Applied Geography 42 (2013) 1–12

Contents lists available at SciVerse ScienceDirect

Applied Geography

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

Integrating landscape connectivity into the evaluation of ecosystem services for biodiversity conservation and its implications for landscape planning

Cho Nam Ng [a], Yu Jing Xie [a,*], Xi Jun Yu [a,b]

[a] Department of Geography, The Jockey Club Tower, Centennial Campus, The University of Hong Kong, Hong Kong
[b] South China Institute of Environmental Sciences, Ministry of Environmental Protection, 7th West Street, Yuancun, Guangzhou 510655, PR China

Keywords:
Landscape connectivity
Ecosystem services
Biodiversity conservation
Temporal analysis
Modeling spatial dynamics
Landscape planning

A B S T R A C T

This paper examines the integration of landscape connectivity and ecosystem services. It is based on the assumption that if a habitat within a landscape has a more significant role in connecting with other habitats, it would have a higher ecosystem services value for biodiversity conservation. The Shenzhen River watershed, a cross-border region shared by the city of Shenzhen and the Hong Kong Special Administrative Region in China, was used as a case study. An area-based functional connectivity index, known as the possibility of connectivity (PC), was implemented to examine the temporal and spatial dynamics of the value of ecosystem services for biodiversity conservation over the period from 1988 to 2008. To evaluate the effectiveness of the PC index, a comparison was made between the conventional assessment method for ecosystem services and the proposed method. Results suggest that our proposed method can identify significant reduction of ecosystem services that was not only due to the decrease of habitat size, but also caused by the damage of connectivity among habitat patches. Also, it can identify sites which should have a high priority in restoring the ecosystem services for biodiversity conservation. In conclusion, this study provides a way to consider landscape connectivity in the evaluation of ecosystem services which is essential for landscape planning and nature conservation.

Introduction

Ecosystem services are benefits that people obtain both directly and indirectly from ecosystems (Koschke, Fürst, Frank, & Makeschin, 2012; Liu, Costanza, Farber, & Troy, 2010; MA, 2005a). The unsustainably increasing utilization of natural resources around the world has led to the widespread degradation of approximately 60% of the world's ecosystem services (MA, 2005b). To reverse this trend, it is crucial to raise public awareness of the value of ecosystem services and goods when dealing with environmental and ecological issues (Liu et al., 2010). Over the past three decades, especially since the release of the Millennium Ecosystem Assessment (MA, 2005a), research on the evaluation of ecosystem services has grown remarkably and has become one of the fastest evolving research areas in environmental and ecological economics (Barbier et al., 2008; De Groot, Alkemade, Braat, Hein, & Willemen, 2010; Straton, 2006; Turner et al., 2003; Willemen, Verburg, Hein, & Van Mensvoort, 2008).

Ecosystem services are increasingly being evaluated from different disciplines (Estoque & Murayama, 2012; Hinojosa & Hennermann, 2012; Kozak, Lant, Shaikh, & Wang, 2011; White, Halpern, & Kappel, 2012), but knowledge regarding landscape spatial characteristics has not been adequately considered (Frank, Fürst, Koschke, & Makeschin, 2012; Syrbe & Walz, 2012). The capacity for providing goods and services within an ecosystem is believed to not be homogeneously distributed across landscapes but rather dependent on the spatial and temporal interactions between different components (Fisher, Turner, & Morling, 2009; Syrbe & Walz, 2012; Willemen et al., 2008). As suggested by Kreuter, Harris, Matlock and Lacey (2001), variables such as patch size, edge effect, contiguity and corridors should be considered to improve the assessment of their impact upon ecosystem services. Landscape connectivity, defined as the ability of the landscape to facilitate or impede movement among habitat patches (Taylor, Fahrig, Henein, & Merriam, 1993), supports ecological flows and the long-term persistence of biodiversity (Fahrig, 1997; Laita, Kotiah, & Mönkkönen, 2011). Connectivity is one of the most critical components for animal dispersal, consequent population persistence and the maintenance of ecological functions (Crist, Wilmer, & Aplet, 2005; Pascual-Hortal & Saura, 2006; Saura &

* Corresponding author. Tel.: +852 39177025; fax: +852 25598994.
E-mail addresses: cnng@hkucc.hku.hk (C.N. Ng), xieyj.nju@gmail.com (Y.J. Xie), yuxijun@graduate.hku.hk (X.J. Yu).

0143-6228/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apgeog.2013.04.015

Pascual-Hortal, 2007b; Taylor, Fahrig, Henein, & Merriam, 1993). While recent research has included habitat size or area in the assessment of ecosystem services, studies that have considered landscape connectivity are very few in number. Neglecting to consider landscape connectivity may lead to a failure in properly accounting for the spatial variability of ecosystem services caused by the dynamics in the landscape configuration.

Biodiversity, in general, is closely and directly related to both landscape connectivity and ecosystem services. As a result, it could act as a bridge to connect these two areas and assist in modeling their relationship. On the one hand, the biodiversity of a site is strongly related to landscape connectivity (isolation), which has been widely discussed at the species and landscape levels (Andrén, 1994; Bender, Contreras, & Fahrig, 1998; Bender, Tischendorf, & Fahrig, 2003; Di Giulio, Holderegger, & Tobias, 2009; Fahrig, 1997, 2003). On the other hand, many researchers agree with or confirm the positive relationship between ecosystem services and biodiversity on local and regional spatial scales (Bai, Zhuang, Ouyang, Zheng, & Jiang, 2011; Balvanera et al., 2006; Bastian, 2013; Kremen, 2005; Schneiders, Van Daele, Van Landuyt, & Van Reeth, 2012; Schwartz et al., 2000; Worm et al., 2006). While there is also considerable disagreement regarding this type of relationship (Aarssen, 1997), Balvanera et al. (2006) observed that a small number of negative relationships reported in the literature on this topic are associated with studies that focus on individual species rather than the community level or the landscape level.

