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ECOMOD-8292; No. of Pages 14
ARTICLE IN PRESS
Ecological Modelling xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Ecological Modelling
journal homepage: www.elsevier.com/locate/ecolmodel

Assessing, valuing and mapping ecosystem services at city level: The case of Uppsala (Sweden)

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ARTICLE INFO

Article history:
Received 31 March 2017
Received in revised form 20 October 2017
Accepted 23 October 2017
Available online xxx

Keywords:
Ecosystem services
Environmental accounting
Cities
Uppsala

ABSTRACT

Urbanization is an important driver of environmental changes causing an increasing demand of ecosystem services while altering natural ecosystems. Yet, the sustainable management of urban areas can support the long-term provision of goods and services typical of healthy and resilient ecosystems and essential for human well-being. In this study, multiple ecosystem services generated by forest, agricultural (cropland and grassland), and urban areas in the municipality of Uppsala (Sweden) were first assessed in biophysical terms and then valued in money units. Afterwards, the economic value of provisioning and regulating services was spatialized using Geographic Information Systems (GIS). The economic value of all investigated services amounted to 1.81 billion Swedish Kronor (SEK) or 198 million € per year, of which: 80% generated by forest areas, 19% by agricultural areas, and 1% by green urban areas. Considering the size of different land uses, the average economic value of green urban areas was the highest (20,000 SEK ha^{-1} or 2200 € ha^{-1}), followed by forest areas (11,387 SEK ha^{-1} or 1250 € ha^{-1}), and agricultural areas (6398 SEK ha^{-1} or 703 € ha^{-1}). The integration between the assessment of the biophysical and economic value of several ecosystem services provided by different land uses as well as their spatial analysis allowed a deeper understanding on the ecological life-support system to the urban area of Uppsala. In conclusion, we maintain that the interplay between nature services and human settlements can be better explored by using an interdisciplinary approach providing ecological and economic information integrated in support of policy makers and urban planners.

1. Introduction

Ecosystem services (ES) are benefits that human obtain directly or indirectly from ecosystems (MA, 2005). Stocks of natural capital and flows of ES are massively exploited to support human economy and well-being, thus emphasizing the dependence of human activities on the ecological life-support system (Daly, 1990).

Over the last century, urbanization in cities has become an important driver of environmental changes, triggering the demand of ES while increasing the amount of waste and emissions in surrounding ecosystems (Eigenbrod et al., 2011). In Europe, about 80% of the population already lives in urban areas, while at global level about 50% of the world population lives in urban areas (Hölzinger et al., 2014; Haase et al., 2014a). In addition, it is projected that 70% of the global population will live in urban areas by 2030, adding an even higher pressure on the fragile balance between human economy and supporting ecosystems (Demuzere et al., 2014).

Folke et al. (1997) estimated the ecosystem surface needed for ES consumption and waste assimilation of the 29 largest cities in the Baltic Sea region. Such ecosystem surface was estimated to be at least 500–1000 times larger than the surface of the cities themselves. Yet, urban areas, if sustainably managed, can play a crucial role in supporting human well-being while containing environmental costs and impacts of human activities (Chrysoulakis et al., 2013; Elmqvist et al., 2015; McPhearson et al., 2016).

The long-term provision of multiple ecosystem goods and services is based on the balanced relationship between the demand of ES by cities and the supply of ES ensured by green urban areas and peri-urban ecosystems. Therefore, a major research and policy effort should be made to better understand and properly manage ES generated within cities and their surrounding environments (Gómez-Baggethun and Barton, 2013; Haase et al., 2014b).

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https://doi.org/10.1016/j.ecolmodel.2017.10.013
0304-3800/

Please cite this article in press as: Nikodinoska, N., et al., Assessing, valuing and mapping ecosystem services at city level: The case of Uppsala (Sweden). Ecol. Model. (2017), https://doi.org/10.1016/j.ecolmodel.2017.10.013

Several biophysical and economic assessment methods have been developed and applied to account for environmental costs and benefits due to the exploitation of ES (Ulgiati et al., 2010; Seppelt et al., 2011; Franzese et al., 2014; Häyhä and Franzese, 2014; Schröter et al., 2014; Nikodinoska et al., 2015, 2017). Spatial analysis is increasingly used to assess the value of multiple ES while investigating their supply, demand and budgets (Burkhard et al., 2012). Mapping ES is also functional to establishing a more rational resource management policy. In particular, landscape and urban planning can be supported by considering additional information including the local provision and consumption of ES, and related biophysical constraints to human development (Ahern et al., 2014; Haase et al., 2014c; Wolff et al., 2015).

The economic assessment of ES can explore different forms of utility (i.e., use and non-use value) provided by ecosystems to humans. Indeed, different money-based valuation methods can be used to assess both marketable (e.g., provisioning) and non-marketable (e.g., regulating) ES. The latter, although vital for human well-being, are often overlooked by market-based valuations (Farber et al., 2002). In addition, many issues arise when ES are valued in money units. The economic value of ES is highly dependent on the chosen market or survey-based assessment method, most often characterized by simplified assumptions (e.g., rational behavior), also relying on subjective preferences. Moreover, the estimated economic value of ES does not necessarily reflect the individual or societal value of the investigated services (Ludwig, 2000).

