development as opposed to targets for the work considered here.

That being said, a number of indicators in Criterion 6 still have a direct bearing on agricultural and urban forests and on the benefits they provide to society. Although it appears that the types of tangible forest products measured in the first subcriterion (production and consumption) are generally lacking in the case of the trees and forests considered in this report, this assumption should be viewed merely as a working hypothesis—it is quite possible that deeper investigation will reveal significant outputs of tangible products, particularly in the nonwood category or in terms of fuel wood and feedstock for energy production. Moreover, this subcriterion contains an indicator measuring payments for forest-based ecosystem services, services that we have identified as a primary aspect of agricultural and urban forests, although, whether we can develop measures of money transfers for these services, and relate them directly to forests and trees, is another question.

Investments in the forest sector, the second subcriterion, can be directly translated into a call for information on investments in agricultural and urban forestry, although once again, the data available to address this question may be sketchy, relying as they do on disparate reporting activities from local and regional entities across the Nation. The third subcriterion, which addresses the needs of forest-dependent industries and communities, is probably the least applicable of the five, because the direct dependence on forests for economic livelihood applies in the case of conventional forestry but not in the case of agricultural and urban forests (with the possible exception of agroforestry systems, but, even in this case, the dependence will be only partial). At the same time, however, the role of trees and forests in providing community amenities must be recognized even though this role cannot be measured in terms of jobs or income generated. Moreover, recreation, the focus of the fourth subcriterion, is often closely related to urban and suburban green spaces, many of which are forested, and it would not be that much of a stretch to claim that the aesthetic contribution of trees to urban and rural landscapes results in a significant, although difficult to define, contribution to tourism activity.

To the extent that forests and trees add to the beauty of developed landscapes and the wellbeing of their inhabitants, the fifth and final subcriterion, will apply to agricultural and urban forests every bit as much as it does to conventional forests. Indicator 44, "The Importance of Forests to People," is of particular note here and has a direct connection to feelings residents have for the forest and trees that occupy their neighborhoods and surrounding lands.

Criterion 7: Legal, Institutional, and Economic Framework for Forest Conservation and Sustainable Management. The indicators in Criterion 7 are used to characterize the policies and institutions countries use to sustainably manage their forest resources. Although the topics addressed in Criterion 7 are central to our efforts to ensure sustainability, they are extremely resistant to quantification and standardized reporting. The *National Report* first addressed the topics in a narrative fashion in 2003, and, more recently in the 2010 edition, using a matrix approach to summarize qualitative judgments. In either case, the result could provide only a framework and descriptive summary of laws and institutions and not a consistent, permanent metric, such as is possible with forest areas and volumes, water quality, etc. The Montréal Process Working Group recently reduced and revised the Criterion 7 indicators, partly in recognition of the practical challenges they present (see Montréal Process 2009 for revised list), but this revision does not alter the fact that developing concise and consistent measures to describe policies and institutions is a very difficult task. These same challenges will also exist in the case of agricultural and urban forests, and perhaps more so because the institutional arrangements for managing these resources are nowhere near as developed at the national level as they are for conventional forests. A likely approach to treating agricultural and urban forest resources in regard to Criterion 7 could involve a narrative description of the various policies and institutions addressing these resources without recourse to the specific indicators found in the MP C&I.

The Relation of the MP C&I as a Whole to Agricultural and Urban Forest Resources

The foregoing discussion demonstrates a considerable overlap between the MP C&I and the types of issues we need to address to understand agricultural and urban forest resources in the United States. At the same time, the fit is not always exact or comfortable. Some of the indicators are directly applicable in this different context, some will call for considerable adjustment, and others simply make no sense when applied to trees on agricultural or urban lands. The MP C&I help us identify and organize our information needs and assess our ability to fill them when viewed at the criterion level. This function is exactly what the MP C&I are designed to accomplish regarding conventional forests, and so the use of this tool in relation to agricultural and urban forests is broadly comparable with the approach applied in the *National Report*, although it would be unrealistic to expect or enforce a one-to-one correspondence between the MP C&I and any candidate system for agricultural and urban forests. Rather, the MP C&I should be viewed as a guide and source of ideas for identifying indicators specific to these resources, with the ultimate aim of enabling us to characterize and integrate them with our understanding of conventional forest resources and their sustainable management. This approach is exemplified in the mapping of MP indicators into provisional measures for agricultural and urban forests provided in chapter 5 of this report.

This report views the MP C&I as a static list through which we can organize information about agricultural and urban forest resources, but, to remain relevant, the MP C&I (or any other C&I framework) must adapt to changing circumstances and societal demands. In fact, identifying the various ways in which agricultural and urban forests affect human welfare (through public health, real estate values, livability, etc.) may help us recast portions of the MP C&I in the future. Likewise, investigating the novel ecosystems that these forest resources represent can help shed light on basic ecosystem processes and point to new measures that are useful in considering conventional forests as well.

References

Baltimore County, MD. 2005. Forest sustainability strategy: steering committee final draft. http://www.resources.baltimorecountymd.gov/Documents/Environment/Workgroup/Forest%20Sustainability/finalstrategy_110505.pdf. (August 2015).

Benjamin, M.T.; Winer, A.M. 1998. Estimating the ozone-forming potential of urban trees and shrubs. Atmospheric Environment. 32(1): 53–68.

Booth, D.B.; Hartley, D.; Jackson, R. 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. Journal of the American Waters Association. 38(3): 835–845.

Donovan, G.H.; Butry, D.T. 2011. The effect of urban trees on the rental price of single-family homes in Portland, Oregon. Urban Forestry & Urban Greening. 10(2011): 163– 168.

Fischer, J.; Stott, J.; Law, B.S. 2010. The disproportionate value of scattered trees. Biological Conservation. 143(2010): 1564–1567.

Gold, M.A.; Rietveld, W.J.; Garrett, H.E.; Fisher, R.F. 2000. Agroforestry nomenclature, concepts and practices for the USA. In: Garrett, H.E., et al., eds. North American agroforestry: an integrated science and practice. Madison, WI: American Society of Agronomy: 63–77.

Kowarik, I. 2011. Novel urban ecosystems, biodiversity, and conservation. Environmental Pollution. 159: 1974–1983.

Lacan, I.; McBride, J.R. 2008. Pest vulnerability matrix (PVM): a graphic model for assessing the interaction between tree species diversity and urban forest susceptibility to insects and diseases. Urban Forestry & Urban Greening. 7(4): 291–300.

Long, A.J.; Ramachandran, N. 1999. Trees outside forests: agro-, community, and urban forestry. New Forests. 17: 145–174.

Lovett, G.M.; Traynor, M.M.; Pouyat, R.V.; Carreiro, M.M.; Zhu, W.X.; Baxter, J.W. 2000. Atmospheric deposition to oak forests along an urban-rural gradient. Environmental Science and Technology. (34): 4294–4430.

Lubowski, R.N.; Marlow, V.; Shawn, B.; Baez, A.; Roberts, M.J. 2005. Major uses of land in the United States, 2002. U.S. Department of Agriculture Economic Information Bulletin No. 14. http://www.ers.usda.gov/publications/EIB14/eib14.pdf. (August 2015).

Manning, A.D.; Fischer, J.; Lindenmayer, D.B. 2006. Scattered trees are keystone structures—implications for conservation. Biological Conservation. 132: 311–321.

Montréal Process. 2007. Annex F, criteria and indicators for the conservation and sustainable management of temperate and boreal forests. 3rd ed. http://www.montrealprocess.org/documents/meetings/working/an-6.pdf. (August 2015).

Montréal Process. 2009. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. 4th ed. http://www.montrealprocess.org/documents/publications/general/2009/2009p_4.pdf. (August 2015).

Munns, E.N.; Stoeckeler, J.H. 1946. How are the Great Plains shelterbelts? Journal of Forestry. 44(4): 237–257.

Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. Trends in Ecology and Evolution. 10(2): 58–62.

National Association of State Foresters (NASF). 2009. All-lands policy platform: a seven-point plan for America's forests. http://www.stateforesters.org/files/110309-NASF-All-Lands-Policy-Platform.pdf. (August 2015).

Nowak, D.J.; Civerolo, K.L.; Rao, S.T.; Sistla, G.; Luley, C.J.; Crane, D.E. 2000. A modeling study of the impact of urban trees on ozone. Atmospheric Environment. 34(10): 1601–1613.

Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002. Compensatory value of urban trees in the United States. Journal of Arboriculture. 28(4): 194–199.

Pires, M. 2004. Watershed protection for a world city: the case of New York. Land Use Policy. 21(2004): 161–175.

Poe, M.R.; McLain, R.J.; Emery, M.; Hurley, P.T. 2013. Urban forest justice and the rights to wild foods, medicines, and materials in the city. Human Ecology. 41: 409–422.

Pouyat, R.V.; Yesilonis, I.D.; Nowak, D.J. 2006. Carbon storage by urban soils in the United States. Journal of Environmental Quality. 35: 1566–1575.

Rasmussen, S. 2009. Great Plains tree and forest invasives initiative: a multi-State cooperative effort for education, mitigation, and utilization. Unpublished document developed by Kansas Forest Service, Nebraska Forest Service, North Dakota Forest Service, South Dakota Division of Resource Conservation and Forestry, and U.S. Department of Agriculture (USDA), Forest Service. http://www.wflccenter.org/ts_dynamic/edu_outreach/43_file.pdf. (August 2015).

Ruark, G.; Josiah, S.; Riemenschneider, D.; Volk, T. 2006. Perennial crops for bio-fuels and conservation. 2006 U.S. Department of Agriculture, Agricultural Outlook Forum—Prospering in Rural America. 1–17 February 2006, Arlington, VA. http://www.digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1017&context=usdafsfacpub. (August 2015).

Schoeneberger, M.M. 2008. Agroforestry: working trees for sequestering carbon on agricultural lands. USDA Forest Service / UNL Faculty Publications. Paper 2. doi:10.1007/s10457-008-9123-8. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1001&context=usdafsfacpub. (August 2015).

Schoeneman, R.S.; Ries, P.D. 1994. Urban forestry: managing the forests where we live. Journal of Forestry. 92(10): 6–10.

Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society. 10(1): 32.

U.S. Department of Agriculture (USDA), Forest Service. 2009. Landscape scale conservation in the Northeast and Midwest. http://www.na.fs.fed.us/stewardship/pubs/conservation/landscale_conservation.pdf. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2011a. National report on sustainable forests—2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 pp. http://www.fs.fed.us/research/sustain/. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2011b. "Release of the Forest Service Action Plan." Chief Tidwell memo to agency leaders, file 1020, January 3, 2011, with enclosure. 11 p.

Vilsack, T., Secretary, U.S. Department of Agriculture. 2009. "National Vision for America's Forests." Speech delivered in Seattle, WA.

Zhang, X.; Friedl, M.A.; Schaaf, C.B.; Strahler, A.H.; Schneider, A. 2004. The footprint of urban climates on vegetation phenology. Geophysical Research Letters, 31, L12209, doi:10.1029/2004GL020137.

Chapter 3

Michele Schoeneberger, Andy Lister,
and Steve Rasmussen

Agricultural Forests

The role of trees in supporting agricultural production and the health and vitality of rural landscapes has long been recognized. Of the two types of forest resources (agricultural and urban) analyzed in this report, however, agricultural forests are perhaps less well understood. Whereas urban forestry has specific educational programs, dedicated activities, and departments in many municipalities, agricultural forestry, when considered at all, is often subsumed under the general heading of farm management. Of course agroforestry, in which trees are integrated with other forms of crop production, is a well-developed area of study and application, but this field encompasses only part of the resources treated here. In any case, the available data for understanding these resources at the national level are very sparse.

Most of this chapter is devoted to establishing definitions and describing important characteristics of agricultural forests. The data we do have rely on several different sources. In 1982, 1987, and 1992, the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) National Resources Inventory (NRI) assessed the extent of windbreaks nationally. The NRCS also tracks the application of new agroforestry practices undertaken through the USDA's technical and financial assistance programs. Neither of these data collection activities represents a wall-to-wall inventory of agricultural forest resources, however. The Great Plains Tree and Forest Invasives Initiative (GPI) recently completed a more comprehensive inventory of windbreaks and other agroforestry plantings, but the scope is geographically limited to only States in the northern Midwest. The 2008-to-2009 GPI inventory was a cooperative effort among the four Great Plains States forestry agencies (Kansas, Nebraska, North Dakota, and South Dakota), made possible with USDA Forest Service funding, and scientifically guided by the agency's National Inventory and Monitoring Applications Center. A modified Forest Service Forest Inventory and Analysis (FIA) protocol was used in the GPI inventory, which lacks some of the data collected on standard FIA plots (Lister et al. 2009b). We use the GPI as a model for understanding the kind of data development efforts that could be applied at the national level.

This chapter begins with a discussion of definitions and characteristics of agricultural forests, followed by a description of available data (primarily from the GPI). Next we describe the various benefits associated with these forests, the risks they face, and the opportunities they present through expanded planting activity. The chapter concludes with an assessment of the adequacy of currently available information and suggested strategies for improving the data, in general and relative to the Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability. This same overall framework is applied to urban forests in the next chapter. When appropriate, we make reference to specific indicators in the *National Report on Sustainable Forests—2010*—hereafter, referred to as the *National Report* (USDA Forest Service 2011).

Definitions and Characteristics of Agricultural Forests

Agricultural forest resources consist of deciduous and coniferous manufactured tree plantings and natural woodlands that generally do not meet conventional definitions of "forest" because of their size and width. Manufactured plantings within agricultural lands (hereafter, referred to as *working trees* or *agroforestry*) are those that have been intentionally established in specific locations, with specific species, and in specific arrangements to achieve specific functions and that are closely associated with agricultural or forage production (USDA NRCS 1996). Naturally occurring woodlands within the agricultural matrix, in contrast, are unintentionally established through wind, water, or animal seed dispersal and root sproutings; they commonly occur as isolated patches of various dimensions, such as upland woods, woody draws, and riparian forests.

Working trees are established through the application of five categories of agroforestry practices, which include (1) field, farmstead, and livestock windbreaks; (2) riparian forest buffers along waterways; (3) silvopasture systems with trees, livestock, and forages growing together; (4) alley cropping that integrates annual crops with high-value tree and shrubs; and (5) forest farming, in which food, herbal (botanical), and decorative products are grown under the protection of a managed forest canopy. Special applications of these five practices can be designed to accomplish a wide range of other economic, environmental, and social objectives, including odor mitigation, organic food production, improved pollinator habitat, snow retention, or biomass feedstock production. A brief description of the practices and their uses is presented in table 3.1. Additional information for each of these practices is available at the USDA National Agroforestry Center Web site (http://nac.unl.edu [August 2015]).

Christmas tree plantations and nut and fruit orchards generally are excluded from the working tree category (Perry et al. 2009), although both types have the potential to become important components within agroforestry practices: for example, the use of Christmas trees in an alley cropping system or bioterraces and the planting of nut and fruit trees in a windbreak design to alter microclimate for adjacent practices and to enhance dispersal of natural enemies of crop pests. As they commonly occur, however, Christmas tree plantations and nut and fruit orchards are not included in the definition of agricultural forest resources considered in this report.

Support for Agroforestry Practices

A wide range of USDA conservation programs support the application of agroforestry practices by providing various forms of financial assistance, including conservation practice payments and rental payments, to establish and manage agroforestry plantings (table 3.2). The Food, Conservation, and Energy Act of 2008 (2008 Farm Bill) actually increased financial assistance to landowners for forestry-related conservation activities, including agroforestry and woodland practices. The recently signed 2014 Farm Bill contains modest budget cuts, but, in general, the conservation title still provides technical and financial assistance in this area for private landowners.

The 2008 and 2014 Farm Bills carry on a long tradition of conservation support for agroforestry practices, beginning with the windbreaks planted after the Dust Bowl in the 1930s. From 1935 to 1942, the Forest Service, working with the Works Progress Administration and Civilian Conservation Corps, planted windbreaks throughout the Great Plains. The Prairie States Forestry Project planted more than 217 million trees on nearly 18,641 miles (30,000 kilometers) of shelterbelts in six Great Plains States from North Dakota to Texas (Sauer et al. 2010). After World War II, the Soil Conservation Service (now the NRCS) was given a leadership role to assist landowners with planning and planting windbreaks throughout the United States.

Table 3.1. The six categories of agroforestry practices commonly established in the United States.

Agroforestry practice	Description	Primary use*
Riparian forest buffer	A combination of trees and other vegetative types established on the banks of streams, rivers, wetlands, and lakes.	• Reduce nonpoint source pollution from adjacent land uses • Reinforce streambank stability • Protect aquatic and terrestrial habitats • Provide economic diversification either through plant production or recreational fees
Windbreak (also referred to as shelterbelt)	Linear plantings of trees and shrubs to form barriers to reduce wind speed. Depending on the primary use, the windbreak may be specifically referred to as crop or field windbreak, livestock windbreak, living snow fence, or farmstead windbreak.	• Control wind erosion • Protect wind-sensitive crops • Enhance crop yields • Reduce animal stress and mortality • Serve as a barrier to dust, odor, and pesticide drift • Modify climate around farmsteads • Manage snow dispersal
Alley cropping	Rows of trees planted at wide spacing intervals while growing annual crops in the alleyways.	• Diversify crops in time and space • Diversify income • Protect soil quality
Silvopasture	Trees combined with pasture and livestock production.	• Diversify crops in time and space • Diversify income
Forest farming (a form of multistory cropping)	Natural stands whose canopies have been manipulated to grow high-value crops in the understory, such as mushrooms, decorative florals, and medicinal herbs (e.g., ginseng).	• Diversify crop production
Special applications (e.g., tree planting)	Use of agroforestry technologies to help solve special concerns such as disposal of animal wastes, filtering irrigation tail water while producing a short- or long-rotation woody crop.	• Provide treatment of municipal and agricultural wastes • Provide treatment of stormwater • Center pivot corner plantings • Produce biofeed stock

*In addition to the targeted benefits listed in the table column, agroforestry plantings can also be simultaneously managed to provide enhanced wildlife provisions for game and nongame species and greenhouse gas mitigation through carbon sequestration and reduction in fuel emissions.

Table 3.2. USDA 2008 Farm Bill programs supporting agroforestry practices.*

Programs[1]	Riparian forest buffer	Windbreak (also referred to as shelterbelt)	Alley cropping	Silvopasture	Forest farming (a form of multistory cropping)	Special applications (e.g., tree planting)
AMA[2]	C	C				C
AWEP[3]	C					C
BCAP						C/I/R
CBWI[4]	C					
CCPI[5]	C	C	C	C	C	C
CCRP	C/I/R	C/I/R	C/I/R			C/I/R
CREP	C/I/R					C/I/R
CRP						C/I/R
CSP	U	U		U	U	U
EQIP	C	C	C	C	C	C
MRBI[6]	C					C
SARE	PG	PG	PG	PG	PG	PG
WHIP	C	C	C	C	C	C
WRP	C/E			C/E	C/E	C/E

C = cost-share payment. E = easement payment. I = incentive payment. PG = producer grant. R = rental payment. U = land use payment.

* Not all combinations, practices, or programs will be available in all States and territories.

