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Response of ecosystem services to socioeconomic development in the Yangtze River Basin, China

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ABSTRACT

The provision of ecosystem services from multifunctional landscapes has contributed to human well-being. However, a general tendency exists to consider only marketed ecosystem services and to ignore non-marketed services, which has become more common when evaluating multiple-ecosystem services at the local level. In this study, we present an integrative index of multiple-ecosystem services (*IMES*) that avoids this tendency. Our main objective is to evaluate how socioeconomic factors interact with the spatial differences between the supply of and demand for multiple-ecosystem services. GlobCover data and a modified ecosystem service "matrix" are used to quantify and map ecosystem service supply and demand at the municipality level in the Yangtze River Basin, China. We used multiple regression analysis to detect relationships between ecosystem services and socioeconomic factors in municipalities to identify the main drivers of change in the supply of and demand for multiple-ecosystem services at the local level, respectively. The results revealed that 111 municipalities in the Yangtze River Basin (84.7% of the area) had an oversupply of multiple-ecosystem services; these municipalities were primarily situated in the western part of the upper reach and the southeast parts of the middle reach. Undersupplied areas were mainly situated in densely populated municipalities in the northern part of the lower reach and in agricultural municipalities in the northeastern part of the middle reach. The driving factors of changes in multiple-ecosystem services are significantly different not only in terms of the supply, demand and balance between the two but also among the three reaches. These differences in the driving factors among the three reaches can produce incorrect conclusions if an entire basin is considered, particularly for large basins. This information may be of interest to policymakers. The first principal component for the supply of and demand for multiple-ecosystem services exhibits a good correlation with the *IMES* in the Yangtze River Basin. Additionally, the integrative index of multiple-ecosystem services (including $IMES_s$ and $IMES_d$) in the study area is relatively reliable according to the sensitivity analysis. Therefore, *IMES* is an effective tool for aggregating the value of multiple-ecosystem services at local scales. This tool can be used to identify the drivers of changes in multiple-ecosystem services based on the relationships between *IMES* and socioeconomic factors at the municipality scale. *IMES* should be useful for policymakers and stakeholders because it can provide important information for local decision-making.

1. Introduction

Humans obtain various benefits from ecosystems (Costanza et al., 1997; MA, 2005). These ecosystem services are usually grouped into four categories, all of which directly or indirectly sustain human survival, health, and well-being throughout the world (Costanza et al., 1997; MA, 2005; Wossink and Swinton, 2007; Bennett et al., 2009; Egoh et al., 2009; Burkhard et al., 2012; Butler et al., 2013; Su et al., 2014a; Zhang et al., 2015). These categories include regulation (e.g., water supply and climate regulation), support (e.g., soil retention and formation and biodiversity protection), provisioning (e.g., food production and raw material), and cultural (e.g., recreation and spiritual reflection) ser-

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vices. Monetary approaches are usually employed to quantify these multiple-ecosystem services (Costanza et al., 1997; Farber et al., 2002; Goldstein et al., 2012; Mononen et al., 2016). However, one of the main drawbacks of this evaluation method for ecosystem services is that quantifying non-marketed ecosystem services, such as climate regulation, pollination, recreation and spiritual reflection, which lack appropriate pricing methods, can be difficult (Ludwig, 2000; Spangenberg and Settele, 2010; Wossink and Swinton, 2007; Burkhard et al., 2012; Baveye et al., 2013; La Rosa et al., 2016).

These non-marketed ecosystem services are often overlooked because they are not directly available for human use. Meanwhile, some special services, such as food and timber, are in danger of overdevelopment (Burkhard et al., 2012; Rodríguez-Loinaz et al., 2015). Enhancing the provision of special ecosystem services has damaged other services; for example, the conversion of woodland and grassland to farmland for food production often increases soil erosion and decreases water supply and biodiversity (Egoh et al., 2009; Jia et al., 2014). Therefore, conserving and enhancing the provision of multiple-ecosystem services, including non-marketed services, are important from both a human and an economic perspective (Rodríguez-Loinaz et al., 2015). To achieve conservation goals, many efforts have been made to promote the provision of multiple-ecosystem services (Liu et al., 2008). These efforts are usually practiced at a landscape scale because landscapes can provide many ecosystem services that are beneficial to humans (Müller and Burkhard, 2012; Willemen et al., 2012; Rodríguez-Loinaz et al., 2015; Fan et al., 2016). However, landscape changes induced by human activities often affect the provision of multiple-ecosystem services in different ways (Willemen et al., 2012). Landscapes are characterized by spatial diversity, meaning that they can provide multiple-ecosystem services with an unequal spatial distribution (Willemen et al., 2012). Human activities (e.g., land management actions) can lead to land use changes and unintended tradeoffs and synergies in the provision of ecosystem services (Zhang et al., 2016). Therefore, it is necessary to study the response of ecosystem services to human activities.

