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Measuring Gross Ecosystem Product (GEP) in Guangxi, China, from 2005 to 2020

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Abstract: The economic and social development evaluation system with the Gross Domestic Product (GDP) as the leading indicator is no longer applicable to the current social progress in China. It is essential to carry out an assessment of the Gross Ecosystem Product (GEP) to integrate ecological benefits into the economic and social evaluation system and promote sustainable socio-economic development. This study took Guangxi, an important province in South China, as the study area. We used four periods of land use and land cover data (LULC), meteorological data, soil data and yearbook statistics to construct a GEP assessment framework based on geographic information system (GIS) and remote sensing (RS) technologies. We accounted for the provisioning services, regulating services, and tourism services provided by Guangxi in 2005, 2010, 2015, and 2020 and analyzed the region's and municipalities' spatial–temporal pattern characteristics and trends of change in GEP. In addition, this study also discusses the relationship between GEP and GDP. The results showed that many important products and services provided by natural ecosystems in Guangxi had enormous economic benefits. GEP had increased from CNY 15,657.37 billion in 2005 to CNY 36,677.04 billion in 2020, and the distribution of GEP showed obvious spatial heterogeneity. The value of ecosystem regulation services was about 65–89% of GEP, which is the main component of GEP. From 2005 to 2020, natural ecosystem protection and socio-economic development have achieved coordinated development in Guangxi. GEP and GDP showed upward trends in general. Although Guangxi is relatively backward in terms of economic development, the scientific quantification of the unrealized value of the services provided by the ecosystem through GEP accounting makes it possible to transform ecological advantages into economic advantages. It could help the local government and people to re-recognize the value of ecological resources and realize the beautiful vision of lucid waters and lush mountains as invaluable assets.

Keywords: ecosystem; ecosystem gross product; accounting; assessment framework; Guangxi

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Citation: Wang, L.; Su, K.; Jiang, X.; Zhou, X.; Yu, Z.; Chen, Z.; Wei, C.; Zhang, Y.; Liao, Z. Measuring Gross Ecosystem Product (GEP) in Guangxi, China, from 2005 to 2020. *Land* **2022**, *11*, 1213. https://doi.org/10.3390/land11081213

Academic Editor: Teodoro Semeraro

Received: 12 July 2022
Accepted: 27 July 2022
Published: 1 August 2022

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1. Introduction

Through primary and secondary production, ecosystems synthesize organic matter and products that are essential for human survival, provide food and vital energy for humans, create and maintain the Earth's life-support systems, and form the environmental conditions on which human survival depends [1,2]. The connotations of ecosystem services (ESs) can include abundant production of material products, provision of biological habitats, climate regulation, renewal and maintenance of soil fertility, air purification, mitigation of natural disasters, culture and entertainment, and many other aspects [3]. However, the Gross Domestic Product (GDP) growth-oriented development model has led to ecological

breakdowns and serious environmental pollution, which is not sufficient as an evaluation indicator for social sustainability and high-quality economic development [4,5]. As the foundation of social development, the value of ecosystems deserves to be an important reference for evaluation. In 2013, the Research Centre for Ecological Environment of the Chinese Academy of Sciences (RCEES) and the International Union for Conservation of Nature (IUCN) proposed the concept of Gross Ecosystem Product (also known as Gross Ecological Product, also known as the value of ESs, GEP). GEP is considered as the products and services value that ecosystems provide for human welfare and economic and social sustainable development in a certain period and region [6,7]. Compared with the traditional GDP accounting system, the GEP accounting system effectively compensates for the failure to measure natural resource consumption, ecological resources, and environmental damage in GDP accounting [8,9]. GEP accounting could provide technical support for the realization of ecosystem value. GEP as a quantitative grasp of ecological assessment together with GDP will become a new yardstick to measure high-quality economic development.

The application and popularization of GEP accounting cannot be separated from its systematic construction, and a standardized and scientific GEP accounting system is the theoretical basis for realizing ecosystem value. GEP as an indicator includes the quantification and valuation of provisioning services, regulation services, and cultural services. Its accounting is carried out from two perspectives: biophysical quantity and value quantity. Finally, the value quantities of individual ESs are added up to represent ecosystem services flow in the form of monetary value [10,11]. In March 2021, the United Nations Statistical Commission officially incorporated GEP into the latest System of Environmental–Economic Accounting, the Framework for Ecosystem Accounting (SEEA-EA) [12]. The biophysical quantity and value of GEP accounting correspond to the stock account and monetary value of the core framework in SEEA-EA. At present, biophysical quantities are mainly obtained by combining geographic information system (GIS), remote sensing (RS) technologies, and InVEST means to calculate the biophysical quantities of agricultural and forestry production and the ecological regulation provided by ecosystems in each period. The monetary values are calculated using both alternative market techniques and simulated market techniques to obtain unit prices corresponding to various ESs.

GEP accounting, as an entry point and breakthrough to improve the evaluation system of economic and social development, has attracted great attention at both the national and regional levels of science and technology development. It has become a research hotspot in ecology in recent years, as well as one of the popular ecological fields supported by national science and technology departments. With the increasing demand for GEP accounting information, Chinese scholars have been successively carrying out pilot work on accounting in many administrative units (global [11], national [13–16], provincial [17,18], municipal [19–21], and county [22,23]). There are also the value calculations of natural geographical units (forests [24], watersheds [25], etc.). At the same time, the accounting of ecosystem value has been adopted and studied extensively in the United States [26,27], the United Kingdom [28,29], Australia [30], India [31], and the Czech Republic [32]. Wherever ecosystem value accounting is being carried out, researchers are actively incorporating their results into local developments in order to provide references for local social and economic development directions. With the continuous exploration of the above research and practice and the continuous improvement of GEP accounting methods, a series of research results have been obtained which play an important role in coordinating economic development and ecological protection. However, there are still some shortcomings, especially in the measurement and selection of the monetary value of ESs. We should adopt a method more in line with the ecological types, environmental conditions, local policies, and economic development level of the study area and master the ontology to make GEP accounting more scientific.

Guangxi is rich in ecosystem types, with valuable forest, ocean, mineral, and biological resources. As an important province in South China, Guangxi has obvious ecological advantages, which not only produce substantial ecological benefits locally but also play a

vital role in maintaining the ecological security of neighboring provinces and even the East Asia region. Guangxi is an important ecological barrier in South China. However, Guangxi, with its backward level of economic development, belongs to a backward area of economic growth and still needs to bear colossal opportunity costs to protect the ecosystem, without being able to benefit from it. With the development of society and the intensification of human activities for resource exploitation and destruction, the regional ecosystem cannot maintain various ecological service functions stably. The problems of regional economic development and environment are intertwined, especially in rocky desertification areas, where improvement processes are slow and the unbalanced distributions of ecological resources and ecological benefits are prominent. Since a mature GEP accounting theoretical system and practical mode have not yet been formed, there is limited support for evaluating the benefits of regional ecological protection policies, establishing ecological compensation mechanisms and transforming economic benefits. This is a severe challenge for Guangxi, and it also provides a rare opportunity. However, there has been no overall research on GEP accounting in Guangxi as a region so far and the research on GEP in Guangxi has mainly focused on a certain region [33] or a single ecosystem type, such as forest [34], karst [35], and wetland [36] ecosystem types. A characteristic and systematic theoretical system and practice mode of GEP accounting for Guangxi has not yet been formed. According to the local conditions in Guangxi, it is of great significance to construct a GEP accounting system that fully reflects the regional characteristics and natural features.

