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Three-dimensional ecological footprint assessment for ecologically sensitive areas: A case study of the Southern Qin Ling piedmont in Shaanxi, China

Yi Yang*, Sun Ling, Ting Zhang, Congxu Yao

School of Economics and Management, Xi'an University of Technology, Xi'an, 710054, China

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ABSTRACT

The ecological management of ecologically sensitive areas is highly sensitive and complex. The three-dimensional ecological footprint assessment for ecologically sensitive areas plays a decisive role in the overall development of a region's ecological environment and can be helpful for promoting the coordinated and sustainable development of economic and natural capital utilization. Taking a typical ecologically sensitive area in the southern Qin Ling piedmont of Shaanxi (southern Shaanxi) as an example, this paper describes the per capita ecological footprint (*EF*) and per capita biological capacity (*BC*) from 2005 to 2015. In addition, based on an analysis of the utilization of capital stocks and flows and the ecological footprint depth (EF_{depth}) and size (EF_{size}), the factors driving changes in the region's ecological footprint size are revealed by a partial least squares model (PLS model). The results indicate that the per capita biological capacity in the southern Qin Ling piedmont of Shaanxi remained stable at 2.100 ha/cap and that the per capita ecological footprint increased, with fluctuations between 1.359 ha/cap and 2.239 ha/cap. After the first appearance of a per capita ecological deficit in 2013, the ecological footprint depth peaked in 2014 at 1.049 ha/cap. The capital stocks consumption rate was well controlled, which meant that capital flows remained the main source of natural capital. The main factors driving the ecological footprint size are commonly used arable land, the per capita disposable income of urban residents and the primary industry output value. Therefore, some suggestions are offered as follows: control the land use for urbanization, accelerate industrial restructuring and upgrading, and establish a mechanism for environmental monitoring and warning.

1. Introduction

An ecologically sensitive area refers to the ecological element and entity that play a decisive role in the overall ecological environment of a region. In addition, the degree of protection, growth and development in an ecologically sensitive area determines the status of the regional ecological environment and is of great significance to regional ecological management, which in turn determines the level of sustainable development (Fang et al., 1997; Da et al., 2004; Yin et al., 2006; Zhang et al., 2007). The Qin Ling Mountains, which divide the northern and southern parts of China, are rich in biotic resources. The southern Qin Ling piedmont of Shaanxi (southern Shaanxi) is located in the climate demarcation line—from the Qin Ling Mountains to the Huaihe River—and is considered a typical ecologically sensitive area. Southern Shaanxi has a typical subtropical climate: the average annual rainfall is more than 800 mm, the climate is humid, and the average annual temperature is between 14 and 15 °C. Due to the luxuriant vegetation, this area is called the "green lung" of China. As the Qin Ling Mountains are the most important ecological protective barrier in Shaanxi, 70% of the provinces' ecological resources (water, forest and biological resource) are distributed in southern Shaanxi, so the ecological management level in this area affects the total biological capacity (*BC*) of the Shaanxi section of the Qin Ling Mountains. The idea of regional integrated ecosystem management is reflected in the form of legislation with the issuance of *Regulations on Ecological Environment Protection of Qin Ling, Shaanxi Province* in 2007. This document outlines a specific plan for environmental resources, a

Abbreviations: Southern Shaanxi, Southern Qin Ling piedmont of Shaanxi; *EF*, ecological footprint; *BC*, biological capacity; EF_{depth}, ecological footprint depth; EF_{sixe}, ecological footprint size; PLS, partial least squares.

* Corresponding author.
E-mail address: yangyi_nwpu@xaut.edu.cn (Y. Yang).

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function area, ecological compensation, financial investment, and a system for investing and financing. Due to climate and terrain limitations, traditional villages are located in the mountains, and villagers rely on farming for their livelihood. Affected by inconvenient transportation and natural disasters, the impoverished population[1] in southern Shaanxi reached 1.609 million in 2016, accounting for 49% impoverished population in of Shaanxi Province. After enacting the *Plan of Emigrant Resettlement in Southern Shaanxi (2011–2020)* in 2010, the *Pro-poor Emigration and Large-scale Disaster Prevention* plan was implemented. Villagers who lived in the mountains gradually began to relocate to the plains, reducing ecological damage in the mountains and protecting ecological resources, but relocation also caused a surge in the urban population, expanded the demand for land and triggered a series of issues such as employment and social security problems. Southern Shaanxi is the upstream water source of the Hanjiang River (the middle route of the south-to-north water diversion). Twenty-eight counties belong to the core water source areas, and twenty three of them are restricted development zones. The ecological protection policy for water source areas includes limited industrial development, and the tension between resource development and environmental protection has become increasingly prominent. The Qin Ling Ecological Environment Protection Committee was restored in 2018, and it issued *Outlines for the Ecological Environment Protection of Qin Ling, Shaanxi Province*, which aimed at solving the problems of tacit approval of mineral resources violations, illegal mining, and serious ecological damage in some areas. Balancing the natural ecological environment and the region's socioeconomic level has become a major issue for regional sustainable development.

