sustainability

Article

Spatial-Temporal Variation and Tradeoffs/Synergies Analysis on Multiple Ecosystem Services: A Case Study in Fujian

Min Li, Peng Zheng * and Wenbin Pan

College of Environment & Safety Engineering, Fuzhou University, Fuzhou 350108, China; limin7810@163.com (M.L.); wenbinpan@fzu.edu.cn (W.P.)
* Correspondence: pengzheng@fzu.edu.cn; Tel.: +86-591-22866077

Abstract: The rapid urbanization process has severely affected the ecological security and ecosystem services (ESs) in China's southern province of Fujian, and threated the sustainable development of the local economy and society in the last two decades. This study mapped the spatial-temporal variation of four types of ESs and evaluated the tradeoffs/synergies among the ESs in Fujian Province from 2000 to 2020 on the three scales of the province, city and county. The results showed that: (1) From 2000 to 2020, the three ESs functions of soil conservation service, carbon storage service, and habitat quality decreased, while the function of food supply service increased. (2) At the provincial scale, soil conservation services, carbon storage services, and habitat quality were in a synergistic relationship, and food supply service was always in tradeoffs relationships with soil conservation services, carbon storage services, and habitat quality. At the prefecture-level scale, the tradeoffs/synergies among ESs vary among prefecture-level cities. At the county scale, the Moran's I index of bivariate spatial autocorrelation was consistent with the correlation coefficient, and the tradeoffs/synergies between ESs showed significant spatial heterogeneity. (3) Based on the correlation analysis method, the Ecosystem Service Tradeoff-synergy Degree (ESTD) model and bivariate spatial autocorrelation analysis can clearly show the relationship between various ESs, and the research results are relatively consistent. The spatial distribution of four ecosystem services in Fujian province showed a specific aggregation pattern. High—high concentrations and low—low concentrations are strong. Low—high agglomeration and high—low agglomeration are weak.

Keywords: ecosystem services; tradeoffs/synergies; spatial-temporal change; multi-scale

Citation: Li, M.; Zheng, P.; Pan, W. Spatial-Temporal Variation and Tradeoffs/Synergies Analysis on Multiple Ecosystem Services: A Case Study in Fujian. *Sustainability* **2022**, *14*, 3086. https://doi.org/10.3390/su14053086

Academic Editors: Giuliano Poli, Daniele Cannatella and Sabrina Sposito

Received: 5 December 2021
Accepted: 27 February 2022
Published: 7 March 2022

1. Introduction

Ecosystem services refer to the ability to maintain the environment and provide a variety of benefits [1,2], which is a necessary consideration of ecosystem management [3] and is closely associated to regional ecological security [4]. Millennium Ecosystem Assessment (MA) divides ecosystem services into four categories: supply services, regulatory services, support services, and cultural services [5]. Ecosystem services are affected by natural factors and social and economic factors [6]. They are characterized by diverse types and uneven spatial distribution, leading to tradeoffs/synergies of varying degrees among ecosystem services [6,7]. Tradeoff refers to the situation where one service increases and the other decreases, and synergy refers to the scenario where both services increase or decrease simultaneously. The global population has increased by about 1.5 billion and the social economy has developed at an excessive speed in the last two decades [8]. The unsustainable demand for materials and resources is in contradiction to the constrained natural resources [8]. In the process of pursuing economic benefits, human beings ignore the tradeoffs and synergies among ecosystem services, leading to the upward push of supply services and the decline of regulation and support functions [9]. The original ecological balance is damaged, leading to significant conflicts between different ecosystem services, which will ultimately harm human wellbeing and development [9]. Therefore, evaluating ecosystem services in terms of tradeoffs/synergies among ecosystem services and spatial distribution differences is of great significance for formulating regional development plans, guiding human beings to sustainably develop and utilize natural resources, and balance economic development and ecological protection [10].

In the 1990s, as an important issue in natural resource management, the tradeoff concept was first proposed in optimization decision literature [11]. In the early 21st century, after distinguishing the concepts of ecosystem services and tradeoffs/synergies [12], domestic and foreign scholars carried out a large number of studies on the tradeoffs/synergies of the services. Research has focused on the theoretical basis [13], manifestation [14], driving mechanism [15], scale effect [16], and spatial distribution of ecosystem service tradeoffs/synergies [17]. Bennett found that the complex relationship among ecosystem services was dictated by common factors and there were complex interactions among services themselves [13]. Carreño evaluated the relationship between ecosystem and land-use types in central Mexico, as well as the synergies and tradeoffs between ecosystems, and found that there was a significant synergistic relationship between virgin forest and hydrological regulation services [14]. Martín-López showed through investigation that with the increasing utilization intensity of ecosystem services by human beings, tradeoffs among ecosystem services became more and more common [15]. Bai studied the tradeoffs and synergies of ecosystem services in Taihu Lake Basin at different scales, and revealed the impact of scale effects on correlation and tradeoffs by using the correlation coefficient method [16]. Qi used the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) carbon storage and sequestration model and habitat quality model to measure ecosystem services in Qinghai Lake Basin from 2010 to 2018, and found that the spatial heterogeneity of ecosystem service tradeoffs in the basin was sizable [17]. From the perspective of research methods, the existing research methods of ecosystem service tradeoffs/synergies can be summarized as correlation analysis [18], GIS spatial analysis [19], scenario simulation analysis [20], and ESTD model [21]. Turner analyzed the scale characteristics of 11 ecosystem services in Denmark by using spatial autocorrelation and principal component analysis [18]. Caiyun used the InVEST water yield model, carbon storage and sequestration model, and habitat quality model and Ecosystem Service Change Index (ESCI) to characterize the spatio-temporal changes of ecosystem services in Bailong River Basin, Gansu Province from 1990 to 2014, and used the correlation analysis method and bivariate spatial autocorrelation method to explore the values and spatial tradeoffs and synergies of four ecosystem services in the study area [19]. Xie predicted the impact of urban expansion on ecosystem services. In rapidly urbanizing areas, forest land and cultivated land with high ecosystem service value should be protected. ZiCheng evaluated the value of ecosystem services in the Minjiang River Basin from 2006 to 2016 by integrating the ecosystem service value table and Ecosystem Service Tradeoff-synergy Degree (ESTD), and analyzed the changing trend of ecosystem service value and tradeoff synergy relationship in the basin [21]. From the perspective of research region, it covers important economic zone, with forest [22], basin [23], watershed [24], farmland [25,26], etc. Jing took Guanzhong-Tianshui Economic Zone as the research object and studied the tradeoffs and synergistic relationships of different ecosystem services in Guanzhong-Tianshui Economic Zone by using correlation coefficient, spatial mapping, rose diagram and production possibility boundary methods, respectively [27]. Mengya measured the value of Net Primary Productivity (NPP), soil conservation value, and food supply value in Guanzhong Basin from 2000 to 2012, and studied the temporal and spatial differences of ecosystem services in different land-use types by using the rose map, so as to explore the tradeoffs and synergies among the three ecosystem services [23]. Zhong studied the impact of farmland consolidation on ecosystem services, estimated crop production capacity, carbon storage, and soil conservation, and quantified the synergies and tradeoffs among these three ecosystem services, further applying ecosystem services research to agricultural production [26].

There have been many studies on tradeoffs/synergies between ecosystem services worldwide. Rodriguez proposed that ecosystem tradeoffs/synergies should be studied at multiple scales and that the inherent complexity of ecosystem management should be recorded to reduce the impact of tradeoffs and maximize the value of ecosystem services [12]. Although scholars have carried out studies on a global scale [28], national scale [29] and village scale [30], they rarely study a specific region from the perspective of multiple scales. Current research has made some progress, but there is still a considerable gap in the depth and breadth of analysis of ecosystem services tradeoffs/synergies. Firstly, most previous studies on tradeoffs and synergies based on spatial mapping analysis only considered the ecosystem services at two time points. Ecosystem service assessment is uncertain, and comparative analysis of ecosystem services over many years can more effectively reveal ecosystem service tradeoffs/synergies [31]. Secondly, the studies are relatively focused on a single scale, whereas the tradeoffs/synergies of ecosystem services may differ at different study scales. Tradeoffs/synergies obtained at one scale often differ from results obtained at another scale [32]. In addition, previous studies mainly used traditional statistical description methods, focusing on the identification of tradeoffs/synergies between two ecosystem services. Studies on tradeoffs between ecosystem services are relatively weak, and spatial heterogeneity analysis of tradeoffs between the services within the studied region is relatively lacking [17]. In this case, it is necessary to supplement the research on the tradeoff relationship between ecosystem services, disclose the tradeoff degree and spatial difference of the services, and provide a scientific basis for the formulation of regional ecological and environmental protection policies.

In this paper, Fujian Province, under the background of rapid urbanization and ecological civilization construction, is chosen as the research area. This paper selects soil conservation and carbon storage as regulating ecosystem services. Habitat quality was selected as supporting ecosystem services. Food supply service was selected as an ecosystem provision service. The selection of the abovementioned ESs took several factors into consideration, such as the availability and feasibility of primary data, and particularly considered the specificity and representativeness of the ES in relation to the geographic and economic characteristics of Fujian Province. Four typical ecosystem services from 2000 to 2020 were estimated using relevant models, and the temporal variation and spatial aggregation characteristics of the four services were explored using global spatial autocorrelation analysis. Correlation analysis was used to identify the overall tradeoffs/synergies relationships among ecosystem services at the provincial scale. The dominant ecosystem services and temporal changes of prefecture-level cities in Fujian Province were identified by the polar coordinate rose graph, and the ecosystem service tradeoffs/synergies degree model was used to quantify the ecosystem service tradeoffs/synergies degree of each city. In addition, bivariate spatial autocorrelation analysis and spatial mapping were used to assess the spatial heterogeneity of tradeoffs/synergies among four ecosystem services at the county scale. In this study, we estimated ecosystem services scientifically and reasonably, described their spatio-temporal evolution characteristics quantitatively, identified the tradeoffs/synergies of the services at provincial, municipal and county scales, and explored the spatial heterogeneity of the services in the region. This can provide an important basis for ecosystem management and decision-making, and has important practical significance for the sustainable and in-depth implementation of ecological province strategy in Fujian Province in the future.

