Landscape and Urban Planning 161 (2017) 22–31

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Mapping ecosystem services for China's ecoregions with a biophysical surrogate approach

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HIGHLIGHTS

- Biophysical indicators were formulated to map ecosystem services (ESs) in China.
- These indicator-based models can reveal the relative order of ESs required for large-scale mapping.
- Land-use change plays a critical role in the significant increase of total ESs in China from 2000 to 2010.

ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form
26 December 2016
Accepted 31 December 2016
Available online 28 January 2017

Keywords:
Ecosystem services mapping
Biophysical indicator
Spatial pattern
Temporal trends
Ecoregions
China

ABSTRACT

Spatially explicit mapping of ecosystem services (ESs) is an essential step in drawing up policies and practices designed to improve human well-being by ensuring the sustainable provision of ESs. This study used a set of quantitative surrogate biophysical indicators to map the capability of China's eleven ecoregions to provide four types of ESs (carbon capture, soil protection, water purification and provision, and habitat provision) from 2000 to 2010. The results revealed the spatial distribution patterns and time trends of the ESs of the eleven ecoregions in China. This study shows that: (1) the average annual total value of ESs provided from 2000 to 2010 increased from northwest to southeast, and in the Middle and lower reaches of the Yangtze River as well as over the entirety of the Yunnan-Guizhou Plateau and South China ecoregions; (2) the temporal trends of annual total ESs from 2000 to 2010 showed increases in most ecoregions except those of northeast China and northern China, which experienced decreases; and (3) the surrogate biophysical method for mapping the spatial and temporal characteristics of ESs gives acceptable results, especially at large spatial scales, compared to research results obtained using more complex modeling approaches. Thus the simple surrogate approach is suitable for the rapid assessment and long-term dynamic surveillance of ESs at broad spatial scales, and for tasks such as priority setting or performance assessments for nature conservation and ecological restoration with ESs as key targets. The methodology is also suitable for land-use impact analysis and trade-off analysis concerning land-use decisions in terrestrial environments.

1. Introduction

Ecosystem services (ESs) are those critical benefits that people receive from natural ecosystems and help to sustain and support human well-being (MEA, 2005). The concept of ESs is increasingly considered pivotal in research into ecological conservation and restoration, land-use management, urban planning and the assessment of ecosystem sustainability — research that covers the policy and decision making arenas (Bateman et al., 2013; Cowling et al., 2008; Daily et al., 2009; MEA, 2005; Trabucchi, Ntshotsho, O'Farrell, & Comín, 2012; Woodruff & BenDor, 2016; Zagonari, 2016). However, projects to safeguard ESs can only be successful if these ESs can be quantified and mapped (Naidoo et al., 2008). Providing the spatially explicit information in maps of key areas supplying ESs is an essential step in the process of drawing up policies that will incorporate ESs into land management, thereby ensuring the sustained supply of ESs and their associated benefits to humans (Burkhard, Crossman, Nedkov, Petz, & Alkemade, 2013; Cowling et al., 2008;

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http://dx.doi.org/10.1016/j.landurbplan.2016.12.015
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Daily & Matson, 2008). Maps of ESs are important communication tools for the stakeholders and decision-makers responsible for land-use planning, because maps enable them to locate those ecosystems which provide high value services (Balvanera et al., 2001; Maes et al., 2013). Although ES maps are helpful tools in the processes of decision-making, a number of challenges will be encountered in their use. These challenges relate to the credibility, salience, and legitimacy of the maps (Hauck et al., 2013). Moreover, the targets, costs, spatiotemporal scales, assessment methods and data availability for the decision-making project significantly impact the accuracy of ES maps (Eigenbrod et al., 2010). Although it is clear that actual investment in and implementation of an environmental plan typically occur at local scales, research and analysis at broad scales can provide decision-makers with macroscopic information and will benefit resource and action prioritization in ecosystem management at broad scales.

Regional or national scale, studies have commonly mapped ESs using surrogate models based on well-known causal relationships between environmental factors; most of these studies were based on secondary data, without the use of validation techniques (Alam, Dupras, & Messier, 2016; Martínez-Harms & Balvanera, 2012). Clearly, the spatially explicit mapping of ESs at a broad scale is significantly limited by data and model availability as well as by the difficulty of validating mapping results. However, these limitations do not lessen the overwhelming demand from stakeholders and decision-makers for evaluations of the spatial patterns and temporal variations of ESs — it is their crucial natural capital. For example, Action 5 of the European Union (EU) Biodiversity Strategy to 2020 requires all Member States to map the state of ESs within their national territories; the assessment results are designed to help resolve complex public issues in the EU (Maes et al., 2013). To meet this demand, the surrogate method deploys knowledge about the relationship between environmental variables and ESs to create new surrogate indicators for ES mapping that can be applied at multiple scales (Alam et al., 2016). This method can improve the mapping of ESs when primary data are absent, but the effectiveness of this method depends on how well the environmental variables determining the distribution of ESs are understood (Martínez-Harms & Balvanera, 2012).