Biodiversity has been included in ecosystem services in many different ways. It is used almost interchangeably with ecosystem services or is often regarded as a type of ecosystem service (Mace, Norris, & Fitter, 2012). Mace et al. (2012) suggest that biodiversity plays multiple roles in delivering ecosystem services, that is, "as a regulator of ecosystem processes, as service in itself and as a good". While in a broad sense biodiversity underpins most ecosystem services (Egoh, Reyers, Rouget, Bode, & Richardson, 2009), it is very difficult to make a direct connection between biodiversity and other ecosystem services, as their relationship varies with different types of ecosystem services (*e.g.,* provision, regulation and supporting). In particular, there are significant trade-offs among ecosystem services, for instance, providing and regulating them (Mace et al., 2012; Rodríguez et al., 2006). Therefore, in this study, biodiversity is regarded as a service, *i.e.,* biodiversity conservation defined by Costanza et al. (1997), and its value will be examined by taking landscape connectivity into account.

This study proposes a method for integrating landscape connectivity into the quantification of ecosystem services for biodiversity conservation. To illustrate its usefulness and effectiveness, the Shenzhen River cross-border watershed, shared by the Hong Kong Special Administrative Region (SAR) and the city of Shenzhen, is used as a case study. This study site has undergone significant habitat loss and isolation due to the rapid growth of the human population and urban sprawl (Ng, Xie, & Yu, 2011; Xie & Ng, 2013), and it exhibits significant spatial discrepancies across the border. In this study, temporal and spatial variations of ecosystem services value for biodiversity conservation were analyzed for all land cover categories derived from Landsat Thematic Mapper (TM) Imagery during the period 1988–2008. To evaluate the effectiveness of considering landscape connectivity, a comparison was made between the conventional assessment of ecosystem services and the proposed method. This study aims to identify the loss of ecosystem services that not only resulted from the reduction of habitat size but was also caused by the damage of the connectivity among habitat patches. Finally, this study also attempts to identify priority sites for restoration and provides useful information for future landscape planning and nature conservation.

Methodology and study area

Methodology

A wide range of research gaps still exist regarding the assessment of ecosystem services from both ecological and economic perspectives (Chee, 2004; Kremen, 2005). Through taking landscape connectivity into consideration, this study seeks to improve the methodology for evaluating ecosystem services from a landscape ecology perspective. The proposed method has made the following assumptions:

(1) The economic value of a habitat patch is positively correlated with the ecological value it presents. While evaluating ecosystem services, one should also take into account the local socio-economic-cultural factors; however, this study focuses only on the ecological aspect (*i.e.,* the capacity of ecosystems to supply services). The differences in the local economy and social welfare between Hong Kong and Shenzhen and their changes over time will not be considered.
(2) The ecological service of biodiversity conservation for a habitat is considered to be positively related to its significance of connectivity with other habitats. Under this assumption, Fig. 1 illustrates different connectivity roles made by habitat patches within a landscape despite their same habitat size. This discrepancy has not yet been considered in other studies.

This study attempts to take the connectivity effect into account based on a unit value of ecosystem services for each land cover type proposed by Costanza et al. (1997). Several different connectivity or isolation indices have been proposed for landscape planning or conservation studies (Ng et al., 2011; Pascual-Hortal & Saura, 2006; Tischendorf, 2001); however, Bender et al. (2003) and Tischendorf, Bender, and, Fahrig (2003) suggested that area-based isolation (connectivity) metrics (such as buffer area and habitat proximity index) are more effective in predicting and reflecting the movement capacity of organisms than the more commonly used distance-based metrics. The index of possibility of connectivity (PC), developed by Saura and Pascual-Hortal (2007b), is an area-based functional connectivity approach that can incorporate two important elements in biodiversity evaluation, namely, habitat size and connectivity, in a single measure. The PC is defined as "the probability that two animals randomly placed within the landscape fall into habitat areas that are reachable from each other (interconnected)" (Saura & Pascual-Hortal, 2007b). This concept is similar to the degree of coherence (Jaeger, 2000), although the concept of coherence does not examine the possibility of dispersal among habitat patches. More importantly, the application of PC could be robust in identifying the critical elements for the maintenance of overall habitat connectivity and can also be easily understood and utilized by planners and managers (Saura & Pascual-Hortal, 2007b). For these reasons, the PC is adopted in this study, and its formula is shown below:

$$PC = \left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j p_{ij}^{*}\right) \Big/ A_L^2 \tag{1}$$

where n is the total number of habitat nodes in a landscape, a_i and a_j are areas of the habitat patches i and j, respectively, and A_L is the total area of the landscape. P_{ij}^{*} indicates the maximum product probability of all possible paths between patches i and j. To further illustrate the concept of P_{ij}^{*}, Fig. 2 provides a simple example of the calculation of P_{ij}^{*} (Saura & Pascual-Hortal, 2007a). The detailed of calculation of P_{ij} can be found in Saura and Pascual-Hortal (2007a, 2007b).