Improving city forests through assessment, modelling and monitoring

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Methods for estimating the costs and benefits of urban and peri-urban forests are increasingly accurate and easy to apply.

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Urban and peri-urban forests produce numerous benefits for society. These include moderating the climate; reducing energy use in buildings; sequestering atmospheric carbon dioxide; improving air and water quality; mitigating rainfall run-off and flooding; providing an aesthetic environment and recreational opportunities; enhancing human health and social well-being; and lowering noise impacts (Dwyer *et al.*, 1992; Nowak and Dwyer, 2007; Dobbs, Martinez-Harms and Kendal, 2017). Inappropriate landscape design, tree selection and tree maintenance, however, can increase environmental costs (e.g. through pollen production and chemical emissions that contribute to air pollution), energy use in buildings, waste disposal, infrastructure repair, and water consumption. These potential costs must be weighed against the benefits when developing natural resource management programmes.

To sustain or enhance the benefits of urban and peri-urban forests for society, it is important to understand the existing forest structure, how this structure affects the magnitude of the benefits and costs, and how the forest structure and therefore benefits change over time. With such understanding, managers can guide forest structure to maximize benefits for society. Significant advances have been made in recent years on urban and peri-urban forest monitoring and assessment

Above: The monitoring and assessment of urban and peri-urban forests enables the development of management plans that optimize forest structure and the benefits such forests provide

and in quantifying the benefits and costs associated with the resource. Many of the benefits are not easily measured in the field, and modelling techniques must therefore be used to estimate their magnitude. This article provides an overview of a four-step process for easily assessing, modelling and monitoring urban and peri-urban forest structure and benefits. Through this process, local management plans can be developed that optimize forest structure to enhance the health and well-being of current and future generations.

STEP 1: ASSESSING FOREST STRUCTURE

Forest structure is a key variable because it is what managers manipulate to influence forest benefits and values. Structure represents the physical attributes of the forest, such as the abundance, size, species, health and location of trees. Managers often choose what species to plant, where and when to plant them, and what trees are removed from the landscape. These actions directly influence structure and consequently the benefits derived from the urban and peri-urban forest resource.

Bottom-up or top-down?

There are two basic ways of quantifying structure in urban and peri-urban forests: 1) top-down aerially based approaches; and 2) bottom-up ground-based assessments. Top-down assessments provide basic metrics on tree cover (e.g. percentage tree cover) and other cover types, and they can map the specific locations of such elements.

Tree cover can often be estimated by interpreting aerial photographs or by developing tree-cover maps using moderate-to-high-resolution imagery (e.g. Nowak, 2012a). If only the amount or percentage of tree cover is needed, photo interpretation provides a cost-effective and accurate means of assessing tree and other cover attributes; it lacks specific information on cover location, however.

If cover locations are needed, tree-cover maps can provide both tree-cover estimates and specific locations of cover elements (e.g. to be integrated into a geographic information system). Tree cover and distribution are important parameters of urban and peri-urban forest structure because they provide a simple way of conveying the magnitude and distribution of the forest resource. More detailed data on forest structure (e.g. species composition, the number of trees, tree size, tree condition, leaf area, leaf biomass and tree biomass) are often needed, however, to

Healthy tree leaves are crucial for the provision of many of the benefits of urban and peri-urban forests

assess the benefits and costs and to guide management. Although various aerially based approaches are being researched and developed to derive specific tree information, the best existing approach for deriving many tree variables is field measurement.

Field data on urban and peri-urban forest structure can be obtained from inventories or by sampling. For large tree populations, field data in conjunction with aerially based assessments will likely provide the best and most cost-effective means for assessing urban and peri-urban structure. The most important parameters are species, diameter, crown dimensions, and tree condition. This information is helpful to managers for population management and in assessing risks to the resource, and it is also essential for estimating benefits and costs.

Attributes for modelling

For most benefits, the most important tree attribute is leaf area. Although not directly measured in the field, this variable can be modelled from information on species, crown size and crown condition, while diameter measures are essential for estimating carbon storage. Leaf and tree biomass can be modelled from these core tree variables. Other important attributes for estimating urban and peri-urban forest benefits are crown competition (important for estimating tree growth and carbon sequestration) and location around buildings (important for estimating energy conservation). Numerous benefits of urban and peri-urban forests can be modelled from these tree variables, in conjunction with other local information (e.g. on weather, pollution and demographics).

