Dynamic Change of Ecological Footprint in Xingtai City in the Years 2003 - 2009

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Abstract Quantitative estimation of the ecological footprint in Xingtai City in the years 2003 - 2009 is carried out by using the Ecological Footprint Model and the Time Series. Result shows that the per capita ecological footprint demand increases in Xingtai City from the year 2003 to 2009; and land use for energy shows a significant increase, accounting for the maximum proportion in per capita ecological footprint demand. Per capita ecological footprint supply gradually decreases. Ecological supply provided by cultivated land occupies the greatest proportion in the supply of per capita ecological carrying capacity, which is the main factor determining the supply of ecological carrying capacity in Xingtai City. In the years 2003 - 2009, ecological footprint of Xingtai City is at the state of ecological deficit. This indicates that the economic and social development of Xingtai City is based on the over-exploitation of resources, especially the cultivated land and energy land. Thus, the development mode of Xingtai City has already been in a state of unsustainable development. Based on this, corresponding countermeasures are put forward for the sustainable development in future, so as to implement the healthy control of the sustainable development in Xingtai City, China.

Key words Ecological footprint, Ecological carrying capacity, Sustainable development, Xingtai City, China

Ecological Footprint Theory is put forward by the Canadian scholars Ree and Wackernagel in the year 1992[1], which analyzes the relationship between human development and ecological environment from a new point of view. This method turns the regional resources and energy consumption into various biological productive areas (ecological footprint demand) necessary for material flow, and compares it with the biological productive area provided by regions (ecological carrying capacity or ecological footprint supply). Thus, whether the development of a region is within the range of ecological carrying capacity is quantitatively analyzed, so as to accurately assess the status of regional sustainable development[2-9]. Population, resources, ecology, and environment of Xingtai City are facing serious challenges. And correct understanding and positioning of its sustainable development status are needed in order to put forward reasonable measures and to provide a scientific basis for the ecological construction.

1 Data sources and research method

1.1 General situation of research region Xingtai City (113°52′ - 115°49′E, 36°50′ - 37°47′N) is located in the southern part of Hebei Province with its total area of 12 486 square kilometers. Xingtai City connects Shandong Province in the east, Shanxi Province in the west, Handan City in the south and Shijiazhuang and Hengshui Cities in the north. The length of the city from east to west is about 185 kilometers and the width from south to north is about 80 kilometers. The municipal government of Xingtai City is 106 kilometers from Shijiazhuang City and 396 kilometers from capital Bejing[10].

1.2 Data source Research data are mainly from the *Statistics Bulletin of the National Economic and Social Development of Xingtai City* (2009)[11], *Hebei Statistical Yearbook* (2003 - 2008)[12], *Hebei Economic Yearbook* (2003 - 2009)[13] and *China Statistical Yearbook* (2003 - 2009)[14].

1.3 Research method Ecological Footprint refers to the areas of productive land and water area needed by the population in a certain area, and the land to absorb the wastes produced by these population[15]. Difference between the ecological footprint (demand of the ecological carrying capacity) and the supply of ecological carrying capacity represents the relationship between the human production and consumption activities and the ecological carrying capacity in a region. When the consumption of ecological footprint exceeds the supply of ecological footprint in a region, there will be ecological deficit, which indicates that the ecological load of this region exceeds its ecological carrying capacity. Thus, the development mode of this region is at the unsustainable state, and the value indicates the unsustainable degree. When the consumption of ecological footprint is smaller than the supply of ecological footprint in a region, there will be ecological surplus, which indicates that the ecological carrying capacity of this region is enough to support the ecological load; and the development mode of this region is relatively sustainable.

According to the differences in land productivity, biological productive land in the world is divided into 6 types by the method of Ecological Footprint, such as fossil energy land, cultivated land, grassland, woodland, construction land and water area[16].

When calculating the ecological footprint of fossil energy land, rate of global average land productivity put forward by Wackernagel is adopted. When calculating the ecological footprints of cultivated land, grassland, woodland and water area, global equilibrium outputs of crop, livestock, forest product and aquatic product of per capita land published by FAO are taken

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as the references. Equivalent factor data published by the World Nature Fund are adopted, such as cultivated land 2.11, grassland 0.47, woodland 1.35, water area 0.35, energy land 1.35, and construction land 2.11[17-18]. Yield factor uses the value obtained by Wackernagel: cultivated land 1.66, grassland 0.19, woodland 0.91, water area 1.00 and energy land 0.

Calculation equation of ecological footprint is[19-21]:

$$EF = Nef = N\sum_{i=1}^{n}(r_i c_i / p_i) \quad (1)$$

where *EF* is the overall ecological footprint of a region, *N* is the overall population of the region, *ef* is the regional per capital ecological footprint, *i* is the type of input and consumption products, r_i is equilibrium factor, c_i is the per capita consumption of the *i*th commodity, and p_i is the world average production capacity of the ith consumption commodity.

