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Article

Ecological Footprint of Biological Resource Consumption in a Typical Area of the Green for Grain Project in Northwestern China

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Abstract: Following the implementation of the Green for Grain Project in 2000 in Guyuan, China, the decrease in cultivated land and subsequent increase in forest and grassland pose substantial challenges for the supply of biological products. Whether the current biologically productive land-use patterns in Guyuan satisfy the biological product requirements for local people is an urgent problem. In this study, the ecological footprints of biological resource consumption in Guyuan were calculated and analyzed based on the 'City Hectare' Ecological Footprint (EF) Method. The EFs of different types of biological resource products consumed from different types of biologically productive land were then analyzed. In addition, the EFs of various biological resource products before and after the implementation of the Green for Grain Project (1998 and 2012) were assessed. The actual EF and bio-capacity (BC) were compared, and differences in the EF and BC for different types of biologically productive lands before and after the project were analyzed. The results showed that the EF of Guyuan's biological resource products was 0.65866 ha/cap, with an EF outflow and EF inflow of 0.2280 ha/cap and 0.0951 ha/cap, respectively. The per capita EF of Guyuan significantly decreased after the project, as did the ecological deficit. Whereas the cultivated land showed a deficit, grasslands were characterized by ecological surplus. The total EF of living resource consumption in Guyuan was 810,941 ha, and the total BC was 768,065 ha. In additional to current biological production areas, approximately 42,876 ha will be needed to satisfy the demands of Guyuan's people. Cultivated land is the main type of biologically productive land that is needed.

Keywords: biological resource consumption; Ecological Footprint (EF); bio-capacity (BC); the Green for Grain Project; Guyuan City

1. Introduction

With the rapid industrialization and population growth of China, the most urgent environmental problems arise from increasing volumes of nationwide production, consumption, and the associated use of natural resources. The Ecological Footprint (EF), a quantitative measure of human utilization of natural resources, is a function of population and the per capita consumption of biologically productive land area. Comparing the EF with the area of biologically productive land can help determine the level of sustainable development of a country or region [1–4] and contribute to a reasonable and effective model for the sustainable utilization of human resources while meeting living requirements. Since Rees and Wackernagel introduced the concept of EF and its specific calculation methods, the theory and methods of EF have been applied at many different scales, such as countries, regions and cities [5–11]. However, most researchers have only accounted for a total population of a nation or local city's EF at the macro-scale and compared different regions; relatively less consideration of EF consumption has been given to resources at the micro-scale (city or county). Collins *et al.* analyzed EF in the capital city of Wales, Cardiff, for example, to examine the environmental impacts of resource consumption at a subnational level and for different socioeconomic groups, and the results showed that lifestyles and consumption decisions in large part impacted the EF [12]. Scotti *et al.* modified the EF calculation scheme to discuss sustainability in the municipality of Piacenza (northern Italy) according to different aspects of local activities, such as industry, agriculture, tertiary sectors, and others [6]. Kissinger *et al.* used data regularly collected from several cities as a proxy for material consumption to analyze urban ecological footprints [13]. Zhang *et al.* presented the 'city hectare' EF accounting method, based on the EF basic theory applied in global hectare models, and calculated the ecological footprint of one county [14]. Most previous studies mainly calculated and analyzed the EF of the biological resources and energy at the micro-scale; fewer have studied the EFs of biological resources or energy separately to clarify the structure of EF consumption. Thus far, research on the EFs of the consumption of biological resources in China is rare, except for studies by Hu *et al.* and He *et al.* who investigated the EFs of biological resources within a city circle [15,16].

The definition of biological resources (bio-resources) is the sum of all living organisms used by humans, which usually refers to plants, animals, and microorganisms [17]. The biological resource consumption of Guyuan mainly includes the following categories of agricultural products: (1) food and cooking oil; (2) vegetables; (3) meat and eggs; (4) aquatic products; (5) fruit; and (6) firewood. In addition, cultivated land, grass, forest, and water bodies are the four major types of bio-resource production lands. Determining the EFs of Guyuan's biological resource consumption has important practical significance for land clearing and enhancing the management and utilization of biological resources.

The first systematic attempts to calculate the EF and bio-capacity (BC) of nations began in 1997 [1]. Building on these assessments, the Global Footprint Network initiated its National Footprint Accounts (NFA) program [18], whose methodology has been continually evolving as researchers have attempted to improve it. A component approach, an input-output method, and an energy method have all been proposed [13,19–24]. The NFA and energy method are most commonly used. The energy EF method transforms a given energy source; such sources are usually of different categories and are difficult to directly convert into a unified solar value. However, this method cannot reflect the actual level of productivity and efficiency of resource use under spatial and temporal conditions. In addition, because the method also considers the bio-capacity of all land, it is unable to distinguish the carrying capacity of different land types [25–27]. The NFA measure is based on the assumption that the Earth's regenerative capacity is the limiting factor for the human economy in times when human demand exceeds the biosphere's ability to replace resources. The NFA uses the world average productivity and the corresponding 'equivalence factor' and 'yield factor,' which are used to scale the contribution of each single land use type so that values can be summed to calculate the EFs [5–11]. This approach uses a global research scale, but it is suitable for application at the national level. For smaller scales (e.g., provinces, cities, and counties), the NFA cannot accurately reflect the actual productivity and regional characteristics of development [28,29]. In this paper, we attempted to use the regional (province or city) average productivity and the corresponding 'equivalence factor' and 'yield factor' to calculate the regional (city or county) footprint [14]. This estimate can more accurately reflect the regional endowment and resource utilization. In addition, it is useful to compare the EFs and BC of different land types at the regional scale, which more truly reflects the utilization of different biologically productive land types.

