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Research on the Response of Ecosystem Service Function to Landscape Pattern Changes Caused by Land Use Transition: A Case Study of the Guangxi Zhuang Autonomous Region, China

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Abstract: Land use transitions cause reconfigurations of regional landscape patterns which can further change the regional ecosystem service functions and its values, especially in environmentally fragile regions. Firstly, this paper theoretically examines the relationships between land use transitions, landscape pattern evolution and the responses of ecosystem service functions in the Guangxi Zhuang Autonomous Region (Guangxi). Then, it explores the spatio-temporal evolution features of land use transition by using land use change matrices, examines landscape patterns by using the landscape pattern index, and studies ecosystem service value (ESV) by revising the coefficients of ESV per unit area. Finally, focus is placed on the empirical analysis of ESV responses to landscape pattern evolution caused by land use transitions in Guangxi. The results show that: (1) Guangxi has undergone an overall intensity-changing process of land use transition at a moderate rate during 1990–2010 and at a drastic rate during 2010–2018. In general, the area of construction land and waterbodies has increased, while forested land, grassland and farmland have decreased. Landscape fragmentation and heterogeneity are higher in the central area than that in the surrounding areas, while patch aggregation and connectivity show an opposite trend. Forested land patches are highly clustered, while grassland and farmland are fragmented and scattered and construction land patches tend to have aggregated. (2) The total loss of ESV has reached 20.56 billion RMB in Guangxi, and all areas' single ESVs have decreased to different degrees during the past 28 years. Spatially, the ESV distribution shows a differentiated pattern of low in the central plain and high in the surrounding mountain regions which are mainly dominated by high-value zones. (3) The total ESV has significant positive correlations with the largest patch index (LPI), COHESION and the Aggregation Index (AI), and significant negative correlations with the Number of Patches (NP) and the Shannon Diversity Index (SHDI), while the correlation with the Landscape Shape Index (LSI) is not significant, indicating that the influence on ESV caused by landscape pattern evolution varies greatly. (4) The change of land area and multi-directional shifts among different land use types caused by land use transitions in Guangxi could both lead to the evolution of landscape patterns. Further, ecological service function responded obviously to the landscape pattern evolution in Guangxi, causing significant changes in strengthening or weakening of the ecological service function and its value. This systematic analysis should help coordinate the relationship of regional land use regulation, landscape pattern optimization and ecosystem operation in Guangxi or even China.

Keywords: land use transition; landscape pattern change; ecosystem service function response; correlation analysis

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1. Introduction

Assessing the spatio-temporal dynamics of land use changes and their consequences on the landscape and ecological functions is essential for understanding the relationships between social and natural phenomena, especially in ecologically fragile areas, and further helps to make more precise decisions that can sustain the balance between economic development and socio-ecological process [1]. Land use transition, as part of one of the most efficient ways of conducting comprehensive research on land use/cover change (LUCC) [2,3], refers to changes in the temporal sequence of land use morphology in a country or region which usually correspond to different regional, economic and social development stages. Rapid economic and urban development have intensified the extent of land use in terms of quantity, structure and function, especially in developing countries such as China, Thailand and Vietnam, which has then led to changes in regional landscape patterns [4–6]. A landscape pattern is a spatial reflection of the shape, proportion and configuration of land cover [7], which is the best perspective from which to explore the mechanism and process of the evolution of coupled human and natural system [8]. Changes in landscape patterns can be regarded as one of the most obvious symbols of land use transition [9], which can further cause dramatic influences on regional ecological processes and eventually ecosystem service functions. For example, the ecological processes of material and energy flow, soil moisture and nutrient maintenance etc., can be associated with various impacts on the delivery of ecosystem goods and services used to serve human needs [10,11], which then produces corresponding feedback into the ecosystem [12].

It is believed that ecosystem services provided by ecological processes are the basic natural resource fundamentals for the sustainable development of human beings [13–15], and their change in value can reflect the degree of impact caused by economic development on resources and the environment [16]. Therefore, the scientific assessment of ESV is undoubtedly the basis for implementing land use and ecological management [17]. The current research on land use transition not only focuses on transition itself, represented by land change monitoring [18], transition theory and mode [19] and driving mechanisms [20,21], but also expands to its ecological effects [22,23]. In general, most studies focus on the land use change monitoring itself [24] or the ecological effects, such as those on ecological service functions [25,26], but both theoretical and empirical studies have paid little attention to the evolution of landscape patterns and the corresponding effects on ecological service functions caused by land use transition [27,28]. In fact, land use directly affects the regional landscape pattern, then influencing the ecosystem service functions and producing corresponding feedback later [29]. However, questions remain: How are the internal connections and feedback performing between these three concepts? To what degree do they relate to each other, especially the landscape pattern changes and ecological service functions? Could empirical analysis give us a clearer picture? All these need to be studied further.

Methodologically, the landscape pattern index based on the morphology of land use is an important method of landscape spatial pattern analysis, which makes it possible to analyze the correlations between ecological processes and landscape patterns [30]. In the practical world, with the increase of population and the development of urbanization, the pressure caused by the shortage of land supply and decline of quality in the ecological environment's quality faced by human beings is growing dramatically, such as the environment pollution, soil degradation and biodiversity reduction [31]. Therefore, this research was developed in response to the increasing demand for natural resources due to population growth, which leads to land use transition and in turn causes the evolution of landscape patterns and changes of ecosystem service functions. Firstly, we attempt to establish a theoretical framework of "land use transition, landscape pattern evolution and ecosystem service function response" to examine the internal relations and feedback among these three. Then, we draw on empirical analysis carried out in Guangxi, due to its richness in natural resources and fragile ecological environment, to further examine the interactions proposed in the theoretical framework by using GIS and landscape ecology methods. By doing this, we aim to coordinate the relationship of regional land use regulation, landscape pattern optimization and ecosystem operation, hopefully providing scientific references for economic development, land resource utilization and ecological environment protection in fast-developing places, especially ecologically fragile regions in developing countries.

2. Materials and Methods

2.1. Study Area

Guangxi is located in Southwest China (104°28′–112°04′ E, 20°54′–26°24′ N) and is inhabited by the Zhuang ethnic minority, with excellent seaports and rich biological resources. It is surrounded by mountains and plateaus, with flat terrain in the center and south which is well known as the "Guangxi Basin" (Figure 1). In 2018, the urbanization rate was 50.22% [32], indicating that Guangxi was in the developing stage of rapid expansion of urban population and fast industrial development, according to the urbanization process curve of Northam "S-type", which means it may be faced with the dual tasks of accelerating economic and social development while protecting the ecological environment. Affected by rapid economic and industrial reforms and the adjustment of its agriculture structure, Guangxi has experienced significant changes in land cover and landscape pattern [33]. At the same time, Guangxi is located at the edge of China's second ladder, with complex terrain and fragile ecological environments, such as the widespread distribution of karst rocky desertification and serious soil erosion problems [34], and thus has become one of China's most ecologically sensitive areas.

