Analysis and Calculation of Ecological Footprint in Shaanxi Province from 2000 to 2010

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Abstract. In this paper, the ecological footprint in Shaanxi Province during the period from 2000 to 2010 is calculated and analyzed. The analysis is based on the theory and methodology of ecological print, with natural resource production and consumption, population and land use data from the FAO database and Shaanxi Statistical Yearbooks. Ecological deficit was demonstrated that from 2000 to 2010, indicating an unsustainable ecological development in Shaanxi province.

Keywords: Ecological footprint · Ecological capacity · Ecological deficit · Sustainable development

1 Introduction

Since the United Nations Conference on Environment and Development (UNCED) in 1992, in-depth studies on sustainable development have been done internationally. Consequently, the quantitative evaluation methods for sustainable development have also become the leading edge and hotspot of researches. Some intuitive and operable index systems and quantitative evaluation methods for sustainability have emerged, for example the Green Gross Domestic Product, the National Wealth index by the World Bank, the Index of Sustainable Economic Welfare model, and the Barometer of Sustainability model. The aim of these index systems and models is to make sustainable development measurable, by converting sustainability to specific indicators to assess whether human being is living within the carrying capacity of ecological system. However, there are certain limitations with these studies and the progress has been slow. The key of sustainable development evaluation is to understand the utilization of nature by human and quantitatively measure whether human demand exceeds nature's re-production capacity. Ecological footprint serves such purpose being a method quantitatively assessing human being's utilization of natural resources and nature's functions of providing human being with support services. In the 1990s, Canadian ecologist and economist Rees raised the concept of ecological footprint. Later on, Wackernagel completed this theory and method. While proposing the concept, indicators and methodology of ecological footprint, they applied the indicators to calculate the ecological footprints of 52 countries and regions. Ecological footprint analysis was

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introduced into China in 1999 and quickly applied to analyses and studies of some provinces, cities and regions' sustainable development as a new theoretical method. The creation of this index system provided a simple framework for the assessment of the natural resource usage in a region, a country or even the world. By measuring the gap between human's demand for nature's ecological services and the ecological services that nature can provide, we can thoroughly understand human's utilization of the ecological system, and compare human's consumption of nature and nature's carrying capacity in a regional, nationwide, or global scale. Therefore, ecological footprint analysis is an advantageous quantitative analysis index for assessing the influence of human activities on natural environment. In recent years, because of its scientific and complete theoretical basis and concise and unified index system, ecological footprint analysis has been applied widely and efficiently in domestic and foreign studies. In this study, we applied the principle and method of ecological footprint to analyze the dynamic evolution pattern of Shaanxi's ecological footprint and ecological capacity during 2000–2010, and calculate the per capita ecological deficit of Shaanxi. The problems in Shaanxi's sustainable development are analyzed in this paper in order to provide reference for the sustainable development within the carrying capacity of the resources and environment.

2 Study Area

2.1 Geography

Located in the central part of China mainland, Shananxi borders Shaanxi to the east with the Yellow River in between, Gansu and Ningxia to the west, Inner Mongolia to the north, and Sichuan, Chongqing, Hubei and Hunan to the south. The province spans across a south-north length of 870 km from 105°29′E to 115°15′E, and an east-west width of 510 km from 31°42′N to 39°35′N, with a total area of 205,800 km^2. Overall, it has a terrain higher in the south and north parts and lower in the middle. In the northern part of Shaanxi is the Shanbei Plateau, which consists of mainly the Loess Plateau, with an altitude of 900–1500 m, and an area accounting for 45 % of the province's total. In the southern part is the Qinba Mountains with an altitude of 1500–300 m and an area accounting for 36 % of the province's total. In the middle is the Guanzhong Plain, which is a typical valley plain with an altitude of 320–650 m, and this region accounts for 19 % of the province's total area.

The Annual mean temperature of Shaanxi is around 11.6 °C. On average, the annual precipitation is 653 mm, and there's about 150 to 270 frost-free days per year. The province can be divided into three regions from south to north according to the climate, including Qinba Mountains with north subtropical humid monsoon climate, Guanzhong Plain and Shanbei Plateau with temperate semi-humid semi-arid monsoon climate, and the blown-sand region with temperature monsoon climate. Currently, 136 kinds of mineral resources have been discovered in Shaanxi, and the proved reserves of 57 kinds rank top 10 in China. In total, there are 11 provincially administrated cities/districts and 107 counties/cities/districts in the province.