2. Materials and Methods

2.1. Study Area

Fujian Province is located in the coastal area of southeast China (Figure 1), with a land area of 124,000 km^2, ranging from 23°33′ N to 28°20′ N and 115°50′ E to 120°40′ E. It adjoins Zhejiang province in the northeast, Jiangxi province in the west and northwest, Guangdong province in the southwest, and Taiwan island across the Taiwan Strait in the east. The terrain of Fujian Province is mainly mountainous and hilly, with mountainous and hilly areas making up 80% of the total area of the province. It is mild and humid with an average annual temperature of 17~21 °C and abundant rainfall, with an average annual rainfall of 1400~2000 mm. The climate of the southeast coastal area of Fujian is southern subtropical, while that of northeast, north and west Fujian have a mid-subtropical climate. Fujian Province has a forest area of 82,000 km^2, covering 66.80%. It is a major ecological barrier in southern China and the first national ecological civilization pilot zone in China [33,34]. From 2000 to 2020, the urbanization rate of Fujian Province has increased from 41.6% to 69.5%, and its Gross Domestic Product (GDP) has increased by nearly 12 times. With rapid economic growth, land-use has also undergone sharp changes. In the past 20 years, forest land decreased by 972.09 km^2, cultivated land decreased by 1236.72 km^2, and construction land increased by 2470.98 km^2. Economic development is mainly at the cost of the expansion of construction land and the decrease of forest land, so all kinds of ecosystems are damaged to varying degrees.

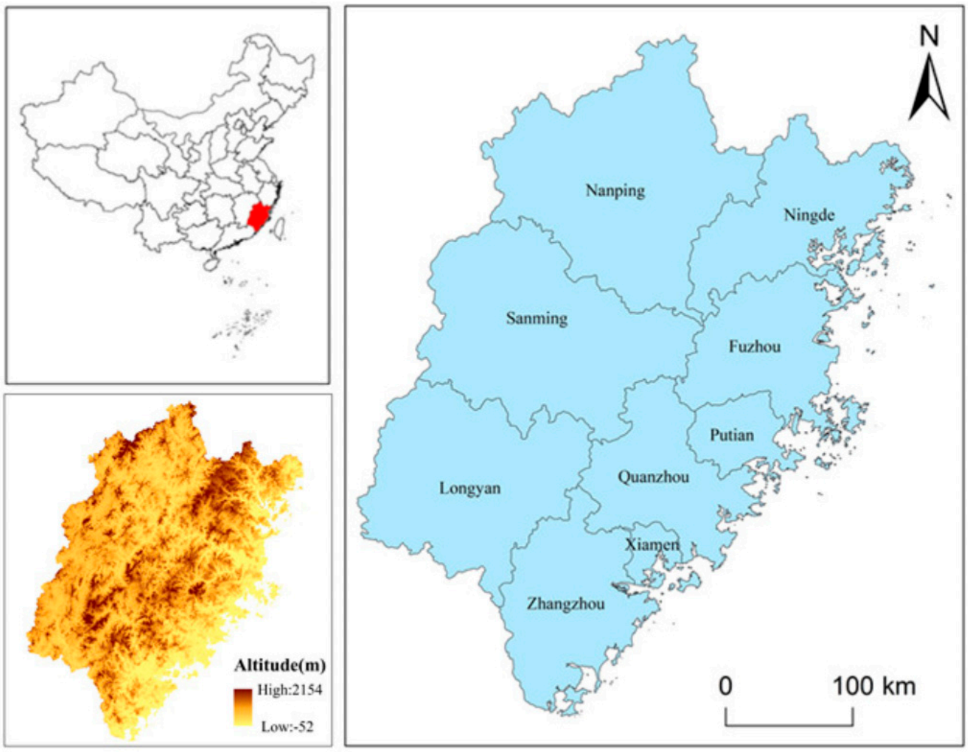

Figure 1. Location of Fujian Province.

2.2. Data Source

Fujian Province is subdivided into six land-use types: forest, grassland, cultivated land, water, construction land and unused land. The spatial distribution of land-use types is derived from GlobeLand30 V2020 of global Landcover Data Product and Service website of National Basic Geographic Information Center (DOI: 10.11769). The spatial resolution is 30 m, the overall accuracy is 85.72%, and the Kappa coefficient is 0.82. The DIGITAL Elevation Model (DEM) used in this paper is ASTER GDEM data with a spatial resolution of 30 m, which is obtained from the geospatial Data Cloud website (http://www.gscloud.cn/, (accessed on 15 June 2021)). The data of soil type and texture were obtained from the 1:250,000 soil evaluation data of Fujian Province in the second national soil survey, with a resolution of 30 m and data type of raster data. Meteorological data came from the China Meteorological Science Data Sharing Network. Socio-economic and demographic data mainly came from the Statistical Yearbook of Fujian Province in 2000, 2010 and 2020.

2.3. Technical Roadmap

In this paper, we used relevant models to estimate four ecosystem services including soil conservation, carbon storage, habitat quality, and food supply services in Fujian province from 2000 to 2020. Global spatial autocorrelation analysis was used to explore the temporal variation and spatial agglomeration characteristics of the four services. Polar rose plots were used to identify the dominant ecosystem services and temporal changes of prefecture-level cities in Fujian Province. In addition, correlation analysis, ESTD model and bivariate spatial autocorrelation analysis were used to analyze the tradeoff/synergy relationships and spatial distribution characteristics of four ecosystem services at provincial, city and county scales. The technical roadmap of this paper is shown in Figure 2.

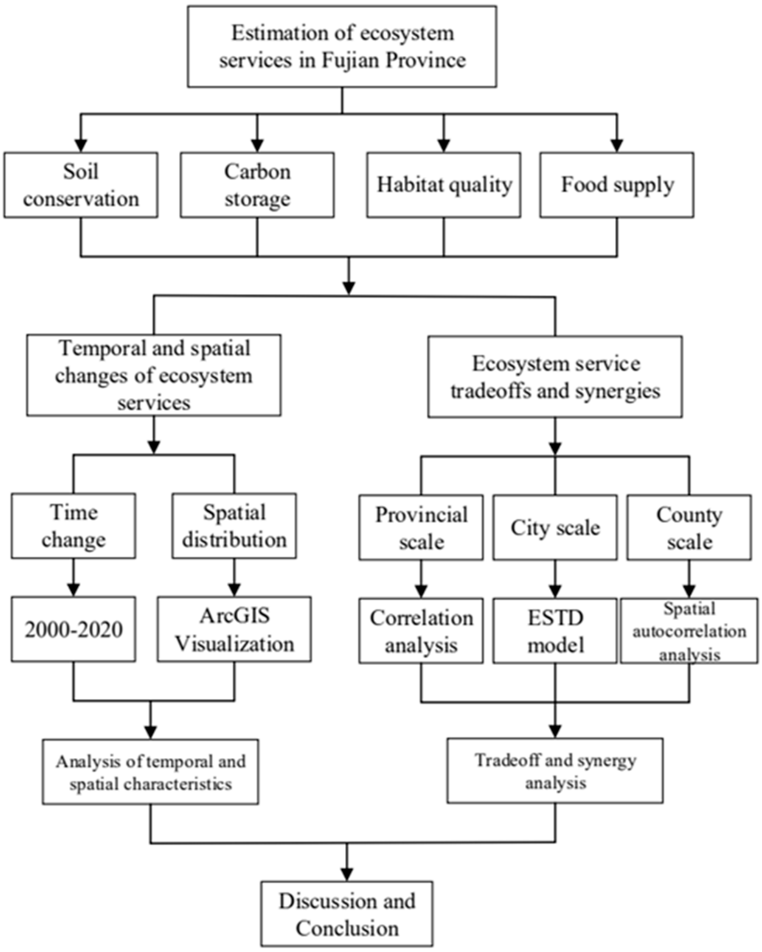

Figure 2. Technical roadmap.

2.4. Measurement of Ecosystem Services

2.4.1. Soil Conservation

The RUSLE (Revised Universal Soil Loss Equation) model was used to measure the soil conservation capacity of Fujian Province [35,36]. The calculation of soil conservation includes two parts, one is the potential soil loss, the other is the actual soil loss, the actual loss minus the potential loss is the soil conservation. The formulas are as follows:

$$A_p = R \times K \times L \times S \tag{1}$$

$$A_r = R \times K \times L \times S \times P \times C \tag{2}$$

$$A_c = R \times K \times L \times S \times (1 - P \times C) \tag{3}$$

A_p is the potential soil erosion; A_r is the actual soil erosion amount; A_c is the soil conservation amount. R is the rainfall erosivity factor (MJ·mm)/(hm^2·h·a); K is the soil erodibility factor (T·hm^2·h)/(MJ·mm·hm^2); LS is the topographic factor, derived from a combination of the slope steepness and slope length measurements (non dimensional); C is the surface vegetation coverage and management factor (non dimensional); P is the factor of soil and water conservation measures (non dimensional).

