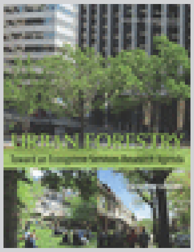

Urban Forestry: Toward an Ecosystem Services Research Agenda: A Workshop Summary

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Katie Thomas and Laurie Geller, Rapporteurs; Board on Atmospheric Sciences and Climate; Division on Earth and Life Studies; National Research Council

URBAN FORESTRY

Toward an Ecosystem Services Research Agenda

A WORKSHOP SUMMARY

Katie Thomas and Laurie Geller, Rapporteurs

Board on Atmospheric Sciences and Climate

Division on Earth and Life Studies

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This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this workshop summary:

GARY ALLEN, Center for Chesapeake Communities, Annapolis, MD
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STEPHANIE PINCETL, University of California, Los Angeles
KATLEEN L. WOLF, University of Washington, Seattle

Although the reviewers listed above have provided many constructive comments and suggestions, they did see the final draft of the workshop summary before its release. The review of this summary was overseen by **George Frederick,** Falcon Consultants, LLC. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authors and the institution.

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CHAPTER 1
INTRODUCTION

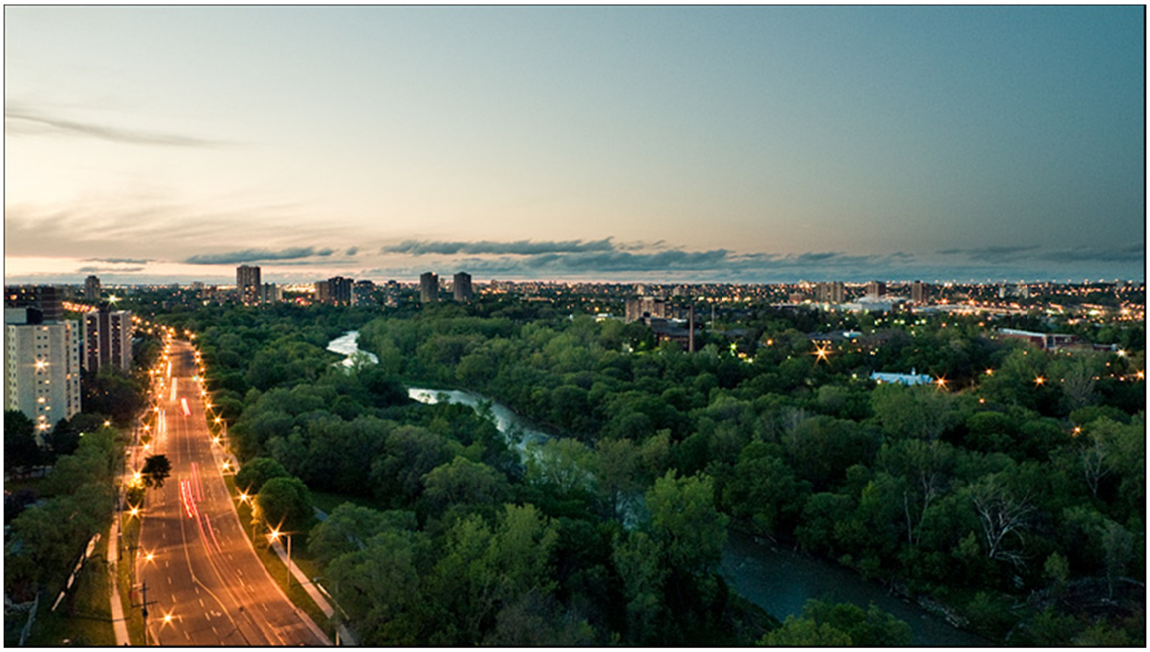

FIGURE 1.1 An urban forest in Etobicoke, Toronto. Photo by Sam Javanrouh.

For most people, the concept of an "ecosystem" brings to mind rural or wilderness areas. And indeed, most ecological research of the past several decades has focused on these remote settings. But today, the frontiers of ecological research can often be found in our cities—the places where most people live, work, and play, and where our everyday decisions (e.g., about housing, transport, consumption) can have profound effects on the environment.

One important element of "urban ecology" is the role of trees in providing a wide variety of environmental benefits, such as

- sequestering of carbon, thus contributing directly to climate change mitigation;
- reduction of air pollution through direct deposition of pollutants and through cooling effects that reduce the formation of ozone;
- shading of buildings, which can lower energy demand for air conditioning;
- reduction of urban heat island (UHI) effects;
- interception of water runoff, thus buffering local waterways from pollution and helping to control stormwater overflow problems;
- provision of vital habitat for wildlife; and
- access to nature.

Many of these benefits, especially those related to air pollution, water pollution, and local cooling effects, have direct, significant impacts on physical human health. There is also growing recognition that exposure to trees and green spaces provides many important socioeconomic and mental health benefits, including enhanced social cohesion, increase in real estate values, improved health and recreational opportunities, and cultural and spiritual values. In fact, one distinction between rural/wildland ecosystems and urban ecosystems in the services they provide is that in urban areas, there is potential daily contact by thousands of people with any single nature element (trees, parks, green space), resulting in a range of possible psychosocial and health benefits.

On Feb 25-26, 2013, the National Academy of Sciences (NAS) held a workshop that brought together over 100 people with a wide diversity of interests in urban forestry research to share information and perspectives, to foster communication across specific areas of ecosystem service research, and to consider integrated approaches that cut across these different realms. The other specific goals of the workshop were to examine the following (see Appendix E for full statement of task):

- current capabilities to characterize and quantify the benefits ("ecosystem services") provided by trees and forest canopy cover within a metropolitan area, which may include benefits to public health and well-being;
- key gaps in our understanding and our ability to model, measure, and monitor such services, and improvements that may be needed to allow tree planting to be sanctioned as a "creditable" strategy in official regulatory control programs (i.e., for air quality, water quality, and climate change response);
- current capabilities for assigning quantitative economic value to these services, and strategies for improving these capabilities (for instance, to allow for rigorous cost/benefit analyses, and for policies that compensate land owners for good forestry conservation and planting practices);
- the challenges of planning and managing urban forests in a manner that optimizes multiple ecosystem services simultaneously (e.g., synergies, tradeoffs in selecting tree species, and determining planting locations); and
- opportunities for enhancing collaboration and coordination among federal agencies, academic researchers, and other stakeholders.

In his introductory remarks, Gary Allen (Executive Director of the Center for Chesapeake Communities and Chair of the workshop planning committee), noted that urbanization can result in most of the available land being utilized for building and "hard" infrastructure development. As cities grow, trees and green spaces are often lost, and with them valuable ecological services, as well as all the benefits stemming from those services. Such concerns are closely related to public health issues and economic and social inequities—all of which, if addressed together, could make cities more sustainable.

While most urban areas in the United States have been losing green space over time, there has been a significant growth in the number of cities declaring ambitious goals for expanding their tree canopy, along with a growing recognition that urban green space is critical to sustaining environmental quality and human well-being. A few regions are now even attempting to include large-scale tree-planting as an official measure in air and water quality control plans, as well as climate change action plans. This represents a potential major step forward in how the ecosystem services provided by trees are valued. But it also entails substantial new requirements to rigorously quantify these ecosystem services.

Our ability to do this sort of quantitative analysis is improving due to a growing base of scientific research, the development of new modeling tools, and advances in remote sensing, Geographic Information Systems (GIS), and other mapping and monitoring technologies. But many uncertainties and challenges remain in developing standard, widely-accepted methods for making such estimates. One challenge, for example, is linking the different types of models needed for these analyses (e.g., forestry and vegetation models, air chemistry and meteorology models, hydrological models, human health impact models) which differ greatly in structure and operate on a wide range of spatial scales. Another challenge is the difficulty in collecting empirical data available to evaluate the effectiveness of specific urban forestry projects in comparison to the modeled estimates of these impacts.

The growing body of (mostly discipline-specific) research aimed at better characterizing the ecosystem services listed above has been accompanied by growing interdisciplinary research on how trees fit into the broader context of urban sustainability (e.g., Dobbs et al., 2011; Chiesura, 2004; Pataki et al., 2011). This research involves not just advancing scientific understanding of the physical, chemical, and ecological processes of urban forestry, but also advancing our social science understanding of public values and attitudes regarding land use decisions, access to nature, and the role of regular citizens as stewards of urban green spaces. Mr. Allen urged the workshop participants to consider such questions in the context of complex governance issues because the land in and around metropolitan areas is often owned and managed by a broad patchwork of federal, state, local government, businesses, and private individuals, all with differing interests and priorities, governance structures, and capacity for forest conservation and stewardship efforts.

Thus there is growing interest in an important, multifaceted area for research that reaches across many disciplines of physical, biological, and social sciences. A major goal of this research is to be able to provide clear, compelling scientific guidance that can help cities grow and sustain forest canopy cover in a way that maximizes and sustains benefits and minimizes costs and potential unintended consequences (such as increased pollen load, risk of fire and storm damages, and greater requirements for water resources). "Smart strategies" for urban forestry include, for instance, selecting the right tree species (e.g., those with low volatile organic compounds [VOC] emissions and high pollution-absorbing capacity, that do not contribute to invasive species problems, or that will have a high survival rate), and choosing strategic planting locations (e.g., should planting strategies focus on maximizing interception of water runoff, on maximizing interception of air pollution plumes, on maximizing cooling of "hotspots," on maximizing social benefits?).

There are a wide array of stakeholders with interests in such issues who can help advance our scientific understanding and technical capabilities. This includes numerous federal agency programs—for instance, the U.S. Forest Service's (USFS) urban forestry programs, the National Science Foundation's (NSF) ecological, social, and geophysical research programs, the Environmental Protection Agency's (EPA) air and water quality research activities, the National Aeronautics and Space Administration's (NASA) remote sensing programs, the public health programs of the Centers for Disease Control and Prevention (CDC), and the Department of Energy's (DOE) energy efficiency programs. It also includes a wide array of state and local forestry and land-management organizations, along with private foundations, non-governmental organizations, and academic researchers.

Mr. Allen closed his remarks by noting that nearly 80 percent of the U.S. population lives in cities, and as these cities continue to grow and develop, there will be both challenges and opportunities for designing more sustainable development pathways. To aid in the design of sustainable cities, urban forest research programs should recognize urban areas as *systems*. Many of the complex human-environment interactions taking place at the urban scale are not yet well understood. A central challenge for the future is to develop strategies for "sustainable stewardship" of urban ecosystems that can support a healthy tree canopy and healthy, safe, diverse environments for the people living in cities and their surrounding metropolitan areas.

WORKSHOP SETTING AND GOALS

A National Research Council (NRC) ad hoc committee of six volunteers, chosen to provide expertise in different elements of urban forestry research, was tasked to plan a workshop that addresses the questions listed in the Statement of Task (Appendix E). The workshop focus was deliberately limited to a particular scope of questions within the boarder realm of urban ecosystem services and sustainability, which center around how to quantify and characterize the biophysical and human health services provided by urban trees. The workshop did not explore questions such as possible alternative strategies for providing such services (e.g. using mechanical structures rather than trees for shading and cooling benefits), or issues such as "cultural ecosystem services" provided by green infrastructure.

Using the Statement of Task as a guide, the planning committee identified the workshop's organizational structure, invited speakers and other participants, and helped facilitate sessions at the workshop itself. The committee organized the workshop around four main themes: (i) urban forestry in the greater urban ecosystem, (ii) biophysical services of the urban forest, (iii) tools for ecosystem service evaluation, and (iv) managing the urban forest. In addition to having a variety of expert speakers on each of these topics, the workshop included substantial time for interactive discussion among all of the participants in four breakout groups. For each of the themes above, the breakout group participants discussed: (a) what are the key remaining questions and challenges, and (b) what is needed to address these questions and challenges? Finally the breakout groups were asked to consider what research activities they themselves would pick as high priorities if in a position to support urban forestry-related research.

This report summarizes the presentations and discussions that took place in all of the various workshop sessions.[1] This effort was designed as a "convening activity" rather than a "consensus study," and thus there was no attempt to reach consensus on specific findings or recommendations. Rather, this report simply presents the full diversity of ideas and suggestions that arose in the workshop discussions.

The committee hopes that this report will provide a useful resource to the wide array of urban forestry stakeholders (e.g., researchers and program managers in agencies such as the USFS and the EPA, academic researchers, and foundations and non-governmental organizations that support community forestry issues), in particular to help shape their support for future research. More generally, this report might help inform some decisions made by urban-level policymakers, planners, and managers regarding investments in large-scale tree planting efforts and other elements of green infrastructure.

Ultimately, the hope is that the field of urban forestry research, in all of its dimensions, will be advanced by the personal interactions and connections that took place at the event and by the summary outcomes presented here.

REPORT ROADMAP

The workshop featured a range of presentations by scientists, stakeholders, and policymakers as well as time spent in breakout groups to allow for interactive discussion. This is reflected in the three chapters of this report:

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[1] This report has been prepared by the workshop rapporteurs as a factual summary of what occurred at the workshop. The planning committee's role was limited to the planning and convening of the workshop. The views contained in this report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Research Council.

- Chapter 1 (this chapter) provides the context for this study and introductory material from the workshop.
- Chapter 2 summarizes the presentations from the four panels: Urban Forestry within the Greater Urban Ecosystem, Biophysical Services of the Urban Forest, Tools for Ecosystem Service Evaluation; and Managing the Urban Forest. Key points from the discussion sessions following each panel are also included in this chapter.
- Chapter 3 presents a brief overview of the issues discussed by the workshop breakout groups (key remaining questions and challenges of urban forestry, strategies to address these challenges, and priorities for future research). The detailed summary of those breakout discussions are presented in Appendix A.

A definition of some key terms used throughout the report can be found in Box 1.1.

BOX 1.1

Definition of Terms

Biophysical services: Ecosystem services provided by the physical environment (water, soil, air, etc.) and the biological activity within it (plants, animals, etc.).

Cultural ecosystem services: Nonmaterial benefits people obtain from ecosystems, such as cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism.

Disservices: Negative or unintended consequences.

Ecosystem services: Life-sustaining benefits humans receive from nature, such as clean air and water, fertile soil, pollination, and flood control.

Gray infrastructure: Refers to traditional practices for stormwater management and wastewater treatment, such as pipes and sewers.

Green infrastructure: A variety of natural elements (trees, grasses, gardens) designed and landscaped to manage water naturally.

Hyperfunctional or hyperfunctionality (referring to systems of managed landscapes, infrastructure): Since cities can only afford to allocate limited space to infrastructure and land, each unit needs to be hyperefficient to achieve its goal (e.g., reductions in pollution, runoff, temperature, etc.).

Street tree: Trees located on a strip of land between a roadway and a sidewalk.

Urban forestry: The care and management of urban forests.

Urban forest[a]: A collection of trees (including any woody plants) that grow within a city, town or a suburb.

Urban heat island: A phenomenon where air temperatures in urban areas are 2-10 F hotter than surrounding rural areas due to the high concentrations of buildings and pavement in urban areas.

Urban metabolism: Quantification of the total resource inputs, outputs, and transformations in a city stemming from urban socioeconomic activities and regional and global biogeochemical processes.

[a] There is no commonly accepted definition of the term "urban forest." Although there are trees in the urban environment, and their density, or canopy cover, varies in different cities, at what point does it constitute an urban forest? Trees in a city, chosen by residents over time from different ecotones and planted together may descriptively be a forest (i.e., a grouping of co-located trees), but functionally it may not.

CHAPTER 2

URBAN FORESTRY: SERVICES, TOOLS, AND MANAGEMENT

SETTING GOALS AND DEVELOPING STRATEGIES IN URBAN FORESTRY

Ann Bartuska, U.S. Department of Agriculture

There has been an increased emphasis on sustainable cities. One component of a sustainable city is the inclusion of trees as part of the greater urban ecosystem. This shift toward the concept of socioecology will require a deliberate integration of social and biophysical sciences, breaking down silos in governance and management, market-based solutions, and valuing green infrastructure.

A significant challenge in urban forestry is fostering a sense of environmental stewardship. How do you engage all the needed stakeholders and provide them with useful tools and information? Environmental stewardship requires various groups to conserve, manage, monitor, advocate for, and educate their friends, neighbors, and representatives about their local environments. Everyone deserves access to green space, which ties into the idea of environmental justice.

Tools developed by the U.S. Department of Agriculture (USDA) are now focusing on an integrated ecological system, rather than simply trees, and are being developed to help foster environmental stewardship. For example, the Stewardship Mapping and Assessment Project (STEW-MAP) is a geospatial tool utilized by several cities, including New York City, to understand the intersections of green space and social space. These maps quantify stewardship networks and linkages by indicating where particular types of organizations are working together and where improvements can be made to encourage more cooperation among these organizations. These networks allow communities to share the skills that they have learned in developing green space in urban areas. STEW-MAP highlights existing stewardship gaps and overlaps to strengthen organizational capacities, enhance citizen monitoring, promote broader public engagement with on-the-ground environmental work, and build effective partnerships between stakeholders involved in urban sustainability.

This shift toward an integrated ecological system is impacting the types of R&D being conducted at USDA. For example, USDA conducts urban research in forest inventory and management, ecosystem services, health and wellbeing, urban sustainability, green infrastructure, water and watersheds, and urban long-term research. Urban agriculture challenges USDA to think about how more traditional aspects of agriculture can contribute to more sustainable urban ecosystems.

USDA is just one of several agencies that study urban issues. In the spirit of environmental stewardship, how can we bring these agencies together with the common goal of sustainable cities? The NSF Long-term Ecological Research (LTER) Program consists of 26 sites with over 1800 scientists and students studying ecological processes over extended temporal and spatial scales. This valuable effort highlights the importance of long-term observations in an interdisciplinary setting. Including urban systems into LTER networks (e.g., Baltimore and Phoenix) has been an important step forward.