In this study, we use a set of surrogate models to map four types of key ESs in China. They were chosen because of their importance in the conservation of ESs at the national scale (Lü, Ma, Zhang, Fu, & Gao, 2013; Ouyang et al., 2016), namely: carbon capture by vegetation, soil protection, water purification and provision, and habitat provision. The objectives of the present research include: (1) adapting a biophysically-based simple surrogate approach for mapping four types of key ESs at the national scale during the period from 2000 to 2010; (2) revealing the spatial pattern of the four types of ESs and the year-to-year trends of the sum-total of these ESs with reference to the eleven ecoregions of China; and (3) analyzing the potential driving factors of ES variation in the specific ecoregions of China. We also discuss the usability of the surrogate approach.

2. Study area

This study is focused on China, a country with an area of about 9.6 million square kilometers and, in 2015, a population of 1.38 billion people. Climate, altitude, and vegetation type vary significantly across China. The climate ranges from cold temperate in the north, through warm temperate, to equatorial tropical in the south (Wu, Yang, & Zheng, 2003; Zheng, Yin, & Li, 2010). The altitude also increases greatly from east to west, with the Qinghai-Tibet Plateau located in southwest China having an average altitude of over four thousand meters above sea level. The diverse range of forest types also varies from north to south, and includes coniferous and deciduous forests, broad-leaved mixed forests, deciduous broad-leaved forests, mixed evergreen forests, broad-leaved forests, seasonal rainforests, and rainforests (Fu, Liu, Lü, Chen, & Ma, 2004; Wu et al., 2003). Following Bailey (1983, 1988) China can be divided into eleven “ecoregions” (Fig. 1), where an ecoregion is defined as a large ecosystem of regional extent or a geographical zone that accommodates associations of similarly functioning ecosystems. Based on the work of Xie et al. (2012), the regions are classified according to their temperature, precipitation, altitude, vegetation index, geomorphological conditions and administrative boundaries. These ecoregions are used as a spatial framework for analyzing the broad spatial patterns and temporal trends of the ESs in China.

3. ES quantifying methods

3.1. Surrogate models

The net primary production (NPP) of vegetation provides the energy that underpins nearly all terrestrial (as well as marine) ecosystems and is a key functional indicator. Directly or indirectly, NPP supports the lives of multiple species as well as maintaining healthy biodiversity and enhancing the efficiency of ecological processes (Maes et al., 2013; MEA, 2005; Zurlini et al., 2014). It is a critical surrogate indicator of ecosystem function and has been shown to be linked with the overall value of ESs (Costanza et al., 1998). Because many ESs are correlated with NPP and tend to shift in concert with it, NPP also governs the flow of many provisioning and regulating services and some cultural services (Costanza et al., 1997, Costanza, Fisher, Mulder, Liu, & Christopher, 2007; Richmond, Kaufmann, & Mynen, 2007; Zurlini et al., 2014). NPP also provides a fundamental supportive service because it represents a measure of the solar energy captured by ecosystems and which drives their overall functioning (Costanza et al., 2007; MEA, 2005; Zurlini et al., 2014). Egoh et al. (2008) evaluated the relationships between five ESs in South Africa, and they revealed that the NPP was positively correlated with four services, namely: surface-water flow regulation, water supply, soil accumulation and soil protection. Petrosillo, Semeraro, and Zaccarelli (2013), Aretano used the NPP as an indicator that quantifies multiple ESs, such as the production of timber and farm produce. The NPP can be readily estimated by combining a remotely sensed vegetation index with other pertinent environmental variables to reveal spatiotemporal characteristics at broad spatiotemporal scales (Potter et al., 1993; Yuan et al., 2014; Zhu, Pan, & Zhang, 2007).

Carreño, Frank, and Viglizzo (2012) formulated a simple biophysical method for estimating relative changes in the capability of ecosystems to provide services following land-use changes in Argentina. This method has been expanded by Barral and Oscar (2012) to evaluate ESs relating to land-use planning in the southeast pampas of Argentina. Both methods used biophysical data, such as biomass or NPP, surface-water area, soil infiltration capacity, slope, precipitation, temperature, and elevation. They also described the theoretical basis and evaluated the results of the approaches before putting these indicators into practical analyses. However, the method is site-specific and needs to be adapted when used in other places. Carreño et al. (2012) used the environmental variables of biomass and its stability, precipitation, temperature and altitude above sea level to map the spatial patterns of the habitat provision ES in Argentina. They assumed that the capability of one biome to provide habitat is high when biomass and water are abundant, temperature is moderate to high, and altitude above sea level is low. However, in China over thousands of years, cultivation and increase in population have led to the severe degradation of the habitat of many species in the plains and lowland areas (Lei, Zhao, & Yin, 2006; López-Pujol, Zhang, & Ge, 2006; Zhang & Ma,