There is interdependence between urban and peri-urban forest structure, benefits and economic valuation. Valuation is dependent on good estimates of the magnitude of the benefit provided, and benefit estimates require good estimates of forest structure and how it affects benefits. Benefits and values cannot be adequately quantified without good data on forest structure. Combining accurate data with sound procedures for quantifying benefits will produce reliable estimates of the magnitude of benefits provided by urban and peri-urban forests. With these, the value of benefits can be estimated using valid economic estimates and procedures. Thus, three crucial elements are needed in sequence to value the benefits of urban and peri-urban forests and to aid their management: structure → benefits → values. Errors with precursor elements will lead to errors in subsequent estimates (e.g. errors in forest structure will lead to errors in estimating benefits and values).

STEP 2: MODELLING URBAN AND PERI-URBAN FOREST BENEFITS, COSTS AND VALUES

Information on forest structure can aid managers by revealing species composition, sizes, locations and potential forest risks (e.g. species composition can reveal potential risks posed by insects and disease infestations). Understanding the links between urban and peri-urban forest structure and the benefits those forests provide is essential for optimizing the benefits through management. Because many benefits cannot be measured easily in the field (e.g. air pollution removal),

A colour-enhanced aerial image of New York City, United States of America. The structure and benefits of urban and peri-urban forests vary across landscapes as forest cover and human populations vary

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models are used to estimate benefits, costs and values based in part on the measured data on forest structure. Once the benefits have been quantified, various methods of market and non-market valuation can be applied to characterize their monetary value (e.g. Hayden, 1989).

Various models exist for quantifying forest benefits; freely available models include InVEST (Natural Capital Project, undated), Biome-BGC (Numerical Terradynamic Simulation Group, undated) and numerous tools for assessing forest carbon (e.g. United States Forest Service, 2016a). Few models quantify urban and peri-urban forests, however. The most comprehensive model developed to date for quantifying urban and peri-urban forest structure, benefits and values is i-Tree,[1] a freely available suite of tools developed by the United States Forest Service through a public–private partnership. i-Tree is based on peer-reviewed science and can be used globally, and it has more than 180 000 users in 130 countries; it was designed to accurately assess local forest structure and its impacts on benefits, costs and values (Table 1). Model results have been validated against field measurements (e.g. Morani *et al*., 2014) to provide sound estimates of the benefits of urban and peri-urban forests. The model focuses on estimating forest structure and the magnitude of services received (e.g. tonnes of carbon removed). It then relies on economic valuation (e.g. dollars per tonne removed) to estimate the value of a given service. The model uses various economic estimates; users can adjust many of these if local economic values are available.

i-Tree Eco

The core programme of the i-Tree suite is i-Tree Eco. This model, which can be used globally, uses sample or inventory data and local environmental data to assess and forecast forest structure, benefits, threats and values for any tree population (Nowak *et al*., 2008). i-Tree Eco includes plot selection tools; mobile data entry applications; tabular and graphic reporting and exporting; and automatic report generation. Assessments of urban and peri-urban forests have been conducted using this model in numerous cities globally, including Barcelona, Spain; Calles, Mexico; Chicago, United States of America; London, United Kingdom of Great Britain and Northern Ireland; Medellín, Colombia; Milan, Italy; New York, United States of America; Perth, Australia; Porto, Portugal; Santiago, Chile; Seoul, Republic of Korea; Strasbourg, France; and Toronto, Canada (Chaparro and Terradas, 2009; Escobedo *et al*., 2006; Graca *et al*., 2017; Nowak *et al*., 2007, 2010, 2013; Rogers *et al*., 2015; Selmi *et al*., 2016).