[1] Programs: AMA = Agricultural Management Assistance Program; AWEP = Agricultural Watershed Enhancement Program; BCAP = Biomass Crop Assistance Program; CBWI = Chesapeake Bay Watershed Initiative; CCPI = Cooperative Conservation Partnership Initiative; CCRP = Continuous Conservation Reserve Program; CREP = Conservation Reserve Enhancement Program; CRP = Conservation Reserve Program; CSP = Conservation Stewardship Program; EQIP = Environmental Quality Incentives Program; MRBI = Mississippi River Basin Healthy Watersheds Initiative; SARE = Sustainable Agriculture Research and Education; WHIP = Wildlife Habitat Incentives Program; WRP = Wetlands Reserve Program.

[2] AMA is available in 16 States: Connecticut, Delaware, Hawaii, Maine, Maryland, Massachusetts, Nevada, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Utah, Vermont, West Virginia, and Wyoming.

[3] AWEP will vary by State and the types of partnership agreements that are funded each year.

[4] CBWI is available in the six Chesapeake Bay States: Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia.

[5] CPPI will vary by State and type of partnership agreements that are funded each year.

[6] MRBI is available in 12 participating States (selected watersheds): Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, Ohio, Tennessee, and Wisconsin.

For many years, financial assistance was provided through the Agricultural Conservation Program administered by the Farm Service Agency with technical assistance from NRCS. The 1985 Farm Bill initiated the Conservation Reserve Program that also included agroforestry practices.

Gold and Garrett (2009) note that agroforestry practice and systems are used interchangeably by many people in the field, but it is in the deliberate design, placement, and integration of practices within agricultural operations that systems are created—systems that are capable of addressing a number of issues at multiple scales of concern (fig. 3.1; table 3.3). Water and riparian zone management is an area of particular focus for efforts that integrate intentional tree planting with agricultural and ecological objectives. For example, the 2008 Farm Bill and a number of related water-quality initiatives[17] have supported the widespread establishment of riparian buffers. Between 2008 and 2010, about 13,000 buffers covering about 123,000 acres (50,000 hectares) were applied on the ground. The practice is most commonly used in Mississippi River Basin States; however, some buffers were installed in a total of 47 States.

In addition, numerous regional and local efforts are being made along these lines. The 2008 Farm Bill and *Range-Wide Conservation Plan for Longleaf Pine* (America's Longleaf 2009), an effort to frame and coordinate longleaf restoration throughout the Southeastern United States, will also likely further promote agroforestry plantings in the Southern United States, with longleaf pine (*Pinus palustris*) trees integrated into either silvopasture or alley cropping systems. Each practice provides a means for reestablishing longleaf pine while giving landowners the opportunity to generate annual income in several ways: (1) through the intensive management of the understory (forage), alley (crops), and livestock components; (2) through a longer term, higher value income from the pine component (e.g., from sawtimber); and (3) potentially from hunting fees, carbon sequestration credits, and other environmental services markets.

Agricultural forest resources also include "naturally established trees." Although not intentionally established, these trees also provide many of the ecosystem services (e.g., carbon sequestration, wildlife habitat, recreational opportunities, and protection of water and soil resources) that landowners and society at large desire. Although they often occur as small, isolated patches, these naturally occurring woodlands, like working tree systems, serve as critical islands for supporting a diversity of floral and faunal species within agricultural settings, and, thus, they have a greater positive impact on biodiversity conservation

[17] These initiatives include the Chesapeake Bay Watershed Initiative, the Mississippi River Basin Healthy Watersheds Initiative, the Upper Mississippi Forestry Partnership, the White Water to Blue Water initiative, and Green Lands to Blue Water initiative.

Figure 3.1. Agroforestry practices and their uses at the practice/site levels and their potential placement throughout the landscape (Schoeneberger et al. 2001; artwork by G. Bentrup, USDA National Agroforestry Center, Lincoln, NE).

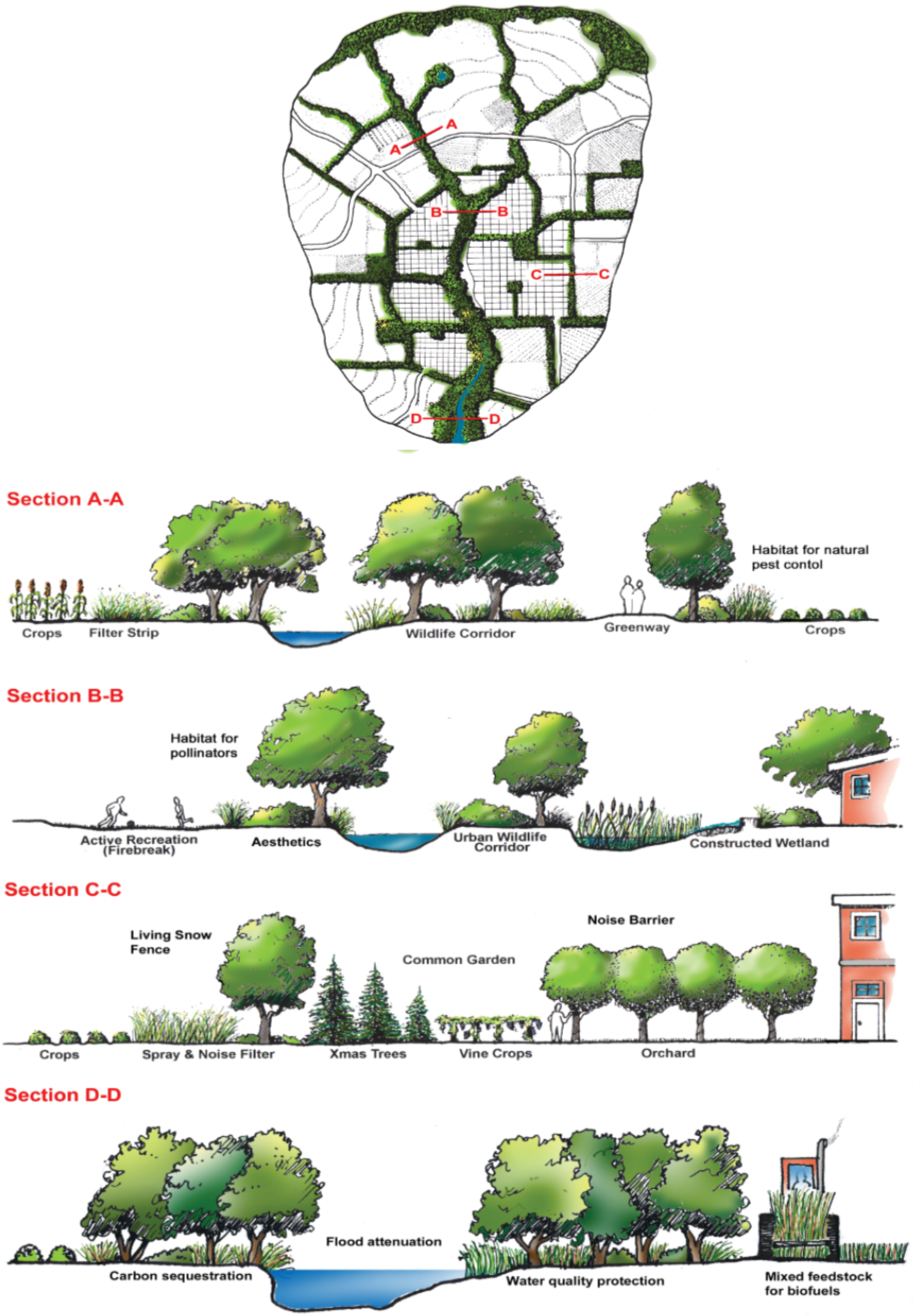


Table 3.3. Issues in temperate and tropical regions that can be addressed by agroforestry technologies.

North America—temperate	Tropical regions
• Income diversification ▪ Market driven • Environmental protection ▪ Water quality ▪ Soil erosion • Wildlife habitat restoration ▪ Biodiversity conservation • Aesthetics, quality of life • Renewable energy production • Climate change ▪ Carbon sequestration, markets	• Food and energy security ▪ Tree fodder ▪ Fuel wood ▪ Security of land and tree tenure • Poverty alleviation ▪ Market-driven income generation • Building human and institutional capacity ▪ Advancement of women • Health and nutrition ▪ Medicinal plants • Biodiversity conservation • Protection of watershed services ▪ Water quality ▪ Soil erosion • Climate change mitigation ▪ Carbon markets ▪ Desertification

Sources: Gold and Garrett (2009), Garrity (2004).

than implied by the relatively small area of land they occupy (Guertin et al. 1997). Numerous naturally occurring strips of trees grow along rivers and streams in sections that may be too narrow to be considered forest in standard inventory definitions, but they exist as remnants of bottomland forests that have been partially cleared. Although not specifically planted as a riparian forest buffer, these remnants provide the same functions as intentionally planted riparian forest buffers. Also, in agricultural areas that still have fencerows, birds perched on the fences often plant volunteer trees. Many landowners have removed these naturally occurring trees, but, if left in place, either managed or unmanaged, these areas serve as wildlife corridors and can also function as windbreaks.

Relationship to Forest Inventory Activities

Most working and naturally established trees on agricultural lands are not explicitly inventoried by either of the two primary natural resource inventories of the United States: the FIA program of the Forest Service and the NRI of the USDA NRCS (Perry et al. 2005). Both programs have slightly differing definitions used for including forest lands in their respective inventories and assign different classifications for those forests that are included. Although some agricultural forest areas are included in the FIA inventory, the shape of these forests is often too narrow and too limited in size (e.g., windbreaks, shelterbelts, and riparian forest buffers) to meet FIA's definition of forested land.

FIA defines "forest" as land at least 120 feet (37 meters) wide, 1 acre (.4 hectares) in size, with at least 10 percent cover (or equivalent stocking) by live trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between forest and nonforest lands that have at least 10 percent cover (or equivalent stocking) of live trees and forest areas that are adjacent to urban and built-up lands. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet (37 meters) and continuous length of at least 363 feet (111 meters) to qualify as forest land. Unimproved roads, trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Tree-covered areas in agricultural production settings, such as fruit orchards, or tree-covered areas in urban settings, such as city parks, are not considered forest land (USDA Forest Service 2007).

NRCS defines "forest land" as a land cover/use category that is at least 10 percent stocked by single-stemmed woody species of any size that will be at least 13 feet (4 meters) tall at maturity. Also included is land bearing evidence of natural regeneration of tree cover (cutover forest or abandoned farmland) that is not currently developed for nonforest use. When viewed from above, 10 percent stocking equates to an aerial-canopy cover of leaves and branches of 25 percent or greater. The minimum area for classification as forest land is 1 acre (.4 hectares), and the area must be at least 100 feet (30 meters) wide (USDA 2009). This definition of forest land is slightly different from FIA, but it similarly excludes many agricultural forest resources.

Getting a complete accounting of all agricultural forest resources, in relation to these inventories, is made even more difficult by the fact that these plantings exist along a tree-density spectrum ranging from many to a few trees, depending on type or practice (e.g., a single-row windbreak, to forest farming for agroforestry practices or savannah-like isolated trees, to wooded draws for naturally occurring trees) and on stage of development (e.g., a practice with newly established seedlings to one with fully mature trees). This continuum can exist even within a single practice, making it more challenging to easily and consistently incorporate the continuum into an inventory scheme. A good example of this continuum is evident with silvopasture, where a site may be established by planting seedlings within a pasture or by thinning an existing stand (fig. 3.2). Although the functions of both approaches will ultimately be similar, they will probably look quite different, even when fully established.

Because many agricultural and urban forest resources do not meet these definitions, current FIA and NRI estimates for forest land do not accurately reflect the area and percent of land cover these forests occupy, not to mention their productivity, species composition, successional stage, age class, and ownership type, or the presence and effects that result from biotic and abiotic agents (e.g., insects, disease, invasive species, weather events, and climate change). The lack of an accurate dataset for agricultural forest resources hinders our ability to estimate and project the magnitude of the ecosystem services they can provide. This

Figure 3.2. Establishment of a silvopasture system from opposite ends of the canopy closure spectrum.

challenge is particularly true for the highly fragmented and linear working tree or agroforestry plantings, such as windbreaks and riparian forest buffers, which make up most agroforestry plantings currently installed throughout the agricultural and urban continuum, and which have been shown to provide significant benefits to landowners and society.

Currently Available Data

Because agricultural forest resources are often not fully included in national-level forest inventories, such as FIA and NRI, no consistent data-reporting stream describes their status over time or for all regions of the United States. In 1982, 1987, and 1992, the NRCS NRI assessed the extent of windbreaks at the national scale, but additional rounds of data collection have not been completed since 1992, and the dataset that was produced is limited only to windbreaks. The 1982-through-1992 trend indicated the quantity of windbreaks nationwide decreased by about 5 percent.

Other data that exist are limited to one-off studies and simply represent a snapshot in time and are applied to limited areas. Perhaps the best and largest example of this type of effort is the GPI, a collaborative effort between State forestry agencies in Kansas, Nebraska, North Dakota, and South Dakota and the Forest Service National Inventory and Monitoring Applications Center. The GPI provides important information about agricultural forests in the Great Plains States, and, more importantly for the purposes of this report, it serves as a model for similar activities that could be extended to develop a national inventory of forest resources on all agricultural lands.

The attributes of interest for agricultural forest resources are much the same as for forest land and urban forests, with a few differences. A useful example is the list of attributes chosen for the 2008-to-2009 inventories of nonforest areas used in the GPI (table 3.4). The goal of the GPI is to "characterize the tree resource using methods compatible with those of FIA so a holistic understanding of the resource can be obtained by integrating the two surveys." (Lister 2009: pg. 1). Additional data, however, such as Function of Trees (e.g., farmstead, field or livestock windbreak, living snowfence), provide an additional level of information needed in directing management decisions specific to agricultural forests at the regional and State levels. The GPI inventory includes trees and forests in agricultural and urban settings (classified as rural land [R] or urban land [U], respectively). In this sense, the GPI mirrors the overall purpose of this report, which seeks to understand agricultural and urban forests in unison and explore the possibility of developing enhanced data within the context of current forest inventory activities.

Table 3.4. A listing of the attribute data collected on the Great Plains Tree and Forest Invasives Initiative inventory plots.

Data type	Attribute	Plot type[1]
Plot	GPS coordinates	U, R
Plot	Rural or urban plot	U, R
Condition	Primary land use[2]	U, R
Condition	Windbreak width (3-m increments)	R
Condition	Windbreak condition[3]	R
Condition	Windbreak age	R
Condition	Planted versus natural	U, R
Condition	Function of trees[4]	R
Condition	NFT land use present/absent	R
Condition	Canopy cover class	U
Condition	Owner group (private or Federal/State/local)	U, R
Tree	Species or genus grouping	U, R
Tree	Diameter (2.54-cm increments)	U, R
Tree	Height to location of diameter measurement	U, R
Tree	Height to base of the live crown (1.5-m increments)	U
Tree	Height to top of tree (1.5-m increments)	U, R
Tree	Crown dimensions—perpendicular axis lengths (1.5-m increments)	U
Tree	Foliage present or absent	U
Tree	Crown light exposure class	U
Tree	Crown dieback class	U, R
Tree	Distance and azimuth to three nearest buildings	U, R

FIA = Forest Inventory and Analysis program. GPS = Global Positioning System. NFT = nonforest tree.

[1] Plot types are urban (U) and rural (R).

[2] This attribute consists of 17 anthropic and natural classes and includes inaccessible and denied-access areas.

[3] Good, fair, or poor, based on criteria including percent of live trees, windbreak completeness, density of trees, presence of invasive species, evidence of diseases, presence of regeneration, and expected longevity.

[4] Tree-planting functions include farmstead, field or livestock windbreak, living snowfence, home acreage planting, wildlife habitat planting, abandoned farmstead, planted riparian buffer, natural riparian forest buffer, or narrow wooded strip.

Notes: On each plot, different types of data were collected. Plot data characterize the entire plot area. Condition data characterize contiguous areas that are formed using land use delineation rules. Tree data are those collected on trees not found in conditions that would be classified by FIA as forest.

Source: Lister et al. (2009a).

Using data collected from lands classified as nonforest with trees, GPI cooperators were able to develop estimates for (1) acres by rural function of the trees (table 3.5), (2) the number of live trees by species and genus (table 3.6), and (3) cubic foot volume by tree species and genus (table 3.7). Because data were collected on working trees (conservation tree plantings) and naturally established trees (natural wooded nonplanted strips and isolated trees) on the nonforest lands with tree acres, the 2008-to-2009 GPI inventory estimates show naturally established tree acreage outnumbering planted and managed tree acreage that provide a specific function or benefit (covering about 5.8 million acres [2.3 million hectares] and 1.4 million acres [.6 million hectares], respectively, as shown in table 3.5) by a factor of nearly four. These findings are counter to what many would generally think of occurring in the "tree-less" Great Plains, and they beg the question as to the ratio of natural to planted stands that may prevail in regions where natural tree cover is considered a normal component of undisturbed landscapes.

Table 3.5. Estimated acres by rural function of trees for nonforest areas from the Great Plains Tree and Forest Invasives Initiative 2008-to-2009 inventories; 1,018 rural plots across Kansas, Nebraska, North Dakota, and South Dakota.

Function of trees/groupings	Four-State total	Sampling error (%)
Total acres of rural nonforest areas with trees (1 + 2 + 3)	7,192,847	3.28
1. Isolated trees (no windbreak effect)	5,236,720	4.47
2. All planted and managed tree groupings that provide agroforestry/conservation benefits	1,430,332	6.21
2a. Farmstead/rural acreage windbreak	380,493	12.42
2b. Field windbreak	567,601	10.29
2c. Livestock windbreak	370,918	11.31
2d. Other (living snowfence, wildlife habitat, planted riparian buffer)	111,320	30.55
3. All natural wooded nonplanted or managed tree groupings that provide agroforestry/conservation benefits	525,795	17.32
3a. Natural riparian forest buffer	311,757	20.69
3b. Narrow wooded strip	214,038	30.98

Source: Rasmussen (2009).

Table 3.6. Number of trees by species for rural and urban nonforest areas from the Great Plains Tree and Forest Invasives Initiative 2008-to-2009 inventories; 1,018 rural plots across Kansas, Nebraska, North Dakota, and South Dakota.