Sustainable development is an important way to achieve harmony between humans and nature by instituting resource saving to realize the coordinated growth of populations, economies, and ecological resources during the process of urbanization (Yin et al., 2017). Recognizing the importance of sustainable development has spurred the creation of a number of metrics or indicators that purport to capture natural capital utilization (Hopton and Berland, 2015). The minimum level of sustainable development would maintain natural capital stocks (Costanza and Daly, 1992; Pearce et al., 1989; Pezzey, 1990). Pearce and Turner (1989) define natural capital as “any natural asset that produces ecological service flows of economic value”, and it can be divided into capital stocks and capital flows. The former refers to the natural capital amount existing in physical form in a geographical space under certain time and space conditions. The latter refers to the output of natural capital in a geographical space at some point in time (Daly, 1996). Natural capital accounting can accurately measure its use and is of great academic value in measuring and evaluating the occupancy, consumption and recovery of ecological resources (Wackernagel et al., 2004). The accounting methods for regional natural capital mainly include the ecological footprint, net productivity, material flow analysis and energy memory measurement methods (Li and Fu, 2013). One commonly used metric of sustainability is the ecological footprint (*EF*). Rees (1992) first proposed the *EF* and determined whether regional economic development was keeping within a reasonable carrying capacity by judging the balance of ecological supply and demand. Wackernagel et al. (1999) were the earliest to apply the *EF* model to natural capital at the global and national levels and proposed summary measures, including the control of population growth and the restriction of high consumption, to curb the decline of natural stock. Chen and Bao (2008) considered the dynamic relationship between industrial economic[2] growth and the *EF* to be an important means by which to analyze a regional economy's sustainable development ability. Liu and Song (2008) quantified the rise and fall of natural capital for Wuhan City in 1995, 2000 and 2005, from which they found that the contradiction between natural capital demand and supply was significant and manifested in the annually increasing per capita ecological deficit. Researching the Selection of metropolises or towns in urbanization in the perspective of sustainable development by *EF* model, Xi et al. (2015) concluded that small and medium-sized urbanization of city population with less than millions increases the ecological footprints and pressures on ecological environment significantly. Natural capital account was improved by comparing the natural capital footprint of more than 200 countries worldwide by Borucke et al. (2013), who used the improved natural capital account to calculate the natural capital footprint of more than 200 countries worldwide, and the results showed that most countries have a biological deficit. The important role of a capital stocks constant was difficult to reflect in maintaining an ecosystem's stability because natural capital is not classified in the two-dimensional *EF* model (Fang and Li, 2012). Therefore, Niccolucci et al. (2011) extended the two-dimensional *EF* model to three dimensions by introducing per capita ecological footprint depth (EF_{depth}) and per capita ecological footprint size (EF_{size}) to measure capital stocks and capital flows, further developing on previous ecological footprint research methods. Fang (2013) discussed the three-dimensional *EF* model systematically and expounded on its calculation method and advantages. Taking as an example the change in the spatial pattern of natural capital utilization in the G20 from 1999 to 2008 in an empirical analysis, Fang (2014) highlighted the nonrenewable land resources, and attached great importance to hysteresis in resource regeneration. By further calculating per capita EF_{depth} and EF_{size}, the three-dimensional *EF* model accurately reflected the utilization of regional capital flows and stocks and showed a clear pattern of regional natural capital use and the level of ecological sustainability. This method was widely used in regional ecological assessments and cause analyses. Geng et al. (2014) evaluated two industrial cities from 1997 to 2009 using the *EF* model (Shenyang, China, and Kawasaki, Japan). In addition, the results from the comparison *EF* study provided valuable insights for urban managers. On the basis of the “City Hectare” *EF* model, Hu et al. (2015) calculated and analyzed *EF*s of various biological resource products before and after the implementation of Guyuan's Green for Grain Project (1998 and 2012). The results showed that the per capita *EF* of Guyuan significantly decreased after the project, as did the ecological deficit. Although cultivated land showed a deficit, grasslands were characterized by an ecological surplus. Taking the Beijing-Tianjin-Hebei urban agglomeration as an example to analyze the regional per capita EF_{depth}, per capita EF_{size}, composition differences and influencing factors in 2010, Du et al. (2016) revealed the degree of natural capital utilization. Taking Jiaozuo as an example, Wang (2016) analyzed ecological sustainability in resource-based cities during a transformation period using the three-dimensional *EF* model, which includes EF_{depth} and EF_{size}. Cao and Zhang (2016) used the improved three-dimensional *EF* model to account for Dali's *EF* and

[1] Impoverished population refers to the total number of people whose income below the standard of China's 2016 poverty line that 3000 RMB yuan per person per year.

[2] According to the explanation of indicators from the National Bureau of Statistics of China, for national economic activities, industries can be classified as primary (provide raw materials to be made into goods; for example, agriculture, forestry, animal husbandry and fishery), secondary (uses raw materials to make goods; such as mining, manufacturing, electricity, gas and water production and supply industries or the construction industry) or tertiary (the part of a country's economy that provides services). Meanwhile, the industrial structure in this article refers to the proportion of industry output value in gross domestic product (GDP).