Since the implementation of the Green for Grain Project in 2000 in Guyuan, large areas of forest and grass vegetation have been restored and the ecological environment has been markedly improved [30]. However, the land use structure has undergone tremendous changes in the area, and cultivated land has decreased while forest and grassland increased. In 2004, the land requirement of grains consumption (per capita) in Guyuan was 1041 m^2; the total of potato, vegetable, and fruit consumption accounted for 203.9 m^2, and plant oil consumption accounted for 159.2 m^2. The land requirement for these three types of food consumption accounted for approximately 92.4% of the total land requirement per capita, in which grain, as the largest category of food consumption, had the largest land requirement. Thus, arable land was the main land requirement type for food production [31]. The decrease in cultivated land under the Green for Grain Project has posed substantial challenges for Guyuan's food security. Whether the current land use structure and area of biological production can satisfy the land requirements of Guyuan has become an urgent issue that must be addressed.

The objectives of this studies were (1) to estimate, based on the EF method using local equivalence and yield factors, the EFs of biological resource consumption from the current production (local production), sales of products (outflow), and purchased products (inflow) in Guyuan; (2) to assess the EFs of various biological products before and after the Green for Grain Project; and (3) to compare the final actual EFs and bio-capacity (BC) and analyze the differences in the EFs and BC in different biologically productive lands before and after the project.

2. Study Area and Research Methods

2.1. The Study Area

The case study region of Guyuan is located in the center of the Loess Plateau in the southern part of the Hui autonomous region of Ningxia. Elevations range from 1248 to 2942 m above mean sea level, and the region consists of Pengyang County, Xiji County, Jingyuan County, Longde County, and Yuzhou District (Figure 1). In 2012, the area had a population of 1.54 million, including a rural population of 1.27 million, representing 82.55% of the total population. The region has a continental monsoon climate, characterized by annual rainfall from 260 to 625 mm and an annual average temperature of 5.7 °C and ranging between −22 and 28 °C. The total land use area is 1.13 million ha, of which cultivated land constitutes 355,000 ha, forest is 311,000 ha, and grassland is 221,400 ha, accounting for 31.45%, 27.56%, and 19.62% of the total, respectively. Cultivated land, forest, and grassland comprise the three main land-use types of Guyuan. These lands are mainly used for the cultivation of wheat, maize, potato, beans, oil-producing plants such as oilseed rape, and a range of vegetables and fruit trees, and for breeding pigs, cattle, sheep and poultry. In 2012, the agricultural output value of Guyuan was 4.91 billion Yuan, the forest output value was 411 million Yuan, and the output value of animal husbandry was 2.10 billion Yuan. Agriculture occupied a leading position in the rural economic structure.

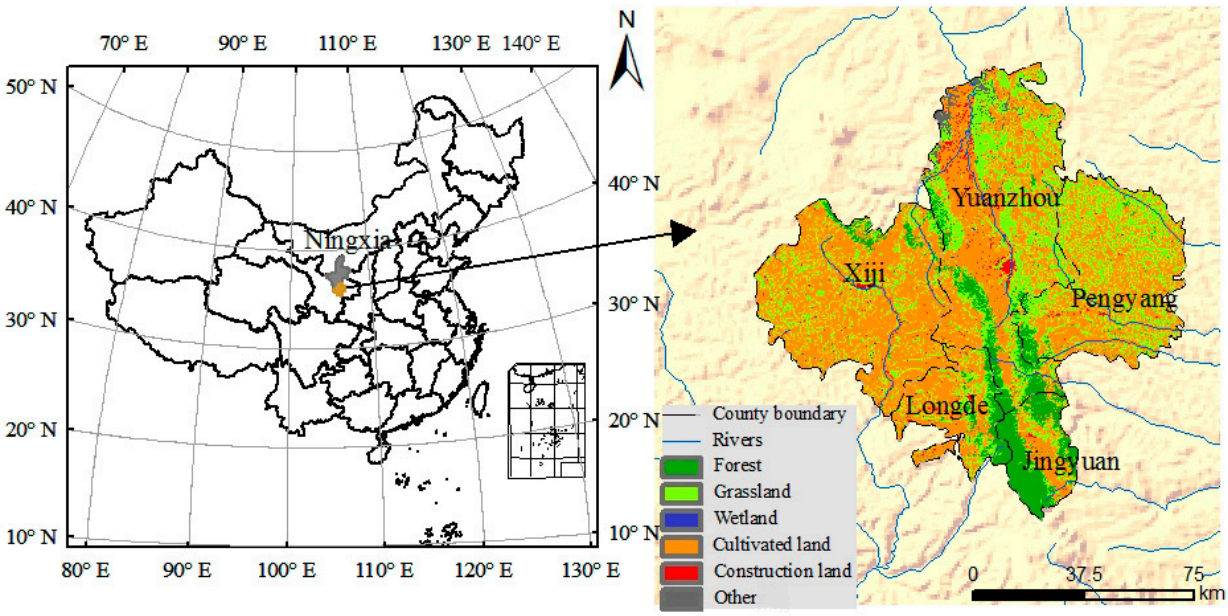

Figure 1. The location and land-use map of Guyuan.