	Number of trees on nonforest areas			Sample error (%)		
	Urban or rural land	Rural land (1,018 plots)	Urban land (900 plots)	Urban or rural land	Rural land	Urban land
All species	457,727,233	405,681,452	52,045,780	4.95	5.39	11.57
Redcedar/juniper spp.	61,150,584	57,395,932	3,754,651	12.04	12.73	23.71
Spruce spp.	2,070,409	1,188,709	881,700	23.3	37.44	21.13
Pine spp.	1,189,481	638,846	550,635	55.92	89.82	61.09
Ponderosa pine	4,697,723	3,371,058	1,326,665	26.82	30.05	56.44
Scotch pine	1,224,399	568,599	655,800	25.52	35.5	36.38
Unknown conifer	161,690	—	161,690	48.03	—	48.03
Maple spp.	4,343,304	1,698,884	2,644,419	39.34	67.49	47.9
Boxelder	16,133,318	15,126,390	1,006,928	18.64	19.76	33.63
Silver maple	1,952,524	1,220,336	732,188	28.59	37.4	43.91
Birch spp.	1,553,839	23,201	1,530,639	70.26	100.43	71.31
Hackberry spp.	42,973,682	37,599,777	5,373,905	12.4	13.75	24.12
Ash spp.	84,948,214	80,851,554	4,096,660	14.18	14.88	16.7
Honeylocust spp.	11,386,682	10,146,011	1,240,671	21.41	23.73	30.92
Walnut spp.	3,498,105	1,212,821	2,285,284	24.85	31.17	34.26
Osage-orange	35,163,159	33,430,768	1,732,391	22.4	23.49	34.92
Apple spp.	1,514,003	491,961	1,022,043	21.01	44.32	22.66
Mulberry spp.	18,452,877	15,653,023	2,799,854	13.38	14.62	33.09
Cottonwood and poplar spp.	23,761,322	22,606,254	1,155,068	17.13	17.89	39.84
Cherry and plum spp.	5,164,658	4,387,627	777,031	26.36	30.79	22.09
White oak	8,990,369	7,075,181	1,915,189	30.25	37.12	36.91
Northern red oak	1,454,589	347,465	1,107,124	23.23	50.32	26.11
Willow spp.	19,369,938	18,397,647	972,291	19.8	20.61	58.83
Mountain-ash spp.	113,522	95,177	18,345	61.33	70.57	100
Basswood spp.	299,437	130,853	168,584	35.2	73.84	24.99
Elm spp.	37,997,665	31,785,504	6,212,161	11.75	12.92	28.27
Siberian elm	48,828,792	45,373,796	3,454,995	15.4	16.45	26.71
Saltcedar	95,883	95,883	—	61.31	61.31	—
Russian-olive	6,851,894	6,775,025	76,869	55.27	55.89	50.73
Unknown hardwood	12,385,171	7,993,169	4,392,002	21.25	30.77	21.31

Source: Rasmussen (2009).

Table 3.7. Volume of wood material by species in Nebraska for rural and urban nonforest areas from the Great Plains Tree and Forest Invasives Initiative 2008-to-2009 inventories; 473 plots.

	Cubic feet (volume)			Sample error (%)		
	Urban or rural land	Rural land (273 plots)	Urban land (200 plots)	Urban or rural land	Rural land	Urban land
All species	1,197,851,451	1,029,114,765	168,736,686	9.31	10.61	13.41
Redcedar/juniper spp.	104,679,072	99,922,733	4,756,338	15.89	16.52	42.56
Spruce spp.	6,826,779	134,636	6,692,143	59.82	56.94	61.01
Pine spp.	1,149,376	2,832	1,146,544	53.73	71.25	53.86
Ponderosa pine	16,355,515	15,676,071	679,444	94.17	98.2	75.05
Scotch pine	13,484,649	8,662,964	4,821,685	29.19	40.02	38.65
Unknown conifer	899,170	—	899,170	79.51	—	79.51
Maple spp.	2,490,979	37,874	2,453,105	63.28	77.58	64.24
Boxelder	19,681,365	18,815,638	865,727	49.6	51.78	69.67
Silver maple	36,515,083	14,144,474	22,370,608	28.82	54.24	32.21
Birch spp.	691,002	—	691,002	73.34	—	73.34
Hackberry spp.	78,128,686	55,767,826	22,360,859	28.06	37.7	27.8
Ash spp.	134,401,630	122,485,896	11,915,734	31.72	34.64	35.12
Honeylocust spp.	30,976,600	24,681,327	6,295,273	37.71	45.7	48.27
Walnut spp.	3,649,265	1,124,073	2,525,193	44.17	42.09	61.01
Osage-orange	16,453,870	16,052,126	401,743	32.51	33.23	100
Apple spp.	2,735,117	252,735	2,482,382	47.18	55.43	51.67
Mulberry spp.	44,514,022	37,340,146	7,173,876	17.75	19.96	36.67
Cottonwood and poplar spp.	348,073,545	331,651,606	16,421,939	25.18	26.31	50.14
Cherry and plum spp.	15,308,859	14,615,034	693,825	89.69	93.93	35.02
White oak	39,428,806	26,116,997	13,311,809	54.91	77.59	57.25
Northern red oak	4,266,768	183,663	4,083,105	32.05	100.43	33.19
Willow spp.	56,101,791	55,166,341	935,451	47.29	48.08	75.23
Basswood spp.	6,646,095	727,083	5,919,012	50.85	99.79	55.77
Elm spp.	53,406,451	45,634,354	7,772,097	21.54	24.33	38.92
Siberian elm	136,747,213	120,601,811	16,145,402	18.83	20.85	34.2
Russian-olive	8,631,554	8,551,995	79,559	92.94	93.8	100
Unknown hardwood	15,608,188	10,764,529	4,843,659	40.77	57.22	33.08

Source: Rasmussen (2009).

Inventory data of this type provide the initial basis for developing assessments of potential economic and ecological effects of agricultural forests and their relation to emerging issues. In the case of the Great Plains, a high-priority concern is the destruction of the ash (*Fraxinus* spp.) resource by the emerald ash borer (*Agrilus planipennis;* EAB). The data in table 3.6, which lists the number of trees by species across all four States, and table 3.7, which lists the volume of wood material by tree species in Nebraska, demonstrate the dominance of ash, and thus emphasizes its relevance to regional- and State-level management directions. Individual State-level information is particularly important, because this level is where practical management decisions commonly occur. This example also illustrates the importance of including data on forest health and disturbance processes in inventory activities. In general, the GPI inventory results strongly support the need for accounting for all tree resources in rural and agricultural landscapes, and not only those established with agroforestry practices and using Farm Bill Program support.

The GPI inventory provides an initial model for future inventory work. The recently completed GPI inventory in Kansas, Nebraska, North Dakota, and South Dakota offers one potential way to efficiently inventory—using consistent protocols—agricultural and urban forest resources nationwide. The GPI State forestry agencies cooperated with the Forest Service National Inventory and Monitoring Applications Center to develop and use a modified FIA protocol that lacks some of the data collected on a standard FIA plot (Lister et al. 2009b). It appears, however, that sufficient data exist to report on several of the most fundamental measures (e.g., area and percent of forest, by age class; effects, by biotic and abiotic agents).

Anecdotal reports from State forestry personnel indicate the cost of the GPI inventory was much less than for a traditional FIA inventory on forest lands. A cost comparison that includes all the direct and indirect costs of the GPI inventory (e.g., support from Forest Service FIA personnel), however, would be needed before broader conclusions can be made. The use of a modification of the Forest Service FIA protocol for the GPI enabled State personnel to leverage the infrastructure and institutional knowledge contained in the FIA program, and the combination of estimates from both surveys produced a more holistic understanding of the tree resources in these States. Furthermore, using proven FIA techniques (including data recorder software and reporting tools) helped to contain costs compared with creating a completely new inventory infrastructure. The GPI is the best example of an inventory spanning agricultural and urban forest resources that we have to date; it serves as a possible model for sustained reporting activities in this area. Any such efforts, however, will likely be modified considerably. Further details of possible strategies to accomplish this goal are addressed in in chapter 5.

Benefits Associated With Agricultural Forests

The benefits and services that have been identified to date from working trees and forests in agricultural settings are wide ranging and are limited as much by our current understanding of landscape systems as by the actual role these resources play. A short list of benefits includes (1) maintaining air, water, and soil quality; (2) mitigating climate change and increasing adaptability to its effects; (3) enhancing crop productivity and protecting livestock; (4) conserving energy; and (5) diversifying income. (See relevant chapters in Garrett [2009]; additional information is also available at http://www.unl.edu/nac/workingtrees.htm [August 2015]). In addition to providing these relatively tangible benefits, trees provide an aesthetic contribution to rural landscapes, and serve a role in preserving biodiversity as a practical benefit to mankind and as a value in its own right. As noted previously, many of these benefits and services are also derived from naturally established trees in agricultural settings.

Agroforestry provides numerous opportunities to enhance the benefits flowing from agricultural forests by applying innovative techniques and time-tested practices. In chapter 1 of *North American Agroforestry: An Integrated Science and Practice* (Garrett 2009), the authors state that "agroforestry in the United States and Canada is driven by sustainable development and growth in the 'green' marketplace, which will help mitigate rural decline and harmful environmental impacts of agriculture" (Gold and Garrett 2009: pg. 46). They add that "global awareness of tropical agroforestry has positively affected the development of agroforestry in the United States and Canada, and many of the practices are adopted from the tropics" (Lassoie et al. 2009: pg. 46). They also note that North American agroforestry "is in an active phase of development and has emerged during the past decade as a science and a defined set of practices, shaped and tailored to address urgent land use sustainability issues" (Lassoie et al. 2009: pg. 46).

Although agroforestry practices can be used to pursue a broad range of objectives in sustainable landscape management, two areas in particular are currently receiving focused attention in policy and management discussions. These practices are (1) the expanded use of agroforestry techniques to enhance ecosystem services and take advantage of the nascent market opportunities associated with them and (2) the potential renewable energy production from agroforestry applications.

Increased Tree Planting for Carbon Sequestration and Other Environmental Service Markets

The 2008 Farm Bill (Section 1245—Environmental Services Markets) and the American Clean Energy and Security Act of 2009 (House Resolution 2454) each provide an initial framework for facilitating participation in carbon offset credit trading and other ecosystem services markets through tree plantings and related forest management on agricultural lands. Should carbon offset markets become widespread, particularly at the national level, they could provide an additional income source to agricultural landowners and, thus, motivate an increased interest in mixing trees with other agricultural production activities. Moreover, considerable development of market mechanisms at the regional level is aimed at preserving and enhancing water quality, biodiversity, and other ecosystem services. Biofuels may represent another growing opportunity to enhance farm incomes using trees.

Agroforestry is an appealing option for sequestering carbon on agricultural lands because it can sequester significant amounts of carbon while leaving the bulk of the land in agricultural production. The cash earnings potentially gained from carbon sequestration can help diversify farm incomes, an important consideration given the unpredictability of crop prices. This sequestration can all be achieved while providing many of the other services associated with agricultural forests (Schoeneberger 2008). The Intergovernmental Panel on Climate Change's Technical Paper V (Gitay et al. 2002), which was developed in response to a request made by the United Nations Convention on Biodiversity, identifies agroforestry as a carbon-sequestering activity that can create more biologically diverse systems than conventional agricultural lands, having beneficial effects on aboveground and belowground biodiversity. Again, the benefit of agroforestry lies in its ability to meet multiple purposes and contribute to the creation of multifunctional landscapes, thereby meeting multiple objectives.

The Congressional Research Service further supports the carbon sequestering potential of agricultural forests in its report, *U.S. Tree Planting for Carbon Sequestration* (Gorte 2009: pg. 1), which states that "tree planting has greater carbon sequestration potential than other land use practices" and that "afforestation of crop or pasture land is estimated to have the potential to sequester between 2.2 and 9.5 metric tons of CO_2 [carbon dioxide] per acre per year" (table 3.8). The report notes that "these estimates have a very wide range of possibilities because tree growth and forest soil carbon accumulation varies widely among species and locations" (Gorte 2009: pg. 1. See also Smith et al. 2006). Of course, tree planting for carbon sequestration would have to be balanced against food production and related activities, and the effect of afforestation would have to take into account

Table 3.8. Estimated sequestration potential for selected U.S. land use practices.

Activity	(in metric tons of CO_2 per acre per year)	
	EPA (2005)	USDA (2004)
Afforestation (previously cropland/pasture)	2.2–9.5	2.7–7.7
Reforestation	1.1–7.7	—
Riparian or conservation buffers (nonforest)	0.4–1.0	0.5–0.9
Reduced/conservation tillage	0.6–1.1	0.3–0.7
Grazing management	0.1–1.9	1.1–4.8

EPA = U.S. Environmental Protection Agency. USDA = U.S. Department of Agriculture. CO_2 = carbon dioxide.

Sources: Adapted from Gorte (2009). EPA: EPA Office of Atmospheric Programs (2005: table 2-1). USDA: Lewandrowski et al. (2004: table 2.2).

potential changes in land use elsewhere. Afforestation and agroforestry applications, however, when appropriate, can provide an effective way to secure carbon sequestration while potentially enhancing other ecosystem services and augmenting farm incomes.

One potential role for an inventory of agricultural forest resources would be to provide a data foundation for better carbon accounting. This database would have to be married to some form of carbon modeling to translate inventory data into estimates of carbon storage and flux. The *National Report* provides exactly such an estimate for conventional forests under Criterion 5. Although we are not able to estimate current national levels of carbon sequestration from tree-based plantings on agricultural lands, tools, such as NRCS's COMET 2.0 (http://www.comet2.colostate.edu/) have been developed to assess tree-contributed carbon at the individual entity (farm/ranch) level. The latest version of COMET (COMET-Farm, released in June of 2013 and available at http://www.cometfarm.nrel.colostate.edu/ [August 2015]) does not currently have this capability but will include an improved component for estimating carbon for agroforestry and other woody perennial plantings on farms and ranches by 2016. Carbon estimates from these plantings can also be made from data collected using FIA inventory protocols (as was used, for example, in the GPI inventory) and potentially with two other Forest Service tools: i-Tree (discussed in the context of urban forests in chapter 4) and the Forest Vegetation Simulator (Dixon 2002). In any case, an inventory of agricultural forests will need to consider exactly what kind of information is needed to render reliable estimates of aboveground and belowground carbon sequestration. In particular, the ability to accurately estimate woody biomass in agroforestry plantings is critical to a full accounting of the current carbon pool and the future potential for carbon sequestration on agricultural lands. Another aspect will be the measurement of revenues generated from the provision of environmental services (Indicator 27 in the *National Report*), which is carbon sequestration in this instance, although coverage certainly can (and should) be extended to other services when revenues do exist.

Renewable Energy Feedstock From Agroforestry

Plant material, such as wood and grass, potentially represents a substantial source of domestic renewable energy feedstock that is considered carbon neutral in the human time scale (because plants grow back). Various methods exist that enable these renewable feedstocks to be produced, harvested, and converted to products; making bioenergy and coproduct production promising options. Although the cost of biomass feedstock is still high relative to its inherent energy content, researchers and investors continue to find new, cost-effective solutions to bring bioenergy and coproducts to the marketplace. Awareness and interest are growing in using agroforestry plantings as a means to augment cellulosic feedstock production here in the United States. Many of the practices, particularly windbreaks, alley cropping, and riparian forest buffers, readily lend themselves to expanded designs and management options that would enable coproduction of feedstock from these plantings with the other services being targeted by landowners and society.

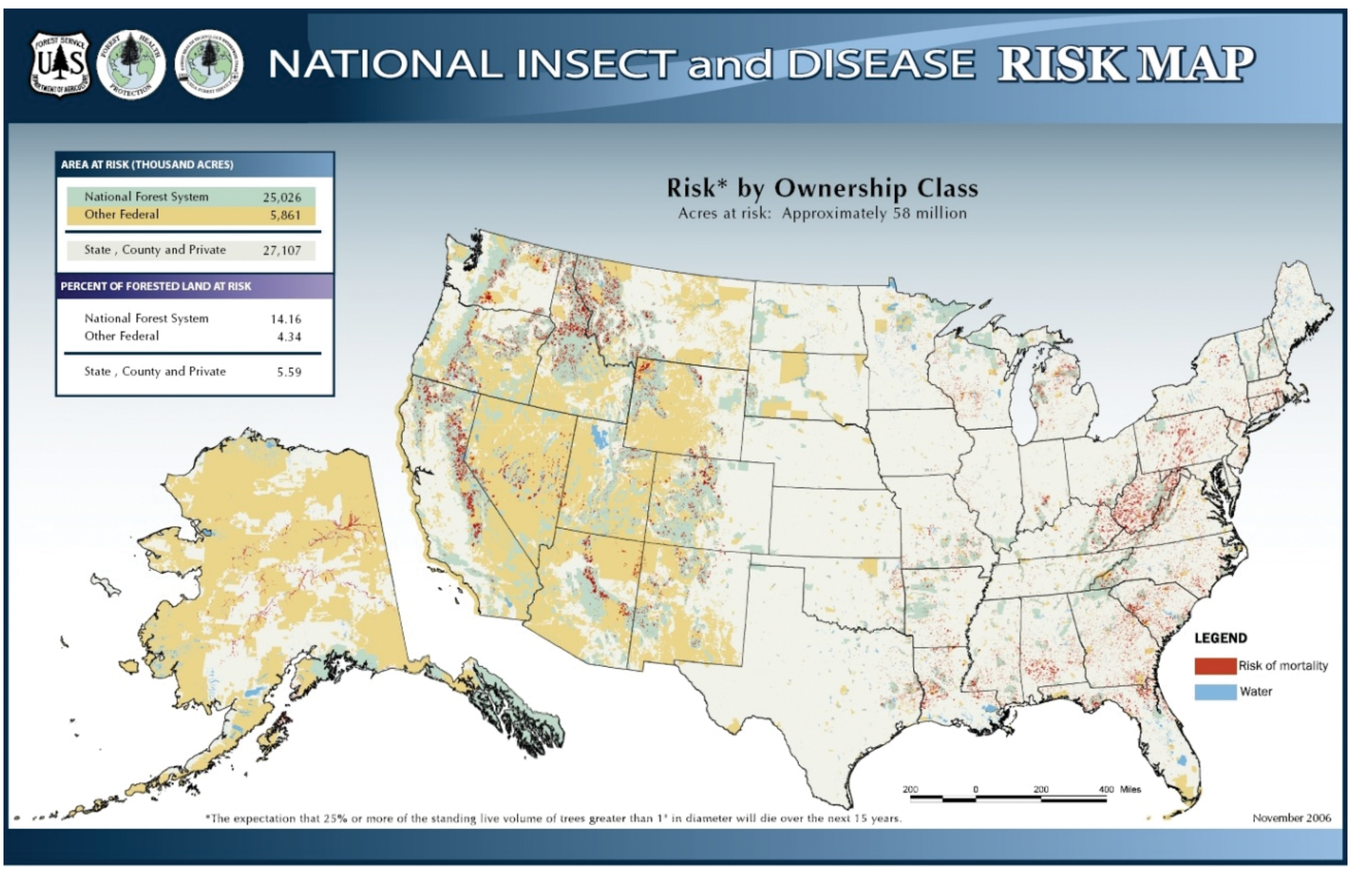
The potential increases in tree planting due to expanding carbon offset markets (as discussed in the previous section) are also likely to result in a greater supply of cellulosic feedstock for energy production from agricultural forests. The definition of "renewable biomass" in HR 2454 is very broad (i.e., any organic matter that is available on a renewable basis from non-Federal land…) and includes woody biomass from agricultural forests and other feedstocks that could potentially be mixed with it, including crop residue and waste from animals, construction, food, yards, etc. The opportunities for using agroforestry applications to produce energy in conjunction with other feedstock streams and with the provision of other environmental services could prove to be fertile ground for developing innovative techniques and diversified income streams. A direct measure of this activity would be the application to agricultural forests of the Montréal Process (MP) indicator measuring the use of forest biomass for energy generation (Indicator 24 in the *National Report*). The advent of any major use of agroforestry in energy production would also lead to major changes in the role and extent that forests and trees have on agricultural lands as a whole, however, and any inventory will need to be flexible enough to register these changes should they occur.