The 2010 NRC report *Pathways to Urban Sustainability: Research and Development on Urban Systems* explores the landscape of urban sustainability research programs in the

United States and provides useful advice that could be used by many agencies that work on urban forestry. The report explores how urban sustainability can move beyond analyses devoted to single disciplines and sectors to systems-level thinking and effective interagency and intergovernmental cooperation. It concludes that it is critical to better integrate science, technology, and research into catalyzing and supporting sustainability initiatives; find commonalities, strengths, and gaps among rating systems; and incorporate critical systems needed for sustainable development in metropolitan areas.

Discussion

Dr. Bartuska was asked how USDA is defining "sustainability" in the context of an increase in population, economy, and agriculture. She said there is a balance of three factors in the context of sustainability: people, planet, and profit. USDA does have a sustainability office and they must continue to be aware of what constitutes sustainability and sustainability practices. For example, USDA's Beginning Farmers and Ranchers Program ensures that participants address water and air issues, as well as biodiversity issues and then incorporate these into practice. Dr. Bartuska also noted that the USDA Agricultural Research Service has a project in small and organic farms in urban areas.

URBAN FORESTRY WITHIN THE GREATER URBAN ECOSYSTEM
Moderator: *Marina Alberti*

Urbanizing regions pose enormous challenges to ecosystem's capacity to deliver important ecological services (Alberti, 2010). At current rates of urban growth, global urban land cover will increase by 1.2 million km^2 by 2030, nearly tripling the global urban land area of 2000, with considerable loss of habitats in key biodiversity hotspots (Seto et al., 2012).

Scientists have made significant progress during the last few decades in studying the role of urban forests in both mitigating urbanization's impact and providing a variety of ecosystem services. Yet scientific understanding of key mechanisms governing ecosystem functions across multiple scales is incomplete. There are important tradeoffs across scale and between functions. There is also great variability across metropolitan areas and biophysical regions.

The goals of this panel were to (1) explore the role of trees within the greater urban ecosystem and the ecosystem services they provide, and (2) review current understanding of the ecosystem services provided by urban forests, and identify research needs.

Urban Ecosystems and their Potential to Provide Ecosystem Services
Richard Pouyat, United States Forest Service (USFS)

The environmental changes and landscape alterations typical of urban areas make it difficult to be "green." Urban areas have highly modified environments, sealed surfaces, and species introductions that are human-caused and thus represent novel habitats made up of novel assemblages of plants and animals. From an evolutionary perspective, these assemblages are relatively new, since cities have been around for only 5,000 or so years. As a result, urban landscapes are typically thought of as artificial, harsh environments where cultivated plants grow outside their native habitats, and where animals introduced as pets (such as domesticated cats) wreak havoc on prey species such as native song birds.

Despite these alterations, urban ecologists are finding high levels of biological activity and biodiversity in urban areas (Gregg et al., 2003; Ziska et al., 2004). Measurements thus far suggest there are high flux rates, large sinks for carbon and nitrogen, and high resource availability (e.g., cities emit large amounts of carbon dioxide which are utilized by plants). Therefore, urban ecosystems possess the potential to provide ecosystem services. However, our ecological knowledge of these systems is lacking because ecologists in North America have only relatively recently begun to study them in a comprehensive way.

Because of the novelty of urban ecosystems, urban landscapes represent a "new heterogeneity" for ecologists to quantify and understand. This term is used because, depending on the scale of observation, urban landscapes are not necessarily more complex. In fact, in some cases urban landscapes may be less heterogeneous since they have been more "homogenized" due to management activities, scales of disturbance, human preferences, and the parcelization of the landscape into management units. Since the level of heterogeneity largely depends on the scale of observation, four dimensions should be considered: longitudinal and lateral spatial dimensions, the vertical dimension (e.g., vertical air column, soil column), and the time dimension (e.g., hydro-curve for an urban stream). One of the biggest challenges for ecologists is accounting for human behavior and decision making, because humans may make irrational decisions, and human culture and value systems vary spatially. It is also difficult to quantify intrinsic and monetary values from an ecosystem services perspective.

Another key point related to ecosystem services is that all life on earth is limited by available energy. Therefore, there are tradeoffs in between ecosystem services and costs. For example, there is no organism that can do everything well—allocating resources for one function takes away resources from another function. The same can be said for ecosystem services.

As mentioned earlier, ecological science is a relatively young science (about 100 years) compared to the physical sciences, and urban ecological science is even younger (less than 50 years). Therefore, there is a steep learning curve. Moreover, an ecological definition of "urban" has yet to be developed (Ellis and Ramankutty, 2008). One possible definition is the threshold in human population density at which the population cannot be sustained with the resources available locally and must depend on resources brought in from outside the local area The importation of resources can cause disservices in areas at great distances from cities (Newman, 1999). Moreover, if imported resources are not used efficiently, there is a waste stream which can impact ecosystems at great distances (another potential disservice). With this definition, one may think that cities are bad; however, densely populated areas such as cities are part of the solution, since the distribution of people from cities across rural landscapes would arguably cause even greater environmental disservices than concentrating people into cities (Brown et al., 2009).

Whatever the case, there are also tradeoffs of ecosystem services occurring within cities. A higher human population density will diminish ecosystem services and resources locally. For instance, cities have many polluting sources, fragmented habitats, built structures, and impervious surfaces, which lead to disrupted nutrient cycles and a loss of native biodiversity. The field of civil engineering was developed to design "gray infrastructure" to overcome some of these disservices. Civil engineers have had many more centuries of experience in developing gray infrastructure than ecologists have had with their new concept of green infrastructure. Good examples of gray infrastructure exist in ancient Rome and more modern "sanitary" cities rising from the industrial revolution such as New York City. However, there are detrimental side effects in the use of gray infrastructure that can lead to disservices. For example, gray infrastructure interrupts natural flow paths such that urban streams can become prone to flash flooding causing stream erosion downstream. Moreover, gray infrastructure degrades with time (Kaushal and Belt, 2012).

Land use change has impacts on ecosystem services, which has been a major concern for converting natural to agricultural systems. Natural systems typically provide multiple ecosystem services, but in converting these systems to agricultural production systems, these services are greatly diminished. To address this issue, efforts are underway to design agricultural production systems so that they provide multiple services along with producing food (Foley et al, 2005; Figure 2.1). In the case of urban land use conversions, much less space (or pervious area) is available to provide ecosystem functions. Therefore, not only do we need to design urban landscapes that provide multiple functions, but those that include hyper-functioning systems as well.

In urban areas, the integration of green (vegetation), brown (soils), and blue (streams) infrastructure is one way to develop a multifunctional landscape. It is best to design these infrastructures in parallel, linking one to another—for example, a green roof that is linked to a rain garden, which is then linked to a retention pond system, so that storm size events are moderated. Advantages of integrating these types of infrastructures include: avoiding side effects (e.g., high peak flows), utilizing biological processes to self-maintain, and preserving the function of pre-existing ecosystems.

Unintended effects, risk, infrastructure performance, system longevity, and the possibility of disservices occurring at great distances all need to be considered when designing green infrastructures and locating those infrastructures in urban landscapes. Natural experiments can be conducted to examine the tradeoffs that occur as landscapes are urbanized. For example, when comparing forest fragments in an urban context to a rural one, roughly half the natural sink for methane, a greenhouse gas (GHG), is lost. When a forest is converted to turfgrass, the entire methane sink is lost (Pouyat et al., 2009). These kinds of unintended effects should be considered, and decision tools are needed that will optimize multiple factors simultaneously, because making a poor decision in designing or locating green infrastructures in urban landscapes may be worse than not doing anything.

Pouyat summarized by stating that (1) a basic understanding of urban ecosystems should be developed, which can be accomplished by utilizing the urban mosaic to conduct "natural experiments," conducting cross-system comparisons (local, regional, global), and developing integrated models that spatially and temporally quantify the "new heterogeneity" represented by urban landscapes; (2) urban observations should be expanded into networks (e.g., a network of urban LTER sites or existing environmental monitoring networks such as the National Atmospheric Deposition Program); (3) decision tools need to be developed that can optimize across factors (e.g., species selection, management) while considering tradeoffs and providing a decision space (e.g., uncertainty, risk); and (4) multifunctional and hyperfunctional infrastructures need to be designed and developed.

Services and Regional Tradeoffs: Resolving the Desert Forest Paradox

Diane Pataki, University of Utah

Urban forests in desert areas are an extreme example of novel ecosystems. Salt Lake City, Utah, for example, is naturally a shrubland, yet the city has an extensive urban tree canopy (Figure 2.2.). Virtually all of these trees are planted and irrigated, making this an extreme example of a human-created and managed forest.

Given that ecosystem services is a concept intended to quantify the value of natural rather than designed ecosystems, urban ecosystems originally were assumed to have negligible monetary value on a global scale. What happens when we are designing ecosystems to have intended values? How do we cope with the costs of designing and managing novel ecosystems that require resource inputs?

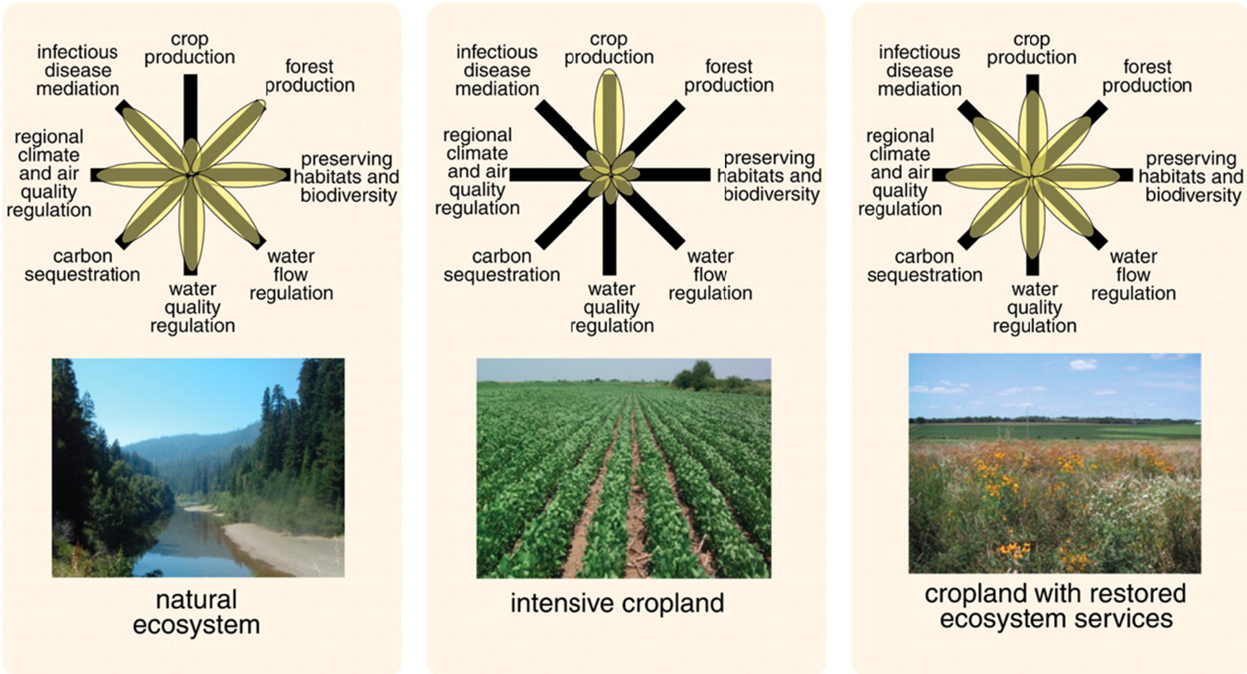

FIGURE 2.1 Conceptual framework for comparing land use and tradeoffs of ecosystem services. The natural ecosystems (left) are able to support many ecosystem services at high levels, except for food production. The intensively managed cropland (middle) is able to produce food in abundance (at least in the short term), but loses other ecosystem services. However, a cropland that is explicitly managed to maintain other ecosystem services may be able to support a broader portfolio of ecosystem services (right). This framework could be applied to urban land use conversions, albeit on a smaller scale since there is less land available in the urban landscape. SOURCE: Foley et al., 2005.

Novel and non-native ecosystems often have significant monetary and environmental costs, but this is not necessarily a bad thing. For example, urban forests in arid and semi-arid cities use a lot of water. These designed ecosystems will often have significant costs, which may be acceptable if benefits outweigh the costs. However our research increasingly shows that the most important benefits of novel urban forests are cultural and thus are very difficult to quantify with existing tools. We need a new set of tools that extends beyond the standard ecosystem services framework to capture the complex relationship between urban residents and the novel urban environment.

One tool we can bring to an expanded toolbox for planning and managing urban forests is urban metabolism (Kennedy et al., 2012). This concept has been used by several different disciplines for decades and has been variously defined, but it generally involves quantifying the total resource inputs, outputs, and transformations in cities. Although there are some data constraints in quantifying urban metabolism, this concept is critical for quantifying the role of urban forests in the functioning of the city as a whole.

Urban metabolism can be used as a tool to help us characterize the benefits of trees in a larger context. Urban forests are often thought of as a tool for mitigating climate change; however, carbon sequestration by urban trees does not have a significant impact in offsetting fossil fuel emissions (Pataki et al., 2006; 2011). Trees do, however, have a significant cooling effect (through evapotranspiration and shade), which may impact GHG emissions indirectly (Franco and Sanstad, 2008). For example, a city can save on energy costs by requiring less air conditioning. It is important to understand these mechanisms because urban forests designed for carbon sequestration may look quite different than forest canopy designed to maximize cooling.

FIGURE 2.2: The left image is a picture of Salt Lake City, UT. Notice the natural shrubland in the foreground and the novel (planted) trees in the city. The right image shows what Salt Lake City would like in its natural state. SOURCE: Barry Howe/Corbis (left image); Diane Pataki (right image).

There are other useful tools for designing and planning urban tree populations that originate in engineering. There is currently a great deal of discussion about substituting green infrastructure for "gray" infrastructure. However, utilizing trees as urban infrastructure requires monitoring and validation to ensure that urban forests meet design targets. For example, to consider pollution removal by trees as urban infrastructure, we need measurements and monitoring of the specific and local impacts of trees on pollutant concentrations. This regularly occurs in gray infrastructure projects; sewage treatment plants, for example, are routinely monitored to ensure that effluent meets water quality standards. It is not necessary to quantify the ecosystem services provided by sewage treatment plants—they are engineered to meet specific regulatory requirements. The scientific methodology necessary to make similar measurements for green infrastructure, such as urban trees, currently exists as shown by the other workshop speakers, and needs to be more commonly implemented along with tree planting programs.

Other tools for designing and planning urban forests are available from the disciplines of architecture, planning, and design. Existing tools can also be used for stakeholder engagement, which can help determine local values. "Envision Utah"[2]" was a well-known program that used a participatory process to develop a set of common, shared scenarios for future urban growth. It is possible and necessary to develop similar planning and visioning processes for urban trees and green space. The beginnings of such programs are underway; "Envision Tomorrow+" is a planning tool being developed to include environmental outcomes and some initial estimates of ecosystem services.

In conclusion, tools for characterizing the net services of urban trees should be place-specific and spatially explicit, have visualization components, include community values and visioning, incorporate urban metabolism stock and flows, and capture measurable performance-based metrics. These tools can also be utilized by people from different disciplines. This approach extends the tools and vision for urban forests beyond the ecosystem services concept, to capture the larger role of urban forests in the functioning of cities.

[2] *http://www.envisionutah.org/*

Challenges for Green Infrastructure at the Interface of Science, Practice, and Policy

Thomas Whitlow, Cornell University

There are many challenges in reaping ecosystem services within a city, including competing agendas (e.g., many goals, many languages, and many metrics), immature science and technology, need for hyperfunctional design, and unanticipated findings in case studies in air pollution. As one example of failing to meet expectations, Bernhardt et al. (2005) found that many stream restoration projects did not accomplish their goals.

Several as-yet-unpublished air quality case studies from the New York City area found that air quality was poorer downwind of trees. In Case Study 1, it was hypothesized that greener surroundings (e.g., trees, shrubs, etc.) in an urban environment leads to cleaner air because leaves filter out pollution. The study found that particulate matter (PM2.5) concentrations were higher ten meters from the curb and downwind of two rows of mature trees than at five meters, suggesting that trees impede dispersion, creating zones of increased pollution. Fifty meters of separation were needed to disconnect a location in the landscape from events occurring on the street (Figure 2.3). In Case Study 2, researchers monitored two transects downwind of Van Wyck Parkway in New York City and found that PM2.5 concentration decayed more rapidly along an open transect than a vegetated transect.

In Case Study 3, measurements were taken at a rural site to test the influence of tree canopy on background concentration. Researchers discovered that air quality was worse more than 90 percent of the time in a stand of either spruce or deciduous trees compared to an open field. In Case Study 4, the extinction of particle plumes was monitored in a wind tunnel containing varying amounts of leaf surface. Leaf area had no effect on the decay rate of the plumes. In Case Study 5, human health implications were studied using cytokines[3] as biomarkers for inflammation. Cell cultures challenged with airborne particulates collected from parks showed higher cytokine induction than samples near streets or rooftops.

In all of these cases, findings ran counter to expectation, indicating that we need a more sophisticated understanding of the mechanisms influencing particulate behavior if we hope to design effective pollution mitigation using green infrastructure.