2.2. Research Methods and Data Collection

In this study, the EF (from a single individual to that of a whole city or a country) is the total area of biologically productive land occupied to produce the resources and services consumed by the local population [1,5] and incorporates impacts of the population on the environment to assess sustainability under the prevailing technology and consumption conditions. The compilation of such accounts starts from a population's resource consumption (city or domestically harvested resources plus imports minus exports) expressed in mass flows (tons per year) [32]. These physical flows are then converted into area equivalents, expressed in the unit of so-called 'city hectares' (hectares with a city's average biological productivity). In this paper, we focus on the EF of biological resources, using the same approach for each of the four major land types: cultivated land, grass, forest, and water bodies. For the 'city hectare' EF accounting, the specific calculation formula of biological resource consumption in Guyuan is as follows [14,29]:

$$EF = N \times (ef) = \mathrm{N} \times [\sum r_j(\frac{C_i}{Y_i}) = \sum r_j(P_i + I_i - E_i)/(Y_i \times N)]\ (j = 1,2,3,\ldots 4), \quad (1)$$

where i is the type of biological product in Guyuan; j is the type of biologically productive land in Guyuan (e.g., cultivated land, forest, grassland, or water body); EF is the total ecological footprint of Guyuan; ef is the per capita ecological footprint, in ha/cap; N is the population of Guyuan; r_j is the equivalence factor for biologically productive land of j in Guyuan, which is a scaling factor needed to convert a specific land-use type into a universal unit of biologically productive area (city hectare); c_i is the per capita consumption of biological product i in Guyuan, in kg/cap; Y_i is the average yield of biological product i in Guyuan, in kg/ha; P_i is the annual production (namely, harvested resources) of biological product i in Guyuan, in kg; I_i is the annual outflow (exports) of biological product i in Guyuan, in kg; and E_i is the annual inflow (imports) of biological product i in Guyuan, in kg. In addition,

$$r_j = \frac{k_j}{K} = \frac{Q_j}{S_j} / \frac{\sum Q_j}{\sum S_j} = \frac{\sum_i (p_i^j \times \gamma_i^j)/S_j}{\sum_j [\sum_i (p_i^j \times \gamma_i^j)] / \sum S_j} \quad (2)$$

where k_j is the average ecological productivity of biologically productive land j in Guyuan, in kJ/ha; K is the average ecological productivity of all types of biologically productive land in Guyuan, in kJ/ha; Q_j is the total biomass of biologically productive land j in Guyuan, in kJ; S_j is the biologically productive area of biologically productive land j in Guyuan, in ha; p_i^j is the annual production of biological products i in biologically productive land j in Guyuan, in kg; and γ_i^j is the calorific value of biological product i in biologically productive land j in Guyuan, in kJ/kg. Because the average productivities of different biological products in a variety of biologically productive land are not identical, and directly summing them will reduce the overall equation's scientific rationality [25], the equilibrium factor accounting transforms the biological product into a unified form of calorific value.

The BC for the population is the number of hectares of each of the four bio-productive land categories in the area under study [1,5]. Not all of that space is available for human use, as this area should also provide habitat for the other species with which humanity shares this planet. According to the latest Footprint 2.0, which was developed by Venetoulis *et al.* at Redefining Progress (http://www.ecologicalfootprint.org/FAQ.html#how), at least 13.4% of the ecological capacity, representing all ecosystem types, should be preserved for biodiversity protection. The specific calculation formula of bio-capacity in Guyuan is as follows [14,29]:

$$BC = N \times (bc) = N \times (a_j \times r_j \times y_j)\ (j = 1,2,3,\ldots 4) \quad (3)$$

where BC is the bio-capacity for the population in Guyuan (EF supply); bc is the per capita bio-capacity, in ha/cap; a_j is the per capita area of biologically productive land of type j in Guyuan; r_j is the same as in Formula (1); and y_j is the yield factor for biologically productive land of type j in Guyuan, which is the ratio of the county average to city average yields. A scaling factor is used to convert from local to average bio-productive land requirements and reflects the average productivity differences of certain types of land in different counties and cities within the scope of the city. Because we only assessed the bio-capacity of Guyuan and have not analyzed the differences between different counties in this paper, the yield factor in this paper is '1'.

The calculation of EF and BC in Guyuan provided a quantitative basis for determining whether Guyuan's production and consumption activities were within the carrying capacity of the local ecosystems, which, as a result of the human consumption of resources in the region, have been incorporated into the city area and have the same ecological productivity level as the broader regional area. If EF exceeds BC, an ecological deficit (ED) exists and the system is considered unsustainable regionally. Conversely, the system is considered sustainable if there is an ecological reserve (EF < BC).