2.4.2. Carbon Storage

The InVEST(version 3.7.0) carbon storage and sequestration model quantifies the amount of carbon stored based on the different land uses and carbon densities [37,38]. Carbon storage generally consists of two parts: vegetation carbon storage (aboveground biomass, underground biomass, and dead organic matter) and soil carbon storage. Due to the limitation of data acquisition, this paper does not consider the dead organic matter carbon pool. The calculation formula is as follows:

$$C_{tot} = C_{above} + C_{below} + C_{soil} + C_{dead} \quad (4)$$

C_{tot} is the total carbon storage (T/hm^2); C_{above} is the carbon storage of aboveground matter (T/hm^2); C_{below} refers to underground carbon storage (t/hm^2); C_{soil} is soil carbon storage (T/hm^2). C_{dead} is the carbon storage of dead leaves (T/hm^2). Tables 1–3 shows the data of carbon density used in this paper by referring to relevant data.

Table 1. Aboveground biomass carbon density (kg/m^2).

Land Use Type	Carbon Density (kg/m^2)	Research Scope	Study Time
Cultivated land	0.57	across China	2003
Forestland	4.24	across China	2004
Grassland	3.53	across China	2004
Water	0.37	across China	2003
Construction land	0.00		
Unused land	0.00		

Table 2. Underground biomass carbon density (kg/m^2).

Land Use Type	Carbon Density (kg/m^2)	Research Scope	Study Time
Cultivated land	8.07	across China	2004
Forestland	11.59	across China	2004
Grassland	8.65	across China	2004
Water	0.65	across China	1999
Construction land	0.00		
Unused land	0.00		

Table 3. Soil carbon density (kg/m^2).

Land Use Type	Carbon Density (kg/m^2)	Research Scope	Study Time
Cultivated land	10.84	across China	2003
Forestland	23.69	across China	2002
Grassland	9.99	across China	2003
Water	0.65	across China	2003
Construction land	0.00		
Unused land	0.00		

2.4.3. Habitat Quality

The InVEST Habitat Quality model is the spatial and temporal distribution of habitat quality based on land-use type and considering its threat factor sensitivity and external threat intensity. This includes habitat degradation index and habitat quality index [39]. The habitat quality index is a dimensionless comprehensive index to evaluate habitat suitability and habitat degradation of regional land-use types [40,41]. The calculation formula is as follows:

$$Q_{xj} = H_j\left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + E^z}\right)\right) \quad (5)$$

Q_{xj} is the habitat quality index of type x grid of type j land-use; H_j is the habitat attribute of type j of land-use; E is the half-saturation constant; z is a normalized constant, usually set to 2.5.

2.4.4. Food Supply

The measurement of food supply service via the InVEST model is still in the testing stage and cannot be fully used. According to the existing public available data in China's Fujian province, we choose to represent the food supply service in monetary values [42]. Based on the land-use data and statistical yearbook data of Fujian Province, this paper estimated the total output value of food for each type of land-use in the study area, taking note of the spatialization of the food supply. The calculation formula is:

$$G_i = A_i \times N_i \tag{6}$$

$$N_i = \frac{F_i}{S_i} \tag{7}$$

G_i is the total output value of the food i corresponding to the grid in the study area (yuan), A_i is the area (km^2) occupied by the food i in each grid, N_i is the output value of food i per unit area (yuan/km^2).

2.5. Tradeoffs and Collaborative Relationship Research Methods

2.5.1. Correlation Analysis

Correlation analysis uses a correlation coefficient to quantitatively describe the degree of linear correlation between variables [43]. ArcGIS was utilized to collect samples of four ecosystem services in Fujian Province: soil conservation, carbon storage, habitat quality, and food supply. Firstly, the grid and points were created by creating fishing net tools. Secondly, the values of the four ecosystem services from 2000 to 2020 were allocated to each point by extraction analysis tools, and the output was a table. Finally, Pearson correlation analysis was performed for different ecosystem services functions in the same year in SPSS. The larger the value of correlation, the stronger the correlation, while the smaller the value, the weaker the correlation. The formula is as follows:

$$R_{\mathrm{xy}} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} \tag{8}$$

R_{xy} is the correlation coefficient; n is the number of samples; $x_i y_i$ is the i value of x and y; $\overline{x}$ and $\overline{y}$ are the averages of the variables x and y, respectively.

2.5.2. Synergy of Ecosystem Services Tradeoff

Based on the study of Lan, this paper uses the ecosystem services tradeoff synergy model established based on linear data fitting to carry out the relevant evaluation [21]. To analyze the degree and direction of interaction between changes in ecosystem services, the formula is as follows:

$$ESTD_{mn} = \frac{ES_{mb} - ES_{ma}}{ES_{nb} - ES_{na}} \tag{9}$$

$ESTD_{mn}$ represents the synergy degree of the m and n ecosystem services; ES_{mb} is the change in amount of the m ecosystem service in period b. ES_{ma} is the change in amount of the m ecosystem service in time period a. The same applies to ES_{nb} and ES_{na}. $ESTD < 0$, represents the tradeoff relationship between the two ecosystem services. $ESTD > 0$, represents the synergistic relationship between the two ecosystem services.

2.5.3. Spatial Autocorrelation Analysis

Spatial autocorrelation analysis is mainly used to reveal whether the distribution of spatial variables and their adjacent regions have agglomeration. It includes two aspects, namely, global spatial autocorrelation and local spatial autocorrelation [44], which are represented by Mora's I and Local Moran's I indices [45].

The global spatial autocorrelation can reflect the similarity between each regional unit and adjacent regional units in the whole research area, and the calculation formula is:

$$I = \frac{\sum_{i=1}^{n}\sum_{j\neq 1}^{n} W_{ij}(y_i - \overline{y})(y_j - \overline{y})}{S^2 \cdot \sum_{i=1}^{n}\sum_{j\neq 1}^{n} W_{ij}} \tag{10}$$

y_i, y_j is the attribute value of unit i and unit j; n is the number of spatial units in the research area; W_{ij} is a weight matrix based on spatial adjacency.

To measure the spatial correlation between multiple variables, Anselin [46] proposed bivariate local spatial autocorrelation on this basis. Compared with the traditional spatial autocorrelation with only one variable, this method can characterize whether the spatial distribution of different variables is correlated with its adjacent regions and the degree of correlation. The formula is as follows:

$$I_{mn}^{p} = z_m^p \cdot \sum_{q=1}^{n} w_{pq} \cdot z_n^q \tag{11}$$

$Z_m^p = \frac{X_m^p - \overline{X}}{e_m}$, $Z_n^p = \frac{X_n^p - \overline{X}}{e_n}$, X_m^p is the value of the property m of the space unit p; X_n^p is the value of the property n of the space unit p; $\overline{X}$ is the average of the property m; $\overline{Y}$ is the average of the property n; e_m is the variance of the property m, and e_n is the variance of the property n.

3. Results

3.1. Temporal and Spatial Changes of Ecosystem Services in Fujian Province

3.1.1. Analysis of Land Cover/Use Change

Combined with the natural geographical characteristics and research objectives, the study area is divided into six types: cultivated land, forest land, grassland, water, construction land and unused land. Finally, a land-use classification map of Fujian Province in 2000, 2010 and 2020 is achieved (Figure 3).

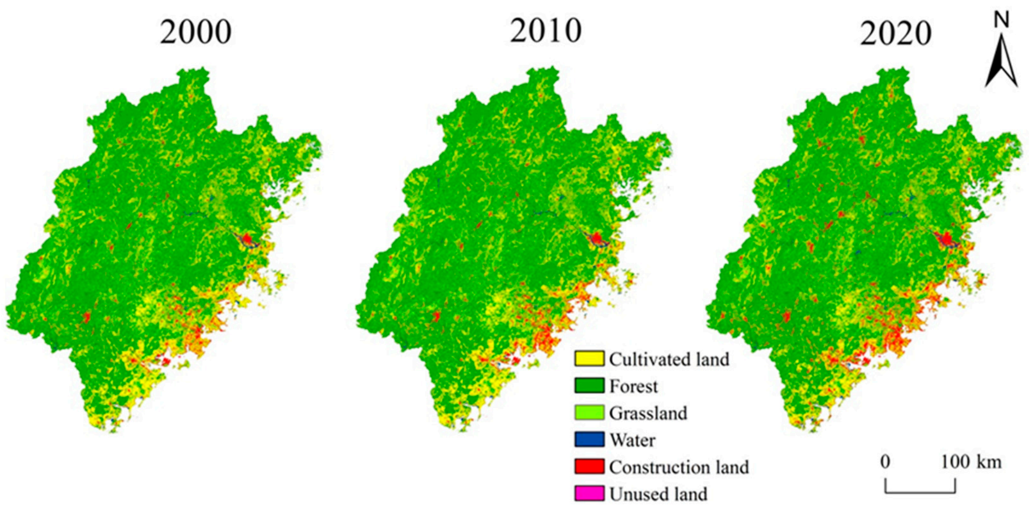

Figure 3. Spatial distribution of land-use types in Fujian Province in 2000, 2010, 2020.

From 2000 to 2020, the unused land in Fujian Province only decreased by 32.46 km^2, with a maximum decrease of 23.18% due to the small overall base. Construction land expanded dramatically, with an increase of 2470.98 km^2, with the largest increase rate of 75.93%. The water area increased by 292 km^2, with a growth rate of 16.44%. Forestland, cultivated land, and grassland decreased by 972.09 km^2, 1236.72 km^2 and 521.63 km^2, respectively, or by 1.17%, 4.95% and 5.64%. In general, the rapid expansion of construction land and the gradual decrease of forestland, cultivated land and grassland resources are the major features of land-use change in Fujian Province (Table 4).

Table 4. Change of land-use types in Fujian Province from 2000 to 2020.