Another challenge for green infrastructure is to move from multi-functionality to intentional hyperfunctionality. That is, if cities can only afford to allocate limited space to green infrastructure, each unit of green needs to be hyperefficient if we intend to achieve meaningful reductions in pollution, runoff and temperature; green space needs to be deliberately designed to enhance its benefits.

In conclusion, we should move beyond the simple notion that "more green is better." Designing hyperfunctional green infrastructure requires an adaptive management approach involving experiments, modeling, ground truthing, and comparative studies in order to promulgate useful policy and effective practices.

Urban Nature: an Artifact of the Industrial City[4]

Stephanie Pincetl, University of California, Los Angeles

We are living in a new age: the Anthropocene[5]. Humans are now an urban species and shape many of Earth processes. This raises questions about what it is to be human in an

[3] Substances that are secreted by specific cells of the immune system and are used extensively in cellular communication.
[4] Dr. Pincetl was unable to attend the workshop, but provided her PowerPoint presentation to all workshop participants.

urban age, how cities are built and grow, as well as our "need for nature." Cities are nature—inert minerals transformed by humans into infrastructure. However, where does living nature fit in?

Until the industrial revolution, cities were essentially devoid of living nature, except for elite gardens. There was a hierarchical order of civilization out toward the wilderness—cities were surrounded by agriculture and the countryside, which were surrounded by wilderness. In fact, nature was feared and powerful. The wilderness had wolves, bears, and other predators. Agriculture was a struggle against weather, weeds, animals, soils, water supply, and trees.

The harnessing of fossil energy enabled industrialization and changed humans' relationship with the planet. This led to a dramatic transformation of nature, enormous increases in manufacturing productivity, and the concentration of humans in urban centers as never before. The Industrial City was polluted, crowded, and insalubrious.

During the early years of the industrial revolution, living conditions in cities were abysmal. Tree-lined streets and parks were seen as agents of change to make cities more livable. Frederick Law Olmsted's Central Park was seen as the lungs of the city for the working class: "A park is a work of art, designed to produce certain effects on the mind of men (Olmsted, 1868)." This led to the rise of landscape architecture and interest in the exotic, including plants that were non-native. This interest reflected the new cosmopolitanism, reaching far beyond the local.

Human views of trees began to change. George Perkins Marsh[6] showed the importance of trees for watershed function, which led to preservation of forests that were still in the public domain. This coincided with the rise of the preservation movement and the idealization of nature.

Eventually there was a tree-planting movement in cities. The urban expansion across the American west into the treeless plains provoked deliberate urban tree planting, starting in the 1870s in Nebraska with the founding of Arbor Day, as lands west of the 100th Meridian were arid and treeless. Citizen-based urban tree planting spread in mostly affluent areas. Tree planting became a civic obsession; there was an association of virtue with trees. In the United States, emphasis was placed on neighborhood trees (planted by individuals along streets). Gifford Pinchot, the first director of the USFS, actively promoted tree planting in cities.

In the 20th century, parks and open space became normalized as part of urban planning and design. Urban trees were seen as part of the health of residents and a sign of a well-tended neighborhood. Postwar prosperity led to urban expansion.

In the mid-20th century, concerns were raised about the preservation of nature and the environment. Rachel Carson (1962) sounded the alarm on chemical impacts, which led to the modern environmental movement. In the 1970s there was formal federal Forest Service assistance for urban tree planting. Eventually Tree City USA was initiated by the National Arbor Day Foundation in cooperation with the U.S. Conference of Mayors, the National League of Cities, the National Association of State Foresters, and the USFS[7].

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[5] An informal geologic chronological term for the present geological epoch (from the time of the Industrial Revolution onwards), during which humanity has begun to have a significant impact on the environment.

[6] For more information on George Perkins Marsh, see *http://www.clarku.edu/departments/marsh/about/*

[7] *http://www.arborday.org/programs/treeCityUSA/about.cfm*

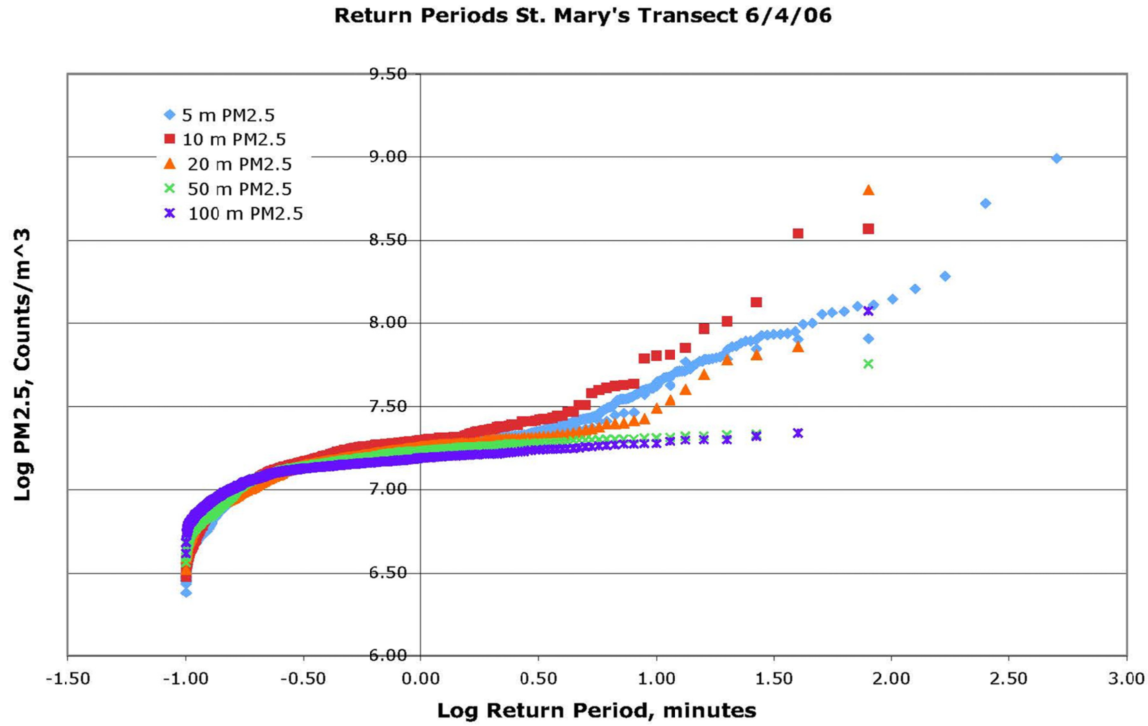

FIGURE 2.3: PM2.5 concentration taken from various distances from a curb and downwind of 2 rows of mature trees plotted against time. Unexpectedly, the air 10m from the mature trees is dirtier than the air 5m from the mature trees. SOURCE: Thomas Whitlow.

Urban sustainability has been part of the public focus since the 1980s. Cities are now seen as sites of their own pollution and impacts remediation. An instrumental urban nature can be developed to help in this endeavor, as it can provide provisioning, regulating, cultural, and possibly supporting services. Trees have become emblematic of urban ecosystem services in cities across the country, and million tree planting programs have become popular.

But what is sustainable for whom and where? Do alleged services add up? Some parts of the country are naturally treeless and water-restricted; yet planting trees requires water resources. Maintaining trees also requires long-term funding and specialized knowledge. This is problematic if residents have neither. It also should be acknowledged that not all people like trees. Some ecosystem service structures such as bioswales, water infiltration, and trenches are also costly and require fundamental changes in urban morphology.

How do we implement the right urban ecosystem services for each place? This will require new forms of public administration and different rules to create new agendas, sharing of budgets, and co-management of new infrastructure (e.g., water and sanitation with street services). New sources of funding are also needed, as well as new skills to maintain “living infrastructure.” Each region will have different climatic tolerances, and ecosystem services will have to be appropriate to the conditions. Success will depend on public acceptance of a different-looking city, and willingness to lend their individual private property to the effort. This will require a deep shift involving public stewardship, and new ideas of property rights and obligations. Finally, the sanitary city[8] of the 20th century needs to be retrofitted so natural processes can work to help mitigate urban impacts and to develop the sustainable city of the twenty-first century.

Urban ecosystems have costs and benefits, and quantifying the benefits is difficult. Trees perform differently across different ecosystems and in different urban locations. Does their performance translate to the benefits claimed such as reducing the use of air conditioning or sequestering GHG emission? Trees that are brutally pruned will see their ecosystem services severely curtailed. These kinds of factors should be taken into account.

What is the value of ecosystem services? This is still largely unknown and represents the instrumentalization of nature. Humans have transitioned from fear of and vulnerability to nature's impacts and processes, to domination and pricing of its functions, with meager quantification compared to the complexity of what is being proposed. There has been minimal effort to address the public administration and land management changes that are necessary to implement the changes proposed. The issues of beauty and wellbeing are also unaddressed. Yet humans are now urban dwellers and our relationship to nature has changed. Do we need nature to feel happy?

Discussion

Some points raised in the open discussion that followed this panel's presentations:

- An important goal for improving urban forestry models is to link hyperfunctional ecosystem services to regulatory requirements.
- Optimizing hyperfunctionality across many outcomes while focusing on the factors that the local community most values, would take into account people's widely differing values and priorities.
- The urban environment brings together many different types of plant and animal species that have no history of co-evolving. The mechanisms of how these unique ecosystems function is therefore largely unknown.
- National-level support could help capture knowledge and foster collaborative learning across cities.

BIOPHYSICAL SERVICES OF THE URBAN FOREST

Moderators: ***Kenneth Potter, University of Wisconsin; ST Rao, North Carolina State University***

As discussed in the previous session, urban forests provide a variety of functions including climate mitigation, carbon sequestration, mitigation of stormwater runoff, and regulation of nutrient cycling, as well as habitats for many species of wildlife. This session was a continuation of the previous session and focused on the biophysical services of trees with respect to air, water, climate, wildlife, and health. Panelists were asked to discuss the current state of the science in their respective disciplines on the biophysical services provided by urban forests. They were also asked to discuss the remaining challenges and open questions surrounding the science and the additional research, data, and observations that are needed to resolve these questions.

[8] An urban form developed to correct the ills and hazards of the industrial city.

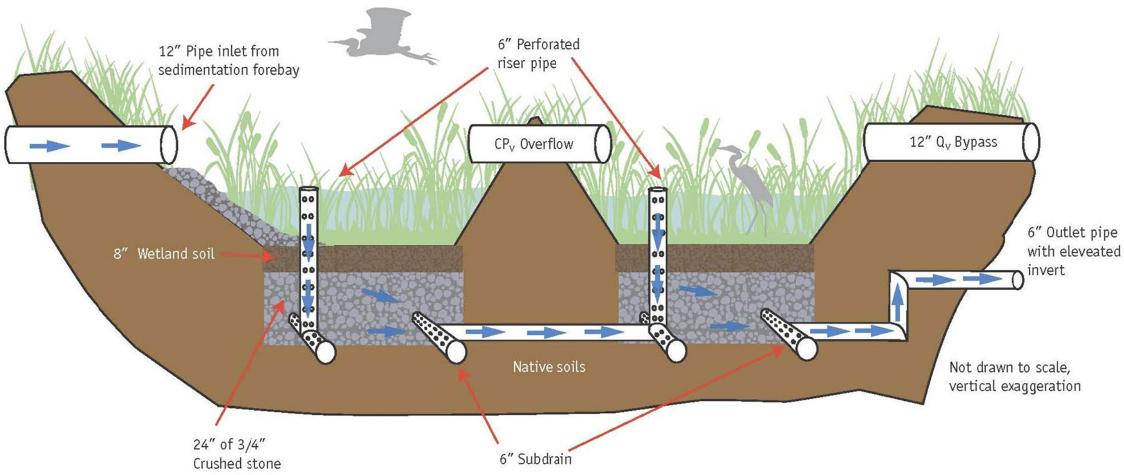

FIGURE 2.4: A schematic of a subsurface gravel wetland. SOURCE: University of New Hampshire Stormwater Center.

Trees Incorporated into Urban Stormwater Management

Tom Ballestero, University of New Hampshire

Sewage treatment utilizes very sophisticated systems, whereas stormwater management is relatively low tech. Many types of processes are utilized in stormwater management, including hydraulic control, storage, sedimentation, filtration, infiltration, sorption, biodegradation (microbial, rhizospheric, plant), and chemical. Systems that perform filtration yield higher water quality effluent than other systems. Common filtration systems can include constructed systems (e.g., permeable pavements and sand filters) and biological systems (e.g., subsurface gravel wetland, tree filter, and bioretention systems).

Green infrastructure can be designed to perform better at stormwater management than pre-development ecosystems. Often, aside from filtration, these designs incorporate infiltration as part of the stormwater management.

A tree box filter is a mini-bioretention system. A bioretention system consists of a high permeability, manufactured organic soil bed planted with suitable, preferably native vegetation. Vegetation in the soil planting bed assists in removing pollutants from stormwater runoff.

Subsurface gravel wetlands, an example of a biological mechanism for filtration, are an innovative variation on the traditional stormwater wetland (Figure 2.4). Subsurface gravel wetlands have high efficiencies for removing sediments, nutrients, and other pollutants commonly found in runoff. The stormwater is filtered as it flows underground, horizontally through the wetland. Because the primary flowpath is subsurface, the system runs anaerobically, which supports denitrification. However, an aerobic zone needs to be placed in front of the subsurface gravel wetland to convert most of the dissolved nitrogen forms to nitrate. As stormwater moves from the aerobic zone through the subsurface gravel, it becomes denitrified. This type of system requires a significant amount of land, but it does allow for more diversity in the types of vegetation that can be planted over it (e.g., native wetland grasses, reeds, herbaceous plants, and shrubs).

There are various metrics that can be used to measure the social benefits of the use of green infrastructure for stormwater management. One example is cost. Conventional technologies (e.g. gray infrastructure) are typically the cheapest initially, however, more advanced methods (e.g., low impact development) have the lowest maintenance costs overall. A normalizing method of comparing costs considers dollars per pound of pollutant removed per watershed area treated. There are hidden costs to gray infrastructure: water quality degradation due to poor removal efficiencies, lost recreational values, watershed impairments, property value loss, uncontrolled contaminants (temperature, energy), and sustainability (water supply, low flow).

It is important to determine the objective of the infrastructure and then match technologies to that objective. Green infrastructure designs should not be considered too generically. There are also low-hanging fruit. For example, a substantial reduction in pollutant loading could be achieved by modifying some of the areas with relatively low land cover but high loading and imperviousness. This includes both commercial and industrial sites (building sites, parking lots, etc.).

There are several barriers to the implementation of green infrastructure. These include: maintenance misperceptions, initial cost, ease of permitting acceptance, designer/regulator unfamiliarity, turf wars in administrative management, and the "impossible challenges" thrown at new technology compared to the general acceptance of conventional technologies (ponds, swales, curb, gutter). The science exists, but implementation remains slow. Green stormwater management is not yet part of the DNA of urban planning and design. Ultimately, in the absence of green infrastructure, everyone will have to continue to subsidize the cultural and ecosystem consequences resulting from conventional land development, whether new development or redevelopment.

Urban Forest Effects on Meteorology and Air Quality[9]

Jonathan Pleim, EPA

In recent years, EPA has been pushing towards integrated, transdiscplinary research where air quality is considered along with climate change and meteorology. Coupled modeling systems are important tools for this research, but the models can become so complex that they are difficult to run and interpret.

There are several key questions related to the effects that urban characteristics and urban forests have on meteorology and air quality. For example, do we have the data and models that can adequately capture and assess these effects? What are the gaps in our understanding and modeling capabilities? How should we consider changes in air quality along with other effects of increased urban tree coverage?

The UHI effect is a well understood phenomenon that leads to hotter daytime and nighttime temperatures in urban areas, compared to surrounding rural areas. Hotter daytime temperatures in cities are a result of widespread dark impervious surfaces and less vegetation, which leads to reduced evapotranspiration and thus greater sensible heat flux. Solar radiation is trapped in the urban street "canyons," adding to surface heating. Warmer nighttime temperatures are caused by the high heat capacity of building materials, which store more daytime heat and release it at night. There are also the effects of limited sky view, which reduces radiational cooling (i.e., buildings in urban areas partially block upwelling long wave radiation from the ground). Anthropogenic energy use from cooling, heating, industrial processes, and vehicular traffic also adds heat during both the day and night.

Trees mitigate the UHI by increasing evapotranspiration, reducing the sensible heat flux and providing shade over high heat capacity surfaces. However, studies have also found that trees impact pollutant dispersion by reducing convective turbulent mixing, boundary layer depth (the zone through which pollutants are well mixed), and ventilation. These three factors all lead to *higher* pollutant concentrations.

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[9] Dr. Pleim was unable to attend the workshop. His presentation was given by S.T. Rao.

Trees also have direct and indirect impacts on air chemistry. They enhance the removal of air pollutants and the emission of volatile organic compounds. The cooler temperatures that can result from trees lead to reduced evaporative anthropogenic emissions, slower photochemistry, and reduced energy use in the summer.

There has been a significant amount of research on trees' impact on pollutant removal. An increased number of trees provides greater leaf surface area for dry deposition of both gas and particulate pollution. Dry deposition of gases occurs via two pathways: onto leaf surfaces and through leaf stomata. Particulate deposition occurs by impaction, interception, and diffusion at leaf surfaces. The efficiency of aerosol uptake depends on the type of tree (i.e. needle leaves are more efficient than broad leaves). Also, reducing the air temperature by a couple of degrees will lower energy [cooling] demand, which in turn reduces pollutant emissions from power generation. These types of feedbacks have not yet been fully taken into account in studies of the effects of urban trees on air quality. The net impacts could be that air pollution levels are lowered by trees, but this is not necessarily the case in all situations.

