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Evaluation of Ecological Security in Qinghai Province Based on Net Primary Productivity-Ecological Footprint Approach

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Abstract

Equilibrium factor and yield factor are the key parameters in the ecological footprint model, which are re-measured in this paper with the NPP values of biologically productive land cover on different land use types. Qinghai Province is the basic study area, and the ecological footprint per capita, ecological carrying capacity, ecological pressure index, and ecological footprint of 10,000 yuan GDP are measured based on the ecological footprint method of net primary productivity (EF-NPP) to analyze Qinghai Province from 2000 to 2022. The results show that: (1) the average ecological footprint of Qinghai Province is 1.71hm²/person, and the per capita ecological footprint shows a growing trend, which will be 2.38hm²/person in 2022; (2) Qinghai Province shows a trend of change with growth followed by a decline, and the per capita ecological carrying capacity from 2000 to 2022 ranges from 5.41 to 5.51hm²/person; (3) the ecological deficit/ecological surplus performance is ecological surplus, and man and nature are in harmony; (4) the mean value of ecological pressure index is 0.31, which is in the first rank, and the degree of safety is very safe; (5) the ecological footprint of 10,000 yuan GDP is in a decreasing trend from 1.43hm²/million yuan in 2000 to 0.39hm²/million yuan in 2022, which indicates that resource utilization rate of the development of Qinghai Province has gradually improved. The results of the study provide certain references and lessons for the high quality of Qinghai Province region.

1. Introduction

The report of the Third Plenary Session of the Twentieth Central Committee of the Communist Party of China points out that Chinese-style modernization is one in which human beings live in harmony with nature. It is necessary to improve the ecological civilization system, synergistically promote carbon reduction, pollution reduction, green expansion and growth, actively respond to climate change, and accelerate the improvement of the institutional mechanism for implementing the concept that green water and green mountains are golden mountains.

With the rapid development of the global economy and the continuous growth of the population, the interference of human activities with the natural environment is increasing, and the issue of ecological security is gradually becoming a focus of global concern. As an important part of the Earth's ecosystem, the Tibetan Plateau, with its unique geographic environment and ecological functions, has a far-reaching impact on the global climate, biodiversity and other aspects.

In March 2016, President Xi Jinping, while participating in the deliberations of the Qinghai delegation of the National People's Congress, for the first time made clear the positioning of the "three greatest" provincial conditions, namely: "Qinghai's greatest value lies in ecology, its greatest responsibility lies in ecology, and its greatest potential also lies in ecology"(Qinghai Daily,2016). It highlights the prominent position of ecological construction in Qinghai Province, and completely elaborates the value, responsibility and potential of ecology.

In March 2021, General Secretary Xi Jinping, while attending the deliberations of the Qinghai delegation of the National People's Congress, proposed for the first time that Qinghai should build "four places" of industry, namely: "Accelerate the construction of a world-class industrial base on the salt lake, and create a national highland for the agricultural and livestock exports, clean energy industry, international ecological tourism destination". exporting place"(Qinghai Daily,2021). The proposal of the construction of "four places" of industry has provided a direction for the development of Qinghai Province.

As the global economy and population continue to grow rapidly,the interference of human activities with the natural environment is increasing, and the issue of ecological security is gradually becoming a focus of global concern. As an important part of the Earth's ecosystem, the Tibetan Plateau, with its unique geography and ecological functions, has far-reaching impacts on global climate and biodiversity. It is important to measure Net Primary Productivity (NPP) of ecosystem productive capacity, which reflects the total amount of organic matter fixed and accumulated by the ecosystem through photosynthesis in a given time(Liu et al., 2024), Ecological footprint (EF), on the other hand, is a quantitative natural resource consumption indicatorand occupation of ecological space, which helps to understand the degree of pressure on ecosystems from human activities(Yao et et al., 2023). Combining net primary productivity and ecological footprint can comprehensively consider the production capacity of ecosystems and the impact of human activities, so as to comprehensively assess the ecological security status of a region(Yong et al., 2023), and through the feedback of the evaluation results, we can clarify the key areas and weak links of ecological security, formulate targeted protection measures and restoration programs, and provide decision-making support for the sustainable development of Qinghai Province, so as to promote the coordination and coexistence of economic development and ecological protection in Qinghai Province. development and ecological protection.