Ecological carrying capacity is the number of biological productive land within the region, its equation is

$$EC = Nec = N\sum_{j=1}^{6}(a_j r_j / y_j) \quad (2)$$

where *EC* is the overall ecological carrying capacity of a region, *N* is the overall population of the region, *ec* is the regional per capital ecological footprint, *j* is the type of regional biological productive land, a_j is the per capita biological productive land in the region, r_j is equilibrium factor, and y_j is yield factor.

Finally, the calculation result of ecological footprint is compared with that of ecological carrying capacity. If ecological footprint is greater than ecological carrying capacity, there is ecological deficit, which is not conducive to sustainable development. If ecological footprint is smaller than ecological carrying capacity, there is ecological surplus, which is conducive to sustainable development. Difference between the ecological footprint and the ecological carrying capacity of research objective can reflect the status of sustainable development and is the most direct application of ecological footprint model.

2 Result and analysis

2.1 Per capita ecological footprint of Xingtai City in the years 2003 – 2009 According to the original data, ecological footprints of biological resource and energy consumption in Xingtai City are calculated in the years 2003 – 2009 based on equations (1) and (2). Through the adjustment of equilibrium factor, Table 1 reports the per capita ecological footprint and the proportion of component structure of biological productive land types in Xingtai City in the years 2003 – 2009.

Table 1 The per capita ecological footprint and the proportion of component structure in Xingtai City in the years 2003 – 2009

Year	Cultivated land		Grassland		Woodland		Water area	
	Ecological footprint//hm²	Proportion %	Ecological footprint//hm²	Proportion %	Ecological footprint//hm²	Proportion %	Ecological footprint//hm²	Proportion %
2003	0.499	26.742	0.680	36.442	0.040	2.144	0.011	0.589
2004	0.497	24.507	0.705	34.763	0.041	2.022	0.009	0.444
2005	0.533	22.964	0.724	31.193	0.042	1.81	0.009	0.388
2006	0.546	25.115	0.749	34.453	0.044	2.024	0.009	0.414
2007	0.56	25.854	0.476	21.976	0.044	2.031	0.009	0.416
2008	0.574	27.797	0.5	24.213	0.046	2.228	0.008	0.387
2009	0.573	27.779	0.523	25.383	0.047	2.265	0.008	0.378

Year	Energy land		Construction land		Per capita ecological footprint	
	Ecological footprint//hm²	Proportion %	Ecological footprint//hm²	Proportion %	Ecological footprint//hm²	Proportion %
2003	0.632	33.869	0.004	0.214	1.866	100
2004	0.771	38.018	0.005	0.247	2.028	100
2005	1.008	43.43	0.005	0.215	2.321	100
2006	0.82	37.718	0.006	0.276	2.174	100
2007	1.071	49.446	0.006	0.277	2.166	100
2008	0.932	45.133	0.005	0.242	2.065	100
2009	0.907	44.01	0.004	0.184	2.062	100

Table 1 indicates that in the years 2003 – 2009, per capita ecological footprint demand of Xingtai City shows a generally upward trend. In the year 2005, per capita ecological footprint reaches its maximum value, because in this year, the per capita ecological footprints of both grassland and energy land are relatively great. At the same time, it can be seen that when the ecological footprint of energy land increases in a certain year, per capita ecological footprint also enhances at the same year. When ecological footprint of energy land decreases in a certain year, per capita ecological footprint also falls at the same time. This shows that there are very close correlation between the ecological footprint and the energy land in Xingtai City. Besides, grassland and cultivated land have relatively great proportions. Proportion of these three land uses reaches more than 97%, while that of woodland, construction land and water area is relatively small, indicating that consumption of Xingtai City is concentrated in energy, grain, vegetable, meet, egg, and milk, which is consistent with the actual local situation. Since Xingtai City has developed iron and steel industry and their related industries, naturally it needs a lot of coal consumption.

2.2 Ecological carrying capacity of Xingtai City in the years 2003 – 2009 There are certain differences among the productive forces of the same biological productive land in different regions. Therefore, the actual areas of the same type of biological productive land in different regions can not be compared directly. When calculating the ecological carrying capacity in a region, yield factor should be introduced in order to transfer the same type of biological productive land in different regions into parameters of comparable areas. At the same time, according to the suggestion of the World Commission on Environment and Development, a total of 12% biological productive land area should be saved in order to protect the biodiversity. Thus, the ecological carrying capacity can be utilized actually is the deduction of area for biodiversity protection from the overall ecological carrying capacity[10 –12]. Table 2 reports the per capita ecological carrying capacity and the structure proportion in Xingtai City in the years 2003 –2009.