Land-Use Type	2000/km^2	2010/km^2	2020/km^2	2000–2010/%	2010–2020/%
Cultivated land	25,008.99	24,513.04	23,772.27	−1.98	−3.02
Forestland	82,919.71	82,761.22	81,947.62	−0.19	−0.98
Grassland	9241.99	9341.42	8720.36	1.08	−6.65
Water	1776.40	1790.98	2068.40	0.82	15.49
Construction land	3254.28	3802.65	5725.25	16.85	50.56
Unused land	140.04	131.37	107.28	−6.19	−18.11

3.1.2. Temporal Changes of Ecosystem Services

Soil conservation services, carbon storage services, habitat quality, and food supply services in Fujian Province in 2000, 2010 and 2020 were obtained by using relevant models. ArcGIS software was used to produce spatial mapping expression (Figure 4). As can be seen in Table 5, from 2000 to 2020, soil conservation services in Fujian Province increase at first and then decrease. The decrease is greater than the increase, resulting in an overall decrease of the services of 137.89 t/hm^2. Carbon storage services showed a decreasing trend, with the annual average reducing from 2362.24 kg/m^2 in 2000 to 2324.60 kg/m^2 in 2020. There was little change in habitat quality. Based on the actual situation of Fujian Province, obtained habitat quality values were divided into four grades: poor (0–0.3), medium (0.3–0.6), good (0.6–0.9) and excellent (0.9–1). The habitat quality in Fujian Province from 2000 to 2020 was 0.82. Food supply services showed an increasing trend, and the annual average of the food supply increased from 5.695 billion yuan/km^2 in 2000 to 27.014 billion yuan/km^2 in 2020.

In order to identify the dominant ecosystem services and dynamic changes of prefecture-level cities in Fujian Province from 2000 to 2020, this paper used the fishing net tool in ArcGIS software to carry out spatial sampling based on the raster graph of the evaluation results of four ecosystem services, and divided the size of those in nine prefecture-level cities in Fujian Province. Through normalization, four ecosystem services were normalized to 0~1. Origin software was used to process and visualize the data, and the polar coordinate map, also known as the rose map, was obtained (Figure 5).

As shown in Figure 5, soil conservation services, carbon storage services, and habitat quality services are particularly prominent in Sanming city, Longyan City, Nanping City, and Ningde city with the large woodland area, but the food supply capacity is weak. In Fuzhou, Xiamen, Putian, Quanzhou, and Zhangzhou, the cultivated land area is large and the food supply capacity is strong, but the soil conservation service, carbon storage service, and habitat quality service are weak. From 2000 to 2020, soil conservation services in Nanping and Ningde were the largest, while those in Xiamen were the smallest. Nanping city has the largest carbon storage service, while Xiamen city has the smallest carbon storage service. Nanping had the highest habitat quality, while Xiamen and Quanzhou had the lowest. From the multi-year average, Xiamen city has the largest food supply service, Longyan city has the smallest food supply service. On the whole, food supply and the other three services do not change at the same time, while soil conservation, carbon storage, and habitat quality show the characteristics of simultaneous increase and decrease.

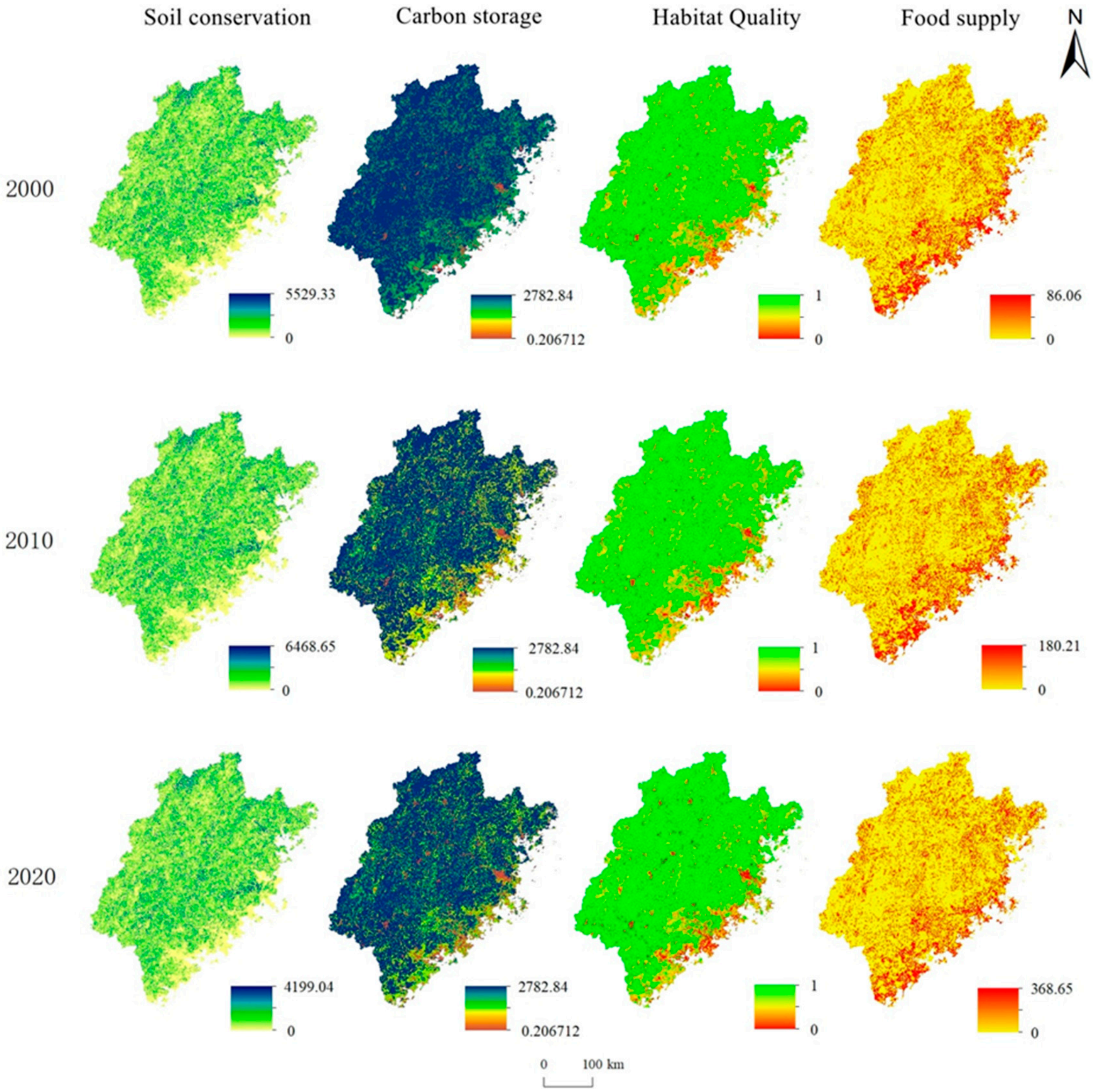

Figure 4. Distribution of four typical ecosystem services in Fujian Province, 2000–2020. (Soil conservation (t/hm^2), Carbon sequestration (kg/m^2), Habitat quality (dimensionless), Food supply (billion yuan)).

Table 5. Ecosystem services in Fujian Province, 2000–2020.

Ecosystem Service Types		Minimum	Maximum	Average
Soil conservation (t/hm^2)	2000	0	5529.33	557.17
	2010	0	6468.65	653.66
	2020	0	4199.04	419.28
Carbon storage (kg/m^2)	2000	0.21	2782.84	2362.24
	2010	0.21	2782.84	2353.14
	2020	0.21	2782.84	2324.60
Habitat quality	2000	0	1	0.83
	2010	0	1	0.82
	2020	0	1	0.81
Food supply (billion yuan)	2000	0	86.06	56.95
	2010	0	180.21	126.29
	2020	0	368.65	270.14

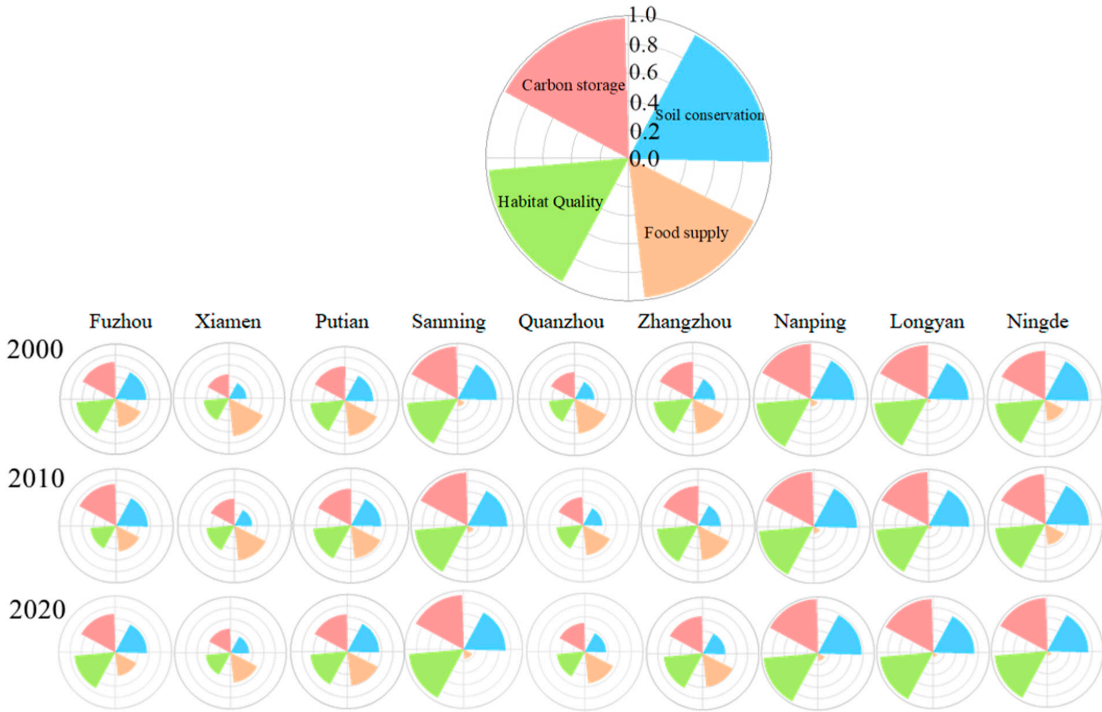

Figure 5. Rose chart of polar coordinates of ecosystem services in nine cities of Fujian Province.