2. Literature Review

The idea of carrying capacity was first proposed by Malthus, who was the first scientist to explain the dialectical relationship between environmental factors and the development of human material society. 1921, Park and Burgess first defined the environmental carrying capacity as follows: the maximum number of individuals that can survive in the territory under stable ecological conditions (e.g., territorial space, available natural resources, etc(Wackernagel et al.,1999).The Ecological Footprint Theory (EFT) is a new perspective on environmental carrying capacity. The ecological footprint theory is a new perspective on the relationship between economic and social development and ecological environment protection.In 1992, Wachernagel, a student of Canadian ecological economist William Rees, introduced it(REES,1992). The concept of ecological carrying capacity has some differences in different periods, and with the advancement of society and the economy domestic scholars have enriched and improved the concept of ecological carrying capacity.

Numerous domestic scholars study ecological carrying capacity from different perspectives. Wang Zhonggen and Xia Jun (1999) believe that ecological carrying capacity is the ability of a region's ecological environment to support human socio-economic activities in a certain environmental state in a certain period of time, which is a comprehensive reflection of the material composition and structure of the ecological environment system(Wang & Xia,1999); Gao Jixi (2001) believes that ecological carrying capacity is the self-sustainability and self-regulation of ecosystems, the capacity of the subsystems of the resources and the environment, and the capacity of socio-economic activities and population with a certain standard of living that can be maintained. activity intensity and the number of people with a certain standard of living(Zhang & Gao,2001); Xu Lianfang (2006) believes that the ecological carrying capacity of a specific time, a specific ecosystem's self-sustainability, self-regulation, the resource and environmental subsystems of the sustainable development of the human social system of a kind of support capacity, ecosystems can be sustained to support a certain degree of development of the socio-economic scale and a certain standard of living of the number of people(Xu,2006). Fang Wei (2016) constructed a system dynamics model of Beijing's ecological carrying capacity with system dynamics as a tool to investigate the connection between ecological carrying capacity and urban economic development(Fang,2016). Zhu Zhenfeng (2023) et al. proposed the concept of ecological carrying capacity of forestry system, and combined the comprehensive measurement model of ecological carrying capacity of forestry system with GM(0,1) gray prediction model and obstacle evaluation model to explore the level of ecological carrying capacity of China's forestry system and the trend of change(Zhu et al.,2022).

The ecological footprint model is mostly used by scholars in the sustainable development of environment and economy. Wang Shuhua (2003) et al. used the ecological footprint method to study the coordinated ecological and economic development of Zhenyuan County in the southwestern mountainous region, and found that the ecological footprint demand of the region was smaller than the ecological supply capacity(Wang,2003). Lin Haiming (2004) et al. used the ecological footprint theory model to study the dynamic change of ecological footprint in the Hexi Oasis Agricultural Area of Gansu Province over the past 51 years since the establishment of New China, and found that the area has been in an ecological deficit since 1991, which impedes the sustainable development of the regional economy(Lin et al.,2004). With the development of society, the importance of ecological environment is gradually emphasized, Yang Xin (2015) and others integrated ecological compensation with the ecological footprint model, which can calculate the spatial transfer amount of ecological compensation for farmland(Yang et al.,2015).

Using the ecological footprint model's equilibrium and yield factors, Guo Hui (2020) et al. investigated how various ecosystems differed in the ecological services they provide(Guo et al.,2020).When Zhang Wanling et al. (2023) examined the ecological footprint of water resources in urban agglomerations, they discovered that an overall fluctuating growth was observed in the ecological footprint of water resources in urban agglomerations in the middle reaches of the Yangtze River(Zhang,2023).

An ecosystem's net productivity, or the rate at which biomass available to other organisms grows, is expressed by Net Primary Productivity (NPP), a crucial aspect of energy flow in ecosystems. The impacts of additional variables, such as soil nutrients and climate change, must be included when calculating NPP. Net primary productivity research has been utilized mostly in recent years to examine climate change, land use, water resource conservation, and other topics(Du et al.,2010).Wu Liyuan et al. (2023) studied the spatial and temporal changes in net primary productivity of herbaceous marsh vegetation and its response to climate change on the Tibetan Plateau, which contributed to the further assessment of the carbon sequestration potential of vegetation(Wu et al.,2024). The effects of land use cover, climate change, and vegetation's net primary productivity were examined by Liu Yidan et al in 2024(Liu et al.,2024).

