CHAPTER 10.4

Quantifying and valuing the role of trees and forests on environmental quality and human health

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Valuing nature

Nature provides numerous services that affect the lives and well-being of people across the globe. Understanding impacts and benefits of nature will lead to better management decisions and designs in sustaining nature within society. One of the most dominant aspects of nature in many areas of the globe is vegetation, and one of the most dominant elements of vegetation in many areas are trees and forests. In addition to environmental quality, these trees and forests, particularly when within urban areas, have substantial impacts on human population health and well-being.

Understanding the myriad of potential services and costs associated with trees and forests is critical to estimating net benefits of vegetation and for guiding appropriate vegetation management plans. However, while many of the ecosystem services and costs of vegetation cannot be adequately quantified or valued at this time, it is important to understand within decision-making processes that these services or costs do exist. Discounting nature or vegetation as having no value leads to uninformed decisions regarding nature (e.g. Costanza *et al.*, 2014). Quantifying or understanding monetary and non-monetary values of nature in a given context, though difficult, will lead to more informed environmental and economic decisions.

Services provided by trees and forests

Trees provide numerous economic and ecosystem services that produce benefits to a community, but also incur various economic or environmental costs. Through proper planning, design, and management, trees can improve human health and well-being in urban areas by moderating climate, reducing building energy use, and atmospheric carbon dioxide (CO_2), improving air quality, mitigating rainfall run-off and flooding, and lowering noise levels (Nowak and Dwyer, 2007). However, inappropriate landscape designs, tree selection, and tree maintenance can increase environmental costs such as pollen production, chemical emissions from trees and maintenance activities that contribute to air pollution, and can also increase building energy use, waste disposal, infrastructure repair, and water consumption (Escobedo *et al.*, 2011). These potential costs must be weighed against the environmental and health benefits in developing natural resource management programmes.

The Millennium Ecosystem Assessment (Hassan *et al.*, 2005) describes four categories of ecosystem services: (a) supporting (e.g. nutrient cycling, primary production); (b) provisioning (e.g. food, fuel); (c) regulating (e.g. climate regulation, water purification); and (d) cultural (e.g. aesthetic, spiritual). While science continues to advance in understanding and quantifying the relationships between forest structure and many of these services, several of these services can be currently quantified based on local forest, environmental, and human population data. Read more in Chapter 8.5 'Ecosystem services and health benefits—an urban perspective' for a full understanding of the ecosystem service concept.

Specific attributes of the vegetation resource such as abundance, size, species, health, and location affect the amount of services and costs provided by vegetation. Many of the services and costs provided by vegetation and their management affect human health. Thus, designing nature and management to maximize these benefits and minimize the costs can help improve human health.

There are four main steps needed to quantify ecosystem services and values from forests (or other ecosystem elements):

1. Quantify the forest structural attributes that provide the service for the area of interest (e.g. number of trees, tree cover). These structural data are essential as they quantify the resource attributes that provide the services.
2. Quantify how the structure influences the ecosystem service (e.g. tree density, tree sizes, and forest species composition are significant drivers for estimating carbon storage).
3. Quantify the impact of the ecosystem service. In many cases, it is not the service itself that is important, but rather the impact that the service has on human health, or other attributes of the environment that provide value to society.

4. Quantify the economic value of the impact provided by the ecosystem service.

There is an interdependence between forest structure and ecosystem services and values. Valuation is dependent upon good estimates of the magnitude of the service provided and the service estimates are dependent upon good estimates of forest structure and how structure affects services. The key starting point to valuing services provided by forests is quality data on forest structure. Services and values cannot be adequately estimated without good forest data. Combining accurate forest data with sound procedures to quantifying ecosystem services will lead to reliable estimates of the magnitude of ecosystem services provided by the forest. Finally, with sound estimates of forest ecosystem services, values of the services can be estimated using valid economic estimates and procedures. Thus, three critical elements in sequence are needed to value forest ecosystem services: structure → services → values. Errors in precursor elements will lead to errors in subsequent estimates (e.g. errors in forest structure will lead to errors in estimating services and valuation). All current estimates and means of estimation can be improved to varying degrees.

By understanding how vegetation affects services and values, better decisions can be made relating to landscape management to improve environmental quality and human health. To this end, tools are being developed that use local data to estimate ecosystem services and its economic value to help guide management and sustain optimal vegetation structure through time.