In this study, the data are mainly from the *Ningxia Statistical Yearbook 2013*, China's first agricultural census in the Ningxia Repertory. Firsthand data were also obtained from the farmers' questionnaire of August 2009; altogether, 234 questionnaires were collected, with a validation rate of 99%. The average productivity of biological products in Guyuan after the Green for Grain Project was calculated using statistical data from *The Handbook of Economy in Guyuan* in 2006. Due to lack of firewood statistical data, the average productivity of firewood in this study was cited from Liu's research [33]. Various units of calorific value of biological products were taken from *Agricultural Ecology* [34]. The raw data used to calculate the equivalence factors are provided in the appendix.

3. Results and Discussion

3.1. Specific Consumption Process of the EF of Biological Resources

Based on the 'City Hectare' EF method, the EFs of biological resource consumption from production, outflow, and inflow in Guyuan in 2012 (Table 1) were 0.65866 ha/cap, 0.2280 ha/cap, and 0.0951 ha/cap, respectively, and were mainly consumed from the cultivated land, grass, and forest. In addition to these three bio-productive land types, there was water space consumed in the EFs of bio-resources from production and inflow. In these three cases, the cultivated land's *EF* consumption was the largest at more than 86%; grassland accounted for the largest proportion of the outflow, and forest accounted for a large proportion of the production and the inflow. The calculations indicated that the EFs of living resource consumption were derived mainly from cultivated land and forest.

The EF of Guyuan was the sum of the bio-resource production's EFs and inflow EFs minus outflow EFs. The contribution of the bio-resource production's EF to the final consumption's EFs accounted for 81.91%, indicating that the EF was mainly used to meet the demand for bio-productive land for local people. The inflow of EF only accounted for 18.09% of the final consumption, and the EF of outflow exceeded that of inflow. This finding indicated that the inflow contributed little to the final EF consumption in the region, and local EF consumption is mainly from local production. With regard to the EF consumption of the four types of bio-productive land, most of the EF from the consumption of water space was derived from outside areas, except for a small part from the local supply, and the outside areas' inflow accounted for 96.43% of the actual water consumption. To a certain extent, the water body land-use type met the EF requirement in Guyuan City, but it affected the other region's

EFs and placed pressure on the EF requirements of other areas. By contrast, the sale of biological resource products in Guyuan City would relieve the EF requirements for cultivated land, grass, and forest of other areas.

Table 1. EFs of bio-resource production, sales of products, and purchased products in Guyuan in 2012 (ha/cap).

Biological Land Type	Per Capita Area	Equivalence Factor	Per Capita EFs	Proportion (%)
Per capita EF of biological resource production in Guyuan City				
Cultivated land	0.3304	1.84	0.6079	92.29
Grass	0.3607	0.10	0.0361	5.48
Forest	0.0215	0.68	0.0146	2.22
Water body	0.0003	0.19	0.00006	0.01
Total EF demand			0.65866	100
Per capita EF of sales of products in Guyuan City				
Cultivated land	0.1071	1.84	0.1971	86.45
Grass	0.3040	0.10	0.0304	13.33
Forest	0.0008	0.68	0.0005	0.22
Total EF demand			0.2280	100
Per capita EF of purchased products in Guyuan City				
Cultivated land	0.0463	1.84	0.0852	89.59
Grass	0.0416	0.10	0.0041	4.31
Forest	0.0045	0.68	0.0031	3.26
Water body	0.0144	0.19	0.0027	2.84
Total EF demand			0.0951	100

Notes: Because fruit and firewood data for 2012 in Guyuan were difficult to obtain, data from the 2008 Guyuan city rural household yearbook were substituted; the outflow and inflow of other biological resources were calculated by the ratio of production and outflow and the ratio of production and inflow.

3.2. EFs of Biological Products

3.2.1. EFs of Biological Products on Different Types of Biologically Productive Land

In the EFs of biological products from production, outflow, and inflow (Table 2), production was dominant, with food oils and meat and eggs making the greatest contribution, accounting for 90.16% and 82.33%, respectively. In addition to vegetables meeting the demands of Guyuan, approximately half (47.36%) flowed out to meet the needs of other regions. The outflow of these three types of products was greater than the inflow. For aquatic products and fruit, inflow was greater than outflow. These two categories of products were mainly derived from inflow from outside areas, which supplemented the market demand. The consumption of firewood was mainly from local production, and there were neither foreign inflows nor local outflow; most of the product was used to meet the demand for biofuels in the local area.

Table 2. The EFs of farmers' consumption of biological resource products in Guyuan in 2012 (ha/cap).