2.2 Demographics and Economy

As of 2010, Shaanxi province hosts a population of 37.35 million, including 17.07 million of urban population and 20.28 million of rural population. The Guanzhong region is the center of population distribution. In the Shanbei Plateau region, the population mostly distributes in the mainstream of the Yellow River and the downstream of its branches. In southern Shaanxi, the population concentrated in valleys and plains in distributions of dots and strips. In the mountain region, the scarce population scatters in low density. The 107 counties/cities/districts of the province include 32 in Guanzhong Plain region and 25 in Weibei Loess Plateau region, thus these two regions have the densest populations of the province.

According to statistical records of 2010, the province owns cropland of 4.05 million hectare, which accounts for 19.68 % of the province's total area. The areas of pasture and forestry are 3.064 and 10.354 million hectares, respectively, accounting for 14.89 % and 50.31 % of the total area. The land use in Shaanxi is characterized by its diversity, and dominated by agricultural use. In different regions, land use exhibits distinct difference. In Guanzhong region, there is more cropland, while in southern Shaanxi there is more forestry, and in northern Shaanxi there is more pasture.

3 Data Source and Methodology

3.1 Data Source

Data used in this study are from the *Shaanxi Statistical Yearbook*, and the global average yield data of products are from the *Analysis of* Ecological *Footprints of Shaanxi Province in 2001* and the *Analysis of Ecological Footprints of Shaanxi Province in 2003*.

3.2 Methodology

Calculation of Ecological Footprint. The per capita ecological footprint for a particular product can be calculated with the following formula.

$$A_i = C_i/Y_i = (P_i + I_i - E_i)/(Y_i * N)(i = 1, 2, 3, \ldots, 6) \quad (1)$$

Where, i marks the product, A_i is the per capita biological area (hm^2) for the i-th product, C_i is the average tonnage of this product consumed per person, Y_i is the global average annual yield (kg/hm^2) of this product produced by corresponding biologically productive land, P_i is the annual production of the product, I_i and E_i are the annual import and export of this product, respectively, and N is the population.

Calculation of Ecological Capacity. The per capita ecological capacity is calculated with the following formula.

$$ec = \sum \left(a_j \times C_j \times y_j \right) (j = 1, 2, 3, \ldots, 6) \quad (2)$$

Where, a_j is the average area of biologically productive land per person, C_j is the equivalence factor, and y_j is the yield factor.

The yield factor is calculated with the following formula.

$$y_j = p_j / P_j (j = 1, 2, 3, \ldots, 6) \quad (3)$$

Where, y_j is the yield factor of the j-th type of biologically productive land, p_j is the average productivity of this land type in Shaanxi, and P_j is the world average productivity of this land type.

The equivalence factor is calculated with the following formula.

$$C_j = d_j / D (j = 1, 2, 3, \ldots 6) \quad (4)$$

Where, C_j is the equivalence factor of the j-th type of biologically productive land, d_j is the global average productivity of this land type, and D is the global average productivity of all biologically productive land.

4 Results and Analysis

4.1 Dynamic Characteristics of the Ecological Footprint in Shaanxi

The calculation of the ecological footprint in Shaanxi is detailed with the calculation for 2010 as an example. We selected 12 products for the calculation of ecological footprint of cropland, including rice, wheat, corn, beans, sorghum, oilseeds, rapeseed, cotton, fiber, tobacco, vegetables, and pork. For the calculation of average ecological footprint of forestry, due to the lack of data, we only selected tung seed, walnut, chestnut and pepper, and the results are relatively low comparing with the data in other literatures. For the ecological footprint of pasture, we selected eggs, beef, lamb, dairy, and hair. For fisheries, consumption of aquatic products was used for calculation. For construction land, residential area, industrial land, and transportation land were included. And for the calculation for energy land, coal, oil, natural gas and electricity were selected.

It can be seen that the ecological footprint of Shaanxi from 2000 to 2010 exhibits a clear ascending trend. Over the 11 years, the per capita ecological footprint increased from 0.9125 to 2.2855. The increase was rapid in the first 4 years and smooth during 2005–2006. Then, after a rapid increase in 2007, the increase became smooth again during 2008–2009. The increase of ecological footprint from 2009 to 2010 was the most intense in the recent decade.

