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Assessment of human consumption of ecosystem services in China from 2000 to 2014 based on an ecosystem service footprint model

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ABSTRACT

Ecosystem services are essential for the well-being of humans, and the measurement of ecosystem service provision and consumption is an effective approach for estimating regional sustainability. In this work, an ecosystem service footprint (ESF) model was presented to calculate ecosystem service consumption in China from 2000 to 2014. Seven service footprints were estimated in this model, namely, food provision, raw material provision, freshwater provision, energy (hydropower) provision, air purification, climate regulation, and tourism and leisure. Results showed that from 2000 to 2014, the average annual ESF was 2.78 ha per capita, and the provisioning, regulation, and cultural service footprints were 1.56, 1.20, and 0.02 ha per capita, respectively. ESF exhibited an increasing trend during this period. National ecosystem services presented a slight upward deficit, with the eastern region having the highest deficit and a slight surplus in the western region. Each provincial-level administrative region can be classified into one of four categories based on two dimensions, gross domestic product (GDP) and their ecosystem service surplus (ESS) or deficit (ESD) situation. High GDP values and ESD situation provinces are mainly located in coastal areas, whereas low-GDP and ESS situation provinces are located in the northwest and southwest regions. The model is expected to provide scientific basis and direction for optimizing environmental management.

1. Introduction

Ecosystems provide humankind with beneficial resources, goods, and services, ranging from nutrient cycling and erosion control to food production and spiritual/religious experiences. The capacity of Earth to produce resources and provide ecosystem services is called biocapacity (BC) or carrying capacity; it refers to the amount and productivity of available biologically productive land and water areas (World Wildlife Fund (WWF), 2014). With the unprecedented rapid growth in population and economic development, Earth is experiencing enormous pressure to provide natural resources to support the lifestyles of people. Sustainable development has become a crucial policy goal worldwide (Brundtland, 1987).

The contributions to human life that ecosystems make up, sustain, and fulfill are called ecosystem services. Some researchers believe that the entire human economy is supplied and constrained by ecosystems (Häyhä and Franzese, 2014). Endless human demands depend on and compete for a finite amount of biologically productive space (Lin et al., 2015). This discourse indicates not only a change in our understanding of planetary functions at the ecosystem scale, but also a fundamental shift in how we perceive the relationship between people and the ecosystems they depend on. People are living beyond the means of Earth, and our planet cannot withstand the pressure that humans are imprinting in the long run (Kitzes et al., 2008; Niccolucci et al., 2012). In 2012, 1.65 planets were required to satisfy the annual demands of humans (WWF, 2016). For the sustainable use of resources and ecosystem service supplies, many high-level programs and agreements, such as Future Earth and Convention on Biological Diversity, have been signed by international leaders. Meanwhile, several tools have been developed to measure and assess the different sides of pressure that humans are exerting on Earth and how much of this pressure Earth can withstand. For example, ecological footprint (EF) theory (Rees, 1992; Wackernagel and Rees, 1995) focuses on the pressure generated during the production and consumption of crops and food and the buildup and emission of carbon. Life cycle assessment (Robèrt et al., 2002) concentrates on the pressure produced from specific products. The water

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footprint method (Hoekstra, 2002) emphasizes the pressure on water resources. However, the inconsistency among methods in quantifying diverse pressures and ecosystem BC causes uncertainty in assessment and evaluation processes. People obtain numerous products and services from the ecosystem, and thus, standardized methodological approaches and frameworks should be developed to quantify and map all the pressures that an ecosystem undertakes and determine its BC (Maes et al., 2012; The Economics of Ecosystems and Biodiversity, 2010; Crossman et al., 2013).

The ecosystem service footprint (ESF) approach, which was first proposed by Burkhard et al. (2012), provides a comprehensive measurement for estimating ecosystem BC and human influences. The concept of ESF is rooted in ecosystem service theory and EF (Wackernagel and Rees, 1995). ESF, which is closely related to the concept of EF, calculates the area required to generate the specific ecosystem goods and services demanded by humans in a certain area at a certain time. Unlike other approaches that concentrate on one or several resources, the ESF method covers all products and services provided by ecosystems. Demands for food safety, clean air, and beautiful natural scenery are also satisfied by ecosystems. Thus, tracking the key aspects of the sustainability challenge that we are facing is critical. In this study, provisioning, regulating, and cultural services were considered representatives of BC in accordance with the Millennium Ecosystem Assessment (MEA) classification. Then, the ESF and BC of China were calculated from 2000 to 2014 at the provincial scale. The following academic questions can be answered based on the ESF concept. (1) From the perspective of ecosystem services, can we develop a simple and thoughtful approach for measuring the contributions of ecosystems to human living? (2) Does ESF in China tend to exceed its domestic extraction? What are the BC trends in China during the past 10 years? (3) What are the spatiotemporal differences in the BC of various provinces in China?

