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Impacts of land-use change on valued ecosystem service in rapidly urbanized North China Plain

Wei Song[a], Xiangzheng Deng[a,b,*], Yongwei Yuan[c], Zhan Wang[b], Zhaohua Li[c]

[a] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China
[c] Resources and Environmental Science, Hubei University, Wuhan 430062, Hubei, China

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ABSTRACT

Land-use change is a major factor driving ecosystem service change. Measuring the ecosystem service variation in response to land-use change is an effective way to assess the environmental costs and benefits of different approaches to policy-based planning. In the present study, we examined the changes in value of the ecosystem services (VES) in the North China Plain (NCP), which is an agricultural region, producing over 35% of the total grain in China, and estimated the changes of VES resulting from land-use change. A model mainly based on net primary productivity (NPP) and soil erosion amount was developed to assess the VES. The results show that the total VES of the NCP increased by $ 21.61 billion in 2000 USD during 2000–2008. However, the land-use change led to a net loss of VES by 0.08 billion USD. The expansion of built-up areas contributed to 84.61% of the loss of VES caused by land-use change. The increase of NPP mainly accounted for the increase of VES since it significantly improved the ecosystem service functions of gas regulation, nutrient cycling, and organic material provision. Overall, compared to other factors, land-use change only accounted for 0.35% of VES change during 2000–2008 in NCP.

1. Introduction

Natural ecosystems provide a great deal of resources and processes to humankind, which are collectively defined as ecosystem services (Daily, 1997). The benefits that people gain from ecosystem services make a great contribution to human well-being because their supportive functions maintain the daily living of organisms on the earth (MEA, 2003; Chen and Chen, 2006, 2007; Chen et al., 2006; Su et al., 2012c). In the past 50 years, human well-being and the economy has undergone sustainable development but at the cost of the "degradation of many ecosystem services, increased risks of nonlinear changes, and exacerbation of poverty for some groups of people" (MEA, 2005). In order to control the further degradation of ecosystems, the preservation of ecosystem services has become a central concept of local policies for water–soil conservation planning and environmental valuation assessment (Burkhard et al., 2010; Fisher and Turner, 2008).

Economic valuation is widely used for the assessment of ecosystem services (MEA, 2005; Dong et al., 2012; Logsdon and Chaubey, 2013; Rodriguez et al., 2013). Since the 1990s, numerous researches have been conducted to investigate the value of ecosystem services (VES). These assessments cover biological resources (Pearce and Moran, 1994; Zhao et al., 2004), biodiversity conversion (Mcneely, 1993), tropical forests (Peters et al., 1989; Tobias and Mendelsohn, 1991), protected areas (Munasinghe, 1994), and endangered species' management (White et al., 1997). A notable assessment of VES by Costanza et al. (1997) reported on the global biosphere, estimating 17 VES provided by 16 dominant global biomes by using a market valuation method. Since then, a large number of scholars have followed Costanza's footsteps to examine the VES of ecosystems. Nevertheless, some researchers have challenged the method and the result proposed by Costanza et al. (1997), arguing that there are the following problems with the method: too little resolution, too much variation, and limitations with the economic evaluation of land-use types (Limburg et al., 2002; Turner et al., 2003; Lu et al., 2012). Furthermore, land use types are used as a proxy for ecosystem services while the biomes used as proxies do not always perfectly match (Kreuter et al., 2001).

VES is directly or indirectly influenced by climate, land use, and other socio-economic factors. Climate affects VES by changing the

* Corresponding author at: Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China. Tel.: +86 10 64888980; fax: +86 10 64856533.
E-mail address: dengxz.ccap@igsnrr.ac.cn (X. Deng).

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biophysical processes of the ecosystem. Land-use change alters the production capacity of an ecosystem, modifies the physical parameters of the earth's surface, influences nutritional transport between soil and vegetation, and affects the composition and structure of ecosystems (Zang et al., 2010). Socio-economic changes influence the VES by market price (Schroter et al., 2005; Metzger et al., 2006). In addition, some other demographic, scientific and technological, cultural, and religious factors may also affect VES in different ways (Kumar, 2011).

Over the past 50 years, humankind has accelerated the change in ecosystem services more rapidly and extensively than at any other periods in human history (Daily, 1997; MEA, 2003; Scolozzi et al., 2012). One of the most important effects of human activities on VES is land-use change (Burkhard et al., 2012). Globally, the most significant land-use change is the expansion of cropland and pastoral land (Lambin and Meyfroidt, 2011; Pijanowski et al., 2014; Tayyebi et al., 2014a). However, land-use change in China is more complicated. With the accelerated economic development, the urbanization rate in China increased from 17.9% in 1978 to 49.7% in 2010, which greatly boosted the expansion of urban areas (Song and Liu, 2014; Song, 2014). The expansion of urban areas in China has simultaneously led to significant cultivated land loss (Tayyebi et al., 2014b). In many developing areas of China, poor farmers have also claimed forestry areas/grassland into cultivated land to increase their incomes. Aware of the negative ecological effects of irrational cultivated land use, the Chinese government has implemented the Grain-for-Green policy to return steeply sloping cultivated land to forests or grassland. These complicated land use-changes have had mixed effects on VES in China.