Major Threats and Influences That Affect Agricultural Forest Resources

Agricultural forest resources are threatened by many of the same native and invasive insects, diseases, invasive plants, and abiotic agents (e.g., wind, drought, flooding, fire, climate change) as conventional and urban forests. For conventional forests, these disturbance agents and their effects are covered under the two indicators in Criterion 3 in the *National Report*. Elevated levels of forest disturbance and mortality, especially those associated with insect infestations, were identified as perhaps the most troubling overall finding of the 2010 edition of *National Report*. In a related 2006 study, the Forest Service completed a strategic assessment for risk of tree morality because of major insects and diseases, and estimated that a total of 58 million acres (23 million hectares) in the contiguous United States (including about 27 million acres [11 million hectares] of private, county, and State lands) are at risk[18] from insects and diseases (USDA Forest Service 2006; fig. 3.3). Most of this risk can be attributed to 42 risk agents, including 13 nonnative (exotic) forest pest species already established in the contiguous United States and Alaska. Although only FIA data from forest land were used in this risk assessment, it should be assumed that risks for tree species on forest land are mostly the same as in agricultural settings where these species also are found.

The ash (*Fraxinus* spp.) species is an example of a tree that is threatened on all lands on which it occurs, and the continuing health of this species is the focus of considerable management activity. The primary goal of the GPI, for example, is to prepare for the arrival of invasive pests, such as the EAB, which the GPI cooperators describe as a "highly invasive, exotic insect that attacks and kills all species of North American ash trees" (Rasmussen 2009: pg. 1). The GPI cooperators note that after its introduction into the United States from China in the 1990s, the EAB has killed more than 50 million ash trees in the Northeastern and North Central United States and in the provinces of Ontario and Quebec in Canada. As of July 2012, the EAB has not been detected west of Iowa, Minnesota, and Missouri, but the threat to the Great Plains States is very real, owing to the large number of ash trees that are found in this region—an estimated 85 million ash trees exist on acres classified as "nonforest-with-trees" in the four Great Plains States

Figure 3.3. Acres of forested land at risk of mortality to insects and diseases (USDA Forest Service 2006).



18 The threshold for mapping risk in the assessment was the expectation that, without remediation, 25 percent or more of the standing live basal area on trees more than 1 inch in diameter will die during the next 15 years because of insects and diseases.

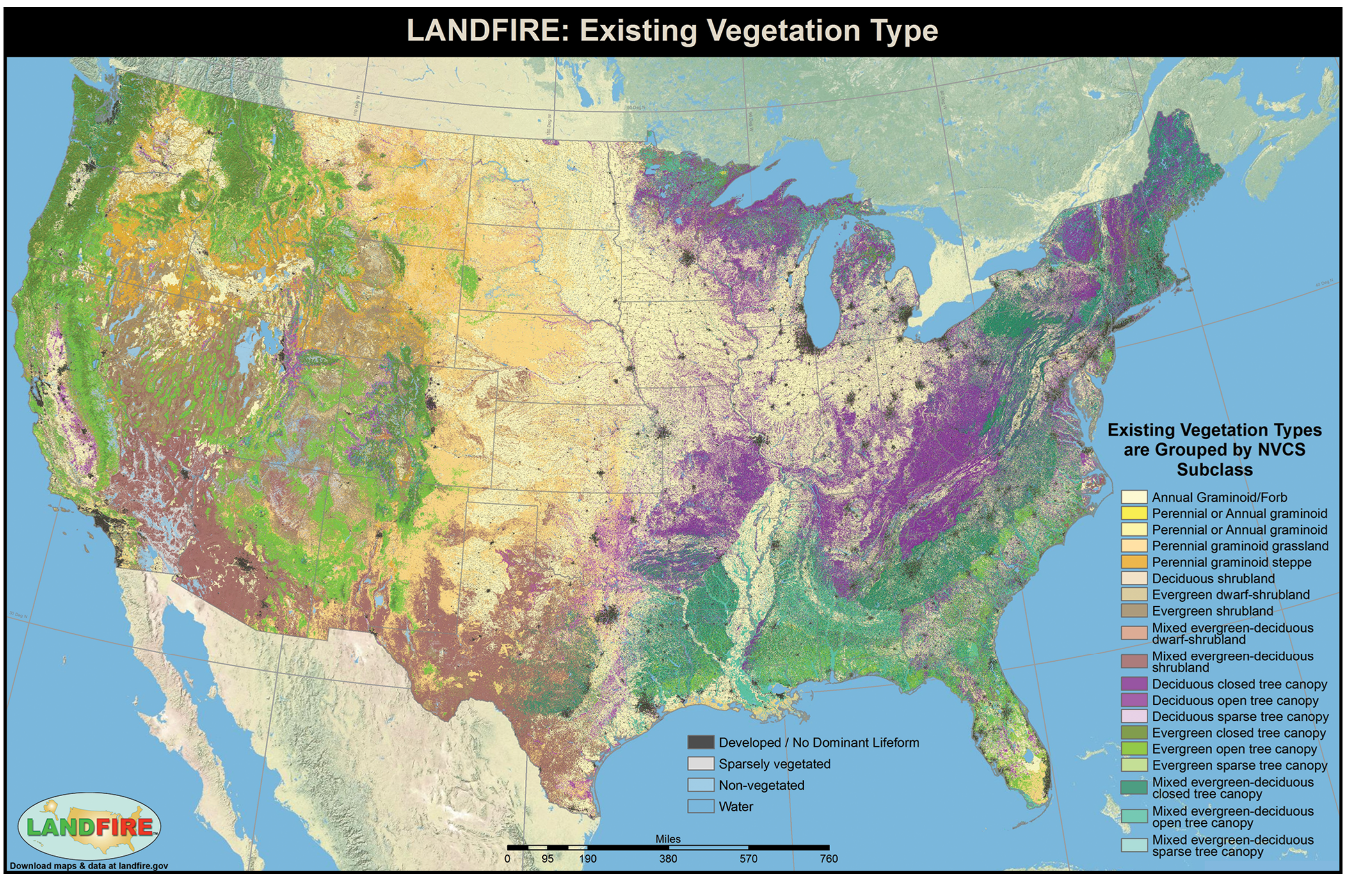
(table 3.6). Resource managers need to know the total area and relative locations of these at-risk species to make informed management decisions and formulate policies and programs supporting management actions.

Wildland fire poses a significant threat to forest land and to some forest resources in agricultural settings, as suggested by the map of departure from reference condition vegetation, fuels, and disturbance regimes in many landscapes in the contiguous United States (fig. 3.4). The large number of wildfires encompassing more than 250 acres (101 hectares) also illustrates the fire threat to agricultural forests in many parts of the United States. Management of agricultural forests and immediately adjacent land is needed to reduce fuel loads but is often not done. With greater use of silvopasture systems, however, potential wildfires in southern and western landscapes could be reduced, because a well-managed silvopasture system maintains low fuel levels.

Data Adequacy and Major Data Gaps

As discussed previously, data for agricultural forest resources are inadequate because many working trees and naturally established trees are not explicitly inventoried by either FIA or NRI, the two primary natural resource inventories of the United States. The incomplete nature of the data is illustrated by the estimated 458 million trees on rural and urban "nonforest-with-tree" acres estimated by the GPI inventory in Kansas, Nebraska, North Dakota, and South Dakota (table 3.6). The 7.2 million acres (2.9 million hectares) estimated by the GPI cooperators (table 3.5) is significantly more than the 4.1 million acres (1.7 million hectares) of private forest reported for the four Great Plains States in *Forest Resources of the United States, 2007* (Smith et al. 2009), which includes only lands that meet the FIA definition for forested land use. The conclusion in this

Figure 3.4. Current Fire Regime Condition Class in the contiguous United States (http://www.frcc.gov [August 2015]).



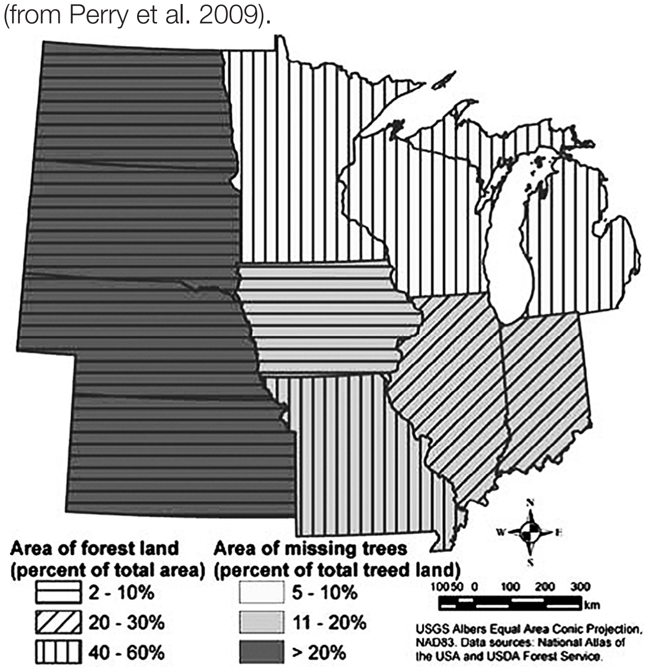
Notes: Fire Regime Condition Class (FRCC) is an interagency, standardized tool for determining the degree of departure from reference condition vegetation, fuels, and disturbance regimes. Assessing FRCC can help guide management objectives and set priorities for treatments. FRCC assessments determine how similar a landscape's fire regime is to its natural or historical state. FRCCs are divided into three categories: FRCC I landscapes contain vegetation, fuels, and disturbances characteristic of the natural regime; FRCC II landscapes are moderately departed from the natural regime; and FRCC III landscapes reflect vegetation, fuels, and disturbances that are uncharacteristic of the natural regime. So, essentially, a landscape in FRCC I has key ecosystem components intact, such as large old trees and soil characteristics that would naturally be found on that site. An FRCC II landscape has land that is not very similar to its natural regime in terms of vegetation, disturbance, or both. An FRCC III landscape has lost key ecosystem components (e.g., the loss of characteristic large trees due to uncharacteristic wildfires that occurred in uncharacteristic fuels).

Source: LANDFIRE: Fire Regime Groups, U.S. Department of Agriculture and U.S. Department of the Interior. Accessed 24 November 2015 at http://www.landfire.gov/geoareasmaps/2012/CONUS_EVT_c12.jpg.

report is that the amount of nonforest land with trees (not covered by existing inventories) is significantly larger than the amount of forest land in the four Great Plains States that is currently inventoried. The extent to which this finding extends to other regions with a high proportion of agricultural lands is very much an open question, one that cannot be answered without adequate inventories of agricultural forests.

Perry et al. (2009) reported large data gaps owing to the exclusion of certain trees and forests from existing inventories for the Great Plains States and smaller gaps for Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin. By comparing estimates of land area with tree cover between the Vegetation Continuous Field (VCF—a global dataset derived from MODIS [MODerate Resolution Imaging Spectrometer] satellite imagery) and FIA, they found significant differences in those estimates in Kansas, Missouri, Nebraska, North Dakota, and South Dakota. They also reported large areas of missing trees that generally increased while moving westward across the 11-State region (fig. 3.5). Moreover, Zomer et al. (2009), in their report on the global extent and patterns of agroforestry, noted that moderate levels of between 10 and 30 percent tree canopy cover describe most agricultural land in Midwestern North America. These tree-cover estimates were made from MODIS VCF remote-sensing data. The fact that significant differences exist between estimates of forest canopy from FIA and VCF estimates indicates that in nonforest areas the information gap is probably even greater.

Figure 3.5. Forest land and missing tree fractions derived from Forest Inventory and Analysis data (from Perry et al. 2009).



Note: Missing tree fraction is determined by comparing FIA (Forest Inventory and Analysis) forest land area estimates with MODIS (MODerate Resolution Imaging Spectrometer) VCF (Vegetation Continuous Field) estimates of tree canopy cover.

The overall conclusion is that the extent of agricultural forests is considerable, in absolute terms and, in some regions at least, relative to the area of conventional forests. With the exception of those States covered by the GPI, however, we have little to no idea as to the actual size of this resource. Satellite imagery and other remotes sensing techniques may provide a relatively cost-effective way to get at this most basic question of total area, but the crucial questions of species composition, stand structure and age, or forest health conditions cannot be answered with a reasonable degree of accuracy through this approach. For this type of information, on-the-ground sampling—similar to that undertaken by the FIA—will be needed.

The foregoing discussion on data gaps focuses on the information needed to produce a biophysical inventory. The MP C&I, however, seek to be comprehensive in their coverage of the information important to understanding forest sustainability, and it includes a number of economic and social indicators that fall outside the scope of standard inventories and are not included in the GPI or similar efforts. Nonetheless, a biophysical inventory is a core requirement of any broader sustainability assessment.

Given the lack of national inventory data, a national-level report on agricultural forests based on the MP C&I would have little or no substance. Using the GPI as a model, however, we can anticipate how a national inventory of agricultural forest resources could meet the general requirements of the MP C&I and similar forest sustainability reporting efforts. Although a number of the 54 MP indicators will not really be applicable to agricultural forests (see discussion in previous chapter), many others, particularly those addressing the biophysical characteristics of forests, can readily be applied to agroforestry plantings and natural forests on agricultural lands. Many of the measures in the GPI (table 3.4) can help derive estimates of such variables as areal extent, stocking volumes, forest health and disturbance incidence, and species composition. These measures are the building blocks of any inventory, and they also fit some basic requirements of the MP C&I.

The MP C&I can be used to suggest additional variables to be sampled in a GPI-type inventory for agricultural (and urban) lands. For example, Criterion 4, with its emphasis on soil and water resources, would suggest the inclusion of some form of soil descriptor, in terms of type or condition, and perhaps a spatial measure, such as distance to nearest body of water. The indicators addressing nontimber forest products (NTFPs) in Criteria 2 and 6 suggest measures that would indicate the presence or absence of regionally important NTFPs. The MP C&I also suggest a number of variables that could be modeled or otherwise derived from the inventory data. In this regard, the GPI attribute of "function" could be used to address several of the socioeconomic indicators in Criterion 6, particularly in relation to environmental services, although the categories used for this attribute (note 3 in table 3.4) would likely have to be expanded to accomplish this task. Likewise, the GPI measure of "Primary Land Use" (note 1 in table 3.4) could provide important information about ownership type and protected status needed to address indicators in Criterion 1.

Other MP indicators would need to be developed largely outside of the inventory-reporting stream. Initial ideas on how to develop these variables are included in the indicator-by-indicator development presented in chapter 5. In any case, the aim is not to fully replicate the MP C&I for agricultural and urban forests, as much as it is to use it as a reference and guide in designing a comprehensive data framework for understanding the sustainability of these forest resources.

References

America's Longleaf. 2009. Range-wide conservation plan for longleaf pine. Prepared by the Regional Working Group for America's Longleaf. http://www.americaslongleaf.org/media/86/conservation_plan.pdf. (August 2015).

Dixon, G.E., comp. 2002. Essential FVS: a user's guide to the forest vegetation simulator. Internal Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 248 p. (Revised: 27 June 2012).

Garrett, H.E., ed. 2009. North American agroforestry: an integrated science and practice, 2nd ed. Madison, WI: American Society of Agronomy. 379 p.

Gitay, H.; Suárez, A.; Watson, RT.; Dokken, D.J., eds. 2002. Climate change and biodiversity: IPCC Technical Paper V. Geneva, Switzerland: Intergovernmental Panel on Climate Change. 85 p. https://www.ipcc.ch/publications_and_data/publications_and_data_technical_papers.shtml. (August 2015).

Gold, M.A.; Garrett, H.E. 2009. Agroforestry nomenclature, concepts, and practices. In: Garrett, H.E., ed. North American agroforestry: an integrated science and practice. Madison, WI: American Society of Agronomy: 45–56.

Gorte, R.W. 2009. U.S. tree planting for carbon sequestration. May 4, 2009. Congressional Research Service. 7-5700 R40562. http://www.fas.org/sgp/crs/misc/R40562.pdf. (August 2015).

Guertin, D.; Easterling, W.; Brandle, J. 1997. Climate change and forests in the Great Plains: issues in modeling fragmented woodlands in intensively managed landscapes. BioScience. 47: 287–295.

Lassoie, P.; Buck, L.; Current, D. 2009. The development of agroforestry as an integrated land use management strategy. In: Garrett, H.E., ed. North American agroforestry: an integrated science and practice, 2nd ed. Madison, WI: American Society of Agronomy: 1–24.

Lewandrowski, J.; Peters, M.; Jones, C.; et al. 2015. Economics of sequestering carbon in the U.S. agricultural sector. Tech. Bull. TB-1909. Washington, DC: U.S. Department of Agriculture, Economic Research Service. 61 p. http://www.ers.usda.gov/media/434512/tb1909_1_.pdf. (August 2015).

Lister, A.; Scott, C.; Rasmussen, S. 2009a. Inventory of trees in nonforest areas in the Great Plains States. In: McWilliams, W.; Moisen, G.; Czaplewski, R., comps. Forest Inventory and Analysis (FIA) Symposium 2008. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/pubs/rmrs_p056/rmrs_p056_17_lister.pdf. (August 2015).

Lister, A.; Scott, C.; Rasmussen, S. 2009b. Great Plains initiative inventory project, data collection procedures, Version 2.0, May 2009. Adapted from Forest Inventory and Analysis (FIA) Northern Region Field Guide, Version 4.0, July 2007; Urban Forest Effects (UFORE) i-Tree Software Suite User's Manual, February 2008; and FIA Urban Forest Health Monitoring (FHM) Manual, June 2002. 68 p.

Perry, C.H.; Woodall, C.W.; Liknes, G.S.; Schoeneberger, M.M. 2009. Filling the gap: improving estimates of working tree resources in agricultural landscapes. Agroforestry Systems. 75: 91–101.

Perry, C.H.; Woodall, C.W.; Schoeneberger, M.M. 2005. Inventorying trees in agricultural landscapes: toward an accounting of working trees. In: Brooks, K.N.; Ffolliott, P.F., eds. Moving agroforestry into the mainstream. Proc. 9th N. American Agroforestry Conference. St. Paul, MN: University of Minnesota, Department of Forest Resources. http://treesearch.fs.fed.us/pubs/13182. (August 2015).

Rasmussen, S. 2009. Great Plains tree and forest invasives initiative: a multi-State cooperative effort for education, mitigation, and utilization. Unpublished document developed by Kansas Forest Service, Nebraska Forest Service, North Dakota Forest Service, South Dakota Division of Resource Conservation and Forestry, and U.S. Department of Agriculture, Forest Service. http://www.wflccenter.org/ts_dynamic/edu_outreach/43_file.pdf. (August 2015).

Sauer, T.J. 2010. The Prairie States forestry project as a model for an effective global climate change mitigation project. In: Kellimore, L.R., ed. Management, practices and environmental impact. Hauppauge, NY: Agroforestry Nova Publishers: 479–482.

Schoeneberger, M.M. 2008. Agroforestry: working trees for sequestering carbon on agricultural lands. USDA Forest Service/University of Nebraska, Lincoln faculty publications. Paper 2. doi:10.1007/s10457-008-9123-8. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1001&context=usdafsfacpub. (August 2015).

Schoeneberger, M.M.; Bentrup, G.; Francis, C.F. 2001. Ecobelts: reconnecting agriculture and communities. In: Flora, C., ed. Interaction between agroecosystems and rural communities. New York: CRC Press: 239–260.

Smith, J.E.; Heath, L.S.; Skog, K.E.; Birdsey, R.A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 216 p.

Smith, W.B.; Miles, P.D.; Perry, C.H.; Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. http://www.nrs.fs.fed.us/pubs/gtr/gtr_wo78.pdf. (August 2015).