Modelling vegetation ecosystem services

Various models exist that quantify and value ecosystem services. InVEST (www.naturalcapitalproject.org/invest/) is a suite of free, open-source software models used to map and value the goods and services from nature that sustain and fulfil human life. InVEST enables decision makers to assess quantified trade-offs associated with alternative management choices and to identify areas where investment in natural capital can enhance human development and conservation. The toolset currently includes 18 distinct ecosystem service models designed for terrestrial, freshwater, marine, and coastal ecosystems (Natural Capital Project, 2016).

Another modelling system that assesses local vegetation structure and its associated ecosystem services and economic values is i-Tree (www.itreetools.org). This free suite of tools was developed through a public-private partnership and has been used across the world. The model requires users to enter local vegetation data, either through an inventory or sample, and combines the vegetation data with local meteorological and pollution data to simulate various ecosystem services: air pollution removal; carbon storage and sequestration; VOC emissions; reduced run-off; and effects on building energy use (Nowak *et al.*, 2008). The model focuses on estimating the magnitude of services received (e.g. tons removed) and relies on economic valuation (e.g. $/ton removed) to estimate a value of the service. These values can vary depending upon how the receivers of the benefits (e.g. humans) are distributed across the landscape relative to the trees. Not all ecosystem services are, or can be, evaluated due to scientific limitations (Fig. 10.4.1).

Other valuation toolkits exist, for example Ecosystem Valuation Toolkit (Earth Economics, 2016) with more models likely to be developed in the coming years.

Estimating the economic values of services and human health impacts

Once the services from nature are quantified, then economic values may be estimated using various methods. Some valuing procedures use direct market costs. For example, for altered building energy use, the local cost of electricity ($/kWh) and heating fuels ($/MBTU) can be applied to changes in energy use due to local vegetation. For other ecosystem services, proxy values often need to be used, as many of the services derived from trees are not accounted for in the cost of a market transaction (e.g. externality costs). An externality arises whenever the actions of one party either positively or negatively affect another party, but the first party neither bears the costs, nor receives the benefits. Externalities are not reflected in the market price of goods and services. A classic example of a negative externality is air pollution, where the health and clean-up costs are paid by society and not the producer of the pollutant. Trees often produce positive externalities (e.g. cleaner air). There are various ways to estimate these non-market-price-based values, including general systems analysis, the social fabric matrix, direct cost, contingent valuation, travel cost, hedonic pricing, mitigation and avoided cost methods, and the property approach (Hayden, 1989; Pascual *et al.*, 2010; TEEB 2010). Each method has its own strengths and weaknesses (Pascual *et al.*, 2010).

The various approaches to estimating the value of ecosystem services may or may not include health valuation. Some studies have estimated health impacts from vegetation by linking vegetation effects on pollution concentrations to human health impacts and values. Various models exist that estimate health values and impacts—for example, the Environmental Benefits Mapping and Analysis Program (BenMAP) (US EPA, 2012) and Air Quality Benefits Assessment Tool (AQBAT) (Judek *et al.*, 2006). These models use population data and concentration-response functions to estimate the change in adverse health effects due to change in air pollutant concentrations. Valuation functions calculate the associated monetary value from health effects. These calculations are based on meta-analyses of epidemiological studies and clinical experiments. Economic valuation is based on estimates of healthcare expenses and productivity losses associated with specific adverse health events, and on the value of a statistical life in the case of mortality. Changes in hourly air pollution concentration combined with population data can be used to estimate health impacts and values.

Based on a national assessment, trees and forests in the conterminous United States were estimated to remove 17.4 million metric tons of air pollution in 2010, with human health effects valued at $6.8 billion (range: $1.5–13.0 billion) (Nowak *et al.*, 2014) (Fig. 10.4.2). Most of the pollution removal occurred in rural areas, while most of the health impacts and values were within urban areas. Health impacts included the avoidance of more than 850 incidences of human mortality and 670,000 incidences of acute respiratory symptoms. Using median air pollution cost factors from Europe that include health costs, building and material damage, and crop losses (van Essen *et al.*, 2011), pollution removal by US trees would jump to over $86 billion, a 13-fold increase over the $6.8 billion health value.

Other studies that have linked pollution removal and health effects include one in London, UK, where a 10 × 10 km grid with 25% tree

Fig. 10.4.1 Example of estimated benefits derived from street trees in Fond du Lac, Wisconsin using the i-Tree model.
Reproduced courtesy of The Wisconsin Department of Natural Resources, available from https://www.itreetools.org/resources/reports/WDNR_Fond_du_Lac_reports.pdf.