The extent of tree cover varies widely across cities. For example, Salt Lake City has more than twice the tree cover of Chicago (EPA, 2008). The greatest effect of urban trees is on the surface energy budget, because cooling results from the latent heat of evapotranspiration. Observations across many cities show that the fraction of surface energy converted to latent heat increases proportionally to vegetation coverage, with the greatest cooling benefits in higher density urban areas.

Urban land surface modeling varies widely in complexity. Models with greater complexity require specifications of a large number of parameters that are difficult to obtain or to specify. There are tradeoffs between complexity and computational requirements, with more complex models generally requiring more computational resources. Also, evaluation studies suggest that increased complexity does not necessarily result in improved performance (Grimmond et al., 2011). Determining the appropriate complexity depends on the scale and application of the model. Accurate specification and modeling of vegetation is crucial for accurate simulation of the surface fluxes. Vegetation data and land surface modeling are especially important for assessing the impacts of urban forests.

Based on model runs, urban trees generally mitigate the UHI effect by partitioning surface energy more into latent heat and less into sensible heat. The cooling benefits of additional tree coverage are greatest in medium- and high-density urban areas. The effects of trees on air quality are complex with opposing tendencies. Trees tend to increase pollutant concentrations by reducing dispersion and increasing biogenic volatile organic compound emissions. Trees decrease air pollutant concentrations through enhanced deposition and cooler photochemistry. Primary pollutants may increase while secondary pollutants (e.g., ozone) may decrease.

Urban canopy models are needed that balance complexity with data requirements and realistic response to changing tree cover and land use. There is also a critical need for accurate high-resolution site-specific land use, impervious, canopy, and vegetation data. Land use and vegetation data need to be harmonized with parameterizations across various scales and all meteorological and chemical processes (e.g., land surface models, dry deposition and bidirectional fluxes, biogenic emissions). Modeling techniques are needed that distinguish trees from other vegetation. Accurate high-resolution emission data are also required in addition to high-resolution, fully coupled meteorology-chemistry models. A comprehensive evaluation of meteorology and air quality in urban areas should also be performed.

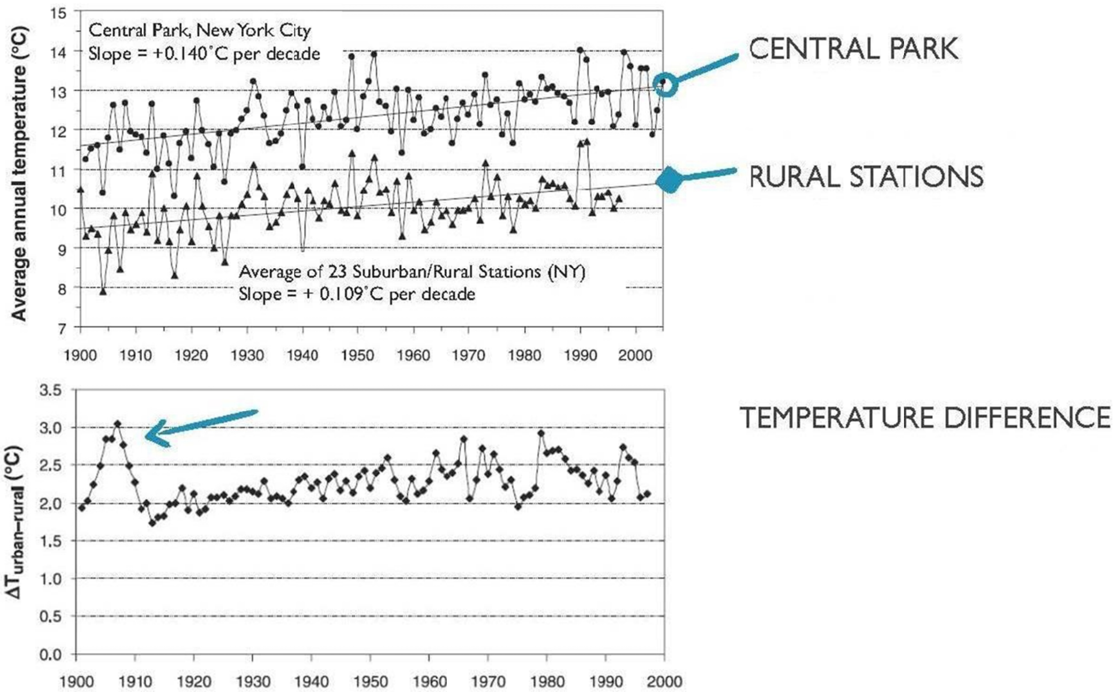

FIGURE 2.5: New York City's historical urban heat island (UHI). Top chart: Central Park's annually averaged temperature from 1900 to the present (upper line) compared to the average of 23 surrounding rural and suburban stations far from the city (lower line; Rosenzweig and Solecki 2001). The UHI is indicated by the vertical offset between the two lines. Bottom chart: The annually average strength of New York City's UHI calculated from the difference between the two historical records shown in the top chart. The blue arrow highlights the city's strong UHI in the early 1900s. SOURCE: Gaffin et al., 2008.

Urban Climate and Urban Forests: A View from New York
Stuart Gaffin, Columbia University

The UHI effect is a significant environmental issue for New York City and will exacerbate local climate change. Two temperature variables are often used to measure the UHI: surface temperature and air temperature. Controlling surface temperature (i.e., what a person feels if they place their hand directly on a surface) is important for mitigating the heat island, whereas controlling air temperature (i.e., what a person feels walking around a city) is more important for determining energy demands. The first priority is to try to reduce surface temperatures, thereby mitigating air temperatures.

New York's UHI has been strong (over 2 degrees Celsius) at least since 1900 (Gaffin et al., 2008; Figure 2.5). The UHI effect is much more pronounced at night than during the daytime. New York's heat burden is increasing due to climate change and an increased UHI effect.

Dr. Gaffin has conducted several studies aimed at using urban trees to help mitigate the UHI in New York. In one study, a LANDSAT map at 60m resolution was used to find hotspots and to assess street-tree cooling benefits. Two streets in the Bronx were compared in the field. Tree-lined streets had lower temperatures, but it is important to note that many other factors (such as building type, etc.) can dominate the causes for differences in temperature. Measuring the temperature of these streets is also a challenge because there is no standard protocol for how to collect these kinds of observations. The lack of a standard data collection protocol needs to be addressed.

Using projections of how the heat burden will change over time, Dr. Gaffin is finding that the temperature extremes are changing rapidly. This is a difficult and important phenomenon to study, and taking representative measurements is a challenge. For instance, a weather station in a forested area of Central Park may not be the best representation for temperature conditions on the street where people live and work and children play.

Another key question is: Are there different levels of urban warming? The projections of future extremes may be greatly underestimated if we are not looking at different microenvironments. There is a broad spectrum of environments that may impact the temperature within a city (e.g., parks, well greened streets, poorly greened streets, poorly greened buildings, etc.).

In conclusion, UHIs are generally well documented on large space and time scales. Urban green infrastructure and albedo strategies are clearly understood as UHI mitigation methods. However, better tools, methods, and strategies are needed to understand small-scale microclimates and benefits of urban green infrastructure. Better modeling capabilities are needed to allow scientists to study large-scale greening and albedo strategies to determine overall and long term benefits vis a vis global warming. More research is needed to understand the potential biases of urban weather stations located in parks and airports and how these may be affecting statistics for extreme heat and precipitation events at the street level, where people work and reside.

The Role of Urban Forests in Biodiversity Restoration
Doug Tallamy, University of Delaware

The planet is losing biodiversity. This is important because the relation between the number of species and ecosystem function is linear (MacArthur, 1955; Maestre et al., 2012; Naeem et al., 2012; Reich et al., 2012). 950 million acres of virginforests in the eastern United States have been converted to tiny patches of secondary-growth woodlots. Most of these habitat fragments are too small to sustain biodiversity. Creating corridors between the fragments allows species to travel from habitat fragment to habitat fragment. This connectedness is one solution to increasing biodiversity. However, this connectedness is typically divided by houses, highways, and other areas where people live and work. Landscapes have been built only from an aesthetic perspective, not from the perspective of managing ecosystems.

It is very difficult for species to survive in parks and land preserves because as habitats shrink, so do the populations. Small populations are more vulnerable to local extinction (Pimm and Redfearn, 1988). Species extinction should be considered on the local level, not just the global level. Our natural areas are not large enough to support the needed biodiversity.

Plants play a significant role in animal biodiversity because they are the first trophic level and the primary producers of energy. Managed landscapes are filled with non-native plants and trees which are not well suited for supporting local and regional biodiversity compared to native plants (Burghardt et al., 2008; 2010; Tallamy, 2004; Tallamy and Shrophsire, 2009; Tallamy et al., 2010;). Non-native plants support fewer insects (e.g., caterpillars). In fact, there are often five times more species and 22 times more insects in native-plant-only areas.

Most insect herbivores are specialized to eat particular plants (Ehrlich and Raven, 1964) and can develop and reproduce only on the plants with which they share an evolutionary history. Insects that are specialized to eat one plant cannot eat other plants. Ninety percent of all phytophagous (i.e., herbivorous or plant-eating) insect species can eat plants in only three or fewer families. Most can tolerate only a few closely related species (Bernays and Graham, 1988).

Insects play a significant role in supporting biodiversity because they are eaten by many animals (e.g., birds, frogs, fish, etc.). 96 percent of terrestrial birds eat insects when making and raising babies. For example, the Carolina chickadee rears its young exclusively on caterpillars, all of which are typically collected within 50 meters of the nest. A chickadee pair brings 390-570 caterpillars to the nest per day (Brewer, 1961). Chickadees feed their young for 16 days before they fledge. This means that to rear one clutch, the parents must catch 6240-9120 caterpillars. Reproduction is the limiting factor for future bird populations and food availability limits reproduction.

The solution to supporting biodiversity in urban areas is not simply to plant native plant species. Some native plants are not as successful as others in sustaining biodiversity. There should be a ranking system of all native plants for this purpose.

There are several key questions related to urban forests' role in biodiversity. Are urban forests ecological traps? Does bird reproduction, for example in restored urban ecosystems, exceed losses from mesopredators (e.g., cats), toxins, window strike, and road kills? What do we do about trophic cascades caused by the loss of top predators (e.g. there is an overpopulation of deer because most of their predators have been removed). Is the claim that native plants cannot survive in hostile urban environments valid?

Given that urban ecosystems are growing and wildly dispersed, we need to find ways to sustain biodiversity within urban ecosystems. As urban forestry science continues to mature, sustaining biodiversity should be considered one of its primary goals.

Urban Greening: Health Benefits and Caveats of the Urban Forest

Shubhayu Saha, Centers for Disease Control and Prevention

A wide array of studies have identified a range of health benefits directly and indirectly associated with urban forests. Some of the potential long-term beneficial health outcomes include physical activity, improved cardiovascular health, and better quality of life. In a systematic review, better access to parks, trails, and sidewalks is found to be associated with increased outdoor physical activity (Ferdinand, et al., 2012). Though the evidence linking access to green space and obesity prevention is tenuous, the American Heart Association recommends development of trails, parks, recreational opportunities and green spaces within communities. Self-rated quality of life was found to improve with density of public parks (Parra et al., 2010).

Studies have found several mental health benefits to be associated with urban forests. Children with greener play settings exhibited less severe ADHD symptoms (Kuo and Taylor, 2004). Residents in neighborhoods with greater walkability are found to be less hypertensive (Mujahid et al., 2008). There is also weak evidence to support that greater green space is associated with fewer depressive symptoms (Miles et al., 2011).

Research also documents several environmental health benefits to be associated with urban forests. For example, urban trees effectively remove large amounts of airborne pollutants, improving air quality (Nowak et al., 2006). Urban green space can reduce runoff and improve water quality (McPherson et al., 2011). Both tree planting and green roofing have been shown to be effective strategies to reduce ambient temperature in highly urbanized areas (Rosenzweig et al, 2009).

There is a growing recognition of the potential role of urban green space in fostering social capital and promoting environmental justice. For example, participation in an urban greening program was found to be associated with community empowerment and social cohesion (Westphal, 2003). In a study in Baltimore, inequitable spatial distribution of parks in relation to race and ethnicity was assessed as a reflection of urban environmental inequality (Boone et al., 2009).

Empirical assessments of how urban forests affect health outcomes pose analytical challenges since the pathways linking the two are numerous. There are direct effects where closeness to nature has intrinsic healing effects. On the other hand, some pathways involve an intermediate step where urban forests either need to change an exposure (like air pollution) or behaviors (like active use of trails) that lead to beneficial health outcomes. Measuring some of these aspects requires pooling expertise from multiple disciplines, as well as recognizing that all variables are commensurate in scale. Cross-sectional studies have limited applicability in drawing causal inferences between urban forests and health outcomes. Given that performing randomized control trials with urban forest interventions and health are practically infeasible, statistical techniques (e.g., propensity-score matching), natural experiments, and carefully designed case-control quasi-experimental studies are necessary to increase the evidence base on this issue.

One needs to be aware of some of the unintended consequences of public policies designed to utilize the health benefits from urban forests. There is a policy push towards urban greening as an effective adaptation strategy to combat an increase in extreme summertime heat. However, Jenerette et al. (2011) found an increasing positive correlation in canopy cover and household income over time in Phoenix, implying that poorer neighborhoods had less tree cover and subsequently less of the heat mitigation effect. Urban greening projects have also been associated with a rise in pollen-related respiratory illnesses like asthma and allergic rhinitis. To lessen the allergy impact when planting urban trees, species biodiversity should be increased, the overuse of male pollinating species should be avoided (Carinanos and Casares-Porcel, 2011), and species with low allergenicity should be planted (Ogren, 2000).

An essential requisite in expanding the evidence base linking urban forests and health outcomes is developing a data repository that allows researchers and practitioners to conduct such analyses. The Centers for Disease Control recently launched the National Environmental Public Health Tracking Network,[10] which is a system of integrated health, environmental exposure, and hazard information and data from a variety of national, state, and city sources. Suitably-created indices of data on urban forests could be linked with a wide range of health outcome data available through the Tracking portal to facilitate research in this field.

In conclusion, urban forests have a multitude of health benefits, but there are significant challenges. Consideration should be given to health guidelines in any urban tree-planting project. There are also obstacles to long-term monitoring of environmental health through, for example, installation of pollen monitors or tracking variables of urban forests. More resources need to be invested in developing protocols to systematically merge remotely sensed ecological data with spatially referenced health datasets.

Discussion

Some points raised in the open discussion that followed this panel's presentations:

- It is common to lose large numbers of trees very quickly at neighborhood scales (e.g., from a major storm). These events may provide opportunities for "paired" neighborhood studies, to look at realtime differences. However, it would take many

[10] *http://ephtracking.cdc.gov*

years to see evidence of differing ecosystem service outcomes; such studies would require long-term observations.

- Additional studies could determine whether there is a correlation between an increase in biodiversity and enhancement of human health and wellbeing.
- "Horticultural therapy[11]" may be a logical consideration when measuring the mental health benefits of urban forests.
- Climate change is shifting the natural range of many tree, animal, and bird species.
- "Cultural ecosystem services" is an important consideration within the field of urban forestry.
- Some regulatory agencies may be prohibited from examining benefits of urban forests if these benefits fall outside their mission.
- The District of Columbia (DC) Park Prescription Rating Tool is an example of a tool with the goal of tracking environmental health benefits.

TOOLS FOR ECOSYSTEM SERVICE EVALUATION: MODELS AND METRICS

Moderators: ***Molly Brown, NASA; Marie O'Neill, University of Michigan***

The first two panels discussed the services of urban forests that are quantified through modeling tools, remote sensing, GIS, and other mapping and monitoring technologies. However, uncertainties and challenges remain in developing standard, widely accepted methods for making such estimates.

Panelists were asked to discuss: (1) key gaps in our ability to model, measure, and monitor ecosystem services, and (2) current capabilities for assigning quantitative economic value to these services and strategies for improving these capabilities (in order, for instance, to allow for rigorous cost/benefit analyses and policies that compensate and incentivize land owners for good forestry conservation and planting practices).

Urban Forestry Models

David Nowak, USFS

i-Tree (*www.i-Treetools.org*), which was released in 2006, is a software suite from the Forest Service that provides urban forestry analysis and benefits assessment tools. It is a collaborative effort and brings users together around one integrated model that assesses many of the functions or ecosystem services of the urban forest. There are approximately 20,000 i-Tree users. i-Tree programs are currently working to integrate with other models such as Biome-BGC[12] (Ecosystem process model from the University of Montana that estimates storage and flux of carbon, nitrogen and water), CENTURY[13] (Soil Organic Matter Model from Colorado State University), BenMAP[14] (EPA's Environmental Benefits Mapping and Analysis Program), and Silvah/NED[15] (a USDA program that emphasizes the analysis of forest inventory data from the perspective of the different forest resources).

About 25 percent of i-Tree users are from outside the United States (Figure 2.6). In 2012, i-Tree released a version for Canada and Australia. In theory, the model could be used anywhere, but in reality, there are challenges with international usage due to differing data formats among different countries.

