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Research article

Identifying hotspots and management of critical ecosystem services in rapidly urbanizing Yangtze River Delta Region, China

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ABSTRACT

Rapid urbanization has altered many ecosystems, causing a decline in many ecosystem services, generating serious ecological crisis. To cope with these challenges, we presented a comprehensive framework comprising five core steps for identifying and managing hotspots of critical ecosystem services in a rapid urbanizing region. This framework was applied in the case study of the Yangtze River Delta (YRD) Region. The study showed that there was large spatial heterogeneity in the hotspots of ecosystem services in the region, hotspots of supporting services and regulating services aggregately distributing in the southwest mountainous areas while hotspots of provisioning services mainly in the northeast plain, and hotspots of cultural services widespread in the waterbodies and southwest mountainous areas. The regionalization of the critical ecosystem services was made through the hotspot analysis. This study provided valuable information for environmental planning and management in a rapid urbanizing region and helped improve China's ecological redlines policy at regional scale.

1. Introduction

With the continuous rise in global population, a simultaneous growth of urban areas is omnipresent (Haas and Ban, 2014). Urban populations are projected to reach nearly 60% of the human population by 2030; while urban areas will grow twice as fast as urban populations (Elmqvist et al., 2013). Rapid urbanization has altered many ecosystems, causing a decline in many ecosystem services, generating ecological crisis such as water shortages and pollution, air pollution, soil pollution and so on (Li B et al., 2016; Li J et al., 2016). The ecological crisis has become a great threat to global and regional sustainable development. In order to address the challenges resulting from rapid urbanization, it is urgent to identify and protect endangered ecosystems.

Ecosystem services (ESs) are the benefits that people obtain from ecosystems, including food, natural fibers, a steady supply of clean water, regulation of pests and diseases, medicinal substances, recreation, and protection from natural hazards such as floods (MA., 2005; Costanza and Folke, 1997; Daily, 1997). ESs were considered as a bridge between environment and human well-being (Van and Kyle, 2014), which provide an important framework for linking ecological infrastructure to social infrastructure in the city, with the potential to benefit humans and ecosystems (McPhearson et al., 2014). The term 'ES hotspot' is increasingly used for the purpose of informing spatial prioritization of ES (Cimon-Morin et al., 2013). Despite this growing use of the term, an ES hotspot is not clearly defined in the literature yet (Schröter and Remme, 2016). The term ES hotspot often refers to areas where high amounts of one particular service are present (Cimon-Morin et al., 2013), but other studies have defined hotspots as areas where multiple ESs overlap (e.g., Gos and Lavorel, 2012).

To facilitate financial incentives for the responsible management of land and habitat, assessments and mapping of ESs provide quantitative information to initiate sustainable ecosystem management (Robinson et al., 2013; Landuyt et al., 2014; MacDonald et al., 2014; Mascarenhas et al., 2014; Van Riper et al., 2014). Alessa et al. (2008) reported that output from hotspot mapping were dependent on the assumptions underlying the methodology. Mola-Yudego and Gritten (2010) used kernel-based hotspot analysis to study forest management conflict clusters based on the number of reported conflicts. Other studies have identified areas

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for conservation efforts, as well as mapping ESs such as water supply, soil quality, and carbon in South Africa (Timilsina et al., 2013). Such assessments help identify which services are declining because of urbanization. Researches on the identification and mapping of 'hotspots' are relatively recent and little formal guidance in the current literature (Karimi et al., 2015).

Several methodologies and frameworks using ESs to support environmental management and decision making have been discussed (Müller and Burkhard, 2007; de Groot et al., 2010; Kroll et al., 2012; Crossman et al., 2013; Albert et al., 2014). Van Jaarsveld et al. (2005) presented a practical application of ESs mapping at the subcontinental scale for Africa. Troy and Wilson, (2006) developed a decision framework or spatially explicit value transfer to estimate ESs flow values and to map results for three case studies that represented a diversity of spatial scales and locations. Paetzold et al. (2010) developed a framework for the assessment of ESs. Kroll et al. (2012) provided a method to quantify and map the ecosystem service supply at the regional scale for a rural-urban region in eastern Germany. Burkhard's framework made a great improvement. Burkhard's ESs matrixes were useful in providing statistical and spatial information and illustrations (maps) in environmental planning and management (Burkhard et al., 2012, 2013). However, these researches failed to provide a complete and systematic framework from problems to management and cannot target to multiple ESs management.