Foreign research on ecological economy can be divided into two stages, the first stage of research to the ecological footprint, carbon dioxide emissions, economic growth, impact, energy consumption, the research direction of the traditional ecological concepts and the relationship between economic development; the second stage of research to the quality of the system institutions, ecological sustainability, the revolution, environmental laws and regulations, technology and science and technology. Encouraging the creation of new green jobs, making full use of clean energy production processes, and changing trade policy to accommodate changes in energy policy, trade policy will move in the direction of improving the quality of the environment and accelerating the achievement of the goal of sustainable development by 2030(Destek,2020). The use of environmentally friendly advanced technologies, reasonable levels of fertilisers and pesticides in agricultural production will contribute to the reduction of CO2 emissions. Increasing the efficiency of the use of agricultural areas to produce more crops from less land will reduce CO2 emissions(Pata,2021).

The aforementioned experts' research findings give this study a strong theoretical underpinning and empirical support. Ecological security has been assessed both domestically and internationally using the ecological footprint model, which is based on net primary productivity. The promotion of high-quality development in Qinghai Province requires consideration of several factors, but few scholars have studied and measured it. This is because Qinghai Province is a significant "Three Rivers Source" national protected area, has a unique geographic environment, is situated in the Tibetan Plateau region, has a high altitude, limited economic development, and more carbon sequestration resources.Many factors need to be taken into account in order to promote high-quality development in Qinghai Province, yet not many academics have studied and measured the province. Thus, this study examines the relationship between Qinghai Province's economic growth and environmental carrying capacity using the net primary productivity-ecological footprint approach, which is extremely relevant to the province's future high-quality development trajectory.

3. Research Methodology and Data Sources

3.1 Overview of the study area

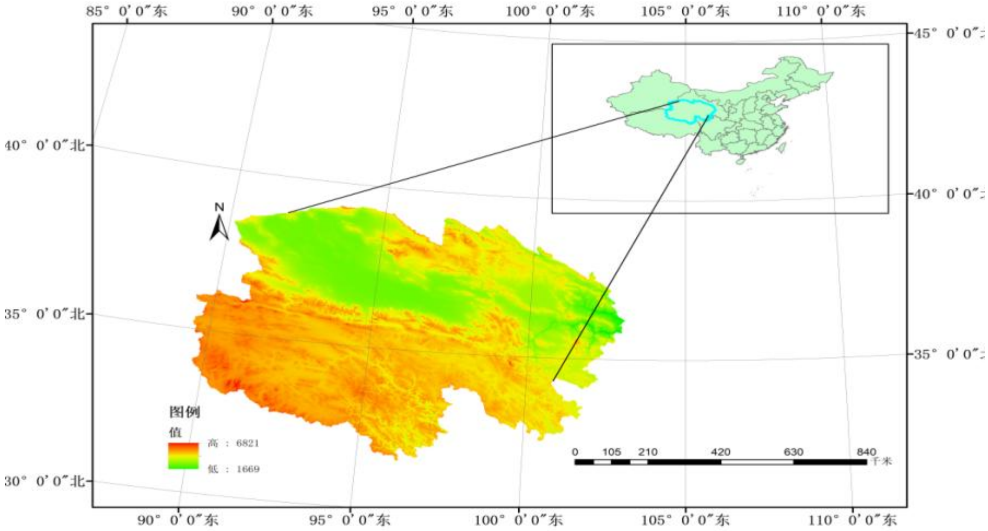

Figure 1 Geographic location map of Qinghai Province

The ecological security status of Qinghai Province, which is situated in the northeast of the Qinghai-Tibetan Plateau, is closely linked to the region's sustainable development and the execution of the country's ecological security strategy. It is also a crucial area for biodiversity conservation in China and an important ecological barrier. Exploring the ecological footprint and ecological carrying capacity of livelihood development in Qinghai Province is crucial because the province's ecosystem is its greatest asset.

3.2 Research data sources

The Statistical Yearbook of Qinghai Province (2000, 2005, 2010, 2015, 2020), the National Statistical Yearbook, the Land and Spatial Planning of Qinghai Province (2021-2035), and the China Economic and Social Big Data Research Platform database are the sources of information on the province's population, GDP, biological resource consumption, and average biological resource production. In order to determine the land use type and net primary productivity, the Resource and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/) provided the land use data, which had a resolution of 30 meters. The land usage and net primary productivity of Qinghai Province were ascertained using the land use data.

