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An ecosystem service-disservice ratio: Using composite indicators to assess the net benefits of urban trees

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ABSTRACT

Considering ecosystem disservices (EDS) of urban forests alongside the services (ES) can lead to better-informed decisions about tree species selection and placement in cities. Finding a common assessment framework, that does not rely on a financial model, can be tricky, and many studies consider, but do not include, EDS in their tree appraisals. Compound indicators represent a means to neatly combine disparate ecosystem data into one meaningful metric. In this study quantitative field measurements, model outputs, and categorical data relating to some of the major ES and EDS of the urban forest of Meran, Italy, were successfully compressed into a single unit, overcoming epistemological boundaries surrounding different urban ecosystem valuation methods. Several methods of compound indicator construction were considered and uncertainty and sensitivity analysis carried out on the species rankings which were produced. Significant differences in ES/EDS provision were observed between trees on public and private land. Spatial analysis revealed hotspots of high ES provision and low EDS provision, and vice versa. With correct use, compound indicators can stand alongside other methods of measuring and valuing positive and negative aspects of urban ecosystems.

1. Introduction

Many cities around the world are promoting and implementing tree planting schemes in order to capitalize on the ecosystem services (ES) that urban forests provide (Jim and Chen, 2009; Pincetl, 2010). These ES range from the biophysical – storm-water modification (Berland et al., 2017), air pollution capture (Escobedo et al., 2011), and phytoremediation of contaminated land (Dadea et al., 2017), to the socio-economic – raising property values (Escobedo et al., 2015), and improving the aesthetic appeal of urban landscapes (Weber et al., 2008). Interactions between urban ecosystems and urban residents are not always positive, however, and these ecosystem disservices (EDS) (Lyytimäki and Sipilä, 2009; Von Döhren and Haase, 2015) are increasingly the subject of research (Pataki et al., 2011; Swain et al., 2013).

This surge in research interest is partly to try and address the imbalance which has been identified within the field of ES research (Lyytimäki and Sipilä, 2009). In a review of urban tree ES literature (Roy et al., 2012) only 15.6% of 115 papers discussed hazards alongside the benefits. There is currently a controversy in the use of the EDS concept in that many feel it only serves to highlight the harm to humans which may be caused by ecosystems, and thus hamper conservation efforts, or justify exploitation of natural resources (Lyytimäki, 2015). Shapiro and Báldi (2014) note that ES and EDS frequently come from the same provider, but society is often quicker to acknowledge the EDS. The concept of EDS thus may exaggerate the harms caused by nature. However, it has sensibly been argued that the controversy surrounding the complexity of ecosystem functions can only be resolved by taking into account the complete bundle of positive and negative functions as perceived by beneficiaries (Lyytimäki, 2015). The goal is to put ES and EDS under the same assessment framework, or bundle, allowing decision makers to weigh the benefits of urban forests against the costs, leading to better-informed decisions (Dobbs et al., 2011).

A common assessment framework utilized is financial (Mullaney et al., 2015). This approach is appealing because it allows tree benefits to be easily communicated to, and understood by, policy makers and corporate entities. Tree-scaping can increase spending in retail outlets (Wolf, 2005), decrease household electricity consumption for cooling via shading effects (Pandit and Laband, 2010), and increase house prices (Donovan and Butry, 2010). When such financial benefits are weighed against the planting, establishment (200–1500 euros per tree (Pauleit et al., 2002)) and maintenance costs, the results can be a very

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persuasive argument for tree planting. The annual net benefit per tree in the US, when financial EDS such as repairing damage to pavement by tree roots are taken into account, is between US$21 and $159 (Mullaney et al., 2015).

Several tools and applications use tree inventory data to quantify the monetary and non-monetary value of the environmental and aesthetic benefits of urban trees (i-Tree STREETS, 2017; Vogt et al., 2017). Often, these models account for ecosystem functions that are detrimental to human well-being and the related costs of management, thus allowing for a better understanding of the urban forest and strategic planning, but unfortunately, they do not consider any specific EDS to balance against the ES (i-Tree STREETS, 2017). Gómez-Baggethun and Barton (2013) describe several valuation methods used in urban ecosystems, such as direct and indirect methods (e.g. hedonic modelling, travel cost, contingent valuation), and other non-monetary methods. They propose that it is possible to obtain a monetary estimation for a wide range of ES, however, again, EDS are not considered in this typology.

A different approach is to consider trade-offs between ES and EDS, which inherently acknowledges that urban tree impacts are complex and dynamic and one cannot simply deal with single impacts separately. Dobbs et al. (2014) spatially quantified a broad range of plot-level ES alongside two EDS - pollen and damage to infrastructure potential. The supply of landscape-level Disservices were higher in the streets, and a moderate trade-off between maintenance of natural heritage and habitat provision was revealed.