Table 2 Per capita ecological carrying capacity and the structure proportion in Xingtai City in the years 2003 –2009

Year	Cultivated land		Grassland		Woodland	
	Ecological footprint // hm^2	Proportion %	Ecological footprint // hm^2	Proportion %	Ecological footprint // hm^2	Proportion %
2003	0.340 08	79.495	2.27E-07	5.31E-05	0.025 10	5.867
2004	0.337 77	79.496	2.27E-07	5.34E-05	0.024 93	5.867
2005	0.333 97	79.471	2.27E-07	5.40E-05	0.024 64	5.863
2006	0.330 81	79.181	2.27E-07	5.43E-05	0.024 50	5.864
2007	0.328 92	79.109	2.27E-07	5.46E-05	0.024 34	5.854
2008	0.326 85	79.100	2.27E-07	5.49E-05	0.024 16	5.847
2009	0.324 30	79.101	2.27E-07	5.54E-05	0.023 97	5.847

Year	Water area		Construction land		Biodiversity protection hm^2/people	Per capita ecological carrying capacity hm^2/people
	Ecological footprint // hm^2	Proportion %	Ecological footprint // hm^2	Proportion %		
2003	0.000 10	0.023	0.062 52	14.614	0.051 34	0.376 46
2004	0.000 10	0.024	0.062 09	14.613	0.050 99	0.373 90
2005	0.000 10	0.024	0.061 53	14.642	0.050 43	0.369 81
2006	0.000 11	0.026	0.062 37	14.929	0.050 13	0.367 66
2007	0.000 11	0.026	0.062 41	15.010	0.049 89	0.365 89
2008	0.000 11	0.027	0.062 09	15.026	0.049 59	0.363 63
2009	0.000 11	0.027	0.061 60	15.025	0.049 20	0.360 78

Table 2 reports that the per capita ecological carrying capacity of Xingtai City declines generally in the years 2003 –2009, with an annual average decrease of 0.26 hm^2/people. Among the structure proportion of per capita ecological carrying capacity, per capita ecological carrying capacity of cultivated land has the maximum proportion. In the years 2003 –2009, proportion of ecological carrying capacity of cultivated land shows a general downward trend, while that of construction land increases slightly. Woodland has relatively large proportion of ecological carrying capacity; and water area and grassland have extremely slight proportions of per capita ecological carrying capacity. Especially, the maximum proportion of grassland only reaches 0.000 055%.

2.3 Analysis of overall ecological deficit (surplus) Fig. 1 illustrates the status of ecological deficit (surplus) based on Table 1 and 2. In the years 2003 –2009, Xingtai City has been in a state of ecological deficit, reaching the minimum value at the year 2005. Variation tendency of ecological deficit is generally in accord with that of per capita ecological footprint. Therefore, ecological supply of Xingtai City decreases annually, when the ecological requirement further increases. According to the current development trend, ecological deficit will further increases. Xingtai City needs a large consumption of energy, which is an important factor determining the ecological footprints of Xingtai City. Moreover, there is no special reserved land for the absorption of CO_2 and other gases, which brings great pressure on the ecological system.

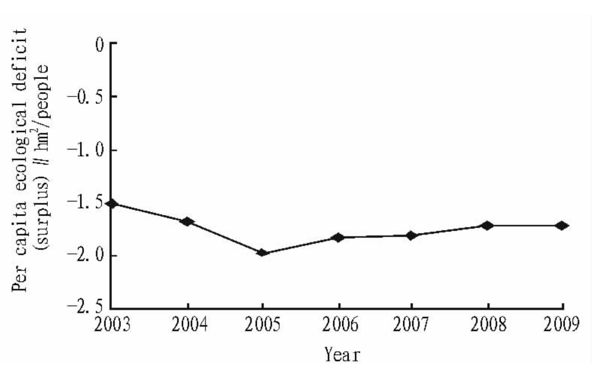

Fig. 1 Changes of ecological deficit (surplus) of Xingtai City in the years 2003 –2009

3 Conclusion and countermeasures

3.1 Conclusion Ecological footprint model is an idea tool to measure the capacity of sustainable development, which intuitively shows the status of sustainable development in a region. Quantitative calculation of the per capita ecological footprints in Xingtai City in the years 2003 –2009 is carried out by ecological footprint model. And we obtained the following conclusions. Firstly, requirement of per capita ecological footprint increases in Xingtai City in the years 2003 –2009; energy land shows the most significant increase, accounting for the maximum proportion in the requirement of per capita ecological footprint, which is an important factor determining the change of ecological footprint. Secondly, in the years 2003 –2009, supply of per capita ecological footprint (ecological carrying capacity) in Xingtai City gradually decreases; ecological supply provided by the cultivated land accounts for the maximum proportion in per capita ecological carrying capacity, which is a major factor determining the supply of ecological carrying capacity in Xingtai City. Thirdly, in the years 2003 – 2009, Xingtai City is at the development status of ecological deficit and this state will continue, indicating that the economic and social development of Xingtai City is based on the cost of over-exploitation of resources. Particularly, the over-exploitation of cultivated land and energy becomes very serious. Thus, the development mode of Xingtai City has already been in a state of unsustainable development.