With a geographical resolution of 500 m and a temporal resolution of 1 a, the NPP data were taken from the 2000, 2005, 2010, 2015, 2020, and 2022 MOD17A3 global NPP data that were supplied by the University of Montana, USA's Numerical Terradynamic Simulation Group (NTSG) (http://www.ntsg.umt.edu).

3.3 Research methodology

Yield and equilibrium factors: The ratio of a particular land type's unit productivity to the productivity of all the land in a region is known as the equalization factor. The equalization factor is determined using the following formula and is the ratio of the NPP of various land types in Qinghai Province to the average NPP of all land in the province:

$$r_j = NPP_j \Big/ \overline{NPP} \qquad (1)$$

In Eq: NPP_j is the NPP value of biologically productive land in category j; $\overline{NPP}$ is the average NPP value of land use types in the province.

The yield factor, which represents the variation between the productive capacity of a specific type of land area in a given location and the related general average, is intended to make it easier to compare biologically productive land areas across different regions(Liu,2019).The following is the formula.

$$y_j = NPP_j \big/ `NPP_j \quad (2)$$

where:NPP_j is the *NPP* value of biologically productive land of type *j*;$`NPP_j$ is the average *NPP* of the province corresponding to *j* land use type.

Table 1 Equilibrium factors for various types of land in Qinghai Province, 2000-2022 (r_j) and yield factor (y_j)

	plow land		woodland		grasslands		body of water		building land		Fossil energy land	
particular year	r_j	y_j	r_j	y_j	r_j	y_j	r_j	y_j	r_j	y_j	r_j	y_j
2000	0.35	1.41	0.39	1.56	0.17	0.68	0.09	0.35	0.35	1.41	0.39	0
2005	0.37	1.47	0.38	1.52	0.17	0.69	0.08	0.32	0.37	1.47	0.38	0
2010	0.36	1.43	0.38	1.50	0.18	0.73	0.08	0.34	0.36	1.43	0.38	0
2015	0.37	1.50	0.38	1.52	0.17	0.68	0.07	0.30	0.37	1.50	0.38	0
2020	0.37	1.49	0.37	1.49	0.18	0.71	0.08	0.31	0.37	1.49	0.37	0
2022	0.37	1.49	0.38	1.50	0.18	0.71	0.08	0.31	0.37	1.49	0.38	0

Data source: extracted by mask using ArcGIS 10.8 software, summarized and organized using excel software.

Note: The traditional ecological footprint model only sets the forest land to absorb the co2 of emissions from energy consumption Therefore the equilibrium factor for fossil energy land is the same as for forest land, with a yield factor of 0(Luet al.,2016).

model of the ecological footprint： William Rees and his economics student Wachernagel developed the Ecological Footprint Analysis (EFA) approach in 1992 as an additional way to gauge economic sustainability. The quantity of each final consumption can be transformed into an area of biologically productive land since human survival requires the consumption of a wide range of natural commodities and services.by turning it into a region of land that is biologically productive and supplies the energy and raw materials required to generate that consumption. The following is the formula:

$$EF = N \times ef = N \times \sum r_j \ (\frac{c_i}{p_i}) \quad (3)$$

where: *EF is total EF*， *N* is the population size; *ef* is the ecological footprint per capita;r_j is the equalization factor;p_i is the equilibrium factor; ef is the average production capacity of is the average production capacity of the consumption goods; ef is the equilibrium factor.

According to the specific land use and consumption type, the ecological footprint model separates the biologically productive land into six categories: cropland, forest land, grassland, water, building land, and energy land. Typically, building land is located on cropland(Ma et al.,2014).and the consumption items of biologically productive land are separated based on the data's accessibility and the research area's production(Lu et al.,2018),and the results are shown in Table 2.

Table 2 Indicators for ecological footprint accounting in Qinghai Province

sports event	Site type	Type of resource consumption
Consumption of biological production	plow land	Cereals, legumes, potatoes, fresh eggs and egg products, vegetable oils
	woodland	Dried and fresh fruits and vegetables, tobacco, tea, sugar
	grasslands	Beef, lamb, poultry, milk and milk products, animal oils
energy consumption	body of water	aquatic product
	building land	electrical power
	energy site	Coal, oil, gas

4. Ecological Footprint Calculation for Qinghai Province 2000-2022

4.1 Ecological footprinting of biological resource accounts

Based on data from the 2000, 2005, 2010, 2015, 2020, and 2022 Qinghai Statistical Yearbooks, the total ecological footprint was determined. The ecological footprint per capita for the same land type was then computed and summarized.