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[11] The engagement of a person in gardening activities, facilitated by a trained therapist, to achieve specific therapeutic treatment goals.
[12] *http://www.ntsg.umt.edu/project/biome-bgc*
[13] *http://www.nrel.colostate.edu/projects/century/*
[14] *http://www.epa.gov/air/benmap/*
[15] *http://www.nrs.fs.fed.us/tools/ned/*

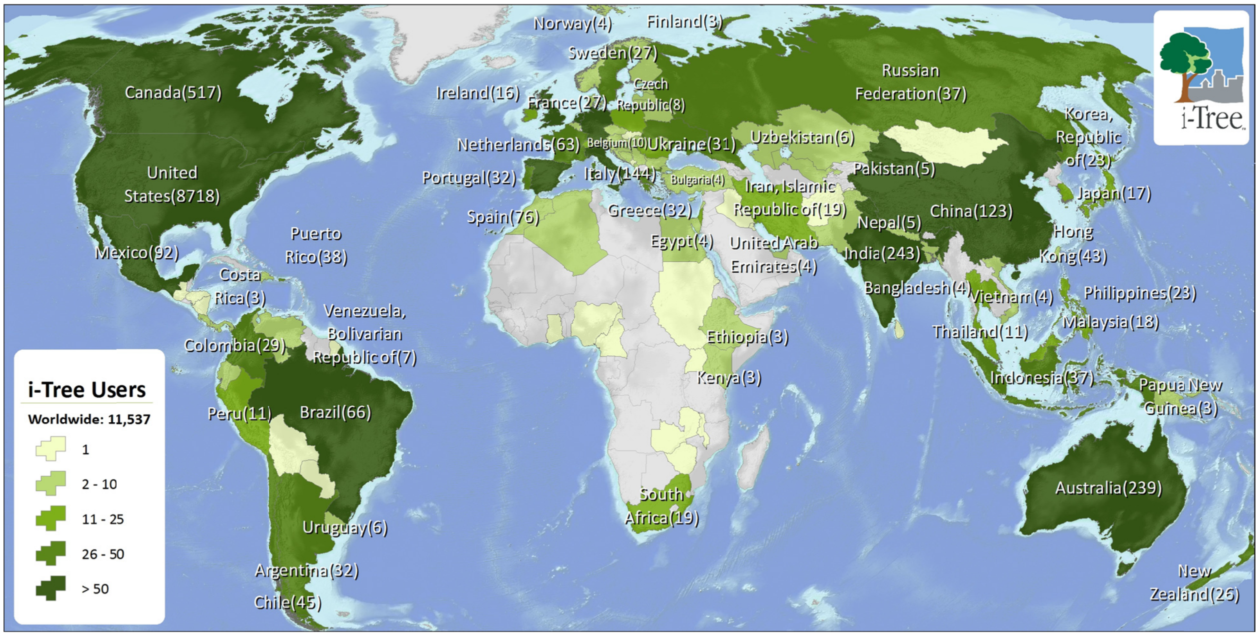

FIGURE 2.6. i-Tree Tools desktop application users by country as of April 2013. The United States has the most users, followed by Canada, and Australia. Source: *www.itreetools.org*.

The framework of an ecosystem service model begins with quantification of the structure of the forest (i.e., the composition of the forest including tree species and density). The function and values of forest resources cannot be calculated without structural information. Urban forestry managers can manipulate the forest structure (what to plant and where), which in turn directly affects forest functions and values. Ideally, they should start by identifying the functions they want to attain, and from that information determine what kind of forest structure is needed to attain those functions.

Models can be used to calculate how trees and the surrounding landscape influence air temperatures. Understanding tree impacts on air temperatures (which is more difficult to accurately model than surface temperature) is critical because it feeds back into many ecosystem services (air pollution, human comfort, stormwater runoff). Air temperature is calculated from regression-based and physical process-based approaches (e.g., EPA's Weather Research and Forecasting [WRF] Model), which tend to be meso-scale models. The challenge is to use physical process-based approaches to model air temperatures (i.e., simulate the underlying processes that affect air temperature) at the micro-scale within a city.

At this time, i-Tree estimates the effects of trees on building energy use through look-up tables based on various model runs for U.S. regions. The numbers from the tables are based on tree size, and distances and directions from a building. A current challenge is developing a system that is more interactive with building energy models. One goal is to link i-Tree to DOE's Energy Plus model, which would make it more dynamic. This will require users to provide more information about building types.

There is some social data that can be used in the models. Census data are being incorporated into the model, but there is a desire to develop equations that link urban tree structure to social benefits. Current estimates focus on who is underserved in terms of tree cover and on populations at higher risk to air pollution and heat stress. More equations are needed that link structure to various functions (e.g., human health benefits).

The air quality component of i-Tree is broad scale and estimates pollution removal by trees and VOC emissions. Some current challenges related to air pollution include linking i-Tree with a more integrated modeling framework, developing fine-scale modeling, integrating secondary effects (energy and temperature effects), improving particulate matter (PM) modeling, estimating pollen loads, and linking to regulations.

There are many water quality models including HSPF (Hydrological Simulation Program—Fortran), BASINS (Better Assessment Science Integrating point and Nonpoint Sources), SWMM (Storm Water Management Model), RHESSes, and i-Tree Hydro. Challenges related to urban hydrologic modeling include: making the models more user friendly for local and program managers, capturing water quality measures and procedures, obtaining water quality data for calibrating and verification, linking to pollution reduction credits, and developing more fully distributed models.

Models capture the storage and sequestration of GHGs, particularly carbon dioxide, via biomass equations and growth rates. They also estimate energy impacts on carbon emissions. Future goals are to expand outputs beyond carbon dioxide, gain a better understanding of urban equations for biomass and growth, improve the modeling of tree effects on energy use, and capture tree species influences on albedo and atmospheric conditions (e.g., moisture).

A module is currently being built to estimate tree effects on exposure to ultraviolet radiation. It will be based on simulating shadows and sky view. Current challenges include utilizing Light Detection and Ranging (LIDAR) data, linking to human health, and capturing diverse atmospheric conditions.

Modeling biodiversity, nutrient cycling, and urban soil conditions is limited at this time. Models can estimate tree species diversity, leaf area and biomass, and some soils information. The challenge is to incorporate even more soils data, link structural data to nutrient cycles, and link to forest nutrient and soils models (e.g., BIOME-BCG, CENTURY).

The modeling of wildlife impacts is still in development. Currently nine bird species will be represented in the model, which is small relative to the total number of bird species. Eventually, modelers would like to capture many more species, develop regional equations, and integrate existing wildlife models with urban data.

Various studies on noise exist, but i-Tree does not currently address this topic.

Researchers are currently investigating conversion factors for urban tree biomass to products and fuel production. It is a challenge to capture mortality rates, pruning debris, storm debris, and market data. For example, urban areas tend to discard substantial amounts of wood. How do we encourage this resource to be more fully utilized?

Incorporating monetary values into the model is fairly straightforward. For example, the value of carbon comes from the Interagency Working Group on the Social Cost of Carbon. Users are free to add or adjust for their own values if they do not like i-Tree values. Monetary values are straight multipliers. Water effects are one of the most difficult services to assign a dollar value.

In conclusion, many areas of modeling can be and are being improved. The framework exists to integrate science and models, which will ultimately lead to a more robust integrated systems approach.

Mapping the Urban Forest from Above

Jarlath O'Neil-Dunne, University of Vermont

The use of aerial monitoring to study tree canopy was motivated by two questions from local forest managers: (1) How much tree canopy do we have now? (2) How much room do we have to plant trees?

Accurate estimates of tree canopy are important, especially when the social context is considered. Within any given city, the land is managed by thousands of individual land owners. Quantifying and modeling tree cover at the scale of the land ownership parcels could help motivate residents to maintain or increase their tree canopy.

It is difficult to map trees in urban areas. Shadows from tall buildings can hide trees. The use of LIDAR data can help address this problem. Mapping tree canopy at high resolution allows for studies to be conducted on multiple scales, from parcel or jurisdiction to watershed. For example, studies can begin with individual households and aggregate up to neighborhood level and city level. Or studies can assess larger metropolitan areas and look across several jurisdictions, up to entire watersheds.

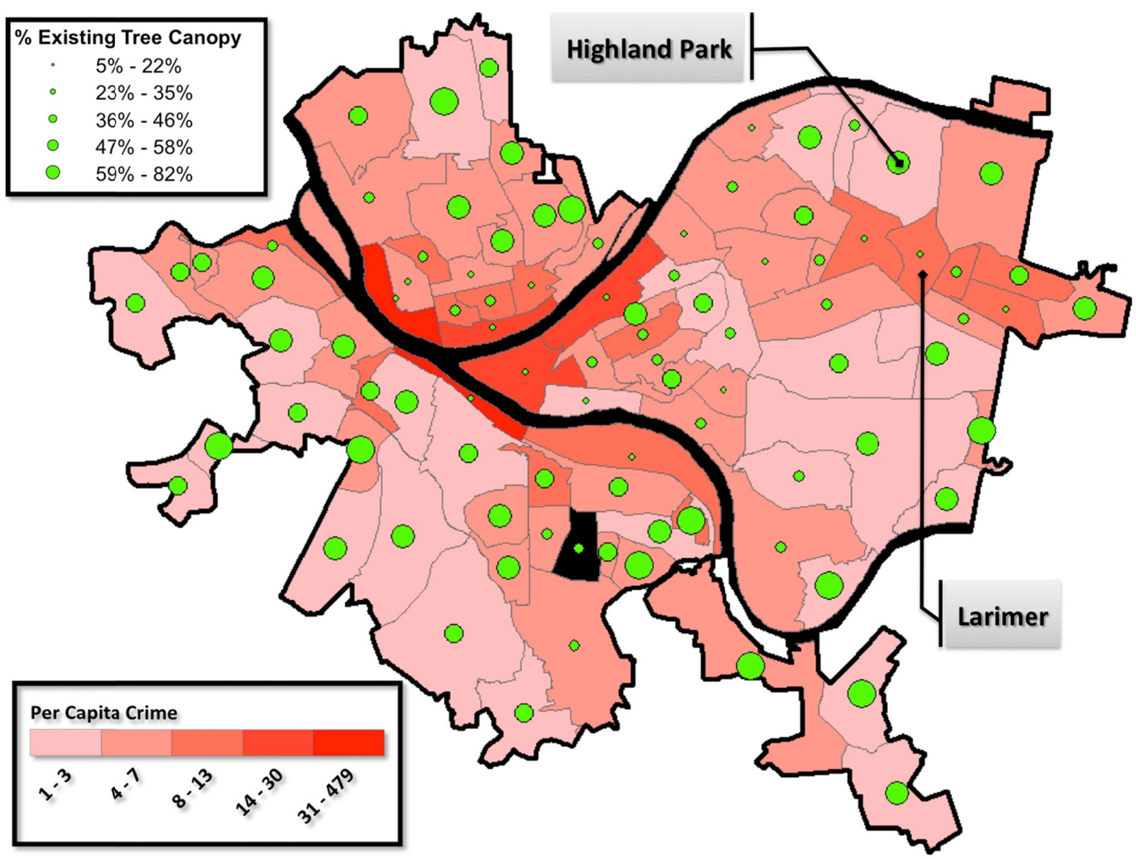

FIGURE 2.7: Crime and Tree Canopy in Pittsburgh, PA. This map shows per capita crime and the percent of existing tree canopy at the neighborhood level. There is an inverse relationship between crime per capita and the percent of existing tree canopy. For example, in Highland Park, with its 49 percent tree canopy, there were three crimes per capita in 2010, as compared to 13 crimes per capita in Larimer, where the tree canopy is 22 percent.

SOURCE: Jarlath O'Neil-Dunne. *http://dx.doi.org/10.6084/m9.figshare.716318.*

Maps need to be affordable, have a high degree of accuracy, and have excellent cartographic representation to be useful to decision makers. It is important to note that mapping does not replace fieldwork. Field inventories provide unique information (e.g., tree species and condition, etc.), that cannot be effectively acquired through overhead mapping. However, unlike field inventories, remotely sensed data can provide a complete census of the tree canopy. High-resolution land cover maps can help resource managers prioritize areas for tree canopy preservation, maintenance, restoration, and plantings. That being said, they will never replace on-the-ground site surveys, as numerous factors go into planting a tree.

These maps do show what areas in the city have a high vs. low percentage of tree canopy and how tree canopy overlays with other variables of interest. For example, tree canopy and crime are closely associated (Figure 2.7).

Mapping larger areas can help address watershed issues across county boundaries. Tree canopy maps can also help city managers and their staff understand ownership patterns, which is important because residents are the primary owners of land where trees can be planted. Many city managers want to increase their cities' tree canopy by planting street trees, but residential areas (not just streetscapes) as a whole provide the most opportunity for increasing tree canopy.

Mapping of tree canopy can also be used in outreach and communication efforts. Mapping different demographic groups and their geographic spread can help city managers develop tactics to reach out to different groups in different places. Researchers can do a change detection analysis which helps city managers understand where changes in tree canopy are occurring and what the drivers may be. Maps can also be used for pest management, but it is very expensive.

Finally, although there is not a mandate to share the data, it is important to move toward a policy of openly shared local and regional data.

The Role of Urban Forestry in Public Health
Laura Jackson, EPA

EPA recently developed EnviroAtlas, a mapping application that allows users to view and analyze multiple ecosystem services nationally and in specific communities. The beta-release of EnviroAtlas is planned for late Spring of 2013, with the first public version available in Fall of 2013.

A key purpose of EnviroAtlas is to communicate how ecosystem services have an impact on human health and well-being. The following science questions were considered in developing EnviroAtlas:

- How can we effectively quantify and communicate the production of the goods and services we receive from ecosystems?
- What is the supply of those services in relationship to the demand and future demand?

How do drivers of ecosystem services such as land use change (e.g., road development), climate change, and pollutant loads impact the delivery of ecosystem services?

- At the screening level, where does it make sense to invest or prioritize land and water restoration, conservation, or use?
- If we invest in green space, can we reduce the costs of gray infrastructure while also gaining other co-benefits?
- How can we promote the incorporation of this type of information into decision making?

- How can we demonstrate how these services explicitly relate to human health and well-being?

The utility of ecosystem services and green infrastructure to buffer impacts from climate change and extreme events is a key message for the public health community. Furthermore, the loss of ecosystem services is frequently disproportionate in low-income neighborhoods, contributes to cumulative community burdens, and is aligned with the public health concept of social stressors in weakening resiliency and increasing vulnerabilities.

The community component of EnviroAtlas is a high-resolution analysis of 50 cities and towns along gradients of interest (e.g., location, population size, demographics, and health and environmental ranking). Mapped metrics calculated for EnviroAtlas by the Forest Service include ambient air pollutants removed, water runoff reduction and filtration, ambient temperature reduction, carbon storage and dollar valuation, and health benefits of urban air filtration. EPA is developing additional metrics and qualitative information about the following topics: near-road tree buffers and adjacent residential population, vulnerability to heat stress and other localized climate-related hazards, homes and schools with limited green window views, and physical and mental health benefits of access to natural amenities.[16]

Where possible, EnviroAtlas estimates environmental value in units of public health and well-being (e.g., senior longevity, chronic illness, hospitalizations, days missed from school or work, self-reported happiness) which can all be converted to dollar amounts. However, research on the role of the natural environment in human well-being has not been uniform; variability in study designs and in the selection of specific dependent and explanatory metrics makes it difficult to conduct a metadata analysis for many of these issues. At a minimum, EnviroAtlas provides fact sheets that qualitatively describe the current state of knowledge. EPA will continue to move toward quantitative analyses where possible.

BenMAP is the EPA Office of Air's model for estimating the human-health benefits of criteria air pollutant rules. It uses data from air quality models and estimates the change in population exposure to certain ambient air pollutants. Based on this information, the model estimates changes in the incidence of a variety of health outcomes. Finally, it places a dollar value on changes in the incidence of health outcomes. Forest Service calculations for EnviroAtlas-Communities include BenMAP estimates at the Census block-group scale.

One significant environmental health issue is the effects of living near roads. Elevated pollutant concentrations (e.g., carbon monoxide, nitrogen oxides, particulate matter mass, benzene, and metals) have been measured near roads. Living, working, or going to school near major roadways has been associated with numerous adverse health effects. These include respiratory and cardiovascular effects, adverse birth outcomes, premature mortality, and cancer. A significantly large portion of the U.S. population lives near large roads, and of those who do not, many work or go to school near large roads.

Can near-road vegetation buffer air pollution? Models and fieldwork suggest that tall, dense vegetation has the potential to improve near-road air quality. However, results vary depending on wind speed, direction, seasonality, road design, and traffic conditions. Barrier type, depth, gaps, and edge effects are also important. Wind tunnel studies and computational fluid dynamics models have respectively shown that roadside vegetation can obstruct ultrafine particles and dilute pollutant concentrations. Field studies show there can be significant buffering of pollution, but the results depend on many variables (including tree type, height, wind conditions). EnviroAtlas is mapping near-road tree buffers, but it is

[16] Please refer to EPA's Eco-Health Relationship Browser at *http://www.epa.gov/research/healthscience/ browser/introduction.html*.

still too soon to do simple predictive calculations. Qualitatively, it appears that having no tree cover is worse for near-road ambient air quality than having a buffer.

In the future, Dr. Jackson would like to replicate published findings on eco-health associations, refine metrics and thresholds for eco exposures,[17] conduct meta -analyses (which requires more replicable studies), and conduct more studies to determine causation (i.e., animal studies) and mechanistic pathways (e.g., of how green space alleviates stress). There are key data needs for studying the effects of urban forests on public health: public health data at sub-country scales, morbidity data (e.g., chronic disease, mental health), school performance, and prescription drug sales. Collaborations among the Department of Health and Human Services, the Department of Education, local health departments, local school districts, regional pharmacies, and schools of public health could help address some of these data and analysis needs.

Discussion

Some points raised in the open discussion that followed this panel's presentations:

- Currently United States Geological Survey (USGS) is attempting to do nationwide LIDAR data collections; it is important that forest-appropriate data is captured.
- Improving public health studies would help quantify the benefits of urban forests.
- Better models could assess the negative outcomes of trees in a larger context, such as allergy impacts.
- i-Tree can quantify the influence trees have on stormwater runoff, which is important for both regulatory credit design and regulatory project review.
- Some regulators recommend using i-Tree-type data over a 20- or 40-year time span because tree benefits will change over time. However, these calculations are difficult to do because tree mortality data are scarce.