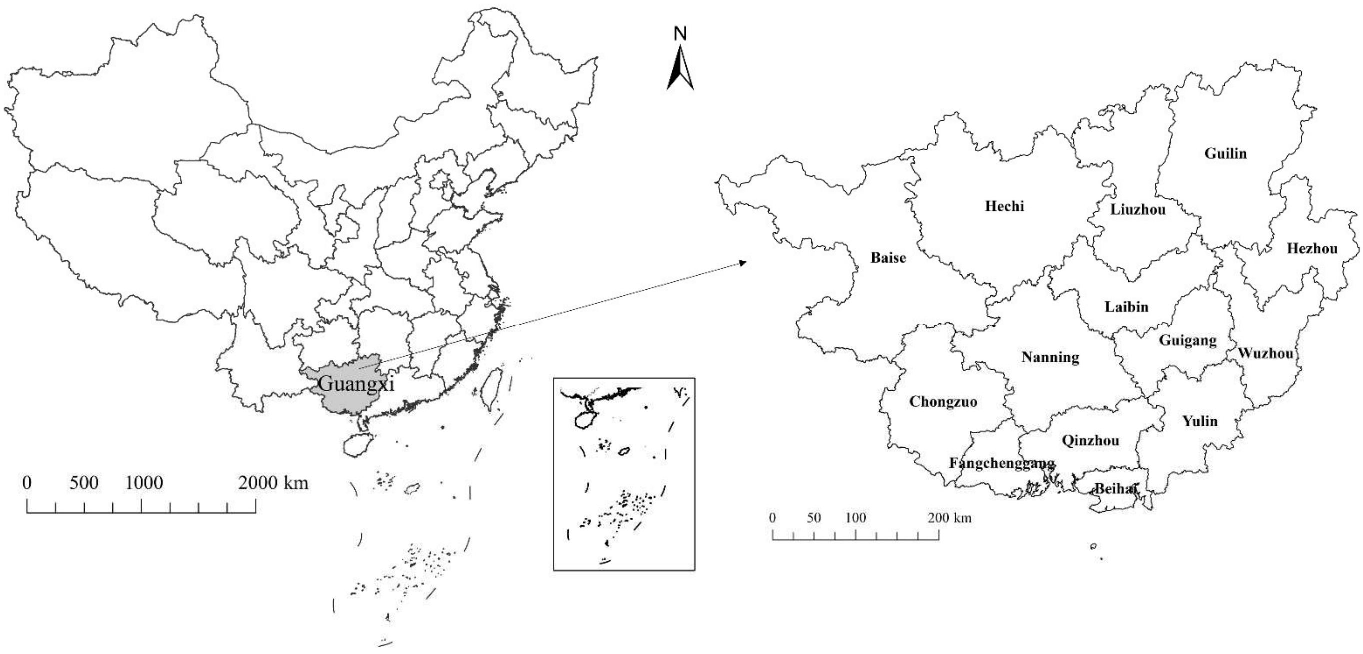

Figure 1. Location of the study area.

2.2. Data Sources

The vector data of land-use and land-cover (LULC) change were obtained through interpretation of Landsat TM imagery from 1990, 2000 and 2010 and Landsat OLI satellite imagery from 2018, sourced from the Resource and Environment Science Data Center of the Chinese Academy of Sciences, all with a spatial resolution of 30 m. After geometrical image correction and geo-referencing, the average location error was estimated at less than 50 m (about two pixels). An outdoor survey and random sample check verified that the average interpretation accuracy for LULC was 91.2% [35]. According to the classification system of China's multi period LULC remote sensing monitoring data, the land types in the study area were classified into six first-class categories: farmland, forested land, waterbody, grassland, construction land and unused land. The data of grain yield and grain price in

Guangxi from 1990 to 2018 were derived from the Statistical Yearbook of Guangxi Zhuang Autonomous Region and the China Price Yearbook (1991–2019) [32].

2.3. Research Methods

2.3.1. Landscape Pattern Index Method

Landscape pattern is a representation of landscape heterogeneity and is the result of the action of various ecological processes at different scales [36]. The landscape pattern index can reveal information about landscape forms and reflect the structure and spatial distribution of different ecological processes [37]. Based on the research purpose and the ecosystem characteristics of the study area, six indices are selected from the patch type level and landscape scale level respectively to represent the spatio-temporal variation of the landscape pattern: NP, characterizing the patch fragmentation; LSI, characterizing the patch regularity; LPI, characterizing the proportion of the largest patch to the whole landscape; AI, characterizing the connectivity among patches of each landscape type; COHESION index, characterizing the patch aggregation and dispersion status; and SHDI, characterizing the landscape's heterogeneity [38,39]. The indices at the patch-scale level mainly include NP, LPI, AI and COHESION, while the landscape-scale level indices mainly include NP, LSI, AI and SHDI. In particular, NP and AI can be both regarded as patch type level and landscape scale level index. The detailed connotation and calculation formula for the selected six landscape indices can be found in the book of Landscape Ecology [40], and the Fragstats 4.2 software is used to calculate values of the landscape indices.

2.3.2. Ecosystem Service Value Evaluation Method

Here, the evaluation of ecosystem service value mainly includes the method based on the price of per unit ecosystem service product and the method based on the equivalent value factor per unit area. The first method has a high standard for data and complex calculation and is difficult to use to form a unified evaluation norm to be widely used [41–43]. However, the second method has the advantages of easy access to data, simple calculation and its ability to be used widely and adapt to the needs of multi-scale research [44]. Therefore, by drawing on the related research results [45,46] and the Chinese Ecosystem Service Value evaluation model proposed by Xie et al. [47], this paper adopts the method of the equivalent value factor per unit area to calculate the coefficients of ESV per unit area in Guangxi.

The economic value of the annual grain output per ha of farmland in Guangxi was revised firstly: according to the statistics of Guangxi, the average grain yield in Guangxi during 1990–2018 was 4697.34 kg/(ha·a), the average grain price was 4.81 yuan/kg in 2018, and the ESV was 1/7 of the economic value of food production per ha of farmland [48]; therefore, the economic value of farmland was 3174.06 yuan/(ha·a). Then, the coefficients of ESV per ha in Guangxi were obtained (Table 1). Exploring the spatial changing trends of ESV per unit area could reflect the difference of land use effects on regional ecosystem caused by human activities. Based on the land use data during 1990–2018, the whole study area was divided into 2578 regions by using the fishing network tool in ArcGIS 10.3, then the kriging interpolation method was used to calculate the ESV per ha. Each land type corresponds to its own biome: farmland, forested land, grassland, waterbody and unused land refer to the ecosystems of cropland, forest, grass/rangelands, lakes/rivers and desert, respectively [49]. The construction land was not included as its ESV was almost 0. The ESV models were as follows [50]:

$$ESV = \sum_{k=1}^{m} A_k \times C_k \tag{1}$$

$$ESV_j = \sum_{y=1}^{n} A_k \times C_{ky} \tag{2}$$

where ESV is the total value of ecosystem services; ESV_j is the single ESV of the biome j; A_k is the area of the land type k; C_k is the value coefficient for land type k; and C_{ky} is the value coefficient of the single ESV.

Table 1. Coefficients of ESV per unit area in Guangxi. (RMB/ha/year).

Ecosystem Service Function Type	Single Ecosystem Service Function Type	Farmland	Forested Land	Grassland	Waterbody	Unused Land
Providing service	food production	3174.06	317.41	952.22	317.41	31.74
	raw material	317.41	8252.56	158.70	31.74	0.00
Regulating service	atmospheric regulation	1587.03	11,109.21	1587.03	0.00	0.00
	climate regulation	2824.91	8569.96	2824.91	1460.07	0.00
	water conservation	1904.44	10,156.99	2539.25	64,687.34	95.22
	waste treatment	5205.46	4158.02	4158.02	57,704.41	31.74
Supporting service	soil conservation	4634.13	12,378.83	6189.42	31.74	63.48
	biodiversity	2253.58	10,347.44	3459.73	7903.41	1079.18
Cultural service	aesthetic landscape	31.74	4062.80	126.96	13,775.42	31.74

2.4. Theoretical Analysis Framework of Land Use Transition, Landscape Pattern Evolution and ESV Response

Driven by economic and social development, land engineering projects and land use regulation based on the natural resource and environment [51], regional land use experiences different and ongoing transition processes. As we all know, land is the carrier of economic and social development, but more importantly, it is the fundamental basis of ecological process, which means land use can directly or indirectly affect the evolutionary process of landscape patterns it consists of, then affecting the size, quality, structure and ecological function of regional ecosystem [52,53]. By constructing a theoretical analysis framework (Figure 2), this paper analyses the intrinsic relations and connections among the land use transition, landscape pattern evolution and ecosystem service function responses.

On one hand, the increase or decrease of land area affects the regional landscape pattern directly and then indirectly has an influence on the ecosystem service functions [54], such as the way a reduction of forested land and farmland due to extensive expansion of urbanization construction deepens the irregularity and fragmentation of patch shapes and affects the supply of ecological services such as climate regulation and water conservation [55]. On the other hand, intensive/extensive land use can strengthen/weaken the predominance of matrix patches in small areas, making similar patches tend to agglomerate/disperse, and improve/reduce the stability of the regional ecosystem, respectively [56]. The spatial agglomeration or dispersion of patches influences ecological service functions through modifying landscape patterns, such as enhancing the internal connectivity of waterbodies, forested land or construction land. This can reshape patch shapes and improve the function of water conservation and ecological aesthetic services, while continued fragmentation of farmland and grassland can reduce the function of food production and soil maintenance services. In addition, one-way or multi-way transitions among different land types can also affect the landscape's heterogeneity and richness; for example, massive construction occupies farmland and grassland, accompanied by the improvement of farmland and the scale of grassland fragmentation. As construction land increases, it is becoming more concentrated in practice due to the lack of division of ecological land, such as the green space in cities, which would reduce the ecological service functions both in the transferred out and in areas.