4.2 Dynamic Characteristics of the Ecological Capacity of Shaanxi

Based on the natural resources data of Shaanxi over the years (Table 2), the ecological capacity was calculated as presented in Table 3. The yield factor was identified according to the ratio of each land type's average productivity to global average productivity. Due to the difficulty in acquiring data, the average productivity data are in national scale. For some of the years, the areas of water were calculated based on available data of other years. The area of construction land is the sum of residential area, industrial land and transportation land.

Table 1. Per capita ecological footprints in Shaanxi from 2000 to 2010 [hm^2]

	Cropland	Forestry	Pasture	Fisheries	Construction land	Energy land	Total
2000	0.3756	0.0012	0.1837	0.0586	0.0200	0.2733	0.9125
2001	0.3765	0.0009	0.1914	0.0586	0.0201	0.3162	0.9636
2002	0.4035	0.0014	0.2202	0.0603	0.0203	0.3584	1.0640
2003	0.4183	0.0014	0.2545	0.0624	0.0204	0.4062	1.1633
2004	0.4643	0.0018	0.2764	0.0639	0.0205	0.5640	1.3909
2005	0.4922	0.0018	0.2981	0.0684	0.0206	0.7211	1.6022
2006	0.4029	0.0018	0.2382	0.0446	0.0207	0.9261	1.6342
2007	0.3776	0.0019	0.2597	0.0464	0.0207	1.0267	1.7330
2008	0.4338	0.0025	0.2867	0.0479	0.0207	1.1535	1.9450
2009	0.4111	0.0029	0.2705	0.0513	0.0208	1.2490	2.0057
2010	0.4290	0.0026	0.2639	0.0557	0.0208	1.5135	2.2855

Note: All consumption data in Table 1 are from *Shaanxi Statistical Yearbook*.

It can be seen that the ecological capacity of Shaanxi from 2000 to 2010 exhibits a clear descending trend. Over the 11 years, the per capita ecological capacity decreased from 0.9803 to 0.8880. As shown in Fig. 2, the capacity decreased drastically during 2000–2005, especially 2001–2003. During 2005–2010, the ecological capacity decr eased in a slower manner. The decrease of ecological capacity indicates the continuously deteriorating ecological environment of Shaanxi.

The increase of ecological footprint is also closely related to the year-by-year decrease of cropland and pasture and the increase of construction land. Although it is suggested in Table 2 that the area of forestry increased, the increase was insufficient to compensate the increasing ecological footprints. In addition, the decrease of cropland and pasture worsened the ecological capacity decrease. The year-by-year increase of ecological footprints and the year-by-year decrease of ecological capacity resulted in the rapid increase of ecological deficit. This indicates the grim condition of ecological development, and the root cause is that the excessive use of natural resource and energy has exceeded the capacity of the ecological system. It can be seen from 4 that the areas of cropland, pasture and water have been reducing over the years, although in slow rates, still affecting the ecological changes in Shaanxi. In the meantime, the per capita ecological footprint for energy land has increased from the 0.2733 of 2000 to the 1.5135 of 2010, with an over 5 times of increment. Apparently, the consumption of energy has

Table 2. Natural resources of 2000–2010 in Shaanxi [104 hm^2]

Year	Cropland	Pasture	Forestry	Fisheries	Construction land
2000	480.0	317.9	962.6	40.3	73.0
2001	468.5	320.3	969.3	40.2	73.4
2002	450.6	321.5	984.3	40.1	74.4
2003	424.2	316.0	1011.9	39.9	74.9
2004	415.4	313.4	1020.3	39.9	75.5
2005	408.9	311.7	1028.5	39.9	75.9
2006	405.8	307.1	1034.7	39.9	76.5
2007	404.9	306.6	1035.4	39.9	76.8
2008	404.9	306.6	1035.4	39.9	76.8
2009	405.0	306.4	1035.4	39.9	77.6
2010	405.0	306.4	1035.4	39.9	77.6

Table 3. Per capita ecological capacity [hm^2]