MANAGING THE URBAN FOREST
Moderator: *Gary G. Allen, Center for Chesapeake Communities*

Given that urban forests are increasingly being viewed as critical to sustaining environmental quality and human well-being, there has been significant growth in the number of urban areas across the United States declaring ambitious goals for expanding their tree canopy. Some cities are going one step further and are attempting to include large-scale tree planting as an official measure in air and water quality control plans. Governance issues of the urban forests is further complicated by the different (and sometimes competing) interests and priorities of the federal, state, and local organizations and private individuals who own and manage the land in cities.

Panelists were asked to discuss: (1) the challenges of planning and managing urban forests in a manner that optimizes multiple ecosystem services simultaneously (e.g., synergies, tradeoffs in selecting tree species, determining planting locations) and (2) opportunities for enhancing collaboration and coordination among federal agencies, academic researchers, and other stakeholders.

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[17] The amount of exposure to ecosystems a person needs to receive various services (and disservices). For example, how long does a person need to sit in a park to relieve stress?

Air Quality and Urban Forestry
Janet McCabe, EPA

Sustaining urban forestry programs is a significant challenge, and it is becoming especially challenging for some states, given budget constraints. Therefore, it is important to explore how urban forestry programs could provide the added benefit of helping cities and states comply with Clean Air Act regulations. Some benefits of trees are well known (e.g. reducing local temperatures). But some less direct benefits are underappreciated. For instance, a yard that has more trees will need less mowing, thus reducing emissions from that activity. Cars parked under shading trees will be much cooler and have less evaporative emissions. Planting programs can also be designed for reducing emissions by, for example, focusing on large trees that absorb more pollution or on low-maintenance trees (given that the maintenance efforts themselves lead to emissions).

EPA recently launched "Ozone advance/PM advance" for areas that are already meeting current clean air standards, but are close to non-compliance or are expecting growth that will jeopardize future compliance. So far, 31 communities have signed up. Through this program, EPA offers partnerships, information resources, and tools, without any formal expectations or mandates for improvement. Communities can use these resources to help expand community engagement, identify new activities to improve air quality, and expand urban forestry programs.

EPA also provides support for areas that are not meeting current air quality standards. EPA just revised the national standards for PM, and state governments are now in the process of identifying which areas will not meet the new standards. EPA will formally designate areas not in compliance. States with areas that are not in compliance must begin the State Implementation Plan (SIP) process, which is a lengthy process of state planning and EPA approval with the end goal of complying with the Clean Air Act. Under this process, national mandates may drive some actions, but there are opportunities for states and cities to identify their own measures. The question therefore is, can urban forests be part of a SIP? Perhaps, but it would be challenging. In order to be counted in a SIP, a measure has to be quantifiable, enforceable, permanent, and surplus (i.e., not already required for other reasons).

Several cities, including Houston, Baltimore, Sacramento, and New York, have proposed using urban forests in their SIPs. But none have yet been approved by EPA. Houston came close, but the quantification requirement has proven to be a challenge. Cities like the idea of including urban forests in SIPs, but EPA needs to find ways to use these nontraditional programs in the SIP. It would be valuable to have this additional air pollution mitigation measure in the tool box since numerous cities have already undertaken many of the reasonable measures that are available.

Climate change is another major issue that EPA considers in the context of urban forestry. EPA does calculate the impact of trees in their annual GHG inventory. They estimated that in 2011, urban trees stored 69 million metric tons of carbon (EPA, 2013). EPA also acknowledges that the local cooling effect of trees leads to less energy demand for air conditioning, resulting in lower emissions. The role of trees in mitigating UHIs is also of great interest to EPA[18].

In conclusion, there are some significant challenges in the regulatory structure, but EPA is committed to encouraging innovative, multi-benefit programs so that in the future, cities can receive regulatory credit for their expansion of the urban forest.

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18 *http://www.epa.gov/hiri/*

From Street Trees to Sustainability: Science, Practice, Tools

Morgan Grove, USFS

Up until now, most urban forestry research on benefits and services has focused on improving science and tools for general planning measures. But research is needed in quantifying the ecosystem services of urban forests so they can be used in a regulatory context.

The quantification of urban tree benefits has led to interest and demand for tree planting goals. There have been a number of cities declaring ambitious planting goals (typically a symbolic number like 1 million trees). However, does a city have enough plantable space for 1 million trees? How does a city prioritize available sites? Assessments are needed to quantify existing and available plantable space at the decision-making scale. Three questions should be asked when prioritizing where to plant trees in any given city: Where is it biophysically feasible to plant trees? Where is it socially desirable to plant trees? Where is it economically likely to plant trees?

City leaders often ask if they can reach their tree-planting goal exclusively by planting public street trees. This is not possible. The opportunities for increased tree planting are largely in residential areas, which is an extremely distributed set of individually owned land parcels. How do city leaders work with the new "forest landowner" (i.e., the private urban homeowner) to produce a public benefit? What happens when private landowners ask to be paid for the benefits they are providing?

Any particular organization usually has insufficient funds to achieve and maintain a significant urban tree canopy goal. Tools are needed to identify opportunities for coordination and collaboration among the various organizations that have an interest in urban forestry. Coordination and collaboration requires an understanding of the types of organizations, their preferences, categories, and areas of interest, and how the organizations are linked.

Stakeholders and local agencies should work together to develop priority areas for tree planting based on the benefits the organizations would like to attain. Every city department with potential relevance should answer the following three questions: Do you have any regulatory requirements that might involve planting trees? What variables would you use to decide where to plant? How do you share that information? Many city agencies and non-governmental organizations (NGOs) have overlapping missions related to tree planting. Analyzing and mapping the data from the different agencies based on areas of interest (e.g., a watershed, a neighborhood, etc.) allows scientists to provide individual maps tailored to the different stakeholders. Areas of overlapping interest can be identified when the individual maps are compared.

Such an analysis was conducted in Baltimore. Among the various departments, the highest priority that emerged was reducing impervious surfaces, followed by mitigating the UHI and identifying opportunities for stewardship. Most groups were focused on street trees, with very few groups focused on utilizing residential lands to increase the number of trees.

There were numerous affinities among the groups, based on metrics such as where they work, what they work on, or areas of interest. Understanding stewardship networks is key to addressing the question of which groups are most likely to want to work together. Stewardship mapping illustrates how organizations are working together, or how they may need to.

In Baltimore, most groups were neighborhood-focused, and only a few were city-wide. There was a lot of redundancy among different groups' goals which encouraged them to focus on more cooperation and collaboration. These kinds of relational databases can help city leaders determine how to achieve that 1 million tree goal (or whether it is feasible).

The next big step is to think about goods that will ultimately come out of the benefits and services. For instance, a lot of the wood biomass coming out of cities is going to landfills. The "Baltimore wood project[19]" is focused on assessing optimal uses for all that wood.

In conclusion, the next major phase in urban forestry will be a shift in focus from street-tree planting to sustainability in a broader sense by including goals that are social, economic, and environmental.

Management Challenges and Opportunities: City of Trees
Mark Buscaino, Casey Trees

A recent tree canopy study by Nowak and Greenfeld (2012) showed tree canopy decline in many U.S. cities over the past 10 years with equal increases in impervious surface cover. Following this national trend, Washington DC's canopy declined 2 percent from 2006 through 2011; historically, aerial photos show that DC's canopy was 50 percent in 1950 compared to 36 percent today.

In short, arboricultural and urban forestry professionals are failing at keeping our cities green, and development pressures will only make our task more difficult. How can this be reversed?

There are several steps that need to be taken to increase urban tree canopy in cities across the United States. First an inventory of the extent and condition of the urban forest is needed so realistic canopy goals can be determined. While these assessments are becoming more common, many jurisdictions lack resources to conduct them. Another challenge is the lack of national standards for monitoring tree canopy—technology changes so rapidly that jurisdictions often receive conflicting data. A national inventory clearinghouse would greatly facilitate efforts and raise local success, and 10-year interval urban canopy change data at the 1-meter level for all major U.S. cities should be the standard provided by the USFS Forest Inventory and Analysis National Program.[20]

Once inventory data are available, canopy goals should be set and clearly communicated to the public in easily understandable terms. Until better guidance is available, goals will be set based on what is attainable, but this will do nothing to reverse the national trend of canopy decline. We must answer the question of what is optimal to truly make a difference. More research is needed to help jurisdictions nationwide determine appropriate canopy goals that are based on the multiple benefits of trees—environmental, economic, social, human health, etc., as well as climate constraints of the various regions. When known, this information could change the face of urban areas from coast to coast, and perhaps globally as well.

Achieving these goals requires devising strategies by city leaders, agency heads, nonprofits, interest groups, and others (Figure 2.8). Tree protection laws and regulations form the foundation for canopy goal attainment and shift our culture's understanding of what is and is not acceptable behavior. From these laws flow other initiatives, but without them it is doubtful that canopy goal achievement will be successful or, even if attained, long-lasting.

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[19] *http://www.fs.fed.us/research/urban/baltimore-wood-project.php*
[20] *http://www.fia.fs.fed.us/*

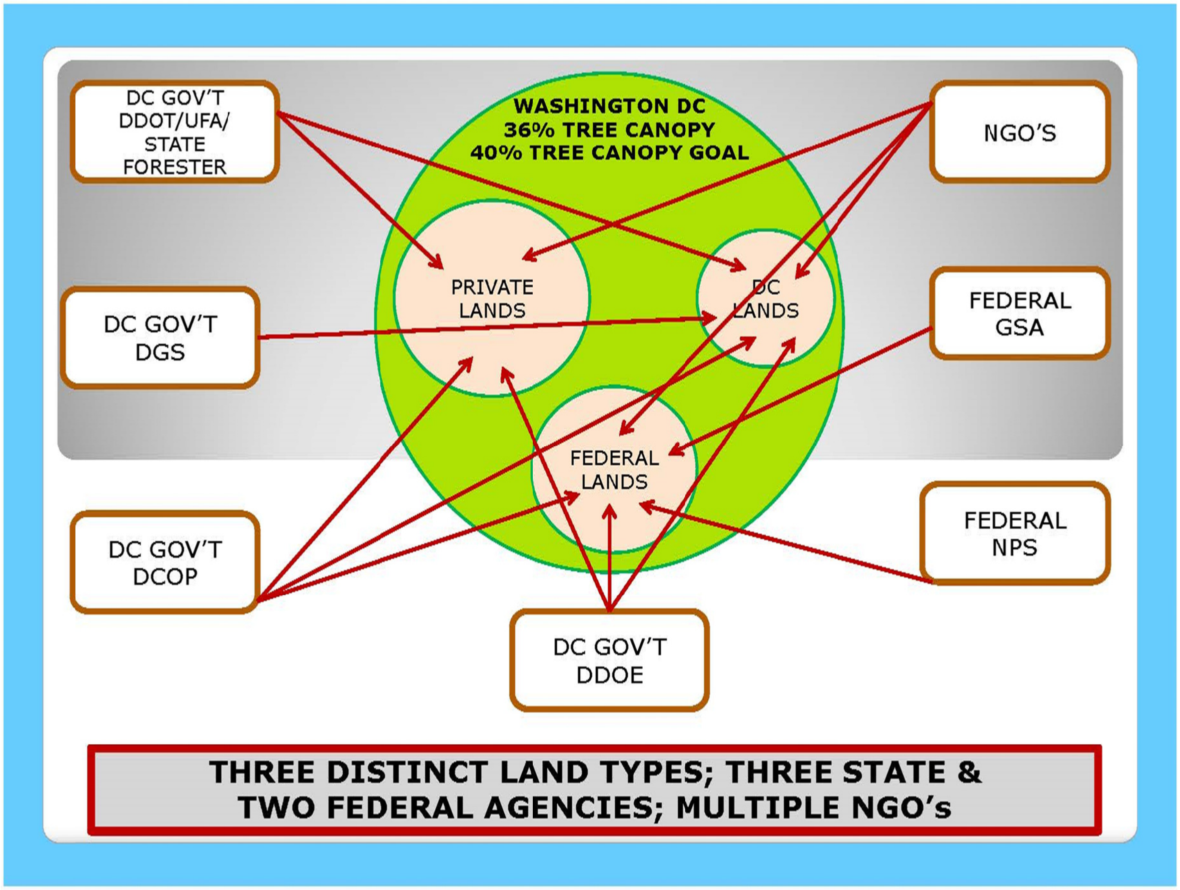

FIGURE 2.8 Washington, DC is a good example to highlight the many organizations involved in achieving tree canopy goals, and the land types impacted. DC is complicated due to the fact that a large portion of land (about 30 percent) is owned by the federal government, with that too divided up to several agencies. DDOT (District Department of Transportation); UFA (Urban Forestry Administration); DGS (Department of General Services); DCOP (Department of Human Resources); DDOE (District Department of Environment); NGO (Non-governmental Organization); GSA (General Services Administration); NPS (National Park Service). SOURCE Mark Buscaino, Casey Trees.

Progress on goal attainment needs to be conveyed clearly and consistently. Accomplishing this communication function has been made easier in recent years with e-media and similar outlets, but reporting is also controversial, and national reporting lacks consistency to be useful. A national registry should be published of urban area canopy and impervious surface levels, as well as progress toward meeting urban canopy goals. A national tree report card based on easily verifiable metrics is another option for reporting. Without such reporting, most goals, once achieved, will have no staying power. Communication is critical to long-term success.

Finally, goal attainment requires periodic data collection and information review to ensure progress is being made and the process stays on track. A feedback loop should be incorporated into the broad strategy to ensure success.

Discussion

Some points raised in the open discussion that followed this panel's presentations:

- Mr. Buscaino indicated that tree mortality is not a major factor when setting canopy goals. The key is to design an effective maintenance plan.
- Models of air quality impacts of trees are not yet sufficient to be used as a basis for regulatory decision making. States are asking EPA to allow the usage of new and alternative tools.
- National standards for assessing urban tree canopy goals would be useful, but one could argue that guidelines for local-level efforts would be even more helpful.
- Giving high priority to addressing research needs in a regulatory context could help pave the way for cities to receive regulatory credit for expansion of their urban forests.

CLOSING REMARKS

In closing the plenary session, Mr. Allen said that the most significant threat to urban forests is not the longhorn beetle or the emerald ash bore, but rather the changing demographics of our communities. More and more people are moving to urban areas. Local governments are trying to accommodate this growing urban population, which often leads to incompatible objectives.

As an example, Mr. Allen cited his local jurisdiction in Maryland, which recently adopted an urban canopy goal of planting 20,000 trees in the next decade, partly in response to a Chesapeake Bay program that advocates for local governments in the watershed to set canopy goals. But at the same time, this community also adopted an electrical reliability standard in response to residents' concerns about power outages due to storms, especially from falling trees. To address these concerns, in less than 18 months the local utilities cut down 30,000 trees—more than the total number of trees slated to be planted in the next 10 years. It is a significant challenge to encourage local stewardship to replace the trees that were cut down for valid electric service reliability reasons (or other local social goods). This example illustrates how the numerous services provided by local governments can be incompatible, and at times, a threat to urban trees. Mr. Allen urged the workshop participants to take a look at service objectives in their local area and determine whether or not they are compatible with preservation, protection, and enhancement of urban forests.

Finally, Mr. Allen noted that the frontier of ecology can be found in urban areas where daily decisions are made about how we live, learn, move, and play. The workshop participants are among the pioneers in this young field. Their work will help focus new research and determine the next steps toward our growing knowledge base. Although much was learned at the workshop, many issues remain, and ultimately it is clear that a broad and challenging agenda lies ahead for urban forestry.

CHAPTER 3
NEXT STEPS FOR THE FUTURE

Time was set aside during the workshop to allow for interactive discussion among all of the participants in breakout groups. For each of the four main themes discussed in the plenary sessions, the breakout groups were asked to suggest what they see as key remaining challenges to advancing our understanding of urban forestry ecosystem services and to identify the steps needed to address these challenges.

The following are some of the general themes that emerged in the groups' discussions about the key remaining challenges—both in terms of expanding our scientific understanding and advancing the reach and effectiveness of current urban forestry programs. (For a more detailed list of the specific questions, challenges, and suggestions raised, see Appendix A.)

- Quantifying both the large- and small-scale ecosystem services and benefits of urban forests
- Conducting economic evaluations of urban forest ecosystem services
- Effectively communicating to the public and decision-makers about the benefits of urban trees
- Encouraging private landowners to plant and maintain trees on their land but also acknowledging that urban trees require public acceptance
- Identifying effective management and maintenance of urban trees to increase their lifespan and maximize the return on investments in urban forestry programs
- Making informed choices about tree species selection and planting location strategies to optimize ecosystem services and tree health
- Promoting collaboration and partnerships among stakeholders (e.g., industry; local, state, and federal government; public; and academia)
- Building the scientific foundation to allow cities and regions to receive official regulatory credit (in air and water pollution programs) for benefits of urban forests
- Improving the tools, models, and methodologies to better meet users' needs
- Balancing competing objectives and values among stakeholders
- Using urban trees as a stepping stone to designing sustainable, resilient cities
- Identifying indicators of a healthy, functioning, sustainable urban ecosystem
- Identifying and quantifying the costs and tradeoffs of urban forests (e.g., water demands, allergy concerns, costs to maintain, etc.)

The groups were then asked to discuss what steps would be needed to make progress in addressing the types of challenges identified above. Some of the general areas of effort that were suggested are listed below. (More detailed lists of suggested steps for each of these general areas are shown in Appendix A.)