The purpose of this study is to solve the research problems mentioned above. Taking Guangxi as the research area and using land use and land cover data (LULC), natural statistics, socio-economic data, and other data, this paper presents a study of the temporal and spatial changes in GEP in Guangxi from 2005 to 2020 in terms of provisioning services, regulation services, and tourism services. According to the regional characteristics of Guangxi, carrying out GEP accounting, optimizing GEP accounting methods, and accurately grasping the value of ecological products and services could not only provide a unified standard for Guangxi's current "two mountains" transformation efficiency evaluation but also provide an index reference for China's future "two mountains" transformation policy path.

2. Study Area

Guangxi is located in the south of China (26° N~21.7° N, 104.5° E~112° E). It belongs to the subtropical monsoon climate zone, with an average annual temperature of 21.50 °C, average rainfall of 1937 mm, and average sunshine duration of 1354 h. The climate is warm, with equal periods of rain and heat. The topography of Guangxi is characterized by extensive mountains and smaller areas of flat land; the surrounding mountains are continuous, and the middle terrain is slightly lower, showing basin-like characteristics. The karst landscape is widely distributed and beautiful in Guangxi and is an important factor in attracting tourists from all over the world. The ecological environment is a golden sign of Guangxi, and the levels of water environment, air environment, and marine environment rank at among the highest in China. The total land area of the whole region is 236,700 km^2, the mainland coastline is about 1500 km long, the maximum span from east to west is about 771 km, and the maximum span from south to north is about 634 km. Guangxi Zhuang Autonomous Region has jurisdiction over 14 prefecture-level cities(Figure 1), including Nanning (NN), Liuzhou (LZ), Guilin (GL), Wuzhou (WZ), Beihai (BH), Fangchenggang (FCG), Qinzhou (QZ), Yulin (YL), Guigang (GG), Baise (BS), Hezhou (HZ), Hechi (HC), Laibin (LB), and Chongzuo (CZ). By the end of 2020, the resident population of Guangxi was 50,126,800, and the GDP was CNY 22,156.69 billion.

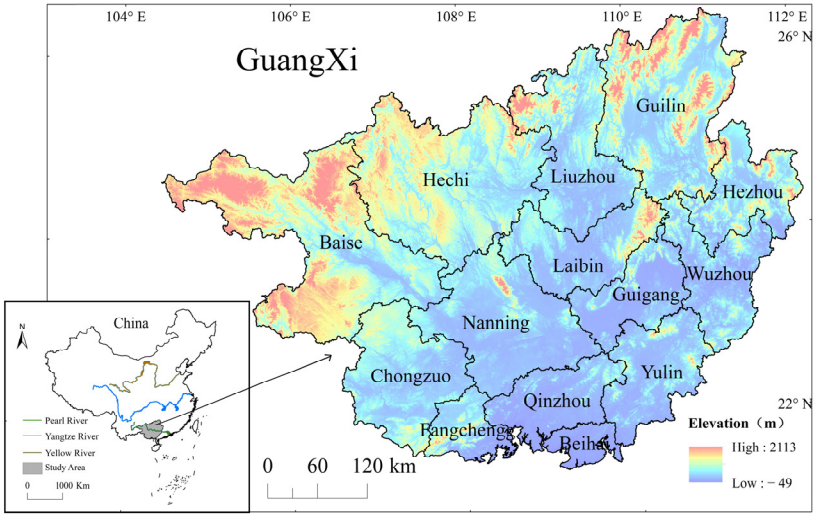


Figure 1. Study area.

3. Materials and Methods

3.1. Index Selection for GEP Accounting

In a natural ecosystem, whether it is a forest, grassland, or agricultural ecosystem, the GEP accounting index should be selected according to the advantages of the ecosystem itself and the characteristics of the basic geomorphological belts and geographical belts in different regions. Guangxi is located in a climate zone that is very favorable to the growth of crops, and there are many kinds of crops grown in the region. In this study, we chose local agricultural products, such as rice, sugar cane, tea, fruit, etc., as statistical objects. Meanwhile, Guangxi has well-developed forestry. The forestry products, such as wood, star anise, and camellia oleifera, were selected for accounting in the study. Husbandry products include meat and milk. Regarding meat, pork and poultry are the main products in Guangxi. In addition, Guangxi is rich in river and sea resources. In this study, we took the quantity of aquatic products as the supply of fishery products. Data on the production and output of agricultural, forestry, husbandry, and fishery products were obtained from the statistical yearbook [37–40]. In the regulation services, in view of Guangxi's karst landscape, which has numerous rivers, well-developed runoff and high forest coverage, we selected four ESs of water conservation, soil conservation, carbon sequestration, oxygen release, and habitat provision as accounting items. Guangxi's tourism industry is relatively developed, with unique landscapes, such as terraced fields, waterfalls, karst landscapes, etc., and strong ethnic artefacts and customs, such as Dong drum towers, Zhuang brocade, and various ethnic costumes, and historically intangible cultural heritages, such as "Liu Sanjie" ballads and "Huashan" murals, etc., which attract large numbers of tourists from home and abroad. Therefore, the numbers of tourists and total tourist consumption are taken as accounting indicators for tourism services, and the total value of the ecosystem due to tourism is counted (Table 1).

3.2. Framework for Accounting GEP

This accounting mainly included three aspects: provisioning services, regulation services, and tourism services (Figure 2). The calculation method used is as follows:

$$GEP = EPS + ERS + ETS \quad (1)$$

where GEP is gross ecosystem product; EPS is the total value of the four ecosystem provisioning services of agriculture, forestry, husbandry, and fishery; ERS is the total value of the ecosystem regulating services of water conservation, soil conservation, carbon sequestration, oxygen release, and habitat provision services; and ETS is the value of tourism services in the cultural function of ecosystems [11]. Units are calculated in billions of yuan (CNY).

Table 1. Elements of accounting for different ecosystem services. The GEP accounting examined three aspects of ecosystem provisioning services (EPSs), ecosystem regulation services (ERSs) and ecosystem tourism services (ETSs), with agriculture, forestry, animal husbandry, fishery, water conservation service (WCS), soil conservation service (SCS), carbon sequestration and oxygen release service (C/O), habitat provision (HP), and tourism services selected as accounting items.

