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Dynamic changes in the value of China's ecosystem services

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ABSTRACT

This study initiated a dynamic assessment method of ecosystem service values (ESV), based on an analogy with the labor theory of value, by modifying and developing the method of equivalence factor per unit area. Using such method, the monthly values from 11 categories of ecosystem services provided by China's ecosystems in 2010 were dynamically estimated. The results indicated that (1) a total ESV of 5.63 trillion US dollars annually was provided, of which forests provided the highest proportion (46.0%), and the regulating services had the highest contribution among the four categories of services (71.3%); (2) the total ESV from 11 categories showed apparent seasonal variation, with higher values from May to September than from November to February which contributed 76.9% and 7.4% to total ESV, respectively; (3) the highest ESV per unit area mainly distributed in southern and eastern areas, and the value generally decreased from southeast to northwest; and (4) the ratio of ESV per capita to the gloss domestic product (GDP) per capita was about 0.87, and such ratio was lowest in the most economically developed and densely populated areas. Therefore, the dynamic assessment method developed in this study can provide a scientific basis for Chinese policy decision-making.

1. Introduction

Ecosystems are natural resources and assets, and serve as the basis of human survival and development (Braat and de Groot, 2012). Ecosystems and their associated ecological processes constantly provide ecological products and services, which form and maintain environmental conditions and materials that sustain humans, other animals, and plants (Millennium Ecosystem Assessment, 2005; TEEB Foundations, 2010). Continuous population growth, industrialization, and urbanization around the world have placed considerable pressure on ecosystems, leading to a growing inability of the available ecosystem services to sustain this pressure. Thus, the protection of natural ecosystems and enhancement of their ecosystem services has become an urgent challenge globally (TEEB Foundations, 2010; Ouyang et al., 2016).

Ecosystem services have a seemingly immeasurable value in terms of their unique role for human well-being, however, ecosystem services were not recognized objectively until the late 1970s (Braat and de Groot, 2012). Before that, ecosystem services have been considered as an abundant and inexhaustible public service that can be exploited at no cost, and the result has been a decreased supply and excessive consumption of ecosystem services (Daily et al., 2000; Egoh et al., 2007; Wainger et al., 2010; Lautenbach et al., 2011). To mitigate the growing scarcity of ecosystem services and support the implementation of ecosystem management and ecological policies, it has become an urgent necessity to fully evaluate the value of ecosystem services (de Groot et al., 2012).

Since 1990s, the exploratory studies have been performed on the valuation of ecosystem service and thereby the evaluation of ecosystem service values (ESV) (Costanza et al., 1997, 2014; Daily et al., 2000; Wainger et al., 2010; Turner et al., 2016). Generally, two kinds of monetary valuation approaches are utilized widely for ESV; one is referred to as primary data based approach in which ESV is estimated by two steps: firstly quantifying ecosystem processes and functions that underlie ES based on a set of ecological models, such as, water conservation model for water conservation, photosynthesis equation for gas regulation, etc. Secondly, valuating ES derived from corresponding functions using economic valuation techniques, such as, market price method, carbon tax method, replacement cost method, travel cost, etc. (e.g., Zhao et al., 2003, 2004a; Wang et al., 2007; SFA, 2008). The other approach is referred to as unit value based approach in which ESV is estimated based on economic value per unit area of ecosystem (e.g., Costanza et al., 1997, 2014; Chen and Zhang, 2000; Xie et al., 2003, 2008; Shi et al., 2012).

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The primary data based approach is usually applied on the small spatial scale (Kareiva and Marvier, 2003) or single ecosystem (Li, 2010; Niu et al., 2012; Zhang et al., 2012; Pei, 2013; Wen et al., 2013). However, this method usually requires many input parameters and contains complex accounting processes, which results in the difficulties for unifying the evaluation method and standardizing the parameters for the valuation of each ecosystem service (Zhang et al., 2010; Sun, 2011; Yu and Bi, 2011a,b). In addition, such method is often performed on one or a few kinds of services rather than the comprehensive ESV due to the intensive parameterization.

The equivalent factor method, which belongs to the unit value based approach (Costanza et al., 1997), developed by Xie et al. (2003) based on a survey from 500 Chinese ecological experts. Such method is the most widely used in China, especially for the ESV evaluation results from land use changes. For this method, the economic value of each ecosystem service from a ecosystem is estimated as the product of an equivalence coefficient (dimensionless) and the economic value (expressed as $/hectare) represented by one standard equivalence factor, which is the value of the product or service provided per unit area. The equivalence coefficient reflects the relative weight of ESV for a certain ecosystem compared to the standard ecosystem (e.g. farmland) (Xie et al., 2003, 2008). Then the total ESV is summed with the value of different ecosystem services. Such method is more convenient to perform an assessment on the spatial-temporal distribution of ESV at regional and global studies (Costanza et al., 1997, 2014; Wang et al., 2014).