U.S. Department of Agriculture (USDA). 2009. Summary report: 2007. Washington, DC: Natural Resources Conservation Service, National Resources Inventory; Ames, IA: Iowa State University, Center for Survey Statistics and Methodology. 123 p. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041379.pdf. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2006. Forest insect and disease risk map database. http://www.fs.fed.us/foresthealth/technology/pdfs/FHTET2007-06_RiskMap.pdf. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2007. Forest inventory and analysis national core field guide, vol. 1: field data collection procedures for phase 2 plots, version 4.0. http://www.nrs.fs.fed.us/fia/data-collection/. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2011. National report on sustainable forests—2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 p. http://www.fs.fed.us/research/sustain/. (August 2015).

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 1996. Agroforestry for farms and ranches. Agroforestry Tech. Note No. 1. Lincoln, NE: U.S. Department of Agriculture, Natural Resources Conservation Service. http://www.nrcs.usda.gov/technical/ECS/forest/technote.html. (August 2015).

U.S. Environmental Protection Agency (EPA), Office of Atmospheric Programs. Greenhouse gas mitigation potential in U.S. forestry and agriculture. EPA 430-R-05-006. Washington, DC: United States Environmental Protection Agency. 152 p. http://www3.epa.gov/climatechange/Downloads/ccs/ghg_mitigation_forestry_ag_2005.pdf. (August 2015).

Zomer, R.J.; Trabucco, A.; Coe, R.; Place, F. 2009. Trees on farm: analysis of global extent and geographic patterns of agroforestry. ICRAF Working Paper No. 89. Nairobi, Kenya: World Agroforestry Centre. 64 p.

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

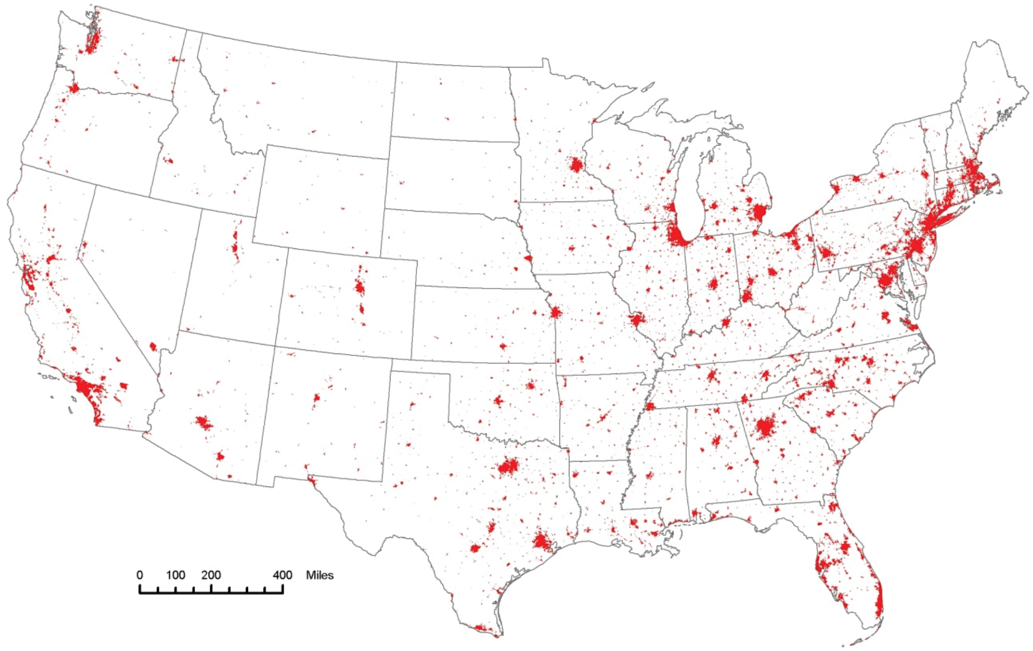
For purposes of this report, *urban forests* are composed of all the trees within our urban lands. The definition conceptually extends to include the various ecosystem components that accompany these trees (e.g., soils or understory flora), although we do not explicitly identify all these components. 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.

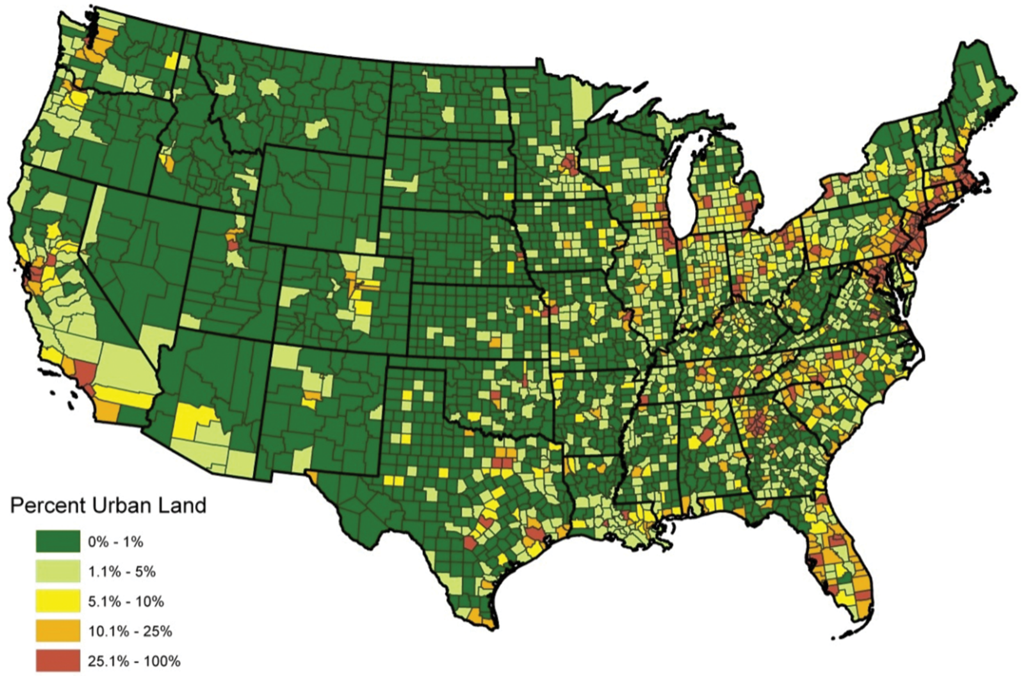
Currently Available Data on U.S. Urban Forests

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).

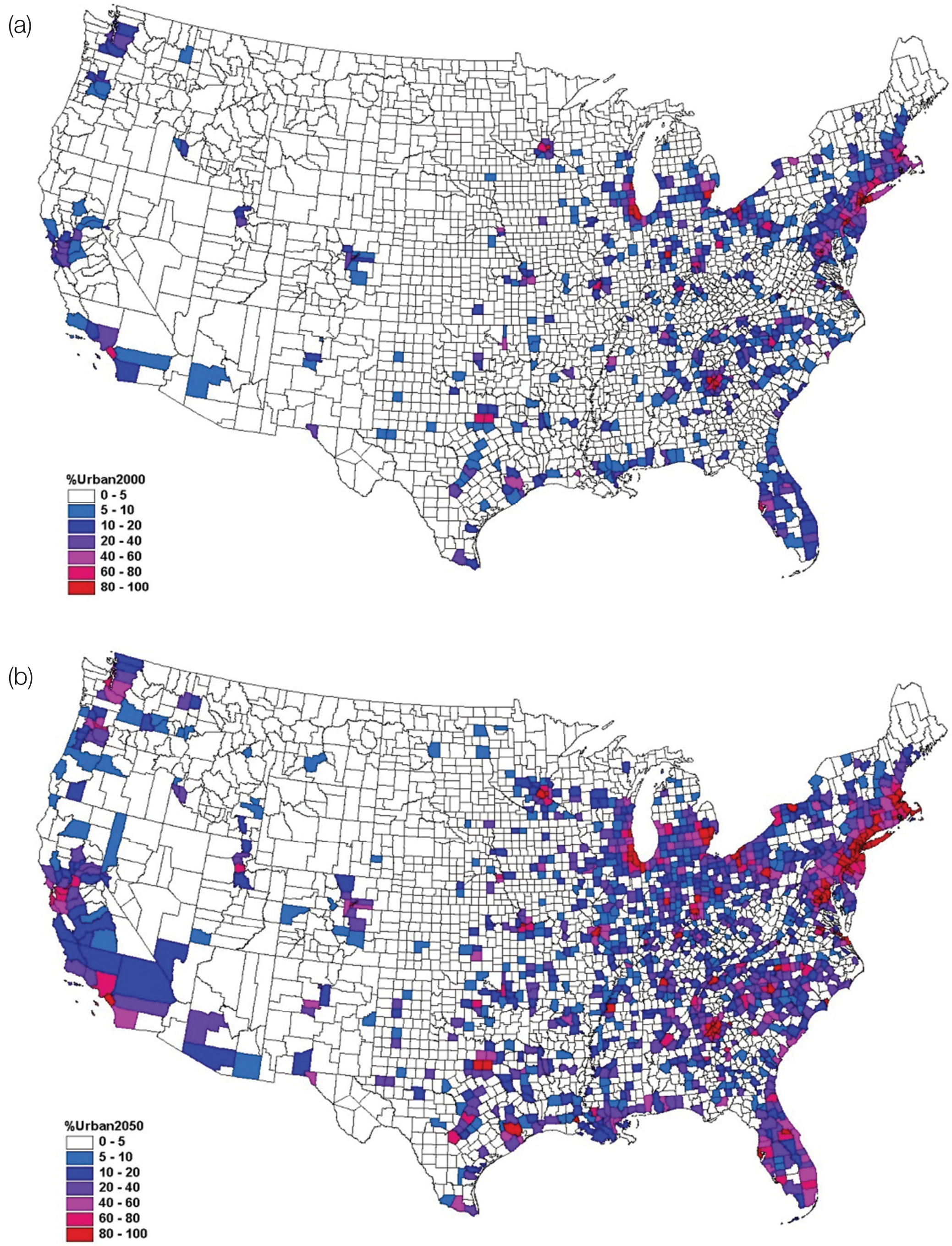
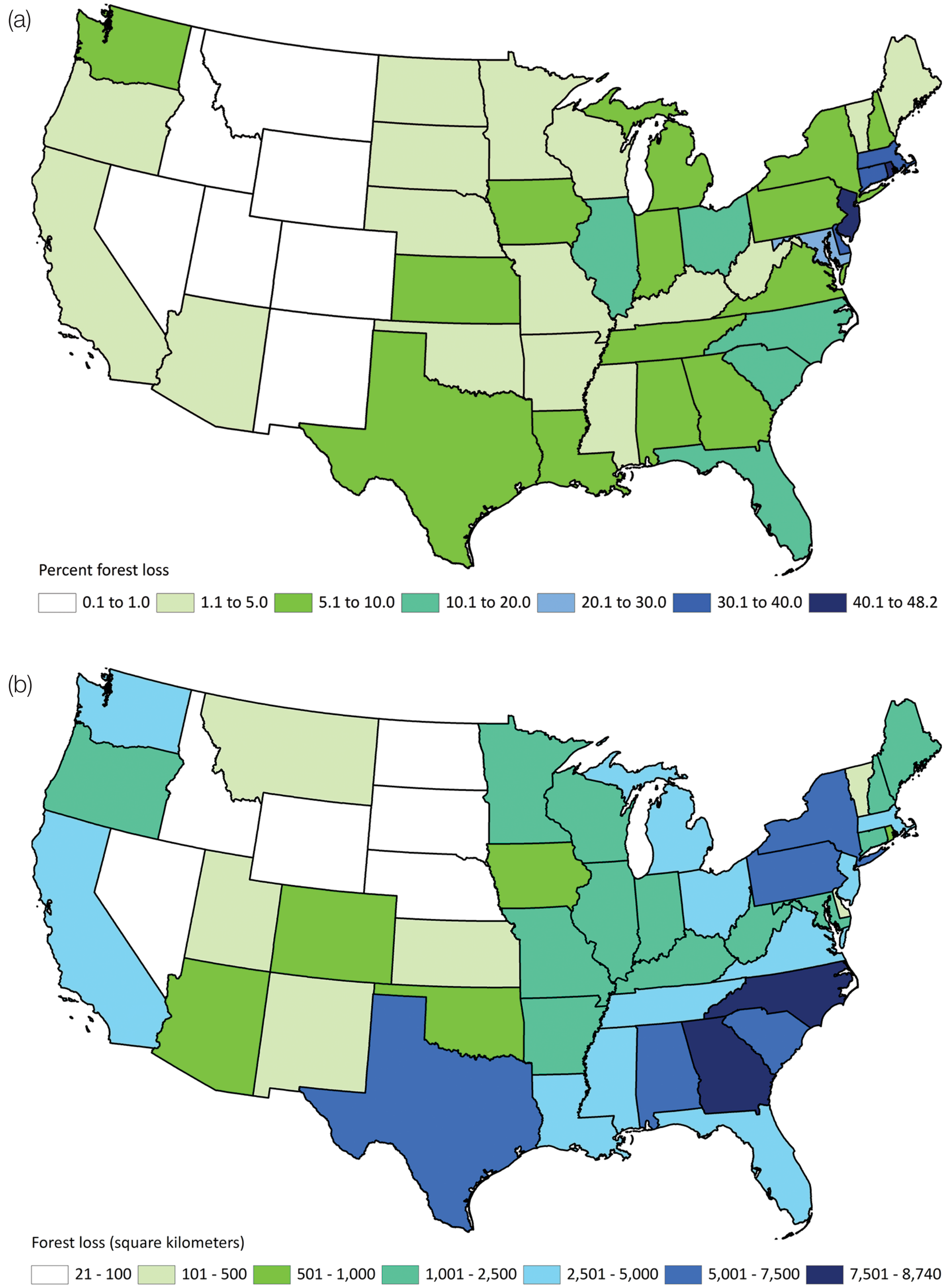


Figure 4.4. Percent (a) and square kilometers (b) of nonurban forest subsumed by projected urban growth, 2000 through 2050, by State (Nowak and Walton 2005).



Urban Tree-Cover Estimates

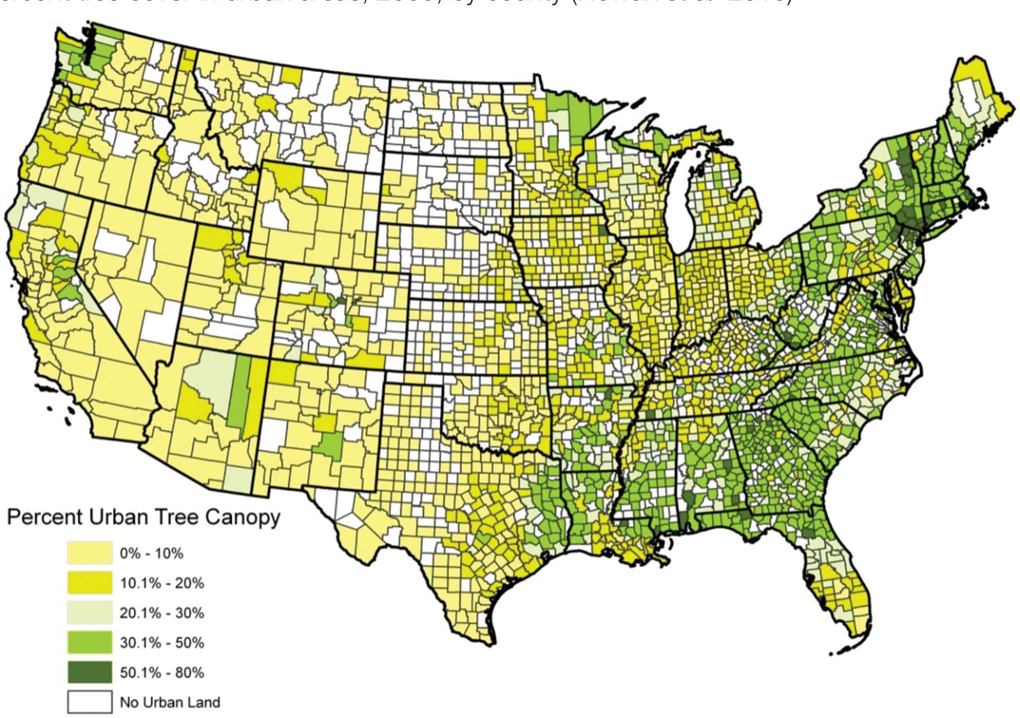
Tree cover in urban lands in the United States (circa [ca.] 2005) is currently estimated at 35.0 percent (Nowak and Greenfield 2012a). Urban tree cover has declined slightly in recent years (ca. 2002 to 2009) with a loss of about 4 million urban trees per year (Nowak and Greenfield 2012b). These estimates 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.

References

Anderson, L.M.; Cordell, H.K. 1988. Influence of trees on residential property values in Athens, Georgia (USA): a survey based on actual sales prices. Landscape and Urban Planning. 15: 153–164.

Anderson, L.M.; Mulligan, B.E.; Goodman, L.S. 1984. Effects of vegetation on human response to sound. Journal of Arboriculture. 10(2): 45–49.

Cook, D.I. 1978. Trees, solid barriers, and combinations: alternatives for noise control. In: Hopkins, G., ed. Proceedings: national urban forest conference. Syracuse: SUNY, The State University of New York, College of Environmental Science and Forestry: 330–339.

Corrill, M.; Lillydahl, J.; Single, L. 1978. The effects of greenbelts on residential property values: some findings on the political economy of open space. Land Economics. 54: 207–217.

Cumming, A.B.; Nowak, D.J.; Twardus, D.B.; Hoehn, R.; Mielke, M.; Rideout, R. 2007. Urban forests of Wisconsin 2002: pilot monitoring project 2002. State and Private Forestry Report NA-FR-05-07. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area. 33 p.

Cumming, A.B.; Twardus, D.B.; Nowak, D.J. 2008. Urban forest health monitoring: large scale assessments in the United States. Arboriculture & Urban Forestry. 34(6): 341–346.

Donovan, G.H.; Butry, D. 2008. Market-based approaches to tree valuation. Arborist News. August: 52–55. http://www.isa-arbor.com. (August 2015).

Dozier, H. 2012. Invasive plants and the restoration of the urban forest ecosystem (Revised). In: Duryea, M.L.; Binelli, E.K.; Korhnak, L.V., eds. Restoring the urban forest ecosystem. Circular 1266, Fact Sheet FOR98. [CD-ROM]. Gainesville, FL: University of Florida, School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences. Chapter 9. http://www.edis.ifas.ufl.edu/pdffiles/fr/fr07300.pdf. (August 2015).

Dwyer, J.F. 1991. Economic value of urban trees. White paper prepared in support of: A national research agenda for urban forestry in the 1990s. Urbana, IL: International Society of Arboriculture: 27–32.

Dwyer, J.F.; McPherson, E.G.; Schroeder, H.W.; Rowntree, R.A. 1992. Assessing the benefits and costs of the urban forest. Journal of Arboriculture. 18(5): 227–234.

Dwyer, J.F.; Schroeder, H.W.; Gobster, P.H. 1991. The significance of urban trees and forests: toward a deeper understanding of values. Journal of Arboriculture. 17: 276–284.

Dwyer, J.F.; Schroeder, H.W.; Louviere, J.J.; Anderson, D.H. 1989. Urbanities willingness to pay for trees and forests in recreation areas. Journal of Arboriculture. 15(10): 247–252.