While landscape pattern evolution affects ecological service functions, the latter also makes positive or negative feedback, correspondingly. The improvement of ecological service functions demonstrates that the circulation of ecosystem material, energy, etc. is continuously improving [57], which promotes the supply of regional ecological goods, the agglomeration of landscape patches and more rational use of land resources through taking more advanced measures, such as comprehensive land consolidation, ecological restoration projects, etc.; otherwise, the decline of ecological service functions indicates that the ecosystem circulation is blocked, usually accompanied by environmental pollution, soil and water loss, desertification, a worsened man-land relationship, scattered and fragmented landscape patches, and land uses need urgent optimization and adjustment through proper actions, such as taking strict measures to protect the ecological land, repair the damaged land and restore the ecosystem. Based on this, the process and direction of land use transitions should focus on carrying out a series of land engineering projects, such as comprehensive consolidation and ecological restoration, supported by innovations of land use policy, so as to promote the scientific transition of regional land use, optimize the configuration of landscape patterns and realize the goal of a healthy and stable ecosystem [58].

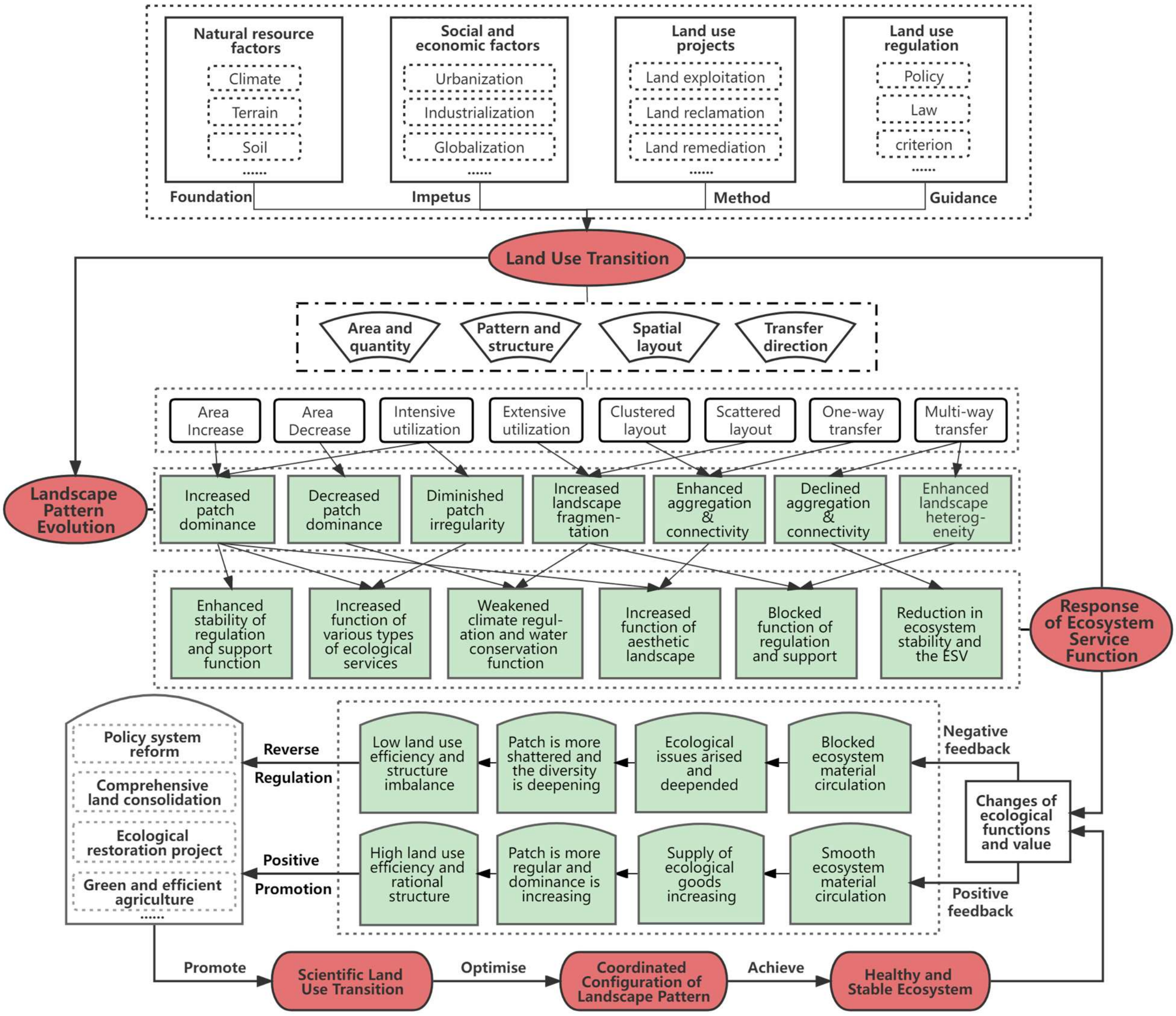

Figure 2. Theoretical analysis framework of land use transition, landscape pattern evolution and ecosystem service function responses.

3. Results

3.1. Spatio-Temporal Characteristics of Land Use Transition and Landscape Patterns Evolution of Guangxi

3.1.1. Spatio-Temporal Characteristics of Land Use Transition

In general, during 1990–2018, Guangxi underwent a process of changing land use transition intensity; i.e., from moderate at the beginning to drastic later, with the area of construction land, waterbodies and unused land increasing, while farmland, forested land and grassland decreased. Specifically, the expansion of construction land was significant, with its area increasing by 205,238 ha, while the area of forested land and grassland decreased by 661,314 ha and 95,146 ha, respectively.

The transition process of each land use type in Guangxi was obtained by using land change matrices (Tables 2 and 3). It is noteworthy that the intensity of land use transition during 2010–2018 was much higher than that during 1990–2010, mainly characterized as follows: (1) the area of construction land, forested land and farmland changed from 0.42 million ha, 15.56 million ha and 5.17 million ha in 1990 to 0.45 million ha, 15.55 million ha and 5.14 million ha in 2010, respectively. The ratio of construction land's increase was 8.30%, while the ratio of forested land and farmland's decrease was only 0.07% and 0.57%, respectively, compared to 1990. The expansion of construction land was mainly derived from farmland and forested land, with 804.75 ha of farmland and 230.98 ha of forested land converted to construction land, respectively. Meanwhile, 1226.18 ha of forested land was converted to farmland. (2) During 2010–2018, the land use transitions were more dramatic, due to the significant development of urbanization and the economy in Guangxi, including the policy and practice of land consolidation and construction of industrial and mining transportation, which all resulted in the expansion of construction land and waterbodies, respectively increasing from 450,840 ha and 411,216 ha up to 621,514 ha and 416,133 ha, with an increase of 37.86% and 1.20%. The significant reduction in the area of forested land and grassland was due to the fact that the scale of their transfer out was much larger than that of their transfer in, resulting in a serious decline of forested land and grassland, with a decrease rate of 0.24% and 1.14%, respectively.

Table 2. Land use change matrix of Guangxi during 1990–2010 (ha).

1990	2010						
	Farmland	**Forested Land**	**Grassland**	**Water Body**	**Construction Land**	**Unused Land**	**Total**
Farmland	49,705.40	826.90	116.65	190.43	804.75	0.97	51,645.1
Forested land	1226.18	153,392.55	604.33	182.65	230.98	0.85	155,637.54
Grassland	187.09	1239.41	20,020.82	46.55	76.14	0.12	21,570.13
Water body	97.73	54.10	24.98	3435.77	32.97	3.98	3649.53
Construction land	151.98	28.33	11.56	24.29	3948.13	0.28	4164.57
Unused land	0.25	0.54	0.50	1.16	0.01	34.01	36.47
Total	51,368.63	155,541.83	20,778.84	3880.85	5092.98	40.21	236,703.34

Table 3. Land use change matrix of Guangxi during 2010–2018 (ha).