ES	Accounting Items	Contents	Data Source
EPS	Agricultural	Agricultural products	Annual Statistical Yearbooks
	Forestry	Forestry products	
	Husbandry	Husbandry products	
	Fishery	Fishery products	
ERS	WCS	Annual precipitation, annual evapotranspiration, annual storm water production	China National Environmental Monitoring Centre
	SCS	Soil erosion	National Soil Information Service Platform of China
	C	Aboveground carbon stocks in terrestrial ecosystems, total ecosystem types, biomass	Resource and Environmental Science Data Center of Chinese Academy of Sciences
	O	Carbon sequestration, oxygen emissions	
	HP	Habitat quality, habitat scarcity	NASA
ETS	Tourism	Domestic and inbound tourism arrivals and tourism receipts	Annual Statistical Yearbooks

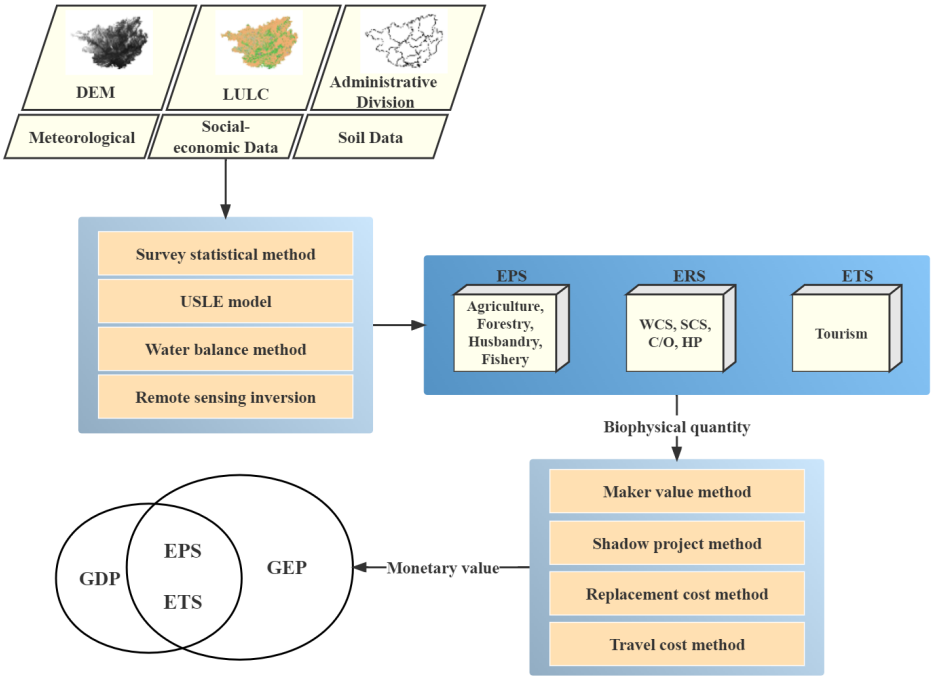


Figure 2. GEP accounting technical route.

3.3. Accounting for Biophysical Quantities

3.3.1. Provision of Ecological Products

According to the characteristics of Guangxi's natural environment and ecosystem, this study counts the total output of material products in the ecosystem as the quantity of provisioning services:

$$E_m = \sum E_i \quad (2)$$

where E_m is the total production of ecosystem products in Guangxi (t); E_i is the production of the ith product (t), i = 1, 2, 3, 4; and i is the product type. The same calculation was made for ecological product provisioning services in other municipalities.

3.3.2. Water Conservation Service

For the calculation of biophysical quantities of water-supporting services, we used the water balance equation. The calculation indexes include annual precipitation, annual evapotranspiration and annual rainstorm yield [41–44]. The calculation formula of the water balance equation is as follows:

$$WC = PRE - ET - QF \quad (3)$$

where WC is water availability, mm; PRE is annual precipitation, mm; QF is storm water runoff, mm; and ET is actual evapotranspiration, mm.

3.3.3. Soil Conservation Service

The biophysical quantity of soil conservation service is characterized by the soil conservation quantity of vegetation [45,46]. The Universal Soil Loss Equation (USLE) is the most widely used and practical remote sensing quantitative model of soil erosion at present, and it has been widely applied in the study of soil conservation in large areas [47,48]. Therefore, USLE was selected in this study to evaluate the soil conservation service of the ecosystem [49]. The calculation formula is as follows:

$$SC = SE_p - SE_a = R \cdot K \cdot LS \cdot (1 - COG) \quad (4)$$

where SC is the soil conservation, [t/(hm^2·a)]; SE_p and SE_a are potential and actual soil erosion, [t/(hm^2·a)]; R is rainfall erosion force factor, MJ·mm/(hm^2·h·a); K is soil erodibility factor, t·hm^2·h/(hm^2·MJ·mm); and LS and COG are the topography factor and vegetation cover factor, respectively, and are dimensionless.

3.3.4. Carbon Sequestration and Oxygen Release Service

The measurements were based on the biomass of each ecosystem and obtained through remote sensing inversions, model simulations, and other technical methods, such as measured data. The main calculation equations are as follows:

$$COS = \sum_{i=1}^{j} AGB_i \times C_i \quad (5)$$

where COS is the aboveground carbon storage of terrestrial ecosystem; i is the type of ecosystem; j is the total number of ecosystem types; AGB_i is the aboveground biomass of the ith ecosystem type; and C_i is the biomass–carbon conversion coefficient of this ecosystem type [50].

The mass of oxygen released by the ecosystem can be measured from the chemical equation for photosynthesis:

$$COP = M_{O_2} / M_{CO_2} \times COS \quad (6)$$

where COP is the oxygen released from the terrestrial ecosystem and M_{O_2}/M_{CO_2} = 32/44 is the coefficient of conversion of CO_2 to O_2 [51].

3.3.5. Habitat Provision Service

Habitat provision was reflected through the biological habitat quality index. In this study, the regional habitat was mainly evaluated from two aspects: regional habitat quality and habitat scarcity, which were calculated using the InVEST model [52]. The calculation formulae are as follows:

① Habitat quality

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r} \right) r_y i_{rxy} \beta_x S_{jr}, \quad (7)$$

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\ max}} \right) \quad (8)$$

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{r\ max}} \right) \quad (9)$$

where D_{xj} is the total stress level of raster x in LULC or habitat type j; w_r is the weight of stress factors, indicating the relative destructive power of a stress factor to all habitats; β_x is the accessibility level of grid x; and S_{jr} is the sensitivity of habitat type j to stress factor r. If $S_{jr} = 0$, D_{xj} is not a function of threat r, r_y is the stress factor in raster y, i_{rxy} is the stress effect of stress factor r in raster x on raster y, and the stress effect is divided into a linear attenuation and an exponential attenuation. d_{xy} is the linear distance between raster x and y and $d_{r\ max}$ is the maximum range of threat r [53].

② Habitat scarcity

$$R_x = \sum_{x=1}^{X} \sigma_{xy} R_j, \quad (10)$$

$$R_j = 1 - \frac{N_j}{N_{jbaseline}} \quad (11)$$

where R_x is the scarcity of raster x; R_j is the scarcity index of LULC type j; N_j is the number of rasters of current land use and land cover j; $N_{jbaseline}$ is the number of rasters of LULC type j in the baseline landscape pattern; and σ_{xy} is a binary number, with σ_{xy} = 1 when raster x is of LULC type j, otherwise $\sigma_{xy} = 0$.

3.3.6. Cultural Services

Concerning the cultural services function, this study only considered the value of leisure tourism. The sum of the total number of international and domestic trips by year was used as an indicator for the evaluation of the cultural services function.

3.4. Accounting for the Value of Monetary

3.4.1. Provision of Ecological Products

The value of ecosystem provisioning services in Guangxi included the total output value of four products: agriculture, forestry, husbandry, and fishery, which was calculated using the alternative market method. According to the statistical yearbook, the calculation range of output value refers to the total amount of products produced by various economic types and modes of operation in the administrative area within the calendar year. The calculated price includes the current price and the constant price. The sum of the output value of each product was used as the total value:

$$V_m = \sum V_i \quad (12)$$

where V_m is the total value of the output of the ecosystem products in Guangxi, in billions of yuan (CNY); V_i is the value of the output of the ith product; i = 1, 2, 3, 4; and i is the product type. The same applies to the calculation of the value for each municipality.