Greenberg, C.H.; McNab, W.H. 1998. Forest disturbance in hurricane-related downbursts in the Appalachian Mountains in North Carolina. Forest Ecology and Management. 104: 179–191.

Greenfield, E.J.; Nowak, D.J.; Walton, J.T. 2009. Assessment of NLCD percent tree and impervious surface cover estimates. Photogrammetric Engineering and Remote Sensing. 75(11): 1279–1286.

Heisler, G.M. 1986. Energy savings with trees. Journal of Arboriculture. 12(5): 113–125.

Interagency Working Group on Social Cost of Carbon, United States Government (Interagency Working Group). 2015. Social cost of carbon for regulatory impact analysis. Technical Support Document. Under Executive Order 12866. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf. (August 2015).

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: the physical science basis—summary for policymakers. Geneva, Switzerland: Intergovernmental Panel on Climate Change Secretariat. 18 p. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. (August 2015).

Irland, L. 2000. Ice storms and forest impacts. Science of the Total Environment. 262: 231–242.

Iverson, L.R.; Prasad, A.M. 2001. Potential changes in tree species richness and forest community types following climate change. Ecosystems. 4: 186–199.

Johnston, M. 2004. Impacts and adaptation for climate change in urban forests. Paper presented at the 6th Canadian urban forest conference. 15 p.

Kuo, F.E.; Sullivan, W.C. 2001a. Environment and crime in the inner city: Does vegetation reduce crime? Environment and Behavior. 33(3): 343–365.

Kuo, F.E.; Sullivan, W.C. 2001b. Aggression and violence in the inner city: impacts of environment via mental fatigue. Environment and Behavior. 33(4): 543–571.

Liebhold, A.M.; MacDonald, W.L.; Bergdahl, D.; Mastro, V.C. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science, Monograph 30: a0001–z0001(1).

National Acid Precipitation Assessment Program (NAPAP). 1991. 1990 integrated assessment report. Washington, DC: National Acid Precipitation Assessment Program. 520 p.

Nowak, D.J. 1993. Historical vegetation change in Oakland and its implications for urban forest management. Journal of Arboriculture. 19(5): 313–319.

Nowak, D.J. 1994. Air pollution removal by Chicago's urban forest. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago urban forest climate project. Gen. Tech. Rep. NE-186. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 63–81.

Nowak, D.J. 2000. The interactions between urban forests and global climate change. In: Abdollahi, K.K.; Ning, Z.H.; Appeaning, A., eds. Global climate change and the urban forest. Baton Rouge: Gulf Coast Climate Change Assessment Council (GCRCC) and Franklin Press: 31–44.

Nowak, D.J. 2010. Urban biodiversity and climate change. In: Muller, N.; Werner, P.; Kelcey, J.G., eds. Urban biodiversity and design. Hoboken, NJ: Wiley-Blackwell Publishing: 101–117.

Nowak, D.J. 2012. Contrasting natural regeneration and tree planting in 14 North American cities. Urban Forestry and Urban Greening. 11: 374–382.

Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002a. Compensatory value of urban trees in the United States. Journal of Arboriculture. 28(4): 194–199.

Nowak, D.J.; Crane, D.E.; Stevens, J.C. 2006a. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening. 4: 115–123.

Nowak, D.J.; Cumming, A.; Twardus, D.; Hoehn, R.E.; Brandeis, T.J.; Oswalt, C.M. 2012. Urban forests of Tennessee, 2009. Gen. Tech. Rep. SRS-149. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 52 p.

Nowak, D.J.; Dwyer, J.F. 2007. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, J., ed. Urban and community forestry in the Northeast. New York: Springer: 25–46.

Nowak, D.J.; Greenfield, E.J. 2010. Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. Environmental Management. 46: 378–390.

Nowak, D.J.; Greenfield, E.J. 2012a. Tree and impervious cover in the United States. Landscape and Urban Planning. 107: 21–30.

Nowak, D.J.; Greenfield, E.J. 2012b. Tree and impervious cover change in U.S. cities. Urban Forestry and Urban Greening. 11: 21–30.

Nowak, D.J; Greenfield, E.J.; Hoehn, R.; LaPoint, E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178: 229–236.

Nowak, D.J.; Hirabayashi, S.; Ellis, E.; Greenfield, E.J. 2014. Tree and forest effects on air quality and human health in the United States. Environmental Pollution. 193: 119–129.

Nowak, D.J.; Hoehn, R.; Crane, D.E.; Stevens, J.C.; Walton, J.T. 2006b. Assessing urban forest effects and values: Washington, D.C.'s urban forest. Res. Bul. NRS-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 24 p.

Nowak, D.J.; Hoehn, R.E.; Crane, D.E.; Stevens, J.C.; Walton, J.T.; Bond, J. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture and Urban Forestry. 34(6): 347–358.

Nowak, D.J.; Noble, M.H.; Sisinni, S.M.; Dwyer, J.F. 2001. Assessing the U.S. urban forest resource. Journal of Forestry. 99(3): 37–42.

Nowak, D.J.; Stein, S.M.; Randler, P.B.; Greenfield, E.J.; Comas, S.J.; Carr, M.A.; Alig, R.J. 2010. Sustaining America's urban trees and forests. Res. Bul. GTR-NRS-62. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 28 p.

Nowak, D.J.; Stevens, J.C.; Sisinni, S.M.; Luley, C.J. 2002b. Effects of urban tree management and species selection on atmospheric carbon dioxide. Journal of Arboriculture. 28(3): 113–122.

Nowak, D.J.; Twardus, D.; Hoehn, R.; Mielke, M.; Smith, B.; Walton, J.; Crane, D.; Cumming, A.; Lake, M.; Marshall, P. 2007. National Forest Health Monitoring Program, monitoring urban forests in Indiana: pilot study 2002, part 2: statewide estimates using the UFORE model. Northeastern Area Report. NA-FR-01-07. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 13 p.

Nowak, D.J.; Walton, J.T. 2005. Projected urban growth and its estimated impact on the U.S. forest resource (2000–2050). Journal of Forestry. 103(8): 383–389.

Nowak, D.J.; Walton, J.T.; Dwyer, J.F.; Kaya, L.G.; Myeong, S. 2005. The increasing influence of urban environments on U.S. forest management. Journal of Forestry. 103(8): 377–382.

Pouyat, R.V.; Yesilonis, I.D.; Nowak, D. 2006. Carbon storage by urban soils in the United States. Journal of Environmental Quality. 35: 1566–1575.

Proulx, O.J.; Greene, D.F. 2001. The relationship between ice thickness and northern hardwood tree damage during ice storms. Canadian Journal of Forest Research. 31: 1758–1767.

Pye, J.M. 1988. Impact of ozone on the growth and yield of trees: a review. Journal of Environmental Quality. 17: 347–360.

Reethof, G.; McDaniel, O.H. 1978. Acoustics and the urban forest. In: Hopkins, G., ed. Proceedings of the National Urban Forest Conference. Syracuse: SUNY, The State University of New York, College of Environmental Science and Forestry: 321–329.

Sanders, R.A. 1986. Urban vegetation impacts on the urban hydrology of Dayton, Ohio. Urban Ecology. 9: 361–376.

Schroeder, H.W. 1989. Environment, behavior, and design research on urban forests. In: Zube, E.H.; Moore, G.L., eds. Advances in environment, behavior, and design. New York: Plenum Press: 87–107.

Schroeder, H.W.; Anderson, L.M. 1984. Perception of personal safety in urban recreation sites. Journal of Leisure Research. 16: 178–194.

Sommer, R.; Learey, F.; Summit, J.; Tirrell, M. 1994a. Social benefits of resident involvement in tree planting: compressions with developer-planted trees. Journal of Arboriculture. 20(6): 323–328.

Sommer, R.; Learey, F.; Summitt, J.; Tirrell, M. 1994b. Social benefits of residential involvement in tree planting. Journal of Arboriculture. 20(3): 170–175.

Spyratos, V.; Bourgeron, P.S.; Ghil, M. 2007. Development at the wildland-urban interface and the mitigation of forest-fire risk. Proceedings of the National Academy of Sciences. 104(36): 14272–14276.

Stolte, K. 1996. The symptomology of ozone injury to pine foliage. In: Miller, P.R.; Stolte, K.W.; Duriscoe, D.M.; Pronos, J., tech. coords. Evaluating ozone air pollution effects on pines in the Western United States. Gen. Tech. Rep. PSW-GTR-155. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 11–18.

Syphard, A.D.; Radeloff, V.C.; Keeley, J.E.; Hawbaker, T.J.; Clayton, M.K.; Stewart, S.I.; Hammer, R.B. 2007. Human influence on California fire regimes. Ecological Applications. 17(5): 1388–1402.

Taylor, A.F.; Kuo, F.E.; Sullivan, W.C. 2001a. Coping with ADD: the surprising connection to green play settings. Environment and Behavior. 33(1): 54–77.

Taylor, A.F.; Kuo, F.E.; Sullivan, W.C. 2001b. Views of nature and self-discipline: evidence from inner-city children. Journal of Environmental Psychology. 21: 49–63.

Ulrich, R.S. 1984. View through a window may influence recovery from surgery. Science. 224: 420–421.

U.S. Department of Agriculture (USDA), Forest Service. 2011. National report on sustainable forests—2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 p. http://www.fs.fed.us/research/sustain/. (August 2015).

U.S. Department of Commerce, Census Bureau (Census Bureau). 2014. Geography. https://www.census.gov/geo/reference/ua/urban-rural-2010.html. (August 2015).

U.S. Environmental Protection Agency (EPA). 2009. Climate change. http://www.epa.gov/climatechange/. (August 2015).

U.S. Environmental Protection Agency (EPA). 2015. The social cost of carbon. http://www.epa.gov/climatechange/EPAactivities/economics/scc.html. (August 2015).

U.S. Geological Survey (USGS). 2008. Multi-resolution land characteristics consortium. http://www.mrlc.gov. (August 2015).

Valinger, E.; Fridman, J. 1997. Modeling probability of snow and wind damage in Scots pine stands using tree characteristics. Forest Ecology and Management. 97: 215–222.

Webb, S.L.; Pendergast, T.H.; Dwyer, M.E. 2001. Response of native and exotic maple seedling banks to removal of exotic, invasive, Norway maple. Journal of the Torrey Botanical Society. 128: 141–149.

Westphal, L.M. 1999. Empowering people through urban greening projects: Does it happen? In: Kollin, C., ed. Proceedings: 1999 national urban forest conference. Washington, DC: American Forests: 60–63.

Westphal, L.M. 2003. Urban greening and social benefits: a study of empowerment outcomes. Journal of Arboriculture. 29(3): 137–147.

Wolf, K.L. 2003. Public response to the urban forest in inner-city business districts. Journal of Arboriculture. 29(3): 117–126.

Wolf, K.L. 2004. Trees and business district preferences: a case study of Athens, Georgia US. Journal of Arboriculture. 30(6): 336–346.

Zhang, Y.; Zhang, D.; Schelhas, J. 2005. Small-scale nonindustrial private forest ownership in the United States: rationale and implications for forest management. Silva Fennica. 39(3): 443–454.

Chapter 5

Charles Perry, Greg Liknes,
Guy Robertson, and Chris Woodall

Developing a Monitoring Framework for Agricultural and Urban Forest Resources

An explicit aim of this report is to lay the groundwork for a consistent and durable national inventory of agricultural and urban forest resources[20] in the United States. The benefits these resources convey are numerous and the values the public holds for them well established (Louman et al. 2009). Moreover, the growing focus on all-lands management and landscape-scale conservation highlights the need for information that spans different land use categories and ecosystem types. The effort to develop a comprehensive estimate of forest-based carbon sequestration for the U.S. Greenhouse Gas Inventory is just one example of this need. Although currently available data enable us to draw some inferences about the general condition and extent of agricultural and urban forests, the level of our knowledge is relatively low, and we lack even the most basic measures of forest condition for most of the country's agricultural lands. Through the use of satellite images to develop forest cover estimates for urban areas, the situation for urban forests is somewhat better. For urban forests, however, we have only incomplete or inconsistent information on forest health, species composition, and a host of other indicators deemed important.

To rectify this problem, a national inventory of agricultural and urban forest resources should be designed and implemented. The purpose of this chapter is to help lay the technical groundwork for such an inventory. In brief, we propose combining on-the-ground survey activities with remote-sensing analysis as a cost-effective means of obtaining the core data needed for a national inventory of agricultural and urban forest resources that is compatible with existing forest land inventory and reporting systems (see Oswalt et al. 2014). Precedents for this work have already been well established in (1) the U.S. Department of Agriculture (USDA), Forest Service Forest Inventory and Analysis (FIA) inventory of conventional forests and the pilot tests it has undertaken for agricultural and urban forests in the Great Plains Tree and Forest Invasives Initiative (GPI) inventory work cited in chapter 3 and (2) satellite-derived forest cover estimates presented for urban areas in chapter 4. Moreover, the pending implementation of an urban FIA inventory will yield valuable information about urban forests and experience that can be applied in agricultural settings. In the final section of this chapter, we discuss the national forest sustainability reporting process and the Montréal Process Criteria and Indicators (MP C&I) for Forest Sustainability[21] as important reference points for developing an agricultural- and urban-focused inventory. What is needed, however, is the consolidation of these disparate pieces to form an integrated data collection and reporting activity that is consistent across space and sustained over time.

This work will entail a substantial amount of technical development in terms of exactly what variables will be included, how they will be measured, and how they will be reported. It will also require institutional development to coordinate activities on a national scale and ensure they are maintained in the future. Most of this chapter is devoted to the first concern, stipulating the technical aspects of a national inventory of agricultural and urban forests. Although we do not recommend explicit institutional arrangements or identify specific tasks for specific agencies, a number of agencies have relevant skills and experience for this work, and interagency collaboration will be essential, particularly at the beginning. Likewise, collaboration with State and local government entities and with stakeholders outside of government will be very important in ensuring public support and in making sure the outputs from any inventory work that is undertaken provide value to the public at large. In this regard, many of the technical recommendations made in this chapter should be viewed as provisional; they will need to be subject to broader interagency and public review, and many will likely

[20] As a matter of definition, *forest resources* referenced in this chapter specifically include and focus on those trees growing on land outside the formal definition of *forest land* used by the Forest Inventory and Analysis program of the Forest Service. (See chapter 2 for an expanded discussion of definitions used in this report.)

[21] The full title is *Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests*.

need to be revised in an adaptive fashion as we learn from experience and as new information needs emerge. That being said, considerable agreement is likely on the core biophysical indicators that could be included in an initial inventory. When such agreement exists, implementation can proceed without undue discussion and debate.

Current State of Information on Agricultural and Urban Forest Resources

No national baseline data currently exist that describe the condition of agricultural or urban tree resources. An inventory of urban trees has been piloted in a number of cities, (e.g., Cumming et al. 2008, Nowak et al. 2011), and forest cover estimates derived from satellite imagery have been generated for urban areas for all regions of the country (see Nowak et al. 2008 and "Regional Reports" at http://www.nrs.fs.fed.us/data/urban/ [August 2015]). In addition, agricultural and urban tree resource inventories have been piloted in some of the Great Plains States, where these resources represent a large fraction of the total forest cover (Lister et al. 2012). Taken together, this work constitutes the foundation for the displays of currently available information on agricultural and urban forests presented in chapters 3 and 4, respectively. In addition to these regional inventories and tree-cover estimates, a great deal of location-specific data exist on urban tree cover, forest structure, and ecological functions and values. This data collection is the result of the efforts of researchers and of numerous municipalities to understand their local forest and tree resources. For urban forests, the opportunity to compare and consolidate this information is enhanced by the growing use of the i-Tree Eco model (see chapter 4 and http://www.itreetools.org/eco/). Comprehensive assessments of urban forest structure, however—number of trees, species composition, diameter distribution, tree health, etc.—are still lacking for most cities and regions of the United States. So, even as the quantity of urban forest data is increasing, these data are not sufficient to adequately monitor or assess urban forests at the regional or national scale. This situation should be greatly improved through the implementation of an urban FIA inventory, although the resulting data will not be available for at least several years. With the exception of those areas inventoried in the GPI described in chapter 3, the state of knowledge for agricultural forest resources is considerably less developed.

The urban pilot inventories and the GPI inventory, discussed previously, were designed and implemented in collaboration with the Forest Service FIA, and the developers were very cognizant of FIA methods and definitions (for details, see http://www.fia.fs.fed.us/library/field-guides-methods-proc/ [August 2015]). It is possible to integrate these pilot studies with the national FIA plot network and resultant analyses, but the actual mechanisms for doing so are not yet fully developed. So, although these inventory efforts represent one-time studies tailored to the specific questions that motivated them, they represent an initial effort at a consistent inventory and can help guide us in determining what a national inventory would look like.

Desired State of Agricultural and Urban Forest Resources Monitoring

A national monitoring system for agricultural and urban forest resources ideally will meet the following overarching criteria.

- The sampling design will be statistically valid and national in scope, and it will be designed in a manner that facilitates comparisons over space and time.
- Sampling and reporting protocols will be explicitly adopted and published.
- These protocols will include an orderly process for suggesting, adopting, and implementing changes to the indicator set and measurement protocols.
- The definition of *land uses* will be comprehensive and include sufficient detail to facilitate the seamless integration of data from all land use categories into a whole without confusion, doublecounting, or undercounting among similar land uses.
- All data collected by each inventory will be entered into a database that is easily accessible to the public and accompanied by full and transparent documentation. Common elements across inventories could be compiled into one database to meet reporting needs.
- The content and format of these databases will facilitate data extraction and use with forecasting models and other analysis techniques (e.g., Urban Forest Effects, or UFORE, and Forest Vegetation Simulator, or FVS).
- Periodic reports and data summaries will be published according to an explicit schedule.
- Data gaps will be explicitly identified across social, economic, and ecological dimensions, and efforts will be made to address these gaps where possible.
- A permanent steering committee or similar governing body will be established to work in collaboration with relevant user communities to review project outputs and revise procedures and measures as needed.
- Permanent institutional and budgetary arrangements will be made to ensure project durability.

Suggested Criteria and Indicator Framework as a Starting Point for Variable Development

Criteria and indicator frameworks involve a hierarchical organization of specific indicators arranged under more general, thematic criteria. A major advantage in using this type of framework is that it provides an explicit and deliberate way to organize, display, assess, and revise diverse collections of information on topics that are widely accepted as relevant to forest sustainability and management. The MP C&I (Montréal Process Working Group 2009) represent one such approach designed to provide a comprehensive view of conventional forests and their sustainability. Although the 54 distinct MP indicators are not all applicable to agricultural and urban forests, the 7 MP criteria (i.e., overarching themes that encompass multiple indicators) provide a good starting point to begin to organize and assess the particular pieces of information needed to better understand agricultural and urban forests and their sustainability. This approach has the added benefit of enabling us to better integrate the information we develop for agricultural and urban lands with that reported periodically for conventional forests in the *National Reports on Sustainable Forests*; the most recent version is the *National Report on Sustainable Forests—2010*, hereafter, the *National Report* (USDA Forest Service 2011). Those reports adhere to the MP C&I framework that 11 other nations also follow.