China is one of the developing countries with rapid urbanization. Over the past 30 years, China has experienced rapid urbanization and an immense growth in population as the consequence of economic and political reforms in 1978 (Haas and Ban, 2014). The Yangtze River Delta (YRD) Region is one of the most rapidly urbanized regions in China and has experienced a remarkable period of population growth (at an annual growth rate of 3.0%), and urbanization (at an annual growth rate of 9.2%) (Xu et al., 2014). Rapid urbanization has dramatically changed land use/land cover patterns and ecosystems in the region, causing widespread environmental problems such as water shortages and decline in water quality, and serious air pollution (Zhang and Chen, 2011; Wang et al., 2012). These environmental problems have posed great threats to the regional eco-safety, adding new challenges to sustainable development in the region.

To overcome management conflicts and secure ESs, China has proposed a new 'ecological redline policy' (ERP) using ESs as a way to meet its targets (Bai et al., 2015). To carry out this policy, it is fundamental and necessary to identify hotspots of critical ESs. Thereupon, the aims of this study are (1) to present a comprehensive framework to identify and manage hotspots of critical ESs in a rapid urbanizing region, (2) to apply the framework to the Yangtze River Delta (YRD) region's environmental management.

2. Methods

We present a comprehensive framework (Fig. 1) for identifying and managing critical ESs hotspots in rapid urbanizing regions. This framework comprises five core steps:

2.1. Identification of major environmental problems and definition of ecosystems conservation objectives

Combining analysis of regional professional materials at different spatial and temporal scales, e.g. environmental assessment reports, land cover/land use, with fieldwork and local experts' consultation, regional major environmental problems can be defined.

Through the socio-ecological context analysis, causal relationships between the environmental problems related to urbanization and the decline of ESs caused by deterioration of ecosystems should be understood, and then objectives of management and priority conservation of critical ecosystems and their services in a region can be defined.

2.2. Classification of ecosystem types combining CORINE with local expert knowledge

The CORINE (Co-ordinated Information on the Environment) data series were established by the European Community (EC) as a means of compiling geo-spatial environmental information in a standardized and comparable manner across the European continent. Although the CORINE focuses on the European continent, it provides a good reference for land cover classification of other continents. To address the difference of land cover in different regions, local land cover or ecosystem classification may be used to adjust the names and types of land cover or ecosystems of CORINE classification.

2.3. Identifying and scoring critical ESs

Firstly, identification of critical ESs should be Millennium-Ecosystem Assessment-based. The MA presented the most-widely used classification system of ESs which grouped ESs into four major categories: provisioning services (PS) consisting of the commodities that people use such as fiber, food, timber, and water; regulating services (RS) affecting climate, disease, floods, wastes, and water quality; cultural services (CS) providing recreational, aesthetic, and spiritual benefits; and supporting services (Ecological integrity: EI) assisting in soil formation, photosynthesis, and nutrient cycling (MA., 2005).

Secondly, for scoring critical ESs, the Burkhard's method constructs an ESs matrix combining land cover information in assessment of the state of ecosystems and their capacities to supply ESs based on MAs' ESs classification system (Burkhard et al., 2012).

Thirdly, the score adjustment of each critical ecosystem service will be made by using local expert knowledge. The local experts familiar with the environment of a study area will be chosen and be invited to score the ESs of the study area. They will firstly be given the explanation of the definition and classification of ESs, and be provided with Burkhard's original supply scores table and the relevant explanation. Next, each expert adjusts the original score of each ecosystem service based on his own expertise. Then, the final scores of critical ESs will be discussed together and determined by all experts.

In addition to using local expert knowledge, ecosystem quality or deterioration grade map may also be used to adjust the original scores of ESs. For example, land cover/land use maps are used for the classification of urban areas, waterbodies and other ecosystems, and water environmental assessment maps can be used to adjust the scores of the different quality grades of waterbodies.

2.4. Defining and mapping hotspot and coldspot of critical ESs

The Critical ESs Hotspot and Coldspot Formulation are designed as follow:

If, $Vmax \leq 5$, $H=Vmax$, $C = Vmin$;

If, $Vmax>5$, $H>\overline{X}+\delta$, $C <\overline{X}-\delta$;

H: hotspot; C: coldspot;

Vmax: the maximum of ESs values;

Vmin: the minimum of ESs values;

Range: the maximum of ESs values - the minimum of ESs values (Range = Vmax-Vmin);

Average$\overline{X}$: the mean of ESs values; the mean stands for the score