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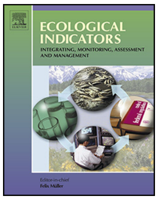

The effects of population density changes on ecosystem services value: A case study in Western Jilin, China

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ABSTRACT

In recent decades, the semi-arid ecosystem of China's Western Jilin province has changed dramatically due to intensive human activities. This article simulated the population density in Western Jilin using a Kernel Density Estimation method and explored the influence of population density on both the value and structure of ecosystem services in various regions. The results showed that lower population density correlated with higher values of ecosystem services per unit area. Apart from food production value, the value of each type of ecosystem service per unit area decreased as population density increased, with the greatest change observed in the value of waste disposal and the lowest in the value of raw materials. Analysis of demographic change on the structure of ecosystem services value produced a Gourd Phenomenon. Sensitivity analysis showed that the sensitivity coefficient of farmland ecosystems was highest, followed by wetland ecosystems and water ecosystems. Therefore, we should restore farmland to grassland and wetland (with its associated rivers and lakes) when reconstructing the eco-environment in Western Jilin.

1. Introduction

Ecosystem services are the benefits and natural ambient conditions formed and maintained during the development of ecosystems; they are necessary for human survival (Costanza et al., 1997a, 1997b; Daily, 1997; Ouyang et al., 1999; MEA, 2005). Ecosystem services not only provide food, pharmaceuticals and other materials for human use, but also create and sustain the earth's life support systems; form the environmental conditions necessary for survival; and supply leisure, entertainment and esthetic enjoyment for people (Chen and Zhang, 2000; Brauman et al., 2007; Kozak et al., 2011). Since the concept of ecosystem services was proposed, many ecologists and economists have analyzed and discussed their value from both the physical parameter and the magnitude of value. Various evaluation methods have been developed for different ecosystem services and biological resources (Peters et al., 1989; Chopra, 1993; Harvey and Pimentel, 1995; Björklund et al., 1999; Lu et al., 2003; Zhao et al., 2004; Xie et al., 2008; Sherrouse et al., 2011). Costanza et al. (1997a, 1997b) summarized the literature and grouped ecosystem services into 17 types, then calculated their values in monetary terms according to ten different biomes. This provided a strong reference point for a comprehensive assessment of the economic value of ecosystem services (Xiao et al., 2003). Some scholars have applied Costanza's worldwide ecosystem services evaluation model to a specific area, species, community or ecosystem (Holmlund and Hammer, 1999; Rönnbäck, 1999). Based on the evaluation model proposed by Costanza, Xie et al. (2001, 2003a, 2003b, 2005) presented *the table of ecosystem services value per unit area of different terrestrial ecosystems in China* by surveying more than 200 ecologists from China. This table evaluated the regional economic value of ecosystem services by using the economic value of agricultural food production services and the account of mutual contributions between ecosystem services, making it more comprehensive and specific for China than previous evaluation methods (Xiao et al., 2003).

The value of ecosystem services is strongly influenced by human activities (MEA, 2005; Zhang et al., 2008). If humans fail to understand or ignore the value of ecosystem services, irrational human activities will lead to a reduction in benefits provided by ecosystems or even threaten the ecological foundation upon which the sustainable development of human society depends

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(Zhang et al., 2000, 2008; Xie et al., 2003a; MEA, 2005). On the other hand, understanding the relationship between human activities and ecosystem services value (ESV) will allow the restoration of damaged ecosystems, which will help improve and enhance the value of ecosystem services by contributing to the development of reasonable policies and management (Zheng et al., 2003; Halpern et al., 2008; Zhang et al., 2008; Brown, 2013). Analyzing the effects of human activities on ESV is important for promoting the sustainable development of human society, economy and the ecological environment (Zheng et al., 2003; Zhang et al., 2008; Estoque and Murayama, 2013).

With the increase in population density and the development of technology, human beings gradually intensified use of the ecosystem to acquire economic profits. At the same time, land reclamation and other human activities significantly changed the structure of ecosystems and seriously affected the maintenance of numerous ecosystem services (Zhang et al., 2008; Kubiszewski et al., 2013). In this paper, we examined the Western Jilin province in China as a case study for understanding the relationship between changes in ESV as they relate to population dynamics. We used the Kernel Density Estimation (KDE) method to quantify the population dynamics in each grid. According to *the table of ecosystem services value per unit area of different terrestrial ecosystems in China* provided by Xie and referring to relevant literature by other scholars (Xie et al., 2001, 2003a, 2005; Xiao et al., 2003; Zhao et al., 2004; Zhang, 2012; Ai, 2013), we developed a table of correction coefficients, which we used to determine the ESV per unit area of different terrestrial ecosystems, and discussed the effects of population dynamics on ESV.