4.2 Ecological footprinting of energy accounts

The global average heat generation per unit of fossil fuel production land area is used as a standard to convert energy consumption to fossil fuel production area in the ecological footprint's energy account(Yue et al.,2011).and the results are summarized.

4.3 Calculation of adjustments to the ecological footprint import and export accounts

The Ecological Footprint Trade Adjustment Account (EFTAA) is a regional ecological footprint calculation that converts exported or purchased consumer goods into the land area needed for biomass production when the biological production of a region's land resources exceeds or is insufficient to meet local consumption.(Sun et al.,2008).

Table 3 Energy component account for ecological footprint calculation in Qinghai Province

sports event	Global average energy footprint (GJ/hm²)	Conversion factor (GJ/t)	Type of production area
coals	55	20.934	Fossil fuel land
petrochemical	93	41.868	Fossil fuel land
petroleum	93	38.978	Fossil fuel land
electricalpower	1000	11.84	building land

4.4 Calculation and Analysis of Ecological Footprint in Qinghai Province

According to Table 4, it can be seen that the ecological footprint of Qinghai Province from 2000 to 2022 shows an upward trend, and the speed and scale of natural resources occupied by human activities gradually increase with the continuous growth of population.

Table 4 Ecological Footprint Calculation Account (hm²/person) in Qinghai Province, 2000-2022

particular year	plow land	woodland	grasslands	water body	Fossil energy land	building site	add up the total
2000	0.0571	0.0092	0.2726	0.0007	0.382	0.009	0.7306
2005	0.0488	0.0054	0.3032	0.0004	0.873	0.016	1.2468
2010	0.0678	0.0005	0.3273	0.0008	1.056	0.028	1.4804
2015	0.0627	0.0005	0.2635	0.0044	1.614	0.038	1.9831
2020	0.0616	0.0004	0.4286	0.0085	1.921	0.039	2.4591
2022	0.0615	0.0045	0.4414	0.0088	1.819	0.042	2.3772

Qinghai Province is a typical pasture-based province, where agricultural and livestock products are mainly exported, and vegetables, grains, fruits, etc. need to rely on a certain amount of imports. The import and export land use types of Qinghai Province are divided, and the import land types include cropland, forest land, water land, and fossil energy land, and grassland is one of the export land use types. Cropland, forest land, water land, and fossil fuel land are all included in the ecological footprint of the import account, while grassland is included in the ecological footprint of the export account.According to Figure 2, it can be seen that the ecological footprint trade in Qinghai Province from 2000 to 2022 shows an upward trend. The ecological footprint of exports maintains a steady growth trend, and the ecological footprint of imports peaks in 2020, with a slow decline thereafter.