3.1.3. Spatial Agglomeration Characteristics of Ecosystem Services

Global spatial autocorrelation analysis aims to reflect the overall agglomeration characteristics between regional units of the whole research area and adjacent regional units [47]. Based on the county-level administrative regions of Fujian Province as the basic unit, this paper obtained the global spatial autocorrelation Moran's I index (Table 6), drawing the LISA map of four ecosystem services in Fujian Province from 2000 to 2020 (Figure 6), and analyzing the spatial agglomeration characteristics of ecosystem services. As Table 6 shows, the p value of Moran's I index was <0.01 and the Z score was >2.58, with a confidence level of 99%, indicating that there was a strong spatial correlation, with obvious clustering rather than random distribution. This method can directly reflect the aggregation and distribution of ecosystem services at a spatial scale and the specific spatial location information.

Table 6. Moran's I estimation of ecosystem services in Fujian Province.

		Soil Conservation	Carbon Storage	Habitat Quality	Food Supply
2000	Moran's I	0.544	0.618	0.656	0.547
	Z score	5.99	7.33	7.76	6.43
	p value	0.001	0.001	0.001	0.001
2010	Moran's I	0.542	0.641	0.674	0.517
	Z score	5.97	7.70	8.30	6.10
	p value	0.001	0.001	0.001	0.001
2020	Moran's I	0.535	0.624	0.662	0.526
	Z score	5.83	7.52	8.13	6.26
	p value	0.001	0.001	0.001	0.001

The four ecosystem services in Fujian Province showed different agglomeration characteristics. As can be seen from Figure 6, the correlation of most regions in Fujian Province is not significant, and the areas with high correlation are mainly high-high aggregation and low-low aggregation. The high-high accumulation area of soil conservation service was mainly distributed in the middle of Fujian Province, while the low-low accumulation area was distributed in the southeast of Fujian Province. Compared with 2000, the number of high-high aggregation units decreased from 13 to 12 in 2020, and the number of low-low aggregation area units was about the same. The high-high accumulation area of carbon storage service is mainly distributed in the west and northwest of Fujian Province, while the low-low accumulation area is distributed in the southeast of Fujian Province. The number of high-high aggregation units increased from 20 in 2000 to 22 in 2020, while the number of low-low aggregation units increased from 4 to 5, and the number of aggregation areas expanded southward. The high-high accumulation area of habitat quality was mainly distributed in the northwest and southwest of Fujian Province, while the low-low accumulation areas were distributed in the southeast of Fujian Province. Compared to 2000, the number of high-high aggregation units increased from 16 to 17 in 2020, while the number of low-low aggregation units increased from 5 to 6, and the aggregation area expanded southward. The high-high areas of the food supply service were mainly distributed in the southeast of Fujian Province, while the low-low areas were found in the west and southwest of Fujian Province. Compared with 2000, the number of high-high aggregation units was the same in 2020, but the aggregation area expanded southward, and the number of low-low aggregation units reduced from 17 to 16. In conclusion, the spatial distribution of four typical ecosystem services in Fujian Province shows specific aggregation patterns. Positive correlation type cluster distribution is characterized by high-high aggregation and low-low aggregation. The negative correlation types, characterized by high-low aggregation and low-high aggregation, are dispersed and weakly concentrated.

3.2. Study on Tradeoffs/Synergies of Ecosystem Services at Multi-Scale

3.2.1. Analysis of Tradeoffs/Synergies of Ecosystem Services at the Provincial Scale

Pearson correlation analysis was performed for different ecosystem services functions in the same year in SPSS software, and the correlation coefficients among the four ecosystem services in Fujian Province were calculated (Table 7). From 2000 to 2020, soil conservation services, carbon storage services and habitat quality showed synergistic relationships, and food supply services showed tradeoffs with soil conservation services, carbon storage services and habitat quality. In addition, synergies between soil conservation services, carbon storage services, and habitat quality tended to weaken, and the tradeoffs between them tended to slow down from 2000 to 2020.

3.2.2. Analysis of Ecosystem Service Tradeoffs/Synergies at the City Scale

In order to further explore the degree and direction of the interactions between ecosystem services and quantitatively evaluate the relationships between the services in different cities in Fujian Province, this paper adopted Ecosystem Service Tradeoff-synergy Degree (ESTD) to obtain the tradeoffs/synergies degree of the services in 9 cities in Fujian Province (Figure 7). It can be seen from Table 8 that in the tradeoffs/synergy relationship of ecosystem services in Fujian Province from 2000 to 2020, there were 54 sets of values among the services, including 25 sets of negative values and 29 sets of positive values. The synergistic effects between soil conservation and carbon storage were mainly observed in Ningde, Nanping, Longyan, Putian, and Quanzhou. The synergistic effects between soil conservation and habitat quality were mainly observed in Nanping, Ningde, and Fuzhou. The tradeoffs between soil conservation and food supply were mainly observed in Longyan, Nanping, Sanming, Fuzhou, and Ningde. The synergistic effect between carbon storage and habitat quality was the highest in Nanping city. The tradeoff between carbon storage and food supply was the most significant in Zhangzhou. The tradeoff between habitat quality and food supply was the highest in Xiamen city.

3.2.3. Analysis of Ecosystem Service Tradeoffs/Synergies at the County Scale

In order to further understand the tradeoffs/synergies of different ecosystem services in the spatial pattern in Fujian Province, this paper takes county-level cities as research units. The significance of the analysis results was always higher than 99%. The Moran's I index and Moran's scatter diagram of bivariate local spatial autocorrelation from 2000 to 2020 are shown in Figures 8–10.

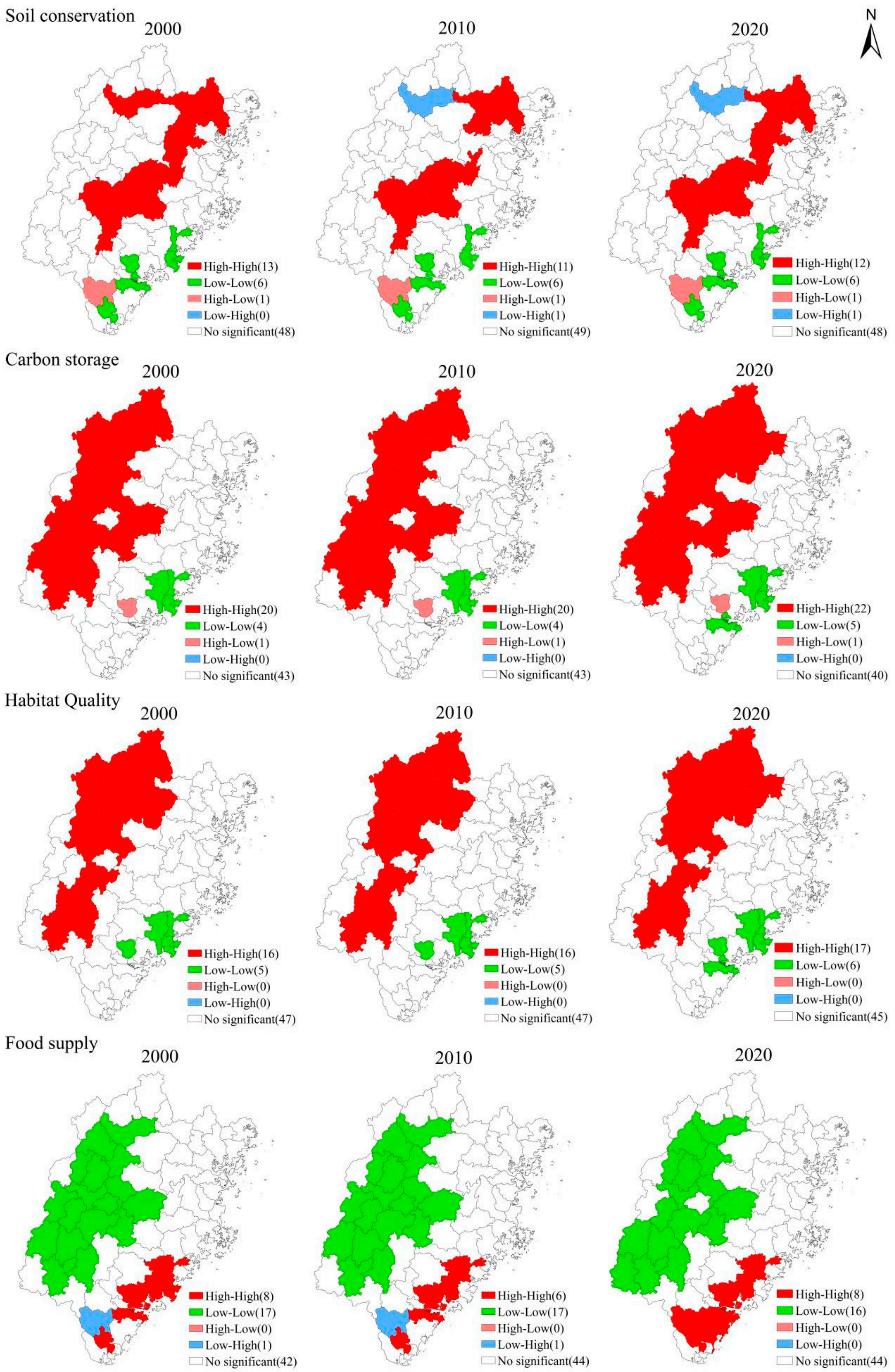

Figure 6. Spatial agglomeration and distribution of four ecosystem services in Fujian Province (the numbers in brackets indicate the number of county units).