3.4.2. Water Conservation Service

Water conservation is related to the ecological function of water conservation and storage, and its value is calculated by the shadow engineering method [54]. Combined with the local reservoir construction market in Guangxi over the years, by calculating the ratio of the annual fixed investment in water conservancy to the reservoir construction capacity, the average construction project cost of the Guangxi reservoir every five calendar years is taken as the price. The water conservation service value was calculated as follows:

$$C_{WC} = \frac{\sum S_i/O_i}{5}, \quad (13)$$

$$V_{WC} = WC \times C_{WC} \quad (14)$$

where V_{WC} is the value of water connotation; C_{WC} is the average construction project cost of reservoirs in Guangxi; S_i is the total fixed investment in water conservancy for each five-year period from 2000–2020; and O_i is the total construction capacity of reservoirs in Guangxi for each corresponding five-calendar-year period. i = 2000–2020, 2000–2005, 2005–2010, 2010–2015, 2015–2020, corresponding to the calculation of the average construction project cost of reservoirs in 2005, 2010, 2015 and 2020, respectively.

3.4.3. Soil Conservation Service

After the soil conservation was calculated by the USLE, the corresponding value was calculated by the alternative cost method [55]. Based on the statistics for the soil and water loss control project cost in Guangxi small watersheds over the years and the ratio of comprehensive control investment to soil and water loss control area, the soil conservation service value was calculated using the cost of the soil and water loss control project in Guangxi for each calendar year:

$$C_{SC} = E_i/R_i, \quad (15)$$

$$V_{SC} = SC \times C_{SC} \quad (16)$$

where V_{SC} is the soil conservation value; C_{SC} is the cost of erosion control works in Guangxi; E_i is the cost of erosion control works in small watersheds in Guangxi for each year; and R_i is the corresponding erosion control area for each year. i = 2005, 2010, 2015, 2020, corresponding to the calculation of the cost of erosion control works in Guangxi for each calendar year, respectively.

3.4.4. Carbon Sequestration Service and Oxygen Release Service

The market price method was used to calculate the value of the ecosystem carbon sequestration service and the oxygen release service. The corresponding economic prices are carbon transaction price and industrial oxygen price, respectively [56–59].

$$V_{CO} = V_{COS} + V_{COP} \quad (17)$$

where V_{CO} is the total value of carbon sequestration and oxygen release; V_{COS} is the value of carbon sequestration service; and C_{COS} is the value of oxygen release service.

Since the first batch of carbon emissions trading pilot projects was launched in China in 2013, in order to make the calculated value more consistent with the situation of China's carbon trading market, the carbon trading prices of major countries in the world in 2005 and 2010 were taken as the unit price of carbon sequestration value in this study. The average carbon trading prices of seven pilot cities in China were adopted in 2015 and 2020. The calculation formula is:

$$V_{COS} = COS \times C_{COS} \quad (18)$$

where V_{COS} is the value of carbon sequestration service and C_{COS} is the carbon trading price.

The price of industrial oxygen over the years was taken as the unit price of oxygen release service value, and the formula is:

$$V_{COP} = COP \times C_{COP} \quad (19)$$

where V_{COP} is the value of oxygen release service and C_{COP} is the price of industrial oxygen.

3.4.5. Habitat Provision Service

The habitat provision service value was calculated by taking the conservation value of species per unit area as the price. Referring to the research on methods and guidelines [60,61], the Shannon–Wiener index in the guidelines [62] is rated as IV, and the corresponding value is CNY 26,700/hm^2·a to calculate the total habitat provision service value.

3.4.6. Cultural Services

According to the statistical survey, the sum of total international and domestic tourism consumption each year was taken as the total value of cultural services.

4. Results

4.1. GEP Assessment in Guangxi

4.1.1. 2020 GEP

In 2020, the GEP of Guangxi was CNY 36,677.04 billion, and the GEP per unit area was CNY 0.15 billion per square kilometer. The value of the water conservation service was CNY 16,233.79 billion, which was the greatest value, accounting for 44% of the total value of GEP, followed by tourism services, with a value of CNY 7267.45 billion, accounting for 20% of GEP; this was followed by soil conservation service, agriculture, habitat provision service, carbon sequestration and oxygen release service, husbandry, fishery, and forestry. For the specific composition and proportions, see Figure 3.

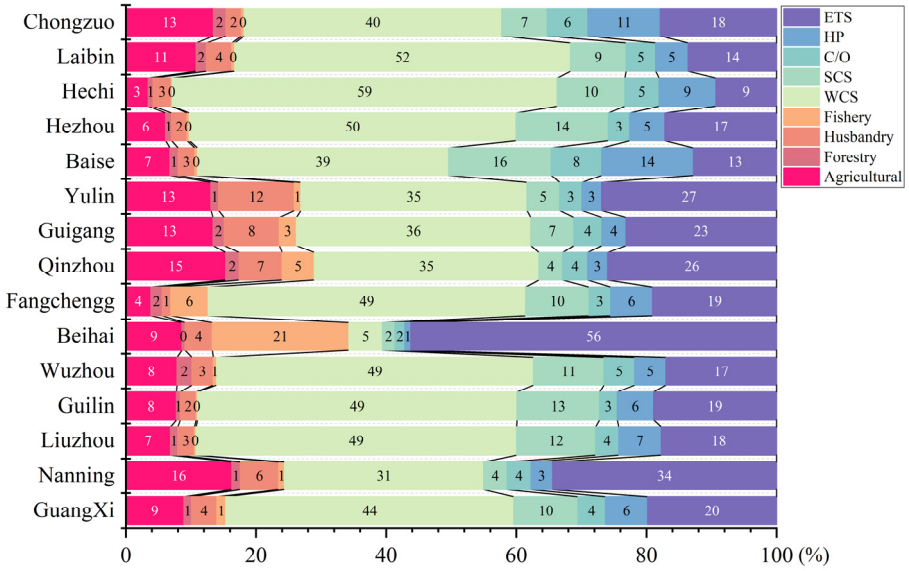


Figure 3. Composition of GEP in 2020.

The value proportions of provisioning services, regulation services, and tourism services in each city were highly unbalanced. LZ, WZ, FCG, BS, HZ, HC, LB, and CZ accounted for a large proportion of provisioning services, reaching more than 65%, of which HC was the most apparent (84%). This showed that ecosystem resources are dominant in these cities. QZ, GG, and YL showed little differences in proportions of GEP structure, the regulation service still reached about 50%, and the proportions of provisioning services and regulation services were basically the same. NN had the most balanced development structure, the

value of provisioning services, regulation services, and tourism services accounting for 24%, 41%, and 34%, respectively. Only BH had the smallest share of regulation services, at 10%, while tourism services accounted for the highest proportion (56%).

The value distribution of each accounting sub-index is shown in Figure 4. The distribution of agricultural output value was the same as that for tourism services value, mainly in NN and GL. Forestry was produced primarily in the cities with high forest coverage, such as WZ and BS. NN and YL had the highest value in animal husbandry. Fishery was mainly produced in coastal cities, such as FCG, QZ, and BH. The value of the water conservation service, soil conservation service, and habitat provision service in the north of Guangxi is higher than that in the south, while the distribution pattern of the carbon sequestration and oxygen release service shows an opposite trend, with that in the south higher than that in the north.