Human activities, particularly those that are socioeconomically based, have been major drivers of land use change. Land use change is generally considered the most important driver of alterations in ecosystem service delivery (Sala et al., 2000; Cardinale et al., 2012; Qi et al., 2014; Elmhagen et al., 2015; Zhang et al., 2015) because this factor can alter the structure, pattern and functionality of ecosystems (Müller et al., 2006; Qi et al., 2014). Therefore, many studies have focused on changes in ecosystem services caused by land use conversion, reporting that ecosystem services vary in response to rapid urbanization and land use change (Liu et al., 2008; Vejre et al., 2010; Shrestha et al., 2011; Qi et al., 2014; Su et al., 2014a,b). Thus, considerable attention has been given to the supply of ecosystem services, whereas the demand for ecosystem services has not been sufficiently considered (Burkhard et al., 2014) although the supply of and demand for single-ecosystem services (e.g., flood regulation or pollination) have been quantified and mapped in Europe (Schulp et al., 2014b; Sturck et al., 2014). The concept of an ecosystem service "matrix" has been recently proposed to quantify and map the supply and demand for multiple-ecosystem services (Burkhard et al., 2012). However, few studies have reported the supply and demand response for ecosystem services to socioeconomic factors (Rodríguez-Loinaz et al., 2015); thus, these relationships remain poorly understood.

Over the past several decades, unprecedented economic growth and rapid urbanization have occurred in China (Liu et al., 2008; Qi et al., 2014). Therefore, land use change has had a major influence on ecosystem services in China (Hao et al., 2012), especially in the Yangtze River Basin (Zhang et al., 2015). Land use changes have been primarily driven by socioeconomic factors (Rodríguez-Loinaz et al., 2015). Considering the response of ecosystem services to socioeconomic factors will enable an understanding of the relationship between natural resources and the human environment. The objectives of this paper are (1) to quantify and map the ecosystem service supply and demand using an ecosystem service matrix in the Yangtze River Basin and (2) to evaluate how socioeconomic factors interact with the spatial differences between the supply and demand for multiple-ecosystem services.

2. Study area

The Yangtze River (or Changjiang River, which extends from 90° to 122° E and from 24° to 36°N) is approximately 6380 km long and has an estimated drainage area of 1.80×10^6 km^2 (Fig. 1). The Yangtze River has the largest river basin in China and is the third longest river in the world (Bao et al., 2006; Gong et al., 2006; Hu et al., 2011; Meng et al., 2015). Its basin constitutes nearly 20% of mainland China (Guan et al., 2015; Li et al., 2015). The area has a transitional subtropical monsoon climate due to its proximity to the southeast Pacific Ocean and Indian Ocean, and it has a mean annual rainfall of 1100–1400 mm/yr (Hu et al., 2011). The southern part of the basin is near the tropical zone, whereas the northern part falls in the temperate zone (Zhang et al., 2005). The annual mean temperature for the middle and lower reaches of the Yangtze River Basin is approximately 19 and 15 °C, respectively (Zhang et al., 2005). The annual mean temperature varies greatly in the upper reaches, ranging from 17 °C in the Sichuan Basin to 0 °C on the eastern Tibetan Plateau (Zhang et al., 2005; Guan et al., 2015).

The Yangtze River Basin is traditionally divided into upper (source to Yichang), middle (Yichang to Hukou) and lower (Hukou to estuary) reaches (Changjiang River Water Resources Commission (CWRC)). According to the CWRC, the upper reach includes a drainage area of 1.00×10^6 km^2 and flows for 4500 km. The upper reach accounts for 70.4% of the Yangtze River Basin's total area and covers predominantly mountainous terrain. The middle reach extends for 955 km and has a drainage area of 0.68×10^6 km^2, which mainly includes fluvial plains. The lower reach spans 938 km and has a drainage area of 0.12×10^6 km^2; the area is extremely flat and only 4–10 m above the mean sea level (Gong et al., 2006; Yu et al., 2009; Hu et al., 2011; Guan et al., 2015).

3. Materials and methods

3.1. Data source and processing

In this paper, ecosystem services were evaluated using the GlobCover dataset for the year 2009 at a spatial resolution of 300 m in the Yangtze River Basin. Global land cover datasets are available at no cost through the World Wide Web (http://www.gscloud.cn). Twenty land cover classes were identified in the Yangtze River Basin by considering the dominant ecosystems in the study area and the categories of the global land cover dataset (Fig. A-1 in Supplementary data). Socioeconomic factors, such as total population, gross domestic product, and built-up land area, are the most common variables used to evaluate Chinese urbanization (Su et al., 2012, 2014a). Municipality-level socioeconomic data, including the total population, gross domestic product, and built-up land area for 2009, were provided by the China City Statistical Yearbook, which was published in 2010 (http://tongji.cnki.net/kns55/index.aspx).

The Yangtze River Basin runs through 18 provinces (Bao et al., 2006) and spans 131 municipalities (including municipalities directly under the central authority, prefecture cities, autonomous prefectures, and prefectures; Fig. 1). The 131 municipalities were used to quantify and map ecosystem service supply and demand. Some municipalities are not fully contained in the Yangtze River Basin (Fig. 1); only municipalities with over 75% of their area within