Table 7. Correlation coefficients of ecosystem services in Fujian Province from 2000 to 2020.

	S-C	S-H	S-F	C-H	C-F	H-F
2000	0.298 **	0.290 **	−0.234 **	0.926 **	−0.652 **	−0.717 **
2010	0.300 **	0.292 **	−0.227 **	0.926 **	−0.621 **	−0.690 **
2020	0.227 **	0.209 **	−0.134 **	0.917 **	−0.540 **	−0.622 **

S: Soil conservation, C: Carbon sequestration, H: Habitat quality, F: Food supply. ** $p < 0.01$.

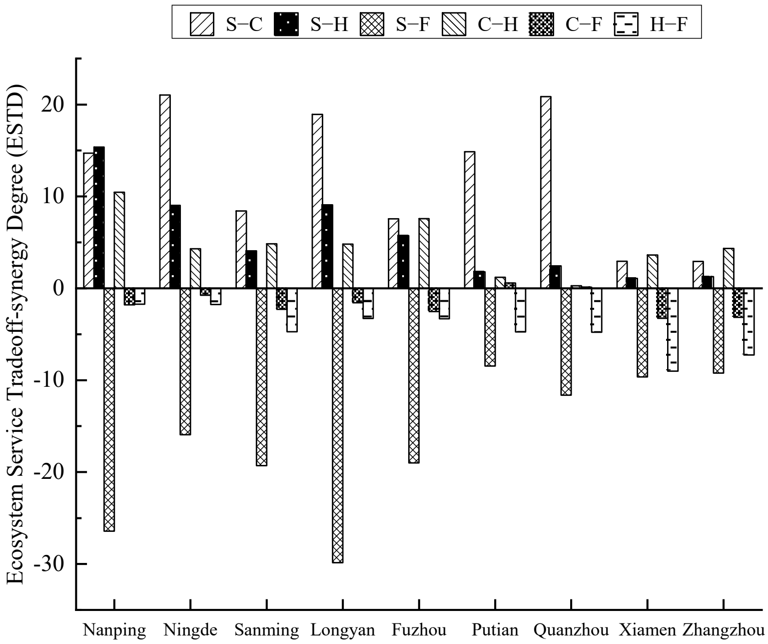

Figure 7. The synergy degree of ecosystem service tradeoff between different cities in Fujian Province. (S: Soil conservation, C: Carbon sequestration, H: Habitat quality, F: Food supply).

Table 8. The synergy degree of ecosystem service tradeoffs in Fujian Province from 2000 to 2020.

	S-C	S-H	S-F	C-H	C-F	H-F
Nanping	14.70	15.36	−26.43	10.45	−1.80	−1.72
Ningde	21.02	9.04	−15.94	4.30	−0.76	−1.76
Sanming	8.43	4.08	−19.28	4.84	−2.29	−4.73.
Longyan	18.93	9.09	−29.85	4.80	−1.58	−3.29
Fuzhou	7.55	5.72	−19.00	7.57	−2.52	−3.32
Putian	14.87	1.79	−8.47	1.20	0.57	−4.74
Quanzhou	20.86	2.44	−11.63	0.27	0.13	−4.78
Xiamen	2.95	1.07	−9.64	3.63	−3.27	−9.01
Zhangzhou	2.93	1.27	−9.23	4.33	−3.15	−7.26

S: Soil conservation. C: Carbon sequestration, H: Habitat quality, F: Food supply.

In bivariate spatial autocorrelation analysis, high-high agglomeration and low-low agglomeration indicated that two ecosystem services were synergies, and the features of the high-low agglomeration and the low-high agglomeration represented tradeoffs. Table 9 shows that there are significant synergies between soil conservation services, carbon storage services and habitat quality, while there are significant trade-offs between food supply services and the other three services. The results correspond to those in Table 7. It may be observed in Figure 11 that the four typical ecosystem services in Fujian Province have strong spatial agglomeration characteristics and significant spatial heterogeneity, with synergistic relationships for S-C, S-H and C-H. The high-high synergistic relationship was mainly in Nanping, Sanming and Longyan in the west of Fujian Province, and the low-low synergistic relationship was in Quanzhou in the southeast of Fujian Province. The high-low tradeoff relationship is mainly manifested in Nanping, Sanming, and Longyan in the middle and west of Fujian Province, while the low-high tradeoff is mainly manifested in Quanzhou, Xiamen and Zhangzhou in the southeast of Fujian Province. From 2000 to 2020, the synergy between soil conservation and carbon storage increased from 22 to 25, and the tradeoff was 3. The synergy between soil conservation and habitat quality increased from 20 to 21 counties, and the tradeoff increased from 1 to 2 counties. The tradeoff between soil conservation and food supply decreased from 22 to 20 counties, and synergy remained in 4 counties. The number of counties with synergistic carbon storage and habitat quality increased from 20 to 22, and the number of tradeoff counties remained unchanged at 1. The tradeoff between carbon storage and food supply was reduced from 24 to 22 counties, and resynergy remained in 2 counties. The tradeoff between habitat quality and food supply decreased from 25 counties to 23 counties, and remained unchanged at 1 county. It can be seen from the changes in the number of synergistic counties that the synergies of soil conservation-carbon storage and soil conservation-habitat quality tended to weaken, while the synergies of carbon conservation-habitat quality tended to strengthen from 2000 to 2020. The tradeoffs between food supply and soil conservation, food supply and carbon storage, and food supply and habitat quality have a tendency to weaken.

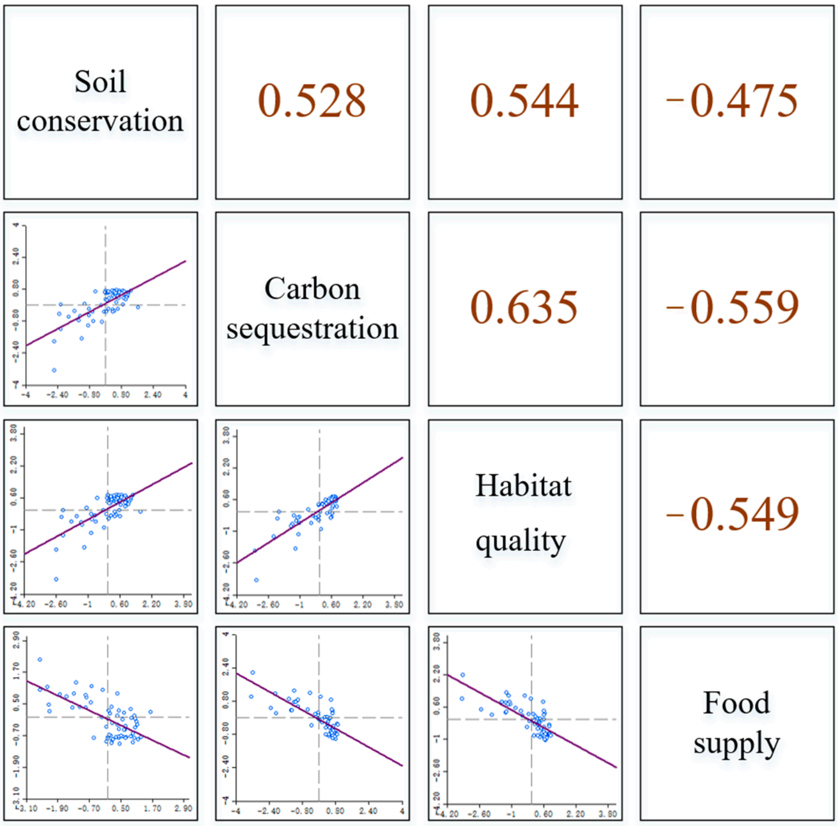

Figure 8. Moran's I of bivariate local spatial autocorrelation of four ecosystem services in Fujian in 2000.

Table 9. Local spatial autocorrelation Moran's I of four typical ecosystem services in Fujian Province from 2000 to 2020.

	S-C	S-H	S-F	C-H	C-F	H-F
2000	0.528	0.544	−0.475	0.635	−0.559	−0.549
2010	0.535	0.549	−0.435	0.652	−0.501	−0.479
2020	0.523	0.541	−0.418	0.641	−0.502	−0.481

S: Soil conservation, C: Carbon sequestration, H: Habitat quality, F: Food supply.