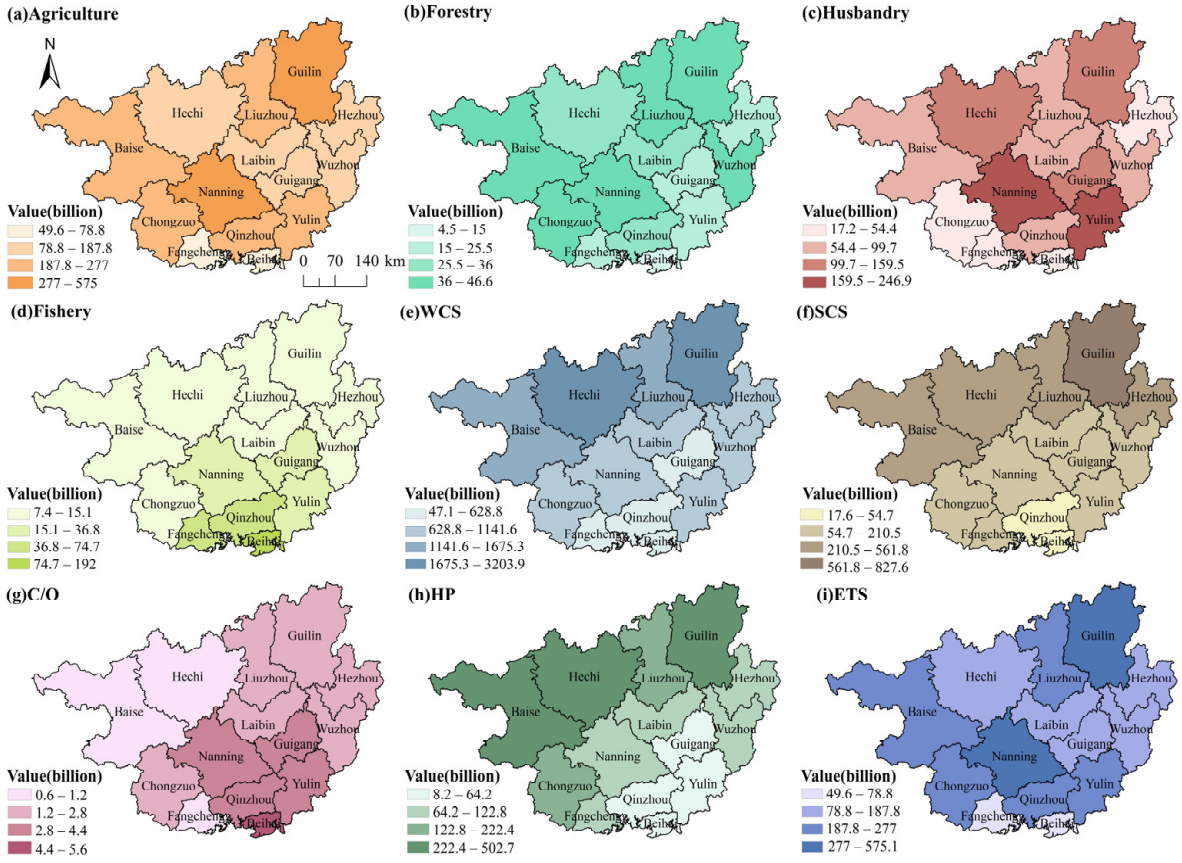


Figure 4. Spatial distribution of sub-indicators in 2020.

4.1.2. Temporal and Spatial Changes of GEP from 2005 to 2020

From 2005 to 2020, the value of provisioning services, regulation services, and tourism services has been increasing, but with differences (Figure 5). The value of regulation services increased the most over the 15 years, by a total of CNY 9846.51 billion. The value of tourism services increased by CNY 6963.72 billion. The value of provisioning services increased by CNY 4209.44 billion.

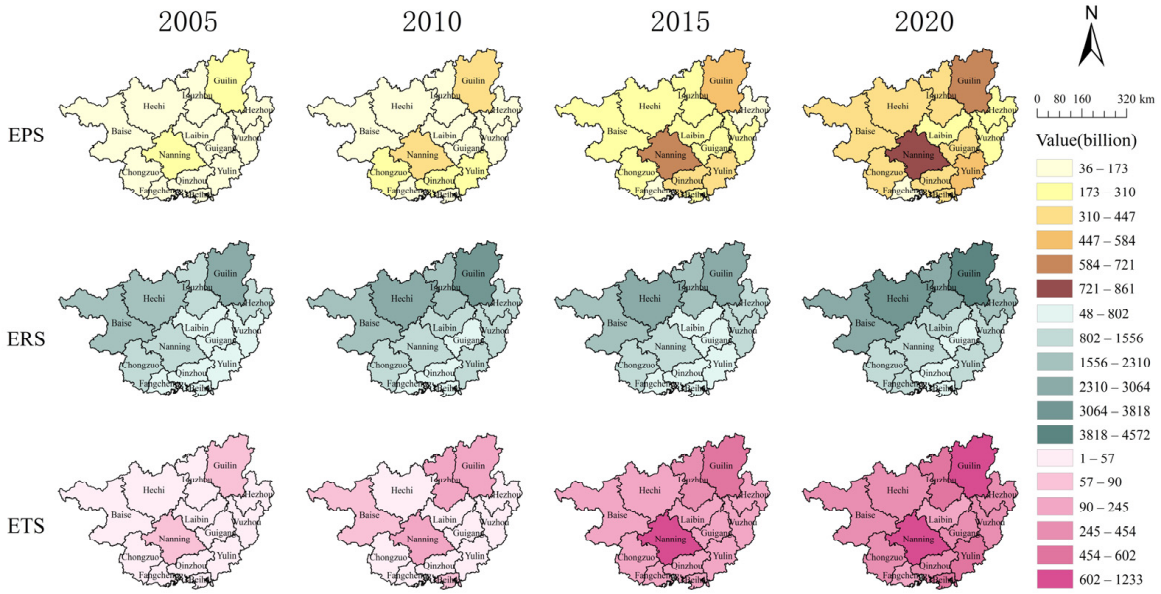


Figure 5. Spatial distribution of the monetary value of terrestrial ecosystem products from 2005 to 2020.

Regarding the value of provisioning services, the largest increase over the 15 years was in NN. From 2010 to 2015, the overall provisioning services value for Guangxi increased the most in these five years, and the provisioning service values of BS, HC, LZ, LB, GG, and WZ exceeded CNY 200 billion in 2015. The distribution of regulation services value showed an increasing trend from southeast to northwest and from the coast to inland. The largest increase in regulating services value during the 15 years was in GL, with a rise of about CNY 2135.36 billion. The value of tourism services increased most obviously between 2015 and 2020, with an increase of CNY 4074.73 billion in five years. Among them, the tourism income of GL and NN in 2020 have both reached more than CNY 1200 billion. YL had substantial growth from 2015 to 2020, with an increase of CNY 551.40 billion, and in 2020 it became the region with the highest tourism services value after GL, NN, and LZ (Figure 5).