When ecosystems are approaching ecological thresholds, natural capital and ES can reach critical levels in both quantity and quality (Farley, 2012). In such cases, money-based methods, used to account for marginal changes in the provision of ES, are not effective estimation tools since an infinitesimal decrease in the physical quantity of natural capital and ES could lead to a dramatic increase of their marginal economic value (Limburg et al., 2002). Therefore, a solid biophysical accounting should precede the economic valuation to reflect the state of ecosystems and their actual provision of services (Franzese et al., 2017; Picone et al., 2017; Vassallo et al., 2017).

Many studies have focused on assessing single or bundle of ES at national level (Gren and Isacs, 2009; UK NEA, 2014; Frélichová et al., 2014; Jäppinen and Heliölä, 2015; Quintas-Soriano et al., 2016), regional level (Raudsepp-Hearne et al., 2010; Frélichová and Fanta, 2015; Queiroz et al., 2015; Zank et al., 2016), and city level (McPhearson et al., 2013a,b; Hölzinger et al., 2014; Elmqvist et al., 2015).

Peng et al. (2015) evaluated the urban ecosystem health in the city of Shenzhen (China) by exploring landscape patterns and their impacts on ES provision. Yang et al. (2015) assessed the biophysical value of water-related ES provided by urban green areas in the city of Yixing (China). Hölzinger et al. (2014) performed an economic assessment of the ES provided by woodland, heathland, wetland, and grassland areas in the city of Birmingham (United Kingdom). Remme et al. (2014, 2015) developed spatial biophysical and monetary accounting of several ES in a cultural landscape in the province of Limburg (the Netherlands). Soares et al. (2011) assessed the ES generated by street trees in the city of Lisbon (Portugal). Strohbach and Haase (2012) assessed the service of carbon storage by urban trees in Leipzing (Germany). Camps-Calvet et al. (2016) assessed the perceived importance of ES generated in urban gardens in Barcelona (Spain) while Buchel and Frantzeskaki (2015) investigated the perceived importance of ES provided by urban parks in Rotterdam (the Netherlands). McPhearson et al. (2013a) mapped multiple ES of urban green areas and explored their relation with social conditions in urban neighborhoods in the city of New York (USA). Derkzen et al. (2015) quantified the ES generated by urban green areas located in the city of Rotterdam (the Netherlands). Elmqvist et al. (2015) estimated in biophysical and money terms the benefits received in terms of ES in 25 urban areas in USA, China, and Canada.

In spite of this broad literature, an integrated biophysical-economic approach to the assessment of ES at municipal level is still a relatively new research area requiring a multi-method and multi-criteria perspective (Gómez-Baggethun and Barton, 2013; Hubacek and Kronenberg, 2013; Haase et al., 2014b; Derkzen et al., 2015; Franzese et al., 2015).

In this study, multiple ES generated by forest, agricultural (cropland and grassland), and urban areas in the municipality of Uppsala (Sweden) were firstly assessed in biophysical terms and then valued in money units. Afterwards, the economic value of provisioning, regulating, and cultural ES was spatialized using Geographic Information Systems (GIS). Finally, the main spatial patterns of ES provision in relation to different land uses as well as the utility of an interdisciplinary and biophysical-based valuation were discussed.

1.1. Added value and usefulness of the study

The added value of the study is the integrated assessment of the ecological and economic benefits that ecosystem services generate for human well-being and local economy in the city of Uppsala. The study was performed by using local and regional data – not international average data. In addition, the integrated use of GIS allowed the spatial representation of the results. The produced tables and maps can support local managers and policy makers while informing the local population and raising the awareness about the ecological and economic importance of the annual flows of ES generated by forest, agricultural, and green urban areas in the city system. Moreover, the findings of this study represent a quantitative and spatially explicit benchmark useful to monitor the future trends in the development of the city system. The same assessment protocol implemented in this study can be applied to any other city worldwide for the investigation of other city systems or for comparative purposes.

2. Material and methods

2.1. Study area

The municipality of Uppsala (59°51′29″N, 17°38′41″E) is located in the East-Central Sweden and it is part of the Uppsala County. The municipality covers a total surface of 2234 km^2 consisting of forests (60%), arable and grazing land (25%), urban areas (6%), water courses (2%), and other land (7%) (Fig. 1).

The city of Uppsala is the fourth largest city of Sweden with a land area of 48.77 km^2 and a total population of 140,454 inhabitants. With a density of population of 2880 inh. km^{-2}, it accounts for 68% of the population of the municipality of Uppsala.

The main land use in the municipality of Uppsala is the forest area (133,292 ha) indicating the importance of such ecosystem for the local economy and human well-being. The main forest types are Scots pine (*Picea abies* L.) forests with 42.6% of the total forest area, Norway spruce (*Pinus sylvestris* L.) forests with 38.4%, and birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) forests with 10.4%. The forest management follows the 1993 Forestry Act giving equal importance to a sustainable and commercial timber production and environmental protection. The forest land in the municipality of Uppsala is divided in productive forests (124,262 ha), providing different types of wood products (i.e., sawlogs, pulpwood, round wood, and fuelwood), and non-productive forests (9030 ha) annually producing less than one cubic meter of wood biomass per hectare.