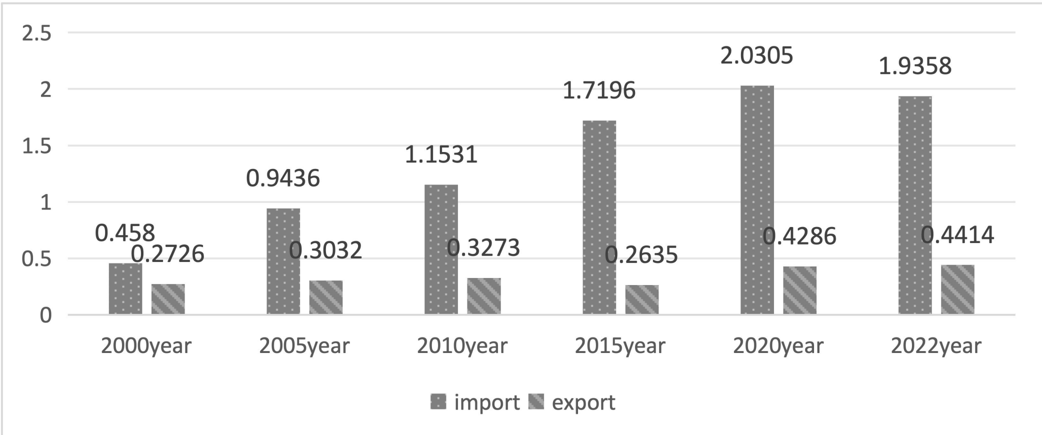

Figure 2 Summary of ecological footprint trade in Qinghai Province, 2000-2022

According to the growth and change of Qinghai Province's ecological footprint between 2000 and 2022, the average ecological footprint per person in the province is 1.71 hm²/person, with a range of 0.73 to 2.38 hm²/person. Qinghai Province's ecological footprint per person has been growing since 2000 and is expected to reach 2.38 hm²/person in 2022. It is evident that the population growth in Qinghai Province has a growing impact on the ecological environment every year. As a result, the province must follow ecological priority development, make sensible use of its natural resources, coordinate the interaction between the economy and ecology, and meet the aspirations of its citizens for a beautiful ecological environment while taking social and economic development into account.

For the comparison of the research results of other scholars, with reference to the average value of ecological footprint in Qinghai Lake area from 1995 to 2005 was 1.95hm²/person, Lu Chunxia et al. calculated that the ecological space of the world's average production needed for per capita consumption under the existing quality of life in Qinghai Province in 1995 was 1.8hm²/person, which is less than the available ecological space per capita possessed by Qinghai(Lu et al.,2001); and the balance of ecological supply and demand in China was calculated that Qinghai is the ecological surplus area in the western region . Measured, Qinghai is an ecological surplus area in the western region(Hong et al.,2020), in summary, it shows that there is a surplus in the ecological footprint of Qinghai Province, which is an important revelation for the subsequent development of Qinghai Province.

Compared with other provinces in the country, especially the western provinces, the ecological footprint development in Qinghai Province has certain advantages. For reference, Yang Yi et al. calculated the mean value of the ecological footprint of Shaanxi Province from 2000-2012 as 2.13hm^2/person(Yang & Jia,2015); Zheng Hui et al. calculated the mean value of the ecological footprint of Gansu Province from 1996-2009 as 1.77hm^2/person(Zheng et al.,2013); Wang Yenning et al. calculated the mean value of the ecological footprint of Inner Mongolia in the last 20 years from 1997-2016 as 8.76hm^2/person(wang,2020); He Aihong et al. calculated the the ecological footprint of Ningxia from 1991-2010 as 2.44hm^2/person(He et al.,2013); Zhang Na et al. calculated the mean ecological footprint of Xinjiang from 2005-2015 as 5.95hm^2/person(Zhang & Niu),2017, and other ecological footprint calculations of western provinces, the per capita ecological footprints of Qinghai Province are lower than those of other western regions, and other provinces and cities in the country, except for Qinghai and Tibet, have ecological deficits, so Qinghai Province has made a ecological protection has made a large contribution.

5. Measurement of Ecological Carrying Capacity in Qinghai Province, 2000-2022

5.1 Model of Ecological Carrying Capacity

The term "ecological carrying capacity" refers to a particular period of time, an ecosystem's capacity for self-sustainability, self-regulation, and the resources and environmental subsystems that contribute to the sustainable development of the human social system. Ecosystems can sustain a certain level of socioeconomic scale development and a particular standard of living for a population. That is, the highest amount of subsistence resources needed for human activity that a region's ecological data may support under the assumption of natural ecological recovery(Li & Li,2023). The calculation formula is as follows:

$$EC = N \times ec \times 0.88 = N \times \sum_{j=1}^{m} a_j \times r_j \times y_j \times 0.88 \quad (4)$$

Where: EC is the regional ecological carrying capacity (hm^2); ec is the per capita ecological carrying capacity hm^2; N is the number of population;a_j is the per capita occupation of the productive area of category j organisms (hm^2); 0.88 is the remaining part available for biological carrying capacity after deducting 12% of the land protection area for biodiversity;r_j is the equalization factor;y_j is the yield factor, see Table 5-1 for the values.