Andersson-Sköld et al. (2018) proposed a cascade model of ES which links measured green space structures to ES delivery by means of functional traits – a quantification based method of assessing ecosystems. The model is comprehensive in that it strives to include (often difficult-to-measure) cultural ES and considers multiple ES arising from measurable ecosystem components, however it does not include EDS and thus only shows the gross benefits.

The aim of this paper is to develop an overall ratio that accounts for several EDS alongside some of the major ES in order to assess the net benefits of urban trees. The two major EDS considered are pollen allergenicity (Cariñanos et al., 2014), and Biogenic Organic Volatile Compound (BVOC) production, which can lead to the formation of tropospheric O_3 with consequent negative impacts on human respiratory health (Calfapietra et al., 2013). These urban EDS can be highly specific to cities i.e. BVOC production by trees is not a problem for human health in rural areas unpolluted by car exhausts. Urban EDS are important to study because they affect city residents daily, where they live, work and commute.

The approach to construct the overall ratio will utilize Composite Indicators (CIs) which have not been previously applied to ecosystem services or disservices. CIs have been criticized for over-simplifying complex issues and being open to misinterpretation or misuse, but as long as they are constructed in a transparent, statistically sound manner they can be very useful (Saisana et al., 2005). They lend themselves particularly well to the problem of considering multiple ES and EDS, which act on different scales and have been measured using different units. The main objective of this research is thus to assess whether simple, disparate measurements of the urban forest can be combined into a single assessment framework. Once a sensitivity analysis has been used to choose the best final metric, tree species will be ranked in order of simultaneous high ES provision and low EDS provision, and spatial patterns in ES and EDS provision will be interpreted. The research is unique as it incorporates a full inventory of public trees alongside extensive fieldwork on private land, because there is a need to identify which trees are favourable in different settings (Churkina et al., 2015).

2. Methodology

2.1. Study site

Meran, a city of about 40,000 inhabitants (ISTAT, 2017), is located in the Autonomous Province of South Tyrol in Northern Italy. The climate is of sub-Mediterranean influence with a mean annual precipitation of ca. 760 mm and the minimum and maximum average temperatures of 5.0 °C and 18.1 °C, respectively (Meteo Alto Adige, 2017). It covers approximately 661 ha, however the actual area available for study was 608 ha, due to the presence of a large military base within the city where fieldwork was prohibited. The city was classified into 17 land types following the i-Trees land classification scheme (i-Tree ECO, 2017) but using subdivisions of the 'commercial' and 'institutional' land types.

Since the year 2000, the Meran municipality has maintained a detailed street-tree inventory containing over 5000 trees in streets and parks, with an interactive online map (Comune di Merano, 2010). In addition to species and location, the inventory contains information on height, trunk diameter at breast height (DBH) and trees' health condition.

2.2. Tree sampling

Fieldwork took place during autumn 2016. Selection of areas to sample was guided by a desire to sample the land types proportionally to their areal coverage of the city. Sampling thus followed an ecological relevé style whereby all trees are sampled within parcels of urban land. This non-random sampling strategy has been shown to be acceptable for capturing the species diversity and tree characteristics of urban forests (Speak et al., 2018). Initially, 964 trees from the three major public spaces included in the city inventory – streets, parks, and cemetery – were re-measured. The measurements in the inventory were not used because some trees had not been measured for several years, DBH had been measured at 1 m above ground instead of 1.37 m and additional measurements consisting of total tree height, height to crown base, crown width, percent canopy missing, and tree-crown condition were required. DBH was measured with calipers and height was measured with a Blume-Leiss BL6 hypsometer from a distance of 30 m. Remaining measurements were recorded according to the i-Tree field guide (i-Tree ECO, 2017). An additional 1215 trees were measured on private land. Table 1 shows the main characteristics of the tree inventory.

Permission was always sought from the landowner. On the infrequent occasions where permission was not granted, the field worker moved to the next neighbouring unit. The patch (urban land parcel) sizes range from 250 m^2 (a single house and garden) to 5.9 ha on public land (cemetery) and 5.5 ha on private land (several adjacent apartment blocks). Tree species were identified mostly to species level and occasionally to genus level using Phillips (1978). Trees were drawn on a map of the area in the field and transferred to a geodatabase within ArcMap 10.4.1 using high-resolution aerial photography from 2013 obtained from the online Geocatalogue (Geocatalogo, 2017). Hourly air pollution concentration and meteorological data for Meran for the year 2013 (Meteo Alto Adige, 2017) were submitted to the i-Trees database and included in the latest software update (v. 6.0.7).

Table 1
Main characteristics of the tree inventory.

Area covered hectares	101.2
Area covered % of total city – excluding military	16.6%
Total trees	6371
Trees private	1215
Trees public	5156
Number of species	222
Number of genera	92
Number of families	40