- Improving tools to inform decision-makers
- Collecting more detailed, comprehensive, and standardized data
- Improving communication and collaboration among stakeholder groups
- Improving public outreach and education
- Conducting research in key areas:
    - to better characterize the biophysical effects of trees

- to identify innovative approaches to incorporating green space into cites (e.g., “green walls”)
- to create and sustain a culture of environmental stewardship (through research of social scientists, psychologists, and marketing specialists)
- to provide the scientific quantification that is needed to integrate urban trees into regulatory management frameworks
- to better understand interactions between natural and human systems in the urban setting

- Promoting regulatory and urban growth policy changes that are more “tree friendly”
- Optimizing the investment of urban trees by planting trees in appropriate locations and emphasizing the importance of maintaining the health of existing trees
- Advancing interdisciplinary high-resolution ecosystem service models
- Developing indicators of tree health and performance
- Developing criteria for setting appropriate tree canopy goals
- Standardizing remote sensing technologies (LANDSAT, National Agriculture Imagery Program [NAIP], LIDAR) to support urban ecosystem assessment
- Securing adequate resources to support urban forestry efforts

In the final stage of the breakout group discussions, participants were asked to focus squarely on the workshop goal of advancing the research agenda for understanding ecosystem services of urban forestry by answering the following question*: “If I were a Program Manager (at a federal agency, private foundation, etc), I would place a priority on supporting research efforts related to: …”* The following is a sample collection of the many answers received in response to that question.

Social/economic based research

- Understanding how individuals relate to trees and forest where they live; public attitudes towards trees (Why do some people not want more trees?)
- Understanding the factors that drive change in behavior and attitudes on managing privately-owned trees. (What motivates citizens to stewardship?)
- Conducting anthropologic and economic analysis of different types of urban forestry programs. (Why do some programs work more effectively than others?)
- Exploring the benefits of “horticulture therapy”
- Evaluating the distribution of urban forestry benefits across socioeconomic divides (environmental justice)
- Quantifying the different types of economic benefits of planting a tree (in order to identify and pursue the highest value benefits first)
- Identifying how urban forests support human and social capital (i.e., cultural ecosystem services)

Regulatory/policy issues

- Improving quantification of urban forest benefits at the level that they can meet regulatory requirements for air and water pollution mitigation efforts
- Developing interagency (and public-private) collaborative pilot projects that lead to development of integrated assessment tools to aid the inclusion of urban forests in State Implementation Plans
- Determining how to use urban tree planting to gain credits for TMDL (Total Maximum Daily Load) water quality

- Developing realistic regional tree-growth models for predicting future canopy coverage
- Exploring how parcel-level land stewardship decisions aggregate at the landscape scale to affect tree canopy goals

Designing urban forestry practices to maximize benefits

- Identifying the optimal ratio for the amount of intact forest required to offset *x* area of impervious surface; apply this in planning tools and regulatory guidelines for development
- Conducting research on bird-urban forest interactions to identify the resources necessary to sustain bird populations
- Assessing how birds and other wildlife are benefiting from urban forests and which tree species are best at supporting food webs and biodiversity
- Identifying tree species that are best for planting under utility lines
- Identifying thresholds or tipping points in ecosystem services (e.g., What is the minimum tree exposure time needed to maintain a positive mental condition? Will these benefits be realized only after the trees have reached a certain size)?

Urban tree health and maintenance

- Conducting statistical analyses of the factors that lead to large "successful" trees
- Assessing how regular management and maintenance efforts can help reduce risks of tree loss, and how to incentivize such efforts
- Evaluating how to make urban forests resilient in a changing climate
- Assessing urban tree growth and morality rates
- Assessing costs and benefits of protecting trees already in place versus planting more trees (relative value for air quality? storm management? water quality?)
- Determining best practices for mature tree restoration in an urban area

Assessments, tools, data

- Assessing tree canopy on a regional scale with an integrated benefits matrix
- Systematically identifying knowledge gaps in health benefits or costs of urban forests, community-based participatory research in local areas to fill these gaps, integrating health into the larger discussion of urban forestry and ecosystem sources
- Creating a centralized, open-access database to collect and share all of the relevant data being collected through different research efforts
- Developing national standards for urban forestry and metrics for ecosystem services
- Collecting national tree inventory data at the municipality level
- Further developing i-Tree, including coverage of natural areas and interactive mapping capabilities

Collaboration and partnerships

- Supporting collaboration between science and regulatory agencies on effective use of urban forestry tools
- Exploring efficiencies to be gained in regional-scale cooperation and collaboration

Outreach, education, and communication

- Determining how to reach the public with best science on tree benefits, and how to deliver relevant scientific findings to users in a way that is useful and applicable (what messages best resonate for municipalities? what messages motivate tree planting activities?) (note: New York City's million trees initiative is evaluating how well their messages reached people)
- Identifying best practices in community engagement, outreach, and "targeted marketing" (what information will work best with specific audiences?)
- Public education covering not just the planting of trees, but also, pruning, tending, etc.

Risk assessment

- Exploring how the risk of falling trees relates to an increase in intensity of storms, aging infrastructure, and lack of good management practices
- Exploring how trees also help reduce risks of some impacts of extreme weather
- Identifying best practices in "proactive" removal of trees that may pose large risks (e.g., during wind and ice storms), and viewing trees as we do other forms of infrastructure that are regularly replaced and maintained.

CONCLUSION

Many participants noted that the workshop provided a valuable opportunity to reflect on the state of science regarding the role of trees in urban ecosystems, and that it identified knowledge gaps and challenges in translating science into practice. These discussions drew on the expertise of scientists from multiple disciplinary perspectives and of stakeholders from a wide variety of public agencies and non-governmental organizations. At the same time however, participants signaled that there is a larger research community that can contribute to this conversation in order to fully understand the potential synergies and tradeoffs of services and disservices provided by trees in the urban ecosystem. Current researchers have made significant progress in studying how trees can mitigate some of the detrimental impacts of urbanization through a variety of ecosystem services. However, a number of workshop participants noted that scientific understanding of key mechanisms governing ecosystem functions across multiple scales is incomplete, and most benefits of urban trees require further investigation. In many specific cases, the existing base of studies is too limited to allow one to make generalizations.

Some participants pointed out the need to ask fundamental questions about the assumptions that guide most urban forestry research. Some emphasized the challenges of informing decision making in the context of this evolving science and noted the potential pitfalls of translating premature conclusions into practice. Others pointed to the need for a shared definition of an "urban forest" and the need to examine the ecological, historical, cultural, and institutional dimensions that shape urban forestry research. Several highlighted how inconsistencies in existing methodological approaches and measurement methods can affect progress of the science. Overall, the workshop discussions indicated that to advance the study of urban trees and their role in providing ecosystem services, it is necessary to continue to raise new questions and to develop new paradigms and new tools that can fully address the complexity of urban ecosystems as human habitats.

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APPENDIX A
OUTPUT FROM THE BREAKOUT GROUP DISCUSSION

PARTICIPANT FEEDBACK ON THE QUESTION: WHAT ARE THE KEY REMAINING QUESTIONS AND CHALLENGES?

Quantifying ecosystem services and other benefits of urban trees

- What is the connection between urban vegetation and public health issues such as domestic violence, crime, and the drug trade?
- How does society currently value biodiversity?
- What tree species are effective for meeting watershed goals and complex food webs, but that also have the appropriate heat/cold tolerance?
- Need to determine quantitative effects of trees on human health based on empirical observations, not just simple correlation studies.
- How can the multiple benefits of urban trees be ranked and quantified so that communities can make informed decisions about the types of tree species they should plant (that will survive in a changing climate), based on their local needs and priorities?
- How far (spatially) do the impacts of a tree-lined street or park extend to the broader urban environment?
- What are the impacts of urban trees on mental health?
- Better quantification of the volume reduction of stormwater due to canopy evaportranspirtation.
- What are the biodiversity benefits of "urbanized" versus "complete" forest systems?
- How do the novel species assemblages seen in urban areas perform compared to fragmented native systems?
- Can we predict what our urban forest will look like in 20-50 years?
- Better quantifying the ecosystem services of individual trees and/or groups of trees would be useful for calculating the monetary value of benefits and for advocating for tree protection.

Environmental economics evaluations of urban forest ecosystem services

- How much are people willing to pay for biodiversity in urban parks?
- How can trees be assigned value for municipal accounting?

Effectively engaging with the public and decision-makers

- How to communicate the idea that urban trees, regardless of location, are a public commodity that benefits all.
- What do urban residents want to know about urban trees?
- What are appropriate methods of translating research so that it is understandable to non-science communities?
- How to engage the community to support expanded and refined urban forestry?
- Cultivating community involvement from the beginning of projects rather than at the end.

- Outreach and marketing strategies that will maximize the effectiveness of ecosystem service results and reports.
- Providing guidance to help municipalities determine "what should our canopy goal be and why?"

Encouraging private landowners to plant and maintain urban trees

- What are effective ways to reach and motivate private landowners to plant and care for trees? Would regulations hamper this effort?
- How to incentivize people to think in a longer time frame and invest in future benefits?
- How are private landowners motivated by what is largely a public good?

Effective management and maintenance of urban trees

- With 50-60 percent tree mortality in urban ecosystems, there is a need to educate tree planters because many trees are being improperly planted.
- Research how tree care and maintenance affect the risk of storm damage or tree failure and the flow of ecosystem service trees provide.
- What is the genetic diversity of urban forests, and how does that relate to tree survival and to broader urban sustainability goals?
- How do trees survive in the long-term under stress? What factors help trees succeed?
- Long-term investment strategies to support urban tree maintenance (e.g., burying power lines)
- How can the number of trees that are removed by power companies be reduced?

Informed tree species selection and planting location strategies to optimize ecosystem services and tree growth

- How do ecosystem services provided by trees vary by species of tree, by how they are maintained, and by their health? These factors are highly variable in cities by neighborhood, street, microclimate, and urban morphology.
- How are best trees selected for dry, dry/wet, wet locations?
- How big do we want our trees? Do we know that more canopy cover actually produces better services? What are the cost issues of size?
- How can research related to climate change be used locally for better plant selection and planning?
- Are green walls just as effective or more effective than trees for absorbing air pollution? (Vertical gardens offer a lot more plantable space in cities).
- Determining the right size of planting programs within urban environments, e.g., a strategic planting of 7,000 trees could have more impact than "1 million tree" campaigns.
- How does the physiological ecology of trees change in an urban setting as opposed to a rural forest setting?
- What ecosystem elements are most important for cultural and psychological benefits (e.g., bird diversity, closed canopy, continuous forest, recreation opportunities)?
- What are the characteristics of effective wildlife corridors in the urban setting?

Coordination, collaboration, and partnerships among stakeholders (e.g., industry; local, state, and federal government; public; and academia)

- How to build a network of stakeholders?

- In light of limited federal funding, what kinds of private sector entities or public private partnerships could support research and data compilation?
- How to streamline local government efforts, e.g., by sharing best practices in reaching urban canopy goals.
- Improving communication between researchers and decision-makers. Models may not be trusted if the decision-maker does not understand how the model was built or run.
- Developing easy to use/follow implementation plans for managers.

Receiving regulatory credit for benefits of urban forests

- How could health benefits of urban forests be quantified in a way that would be relevant to policy?
- How to connect ecosystem services to pollution standards and regulations and national regulatory offsets?
- How do we develop and institute regulations that will support green infrastructure and urban trees?
- Developing ecosystem service metrics that can be used in the regulatory process, and tools that address regulatory issues and are accepted by regulators.

Improving the tools, models, and methodologies to meet users' needs

- Standardized sampling methodologies that can allow one to see error deviation and confidence level data.
- How to create a street tree inventory that is useful on a county wide scale?
- How confident are we in the air pollution benefit estimates for tools such as i-Tree?
- Need a better understanding of uncertainties in modeling estimates.
- Need low-cost tools that can be used by small cities and communities.
- Can all tools be standardized and linked to ESRI and the Arc GIs suite (e.g., i-Tree)?
- How to incorporate more tree benefit values (e.g., public health variables) into modeling tools?

Balancing competing objectives and values of stakeholders

- How to design projects to meet multiple needs, especially when multiple agencies and programs are involved?
- Balancing multiple land use needs in public urban spaces.
- Who benefits from tree planting and stewardship programs and who does not?
- How to balance increased human density with the space needed for functioning biota.
- How to reconcile the habitat requirements of people and wildlife?

Using urban trees as a stepping stone for design of sustainable, resilient cities

- Moving from specific projects to a more holistic/city-wide green infrastructure approaches.
- Integrating trees with other infrastructure.
- What is the best possible city we can design?
- Identifying indicators of a healthy, functioning, sustainable urban ecosystem.
- What motivates communities to pursue green infrastructure?
- What are effective and efficient strategies for maintaining green infrastructure?

Other questions and challenges

- Defining "urban" in the context of urban forestry.
- Who is responsible for the management of and funding support for urban forestry programs?
- What is the distribution of urban forest resources, services and disservices with respect to socioeconomic patterns?
- What are the opportunities for green job creation for planting and maintaining urban vegetation?

PARTICIPANT RESPONSES TO THE QUESTION: WHAT IS NEEDED TO ADDRESS THESE QUESTIONS AND CHALLENGES?

To improve tools, models, and methodologies

- Develop a new urban tree database that combines abiotic tolerances and ecosystem services provided by a given tree species.
- Develop better urban climate models to study greening scenarios.
- Standardize urban tree canopy assessments so all ecosystem services data can use the urban tree canopy data.
- Create an urban site index by using a multi-city research approach looking at various factors affecting tree growth.
- Develop predictive tools for impacts of extreme weather events on trees and potential actions to reduce those negative impacts.
- Standardize remote sensing technologies (Landsat, NAIP, LIDAR) to support urban ecosystem assessment. (Current studies draw from different platforms and make comparison difficult from one study to another.)
- Develop tools that can assess the multiple benefits of trees, evaluate the ecosystem services for trees in natural areas, and demonstrate the value of green infrastructure intensity applied at subwater-shed and sewer-shed scale for storm-water management.

To support more data, open data, improved data collection and management

- Develop standardized protocols for collecting data across cities.
- Develop tree species lists by region that highlight or identify the species that address multiple objectives (e.g., biodiversity, storm water, nutrient removal, air quality).
- Bring different data sets together for analysis through data aggregation networks.
- Enable managers to build urban forestry program capacity through data clearinghouses by topic (e.g., local code, benefits).
- Validate modelswith more detailed, comprehensive, and standardized data on
    - Sub-community scales on school test scores, disease and mental illness, prescription drug sales, and other direct and proxy measures of public health and well-being.
    - Ecosystem services at the intra-urban scale, to gain understanding of factors driving differences in the flow of services.
    - Stormwater runoff.
    - Tree species performance across urban site and soil types.

To improve public outreach and education

- Survey public attitudes about trees, to better understand what the public needs to know about ecosystem services.
- Produce and widely distribute an easy-to-read set of guidelines and recommendations for increasing tree cover (for use by teachers, local government, landscaping companies, and homeowner associations).
- Develop appealing citizen science and social media approaches to mobilize communities.
- Communicate to the public the connection between compact, transit-oriented land use and preservation of green space.
- Develop user-friendly tools to help cities and communities understand the environmental and economic benefits of planting trees.
- Distill research into usable but qualitative information to be shared with decision makers, policy makers, homeowners, etc.

To foster coordination and collaboration among key stakeholders

- Foster new partnerships among (for instance) urban planners, urban forest and urban wildlife researchers, city managers, city/state epidemidologists, the electric utility industry, as well as partnerships
    - Between green groups and other community organizations such as school sports teams and community religious groups.
    - Between regulatory agencies and urban forestry implementing organizations.
    - Among federal agencies to ensure common acceptance of models and measurements
- Support such collaborations by
    - Designing a forum, such as a community blog, for sharing best practices among local urban foresters.
    - Implementing an urban forestry network that meets regularly to discuss new research and foster an ongoing dialogue.
    - Developing networks of managers and scientists to frame questions and standardize data collection techniques.

To advance research on the biophysical effects of trees and design innovative approaches to incorporate green space into cities.

- Support research on topics such as
    - Water usage of trees, best species for intercepting pollutants, and linking urban tree vegetation and quality of life, especially in Midwest, Great Plains and arid/semi arid regions.
    - Tree sensors and when trees should be removed to maximize benefits or remove trees prior to failure.
    - How trees affect air pollution (including chemistry, meteorology, mixing)
    - Effect of mortality rates for urban trees on ecosystem services models for urban forests.
    - Stormwater benefits of trees as compared to other vegetation types such as nature, grasses and shrubs.
    - Urban tree growth and expectations.
- Develop research infrastructure that includes information exchange, technology, transfer, design standards.

- Address multiple benefits and costs of urban ecosystems holistically and to avoid unintended consequences of decisions, systems analyses should be implemented.
- Conduct comparative and complimentary analyses of green vs. gray vs. hybrid technologies.

To advance social science research involving social scientists, psychologists, and marketers to create and sustain a culture of urban tree stewardship.

- Develop an integrated approach to socio-ecological research.
- Conduct applied research on culture and behavior.
- Conduct cross-comparative studies on cities of different climates, geographies, histories political and economic contexts.
- Add cultural ecosystem services to research agenda.
- Identify and studyi tree-friendly demographics to determine why the residents have positive attitude about trees.

To advance the research needed to help integrate urban trees into regulatory programs and systems. For example:

- Analyze how policies help or hinder extent and health of urban forests.
- Document comparative costs for meeting regulatory requirements and community goals.
- Research on tree canopy standards and ordinances for parking lots.
- Align research with regulatory drivers: air quality, water quality, and development regulations.