In 2005, 2010, and 2015, the value of regulation services accounted for the largest proportion, provisioning services the second, followed, finally, by tourism services. However, in 2020, the value of tourism services exceeded the value of provisioning services and ranked second. In 2020, the total value of the four provisioning services of agriculture, forestry, husbandry, and fishery in Guangxi was CNY 5638.22 billion, of which the output value of agricultural products was CNY 3268.80 billion, accounting for 58% of GEP. The proportion of the value of regulation services gradually decreased, from 89% in 2005 to 65% in 2020 in GEP. The value of tourism services was CNY 7267.45 billion, accounting for 20% of GEP in 2020, while in 2005, the value of tourism services was only CNY 303.73 billion, accounting for only 2%.

In general, the GEP in Guangxi was dominated by water-related services (Figure 6), and the value of water-related ESs, such as water conservation, soil conservation, and agriculture, were high. In the four accounting periods, water conservation service always maintained the most significant contribution. In 2020, the total value of water conservation service in Guangxi was CNY 16,233.79 billion, which increased by CNY 6504.03 billion compared with 2005. The northwest of Guangxi is a karst area with severe soil erosion, so the function of soil conservation is particularly crucial. The total value of soil conservation service in Guangxi increased from CNY 900.58 billion in 2005 to CNY 3612.81 billion in 2020, which indicates that ecological engineering plays a vital role in controlling soil erosion and improving the ecological environment in Guangxi. In 2020, the total value of carbon sequestration and oxygen release service in Guangxi was CNY 1554.24 billion, of which the values for the carbon sequestration service and oxygen release service were

CNY 91.25 billion and CNY 1462.99 billion, respectively. Agricultural products accounted for about 53% of the value of provisioning services, followed by husbandry products at about 30%. Forestry was very well developed, but its unit output value and total output value were not as good as those for agriculture, and the value provided by forestry was less compared to the share provided by agriculture, husbandry, and fishery, which was only 13% of agricultural products. During the 15 years, the value of tourism services has changed the most. Compared with 2005, the value of tourism services in 2020 increased by CNY 6963.72 billion, accounting for about 20% of GEP in 2020, which is an important figure that cannot be ignored.

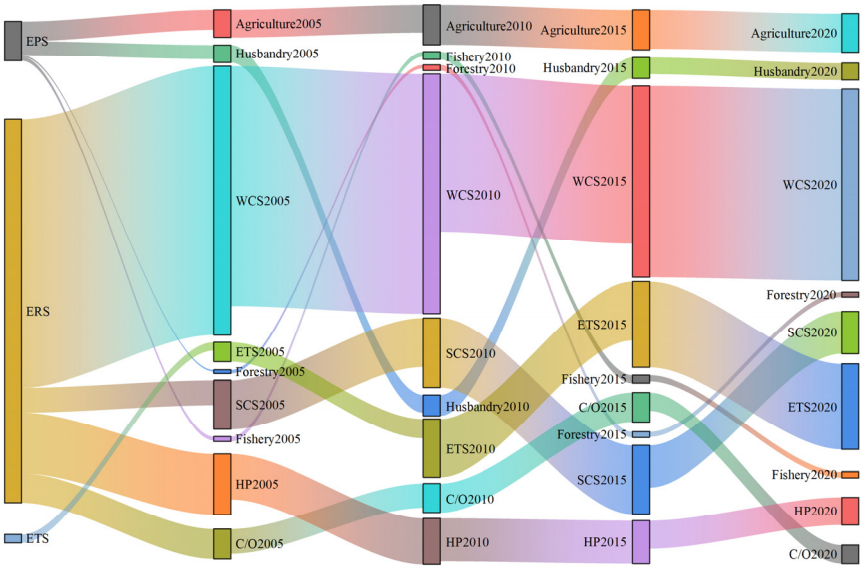


Figure 6. Cumulative change rate (%) of sub-indicators from 2005 to 2020.

4.2. Trends of Ecosystem Regulation Services from 2005 to 2020

The value of ecosystem regulation services was about 65–89% of GEP, which was the main component of GEP. The change in ERSs will have a crucial impact on GEP. From 2005 to 2020, the ecosystem regulation services showed an increasing trend, but there were differences among cities (Table 2). All the ESs in LZ, GG, YL, HC, and LB showed increasing trends, while one or two services decreased in other cities.

Table 2. Changes in regulation services from 2005 to 2020.

ZONE	WCS	SCS	C/O	Unit: billion t/a HP
Guangxi	2585.13	5509.52	3950.39	155.09
NN	54.22	198.63	−525.77	7.76
LZ	354.69	164.19	897.07	7.39
GL	1020.05	−461.76	2357.85	6.98
WZ	53.31	−12.80	177.05	1.15
BH	0.96	6.67	−3.05	0.05
FCG	−27.96	6.05	−95.67	1.13
QZ	16.37	38.98	−115.53	1.83
GG	30.23	31.88	53.22	1.38
YL	45.91	40.17	103.64	1.54
BS	246.60	4091.41	−373.67	77.03
HZ	51.43	−60.45	141.80	0.56
HC	690.02	1290.98	1909.42	35.78
LB	109.09	85.03	131.20	3.41
CZ	−59.80	90.55	−707.18	9.10

The extremely significant increase in water conservation service was in the north of GL, the north of LZ, and the middle of LB, which has a typical karst landscape, with GL taking priority, providing 39% of services. The significant reduction in water conservation services occurred in most areas of CZ and FCG, with a decrease of 59.8 billion t/a and 27.96 billion t/a respectively (Figure 7a). The spatial distribution of the carbon sequestration and oxygen release service showed a similar pattern to that of the water conservation service; the law is more prominent, with a trend of decreasing to increasing from southwest to northeast. Among them, CZ in southwest Guangxi had the largest decrease in carbon sequestration and oxygen release service, with a decrease of 707.18 billion t/a, and FCG had a significant decrease, representing arid areas and coastal areas, respectively. GL and HC in northeast Guangxi had the largest increase in the carbon sequestration and oxygen release service, reaching 60% and 48%, respectively, with corresponding values of 2357.85 billion t/a and 1909.42 billion t/a (Figure 7c). Soil conservation service remained basically unchanged in most areas of the whole region but increased significantly only in BS, providing 74% of services, with an increase of 4091.41 billion t/a; the significant decrease was mainly in GL and concentrated in the northern part of GL with a significant change, with a decrease of 461.76 billion t/a, followed by HZ and WZ, with a decrease of 60.45 billion t/a and 12.80 billion t/a, respectively (Figure 7b). Habitat provision service in all cities has increased. The significant increase was still mainly located in BS, and the contribution of BS to the rise of habitat provision service in the whole region has reached 50%. The significant decrease was distributed in the main urban areas of each city, and the degree of decrease was related to the level of urban development. Except for NN, FCG, BH, and YL, the spatial distribution patterns of habitat provision service change and soil conservation service change were similar, and there was a close relationship between them (Figure 7d).