Year	Cropland	Pasture	Forestry	Fisheries	Construction land	Total
2000	0.6123	0.0083	0.2644	0.0022	0.0931	0.9803
2001	0.5961	0.0083	0.2656	0.0022	0.0934	0.9656
2002	0.5719	0.0083	0.2691	0.0022	0.0944	0.9459
2003	0.5370	0.0082	0.2758	0.0022	0.0948	0.9180
2004	0.5245	0.0081	0.2775	0.0022	0.0953	0.9076
2005	0.5151	0.0080	0.2790	0.0022	0.0956	0.8999
2006	0.5099	0.0079	0.2800	0.0022	0.0961	0.8961
2007	0.5075	0.0079	0.2795	0.0022	0.0963	0.8933
2008	0.5062	0.0078	0.2788	0.0021	0.0960	0.8909
2009	0.5051	0.0078	0.2781	0.0021	0.0968	0.8899
2010	0.5040	0.0078	0.2775	0.0021	0.0966	0.8880

Note: Since the ecological capacity of energy land is 0, it is not listed in Table 4.

Table 4. The equivalence factors and yield factors [4]

	Cropland	Pasture	Forestry	Fisheries	Construction land
Equivalence Factor	2.8	0.5	1.1	0.2	2.8
Yield Factor	1.66	0.19	0.91	1	1.66

been rapidly increasing during the 11 years. Therefore, there is a close relation between the ecological deficit and the excessive consumption of energy. Moreover, the increase of population, the decrease of cropland, pasture and water, and the increase of construction land all resulted in the increase of per capita ecological footprints. Accompanied by the decrease of ecological capacity, the ecological deficits keep growing. Therefore, we can conclude that from 2000 to 2010, Shaanxi was in an unbalanced and unsustainable mode of development, and such condition is getting worse.

During the calculation of annual per capita ecological footprints, we didn't consider the consumption of fruits and wood, thus the footprints calculated for cropland and forestry are smaller than actual numbers. Meanwhile, the areas of fisheries for some of the years were deduced from available data of other years during the calculation of ecological capacity. These factors would cause deviations from the actual ecological deficit/surplus. However, the deviation does not significantly impact the determination of whether the ecological development in Shaanxi is sustainable.

5 Discussion

The calculations and analyses presented in this paper demonstrated that the economic social development mode of Shaanxi is unsustainable and the ecological environment is in a dangerous status. To maintain the sustainable development of this region, it is necessary to reduce ecological deficits, reduce ecological footprint and improve ecological capacity. Existing studies showed that the more economically developed a region is, the greater its ecological footprints. With economic development, the ecological footprint in Shaanxi is likely to continue increasing. In order to keep the pressure on nature from exceeding the threshold of the ecological environment and maintain sustainable development, it is crucial to reduce the ecological deficits. For such situation, we propose three types of countermeasures based on Wackernagel model, including adopting high-tech to improve the productivity of unit natural system, utilizing available resource reserves efficiently, and controlling the population in order to reduce consumption and change people's production and living and consumption styles in order to establish resource-saving social production and consumption system.

These three measures are fundamental for reducing ecological deficits, and they can be applied for any regions, however different regions should come up with more practical solutions and measures based on their own situations. The ecological condition under the original economic pattern of Shaanxi can no longer satisfy the demands of the rapidly developing society and economy. To ensure sustainable development, more practical solutions should be formulated for Shaanxi on the basis of these three ecological deficit-reducing measures. Based on existing studies, five measures can be adopted in Shaanxi. First, use high-tech to improve the productivity of unit natural ecological system. With the help of high-tech, we can prevent the per capita ecological capacity from decreasing drastically because of population increase and cropland decrease. Second, use available resources efficiently. Currently, China's energy consumption of unit product is about 50 % to 70 % higher than the ones of developed countries, and the energy consumption of unit GDP is 318 times of global average. Third, control the population and reduce per capita consumption, change people's production, living and consuming styles, and build a resource-saving social production and consumption system. Limited resources decided that the ecological capacity is also limited, and the increasing population and enjoyment-pursuing lifestyles will continuously increase ecological footprints. Fourth, enforce the current resource protection measures and reduce cropland loss. The decrease of cropland in Shaanxi over the past half century was also an important reason for the increase of ecological deficits. In particular, in the loess hilly-gully region of northern Shaanxi, the

Weibei gully region of Loess Plateau, and the hilly region of southern Shaanxi, soil erosion has been the primary reason for cropland decrease. Fifth, develop circular economy, find ways to recycle and reuse wastes and intermediate products in order to tap the potential of resources and energy. For Shaanxi, a province with large population and limited resources, implementing these measures will help reduce the pressure human being pose on nature, reduce ecological deficits and gradually realize sustainable development.

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