5.2 Ecological deficit/surplus

The difference between ecological footprint and ecological carrying capacity, which might indicate a region's sustainable development, is known as ecological deficit/ecological surplus. An ecological surplus is present in the area when ED>0. This indicates that the ecological environment and human activities have a better interaction and that the means of living needed for human activities in the area fall within the range that the region's natural ecosystem can supply and transport. An ecological deficit is present in the area when ED is less than zero. The link between the ecological environment and human activities needs to be further altered because the means of living needed for human activities in the area have surpassed the range that the natural system can give to maintain sustainable development(Zhao et al.,2021). The calculation formula is as follows:

$$ED = EC - EF \tag{5}$$

Where: ED is ecological deficit/ecological surplus; EC is regional ecological carrying capacity (hm^2); EF is regional ecological footprint (hm^2).

5.3 Ecological stress index

Ecological pressure index is the ratio of ecological footprint to ecological carrying capacity, reflecting the degree of ecological environment under pressure, reflecting the degree of ecological environment under pressure(Qin et al.,2023). The calculation formula is as follows:

$$T = ef/ec \tag{6}$$

Where: T is the per capita ecological pressure index; ef is the per capita ecological footprint; ec is the per capita ecological carrying capacity. This paper draws on Wang Tao (2020) and others to determine the ecological pressure index level division, as shown in Table 5.

Table 5 Classification of ecological stress indices

hierarchy	I	II	III	IV	V	VI
form	<0.50	0.51~0.80	0.81~1.00	1.01~2.00	1.51~2.00	>2.00
degree of safety	very safe	safer	slightly insecure	less secure	very unsafe	Highly insecure

5.4 million yuan GDP ecological footprint

The region's ecological resource consumption per 10,000 yuan GDP is directly reflected in the ecological footprint of 10,000 yuan GDP, which indicates how efficiently ecological resources are used. The ecological resource utilization efficiency increases with a smaller ecological footprint of 10,000 Yuan GDP; conversely, the ecological resource utilization efficiency decreases with a larger ecological footprint(Lu et al.,2018).domestic product per capita, unit million yuan.

5.5 Calculation and Analysis of Ecological Footprint in Qinghai Province

According to calculations, the per capita ecological carrying capacity between 2000 and 2022 was between 5.41 and 5.51 hm^2/person, and the ecological footprint per capita is continuing growing within this range. With an average ecological surplus of 3.77 hm^2/person, Qinghai Province's ecological footprint development is still within a reasonable ecological carrying capacity range. The stunning ecological setting of Qinghai Province is further preserved, and human activities remain within the acceptable bounds of nature.

For the comparison of other scholars' research results, with reference to the average value of ecological carrying capacity of Qinghai Lake area in 1995-2005 was 3.97hm^2/person, Lu Chunxia et al. calculated the ecological carrying capacity of Qinghai Province in 1995 was 5.11hm^2/person; Lu Yu et al. calculated the ecological safety evaluation of Northwest China in 2009-2017, and the ecological safety of Qinghai Province was good(Lu et al.,2022). In summary, it shows that the human activities in Qinghai Province are still within the range that can be accommodated by the ecological carrying capacity, which provides certain reference for the green and healthy development of Qinghai Province.

Compared to other provinces in the nation, particularly the western provinces, Qinghai Province's ecological carrying capacity development is extremely important. For example, Yang Yi et al. determined that the average ecological carrying capacity in Shaanxi Province between 2000 and 2012 was 0.87 hm^2/person; Zheng Hui et al. determined that the average ecological carrying capacity in Gansu Province between 1996 and 2009 was 0.93 hm^2/person; Wang Yenning et al. determined that the average ecological carrying capacity in Inner Mongolia during the last 20 years, from 1997 to 2016, was 1.92 hm^2/person; He Aihong et al. calculated that the average ecological carrying capacity in 1991–2010 was 1.12 hm^2/person; Zhang Na et al. determined the average ecological carrying capacity in Xinjiang between 2005 and 2015 to be 1.52hm^2/person. When calculating the ecological carrying capacity of western provinces, Qinghai Province has contributed more to ecological conservation in the western region and has a higher ecological carrying capacity per capita than other western regions.