The other tools in i-Tree are:

- **i-Tree Species** – selects the most appropriate tree species based on desired environmental functions and geographic area;
- **i-Tree Hydro** – simulates the effects of changes in tree cover and impervious cover on run-off, stream flow and water quality;
- **i-Tree Canopy*** – allows users to easily photo-interpret Google aerial images to produce statistical estimates

TABLE 1. Benefits and costs of trees currently quantified and in development in i-Tree

Ecosystem effect	Attribute	Quantified	Valued
Atmosphere	Air temperature	○	○
	Avoided emissions	●	●
	Building energy use	●	●
	Carbon sequestration	●	●
	Carbon storage	●	●
	Human comfort	○	
	Pollen	○	
	Pollution removal	●	●
	Transpiration	●	
	Ultraviolet radiation	●	○
	Volatile organic compound emissions	●	
Community/social	Aesthetics/property value	○	○
	Food/medicine	○	
	Health index[1]	○	
	Forest products[2]	○	○
	Underserved areas	●	
Terrestrial	Biodiversity	○	
	Invasive plants	●	
	Nutrient cycling	○	
	Wildlife habitat	●	
Water	Avoided run-off	●	●
	Flooding	○	○
	Rainfall interception	●	
	Water quality	●	○

Notes: ● = attribute currently quantified or valued in i-Tree; ○ = attribute in development in i-Tree;
1 = developing a health index based on mapping of green viewing (“forest bathing”); 2 = estimating product potential based on forest structure (e.g. timber, wood pellets, ethanol).

Source: Nowak (2017).

[1] www.itreetools.org

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A tree-lined street in Honolulu, Hawaii, United States of America. The design of urban and peri-urban forests is important for minimizing potential negative effects, such as trapping pollutants near roadways

of land-cover types. Historical imagery in Google Earth can also be used in analysing changes in land-cover types;

- **i-Tree Design** – links to Google Maps and enables users to quantify the current and future benefits of trees on their properties;
- **MyTree** – easily assesses the benefits of one to a few trees using a phone via a mobile web browser; and
- **i-Tree Landscape** – allows users to explore tree canopy, land cover, tree benefits, forest and health risks, and basic demographic information anywhere in the United States of America and to prioritize areas for tree planting and protection.

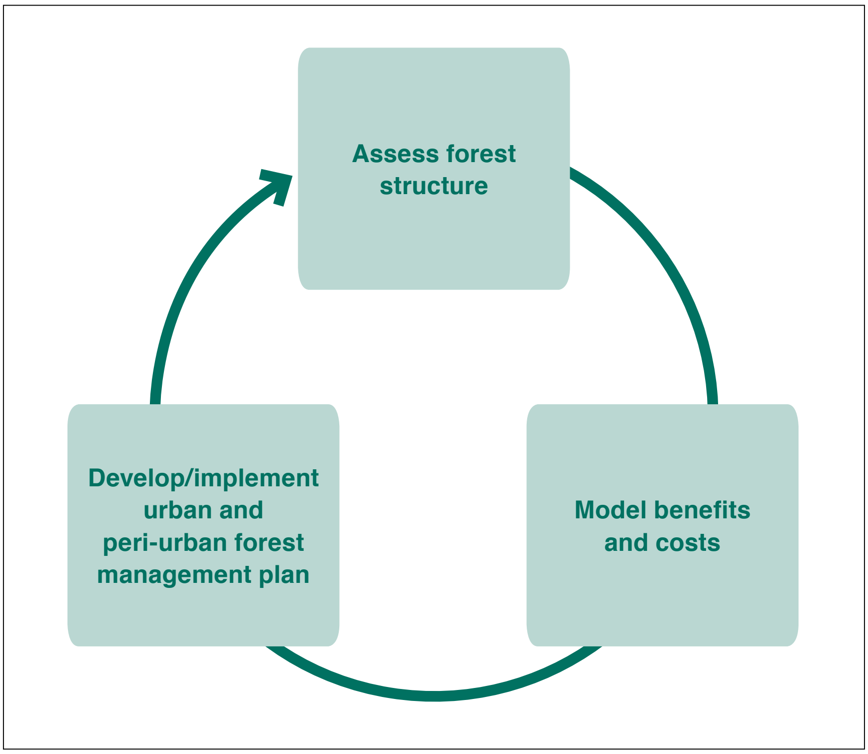
i-Tree is being developed through a collaborative effort among numerous partners to better understand and quantify how changes in forest structure will affect benefits and values and to aid in urban and peri-urban forest management and planning. Many new forest benefits and costs are being added to the model (Table 1).