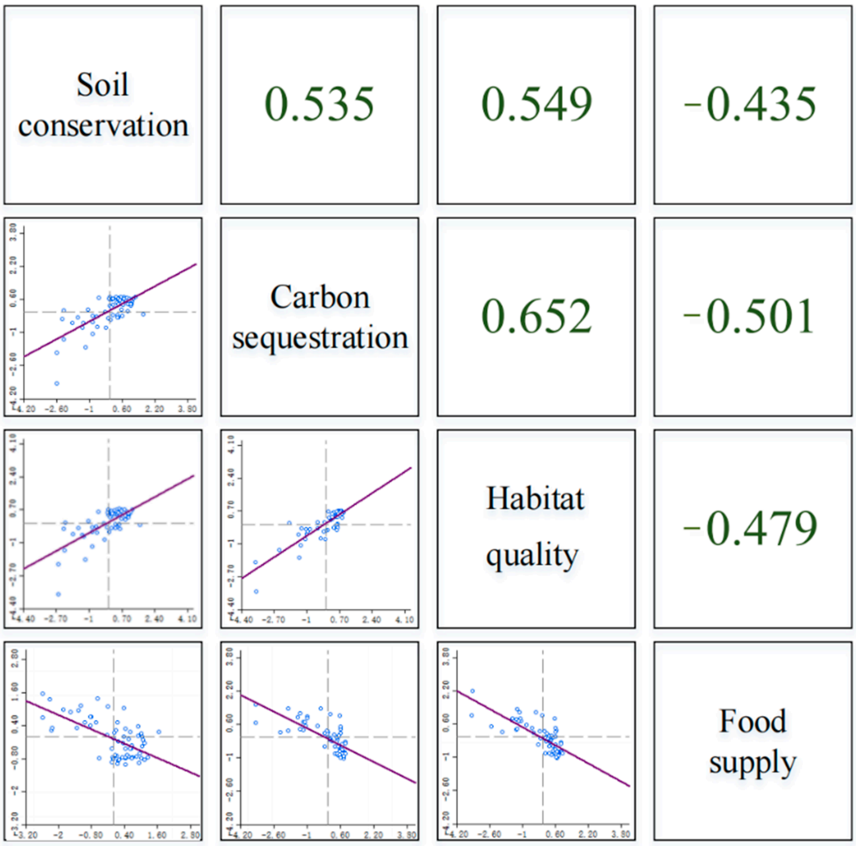

Figure 9. Moran's I of bivariate local spatial autocorrelation of four ecosystem services in Fujian in 2010.

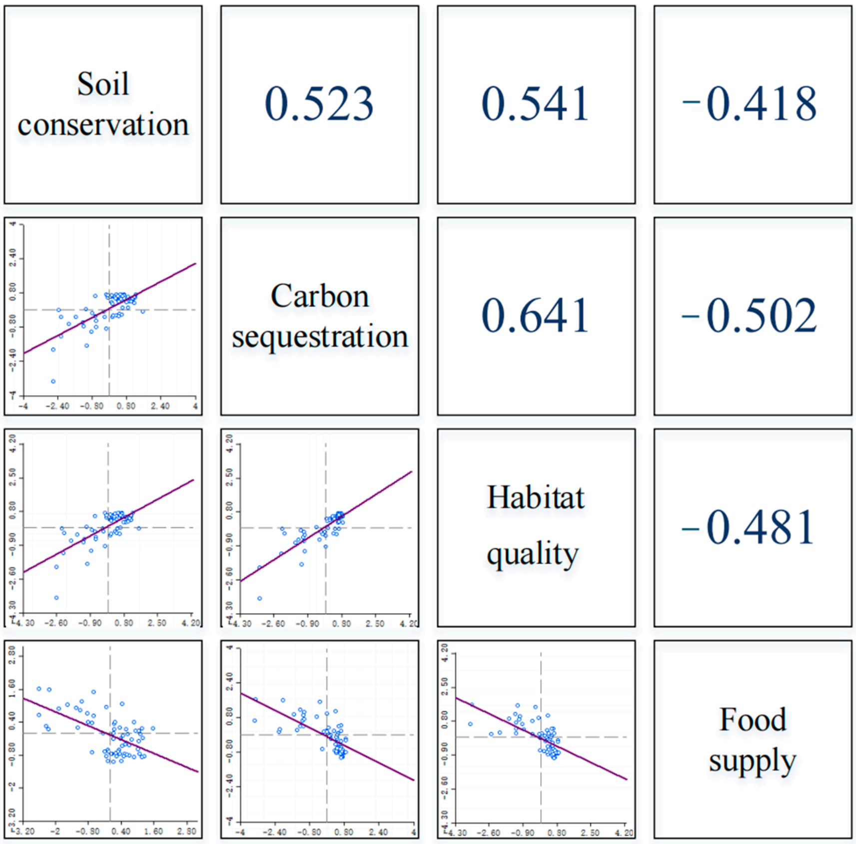

Figure 10. Moran's I of bivariate local spatial autocorrelation of four ecosystem services in Fujian in 2020.

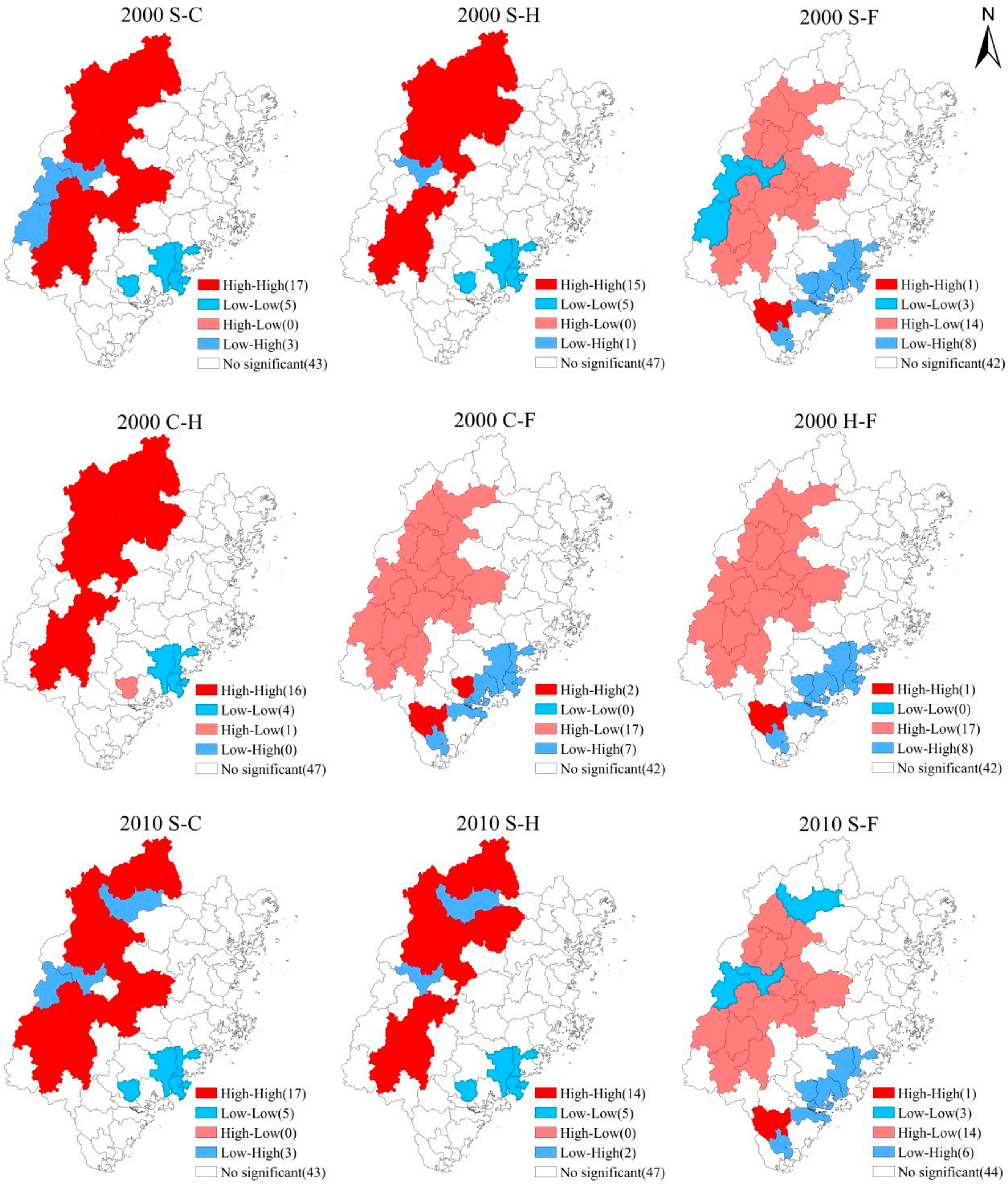

Figure 11. *Cont*.