2. Background of the study

The field of EF, which considers human impact on environment and natural resources, has been continuously developing since 1992 (Wackernagel and Rees, 1995). EF equates the demand of humanity on nature to the amount of biologically productive area, including crop land, grazing land, forest land, infrastructure land, water bodies for fishing, and carbon land, that is required to provide resources and absorb waste, particularly the CO_2 emitted by human activities. EF has been widely applied to different geographical regions, spatial scales, and time series because of its efficiency and has been constantly improved and modified (Lin et al., 2015; Galli et al., 2016). In recent years, an increasing number of researchers have proposed the improvement of EF based on the concept of ecosystem services (Jenerette et al., 2006; Häyhä and Franzese, 2014; Liu, Liu, and Yang, 2016). From the perspective of human demand, EF measures the area of productive land and sea that provides people with the necessary ecological assets, including renewable resources and ecosystem services. From the perspective of ecosystem supply, BC represents the ecological assets that can be used in each region and the capability to generate renewable resources and ecosystem services (Galli et al., 2014). Ecosystem services are the source of BC. The total amount of EF obtained from the ecosystem is essentially the consumption of ecosystem services. To ensure a sustainable resource supply, human socioeconomic metabolism must restrict human ecosystem service demands within the BC of Earth's life system. Burkhard et al. (2012) proposed the concept of ESF in 2012, believing that ESF is similar to EF. ESF refers to the amount of land available to satisfy human needs for ecosystem products and services within a period within a region. Ecosystem Service Biocapacity (ESBC) represents the amount of land that can provide ecosystem services to humans. These areas include forests, pastures, croplands, fisheries, and wetlands. Different types of ecosystem services should be considered, such as supply capacity and pollution purification. ESF can be divided into different types, such as pollution absorption service footprint and climate regulation service footprint, according to products and services from different ecosystems.

Other scholars have adopted this conceptual framework and constructed different computational ESF models based on the proposal of Burkhard. Jiao et al. (2013, 2015) presented the calculation method for waste purification service footprint, including nitrogen and phosphorus, and used the "pollution service equilibrium factor" and the "pollution service yield factor" in the measurement. They concluded that the pollution service footprint, which became the index of the natural bearing capacity of a region, should be parallel to the traditional EF model. On the basis of this framework, Gao et al. (2014) constructed a freshwater supply ecosystem service footprint model with the support of the Integrated Valuation of Ecosystem Services and Trade-offs model and geographic information systems; they represented the sustainable development level of regional freshwater at the basin scale. In China, Zhang et al. (2013) proposed the concept, theoretical basis, and calculation method of water EF based on ecosystem service. Although these improvements led to a more accurate and operational concept of ESF, no complete and computable model can illustrate the entire ESF calculation.

3. Methods

In accordance with EF theory, the ESF model is comparable among different land types and various types of ecosystem services, thereby reflecting the use of ecosystem services by the human society and its relationship to the ecosystem supply. In conventional EF theory, the core of the calculation is the use of the "yield factor" and the "equilibrium factor" to measure consumption and supply as a productive "area." The results of EF can either be global or regional by considering these factors as weighted factors and can then be compared by using a unique metric, i.e., global hectare. On the basis of the EF concept, the ESF model should inherit the aforementioned characteristics and estimate under the same "hectare" unit, which refers to how much hectares can provide the human consumption of ecosystem services.

The ecosystem service footprint is divided into three primary categories, namely, provisioning, regulating, and cultural service footprints (Fig. 1), according to mainstream classification, such as those of Natural Capital Project and Common International Classification of Ecosystem Services (CICES). In the classification of ecosystem services in MEA, the supporting ecosystem service is one of the four main ecosystem services. With the deepening of the ecosystem service research, more and more researchers hold the view that supporting ecosystem services underpin other ecosystem services as an intermediate service, but do

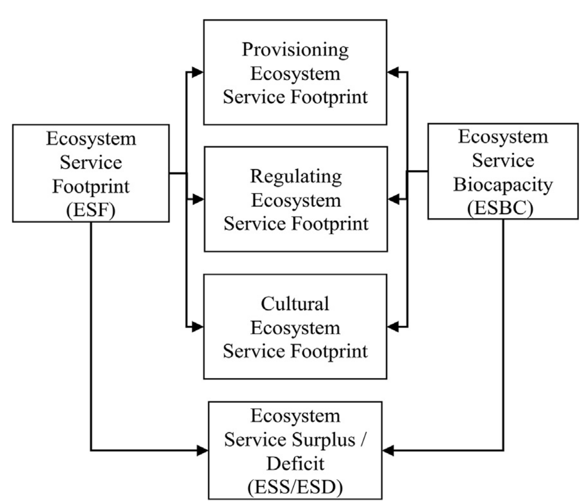

Fig. 1. Framework of the *ESF* model.