To conduct interdisciplinary research to understand the urban natural-human environment. For example:

- Examine correlations between environmental factors, health, food security.
- Determine how accurate models must be to inform decisions.
- Use comparative neighborhoods could be used as multi-disciplinary research sites.

To implement regulatory and policy changes that are more "tree friendly."

- Refine benefit determinations to meet epa and state environmental standards and guidelines.
- Develop modeling programs and protocols that integrate urban trees into stormwater regulatory analysis.
- Design appropriate policies that manage costs and benefits of urban ecosystem services that are borne by different parties.
- Incorporate changes in building codes, building development, and tax policies that make it easier to meet tree canopy goals.
- Design policies that limit the liability associated with trees.
- Overhaul tax and utility fees to credit green infrastructure and trees, tax impervious cover or lack of trees, and to move to incentive-based structures that are careful to avoid environmental or economic injustice.
- Develop regulatory programs that require developers to pay for the ecosystem services lost when trees are removed.

To develop improved ecosystem service models

- Develop finer scale model resolutions, from city scale to land scale.
- Develop models that calculate the global climate change benefits of urban forests.
- Develop better urban climate models to study greening scenarios.
- Integrate tree modeling programs into stormwater and air quality models.
- Design a meta-framework for developing function- and service-specific models that can be synthesized or used in parallel.
- Design inter-disciplinary models that incorporate economic valuations of urban tree canopies that can be used across the agro-ecosystem.

To identify indicators of tree health and performance

- Improve understanding of the capacity of urban trees to mediate stormwater pollutants.
- Identify the relative performance of trees and other landscape components for improving water quality or quantity (e.g., for pricing stormwater utility).
- To develop regionally-appropriate standards and strategies for enhancing and expanding urban forestry.

To set appropriate tree canopy goals

- Determine the minimum urban tree canopy needed to optimize health and biodiversity benefits.
- Encourage practitioners to set goals for their projects based on desired specific ecosystem outcomes, and to assess success of these goals.
- Set attainable urban tree canopy goals with a better understanding of urban tree mortality.

Other needs

- Conduct a predictable available tree canopy assessment and accessible tree planting tracking methods.
- Secure adequate resources to support urban forestry efforts.
- Expand the vision of urban forestry to all areas that are human-dominated. (Trees benefit suburban and exurban areas as well as urban areas).
- Use public health as the common denominator for all urban forest benefits (air quality, water quality, wildlife diversity, GHG mitigation, etc.).
- Better integrate the benefits of trees across disciplines to create a matrix that can be embedded in an economic development matrix.

APPENDIX B
WORKSHOP AGENDA

MONDAY, FEBRUARY 25

8:30 A.M.	Welcome and Purpose of Workshop	Gary G. Allen *(chair)* *Center for Chesapeake Communities*
8:45 A.M.	Keynote remarks	Ann Bartuska *USDA*

Urban Forestry within the Greater Urban Ecosystem
Moderator: Marina Alberti, *University of Washington*

9:15 A.M.	Session Introduction	
9:20 A.M.	Urban Ecosystems and the Services they Provide	Richard Pouyat *USFS*
9:40 A.M.	Services and Regional Tradeoffs	Diane Pataki *University of Utah*
10:00 A.M.	Challenges for Green Infrastructure at the Interface of Science, Practice and Policy	Thomas Whitlow *Cornell University*
10:20 A.M	*Break*	
10:35 A.M.	Long term Goals and Public Engagement	Stephanie Pincetl[21] *University of California L.A.*
10:55 A.M.	Panel Discussion	

Biophysical Services of the Urban Forest
Moderators: Kenneth Potter, *University of Wisconsin;* ST Rao, *North Carolina State University*

11:15 A.M.	Session Introduction	
11:20 A.M.	Trees Incorporated into Urban Stormwater Management	Thomas Ballestero *University of New Hampshire*
11:40 A.M.	Urban Forest Effects on Meteorology and Air Quality	Jonathan Pleim[22] *EPA*
12:00 P.M.	*Lunch*	

[21] Dr. Pincetl was unable to participate at the workshop
[22] Dr. Pleim was unable to participate at the workshop

1:00 P.M.	Urban Climate and Urban Forests: A View from New York	Stuart Gaffin *Columbia University*
1:20 P.M.	The Role of Urban Forests in Sustaining Biodiversity	Doug Tallamy *University of Delaware*
1:40 P.M.	Urban Greening: Health Benefits and Caveats of the Urban Forest	Shubhayu Saha *CDC*
2:00 P.M.	Panel Discussion	
2:30 P.M.	Break and assemble into working groups	*Committee members moderate*
4:20 P.M.	Rapporteur Reports	

5:30 - 7:30 P.M. *Reception* ***(sponsored by the Sustainable Urban Forestry Coalition, International Society for Arboriculture, SavATree, Davey Tree)***

TUESDAY, FEBRUARY 26

8:25 A.M.	Day 2 introduction	Gary Allen (chair)

Tools for Ecosystem Service Evaluation (models and metrics)
Moderators: Molly Brown, *NASA;* Marie O'Neill, *University of Michigan*

8:30 A.M.	Session Introduction	
8:35 A.M.	Urban Forestry Models	Dave Nowak *USFS*
8:55 A.M.	Mapping the Urban Forest from Above	Jarlath O'Neil-Dunne *University of Vermont*
9:15 A.M.	The Role of Urban Forestry in Public Health: Using Science in EPA Decision Tools	Laura Jackson *EPA*
9:35 A.M.	Panel Discussion	
10:00 A.M.	*Break*	

Managing the Urban Forest
Moderator: Gary Allen, *Center for Chesapeake Communities*

10:20 A.M.	Session Introduction	
10:25 A.M.	Air Quality and Urban Forestry	Janet McCabe EPA
10:45 A.M.	From Street Trees to Sustainability: Science, Practice, and Tools	Morgan Grove *USFS*

11:05 A.M.	Management Challenges and Opportunities	Mark Buscaino *Casey Trees*
11:25 A.M.	Panel Discussion	
12:00 P.M.	Lunch; meet back in working groups	*Committee members moderate*
1:00 P.M	Working Groups	
3:00 P.M.	*Break*	
3:15 P.M	Rapporteur Reports	
4:00 P.M	Closing Remarks	Gary Allen
4:30 P.M.	*Workshop Adjourns*	

APPENDIX C
PARTICIPANT LIST

Arthur Acoca	Penn Institute for Urban Research
Marina Alberti	University of Washington
Ashley Allen	US EPA
Gary G. Allen	Center for Chesapeake Communities
Thomas Ballestero	University of New Hampshire
Ann Bartuska	USDA
John Barnwell	Society of American Forests
Kenneth Belt	US Forest Service
Cindy Blain	Sacramento Tree Foundation
Cara Boucher	National Association of State Foresters
Deborah Boyer	Azavea
Molly Brown	NASA
Jennifer Bruhler	DCH
Mark Buscaino	Casey Trees
Amanda Campbell	MWCOG
Robert Cheetham	Azavea
Keith Cline	US Forest Service
Kathryn Conlon	University of Michigan
Zach Cravens	US Fish and Wildlife Service
Sara Davis	County of Denver
Danielle Dills	National Association of Conservation Districts
Chris Donnelly	CT Dept. of Energy and Environmental Protection
Alice Ewen	US Forest Service
Earl Eutsler	DDOT Trees
Nancy Falxa-Raymond	US Forest Service
Shelly Freeland	National Research Council
Alex Friend	US Forest Service
Stuart Gaffin	Columbia University
Michael Galvin	SavATree
Laurie Geller	National Research Council
Robert Alec Giffen	Clean Air Task Force
Robert Goo	US EPA
Ann Gosline	Clean Air Task Force
Gerry Gray	SUFC Steering Committee and NUCFAC
Matt Greenstone	USDA, Agriculture Research Service
Rob Greenway	National Research Council

Morgan Grove	USFS
Lisa Hair	US EPA
Anne Hairston-Strang	MD DNR Forest Service
Richard Hallett	US Forest Service, Northern Research Station
Ian Hanou	Plan-it Geo
Everett Hinkley	US Forest Service
Kris Hoellen	Conservation Fund
Dianna Hogan	USGS
Melinda Housholder	American Forests
Laura Jackson	EPA
Scott Josiah	Nebraska Forest Service
Stephanie Juchs	Casey Trees
Michael Knapp	Fairfax County, VA
Kimberly Koch	NACD - Intern
Michelle Kondo	University of Pennsylvania
CJ Lammers	Maryland-National Capital Park and Planning Commission
Elizabeth Larry	US Forest Service
Monica Lear	DC Urban Forestry Administration
Brian LeCouteur	Metropolitan Washington Council of Governments
Michael Leff	Davey Institute/USFS
Susannah Lerman	University of Massachusetts and US Forest Service Northern Research Station
Sarah Low	US Forest Service
Jacqueline Lu	NYC Parks and Recreation
Carl Lucero	US Forest Service
Edward Macie	US Forest Service
Scott Maco	Urban Forestry
Gary Man	US Forest Service
Janet McCabe	EPA
Mikaila Milton	National Park Service
Gary Moll	Global Ecosystem Center
Janette Monear	Texas Trees Foundation
Daniel Muth	National Research Council
Randy Neprash	MN Cities Stormwater Coalition; Stantec Consulting
Robert Northrop	University of Florida
Dave Nowak	USFS
Richard Olsen	US National Arboretum
Jarlath O'Neil-Dunne	University of Vermont
Marie O'Neill	University of Michigan
Diane Pataki	University of Utah
Jose Perez	
Stephanie Pincetl	University of California, Los Angeles

Emily Pindilli	US Geological Survey
Jonathan Pleim	EPA
Kenneth Potter	University of Wisconsin
Richard Pouyat	USFS
Serenity Purcell	University of Maryland
Shannon Ramsay	Trees Forever
S. T. Rao	North Carolina State University
Kara Reeve	National Wildlife Federation
Guy Robertson	USDA Forest Service
Phillip Rodbell	US Forest Service
Michele Romolini	Univ. Vermont/US Forest Service
Shubhayu Saha	CDC
Jessica Sanders	Casey Trees
Lydia Scott	The Morton Arboretum
Chris Sequeira	Sustainability Strategist
Carl Shapiro	US Geological Survey
Christopher Solloway	US EPA
William Sommers	George Mason University
Sandy Spencer	USFWS Patuxent Research Refuge
Eric Sprague	Alliance for the Chesapeake Bay
Eric Strauss	Loyola Marymount University
William Sullivan	University of Illinois at Urbana-Champaign
Doug Tallamy	University of Delaware
John Thomas	District Department of Transportation
Katie Thomas	National Research Council
William Toomey	The Nature Conservancy
Joseph Townsend	University of Delaware
Amy Trice	American Rivers
Cynthia West	US Forest Service
Dan Whitehead	Abby Farms
Thomas Whitlow	Cornell University
Laurence Wiseman	CenterLine Strategy, LLC
Kathleen Wolf	University of Washington

APPENDIX D
ACRONYM LIST

BASINS	Better Assessment Science Integrating point and Nonpoint Sources
BenMAP	EPA's Environmental Benefits Mapping and Analysis Program
BIOME-BGC	Ecosystem process model from the University of Montana
CENTURY	Soil Organic Matter Model from Colorado State University
DCOP	Department of Human Resources
DDOE	District Department of Environment
DDOT	District Department of Transportation
DGS	Department of General Services
DOE	Department of Energy
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GSA	General Services Administration
HSPF	Hydrological Simulation Program—Fortran
LIDAR	Light Detection and Ranging
LTER	Long-term Ecological Research
LTER	Long-term Ecological Research
NAIP	National Agriculture Imagery Program
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NPS	National Park Service
NRC	National Research Council
NSF	National Science Foundation
R&D	Research and Development
SIP	State Implementation Plan
STEW-MAP	Stewardship Mapping and Assessment Project
SWMM	Storm Water Management Model
TMDL	Total Maximum Daily Load
UF	Urban Forestry
UFA	Urban Forestry Administration
UHI	Urban Heat Island
USDA	U.S. Department of Agriculture
USFS	United States Forest Service
VOC	Volatile Organic Compound

APPENDIX E
STATEMENT OF TASK

The National Academy of Sciences / National Research Council will organize a workshop to examine the following:

- current capabilities to characterize and quantify the benefits (“ecosystem services”) provided by trees and forest canopy cover within a metropolitan area - including air pollution mitigation; water pollution mitigation; carbon sequestration; UHI mitigation; reduced energy demand from shading of buildings. The discussions may also consider benefits to public health and well-being.
- key gaps in our understanding, and our ability to model, measure, and monitor such services; and improvements that may be needed to allow tree planting to be sanctioned as a “creditable” strategy in official regulatory control programs (i.e. for air quality, water quality, climate change response).
- current capabilities for assigning quantitative economic value to these services, and strategies for improving these capabilities (in order, for instance, to allow for rigorous cost/benefit analyses, and for policies that compensate land owners for good forestry conservation and planting practices).
- the challenges of planning/managing urban forests in a manner that optimizes multiple ecosystem services simultaneously (e.g. synergies, tradeoffs in selecting tree species, determining planting locations)
- opportunities for enhancing collaboration and coordination among federal agencies, academic researchers, and other stakeholders.

APPENDIX F
BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

Gary G. Allen (Chair) is the Executive Director of the Center for Chesapeake Communities located in Annapolis, Maryland. The Center aims to facilitate local governments' efforts to plan for growth, development, and protection of local natural resources and the Chesapeake Bay. The Center assists local governments by providing tools, techniques, and technical assistance required to carry out the local governments' watershed goals and projects. Mr. Allen holds a Master of Public Policy and Administration from American University as well as a B.S. from Indiana State University. With over thirty years of experience, he offers expertise in public policy, outreach, management and advocacy in areas of education and environmental resources for federal, state and local government. Mr Allen's research interests include urban forest ecology, public policy and urban ecology, as well as the role of green infrastructure in air quality planning.

Marina Alberti is Professor of Urban and Environmental Planning in the Department of Urban Design and Planning at the University of Washington. She is the Director of both the Interdisciplinary Ph.D. Program in Urban Design and Planning as well as the Urban Ecology Research Laboratory. Her research interests pertain to the impacts of alternative urban development patterns on ecosystem dynamics. Furthermore, her work addresses measures of urban environmental performance that can be utilized to monitor progress and inform policy-making and scenario planning. Of particular interest to Dr. Alberti is the development and analysis of advanced interdisciplinary approaches to modern ecological problems. She is currently serving as the Principal Investigator for several grant-funded research projects, including a Biocomplexity Grant project sponsored by the National Science Foundation. This project seeks to address the emergent properties of urban landscapes in Seattle, Washington and Phoenix, Arizona.

Molly Brown is a Research Scientist with the Biospheric Sciences Branch at NASA's Goddard Space Flight Center. She holds a Ph.D. in Geography from the University of Maryland College Park, where she specialized in Remote Sensing, Economics, and Development. Dr. Brown conducts her research in four areas: data fusion to develop long term data records of vegetation dynamics for carbon cycle and terrestrial ecosystem modeling; research to develop science data and analysis for societal applications; modeling of land cover and land use in the context of climate variability; and the development of models and methods that enable the quantification of the impact of climate change on human economic and political systems. In addition to her research, Dr. Brown is an advisor to NASA's Application Division's International Sustainable Development initiative.

Marie O'Neill is an Associate Professor of Environmental Health Sciences and Epidemiology at the University of Michigan's School of Public Health. Dr. O'Neill earned her M.S. in Environmental Health Sciences from Harvard University and her Ph.D. in Epidemiology from the University of North Carolina. Her research interests include health effects of air pollution, temperature extremes and climate change, environmental exposure assessment, and socioeconomic influences on health. Prior to joining the faculty at the University of Michigan, Dr. O'Neill held positions at the U.S. Environmental Protection Agency; the Pan American Health Organization in Mexico at the National Institute of Public Health and the National Center for Environmental Health as a Fulbright Scholar; and at the Harvard School of Public Health as a Research Fellow in Environmental Epidemiology. In addition to these accomplishments, between 2004 and 2006, she was a Robert Wood Johnson Health & Society Scholar at the University of Michigan. Dr. O'Neill is a member of the International Society for Environmental Epidemiology and the Society for Epidemiologic Research.

Kenneth Potter is a Professor in the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison. Dr. Potter received his B.S. from Louisiana State University and his Ph.D. from Johns Hopkins University. His fields of interest include the following: hydrological modeling and design; stormwater modeling, management, and design; estimation of hydrologic risk; estimation of hydrological budgets; and restoration of aquatic systems. Utilizing an interdisciplinary approach, Dr. Potter's research focuses on providing a technical basis for the sustainable use of aquatic resources and for the restoration of degraded aquatic resources. As the expansion of urban areas poses a major threat to aquatic resources, "low impact development" may permit population growth without excessive environmental concessions. Dr. Potter's research seeks to design and evaluate various strategies for low-impact land development. Furthermore, his research includes the evaluation of hydrologic conditions under past, present, and varying future conditions, so as to facilitate the restoration of degraded aquatic systems.

S.T. Rao is an Adjunct Professor in the Department of Marine, Earth and Atmospheric Sciences at North Carolina State University in Raleigh. Previously he served as the Director of the U.S. Environmental Protection Agency's Atmospheric Modeling and Analysis Division, which develops advanced air quality models capable of simulating both the transport and fate of atmospheric pollutants. Dr. Rao's leadership responsibilities included developing and executing research plans for atmospheric modeling, air pollution meteorology, and analysis and interpretation of complex environmental data corresponding to other federal agencies as well as the national and international scientific community. Dr. Rao has co-authored numerous peer-reviewed journal articles in his field. He is a member of the American Meteorological Society and the Air & Waste Management Association.