Types of Biological Resource Production	Food and Cooking Oil	Vegetables	Meat and Eggs	Aquatic Products	Fruit	Firewood
Production	0.4063	0.1003	0.1374	0.00005	0.0034	0.0112
Outflow	0.1297	0.0475	0.0503	0	0.0005	0
Inflow	0.0302	0.0405	0.0187	0.0027	0.0030	0
Per capita EF	0.3068	0.0933	0.1058	0.0028	0.0059	0.0112
Proportion (%)	58.36	17.75	20.12	0.52	1.12	2.13

The EFs of different biological products varied with different biologically productive land types. As shown in Figure 2, food oils and vegetables were the main EF consumption of arable land, and their proportions were 61.84% and 18.81%, respectively. The main products were wheat, corn, potatoes, beans, oil, vegetables, and melons. Because pig and poultry breeding rely mainly on food crops or products, part of the meat and eggs' production relied on arable land, and their proportion of the consumption of cultivated land was up to 19.35%. The EF of grassland is mainly accounted for by herbivorous animal product consumption, such as beef, mutton, and milk. Firewood and fruit mainly accounted for the EFs from forested land. The proportion of EF consumption of firewood accounted for 65.50%, and fruit accounted for 34.50% and included apples, pears, peaches, apricots, dates, and so on. The aquatic products' consumption accounted for the EF consumption of water, primarily from supplies from outside areas and a small amount of the local supply (see Table 2).

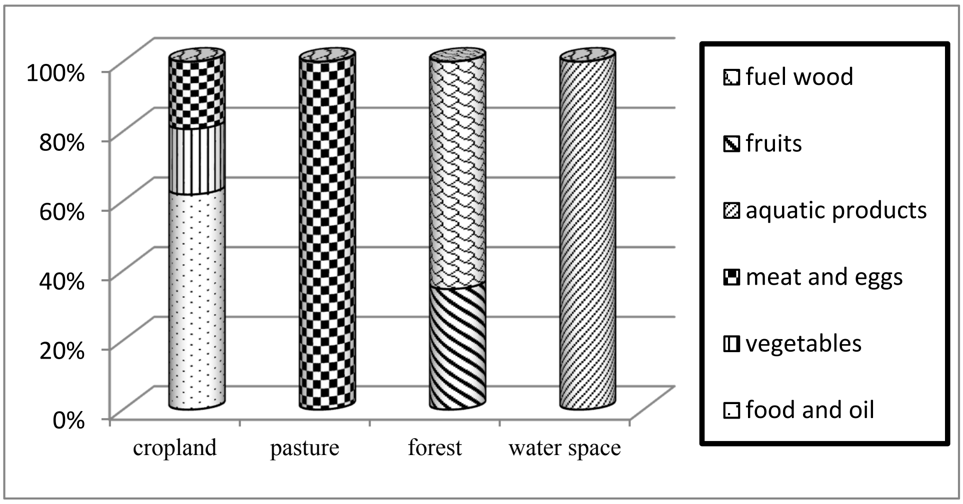

Figure 2. The ratios of the EFs from consumption of biological products in 2012.

3.2.2. The EF from Biological Production Consumption before and after the Green for Grain Project

By comparing the EFs from the consumption of different biological products between 1998 and 2012 (Figure 3), we found that the EF of Guyuan's biological products in 1998 (before the Green for Grain Project) was mainly meat and eggs and food oils (due to missing data, this figure includes only food), which made up 69.66% and 22.58% of the total EF, respectively. In 2012, after the implementation of the project, food oils contributed the most to EF (58.35%). The next highest contributors were meat and eggs (20.12%) and vegetables (17.75%). Various types of biological production consumption corresponded to demand for different land types [31]. After the implementation of the project in Guyuan, the arable land area in the region decreased and forested land area increased. When various types of land area changed, so did crop species and planting structure [35], which changed the overall consumption structure of biological products. As shown in Figure 3, the forested land area increased in the wake of the Green for Grain Project's grazing prohibition requirements. Because grass can only come from the cultivation of grassland farming, the EFs of meat and eggs (mainly on grassland) consumption significantly decreased. The stress on grasslands from people has been reduced to ensure the effectiveness of the implementation of the project and promote regional sustainable development. The widespread use of alternative energy sources, such as fossil fuels and electricity, and increases in firewood gathering time and cost have lowered willingness to use firewood. In recent years, a shifting trend in energy consumption has been observed in Guyuan, especially with regard to firewood and coal; although electricity consumption is relatively low, it is on the rise and rose significantly (400%) from 1999 to 2009 [36]. The EF of firewood consumption has been significantly reduced to a certain extent to protect the local woodlands. However, the use of natural gas, coal, and other fossil fuels increased CO_2 emissions to a certain extent. More forested land will be needed to absorb CO_2, which poses new pressures for local forest ecological carrying capacity. The widespread use of electricity and other renewable energy (such as solar or wind energy) may be more conducive to environmental sustainability and to ensure sustainable development in the future. We can see from Figure 3 that except for the food oils, the per capita EF of other biological resource products after returning farmland to forest (or grassland) was lower after the project than before. The total population of the area was reduced by 18.69% after the implementation of the project. The decline of population was an important reason for the decrease in EF [37].

(hm²/cap)	food and cooking oil	vegetables	meat and eggs	aquatic products	fruits	fuel wood
per capita EF in 2012	0.3068	0.0933	0.1058	0.0028	0.0059	0.0112
per capita EF in 1998	0.2222	0.0207	0.6855	—	—	0.0557

Figure 3. The EFs' percentage accumulation areas of various types of biological product consumption before and after the Green for Grain Project (1998 and 2012).

