Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2012, 24(3) 419–426
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Modeling soil conservation, water conservation and their tradeoffs: A case study in Beijing

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Received 04 December 2010; revised 30 January 2011; accepted 23 June 2011

Abstract

Natural ecosystems provide society with important goods and services. With the rapid increase in human populations and excessive utilization of natural resources, humans frequently enhance the production of some services at the expense of the others. Although the need for tradeoffs between conservation and development is urgent, the lack of efficient methods to assess such tradeoffs has impeded progress. Three land use strategy scenarios (development scenario, plan trend scenario and conservation scenario) were created to forecast potential changes in ecosystem services from 2007 to 2050 in Beijing, China. GIS-based techniques were used to map spatial and temporal distribution and changes in ecosystem services for each scenario. The provision of ecosystem services differed spatially, with significant changes being associated with different scenarios. Scenario analysis of water yield (as average annual yield) and soil retention (as retention rate per unit area) for the period 2007 to 2050 indicated that the highest values for these parameters were predicted for the forest habitat under all three scenarios. Annual yield/retention of forest, shrub, and grassland ranked the highest in the conservation scenario. Total water yield and soil retention increased in the conservation scenario and declined dramatically in the other two scenarios, especially the development scenario. The conservation scenario was the optimal land use strategy, resulting in the highest soil retention and water yield. Our study suggests that the evaluation and visualization of ecosystem services can effectively assist in understanding the tradeoffs between conservation and development. Results of this study have implications for planning and monitoring future management of natural capital and ecosystem services, which can be integrated into land use decision-making.

Key words: ecosystem services; tradeoffs; scenario; management
DOI: 10.1016/S1001-0742(11)60790-0

Introduction

Ecosystem services are the benefits that humans derive from ecosystems, which include provisioning, regulating, supporting and cultural services (MEA, 2003; de Groot et al., 2002; Egoh et al., 2009). Ecosystem service evaluation is a popular technique used in ecological economics (Costanza et al., 1997; Daily et al., 2000) since it aims to analyze and quantify the importance of ecosystems to the well-being of humans (Chen et al., 2009). Nevertheless, the Millennium Ecosystem Assessment (MEA, 2005) showed a significant decline in the majority of ecosystem services for various ecosystems worldwide (Dolinar et al., 2009). Many ecosystem services are prone to decline and/or degradation under current natural resource use practices since they are typically considered public goods, making them prone to exploitation (Swinton et al., 2007; Guariguata and Balvanera, 2009). The ongoing loss of ecosystem services highlights the urgent need to develop techniques for rapid assessment and monitoring of changes in ecosystem services (Balvanera et al., 2001; Menon and Bawa, 1997; Margules and Pressey, 2000; Stork and Samways, 1995; Krishnaswamy et al., 2009).

Land use changes influence system properties, processes and components, which are the basis of service provision (de Groot et al., 2009). Over the last 50 years, they have been immense (Metzger et al., 2006), resulting in significantly threats to, and degradation of, many natural ecosystems (Martnez et al., 2009). Many studies have shown decreases in ecosystem services due to land use changes, as in the case of pollination services (Priess et al., 2007; Ricketts et al., 2008; Steffan-Dewenter and Westphal, 2008), carbon storage (Huston and Marland, 2003; Kirby and Potvin, 2007) and hydrology (Strange et al., 1999). These changes have significant implications for human well-being (Balmford and Bond, 2005; Pattanayak and Wendland, 2007; Martnez et al., 2009).

A rapid increase in human populations with a concomitant excessive utilization of natural resources may also lead to enhanced production of some services at the expense of the others. To improve the reliability of 'tradeoffs'

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decisions relating to land use changes, a systematic account of the relationships between ecosystem management and ecosystem services generated is needed (de Groot et al., 2009). In spite of recent advances in mapping of natural capital and ecosystem services (Blashke, 2005; Haines-Young et al., 2006; Chan et al., 2006; Naidoo and Ricketts, 2006; Gimona and van der Horst, 2007; Egoh et al., 2008; Meyer and Grabaum, 2008; Grêt-Regamey et al., 2008; Naidoo et al., 2008; Raymond et al., 2009), such techniques are still unable to account for spatial and temporal dynamics of service delivery. Dynamic visualization alternatives under various development scenarios need to be explored as a means of representing changes in services across space and time; yet these techniques remain scarce in literature (de Groot et al., 2009).