In the following framework, we explicitly use the MP criteria to organize a list of suggested indicators for monitoring agricultural and urban forests. A number of these indicators are already included in the inventory activities noted previously and in chapters 3 and 4. Others are suggested by certain MP indicators that make sense in the context of agricultural and urban forests but are not included in current pilot inventories, and still others are added as a potential means of augmenting the information for a given criterion, even if a close analog does not exist in either existing inventory activities or the MP indicator set. As a result, the indicators listed here range from existing field-tested measures that would likely be included as core variables without substantial modification in any future inventory, to measures that are feasible but may require some modification, to measures that would need substantial revision or new development before implementation. In light of the different status and feasibility associated with each indicator, we have included a priority recommendation ("core," "suggested for consideration," and "possible for consideration"), and we have listed possible data sources for each. The following indicator list does not represent an attempt to replicate the full range of MP C&I for agricultural and urban forests; it is merely a starting point.

MP Criterion 1: Conservation of Biological Diversity

Criterion 1 describes biological characteristics of forest ecosystems, the distribution and diversity of forest species, and efforts to preserve them. Measures of forest extent and cover, tree species distribution, and the diversity of forest flora and fauna are considered under Criterion 1.

1.1 Ecosystem diversity

1.1a **Area and percent of tree cover in agricultural and urban settings.** The spatial configuration of these resources will present challenges in devising consistent measures. A potential strategy here would be to report acres by well-defined cover classes (e.g., scattered trees, natural woodlands, agroforestry plantings) as was provided in the GPI inventory. Additional descriptors such as species grouping (e.g., coniferous, broadleaved), age class, diameter class, or vigor may be included. Total percent forest cover estimated using remote-sensing techniques would be a complimentary measure.

Status: Core indicator in any inventory. Included in the GPI inventory (e.g., Lister et al. 2012), Urban Inventory Pilots (e.g., Nowak et al. 2011), and satellite-derived urban forest cover estimates.

Data sources: Plot-based inventory sampling; satellite and related remote-sensing imagery.

1.1b **Area and percent of forest by ownership and protection status** (e.g., parks, conservation easements). Field-level sampling or Geographic Information System, or GIS, mapping combining forest cover information (developed in Indicator 1.1) with landowner and land use designations. It is often difficult to achieve consistency in these determinations, so the challenges associated with this task should not be overlooked.

Status: Core indicator. Generally addressed in the GPI inventory ("Primary Land Use" condition attribute; Lister et al. 2012), Urban Inventory Pilots (e.g., Nowak et al. 2011), and i-Tree Eco model (through observed land use; see http://www.itreetools.org/eco/ [August 2015]).

Data sources: Plot-based inventory sampling in combination with publicly available land ownership information, including the Protected Areas Database, or PAD (see http://www.protectedlands.net [August 2015]) and the National Conservation Easement Database, or NCED (see http://www.nced.conservationregistry.org [August 2015]).

1.1c **Fragmentation of tree cover.** Average patch size or other fragmentation metric.

Status: Suggested for consideration. Developing meaningful metrics will be a challenge.

Data sources: Forest cover information developed in Indicator 1.1a combined with spatial analysis techniques such as FRAGSTATS (see http://www.umass.edu/landeco/research/fragstats/fragstats.html [August 2015]).

1.2 Species diversity

1.2.a **Number of tree species.** Tree species is a common attribute collected for individual trees in plot-sampling protocols. The ability to collate and present species counts in summary statistics will require further development. Candidate measures include the relative proportion of native to nonnative species, indexes describing overall tree species diversity, and counts for species of specific interest (e.g., ash [*Fraxinus* spp.] in the GPI inventory. To the extent possible, trees should be identified as cultivated or naturalized.

Status: Core indicator, although level of reporting detail will need to be considered.

Data sources: This information ideally would be collected through tree-level sampling in plot-based inventory. It may be more cost effective to integrate existing street tree inventories, but these inventories would have to meet a common standard.

Note: The MP C&I here includes an indicator for the number of forest associated species for fauna and flora, which includes animal and nontree plant species. Certain fauna (notably bird species through the U.S. Geological Survey North American Breeding Bird Survey) are currently tallied by ecoregion. Information on shrub cover is included in the i-Tree Eco urban tree sampling methodology, but a tally of shrub species is not incorporated in any of the current inventory activities. As a result, we are not suggesting measurement of fauna and shrub species at this time.

1.2.b **Presence of species at risk.** This indicator would register the presence of threatened or endangered (as defined by law) flora and fauna species in agricultural and urban forests.

Status: Suggested for consideration. Measurement and reporting protocols would require development.

Data sources: Mapping of threatened and endangered species sightings and known ranges into forest cover and land use data developed in Indicator 1.1a.

Note: The MP C&I include indicators on forest-related genetic diversity. At this time, we are not suggesting coverage of genetic diversity associated with agricultural and urban forest resources, although it should be noted that genetic diversity (or the lack thereof) is an important factor affecting agricultural and urban forests, especially those that are planted.

MP Criterion 2: Maintenance of Productive Capacity of Forest Ecosystems

Criterion 2 measures the balance between the capacity of forests to produce valued outputs for society and current rates of extraction of those products. The relationship between tree growth rates, timber stocking volumes, and timber harvest levels is a central focus, although this focus has been extended in the MP C&I to nonwood forest products as well. It is not clear how this focus could be directly applied to agricultural and urban forests, where numerous forest-related benefits are produced in combination and most often are not measured or traded. At the same time, the qualitative value of specific ecosystem services from these resources is increasingly recognized by society, and future measures relating the flows of specific services to the capacity of agricultural and urban forests to produce them could be incorporated here. Several examples are suggested in the following section.

2.1 **Area and percent of agricultural and urban forests explicitly devoted to goods production.** This indicator would include natural and planted forests managed for bioenergy production, agroforestry production systems, the production of foodstuffs and other products, and timber or wood fiber production. Volume and area measures of agroforestry plantings would be the most likely focus.

Status: possible for consideration. Substantial development required.

Data sources: plot-based inventory sampling, USDA Census of Agriculture.

2.2 **Presence of nonwood forest products and harvest of same.** This indicator would register the presence of important nonwood forest products at a given location and indicate whether harvest activity is currently occurring.

Status: Possible for consideration. Substantial development required.

Data sources: Plot-based inventory sampling and USDA Census of Agriculture augmented with local user surveys.

MP Criterion 3: Maintenance of Forest Ecosystem Health and Vitality (Disturbance)

Criterion 3 measures the occurrence of forest disturbance processes resulting in tree mortality or loss of vigor. The MP C&I divide disturbance processes into two main categories: (1) biotic (insects, disease, and nonnative invasive species) and (2) abiotic (fire, weather, pollution, and land clearing for development).[22] As is true with the conventional forests addressed in the *National Report*, the indicators in Criterion 3 have direct relevance for understanding the sustainability of our agricultural and urban forests and managing them accordingly.

3.1 **Incidence of tree mortality or damage by disturbance type.** This indicator would register tree mortality and evidence of damage by general disturbance category (when possible).

Status: Core indicator. Current inventories contain various measures for tree vigor and presence of damage. Developing meaningful metrics will be a challenge, as will identifying specific disturbance agents in many cases.

Data sources: Ideally these data would be collected through tree-level sampling in plot-based inventories. It may be more cost effective to integrated existing street tree inventories, but these would have to meet a common standard.

3.2 **Incidence of wildfire in agricultural and urban areas.** This indicator measures incidence and extent of wildfires in agricultural and urban areas. Number of structures destroyed could also be tracked.

Status: Suggested for consideration.

Data sources: Tally of major incidences from relevant sources such as the Monitoring Trends in Burn Severity database.[23]

3.3 **Forest cover lost to development.** Agricultural and urban forests are particularly prone to conversion to other land uses through the process of development. This indicator would measure the area of forests lost to this particular disturbance factor.

Status: Core indicator. Change analysis associated with Indicator 1.1.a, although additional analysis to identify developed areas is needed.

Data sources: Plot-based sampling and remote-sensing techniques used for Indicator 1.1a.

MP Criterion 4: Conservation and Maintenance of Soil and Water Resources

Criterion 4 measures soil and water conditions within forests and describes management activity aimed at protecting and enhancing these conditions. Reporting for conventional forests in the *National Report* is limited by the absence of consistent data on resource conditions and on management prescriptions and compliance. It is also hampered by the fact that forest management and conservation is most often directed at sustaining multiple benefits, with soil and water resources not identified explicitly as the primary management objective, although it should be noted that water conservation and management are increasingly being identified as specific goals for urban forest management. These same obstacles apply in the case of agricultural and urban forests.

4.1 Soil

4.1a **Area and percent of tree cover for which the land-management focus is the protection of soil resources.** Measures tree area explicitly managed for soil conservation and enhancement. May be more relevant in agricultural settings.

Status: Possible for consideration; NRCS data may address some of these issues. Stronger linkages required.

Data sources: Tree-cover information developed in 1.1a combined with land use and protective status mapping.

4.1b **Area and percent of forest land with degraded soils.** This indicator measures extent of forest land in agricultural and urban areas exhibiting significant soil degradation.

Status: Suggested for consideration.

Data sources: Plot-based inventory sampling. It may be possible to intersect tree cover on agricultural and urban land with USDA Natural Resources Conservation Service maps of highly erodible soils. (Note: FIA sampling for conventional forests now includes sampling of soil conditions on a subset of plots. Similar measures may be feasible for agricultural and urban forests.)

4.2 Water

4.2.a **Area and percent of tree cover for which the land management focus is the protection of water resources.** This indicator measures agricultural and urban forest

[22] Climate change is also listed as an abiotic disturbance agent in the *National Report*, although its potential impact is complex and will encompass many of the other biotic and abiotic disturbance factors.

[23] The Monitoring Trends in Burn Severity project is a multiagency effort to map the burn severity and fire perimeters across all lands of the United States. See Eidenshink et al. (2007) for an overview and http://www.mtbs.gov/ (August 2015) for the project Web site.

area explicitly managed for water conservation and enhancement. In urban settings, consideration could extend beyond urban boundaries to include upland forests and riparian areas in water catchment areas. One strategy would be simply to measure the area of forest land occurring in officially designated municipal watershed areas (e.g., Portland, Oregon's Bull Run Watershed Management Unit or Boston's Quabbin reservoir). Note, however, that the resulting area measures will include conventional forest lands as currently inventoried by FIA.

Status: Possible for consideration. Substantial development required.

Data sources: Plot-based inventory sampling and land use designations.

4.2b **Area and percent of degraded water bodies, or stream length in the vicinity of agricultural and urban tree cover.** This indicator measures extent of forest-associated water bodies exhibiting significant degradation in agricultural and urban areas. The separation of "forest-associated water bodies" from other water bodies may not make sense in agricultural and urban contexts, and this indicator may be redundant in the context of more general surveys of water conditions in these areas.

Status: Possible for consideration. Significant development required.

Data sources: Water condition surveys combined with forest cover information developed in Indicator 1.1a.

4.2c **Area and percent of impermeable surfaces underlying agricultural and urban tree resources.** This indicator measures the extent of impermeable surfaces (e.g., asphalt, concrete) underlying agricultural and urban forests and trees. Most applicable in urban settings. Indicator may be redundant with general measures of impermeable surface in developed areas.

Status: suggested for consideration. Already a component of i-Tree Eco model. Development of summary measures required.

Data sources: plot-based inventory sampling.

MP Criterion 5: Maintenance of Forest Contributions to Global Carbon Cycles

Criterion 5 addresses the relationship between forests and atmospheric carbon. It relies on three principal measures: (1) carbon stocks and fluxes in forested ecosystems, (2) carbon stocks and fluxes in durable forest products, and (3) avoided carbon emissions from the use of wood for energy. The first of these measures will be most relevant for the monitoring of agricultural and urban forests proposed in this report. Carbon pools in forest products and avoided emissions may also be relevant for agricultural and urban forests in general, but these measures are already incorporated into the MP indicators covered in the *National Report*.[24]

5.1 **Total and unit-area agricultural and urban forest ecosystem carbon stocks and fluxes.** Measures carbon stocks and net carbon sequestration for forest resources on agricultural and urban lands.

Status: Core indicator. Preliminary estimates already developed for urban areas based on tree-cover estimates. Models for calculating carbon balance already fully developed for conventional forests.

Data sources: Forest inventory data developed in Criterion 1 in combination with forest carbon modeling techniques.

5.2 **Effects of agricultural and urban forests on energy consumption.** Measures the influence of agricultural and urban forests on energy consumption. Likely most applicable to urban areas where trees may serve to mitigate temperature extremes through shading or wind protection (note that windbreaks around rural buildings will serve the same purpose but low population density will limit total contribution). Other factors may also be applicable.

Status: Possible for consideration. i-Tree eco is an important foundation (http://www.itreetools.org/eco/index.php [August 2015]).

Data sources: Forest inventory and tree-cover estimates developed in Indicator 1.1a in combination with modeling and analysis techniques (preliminary estimation is likely feasible, but precision will be an issue).

MP Criterion 6: Maintenance and Enhancement of Long-Term Socioeconomic Benefits

Criterion 6 measures a broad array of socioeconomic benefits and functions related to forested ecosystems. In the MP C&I, Criterion 6 contains 20 indicators with focus areas in (1) production and consumption (of forest products and services); (2) investment in the forest sector; (3) employment and community needs;

[24] The data used to calculate these numbers in the *National Report* are derived from tallies of final production of wood products and wood-based energy from all sources and would include those produced from agricultural and urban forest resources. The estimates for forest ecosystem carbon pools and fluxes presented in the *National Report*, on the other hand, are derived from FIA survey data of conventional forests and do not include agricultural and urban areas.

(4) recreation and tourism; and (5) cultural, social, and spiritual needs and values. All these indicators are broadly applicable to agricultural and urban forests, but they present a number of challenges in regard to devising and implementing specific measures. First, there is the lack of management focus noted in chapter 2, in which agricultural and urban forests are seldom managed specifically for forest outputs but rather for their broader contribution to landscape functions and in combination with other land cover and use classes. Second, many of the indicators in Criterion 6 rely on disparate datastreams and sampling activities. Whereas many of the indicators in Criteria 1 through 5 can be addressed using data on tree cover, species, size, and health generated through remote-sensing or inventory-sampling activities (note how many of the indicators suggested previously are derived from information developed in Indicator 1.1a), indicators in Criterion 6 often require data-gathering efforts tailored to a single indicator. As a result of these challenges, the indicator list we present for Criterion 6 is less fully developed than those presented for the previous five criteria, and the specific indicators are more provisional in nature.

This lack of development should not be taken as an indication of the relative importance of Criterion 6 so much as the difficulty in addressing it with the data and resources currently at hand. Criterion 6 would be a likely place to focus future efforts to further develop and refine indicators and the data-gathering efforts needed to support them. The following section is merely a starting point for this process.

6.1 Production and consumption

6.1a **Production and consumption of tangible products from agricultural and urban forests.** Measures volume and value of tangible products derived from agricultural and urban forests. Tangible products include wood *and* nonwood forest products that can be bought and sold or otherwise gathered and consumed. Agroforestry would likely be the main focus, but outputs from other forest and tree resources should not be ignored. Initial efforts could concentrate on identifying major product categories for future data-gathering and compilation efforts (e.g., biomass for bioenergy applications).

Status: Suggested for consideration. Substantial development required. Universal coverage likely not feasible.

Data sources: To be determined.

6.1b **Production of ecosystem services from agricultural and urban forests.** Measures volume (in appropriate units) of ecosystem services derived from agricultural and urban forests. The potential range of these services is outlined in the previous chapters but could include, for example, water quality and flow regulation, wildlife habitat, or carbon sequestration. Comprehensive, quantitative measures are likely not feasible, but indicative information from analysis of inventory data and review of current literature can help describe the dimensions of the various ecosystem services associated with these resources.

Status: Suggested for consideration. Substantial development required.

Data sources: Inventory information developed in Criterion 1 combined with estimation techniques equating forest area or tree counts with supply of ecosystem services.

6.1c **Revenue from forest-based ecosystem services on agricultural and urban lands.** Measures actual payments for ecosystem services derived from agricultural and urban forest resources. This measure would track market activity and not actual value (the value of these resources will usually be much higher). A comprehensive survey is probably not feasible, but major categories of payment and their magnitudes can be identified. In many cases, however, these revenues will not be specific to forests or trees (e.g., conservation easements for mixed forest and field lands).

Status: Possible for consideration. Substantial development required.

Data sources: Reports documenting program budgets, payments for conservation easements, and related payments.

6.2 Investments in agricultural and urban forestry

6.2a **Investment in agricultural and urban forest resource management.** Measures money invested in creating and managing agricultural and urban forests, including municipal budgets devoted to urban forestry, government payments to support forest management and conservation on agricultural lands, and investments in agroforestry plantings. Comprehensive measurement will be challenging given the number and variety of data sources that must be aggregated.

Status: Suggested for consideration. Substantial development required.

Data sources: Municipal budgets, State and Federal program budgets, and others.

6.2b **Investment in research and education related to agricultural and urban forest resource management.** Measures money invested in research and education directed to urban forestry and agroforestry. Would include financial support for accredited university programs and research institutions. Students enrolled or degrees granted could be used as an alternate measure.

Status: Suggested for consideration.

Data sources: Institutional budgets, scholarship programs, and related support.

6.3 Employment and community needs

6.3a **Employment related to agricultural and urban forestry.** Measures number of employees engaged in the management of agricultural and urban forest resources. Could include municipal employees working in urban forestry, arboriculturalists, and workers engaged in agroforestry. Comprehensive measurement will be challenging.

Status: Possible for consideration. Substantial development required.

Data sources: Municipal reports, U.S. Bureau of Labor Statistics.

6.3b **Distribution of benefits from agricultural and urban forest resources.** Measures percent of tree cover or other relevant descriptors, including contextual elements like tree location and health, in relation to population by income class or minority status. Primarily directed to urban forestry and designed to explore issues of environmental justice.

Status: Possible for consideration.

Data sources: Inventory and forest cover estimates developed in Criterion 1 in combination with Census Bureau and similar demographic data sources.

6.4 **Recreation and tourism.** Although agricultural and urban forests positively affect recreation and tourism values through the amenities they provide (indeed the amenity benefits of these forests may be their most important value), delineating them from the more general category of green space or related recreational lands/facilities is impossible in this context. No indicators are suggested for this subcriterion at this time.

6.5 **Cultural, social, and spiritual values associated with agricultural and urban forests.** The same limitations as noted for recreation and tourism previously apply. The values associated with these resources are a fundamental concern for this report, but their concise measurement remains elusive. This subcriterion could be the focus of indicator development in the future.

MP Criterion 7: Legal, Institutional, and Economic Framework for the Sustainable Management of Agricultural and Urban Forest Resources

Criterion 7 addresses a core issue in sustainable resource management. At the same time, the institutions, laws, and economic arrangements it seeks to assess are extremely difficult to measure in a concise, quantitative fashion. This difficulty resulted in a more flexible and qualitative approach being applied to conventional forests in the *National Report*, and a similar degree of flexibility will be required in the case of agricultural and urban forests.

7.1 Legal framework

7.1a **National laws and regulations relating to urban forest resources.** Lists current Federal laws and regulations that are relevant to urban forestry and forest resources. Case studies of relevant State, county, and/or local laws and regulations may be included for context.

Status: Suggested for consideration.

Data sources: Congressional legislation and agency regulations.

7.1b **National laws and regulations relating to agricultural forests.** Lists current Federal laws and regulations that are relevant to agroforestry and agricultural forest resources. Case studies of relevant State, county, and local laws and regulations may be included for context.

Status: Suggested for consideration.