Notes: Because aquatic products and fruit data are difficult to obtain, "—" is used to express a lack of data.

3.3. Comparison of Supply and Demand of Biological Production's EFs before and after the Project

3.3.1. The Final EFs and BC of Bio-Resource Consumption before and after the Green for Grain Project

As shown in Table 3, we found that the per capita EF of bio-resources in Guyuan in 1998 (before the project) was 0.9841 ha/cap, the per capita BC was 0.6101 ha/cap, and the ED was 0.3739 ha/cap. The ED indicates that Guyuan's influence on the local natural ecosystem has already surpassed the local natural ecology threshold value, which includes ratios up to 61.29%. The per capita EF of bio-resource consumption in this area in 2012 (after the project) was 0.5258 ha/cap, the per capita BC was 0.4980 ha/cap, the per capita ED was 0.0278 ha/cap, and the ratio of ED was 5.58%. Comparing the data from before and after the project, we can see that the per capita EF since the implementation of the project has significantly decreased and the ED has been alleviated. Thus, the total final EF of bio-resource consumption in Guyuan in 2012 was 810,941 ha, and the total BC was 768,065 ha. There was still a need for 42,876 ha to meet the EF demand of biological resources in the area.

Table 3. The EFs and EC of consumption in Guyuan in 1998 and 2012.

EFs	**Biological Land Type**		**Cultivated Land**	**Grass**	**Forest**	**Waters**			
Demand of EFs	Per capita area (ha/cap)	1998	0.4821	0.5773	0.0993	—	The total EF		
		2012	0.2696	0.0983	0.0252	0.0147			
	Equivalence factor	1998	1.89	0.03	0.56	0.32			
		2012	1.84	0.10	0.68	0.19			
	Per capita EF (ha/cap)	**1998**	0.9112	0.0173	0.0556	—	**0.9841**		
		2012	0.4961	0.0098	0.0171	0.0028	**0.5258**		
Supply of EFs (BC))	Per capita area (ha/cap)	1998	0.3420	0.2714	0.0892	0.0002	The total supply area	The biodiversity protection	The total available area
		2012	0.2302	0.1436	0.2016	0.0003			
	Equivalence factor	1998	1.89	0.03	0.56	0.32			
		2012	1.84	0.10	0.68	0.19			
	Yield factor	1998	1	1	1	1			
		2012	1	1	1	1			
	Per capita BC (ha/cap)	**1998**	0.6464	0.0081	0.0499	0.0001	0.7045	0.0944	**0.6101**
		2012	0.4235	0.0144	0.1371	0.0001	0.5751	0.0771	**0.4980**

Notes: Because the land use data in 1998 were difficult to obtain, they have been replaced with 1996 data from China's first agricultural census in the Ningxia Repertory. The reservoir area was used as an alternative for the depletion of living resources of the waters in Guyuan. Where there is lack of water space, "—" is used. Based on the average productivity of Guyuan, the equilibrium factor was calculated and the yield factor was 1.

3.3.2. The Differences in EF and BC in Biologically Productive Land Types before and after the Green for Grain Project

Figure 4 shows that cultivated land was the main contributor to the EFs of biologically productive land consumption both before and after the Green for Grain Project. The contribution of cultivated land to the EFs was more than 90%. Taking into account supply and demand of various biologically productive land-use types' EFs, cultivated land, grass, and forest in 1998 were characterized by ecological deficits, of which the ratio of ED to grass is the highest (up to 147.14%), followed by cultivated land (approximately 62.77%) and forest (approximately 28.70%). In 2012, only arable land showed ED (0.1294 ha/cap), with a ratio of 35.29%. As one of the main land-use types in Guyuan, cultivated land was the basic resource for people's livelihood and still required 199,574 ha to meet the demand for land in the area. By contrast, the forest and grass land types both displayed ecological surpluses, for which the forest land value was 0.1016 ha/cap and the grassland value was 0.0027 ha/cap. In addition to meeting the local demand, the forest and grassland can also provide 160,862 ha of biological production land area to meet people's EF demands. After implementing the Green of Grain Project policies, widespread farmland in Guyuan was transferred to forest and grassland and the land space functions changed. Woodlands and grasslands play a special role in regulating the climate, conserving water and soil resources, blocking wind and fixing sediment, and maintaining biodiversity. The ecological functions of the forest and grasslands in Guyuan have been notably improved [38]. With the development of society, firewood has gradually been replaced by coal, natural gas, and other fossil fuels, and demand for firewood has decreased.