According to the remote-sensing survey in 2000, the soil erosion area in Beijing, China was 4088.91 km^2. Affected by monsoon climate, spatial and temporal distribution of precipitation is uneven resulting in dry season and wet season. Meanwhile, Beijing is severe short of water; with per capita water resource is only 300 m^3, as 1/8 of the national average, the world's 1/30. The contradictions between water supply and demand are very conspicuous, especially with the economic development and the process of urban population increasing. Soil erosion and water shortage has become a major obstacle to the socio-economic sustainable development in Beijing.

In this study, we developed an approach to spatially and temporally visualize the potential for soil conservation and water conservation in Beijing. We developed scenarios (a typology of management states) to analyze the changes of service provision by each scenario across space and time for ecosystems and land use types. These scenarios will help to inform policy and decision-making regarding conservation and environmental management. Our study addressed two questions: (1) How will ecosystem services change (in terms of spatial and temporal parameters) under different scenarios? and (2) Can an effective and reasonable management proposal, based on tradeoffs between conservation and development, be designed?

1 Methods

1.1 Study site

Beijing lies on the northern edge of the North China Plain (between 39°28′–41°05′N, 115°25′–117°30′E). It covers 16,807 km^2, of which 62% is mountainous (Yang et al., 2005). The city is located on the eastern rim of the Eurasian land mass and belongs to the West Wind Belt. It is characterized by a warm temperate continental monsoon climate and has four distinct seasons with an annual average temperature of 11.5°C, and an annual average precipitation of 554.5 mm, of which 80% falls between June and September (Sun et al., 2007). Beijing is vulnerable to fluctuating climate patterns and in the last decade extreme climate events and meteorological disasters have caused significant droughts, floods and extreme high temperatures (Zheng et al., 2000; Zhang et al., 2008).

1.2 Data

Land use was calculated from 1994 and 2007 spot images and the following types were characterized: forest, shrub, grassland, water area, dry land, paddy land, rural area, urban area, and bare ground. Land use data were converted to image format (see Appendix 1 for details).

1.3 Scenarios

We created three scenarios of Land use change, from 2007 to 2050, each of which includes a set of spatially explicit raster grid maps (50 m × 50 m grid cells) at 10-year intervals, from 2007 to 2050 (Figs. 1 and 2): The US EPA (2002) descriptions of these scenarios are outlined below:

Plan trend (PS): the expected future landscape, should current policies be implemented as written and recent trends continue.

Development (DS): a loosening of current policies, to allow freer rein to market forces across all components of the landscape, but still within the range of what stakeholders considered plausible.

Conservation (CS): this scenario placed greater emphasis on ecosystem protection and restoration. As with the development scenario, the model reflects 'a plausible balance among ecological, social, and economic considerations, as defined by stakeholders'.

1.4 Ecosystem services evaluation

Soil conservation and water conservation are a function of precipitation, land characteristics and the land use pattern (see Appendix 2 and 3 for details).

1.4.1 Soil conservation

The universal soil loss equation (USLE) was used to evaluate soil conservation. We predicted the average annual rate of soil erosion and soil retention in Beijing:

$$A = R \times K \times \mathrm{LS} \times C \times P \quad (1)$$

where, A (ton/ha) is the average annual soil loss; R is the

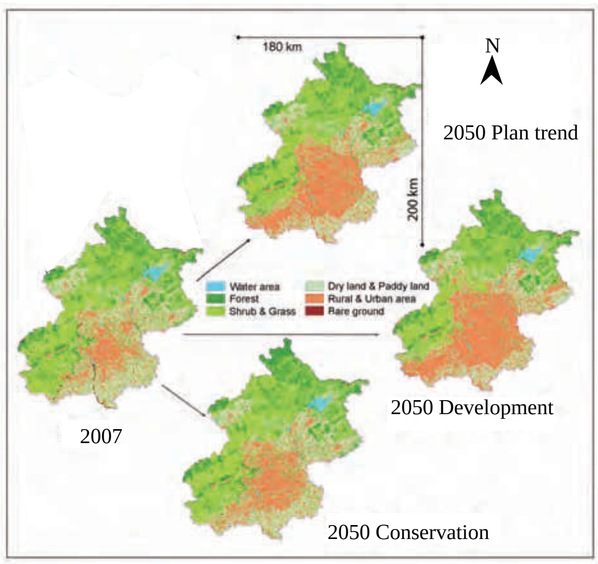

Fig. 1 Location of Beijing, showing land use patterns for 2007, and projected land use patterns for 2050, under three different scenarios.