Analysis on The Dynamic Evolution Characteristics of Three-Dimensional Ecological Footprint in Shaanxi Province

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Abstract: With the accelerated pace of industrialization and urbanization, the rapid economic development of Shaanxi Province is accompanied by increasingly prominent ecological and environmental problems. An improved three-dimensional ecological footprint model was used to analyze the evolution characteristics of ecological footprint in Shaanxi Province from 2010 to 2019. The results showed that 1) The per capita footprint size and per capita footprint depth in Shaanxi Province from 2010-2019 showed an overall increasing trend. 2) The per capita three-dimensional ecological footprint increased at a rate of 10% year by year, and the per capita ecological carrying capacity has been maintained at about 0.8 hm^2; By 2019, the per capita ecological deficit reached 3.0264 hm^2, and Shaanxi Province's ecological development was in an unsustainable state. In the future, we need to pay attention to the reasonable control of urbanization process, improve the efficiency of energy utilization, and advocate economical consumption patterns, so as to realize the sustainable development of Shaanxi Province.

1 INTRODUCTION

With the economic development and the improvement of people's living standards, the uncontrolled use of resources by humans has led to land degradation, soil erosion, and a sharp decrease in biodiversity, which has seriously restricted the sustainable development of urban ecological construction. In 1992, William E. Rees, a Canadian scholar, proposed the "ecological footprint model", which is mainly used to measure the harmony of human-land relationship and ecological sustainable development in the region (Rees, 1992), and Wackernagel further supplemented and improved the ecological footprint model (Wackernagel, 1999). Later, Chinese scholars such as Xu Zhongmin and Zhang Zhiqiang introduced the model into China (Xu, 2000; Mo, 2020). It has been widely used by scholars at home and abroad because of its concise framework and easy operation (Niccolucci, 2009). However, with further research, it was found that the model only focuses on capital flow in natural capital and ignores the capital stock. Therefore, Niccolucci introduced two indicators of footprint depth and footprint size to classify and measure natural capital use, which solved the problem that capital stock was ignored in previous models and developed the research scale from two-dimensional to three-dimensional (Fang, Gao, Li, 2013). Fang Kai further improved the defects of the three-dimensional ecological footprint model (Fang, 2012; Zhang, 2019), which not only measured the use of natural capital from the time and space levels, but also overcame the situation that the ecological deficit or ecological surplus among different land types offset each other in the accumulation process of the traditional three-dimensional ecological footprint model.

Through the summary of relevant ecological footprint studies, it can be seen that ecological footprint theory and models have been applied by some scholars to evaluate the natural capital utilization of land, water and other resources (Wu, 2020; Niccolucci, 2011), but most of them are still based on two-dimensional ecological footprint models, and the application of improved three-dimensional ecological footprint models is still relatively lacking, and previous studies have focused on macroscopic scales such as global, national, and urban clusters (Niccolucci, 2011; Zheng, 2018). Therefore, this paper analyzes the dynamic evolution characteristics of the ecological footprint of Shaanxi

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Province from 2010 to 2019 based on the improved three-dimensional ecological footprint model, in order to promote its ecological environment construction and sustainable development level.

2 RESEARCH DESIGN

2.1 Research Method

Footprint size refers to the area of biologically productive land actually occupied within the carrying capacity and indicates the level of human appropriation of capital flows, with spatial attributes. Footprint depth refers to the number of multiples of the land area that humans need for themselves to meet the actual resource consumption and the number of years required to regenerate these resources, indicating the level of human depletion of the capital stock with temporal attributes (Fang, 2013). The calculation equation is as follows:

$$EF_{size,region} = \sum_{i=1}^{n} (EF_i, EC_i) \quad (1)$$

$$EF_{3D} = EF_{size,region} \times EF_{depth,region} \quad (2)$$

$$EF_{depth,region} = 1 + \frac{\sum_{i=1}^{n} (EF_i - EC_i, 0)}{\sum_{i=1}^{n} EC_i} \quad (3)$$

where $EF_{size,region}$ represents the size of the regional footprint; $EF_{depth,region}$ represents the depth of the regional footprint; EF_i, EC_i are the ecological footprint and ecological carrying capacity of the i-th land type; EF_{3D} represents the regional three-dimensional ecological footprint.

2.2 Data Source and Processing

According to the resource consumption status of Shaanxi Province, this paper combines the research results of Guo Xiurui, Wang Ruijie and Shi Lei (Guo, 2003; Wang, 2020; Shi, 2017), and constructs the type of ecological footprint account as shown in Table 1. The consumption data of the main products of biological resources account and fossil energy account in Shaanxi Province are obtained from the Shaanxi Statistical Yearbook and Shaanxi Economic and Social Development Statistical Bulletin from 2011 to 2020.

