Ecological Indicators 43 (2014) 44–55

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Multiple ecosystem services and disservices of the urban forest establishing their connections with landscape structure and sociodemographics

Cynnamon Dobbs*, Dave Kendal, Craig R. Nitschke

School of Botany, School of Land and Environment, Department of Forest and Ecosystem Science, University of Melbourne, Victoria 3010, Australia

ARTICLE INFO

Article history:
Received 29 June 2013
Received in revised form 20 January 2014
Accepted 5 February 2014

Keywords:
Sustainable cities
Vegetation
Indicators
Recreation
Carbon
Spatial analysis

ABSTRACT

The promotion of sustainable cities is critical under future environmental change and population growth. Cities in the present and future can ensure the provision of ecosystem services to their urban inhabitants. The urban forest is one of the main suppliers of ecosystem services in urban areas, and can provide the base information to quantify ecosystem services and disservices, detecting the areas were low provision of those occur. In this study multiple ecosystem services and disservices were quantified using transferable indicators in order to detect areas for environmental improvement. The set of spatially explicit indicators enables the detection of areas of low and high provision of ecosystem services. The analysis showed synergies existing among regulating, provisioning and supporting services, while trade-offs were found with cultural services and regulating, provisioning and supporting services. Ecosystem services provision was positively related to the amount of vegetation and negatively related to its degree of fragmentation. A high provision of ecosystem services was found in less populated areas, with more educated and affluent people, highlighting the strong relations existing between social vulnerabilities and areas of low provision of services. Results from this research provide insights on the role of policy makers on better distributed supply of ecosystem services and on how the landscape structure can be modified to plan for sustainable cities.

1. Introduction

Ecosystem services are defined as the direct and indirect benefits provided by ecosystems for human well-being (De Groot et al., 2010a; Haines-Young and Potschin, 2010). The ecosystem services concept is increasingly being used within research on sustainable development to detect and reduce areas of lower provision of ecosystem services (Elmqvist et al., 2003; Schröter et al., 2005; Collins et al., 2011). Though the creation of sustainable cities based on ecosystem services allows for policies and management to be tailored towards the services that will permit the development of environmentally, economically and socially sustainable societies while enhancing ecological processes. This sustainable provision of ecosystem services is a critical response to ongoing urbanization that is placing enormous pressures on natural resources within and around urban landscapes (Grimm et al., 2008; Collins et al., 2011; Griggs et al., 2013), and to the inequalities that lead to the biotic impoverishment of socially disadvantaged communities (Luck et al., 2009). Vegetation in urban landscapes provides important ecosystem services, such as air pollution removal, aesthetics or the provision of shade, which supports the maintenance of human well-being (Pataki et al., 2006; De Groot et al., 2010b; Dobbs et al., 2011). Understanding how the provision of ecosystem services from vegetation is related to the structure and social context of the urban landscape is important for promoting the development of sustainable cities (Carpenter et al., 2006; Liu et al., 2007).

Studies of the ecosystem services produced in urban areas have increased in recent years, largely in response to the recognised benefits of ecosystems for human health (Tzoulas et al., 2007; Lachowycz and Jones, 2012), security (Whitford et al., 2001) and economy (McPherson and Simpson, 2001; TEEB, 2011; Tyrväinen et al., 2000). However, little is known about patterns in the provision of ecosystem services and disservices (i.e. functions of the ecosystem that are perceived negative by human well-being) in urban landscapes (Pauleit et al., 2005; Tratalos et al., 2007; Barbosa et al., 2007; Lyytimäki et al., 2009). Socio-ecological systems, such as urban landscapes, have strongly connected components, are complex, and evolve as integrated systems (Folke et al., 2002). Spatial heterogeneity in the supply of ecosystem services is not

* Corresponding author: Tel.: +61 0425481181.

http://dx.doi.org/10.1016/j.ecolind.2014.02.007
1470-160X/

only a result of the physical environment, but also of the socioeconomic conditions that exist within cities (De Groot et al., 2010a). There is also little known about interactions between ecosystem services in urban areas, with the majority of the research focusing on conservation, agricultural and forest landscapes (Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Ruijs et al., 2013; Schulp et al., 2012). Interactions are typically analysed as trade-offs and synergies. Trade-offs occur when one service is enhanced at the expense of another, while synergies exist when the improvement of one service has a positive effect on another service (Raudsepp-Hearne et al., 2010).

The urban forest corresponds to all trees, shrubs, lawns and pervious soils found in urban areas (Dobbs et al., 2011; Escobedo et al., 2011), in this study we focused on the tree component. The use of urban forest structure as input data is a logical pathway for quantifying ecosystem services in the urban environment (Borgström et al., 2006), since urban trees provide multiple services including shade, cooling, habitat, carbon sequestration and storage, air pollution removal and rainfall interception (Whitford et al., 2001., Nowak et al., 2008; Dobbs et al., 2011; Gomez-Baggethun and Barton 2013). Trees are also an important indicator of recreational opportunities, and contribute to positive aesthetics, connection to nature and physical and psychological enjoyment (Bastian et al., 2012; Dobbs et al., 2011; Tratalos et al., 2007; Tzoulas et al., 2007) and can also contribute to the provision of food and wood. Because the urban forest is intensively managed, landscape metrics such as patch size and compactness (see for further detail Schneider and Woodcock, 2008; Seto and Shepherd, 2009) may be useful indicators for identifying areas with cities that do not promote sustainability (Carpenter et al., 2009; Daily et al., 2009).