Table 6 Per capita ecological footprint, per capita ecological carrying capacity and ecological surplus in Qinghai Province, 2000-202

particular year	Ecological footprint (hm^2)	Ecological carrying capacity (hm^2)	Ecological deficit/surplus	ecological stress index (ESI)	Ecological footprint of 10,000 GDP
2000	0.7306	5.4122	4.6816	0.1350	1.4325
2005	1.2468	5.3629	4.1161	0.2325	1.3556
2010	1.4804	5.9904	4.51	0.2471	0.7284
2015	1.9831	5.2791	3.296	0.3757	0.5690
2020	2.4591	5.3507	2.8916	0.4596	0.4845
2022	2.3772	5.5172	3.14	0.4309	0.3918

6. Discussion and analysis

This study looks at the ecological carrying capacity and ecological footprint growth of Qinghai Province from 2000 to 2022 for the debate that follows:

From a temporal perspective, Qinghai Province's ecological footprint per person has developed in a comparatively steady manner. Despite the impact of a number of variables, including population increase, economic development, shifting consumer habits, etc., the ecological footprint of Qinghai Province demonstrated a gradual rising trend from 2000 to 2020 rather than sharp swings. This suggests that, in spite of Qinghai Province's ongoing social and economic advancement, the demand for and consumption of natural resources has not increased dramatically, which somewhat reflects the province's efforts and successes in sustainable development.

Qinghai Province's ecological carrying capacity per capita is changing, first increasing and then declining. The degree of coordination between ecological environmental protection and economic development is relatively low in Qinghai Province due to the fragility of the environment, the lagging nature of economic development, and the transformation of scientific and technological innovation. This may be related to the rapid development of industrialization and urbanization in recent years, which has put some pressure on the ecological environment while promoting economic development(Zhang et al.,2008).It has caused the ecological carrying capacity per capita to decline. Therefore, in order to achieve the coordinated growth of economy and ecology, Qinghai Province must give the preservation and restoration of the ecological environment more consideration in the future development process.

There are several hazards to Qinghai Province's ecological security status from an ecological security standpoint. The ecological security of Qinghai Province is in the first pressure level, or a safer state, based on the findings of the ecological pressure index evaluation model. This suggests that Qinghai Province's ecology is functioning well, but in order to guarantee the province's green and healthy growth, ecological preservation and economic growth still need to be prioritized.

The ecological footprint of 10,000 yuan GDP in Qinghai Province is trending downward in terms of resource usage efficiency. This suggests that as Qinghai Province's economy and society continue to grow, resource utilization efficiency is likewise increasing annually, and the standard of economic development has been successfully raised(Zhou & Chao,2023).This trend's emergence is closely related to the green development strategy that Qinghai Province has been implementing lately, as well as other initiatives that support sustainable and circular economic development.

In conclusion, this paper offers a thorough analysis of Qinghai Province's ecological footprint from 2000 to 2022 based on net primary productivity. This analysis further reveals the ecological footprint's trend and characteristics and offers crucial insights for the province's economic development and ecological environmental protection.

7. Recommendation

7.1 Integration research on ecological footprint and rural revitalisation

Actively explore the impact of human production and life on nature in the ecological footprint, and coordinate and promote the integration research of rural revitalisation in the new era. Continuously promote the comprehensive and coordinated development of the ecological footprint from ‘point’ to ‘line’ to ‘surface’, and explore a new research stage of ecological footprint research and rural revitalisation research in the new era.

7.2 Strengthening the compensation mechanism for the ecological footprints of the east and the west

In human activities, the eastern part of the country has a large population and high urban density, and the impact of human activities on the ecological environment is increasing, while the western part of the country has a relatively small population, and the impact of human activities on the ecological environment is small. Explore the compensation mechanism of ecological footprint in the western region, innovate a new model of harmonious development between human beings and nature in the western region, and strengthen the protection and restoration of the environment.

7.3 Explore the coordination mechanism of ecological footprint in urban and rural areas.

Chinese modernisation is the modernisation of harmonious coexistence between human beings and nature, and it is important to actively explore new ways of integrated development in urban and rural areas. The human production and living footprints in urban and rural areas are different, with different impact mechanisms on the ecological environment. Reasonable planning and research on new paths for urban and rural regional development, and the continuous exploration and development of urban and rural regional ecological footprint coordination mechanisms are also conducive to solving the problems of urban and rural regional development, and alleviating the problem of the excessive gap between urban and rural areas.

7.4 Pioneering a new path of ecological footprint development in ethnic regions

The development of ethnic areas is slower than that of other regions, and the production and life style of people in ethnic areas is more natural, which has a certain impact on the ecological environment. Ethnic areas are the regions we focus on helping and supporting, advocating that people in ethnic areas travel in a low-carbon and environmentally friendly way, and contributing to the beautiful ecological contribution of ethnic areas themselves.

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