3 RESULTS

3.1 Dynamic Change of Per Capita Footprint Size

It can be seen from Table 2, the per capita footprint size in Shaanxi Province showed a slow upward trend from 0.5105hm^2 in 2010 to 0.6352hm^2 in 2019, with an average annual growth rate of 2.4%, reflecting the increasing occupation of natural capital flow by residents in Shaanxi Province. In terms of different land types, the per capita footprint size of cultivated land decreased slowly during the decade; forest land and construction land were on the rise as a whole; grassland and water area did not change significantly, remaining at 0.0062 hm^2 and 0.0014 hm^2, respectively. The contribution of per capita footprint size of each land type was in the following order: cultivated land > forest land > construction land > grassland > water area, which indicated that the main carriers of natural capital flow in Shaanxi Province were cultivated land and forest land. Cultivated land accounts for more than 66% of the footprint size in Shaanxi Province, providing food demand for residents; forest land occupies the second largest share, which is mainly used to provide wood for economic construction and absorb greenhouse gases such as CO_2 produced by human activities.

Table 1: Types of ecological footprint accounts in Shaanxi Province.

Account type	Consumption items	Land type
Biological resources account	Grain, oilseeds, vegetables, melons and fruits, pork, poultry eggs, pastries, flue-cured tobacco, tea, wine, cotton	Cultivated land
	Beef, mutton, poultry, milk	Grassland
	Wood, walnut, chestnut	Forest land
	Aquatic product	Water area
Fossil energy account	Electric power	Construction land
	Raw coal, coke, crude oil, gasoline, kerosene, diesel oil, natural gas	Fossil energy land

Table 2: Per capita footprint size of Shaanxi Province from 2010 to 2019.

Year	Cultivated land	Forest land	Grassland	Water area	Construction land	Per capita footprint size
2010	0.4435	0.0355	0.0069	0.0014	0.0232	0.5105
2011	0.4363	0.0514	0.0049	0.0014	0.0265	0.5205
2012	0.4346	0.1000	0.0064	0.0015	0.0286	0.5712
2013	0.4330	0.0876	0.0064	0.0014	0.0309	0.5594
2014	0.4317	0.0997	0.0063	0.0014	0.0327	0.5719
2015	0.4305	0.1117	0.0063	0.0014	0.0325	0.5824
2016	0.4286	0.1236	0.0062	0.0014	0.0384	0.5982
2017	0.4255	0.1355	0.0062	0.0014	0.0416	0.6102
2018	0.4216	0.1453	0.0062	0.0014	0.0455	0.6201
2019	0.4197	0.1583	0.0062	0.0014	0.0497	0.6352

Table 3: Per capita footprint depth of Shaanxi Province from 2010 to 2019.

Year	Cultivated land	Forest land	Grassland	Water area	Construction land	Per capita footprint depth
2010	1.5248	1.0000	21.0519	19.8571	1.0000	3.7360
2011	1.5517	1.0000	30.2354	18.7857	1.0000	3.9406
2012	1.6188	1.0000	23.1009	19.1845	1.0000	4.3965
2013	1.1957	1.0000	8.3126	8.3097	1.0000	4.5885
2014	1.2367	1.0000	8.7595	7.8125	1.0000	4.8522
2015	1.3122	1.0000	9.8327	8.8068	1.0000	5.1915
2016	1.2974	1.0000	11.0435	9.0909	1.0000	5.6478
2017	1.3737	1.0000	11.1076	10.0142	1.0000	6.0425
2018	1.4895	1.0000	11.7318	10.7955	1.0000	5.7141
2019	1.4449	1.0000	14.3182	12.7131	1.0000	6.0183

3.2 Dynamic Change of Per Capita Footprint Depth

As can be seen from Table 3, the per capita footprint depth in Shaanxi Province showed a continuous upward trend from 2010 to 2019, from 3.7360 hm^2 in 2010 to 6.0183 hm^2 in 2019, with an average annual growth rate of 8.3%. In the past 10 years, the per capita footprint depth of Shaanxi Province has always been greater than 1, indicating that the capital flow can no longer meet people's demand for natural resources, and the capital stock needs to be consumed to make up for the shortage of capital flow. From the perspective of different land types, the per capita footprint depth of cultivated land changed little and was basically the same as that in 2010; grassland and water area showed a fluctuating downward state. The per capita footprint depth of cultivated land, forest land and grassland were all greater than 1. Therefore, these three types of land could not meet the ecological needs and the capital stock was excessively consumed. The per capita footprint depth of forest land and construction land was equal to 1, indicating that these two types of land were in ecological surplus, and the consumption of capital flow could meet people's consumption demand for these two types of natural resources. The contribution of the per capita footprint depth of each land type was in the following order: grassland > water area > cultivated land > forest land = construction land, which indicated that the residents of Shaanxi Province consume the most capital stock in grassland and water area. The per capita footprint depth reached 6.0183hm^2 in 2019, which indicated that Shaanxi Province needs 6.0183 times the existing land area to meet the demand for natural resources for socio-economic development.