2010	2018						
	Farmland	**Forested Land**	**Grassland**	**Water Body**	**Construction Land**	**Unused Land**	**Total**
Farmland	50,753.48	12.40	8.28	21.61	574.31	0.77	51,370.85
Forested land	14.17	155,000.49	159.21	19.68	354.81	2.83	155,551.19
Grassland	0.63	172.41	20,477.69	31.84	97.94	0	20,780.51
Water body	0.84	0.39	2.87	4062.53	43.36	1.83	4111.82
Construction land	4.45	3.07	2.05	4.29	5135.82	0	5149.68
Unused land	0.00	0.00	0.45	1.44	0.96	37.44	40.29
Total	50,773.57	155,188.8	20,650.55	4161.39	6207.2	42.87	237,004.34

Spatially, there was a significant multi-way characteristic of land use transition, i.e., each land use type could transfer to several other types at the same time and vice versa. A large amount of forested land and grassland was converted to construction land, and some to farmland (Figure 3). Further, natural disasters and overgrazing also led to serious degradation of forested land and grassland. For example, in the central basin of Guangxi, the scale of the transfer in of construction land was the largest; also, a large amount of grassland along the southern coast was transferred to construction land, farmland and waterbodies. At the same time, some forested land and grass land in the surrounding hilly areas have been gradually restored via transfer in from other land types. Over the past 28 years, the huge differences in land use transition in terms of the different time period and land use types, and the obvious multi-directional transfer, indicate that the land use of Guangxi was in a violent and unbalanced situation.

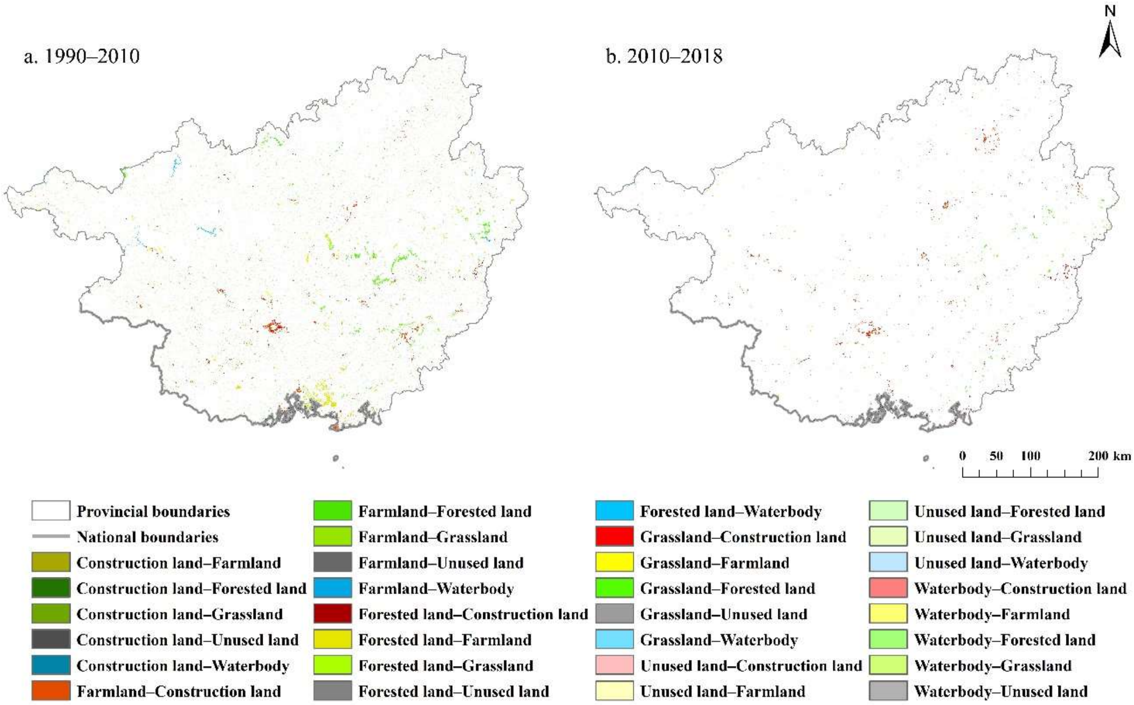

Figure 3. The spatial distribution of land use transitions in Guangxi during 1990–2018.

3.1.2. Spatio-Temporal Characteristics of Landscape Pattern Change

At the patch-scale level, the changes of the landscape pattern were very significant during 1990–2018 (Table 4). The patch fragmentation of farmland and grassland was the highest and the patch shapes were becoming more irregular. It is noteworthy that the patch fragmentation of forested land increased by about 52%, from 202 to 307, during 1990–2018, which was mainly caused by frequent and massive transfers in/out. The connectivity between old and new patches of construction land was strengthened and tended to aggregate. As the basic patch type of the study area, the forested land had the highest degree of dominance, while the connectivity of water patches became more complicated and their spatial accessibility needed to be strengthened.

Specifically, the NP of farmland first dropped and then rose, while the values of AI and COHESION changed little, indicating that farmland was deeply disturbed by human activities and had a high degree of spatial fragmentation. Interestingly, although the forested land covered the largest area, its highest value of NP was only 307, which means it had high regular patch shape and integrity. Its LPI and AI were as high as 63.64 and 75.64, respectively, which affected the landscape pattern with absolute dominance in Guangxi. The NP value of grassland was 1686 in 2010, which was the highest among all the land use types and almost five times that of the forested land. Further, the COHESION and AI of grassland patches showed an upward trend indicating the aggregation degree was improving and the situation of high fragmentation was ameliorating. The construction land kept expanding during the study period accompanied by the increasing patch fragmentation. From the dynamics of COHESION and AI value, the spatial accessibility among construction land patches was enhanced and it tended to aggregation. The decrease of COHESION and AI values of the waterbodies indicated that its internal accessibility was weakening, while the opposite trend of COHESION and AI values was caused by the development of green aquaculture, which reduced the impacts to the water landscape and its spatial connectivity gradually increased. The patches of unused land were scattered spatially and did not show any significant changing characteristics.

Table 4. Landscape pattern indices at patch type level during 1990–2018 in Guangxi.

Landscape Index	Year	Forested Land	Farmland	Grassland	Water Body	Construction Land	Unused Land
NP	1990	202.00	1454.00	1446.00	417.00	502.00	6.00
	2000	196.00	1452.00	1419.00	426.00	515.00	6.00
	2010	308.00	1635.00	1686.00	549.00	604.00	5.00
	2018	307.00	1652.00	1689.00	657.00	556.00	5.00
LPI	1990	63.40	4.35	0.36	0.03	0.05	0.01
	2000	63.64	4.31	0.36	0.05	0.06	0.01
	2010	63.25	4.20	0.25	0.04	0.09	0.02
	2018	63.09	4.17	0.25	0.15	0.04	0.00
COHESION	1990	99.81	90.79	59.97	29.52	24.34	0.00
	2000	99.82	90.82	60.00	33.56	28.10	0.00
	2010	99.83	91.51	60.35	31.68	35.27	0.00
	2018	99.83	91.17	60.34	43.38	30.75	0.00
AI	1990	75.64	41.90	23.98	12.03	11.12	0.00
	2000	75.60	41.62	23.66	14.13	13.62	0.00
	2010	75.33	41.82	25.10	13.98	15.59	0.00
	2018	75.25	41.43	25.15	20.15	13.64	0.00

At the landscape-scale level, the difference of spatial distribution of landscape patterns reflected by the NP and LSI was also very significant in Guangxi, characterized by an increasing degree of fragmentation, diversification and obvious regional differences mainly due to massive urban expansion and land exploitation (Figure 4). In terms of spatial distribution, the fragmentation was higher in the central than that of the surrounding area, and higher in the south than that of the north. The high-value regions of NP were mostly distributed in the middle plains of Guangxi where the landscape was interlaced, as the patches were complicated and diversified due to the higher intensity of human activities compared to mountain areas. In recent years, Guangxi has made great efforts to implement land consolidation and construct beautiful villages in rural areas; as such, the construction land has tended to converge while expanding outward and the degree of fragmentation has been alleviated. Further, its SHDI rose while AI was falling, which showed the upward trend of landscape heterogeneity and structural complexity. This could be attributed to the narrowed proportion gap among different land use types which promoted the diversified and balanced development of the landscape in Guangxi. The low value area of SHDI was mainly distributed in the northern plateau and the eastern mountainous areas with high proportion of forest landscape. Further, the central plain was strongly disturbed by human activities, with complicate layout composed by forested land, grassland, farmland, rivers, cities and villages, etc., which all led to the intensified diversity and richness of various landscapes in Guangxi.