Assessments and modelling in the United States of America indicate that there are an estimated 5.5 billion trees (39.4 percent tree cover) in urban areas nationally, containing 51.5 million hectares of leaf area and 40 million tonnes of dry-weight leaf biomass. Annually, these trees produce a total of USD 18.3 billion in value, comprising air pollution removal (USD 5.4 billion), reduced building energy use (USD 5.4 billion), carbon sequestration (USD 4.8 billion) and avoided pollutant emissions (USD 2.7 billion) (Nowak and Greenfield, in press).

STEP 3: DEVELOPING MANAGEMENT PLANS

Urban and peri-urban forests change constantly, and the goal of management is to guide such forests towards desirable outcomes that maximize benefits for present and future generations. A crucial step towards achieving this goal is to develop an urban and peri-urban forest management plan that optimizes forest structure over time. Data from local assessments and modelling, in conjunction with inputs from residents, can be used to develop plans to sustain or enhance urban and peri-urban forest structure and benefits. These plans can be as simple as detailing the means (e.g. funding) for attaining desired tree-cover goals at specific locations, or they can provide detailed information on planting rates by species and location.

Urban tree cover is on the decline in the United States of America (Nowak and Greenfield, 2012). Management plans need to consider various forces that are likely to alter forest structure over time, including forces that decrease tree cover (e.g. development, storms, insects and diseases, and old age) and increase tree cover (e.g. tree planting, natural regeneration and invasive species). In the United States of America, it is estimated that two-thirds of the existing urban forest is from natural regeneration (Nowak, 2012b). The influence of tree planting tends to increase in cities in grassland and desert areas, in more densely populated cities, and on land uses that are highly managed in relation to trees (e.g. residential lands). Planning for both human- and nature-driven changes in urban and peri-urban forests will facilitate better management plans that can sustain forest structure and benefits over time.



1
Cycle of urban and peri-urban forest assessments and monitoring for sustaining forest benefits over time

STEP 4: MONITORING CHANGE IN URBAN AND PERI-URBAN FORESTS

The last step in the assessment process is to remeasure the forest periodically (i.e. monitoring) to determine how it is changing and whether management goals are being met. This step is a remeasurement of the forest structure, as conducted in step 1, thereby restarting the cycle of modelling benefits and evaluating or updating management plans (Figure 1). The evaluation cycle (e.g. every 5–10 years) can ensure that the structure of the urban and peri-urban forest is progressing in the desired fashion to sustain benefits and values for society.

An increasing number of cities globally are assessing their urban and peri-urban forests so as to better understand the benefits and costs. The United States Forest Service Forest Inventory and Analysis programme, in partnership with states and cities, is undertaking long-term urban forest monitoring in the United States of America. This programme collects urban forest data annually to assess forest structure, benefits and values and changes in these over time. The first city to complete a baseline assessment was Austin, Texas (Nowak *et al*., 2016); 26 cities were monitored in 2017, and new cities will be added to the monitoring programme over the next few years (United States Forest Service, 2016b).

KEY FINDINGS

The main points made in this article can be summarized as follows:

- Understanding and accounting for the benefits provided by urban and peri-urban forests enables better planning, design and economic decisions for using those forests to improve environmental quality and human health and well-being.
- Data on urban and peri-urban forest structure (e.g. species composition and tree locations), and how that structure affects benefits and values, are crucial for such improvement.
- i-Tree is a simple and freely available set of tools for assessing and valuing the impact of trees and forests – from the scale of local forest parcels to regional landscapes – on environmental quality and human health and well-being.
- Monitoring urban and peri-urban forests is crucial for assessing change and evaluating management plans. The United States of America has recently begun a national urban forest monitoring programme in several cities and states.
- Future assessments, monitoring and management plans can help lower costs and sustain the benefits of urban and peri-urban forests. ◆

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