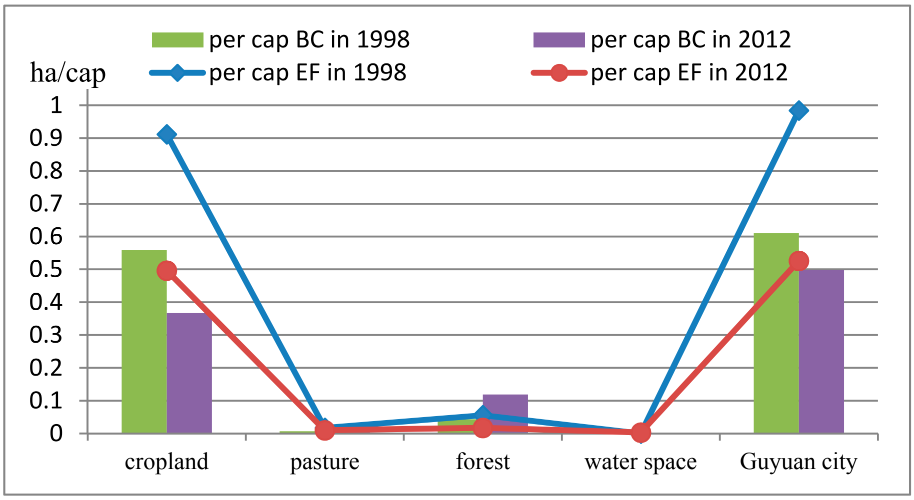

Figure 4. The EF and BC before and after the Green for Grain Project (1998 and 2012).

4. Conclusions

This study clarified the existing areas of bio-production in Guyuan and analyzed whether those lands can satisfy the demand for biological resource consumption (*i.e.*, the EF demands), contribute to sustainable land use and management, reduce the devastating impacts on natural environments, and maintain the achievements and effectiveness of the Green for Grain Project.

Concerning the specific consumption processes of the actual biological resources' EFs, the EF of the current (2012) consumption of locally produced biological products was the largest. The second highest was the EF consumption of purchased products, and the last was EF consumption of sales of products. In each of the above three cases, the EF of arable land made the greatest contribution (more than 86%), which includes biological products such as food and cooking oil, vegetables, and some meat and eggs. The total EF consumption of these three types of products accounted for 96.22% of the actual EFs. The consumption structure of biological products has substantially changed in this area since the implementation of the Green for Grain Project. Before the project, the main products consumed were meat and eggs, which changed to a balance of grain, vegetables, and meat and eggs after the project. Firewood consumption also greatly decreased after implementation of the project. The per capita EF after the project was less than before the project, which indicated the ratio of ED. Cultivated land was the most important bio-productive land type for ED. The development of Guyuan City is unsustainable. The best way to meet the needs of contemporary people that does not damage the ability of the next generation to meet its needs is to reduce the EFs, improve the BC, and keep the EFs of people within the threshold range. Guyuan could further improve its land resource utilization efficiency in an effort to reduce EFs with regard to production and management processes. Additionally, the city should strengthen the conservation of the environment and improve the biological supply capacity per unit land area.

In this study, we used the 'city hectare' ecological footprint calculation method to accurately reflect the status of resource utilization in Guyuan. However, due to a lack of spatial data from four counties and a district of Guyuan and different years of data, there is no smaller-scale regional spatial-temporal comparison in this area that clearly reflects the spatial-temporal differences of regional resource use. In addition, there are a number of deficiencies in the integrity of the data. There are some deviations in the supply and demand of EF analysis, which will be further improved in follow-up research.

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Author Contributions

Jie Hu executed the study, analyzed the data, and drafted the manuscript based on discussions with co-authors. Lin Zhen, listed as one of the co-authors, conceived the original idea and supervised the research and paper writing.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Table A1. Main biological production of Guyuan used to calculate the equilibrium factor in 2012.

Agricultural Products	Biomass (10^3 kg)	Caloric Value (10^3 J/kg)	Total Calories (10^6 J)	Land Categories
Wheat	190,378	16,138.98	3,072,506,734.44	Cropland
Barley	2526	16,205.86	40,936,002.36	Cropland
Other grains	2459	15,800.4	38,853,183.6	Cropland
Pea (broad bean)	24,615	17,138	421,851,870	Cropland
Other legumes	15,154	16,700	253,071,800	Cropland
Maize	119,266	16,444.12	1,961,224,415.92	Cropland
Millet	1043	15,800.4	16,479,817.2	Cropland
Oat	1877	15,800.4	29,657,350.8	Cropland
Buckwheat	6887	15,800.4	108,817,354.8	Cropland
Proso millet	11,780	15,800.4	186,128,712	Cropland
Potato	228,665	5,709.88	1,305,649,710.2	Cropland
Rapeseed	93	26,334	2,449,062	Cropland
Flaxseed	44,633	15,906.24	709,943,209.92	Cropland
Hempseed	611	21,766.43	13,299,288.73	Cropland
Helianthus	17,408	41,858.52	728,673,116.16	Cropland
Hemp	11	14,462.8	159,090.8	Cropland
Tobacco leaf	751	15,925.8	11,960,275.8	Cropland
Medical material	9655	17,263.4	166,678,127	Cropland
Vegetable	267,642	1463	391,560,246	Cropland
Melon	50,819	1,061.72	53,955,548.68	Cropland
Other crops	272,921	2,173.6	593,221,085.6	Cropland
Pork	15,205	25,038.2	380,705,831	Cropland
Beef	15,361	13,731.3	210,926,499.3	Grassland
Mutton	8971	13,731.3	123,183,492.3	Grassland
Poultry meat	2126	6,863.56	14,591,928.56	Cropland
Milk	4301	2,842.4	12,225,162.4	Grassland
Goat wool	40	5016	200,640	Grassland
Sheep wool	1148	5016	5,758,368	Grassland
Cashmere	5	5016	25,080	Grassland
Honey	643	20,958.52	13,476,328.36	Cropland
Egg	6715	8,790.54	59,028,476.1	Cropland
Pod (kg)	20,100	15,925.8	320,108,580	Cropland
Fruit	6642	3300	21,918,600	Cropland
Chinese wolfberry	9000	18,360	165,240,000	Forest
Nursery stock	201,705.4	16,744	3,377,355,217.6	Forest
Aquatic products	336	5450	1,831,200	Water body