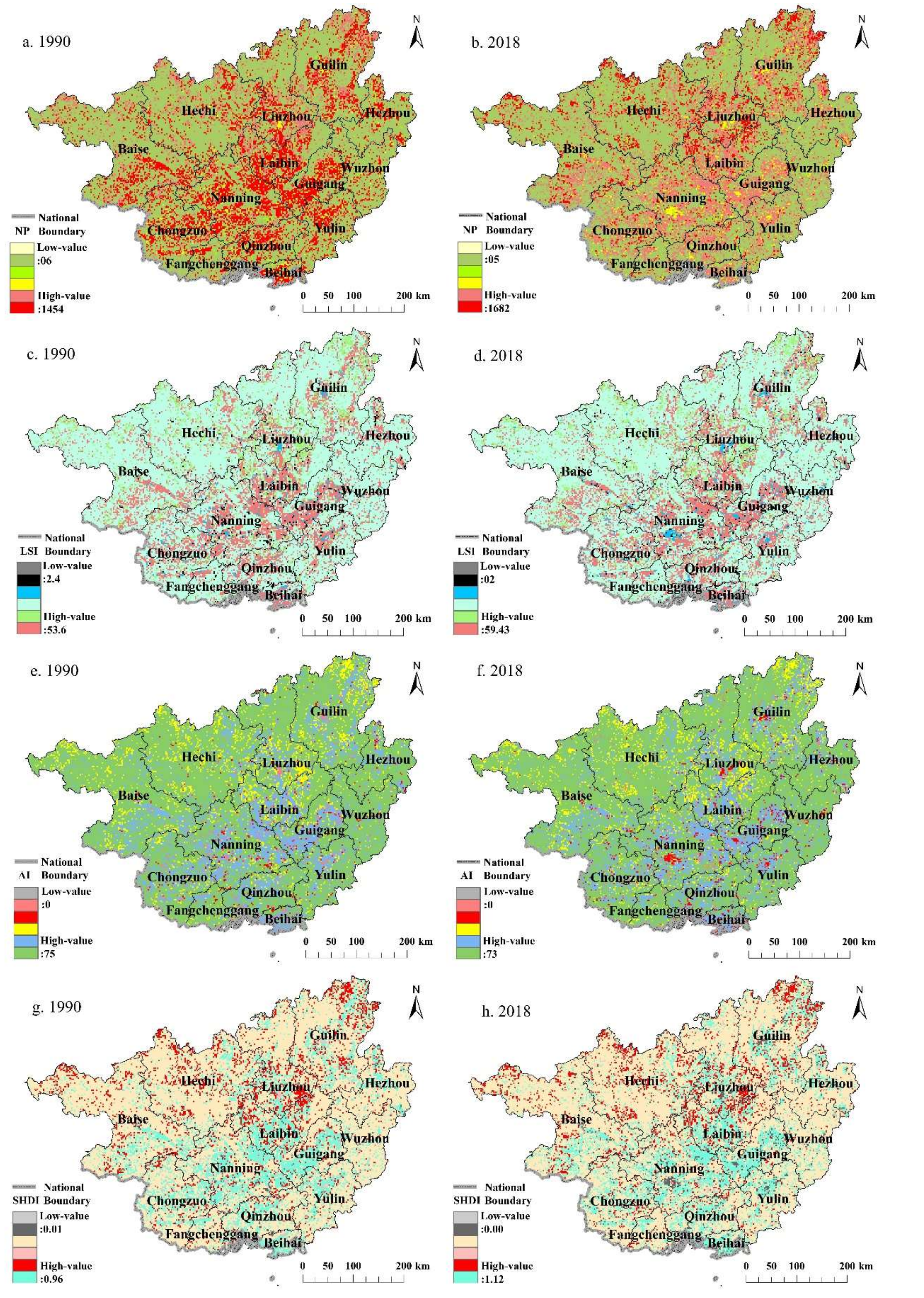

Figure 4. Spatio-temporal distribution of NP, LSI, AI, SHDI at the landscape scale level in Guangxi.

3.1.3. Landscape Pattern Changes Caused by Land Use Transition

Through the above analysis, it can be clearly seen that the changes of land use area and the multi-directional transfer can both lead to the evolution of landscape patterns. Over the past 28 years, the land use in Guangxi was characterized by the significant reduction of farmland, forested land and grassland and the growth of construction land and waterbodies, which correspondingly caused a drop of landscape dominance and improvement of overall heterogeneity at the patch-scale level. Although the patch fragmentation was relatively high, it still showed a decreasing trend gradually. For example, the landscape dominance of forested land was the highest, but with the decrease of forested land area, its LPI value reduced from 63.40 in 1990 to 63.09 in 2018 showing that its landscape dominance was declining. Due to the decreased proportion gap among different land use types in Guangxi, the complexity of patch shape and landscape richness were continuously improving at the landscape scale level. For example, the highest values of LSI and SHDI increased from 53.6 and 0.96 in 1990 to 59.43 and 1.12 in 2018 respectively. As such, the evolution of the landscape pattern could be obviously regarded as the results of positive or negative response to the increase or decrease of different land use types both at the patch-type level and landscape-scale level. In addition, the difference in land use transitions between the two periods also produced different impacts on the landscape pattern. For example, the growth of construction land was relatively stable in the early time and significantly accelerated later, resulting in a changing trend of first increase and then decrease in the NP and LPI values, which showed that the landscape pattern responded differently according to the varying intensity of land use transition.

Before 2010, the landscape patches had low fragmentation and regular shapes, also because of the relatively slow and moderate transition process. Then, with the development of urbanization and agriculture modernization, significant and frequent multi-way transfers occurred at different regions among different land use types, and the landscape pattern dominated by forested land and farmland gradually turned into more diversified and equilibrium pattern. Due to the high frequency of multi-directional transfers among different land use types, such as the transfer from forested land and grassland to farmland and construction land, farmland to construction land and the mutual transfer between forested land and farmland, the regional landscape pattern was dramatically modified. For example, there was about 1239.41 ha of grassland transferred to forested land according to the land use change matrix during 1990–2010 (Table 2), which caused the NP value of grassland to rise from 1446 to 1686 during that period, while the massive transfer out of forested land and grassland led to the reduction of the landscape dominance of forested land and the intensified fragmentation of grassland.

The mutual transfer between farmland and forested due to the great efforts in developing mountainous agriculture in Guangxi helped to improve the internal connectivity of forested land patches and the spatial aggregation of farmland patches at a certain extent. The disorderly expansion of construction land in the early period, especially before 2010, led to the large-scale fragmentation of new construction land patches, while the agglomeration degree between new and old patches was strengthened later via land consolidation and reclamation. On the whole, the spatial landscape pattern of Guangxi varied significantly due to the changing intensity of land use transitions over the past 28 years. The ecological and agricultural landscape dominated by forested land, farmland and grassland have been modified and gradually switched to the urban landscape dominated by construction land. With the development of the increasing intensity of land use transitions and the narrowed gap in the proportion of different land use types in Guangxi, the shape, connectivity, fragmentation and heterogeneity of landscape patches have gone through constant evolution, and the landscape richness has continuously improved.

3.2. Analysis of Ecosystem Services Value of Guangxi

3.2.1. The Changes of Ecological Services Value

The total ESV of Guangxi showed an overall "∨" shape trend over the past 28 years, i.e., increased first to the highest value of 1297.60 billion RMB in 2000 and then decreased to 1293.41 billion RMB in 2018. Although the ESV provided by forested land and grassland decreased about 5.30 billion RMB, the forested land still contributed the most, about 83.42% of the total ESV. The ESV provided by waterbodies showed an upward trend, growing by about 6.68 billion RMB, which could be attributed to the reduction of ecological space damage caused by agricultural reform, the implementation of policy of returning grain plots to forestry and developing green aquaculture in Guangxi. In terms of single ecological service function, the value of soil conservation, biodiversity, atmosphere and climate regulation, and water conservation functions accounted for about 73% of the total ESV (Figure 5), while the food production only accounted for little.