The determination of standard equivalent factor and the establishment of an equivalence factor table for diverse ecosystem service from different ecosystems are the two prerequisites for equivalent value method. The standard equivalence factor for ecosystem services was defined as the economic value of the natural grain output per unit area of farmland based on the national average yield (Xie et al., 2008), which is easy to derive and determine objectively. For the establishment of an equivalent coefficient table, Xie et al. (2003, 2008) has developed an expert-based method for ecosystem services valuation using the similar classification from Costanza et al. (1997), which has been widely applied to assess ESV at local, regional, and national scales in China (Xie et al., 2008; Zhao et al., 2011; Wang et al., 2014).

With the deepening of the research, an increasing number of researchers have realized that ecosystem services are regulated by a range of ecological mechanisms and exhibit dynamic spatial and temporal variation that is closely related to ecological structure and processes (Wu et al., 2001; Zhao et al., 2004a,b). However, the equivalent factor method that has been used in current research generally provides only a static assessment that ignores spatial and temporal variations in the nature and quality of ecosystems; thus, the results cannot reflect the spatial and temporal dynamics of ecosystem services that occur in ecosystems (He et al., 2005; Zhang et al., 2010; Sun, 2011). Such situation has restricted the practical application of ESV in ecological research and environmental management (Yu and Bi, 2011a,b).

Because of its large population, the quantities of ecological assets per capita are lower in China than in other countries, and then it is very important to recognize ESV and its variations provided by different ecosystems. At the same time, the implementation of ecological civilization strategy, including sustainable natural resource management and ecological compensation etc., also put forward an urgent requirement for policy making based on the dynamic ESV evaluation. In the present study, a dynamic ESV assessment method was developed based on the current equivalent factor assessment method; after that, the temporal and spatial variations of ESV in China were evaluated. The ultimate goal of this study was to provide a theoretical and methodological support for the management of natural assets and ecological compensation programs in China.

2. Principles and methods

2.1. Theoretical basis for evaluation of ESV

The human socioeconomic system and natural ecosystems coexist everywhere. The socioeconomic system provides economic products and services through human activities to maintain human survival and socioeconomic development. To accurately assess the total economic products and services provided by all human activities, a large and complex statistical system has been established to estimate the gross domestic product (GDP), which provides a measure of the economic output of a nation's whole socioeconomic system. GDP measurement is based on the assumptions of the labor theory of value (Meng, 2010): the value generated by human activities represents the social average labor time that is condensed (made tangible) in the form of products and services.

The labor theory of value can be extended to ecosystem services. Similar to human labor creates socioeconomic goods and services, ecosystem also provides goods and services through diverse ecological functions, and ESV is assumed to represent the average role of ecosystems over time, condensed into ecological products and services. Using such an analogy, we can define ESV as the value of products and services provided by ecosystems for human well-being.

Sufficient ecosystem services play key roles for the sustained and healthy of socioeconomic development. From the perspective of sustainable development, the maximizing both of GDP and ESV should be the common goal of human activities in a region, but it is very difficult to achieve. However, it's also necessary to ensure that the maximizing GDP does not lead to declining ESV. If the carrying capacity of ecosystem is exceeded for a long term, such overexploitation can inevitably weaken the ecosystem services, leading to a decrease of the ESV and unsustainable development of the ecosystems and the national economy. Such situation should be received more attention for China because of the relatively lower ecological assets per capita.

2.2. An evaluation method based on the ESV per unit area

The existing socioeconomic statistical system does not fully account for ESV due to the difficulty in estimating the value from the non-marketed components of ecosystem services. Although many studies (Costanza et al., 1997; Ouyang et al., 1999a; Xie et al., 2003, 2008; Shi et al., 2012) have examined the valuation of ecosystem services, it is still difficult to identify, quantify, and monetarize ESV and there is still no unified and complete set of scientific assessment or accounting methods for ESV (Zhang et al., 2010; Sun, 2011; Yu and Bi, 2011a,b). Before a globally recognized ESV pricing method can be developed, the substitution methods such as substitute cost or willingness-to-pay can be used to describe the benefits obtained from ecosystems.

The method based on an equivalent factor (Xie et al., 2003, 2008) assumes that each unit area of ecosystem serves as a functional unit to provide ecosystem services and products. If the monetary value of different ecosystem services from per unit land area can be identified, the total ESV will be quantified for the certain ecosystems and regions with the land area of different ecosystems. Therefore, such assumption provides a simplistic but operable approach for ecosystem service valuation.

In the present study, we surveyed the literature and government statistics to find data on net primary productivity (NPP) of