Table A2. Productivity and equivalence factors of land in Guyuan in 2012.

Land Categories	Total Calories (10^9 J)	Total Land Area (ha)	Average Prolificacy (10^9 J/ha)	Equivalence Factor
Cropland	10,916,905.746	357,747.4	30.51568063	1.84
Forest	3,542,595.218	313,449.9	11.30194873	0.68
Grassland	352,319.242	222,108.4	1.586249136	0.10
Water body	1831.200	594	3.082828283	0.19
Area land	14,813,651.406	893,899.7	16.57193824	1.00

Table A3. Main biological production of Guyuan used to calculate the equilibrium factor in 1998.

Agricultural Products	Biomass (10^3 kg)	Caloric Value (10^3 J/kg)	Total Caloric (10^6 J)	Land Categories
Wheat	248,131	16,138.98	4,004,581,246	Cropland
Barley	2916	16,205.86	47,256,287.76	Cropland
Other grains	3760	15,800.4	59,409,504	Cropland
Pea (broad bean)	27,577	17,138	472,614,626	Cropland
Rice	1908	15,934.16	30,402,377.28	Cropland
Maize	163,480	16,444.12	2,688,284,738	Cropland
Millet	5089	15,800.4	80,408,235.6	Cropland
Jowar	540	15,800.4	8,532,216	Cropland
Buckwheat	5343	15,800.4	84,421,537.2	Cropland
Proso millet	17,012	15,800.4	268,796,404.8	Cropland
Soybean	1760	21,025.4	37,004,704	Cropland
Potato	172,571	5,709.88	985,359,701.5	Cropland
Rapeseed	185	26,334	4,871,790	Cropland
Flaxseed	36,056	15,906.24	573,515,389.4	Cropland
Hempseed	180	21,766.43	3,917,957.4	Cropland
Helianthus	5439	41,858.52	227,668,490.3	Cropland
Hemp	305	14,462.8	4,411,154	Cropland
Sugar beet	109,858	2,792.24	306,749,901.9	Cropland
Tobacco leaf	485	15,925.8	7,724,013	Cropland
Medical material	327	17,263.4	5,645,131.8	Cropland
Vegetable	144,824	1463	211,877,512	Cropland
Melon	85,514	1,061.72	90,791,924.08	Cropland
Pork	12,914	25,038.2	323,343,314.8	Cropland
Beef	6238	13,731.3	85,655,849.4	Grassland
Mutton	3011	13,731.3	41,344,944.3	Grassland
Poultry meat	1250	6,863.56	8,579,450	Cropland
Rabbit meat	15	5,195.74	77,936.1	Grassland
Goat wool	73	5016	366,168	Grassland
Sheep wool	1032	5016	5,176,512	Grassland
Cashmere	21	5016	105,336	Grassland
Honey	158	20,958.52	3,311,446.16	Cropland
Egg	4506	8,790.54	39,610,173.24	Cropland
Pod (kg)	312	15,925.8	4,968,849.6	Cropland
Milk	138	2842.4	392,251.2	Grassland

Table A3. *Cont.*

Agricultural Products	Biomass (10^3 kg)	Caloric Value (10^3 J/kg)	Total Caloric (10^6 J)	Land Categories
Aquatic products	630	5450	3,433,500	Water body
Apple	9847	1841.77	18,135,909.19	Forest
Pear	2100	2060.74	4,327,554	Forest
Jujube	17	5106.74	86,814.58	Forest
Grape	456	2260.36	1,030,724.16	Forest
Other fruits	9507	2202.86	20,942,590.02	Forest
Chinese wolfberry	489	18,360	8,978,040	Forest
Nut	85	31,253.86	2,656,578.1	Forest
Pepper	26	10,799.5	280,787	Forest
Nursery stock	45,140.13	16,744	755,826,336.7	Forest
Wood	7.2003	12,310.1	88,636.41303	Forest

Table A4. Productivity and equivalence factors of land in Guyuan in 1998.

Land Categories	Total Calories (10^9 J)	Total Land Area (ha)	Average Prolificacy (10^9 J/ha)	Equivalence Factor
Cropland	10,584,058.076	648,781	16.31376085	1.89
Forest	812,353.9702	169,183	4.801628829	0.56
Grassland	133,118.997	514,779	0.258594459	0.03
Water body	3,433.500	1247	2.75340818	0.32
Area land	11,532,964.543	1,333,990	8.645465515	1.00