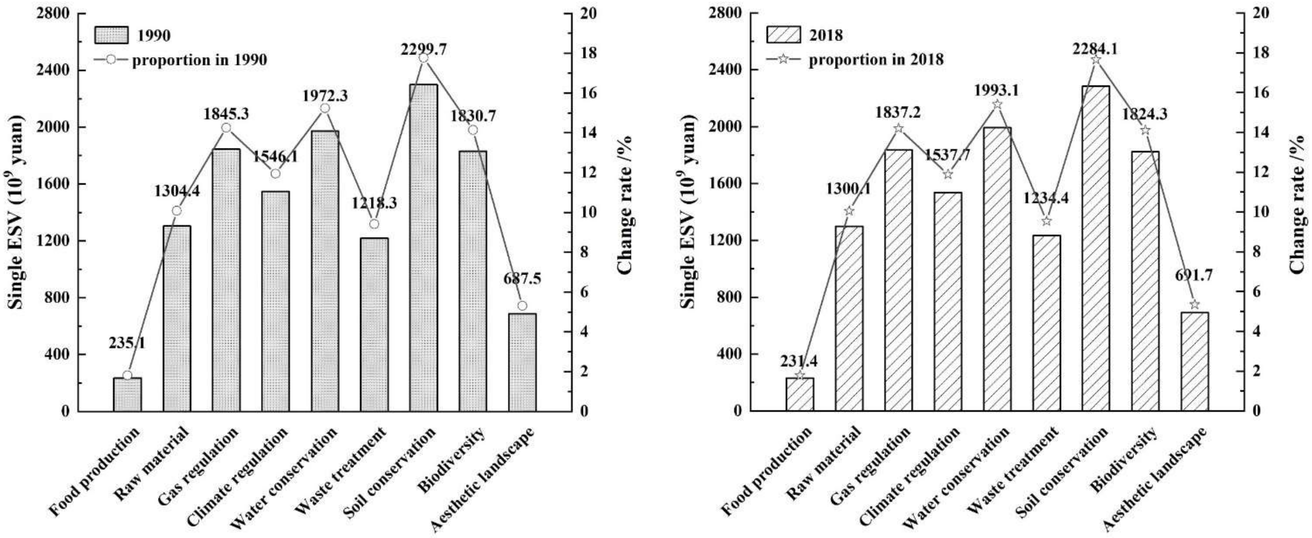

Figure 5. Single ESV of Guangxi in 1990 and 2018.

Except for the growth in water conservation, waste treatment and aesthetic landscape, other single ESVs tended to decline, especially the reduction of soil maintenance and climate regulation, which exceeded 2.40 billion RMB. The reduction of ESV was mostly related to the decrease of forested land, grassland and farmland in Guangxi. The increase of waterbody area contributed to the ecological value-add of Guangxi. Human activities not only had direct impacts on land use, but also indirect impacts on ecological service functions through environment restoration measures, such as the control of soil and water loss, rocky desertification in karst hilly areas and large-scale construction activities in Guangxi, all of which had significant impacts on ESV. In addition, the land use policies also affected the land use transitions and the reconstruction of the landscape pattern, and then caused corresponding changes in the function and value of ecosystem services. For example, through land consolidation policies, represented by land engineering projects such as Taiyang village in Liuzhou city, Guangxi carried out large-scale land consolidation in 2019 which had comprehensive effects on the improvement of the farmland quality, water environment, landscape and even the ecological environment as a whole.

3.2.2. The Spatial Distribution of Ecological Services Value

Guangxi was divided into five zones based on the analysis results: the lowest-value zone means that the ESV per ha was less than 95,000 RMB; the low-value zone means that the ESV per ha was 95,000–125,000 RMB; the medium-value zone means that the ESV per ha was 125,000–155,000 RMB; the high-value zone means that the ESV per ha was 155,000–185,000 RMB; the highest-value zone means that the ESV per ha was over 185,000 RMB. Finally, the spatial distribution of ESV per ha during 1990–2018 in Guangxi was obtained (Figure 6).

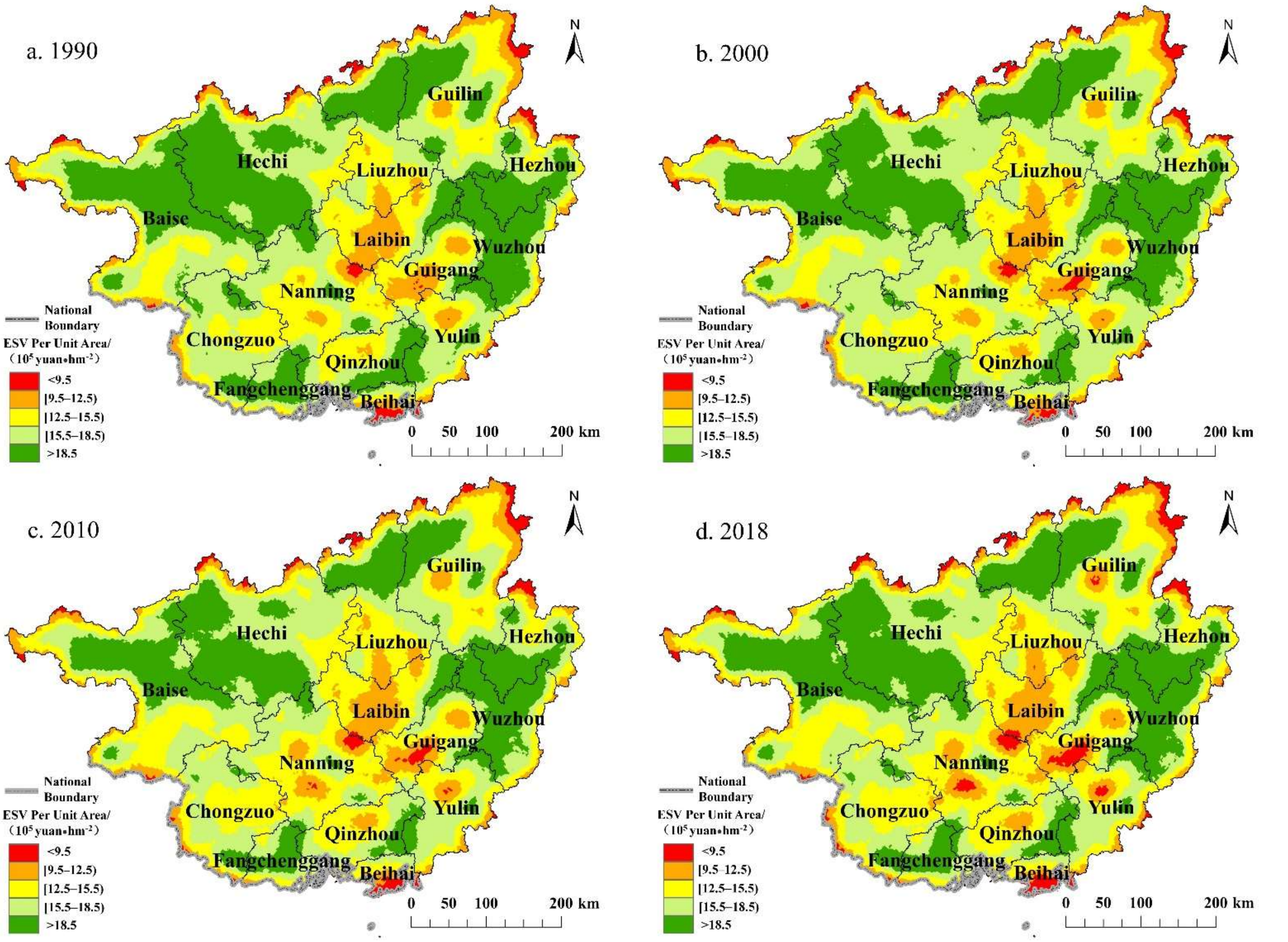

Figure 6. Spatial distribution of total ESV per unit area of Guangxi in 1990 and 2018.