To strategically plan and inform policy for the development of sustainable cities it is necessary to be able to characterize the vegetative structure of cities and measure the impacts of development in time and space. The objective of this study is to present a meta-model that allows the quantification of ecosystem services and disservices under a socio-ecological framework. To achieve this, indicators of ecosystem services that are spatially relevant and transferable to other cities were established to then quantify the relationships between landscape vegetation structure and the provision of both services and disservices. Furthermore, we seek to integrate social and demographic factors into our assessment framework and quantify their relationship to ecosystem services (Carpenter et al., 2009; De Groot et al., 2010a).

This study presents a systematic quantitative assessment of the structure and services from an urban forest using a scale relevant to inform policy decisions at the municipal level. While previous studies (e.g. Dobbs et al., 2011) have explored the provision of ecosystem services using detailed information from intensive survey of soils and vegetation in urban areas, this research aims to explore how the urban forest drives the provision of ecosystem services and disservices using transferable indicators derived from more readily available datasets and to explore how the trade-offs and synergies exist among provisioning, supporting, regulating and cultural services (Daniel et al., 2012). Understanding how landscape structure and socio-demographics relates to the provision of ecosystem services will inform management decisions and policy making to aid in the progression towards improving sustainability within urban centres by detecting highly fragmented areas or with low provision of ecosystem services.

2. Methods

The study was conducted within the City of Melbourne council, a local government area responsible for the city centre in Melbourne, Australia (Dobbs et al., 2013). The municipality encompasses 3760 ha and comprises less than 10% of the Greater Metropolitan Melbourne area. The selection of one municipality for this study allows for a comprehensive assessment of ecosystem services and disservices at the management level.

2.1. Quantification of ecosystem services and disservices

Ecosystem services and disservices were derived from information extracted from aerial photographs (year 2008, 50 cm pixels), thermal imagery (2011, 1 m pixel), land use, soils, water flow, climate data and forest inventories provided by the City of Melbourne. The selected services and disservices are quantifiable spatially (van Oudenhoven et al., 2012; Burkhard et al., 2012) and have been proven to affect human well-being and are relevant for urban landscapes (Davies et al., 2011; Dobbs et al., 2011; Escobedo et al., 2010; Jim and Chen, 2009; Tratalos et al., 2007; Tzoulas et al., 2007; Table 1). Data and methods used to calculate each service and disservice are detailed in Table 1 and Supplementary material (Appendix A). Services were categorised following on Gomez-Baggethun and Barton (2013) classification. A flow chart illustrating input, process and outputs is provided in Fig. 1.

Areas of low and high provision of ecosystem services were identified based on the equally weighted sum of all standardized services and disservices at the pixel level, following the approach of Banzhaf and Boyd (2005), Dobbs et al. (2011) and Van der Biest et al. (2014). The purpose of managing multiple ecosystem services is to prevent further degradation, minimizing areas of low provisioning of ecosystem services. Because no information on the importance of the different services was available they were equally weighted in the analysis (Wainger et al., 2010). Spatial autocorrelation using Moran's I was used to test whether clustering of vulnerabilities occurred (Anselin, 1995). Additionally, clusters of high and low provision of services were identified using the Getis Ord statistic (Getis and Ord, 1992) for areas that had values different to null. Relationships between services, i.e. synergies and trade-offs were quantified by using a spatially explicit Pearson correlation analysis of the raster, based on the correlation coefficient (r^2) of pairs of services and disservices. All analysis and quantification of services and disservices were performed using ArcGIS (version 10.1 ESRI 2011, Redlands CA) and SAS (version 9.3 SAS Institute, Cary NC).

2.2. Relations between ecosystem services and disservice provision, landscape structure and socio-demographics

There is a feedback loop between the provision of ecosystem services and disservices, and the components of the urban environment (expressed in a conceptual model in Fig. 2). This conceptual model is able to integrate multiple ecosystem services to represent areas of low provision of ecosystem services within the urban environment. The framework includes a spatially explicit component, illustrating the highly variable structure existing in the urban environment. The structure of the urban forest regulates how ecological functions occur in the urban environment determining the quantity of ecosystem services and disservices in the study area. The amount of multiple ecosystem services and disservices provided directly and indirectly affect human well-being from a social, economic and health point of view. However, the structure of the urban forest is not static, but dynamic, and can be modified by demographic and economic changes, and also changes derived from policies and management. In addition to variation derived from environmental changes such as natural disasters. All these previously mentioned factors of change relate to the urban forest structure and have consequences in the provision of ecosystem services, therefore detecting areas of low provision, closing the loop.

Landscape structure was mapped using values for tree cover, number of vegetation patches, mean area of the vegetation patch and compactness index (the shape of the patch in relation to the