Measuring the changes in VES in response to the land-use change is an effective way to assess the environmental costs and benefits of different land-use planning decisions. There is a rapidly growing body of literature about the effects of land-use change on VES. For example, Zhao et al. (2004) investigated the changes in VES resulting from land-use change in Chongming Island, China; Kreuter et al. (2001) measured the changes in VES due to urbanization in the San Antonio area; Martinez et al. (2009) examined the effects of land-use change on the provision of ecosystem services in tropical montane cloud forests; and, Yoshida et al. (2010) assessed the changes in the valuation of ecosystem services in each land use category by using the coefficients published by Costanza et al. (1997).

When assessing the changes in VES in response to land-use change, a proxy method has been widely adopted, which views land-use type as a proxy for ecosystem services by matching the land-use types to equivalent biomes. The variation in VES is estimated by observing the changes in land-use structure. However, three problems have emerged when using this method. First, it ignores the spatial heterogeneity of VES, which may have significant influence on the process and pattern of ecosystem changes (Pickett et al., 1997). In particular, the VES can be even different within the same land-use type due to the variation in the physical parameters of the earth's surface. Second, the VES per unit area of each land-use type may change as the time goes by, which has not been considered in this method. Lastly, the VES per unit area of some land-use types is lacking, which limits the application of this method.

The visualizations of ecosystem services and the analysis of factors influencing them are useful tools for environmental managers and policy decision makers (Swetnam et al., 2011). However, before ecosystem services maps are eventually available for use in environmental risk management and related spatial planning, the methods need to be developed further (Daily and Matson, 2008; Burkhard et al., 2012; Kaiser et al., 2013). In this study, we attempt to develop a new model for mapping VES and to assess the changes in VES due to land-use change. Specifically, the purposes of this paper are to: (1) assess the dynamic changes in VES in the North China Plain (NCP); (2) quantitatively differentiate the changes in VES in response to land-use change from other factors; and (3) parameterize the VES per unit area of several land-use types that are usually lacking in previous literatures.

2. Study area and data sources

2.1. Study area

NCP is located in northern China (112°48′–122°45′E, 32°00′–40°24′N) (Fig. 1). It covers an area over 440,000 km^2, with plains accounting for 70% of this area and mountains about 30%. The mountains are mainly in the west and central region and plains mostly in the north and south of the region. The NCP lies in the warm-temperate zone and has a continental monsoon climate.

NCP is a vital agricultural region in China, characterized by the intensive use of irrigation and chemical fertilizers. The predominant cropping system of the NCP is the double-cropping of winter wheat and summer maize. NCP annually produces over 35% of the total grain and, particularly, over 60% of the wheat in China. In the past few years, the NCP has experienced intensive land-use changes due to rapid urbanization, which draws the public's attention to the need to research the consequent changes in VES.

2.2. Data sources

The data that we used for analyzing land-use changes in NCP were based on two maps of land use in 2000 and 2008 at the scale of 1:100,000. The maps were generated by Chinese Academy of Sciences (Liu et al., 2010; Deng et al., 2011; Liu et al., 2014) and the China National Environmental Monitoring Center using historical U.S. Landsat TM (Thematic Mapper) satellite images from 2000 to 2008. The remote sensing data were interpreted by the human–machine interactive approach with an average interpretative accuracy of over 95% (Liu et al., 2005). The land use was divided into six primary types (cultivated land, forestry area, grasslands, water areas, built-up area, and unused land) and 25 sub-classes (Deng et al., 2010a,b).

The net primary productivity (NPP) data in the NCP during 2000–2008, with a spatial resolution of 1 km, are the products of NASA's EOS/MODIS (i.e., MOD17A3), which contain annual NPP and QC datasets. The Normalized Difference Vegetation Index (NDVI) data in NCP were sourced from SPOT-vegetation data, with a temporal step of 10 days and spatial resolution of 1 km. The climate data, such as precipitation and temperature, were collected from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do). The soil nutrient map of NCP was generated from the second soil survey in China. The actual evapotranspiration data utilized in this study are sourced from Data Sharing Infrastructure of Earth System Science, China, which were calculated with the IBIS model.

3. Method

3.1. Value quantification of ecosystem service

The circulation of materials and energy flows in ecosystems, which decide the diversity of the ecosystem service, are extremely complex. The MEA (2003) classifies the ecosystem services into provisioning (e.g., provision of food and fiber), regulation (e.g., regulation of climate through carbon storage), cultural (e.g., recreational values), and supporting services (e.g., nutrient cycling and soil formation). However, humankind may still not discern the ecosystem services as a whole due to the limitations of

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