2. Materials and methodology

2.1. Study area

Western Jilin, one of the most saline-alkali areas in the world, was selected as an example to evaluate the effect of population dynamics on change patterns in land ecosystems. Western Jilin extends from 43°22′ N to 46°18′ N latitude and from 121°36′ E to 126°12′ E longitude, covers an area of 55,340 km^2 and includes 12 counties (cities), including Baicheng, Zhenlai, Taonan, Tongyu, Daan, Songyuan, Qianguo, Qianan, Changling, Fuyu, Nongan and Shuangliao (Fig. 1). The area is flat and sited mainly on an alluvial plain with an average altitude of 200 m (Fig. 1). Since China's reform and the introduction of its open-door policy, the population of Western Jilin has increased from 4.83 million people to 6.45 million, with rapid urban expansion and land ecosystem change. From 1975 to 2010, the percentage of the non-agricultural population increased from 17.8% to 30.9% and the urban area increased by about 90 km^2. The severe overgrazing, wasteland reclamation and ecosystem destruction associated with rapid population growth resulted in desertification, alkalization and grassland degradation (Yue et al., 2007).

2.2. Land ecosystems

Land ecosystem reconstruction requires the integration of multi-source data to create historical land ecosystem spatial data. There are three main methods to reconstruct land ecosystems. First, information about land ecosystem spatial distribution patterns can be extracted from historical maps (such as topographic or thematic maps). Second, possible land ecosystem spatial distributions can be predicted based on natural environmental background and socio-economic data. Third, the spatial distribution of land ecosystems can be simulated at certain points in time by mastering dynamic changes in land ecosystems using remote sensing data (Bai and Zhang, 2004; Bai et al., 2007).

Here, we combined remote sensing data, terrain data, thematic maps, socio-economic statistical data and survey data. The remote sensing data included Landsat/TM image data (2010) and MSS image data (1975). Terrain data was examined at scales of 1:10,000 and 1:50,000 in 1975. Natural environmental background data was taken primarily from maps of soil, hydrology, vegetation, and topography. All data included spatial and attribute information, and was processed by digitization using the Beijing 1954 Gauss–Kruger projection. Land use data in 2010 and 1975 was acquired by digitizing TM and MSS images based respectively on the 1:10,000 and 1:50,000 topographic maps from 1975.

We used a primary classification system to divide land ecosystems into six categories, including unused land. Considering the severe soil alkalization and wetland degradation, we removed alkali-land and wetland from the unused land category to form two additional land ecosystem classes. Thus, we formed a total of eight unique categories for our study: farmland, forest, grassland, water, built-up land, alkali-land, wetland and unused land (Fig. 3).

2.3. Demographic data

Demographic data used herein is taken mainly from National economy statistics data of Jilin Province (1949–1978) and National counties and cities population statistics data of China (2010), both of which were collected by the county. The demographic data included total population, non-agricultural population and agricultural population. Between 1975 and 2010, the total population of Western Jilin increased by about 1.6 million and the non-agricultural population increased by 1.14 million, while the rural population increased by only 490,000 and accounted for just 30.6% of the total increase in population.

Because the demographic data used in this article was collected by the county, the population density calculated using this data could not reflect changes within the county. Thus, we needed the spatial information provided by demographic data to acquire new insight into the population distribution and changes therein. Given the geographic characteristics of Western Jilin, we selected KDE to simulate the raster surface of resident density and acquire the spatial distribution of population density. This allowed us to calculate the population density of each grid, according to

$$PD = \frac{TP}{N} \times \phi_i \tag{1}$$

where the PD is the population density, TP is the total population of study area, N is the number of settlements within the study area and ϕ_i is the resident density for each grid (Lü et al., 2002; Yan et al., 2011).

We divided settlement areas into two types, urban and rural, then calculated the density of each using the KDE method. The population density of urban and rural areas was calculated according to

$$\min f = \sum_{i=1}^{n} [TP_i - (a_{ui} \times PD_u + a_{ri} \times PD_r)]^2 \qquad s.t. \begin{cases} PD_u > 0 \\ PD_r > 0 \\ PD_u - PD_r \geq 0 \end{cases} \tag{2}$$

where TP_i is the i-th county's total population, a_{ui} is the urban area in the i-th county, PD_u is the population density of urban areas, a_{ri} is the rural area in i-th county, PD_r is the population density of rural

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