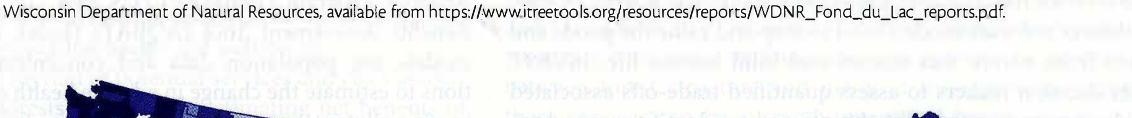

Fig. 10.4.2 Estimated removal per square kilometre of land (metric tons km^{-2}) of four pollutants (nitrogen dioxide, ozone, particulate matter less than 2.5 microns, sulphur dioxide) by trees per county in the conterminous United States in 2010.
Reprinted from *Environmental Pollution*, Volume 193, Nowak DJ *et al.*, 'Tree and forest effects on air quality and human health in the United States,' pp. 119–129, Copyright © 2014 published by Elsevier Ltd, with permission from Elsevier, http://www.sciencedirect.com/science/journal/02697491.

Table 10.4.1 Summary of total monetary value per ecosystem biome in international $ per hectare per year, 2007 price levels

Ecosystem biome	Annual value per hectare
Coral reefs	$352,249
Coastal wetlands	$193,845
Coastal systems	$28,917
Inland wetlands	$25,682
Tropical forests	$5,264
Fresh water (lakes and rivers)	$4,267
Temperate forests	$3,013
Grasslands	$2,871
Woodlands	$1,588
Open ocean	$491

Source: data from De Groot R *et al.*, 'Global estimates of the value of ecosystems and their services in monetary units,' *Ecosystem Services*, Volume 1, Issue 1, pp. 50-61, Copyright © 2012 Elsevier B.V. Published by Elsevier B.V.

cover was estimated to remove 90.4 t of PM_{10} annually, which equated to the avoidance of two deaths and two hospital admissions per year (Tiwary *et al.*, 2009). In addition, Nowak *et al.* (2013) reported that the total amount of $PM_{2.5}$ removed annually by trees in 10 US cities in 2010 varied from 4.7 t in Syracuse to 64.5 t in Atlanta. Estimates of the annual monetary value of human health effects associated with $PM_{2.5}$ removal in these same cities (e.g. changes in mortality, hospital admissions, respiratory symptoms) ranged from $1.1 million in Syracuse to $60.1 million in New York City. Mortality avoided was typically around one person per year per city, but was as high as 7.6 people per year in New York City. These are just a few examples of linking ecosystem services to health impacts and values. These studies focus on tree effects on air pollution, often in cities, but there are numerous other studies, ecosystems, and ecosystem services and values that can be derived from nature.

The estimated total annual value per hectare from ten ecosystem biomes ranges from $490 international dollars for open oceans to $350,000 international dollars for coral reefs (de Groot *et al.*, 2012, Table 10.4.1). These average values vary among ecosystem type and are mostly outside the market and best considered as non-tradable public benefits. The total values include provisioning, regulating, habitat, and cultural services. Numerous other estimates of ecosystem values exist (e.g. TEEB 2010), yet many services remain to be adequately quantified and valued.

While valuing ecosystem services in monetary terms can be complex and controversial, natural resources are economic assets, whether they enter the marketplace or not, and could be accounted for in land management decisions (TEEB, 2010). The Economics of Ecosystems and Biodiversity report (TEEB, 2010) provides several recommendations to analysing and structuring the valuation of ecosystem services.

Even though models can calculate some ecosystem and health benefits and costs, there are multiple benefits and costs yet to be quantified. More research is needed to quantify the numerous health and environmental benefits provided by vegetation and other ecosystems. In addition, the potential environmental and maintenance or management costs associated with vegetation and ecosystems need to be quantified to facilitate vegetation management that optimizes economic, environmental, and health benefits from vegetation.

Conclusion

By understanding and accounting for the ecosystem and health benefits provided by nature, better planning, design, and economic decisions can be made toward utilizing nature as a means to improve human health. InVEST, i-Tree, and other tools offer a means to assess and value the impact of trees, forests, and other ecosystem elements at varying scales for several key ecosystem services. While more research is needed regarding several ecosystem services and impacts on human health, landscape management plans and designs should incorporate the role of vegetation and nature to lower costs and improve human health and environmental quality, and thereby provide substantial economic savings to society.

Disclaimer

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