Data sources: Congressional legislation and agency regulations.

(Note: 7.1a and 7.1b could be combined.)

7.2 Institutional framework

7.2a **National institutions with a primary focus in urban forestry.** Lists national institutions that are relevant to urban forestry and forest resources. International and prominent regional institutions may also be listed.

Status: Suggested for consideration.

Data sources: Miscellaneous.

7.2b **National institutions with a primary focus in agroforestry and agricultural forest resources.** Lists national institutions that are relevant to agroforestry and agricultural forest resources. International and prominent regional institutions may also be listed.

Status: Suggested for consideration.

Data sources: Miscellaneous.

(Note: 7.2a and 7.2b could be combined.)

7.3 Economic framework

7.3a **Economic instruments available to promote sustainable management of agricultural and urban forest resources.** Identifies principal economic instruments and strategies that can be used to promote sustainable forest management in agricultural and urban settings.

Status: Possible for consideration.

Data sources: Literature review, case studies, digital maps of conservation easements and land trusts, and others.

Instituting a National Agricultural and Urban Tree Resource Monitoring Program

A major first step in developing a national monitoring system for agricultural and urban forests resources will be to consolidate existing data and extend the coverage to other regions and localities to develop nationwide coverage. This expansion will rely heavily on existing inventory activities (GPI, i-Tree Eco, and FIA urban pilots) as a starting point for developing variables and measurement protocols. The national urban forest inventory being developed by FIA will likewise serve as a foundation, especially if it can be extended to agricultural lands sometime in the future. However the activity proceeds, the resulting inventory data must be as consistent as possible with that developed by FIA for conventional forests. In fact, application of the current FIA sampling grid and remote-sensing stratification approaches with expanded definitions that appropriately encompass agricultural and urban tree resources may be the most straightforward way to develop a nationally consistent inventory.

At the same time, opportunities for further refining current measures and including new ones should be considered on an ongoing basis. This process needs to be flexible and draw from ideas from various quarters ranging from stakeholder consultations to broader sustainability frameworks such as the MP C&I, and it will involve numerous compromises balancing information needs with the practical feasibility of data acquisition and reporting. Although developing a set of information covering all the criteria in the MP C&I (or similar comprehensive framework) is our ideal goal, initial efforts should be focused on developing a nationally consistent database of inventory data as stipulated in MP Criterion 1 (see framework in previous section).

User groups need to be involved at the beginning in the development of the fundamental questions to be addressed by the inventory and of the techniques needed to answer those questions. It is critical to achieve agreement between the user community and the agencies conducting the inventory. A diverse and vibrant user community (e.g., States, counties, local communities, private businesses, and relevant nongovernmental organizations) provides context for criteria and indicator assessments, and it is crucial for providing support for monitoring efforts over the long run. User communities need to be engaged at scoping sessions (e.g., through the Roundtable on Sustainable Forests) for criteria and indicator development and alignment with corresponding information needs. The criteria and indicator framework outlined previously can serve as a starting point for these discussions. In addition, it will be important to partner and align with FIA's inventory of forested landscapes. Other relevant criteria and indicator schemes should be reviewed at the criterion level, with the acknowledgment that many indicators will not cross over to agricultural and urban tree resources on a one-to-one basis. Official definitions of populations and attributes of interest to satisfy criteria and indicator reporting need to be developed: urban (e.g., near homes for cooling) and agricultural (e.g., near fields for windbreaks or near streams for sediment control). The importance of explicit definitions of indicators and measures to be sampled cannot be overstated.

Possible Monitoring Directions

The core strategy suggested in this report for developing an inventory of agricultural and urban forests involves the combination of remote-sensing data with plot-based, on-the-ground sampling activities. The techniques for implementing this strategy are largely in place, having been developed for conventional forests by FIA, though the novel configurations of agricultural and urban forests may present new technical issues in terms of measurement and reporting. The greatest challenges associated with developing this inventory, however, are more organizational than technical, because it will require the coordination of numerous actors over a sustained period of time. In addition, the biophysical inventory envisioned here will not, by itself, address many aspects of forest sustainability, particularly in regard to its social and economic dimensions—further development in these areas will be required.

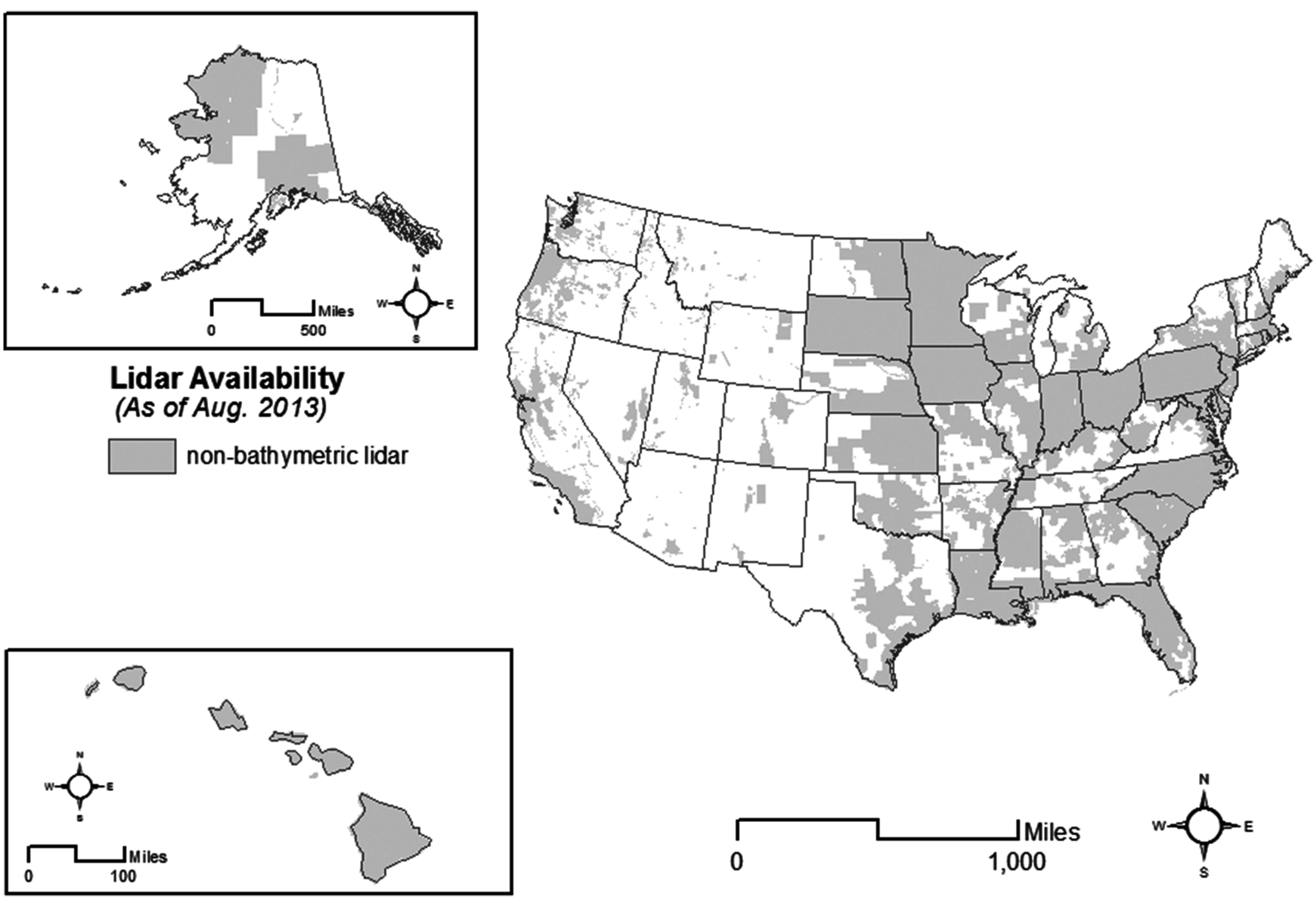
Remote sensing provides context. Aerial photography historically has been used in a variety of forest resource monitoring applications. In recent decades, satellite remote sensing along with digital aerial imagery have become popular data sources for augmenting on-the-ground field data collection. Agricultural and urban trees present a special challenge regarding remote sensing because their spatial extent is frequently smaller than can be discerned by medium-resolution sensors, such as Landsat (30-meter) and MODIS (250-meter) sensors; a host of sensors on satellites have a much finer spatial resolution (e.g., Quickbird, IKONOS). The major trade-offs with finer spatial resolution are typically narrower coverage (less spatial extent) and increased processing time and storage requirements. Improvements in computing resources are quickly overcoming these trade-offs, and a host of methods are being developed to map tree cover across large areas using high-resolution imagery. The National Agriculture Imagery Program (NAIP) of the USDA is currently delivering 1-meter resolution imagery for most of the United States with an approximate 3-year return interval. The NAIP data are delivered to some States as color imagery, although, in some cases, extra funding has been acquired to supply color-infrared imagery.

Yet another source of remote-sensing data that could help in monitoring agricultural and urban tree resources is LIDAR (Light Detection and Ranging). Although LIDAR has been shown to provide valuable information about structure and diversity of tree cover (see, for example, Lefsky, Cohen et al. 1999; Lefsky, Harding et al. 1999; and Wulder 1998), it is not yet widely available. For example, the U.S. Geological Survey aggregates LIDAR datasets at a Web portal (http://lidar.cr.usgs.gov [August 2015]), and coverage as of November 2012 is far from nationwide (fig. 5.1).

Whether to produce wall-to-wall maps and geospatial datasets of agricultural and urban tree resources, or to augment in situ sampling efforts via stratified estimation or other techniques, NAIP and LIDAR data are promising sources of information. A successful agricultural and urban tree-monitoring program would benefit from ongoing support of the NAIP (or NAIP-like) program, especially with the addition of color-infrared information in all States. LIDAR is rapidly becoming available in many areas, but most of the acquisition is driven by local, regional, or statewide efforts. To leverage these data in combination with plot-based sampling, the effort would have to procure funding to acquire LIDAR in a consistent, nationwide manner, which is the goal of the 3D Elevation Program (Snyder 2012). Also, the schedule in which images are made available will have to be integrated with on-the-ground-sampling activities and periodic data development and reporting to ensure temporal and spatial consistency.

Plot-based sampling enriches remote-sensing estimates. Although remote-sensing techniques and the data they yield are continually improving, they cannot take the place of on-the-ground sampling when it comes to developing information of important forest attributes such as species distribution, forest health, and tree size or age. Plot-based sampling will be a key element in any nationwide monitoring program for agricultural and urban areas. Through FIA sampling of conventional forest lands and the use of similar techniques for agricultural and urban forests in the programs outlined in chapters 3 and 4, we now have ample experience in sampling forests and trees on agricultural and urban lands. The challenge in extending this activity to a national scale lies in harmonizing current activities, fixing national standards for measurement, and developing a statistically sound sampling frame so that data can be aggregated over space and time. One promising approach would be to build on the FIA national grid to establish a sampling frame that encompasses all landowners and uses, with neither gaps nor overlaps. This approach would facilitate scaling from site-specific

Figure 5.1. Available LIDAR (Light Detection and Ranging) datasets as of August 2013, with potential application to tree inventory outlined in gray (U.S. Interagency Elevation Inventory, http://coast.noaa.gov/inventory/ [August 2015]).



observations to the State, regional, and national scales, and, from a statistical standpoint, the approach would be quite similar to FIA's current work. The scientific foundation for this type of activity is well established. Establishing a national sampling frame, however, will still require substantial statistical analysis up front to establish consistency and validity, coordination between different regions and actors, and focused attention over time.

Possible Program Solutions

We have proposed a national monitoring system for agricultural and urban trees and forests that combines plot-based sampling activities with remote-sensing techniques. This solution would go a long way in addressing the core biophysical indicators identified previously in relation to the MP Criterion 1 and many other indicators that are keyed off of these data. The specific institutional arrangements for this work are beyond the scope of this report. The Forest Service FIA program obviously has a role to play, especially given its pending expansion into regular sampling in urban areas. Other agencies within the USDA (notably the Natural Resources Conservation Service and the National Agricultural Statistics Service) constitute likely contributors, as does the U.S. Geological Survey in the U.S. Department of the Interior, and the National Aeronautics and Space Administration. At this stage, however, it is important to be open to new ideas and potential collaborators beyond the agencies traditionally charged with monitoring and managing public lands. An associated opportunity and challenge will be engaging and integrating the various State and local governments and private-sector entities that can contribute to the project or otherwise have a stake in its outcome.

The involvement of other agencies, stakeholders, and interested parties could suggest a number of new attributes that can be measured. On urban forest land, for example, it is important to know the distance to buildings or distance to streams; in agricultural landscapes, it is useful to know the length of tree resources, distance to streams, orientation to prevailing winds, any associated agricultural practices and uses, associated land use, distance to buildings, and soil volume and chemistry. One strength of a criteria and indicator framework such as MP C&I is that it provides an orderly process for adjusting and augmenting the types of information to be gathered, and similar arrangements should be specified for any monitoring program for agricultural and urban forest resources.

Cost estimates for an inventory could be derived from past experiences or pilot studies (i.e., the GPI inventory and urban pilots), but it is important to consider how relevant these costs might be to a different sampling design. For example, the cost of establishing a national urban forest inventory using existing FIA plot densities and annualized panel system has been estimated to be approximately $2.5 million per year, but whether similar costs would be associated with agricultural lands or the resulting data for agricultural and urban areas sufficient to meet user needs remains an open question. Likewise, although explicit cost information is not available for the GPI inventory, anecdotal reports from State forestry personnel indicate the cost was much less than for a traditional FIA inventory on forest land. In each of these cases, the indications are that a national inventory of agricultural and urban forest resources could be had for a relatively modest cost—less than $10 million per year, but additional work will be needed to verify this cost.

Temporal consistency is as important as spatial consistency; sustained attention and energy are paramount to develop any nationwide monitoring program, or the program could become another one-off national study. Regarding implementation, the data-gathering cycle (e.g., 1 to 10 years) and the reporting cycle (couched in the context of user-group desired outputs) need to be determined. Arrangements and support for ongoing sampling activity will be necessary as will a schedule for expected reports and related data outputs to be produced on a rolling basis.

Conclusions

Adequate information is a prerequisite for sustainable forest resource management. This assumption is the foundation for forest inventory activities under the FIA and for comprehensive forest sustainability reporting under the Montréal Process. The extension of these activities in some form to agricultural and urban forests is an obvious step in our efforts to better understand and manage these resources and the landscapes in which they occur. Developing a national inventory for agricultural and urban forests, however, will not be an easy task. In the first place, it will demand a dedicated funding stream. On a yearly basis, the amount may not be all that large, perhaps on the order of $10 million (as opposed to approximately $60 million for FIA inventory of forest lands), but the expenditure will have to be sustained. A bigger challenge will likely be achieving the agreement and coordination needed to institute a national inventory that is consistent over space and time. This effort will require the integration of different activities undertaken by multiple agencies and individuals across the Nation and a sustained dedication to compiling and publishing the resulting information. On the whole, a considerable amount of data is available, as is expertise at all levels of our society, but coordination and consolidation of these resources remain an issue.

The development and implementation of a national urban forest inventory by FIA will go a long way in establishing the technical and institutional capacity for a broader forest inventory covering all lands in the United States. The extension of FIA-type sampling to agricultural lands, however, will entail various adjustments, exactly as the extension of conventional

FIA sampling to urban lands has required. It is not too early to explicitly consider exactly what would be involved in an FIA-type inventory of agricultural forests.

The first step in this process will be to engage the potential user community—understanding their perspectives and meeting their needs are critical for developing an effective inventory. Most of the information presented in this report is designed to aid in this engagement by identifying important dimensions and issues associated with agricultural and urban forest resources and providing ideas about how they might be measured. Another priority from the onset will be to fully use existing information sources and applicable technologies; we have focused throughout this report on identifying available tools and data and how they might be used in the context of a national inventory. At the same time, it is important that we do not limit ourselves simply to the data that are currently available or the immediate issues that are foremost in the minds of stakeholders; the comprehensive framework of the MP C&I helps remind us of the broader range of issues that need to be considered, even if quantitative measurement for many is likely not attainable. The end result ideally will be (1) a wall-to-wall inventory of forest resources spanning forest, agricultural, and urban lands and (2) an inventory that draws on plot-sampling and remote-sensing data sources, meets the needs of the diverse user communities, and enables us to assess the sustainability of these resources. This report has been designed to lay the foundation for the dialogue and decisions needed to achieve this goal.

References

Cumming, A.B.; Twardus, D.B.; Nowak, D.J. 2008. Urban forest health monitoring: large-scale assessments in the United States. Arboriculture & Urban Forestry. 34(6): 341–346.

Eidenshink, J.; Schwind, B.; Brewer, K.; Zhu, Z.; Quayle, B.; Howard, S. 2007. A project for monitoring trends in burn severity. Fire Ecology (special issue). 3(1): 3–21.

Lefsky, M.A.; Cohen, W.B.; Acker, S.A.; Parker, G.G.; Spies, T.A.; Harding, D. 1999. LIDAR remote sensing of the canopy structure and biophysical properties of Douglas-fir western hemlock forests. Remote Sensing of Environment. 70: 339–361.

Lefsky, M.A.; Harding, D.; Cohen, W.B.; Parker, G.; Shugart, H.H. 1999. Surface LIDAR remote sensing of basal area and biomass in deciduous forests of eastern Maryland, USA. Remote Sensing of Environment. 67: 83–98.

Lister, A.; Scott, C.T.; Rasmussen, S. 2012. Inventory methods for trees in nonforest areas in the Great Plains States. Environmental Monitoring and Assessment. 184(4): 2465–2474.

Louman, B.; Fischlin, A.; Glück, P.; Lucier, A.; Parrotta, J.; Santososo, H.; Thompson, I.; Wreford, A. 2009. Forest ecosystem services: a cornerstone for human well-being. In: Seppälä, R.; Buck, A.; Katila, P., eds. Adaptation of forests and people to climate change—a global assessment report. IUFRO World Series Vol. 22. Helsinki, Finland: International Union of Forest Research Organizations (IUFRO). 224 p. http://www.iufro.org/download/file/4485/4496/Full_Report_pdf/. (August 2015).

Montréal Process Working Group. 2009. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. 4th ed. http://www.montrealprocess.org/Resources/Criteria_and_Indicators/index.shtml. (August 2015).

Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E.; Walton, J.T.; Bond, J. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture & Urban Forestry. 34(6): 347–358.

Nowak, D.J.; Cumming, A.B.; Twardus, D.; Hoehn, R.E.; Oswalt, C.M.; Brandeis, T.J. 2011. Urban forests of Tennessee, 2009. Gen. Tech. Rep. SRS–149. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 52 p.

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A. 2014. Forest resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment. Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture.

Snyder, G.I. 2012. The 3D Elevation Program—summary of program direction: U.S. Geological Survey Fact Sheet 2012-3089. 2 p. http://pubs.usgs.gov/fs/2012/3089/. (August 2015).

U.S. Department of Agriculture (USDA), Forest Service. 2011. National report on sustainable forests—2010. FS-979. Washington, DC: U.S. Department of Agriculture, Forest Service. 212 p. http://www.fs.fed.us/research/sustain/. (August 2015).

Wulder, M. 1998. Optical remote-sensing techniques for the assessment of forest inventory and biophysical parameters. Progress in Physical Geography. 22: 449–476.