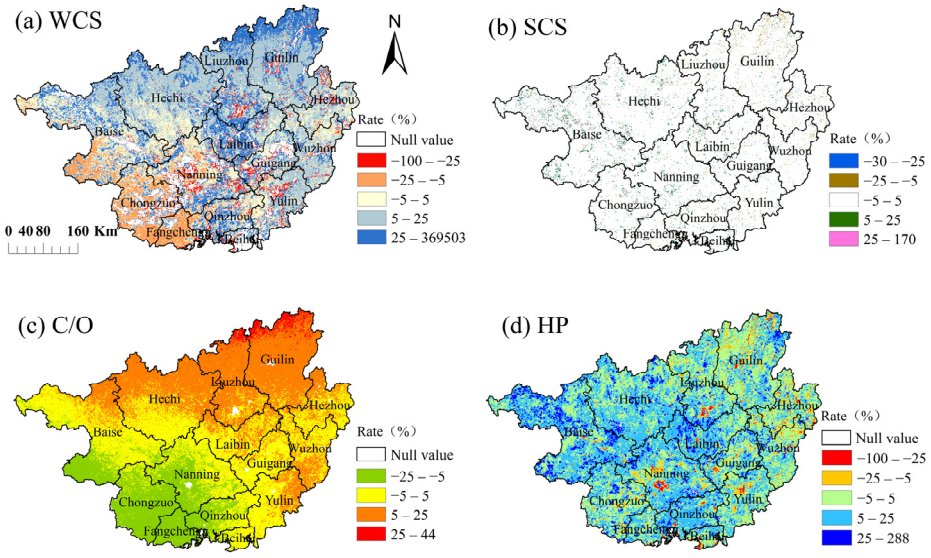


Figure 7. Distribution of ecosystem regulation services changes from 2005 to 2020.

4.3. Comparison between GEP and GDP

From 2005 to 2020, natural ecosystem protection and socio-economic development achieved coordinated development in Guangxi, and GEP and GDP showed upward trends (Figure 8). In 15 years, the GEP and GDP of the whole province increased by 134% and 492%, respectively.

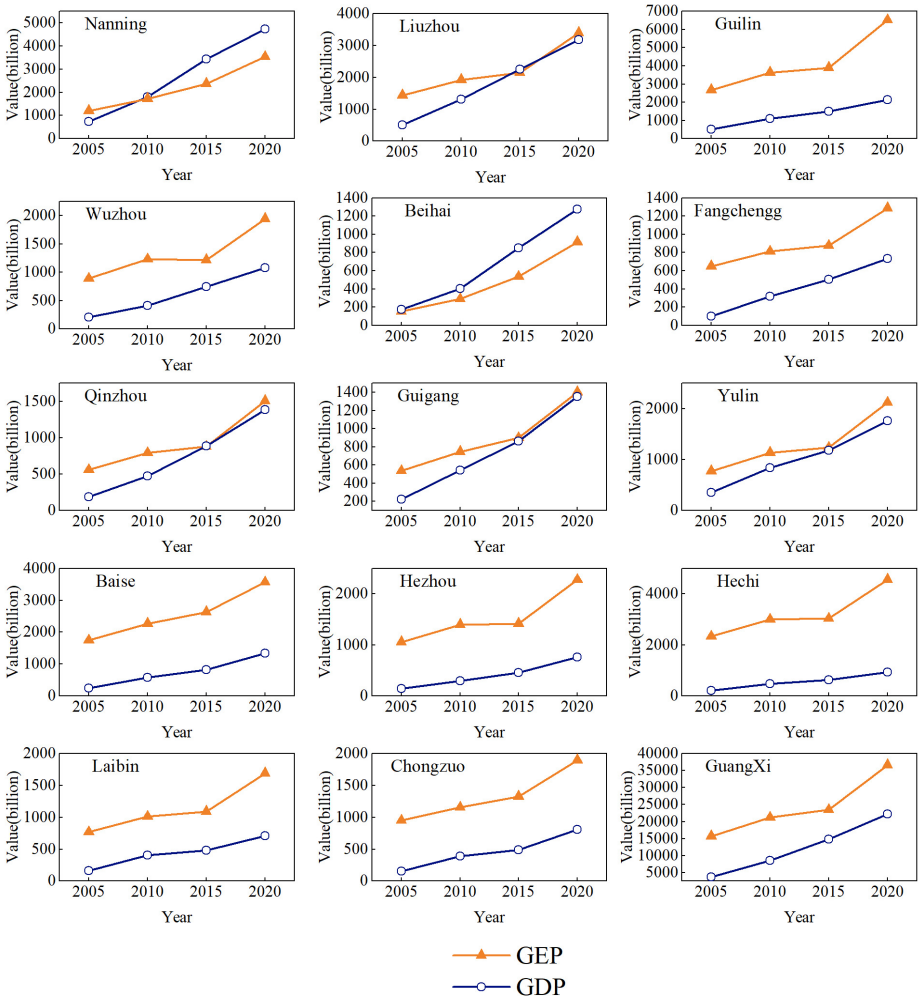


Figure 8. Comparison of GEP and GDP changes in various cities.

Looking at the changes in GEP and GDP in each municipality, although only NN's and BH's GEP were always lower than GDP, GEP and GDP showed an increasing trend during 2005–2020, as did all other municipalities, and the growth rate of GEP was significantly greater after 2015 than from 2005 to 2015, which may be closely related to the work and policy of comprehensively promoting water environment consolidation, strengthening the construction of nature reserves, and carrying out the red line delineation of ecological protection. For NN, the GDP of NN has exceeded GEP since 2010 and continued to grow rapidly. After the growth of GDP, GEP also showed a synchronous growth trend. Over 15 years, the GDP and GEP of NN increased by 373% and 445%, respectively. This shows that socio-economic development has not had a negative impact on NN's natural ecosystem. On the contrary, socio-economic development may promote the protection of the natural ecosystem and make GEP increase. However, BS and HC had extremely high GEP, despite being still relatively economically backward because they are located in a remote inland area, not giving full play to their ecological advantages like NN and GL. Although both GEP and GDP showed a growing trend, the difference between GEP and GDP had gradually decreased since 2015 in LZ, QZ, and GG, which indicates that, compared with other cities, these three cities could more rationally develop and utilize ecosystems, which can promote social and economic development.

5. Discussion

The natural ecosystem is an essential foundation for the sustainable development of the economy and society, and protecting the ecosystem helps to protect the homeland of

human beings. Most previous studies have focused on the ecological benefits of ecosystems, but the research on their economic benefits was limited [63]. In this study, the GEP of Guangxi in 2005, 2010, 2015, and 2020 was calculated using LULC, meteorological data, soil data, vegetation coverage, remote sensing data, and socio-economic data. The results show that many important products and services provided by natural ecosystems in Guangxi have tremendous economic benefits. GEP has increased from CNY 15,657.37 billion in 2005 to CNY 36,677.04 billion in 2020. Compared with other provinces, Guangxi is backward in terms of its economy, but GEP accounting makes it possible to transform ecological advantages into economic advantages.

The output values for agriculture, forestry, husbandry, and fishery used in the research and calculations herein refer to the total monetary values of all products of agriculture, forestry, animal husbandry, and fishery, which reflect the total achievements or scales of production in the various industries at that time according to the current price of that year. The calculation of GEP in Guangxi in this study is lower than that in previous studies [64] because of the difference in index selection and evaluation methods. In the selection of indicators, we only calculated the nine indicators listed in this paper. Compared with other GEP studies, we did not evaluate energy and flood storage but calculated the value of habitat provision service. In the evaluation method, especially for the accounting of regulating services value, previous studies mostly adopted the national average price. In contrast, this study determined the unit area cost of reservoir construction and the unit area cost of soil erosion control by collecting and sorting out the local investment amounts and construction areas in statistical yearbooks of various counties and cities in different periods. The difference between the value of the carbon sequestration service and oxygen release service and that of other studies is due to the difference in unit price (such as carbon tax, carbon trading, afforestation cost, industrial emission reduction cost, etc.) in different studies. Since the end of 2019, all industries have been affected by the COVID-19 pandemic. Although the number of tourists and tourism consumption in 2020 has increased significantly compared with 2015, this is due to the rapid development of tourism in Guangxi from 2015 to 2020. In 2015, total tourism consumption in Guangxi amounted to CNY 325.42 billion, CNY 558.04 billion in 2017, CNY 761.99 billion in 2018, and reached three times the 2015 level, with CNY 102.44 billion in 2019.