3.3 Change in Supply and Demand of Per Capita Ecological Footprint

It can be seen from Figure 1, the per capita three-dimensional ecological footprint showed an overall upward trend, from 1.9072 hm^2 in 2010 to 3.8231 hm^2 in 2019, with an average annual growth rate of 10%, indicating that the residents of Shaanxi Province have an increasing demand for resources. The per capita ecological carrying capacity has not fluctuated

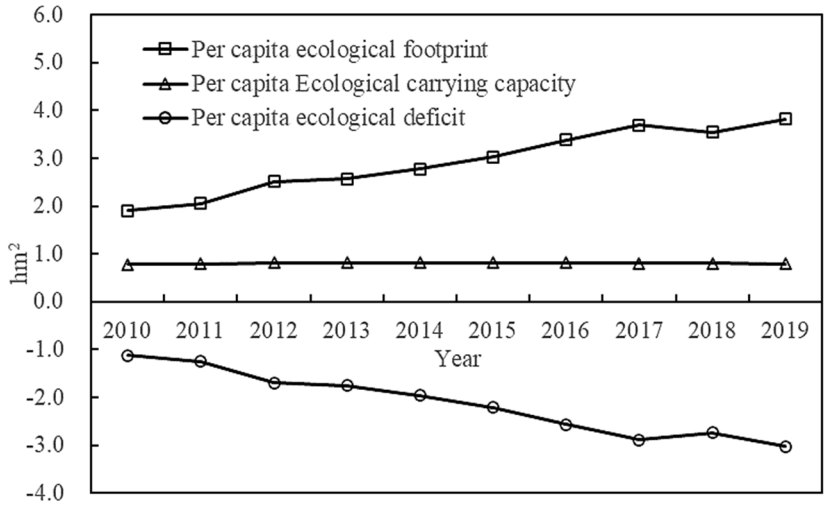

Figure 1: Per capita ecological footprint, carrying capacity and ecological deficit of Shaanxi Province from 2010 to 2019.

greatly and has been maintained at 0.8 hm^2, indicating that the ecological supply in Shaanxi Province was relatively stable. The per capita ecological deficit increased from 1.1262hm^2 in 2010 to 3.0264hm^2 in 2019, which was consistent with the change trend of per capita ecological footprint. As of 2019, the per capita ecological footprint was 4.8 times of the per capita carrying capacity, indicating that residents' demand for resources has far exceeded the supply of environmental ecology, and the ecological economic development of Shaanxi Province has been in an unsustainable state. The intensification of resource consumption due to rapid population growth and the consumption of fossil energy due to the need for vigorous industrial development for economic and social development are important reasons for the continuous increase of ecological deficit in Shaanxi Province.

4 CONCLUSION AND DISCUSSION

Based on the improved three-dimensional ecological footprint model, this paper analyzes the dynamic change characteristics of the footprint size, footprint depth and ecological deficit in Shaanxi Province. The main conclusions are as follows:

(1) From 2010 to 2019, the per capita footprint size of Shaanxi Province showed a slow upward trend, indicating that residents' occupation of capital flow was increasing day by day. The per capita footprint depth showed a continuous upward trend, indicating that the capital flow could not meet the needs of residents, and the capital stock was continuously consumed.

(2) The per capita three-dimensional ecological footprint was on the rise, with an average annual growth rate of 10%. The development of per capita ecological carrying capacity was relatively stable, which has been maintained at 0.8 hm^2. The trend of per capita ecological deficit was consistent with that of per capita ecological footprint. By 2019, the per capita ecological footprint was 4.8 times of the per capita carrying capacity, indicating that the human-land relationship was tense and the sustainable development situation was grim in Shaanxi Province.

Considering the availability of the data and the characteristics of the analysis model, in the calculation of ecological footprint, the missing data or small negligible values of some consumption items in the ecological footprint calculation lead to the small calculation result of per capita ecological footprint, indicating that the per capita ecological deficit of Shaanxi Province may be larger. In addition, indicators such as ecological stress index and ecological diversity index are not introduced in the paper, and future studies can introduce these indicators for a more in-depth exploration of natural capital utilization and sustainable development.

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