In general, the most striking spatial characteristic was that the high ESVs were mainly distributed in the surrounding mountainous area and low in the central plain area. Specifically, the area of the highest-value and high-value zones of ESVs shrank, while the area of medium-value and low-value zones was gradually increasing, among which the total area of the high-value zone reached 53%, yet the area of the highest-value, medium-value and low-value zones accounted for a relatively small proportion. Spatially, the high-value zone of ESV per ha contained Guilin, Hechi and other northern cities, as well as Hezhou, Yulin and other southeast cities as its core regions, showing a strip layout; the southern cities located in the central basin, such as Nanning, Laibin, Guigang and Beihai mainly belonged to the low-value and medium-value zones, showing a dotted layout; the highest-value zone was mainly distributed in the surrounding hilly areas covered with forest, grass, etc., with high ecological functions. Since the 21st century, the difference of the spatial distribution of ESV has become more complicated. Accompanied with land consolidation, coastal aquaculture and urbanization, a large number of highest-value zones have transferred to high-value and medium-value zones, especially in Hechi, Fangchenggang and northern Guilin, while the areas of medium-value and low-value zones in Laibin, Guigang, Nanning and Beihai increased significantly. The area of highest-value zones and high-value zones that turned into medium-value and low-value zones was much larger than the area of the low-value zones that switched to high-value zones, which indicates that the overall ecological service function was deteriorating.

3.3. Correlation Analysis of Landscape Pattern and ESV

As we can see from the above analysis, the spatial differences in landscapes caused by the changes of land use area and spatial transfer can influence both the ecosystem service function and value. Further, the significance of influence between the total ESV and the landscape indices was measured by the Pearson Test in order to examine the response degree of ESV to the landscape pattern evolution in the study area (Table 5). The total ESV had significant positive correlation with LPI, COHESION and AI, and significant negative correlation with NP and SHDI, while the correlation with the LSI was not significant. The results indicate that the ESV changed dramatically in the regions with obvious evolution in landscape pattern, whether it was becoming complex or simple. The scattered and fragmented distribution of patches, especially with the high richness and heterogeneity in small regions, can also lead to the decrease of ESV, while the increase of land area of the dominant landscape, high assemblage and connection of similar patches are more likely to promote the total ESV.

Table 5. Correlation between the total ESV and landscape pattern indices.

Landscape Index	NP	LSI	LPI	COHESION	AI	SHDI
Correlation Coefficient	−0.809 *	+0.467	+0.849 *	+0.902 **	+0.914 **	−0.849 *
Correlations	S-C	N-C	S-C	S-C	S-C	S-C

* means significant correlation at 0.05 level; ** shows significant correlation at 0.01 level. The N-C stands for non-significant correlation and the S-C means significant correlation; + means positive correlation; − means negative correlation.

The highest-value and high-value zones of ESV in Guangxi have gradually been turning into middle-value and low-value zones due to the sharp reduction of the areas of ecological land with high value, such as forested land and grassland, which led to the rise of the fragmentation of land patches. The low-value and medium-value zones of ESV were mostly consistent with the distribution of farmland and construction land. Due to the continuous influence of human activities, the total area of farmland decreased during the whole period; for example, the NP of farmland increased from 1454 to 1652. The high fragmentation of patches led to the ESV of farmland decreasing continuously. As the matrix landscape, the LPI of forested land was as high as 63.64, but the NP and AI dropped dramatically, causing the low spatial agglomeration of the patches and the supply shortage of atmosphere and climate regulation function, and the ESV of forested land has reduced by 3.29 billion RMB. The strengthened internal accessibility of the waterbodies improved the water conservation function, with an added ESV of 6.68 billion RMB. However, the NP of farmland and grassland both exceeded 1400, showing a high degree of fragmentation and irregularity, leading to significant degradation in the value of soil conservation and biodiversity.

3.4. Empirical Analysis of Land Use Transition, Landscape Pattern Evolution and Ecological Services Function Response in Guangxi

Affected by economic development, land engineering projects and ecological protection policies, the land use of Guangxi has undergone an intensity-changing process of land use transition, and the spatial morphology of patches and ecological service functions influenced by land use transition have also changed accordingly. As such, in this part, we attempt to empirically analyse the relationship among land use transitions, landscape pattern evolution and ecological services function responses in Guangxi, guided by the theoretical analysis framework proposed in Section 2.4 (Figure 7). The natural landscape patches remained relatively intact with well-maintained ecological environment at the beginning of the study period, but the original ecological landscape was gradually replaced by urban landscape after 2010 due to the large-scale expansion of construction, resulting in the obstruction of the ecosystem material cycle and energy flow.

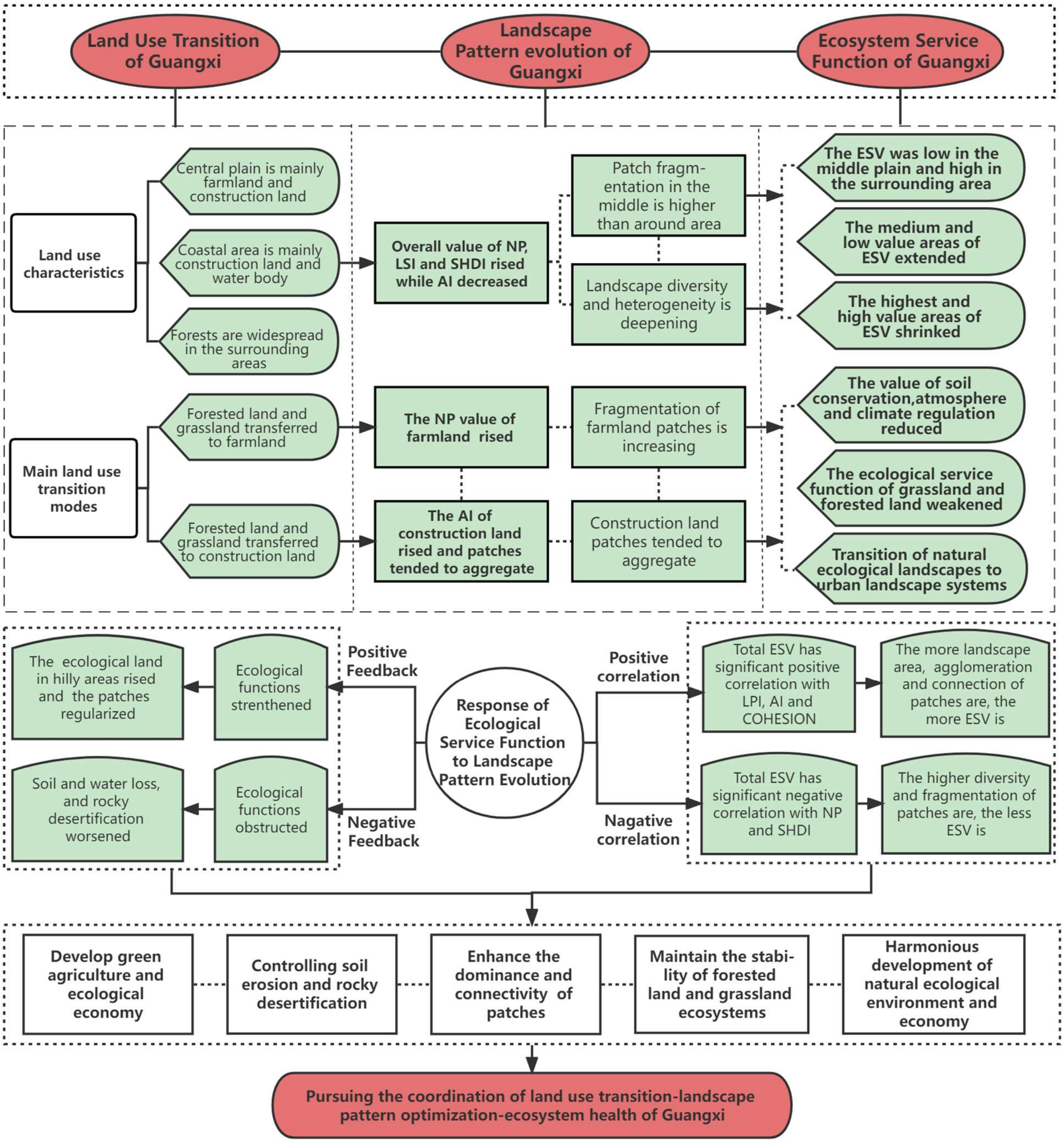

Figure 7. Empirical analysis framework of land use transition, landscape pattern evolution, Ecological Services Function response in Guangxi.