3.2 Countermeasures According to the causes for ecological deficit, measures for the sustainable development of Xingtai City are put forward, considering the development of regional economy and the stability of ecosystem.

3.2.1 Strictly controlling the population growth. Equation of per capita ecological footprints shows that overall population is an important radix for the calculation of ecological footprint and ecological carrying capacity. Therefore, we must resolutely implement the basic national policy of family planning, reduce the birth rate and overall population, improve the ecological carrying capacity, lower the per capita ecological footprint and ecological deficit, and achieve the coordinated development between population and economy, society, resource and environment.

3.2.2 Improving the utilization rate of resources. We should enhance our scientific and technological level, and actively apply the high and new technologies in the production and life, in order to improve the utilization rate of resources. At the same time, we should improve the living standards of people, change their consumption idea and the way of living, set the scientific concept of development, and adopt the intensive, efficiency and economization-based development mode of circular economy[22–23].

3.2.3 Maintaining the dynamic balance of cultivated land. Government should carry out the overall land use planning from macroscopic perspective, strictly control the scale of non-agricultural construction land, actively protect the biological productive land, strengthen the management of land resources, carry out land consolidation and rehabilitation, increase land reserve resources, strengthen the management of construction land, encourage farmers to live in towns and cities, promote the industries to set up in industrial parks, conscientiously implement the policy of cultivated land, and realize the dynamic balance of cultivated land resources[19].

3.2.4 Enhancing the biological production per unit land area. Under the unchanged area of biological productive land, greater financial investment in science and technology leads to higher technological development level, and greater regional biological productivity and ecological carrying capacity. Therefore, government should develop high-efficiency agriculture according to local conditions, improve the productivity of agricultural labor forces, enhance regional biological productivity, and reduce ecological deficit.

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show clearly the that rural environment in hilly area in Sichuan Province is influenced by four factors, mainly livestock and poultry breeding, followed by crop planting, rural life, and township enterprise production. Currently, the industrial development direction determined by counties (cities, districts) in the hilly area is " laying stress on two traditional advantageous industries, *i. e.* crop planting and animal husbandry, and striving to develop typical township enterprises, mainly labor force-intensive agricultural product processing enterprises". It can be seen that the above four factors are closely linked to the degree of influence to rural environment and the development direction of regional rural economy. With the improvement of rural economic activity and rural economic level, the degree of influence will be further increased.

3 Conclusion and suggestions

3.1 Conclusions The study on rural environmental problem is a dynamic process. The environmental pollution of countryside in the hilly area in the upper reaches of Yangtze River, typically the hilly area in Sichuan, is caused mainly by livestock and poultry breeding, followed by crop planting rural life, and township enterprise production. Therefore, future pollution prevention and control should set about from livestock and poultry breeding. Meanwhile, attention should also be paid to prevention and control of rural environmental pollution caused by rural life and township enterprise production.

3.2 Suggestions In the first place, the key to preventing the environmental pollution caused by crop planting is to have a good command of crop planting technologies, which fit for regional actual situation, *e. g.* optimal cropland nutriment technology and agricultural water and soil conservation technology, *etc.*. The central feature of these technologies is to help farmers use fertilizers and pesticides scientifically according to standards, increase the degree of precision of cropland nutriment management, put in production factors purposely, improve fertilizer and pesticide utilization efficiency rate. The use of poisonous and residue-prone should be prohibited or restricted and great efforts should be made to develop highly-effective, low-toxicity, and low-residual pesticides and take biological prevention and treatment measures so as to reduce the influence on environment.

In the second place, the key to preventing the environmental pollution caused by rural life is to research and develop economical, suitable, and environmental-friendly rural life facilities and technical systems, *e. g.* regional characteristic garbage collector, highly-effective low-pollution kitchen stoves, clean fuels, *etc.*. The essential feature of these technologies is to reduce or even avoid life pollutants before occurrence of pollution so as to strive to prevent the environment from being polluted as much as possible.

In the third place, a common means used to preventing the environmental pollution caused by livestock and poultry breeding is to design matching biogas and research, develop and popularize eco-made technologies, such as, " one pool, three changes", " four in one", *etc*, so as to prevent pollution effectively.

In the forth place, the key to prevent the environmental pollution caused by township enterprise production is to research and develop necessary waste gas filtering equipment and waste water treatment system, *etc*, according to such enterprises' discharge capability so as to prevent pollutants from entering soil and water in the process of production and reduce or even avoid occurrence of pollution.

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