Guangxi is a famous forestry province, but the results of this study show that the contribution of forestry to GEP is lower than our estimate. Compared with the statistical data published by the Guangxi Zhuang Autonomous Region Forestry Bureau (http://lyj.gxzf.gov.cn/ (accessed on 2 March 2022)), this study's results are low. For example, based on the statistical yearbook, the output value of Guangxi forestry in 2020 was CNY 437.35 billion, while the official statistical result was CNY 7521 billion. The difference in the results mainly lies in the difference of statistical caliber: the officially counted forestry output value is the total output value of the primary industry (forest resources cultivation, forest products output, forest quality, etc.), the secondary industry (wood and economic forest product processing industry, forest product chemical industry, wood pulp and paper industry, etc.), and the tertiary industry (forest health care, forestry tourism and leisure services, eco-cultural industry, forestry exhibition, etc.). The data used in this study come from the statistical yearbook, which mainly counts the forestry output value of timber, medicinal materials, forest products, etc. Moreover, in order to facilitate comparison between different prefecture-level cities, the selected statistical indicators exist in all local cities, so the statistical results of forestry output value in this research are lower than the official statistics.

From the spatial and temporal changes relating to GEP, the values of provisioning services and tourism services are basically the same in terms of spatial distribution, but there are also subtle differences: for example, in 2010, YL had a good income from husbandry, and pig production accounted for a large proportion; QZ's fruit was the greatest contribution to the output value of agriculture, forestry, animal husbandry, and fishery; CZ is known as "China's sugar capital" and sugar cane was its pillar industry. As a result, each city

had its characteristic industries to support the development of provisioning services. In the tourism services, BH and FCG reflected the characteristics of coastal areas and had great advantages in developing the tourism industry. GL had the reputation of "The mountains and waters of Guilin are the finest under heaven." Meanwhile, NN is closer to the subtropical region and has a strong Southeast Asian flavor, so the tourism industry became its advantage. At the same time, the tourism development of GL and NN has also played a role in radiating the surrounding areas. With the development over time, the number of tourists and income from other counties and cities are also gradually rising, such as in LZ, BS, and CZ.

By 2020, the GEP sizes of Guangxi cities were ranked as follows: GL > HC > BS > NN > LZ > HZ > YL WZ > CZ > LB > QZ > GG > FCG > BH. GL, NN, LZ, and YL had both advantages in economy and ecology, while HC, BS, HZ, CZ, and LB were underdeveloped in their economies but rich in ecological assets. It can be seen that Guangxi had no consistent development of economy or ecology unilaterally. In addition, the study also found that NN and BH have higher tourism service values, while other cities have higher water conservation service and carbon sequestration and oxygen release service capabilities. Against the background of vigorously promoting ecological construction advocated by the state, especially against the background of global carbon neutrality and ecological compensation, Guangxi and all cities have their advantages; it is necessary to carry out scientific planning of urban development and targeted protection and management of ecosystems and to try to convert the ecological benefits of ecosystems into economic benefits through ecological compensation [65], that is, to convert the "green water and green mountains" into real "golden mountains" to achieve sustainable growth of the regional economies.

It is meaningful to carry out GEP accounting, which could provide a scientific understanding of the unrealized value of the services provided by the ecosystem. According to the GEP accounting results for Guangxi from 2005 to 2020, the following suggestions and countermeasures for ecological protection are put forward: (1) Regular and long-term GEP accounting should be carried out to assess the ecological environment over time, especially in areas with fragile ecological environments and areas with declining ecological service functions found in accounting. GEP accounting and monitoring are helpful to quickly find problems and put forward relevant countermeasures, such as whether it is necessary to focus on regional protection or what kind of ecological engineering construction should be implemented to solve the problems to adjust the ecology. (2) Due to the complexity and differences in geographical regions and ecosystems, the evaluation method should be further improved to form a unified GEP evaluation index system that can be popularized at different scales and in different regions to facilitate a more comprehensive and accurate comparative analysis of GEPs in different places in the later period. What is needed is to be able to simulate and forecast results and changes on the basis of GEP accounting. (3) This study involved comparative accounting in time series and among cities, providing an analysis of GEP results for Guangxi in 2020 and the spatial and temporal changes in GEP over a period of 15 years. In future studies, we will build on this research to conduct more detailed studies using more accurate and indicator-rich ecosystem service datasets, such as GEP accounting for one year for each city, multi-year comparisons, and accounting for smaller administrative areas such as counties and townships.

6. Conclusions

This study used multi-source data and multi-indicators to calculate the changes in GEP in Guangxi from 2005 to 2020. The main conclusions are as follows.

1. Guangxi's natural ecosystem has a considerable value. In 2020, GEP reached CNY 36,677.04 billion, about 1.66 times the GDP. Among the many accounting indicators, the value of water conservation service was the largest, at CNY 16,233.79 billion, accounting for about 44% of GEP. From 2005 to 2020, GEP increased significantly, with the GEP increasing by 134% in 15 years. However, the proportions of the values

of provisioning services, regulation services, and tourism services were obviously different among cities.

2. ERS was the main component of GEP, showing a spatial distribution pattern that was high in the north and low in the south. From 2005 to 2020, ERS generally showed an increasing trend. Among the four ESs, the water conservation service accounted for more than 52% of ERS, followed by the soil conservation service, which accounted for about 15% on average.
3. From 2005 to 2020, GEP and GDP showed a synergistic upward trend, but there were differences among prefecture-level cities. Due to their location in the remote inland area, BS and HC were relatively backward economically but had extremely high GEPs. Through rational development and utilization of ecosystems, as in LZ, QZ and GG, ecological advantages could be transformed into economic advantages to promote economic development.

Author Contributions: Conceptualization, L.W. and K.S.; methodology, L.W. and K.S.; software, L.W.; validation, X.Z., Z.Y. and Z.C.; formal analysis, L.W. and K.S.; resources, K.S.; data curation, L.W., C.W., Z.L. and Y.Z.; writing—original draft preparation, L.W. and K.S.; writing—review and editing, K.S. and X.J.; visualization, L.W., C.W., Z.L. and Y.Z.; supervision, project administration, K.S.; funding acquisition, K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Talent Introduction Program of Guangxi University, grant number A3360051018 and the Youth Science Foundation of National Natural Science Foundation of Guangxi Province (2022GXNSFBA035570).

Institutional Review Board Statement: This study did not require ethical approval.

Informed Consent Statement: Not applicable.

Data Availability Statement: The meteorological data, soil data, land cover data are available in this research, upon any reasonable request, by emailing the authors.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could appear to have influenced the work reported in this paper.

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