In terms of the spatial distribution of land use, forested land was widespread in the surrounding areas of Guangxi, while the central plain basin was dominated by farmland and construction land, and the area of farmland and intertidal zone in the south declined due to coastal reclamation practices. As a result, the NP, LSI and SHDI were increasing, but the AI was descending, which indicates that the degree of landscape heterogeneity and fragmentation was deepening and forming an inhibitory effect on ecological service function. In the central region of Guangxi, the shift from high-value zone to medium-value and low-value zone was accompanied by serious soil and water loss and rock desertification, and the ESV value of soil conservation, climate regulation and biodiversity decreased by 3.05 billion RMB. The forested land and grassland transferred to farmland and construction land could be regarded as the main land-use transition modes of Guangxi, which caused the area of construction land to increase by 205,238 ha. Meanwhile, the ecological land, such as forested land and grassland, shrunk by 138,737 ha. During the above land transition process, the NP of farmland rose from 1454 to 1652, showing an increasing trend of dispersed farmland patches in Guangxi, while the AI of construction land rose from 11.12 to 13.64, showing that the patches of construction land tended to aggregate. As a result, the material circulation and energy flow of the ecosystem were hindered or even blocked, which then affected the ecosystem service functions, such as soil conservation, gas and climate regulation, etc., and the natural ecosystem gradually switched to an urban ecosystem dominated by construction land.

According to the correlation analysis between the ESV and landscape pattern indices, we know that the higher the value of ecological land area and agglomeration and connection of patches are, the higher ESV is, and the higher diversity and fragmentation of patches are, the lower ESV is. Accordingly, positive or negative feedback of ecological service functions to landscape pattern evolution arises, i.e., the increase of ESV can further stimulate the increase of ecological land area with high value in return, such as the forest expanding in hilly areas, and the regularization of the shape of patches to improve the inner connections; otherwise, the decrease of ESV can depress the enthusiasm and efforts of local government and people to maintain or improve the ecological environment, which can then create new ecological issues or even worsen the current ecological situation. In recent years, Guangxi has placed more emphasis on ecological environment protection in order to realize ecological benefits; for example, making corresponding plans for eco-agricultural production, forest and grass protection and environment-friendly industrial development in order to develop green agriculture and ecological economy with multiple modes. By implementing land projects such as changing dry land to paddy fields, returning grain plots to forestry, etc., supported by active land policies and regulations to control soil erosion and rocky desertification in environmentally sensitive areas, the land use has been optimized and the corresponding landscape dominance and patchy connectivity has been enhanced. On the basis of scientific control of land use transitions, the reshaping of landscape patterns could promote the good operation of regional ecosystems and provide higher quality ecological goods and services.

4. Discussion

The mountainous, hilly and rocky areas in Guangxi account for about 69.7% of the total land area [59], which would be apt to produce ecological issues, and the ecological environment is relatively fragile. Under this context, the land use transitions in Guangxi are actually also a process of the reshaping of landscape patterns. With the acceleration of industrialization and urbanization, the intensity of land use transition will continue to increase and the influence on the land's ecological environment may become more and more dramatic in Guangxi. It is of great importance to coordinate the relationship between land use and ecological construction while achieving the goals of economic and social development [60]. In recent years, Guangxi has made great efforts to improve its ecological environment's quality, such as developing its green agriculture and ecological economy as well as making forest and grass protection plans [61] in order to optimize land use, maintain the connectivity and dominance of landscape patches as shown in Figure 7. Specially, land engineering technologies which proved to be successful need to be strengthened, such as land consolidation and reclamation projects. For example, implementing comprehensive land consolidation in western, central and northern Guangxi to improve karst rocky desertification and severe soil and water loss in sloping farmland in ecologically fragile areas [62], all of which worked together aim to improve comprehensive protection of ecological land and promote the healthy operation of ecosystem [63]. As a result, about 191,269 ha of soil and water loss was treated in Guangxi in 2018, an increase of 12,394 ha compared with 2017 [64]. Compared with the results of the second rocky desertification monitoring program in Guangxi, rocky desertification land decreased by 393,000 ha in 2018, a reduction rate of 20.4% [65].

As the previous analysis clearly shows that the response of ESV to landscape pattern evolution caused by the dominant land use transition, i.e., the change of land area and structure, in Guangxi has had a significant influence on landscape pattern and ESV. For example, the increase and decrease of land areas and the changes in spatial layout led to changes in the shape and connectivity of patches in the study area, which further affected the value of ecosystem services. However, recessive morphology changes of land use (land quality, land input and output, property rights, etc.) can also affect the regional landscape pattern and ESV, or even have more influence than the dominant morphology changes in some aspects. As such, more consideration may be given to the response of ecological service functions to landscape pattern changes caused by land recessive morphology transitions in the future. In addition, correlation analysis between the singular ESVs and landscape indices should be further carried out by using more scientific qualitative and quantitative methods to explore a more detailed picture of the internal relations and feedbacks among different modes of land use transition, landscape pattern evolution and ecological service function responses in typical areas.

Although this paper theoretically and empirically examines the relationships between land use transition, landscape pattern evolution and the response of ecosystem service functions, it has several limitations that should be recognized as opportunities for further research. The 30 m resolution of the vector data of LULC change limits the accuracy of observable land-cover classes, so higher resolution imageries are more preferable for analysis of the spatio-temporal features of land use. Further, due to the limitations of data acquisition, such as the recessive attributes of land resources, this paper only analyses the dominant land use transitions, their impacts on the landscape pattern and the feedback of ecological service functions. In addition, predicting and simulating the characteristics of land use transitions, the following impacts on the landscape pattern and the responses of ecosystem service functions in future periods is very useful for scientific and efficient land use management, which needs to be paid more attention.

5. Conclusions

This paper explores the relationships among regional land use transitions, landscape patterns and ecological service functions, particularly focusing on the feedback of ESV to landscape pattern evolution in the context of land use transition by putting forward the "land use transition, landscape pattern evolution, ecosystem service function response" theoretical analysis framework, and further carries out empirical analysis in Guangxi, China. The main findings are drawn as follows:

(1) Guangxi has undergone an intensity-changing process of land use transition during 1990–2018, i.e., a slow and moderate transition at the beginning, but switching to a fast and drastic one after 2010, which was characterized by the decrease of forested land, grassland and farmland and the increase of construction land and waterbodies. Spatially, a large amount of farmland and forested land transferred to construction land in the central basin of Guangxi. Further, the landscape pattern has gone through a complicated process of evolution. Specifically, the fragmentation and heterogeneity of patches are now higher in the central area than the surrounding areas, while the landscape connectivity and agglomeration are just the opposite. The fragmentation scale of farmland and grassland patches is very large and tends to be irregular in shape, while the forested land patches are highly clustered with the highest degree of landscape dominance. The internal connectivity of the waterbody areas is complicated, while the new and old patches of construction land are more concentrated.

(2) Based on the revised coefficients of ESV, the total ESV of Guangxi decreased by 20.56 billion RMB during the study period, among which the ESV provided by forested land and grassland decreased the most, while the ESV provided by waterbodies in-

creased. In terms of the single ESVs, the value of soil conservation, biodiversity, atmosphere and climate regulation, and water conservation account for about 73% of the total ESV. Spatially, ESV is low in the central area but high in the surrounding areas in Guangxi. The high-value zone is the major zone and accounts for about 53% of the total area, while the areas of the high-value and highest-value zones that transferred into medium-value and low-value zones are much larger than the areas of low-value zones that transferred into medium-value and high-value zones, which indicates the overall regional ecological service functions have deteriorated and that it is urgent to deal with the conflicts between land use and ecological environmental protection.

(3) The ecological service functions responded obviously to the land use transitions and landscape pattern changes in Guangxi. According to the Pearson Test, the total ESV has a significant positive correlation with LPI, COHESION and AI, and a significant negative correlation with SHDI and NP, indicating that the scattered and fragmented layout of patches could weaken ecological functions dramatically, while strengthened landscape dominance and spatial aggregation can obviously improve the total ESV and the ecosystem stability of Guangxi.

(4) The empirical analysis in Guangxi guided by the proposed theoretical analysis framework could soundly verify the interactions of land use transitions, landscape pattern evolution, ecosystem service function responses. Landscape pattern changes in Guangxi, such as the patch fragmentation and agglomeration caused by land use transitions, had different influences on the ecological service function, engendering positive or negative feedback of the ecological services' functions to landscape pattern evolution. Optimizing the land use mode to improve landscape dominance and patch connectivity could reshape the landscape pattern and promote the good operation of the regional ecosystem, which could then provide higher-quality ecological goods and services.

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