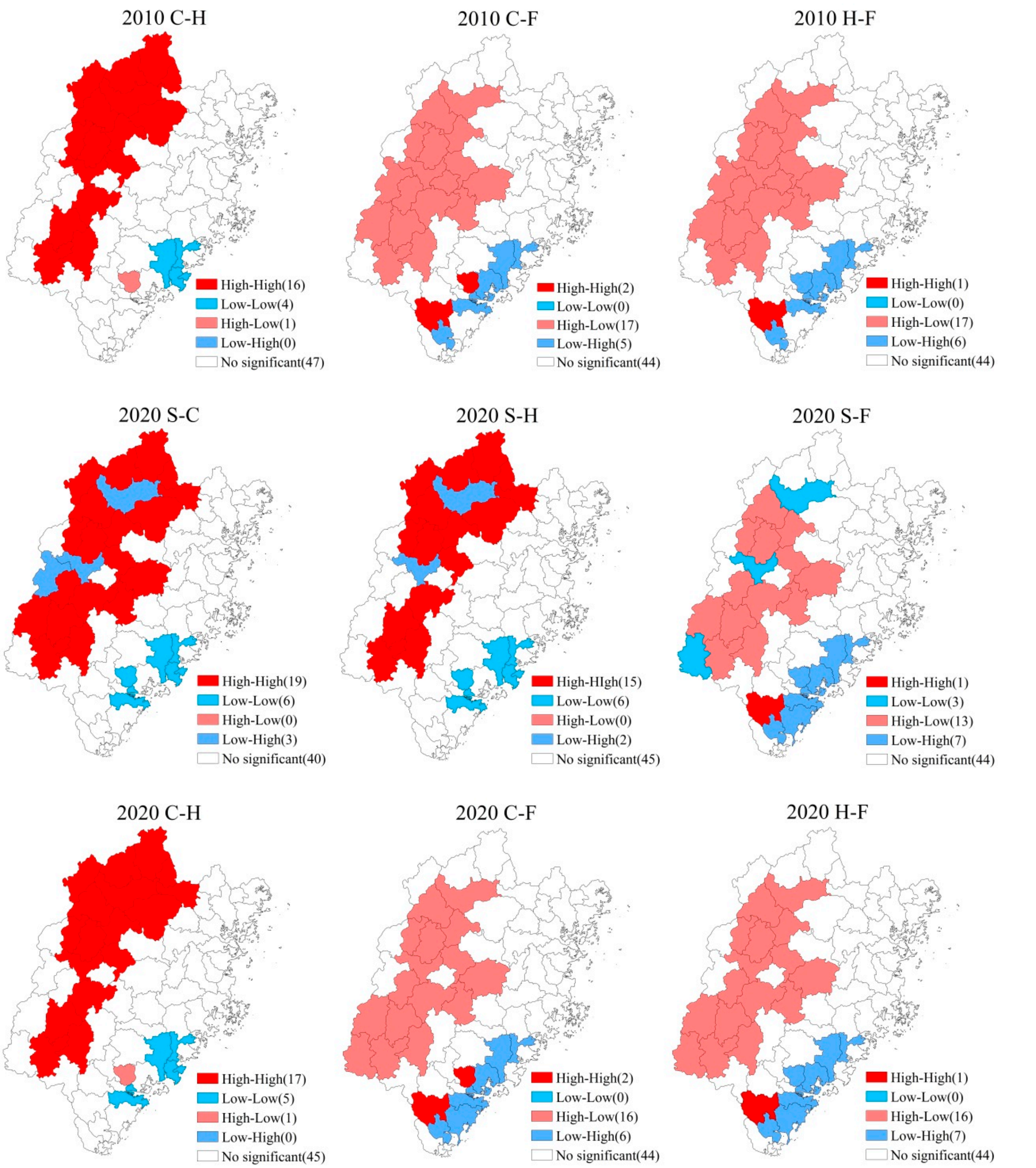

Figure 11. LISA map of bivariate spatial autocorrelation agglomeration distribution of four typical ecosystem services in Fujian Province from 2000 to 2020.

4. Discussion

4.1. Ecosystem Services Assessment

Comprehensive and systematic simulation and estimation of ecosystem services are important conditions for ecosystem service management and related policy formulation [33]. It is found that the land-use pattern in Fujian Province has changed significantly due to the large expansion of construction land in the past 20 years, leading to significant changes in ecosystem structure. The four ecosystem services have significant spatial heterogeneity in their spatial distribution. These findings are consistent with the studies of Xu [48] and Zhang [49]. The characteristics of ecosystem services and their tradeoffs/synergies in Fujian Province are related to topography, geomorphology, climate, and human activities. The terrain of Fujian Province is generally high in the northwest and low in the southeast, and the landforms are diverse. The central and western regions are dominated by mountains and hills, while the eastern and southeastern coastal regions are dominated by plains. In addition, relevant studies show that human development activities are positively correlated with food supply services, while negatively correlated with other ecosystem services [6]. The mountainous and hilly areas in the central and western part of Fujian Province are mainly woodland and grassland, which are not affected by human activities. Therefore, soil conservation service and carbon storage service capacity are high, and the habitat quality grade is high, but the food supply capacity is weak. The eastern plain is mainly cultivated land and construction land, and is greatly affected by human activities. In addition to food supply service capacity, soil conservation service, carbon storage service, and habitat quality are minimal in the eastern plain. The climate of Fujian Province has significant intra-regional differences. The southeast coastal area has a southern subtropical climate. The western and northern regions have a mid-subtropical climate. The precipitation in the west is higher than in the east. According to the vegetation types in Fujian, the carbon storage of forest vegetation is positively correlated with precipitation and negatively correlated with temperature in a certain threshold range [50,51]. As can be seen from Table 7, the correlation coefficients between habitat quality and carbon storage from 2000 to 2020 were all over 0.8, indicating a highly positive correlation. Western Fujian is mountainous, with high altitude and low temperature, and more precipitation than eastern Fujian; the former are more conducive to carbon sequestration of ecosystem and improvement of habitat quality [47]. There are many plains in eastern Fujian, where the temperature is higher and the precipitation is less than that in western Fujian. The carbon sequestration capacity of the ecosystem is relatively weak, and the habitat quality is also lower than that in western Fujian. In addition, areas with high precipitation and high vegetation coverage also have a large amount of soil conservation.

As can be explained by the above, high-high concentrations of soil conservation services, carbon storage services, and habitat quality were all distributed in the central and western regions, while the low-low concentrations were distributed in the southeast region during 2000–2020. A high-high aggregation of food supply services was noted in the southeast, and low-low aggregation in the Midwest.

4.2. Ecosystem Services Tradeoff and Synergy

Research on ecosystem service tradeoffs and synergies aims to achieve a sustainable supply of ecosystem services at different levels, such as watersheds, lakes, districts, etc. Based on fully understanding and mastering the multiple nonlinear relations, type characteristics and scale effects among ecosystem services, the balance between regional economic development and ecological environmental protection should be sought, in order to maximize the benefits of stakeholders [49]. In the study of tradeoffs/synergies among ecosystem services, we compared the results of previous similar studies. Wei obtained the global relationship between two ecosystem services based on correlation analysis of correlation coefficients [52]. The conclusion is consistent with this paper. The synergy relationship was the main one, and the tradeoff relationship mainly occurred between food supply service and other services. This shows that the method used has a distinguished scientific nature and applicability. There is a significant negative correlation between food supply services and the other three ecosystem services, which is caused by the interaction between ecosystem services [53,54]. Trade-off between food supply service and other services not only reflects the competition between agricultural land and other land (especially forest land and grassland), but also reflects the contradiction and conflict between regional food production and environmental protection. Therefore, when making the overall plan of land-use, it is necessary to carefully weigh all kinds of land-use from a holistic point of view. Scientifical delineation of “cultivated land red line” and formulation of a cultivated land protection policy according to local conditions can help meet the aim to “safeguard food security, protect ecological environment” in a win-win situation.

Bennett proposed that the common driving factors and interactions between ecosystem services may affect the mechanism of ecosystem service relationships [13]. Among them, the most important driving factor is the type of land use. Xu classified land use conditions affecting tradeoffs/synergies between ecosystem services into two categories: land use conflict and land use congruence [48]. Land use conflict means that a piece of land can only be used for one kind of ecosystem service, which is prone to tradeoffs. Land use congruence means that a certain type of land benefits two or more ecosystem services at the same time, which is prone to synergies. If a certain service has a large proportion of land use types in the region and the land use type has a significant supporting effect on the service, the service will become an advantage in the region. Accordingly, other services become inferior services. To a certain extent, whether synergies or tradeoffs occur depends on the ratio of the areas of supporting and non-supporting land types and their support level for various services. The tradeoffs and synergies among ecosystem services in this paper can be explained by the mechanism mentioned above. For example, the dominant land type for carbon storage services is forest and grassland, and the dominant land type for food supply services is cultivated land. The relationship between food supply and carbon storage is synergistic in areas with a moderate ratio of arable land to forest and grassland (Figure 11). Preserving part of the forest near cultivated land can increase crop pollination and thus food production [55,56]. In addition, crops also have carbon sequestration capacity, and food supply and carbon storage are consistent with land use, so there is a synergistic relationship in this region. There is a tradeoff between food supply and carbon storage in areas with intensive farmland. The reason may be that there is a land use conflict between carbon storage and food supply. Although crops have a certain capacity for carbon sequestration, their capacity is much lower than that of forests and grasslands. In addition, over-cultivation will also lead to soil quality degradation, which will hinder the carbon cycle [51].

The tradeoff of ecosystem services has spatial scale and time scale. Spatial scale refers to the size of the region where the tradeoff occurs. Time scale is a measure of how long it will last [57]. Correlation coefficients and bivariate spatial autocorrelation methods can directly reveal the temporal and spatial tradeoffs/synergies of ecosystem services. The response period of supply service is short, but the response period of regulation and support service is long. The tradeoffs/synergies of ecosystem services require a long time span of study, so we chose a 20-year time span for our study.

It was found that the evaluation results at provincial scale, city scale and county scale are basically consistent. The results showed that there were significant synergies among most ecosystem services in Fujian province, which provided good benefits for regional ecological restoration and protection policies. However, the relationship between carbon storage and food supply is different at the provincial scale and the municipal scale. At the provincial scale, there is a tradeoff relationship between carbon storage and food supply, but at the municipal scale, the tradeoff relationship is not complete. In Putian and Quanzhou, these services had a slight synergistic relationship, which was due to the strong regional heterogeneity and city-scale dependence of ecosystem service trade-off and synergistic relationship. This suggests that tradeoffs/synergies at the regional scale do not represent the same relationship at the sub-level or even at the micro scale. There are differences in the spatial pattern, which is due to the influence of constraint thresholds on ecosystem service relationships [34]. For instance, areas with higher carbon storage have higher vegetation coverage, which inhibits soil erosion. In this case, carbon storage and soil conservation services have a synergistic relationship, while areas with higher vegetation coverage have more abundant precipitation and intensified soil erosion, and carbon sequestration and soil conservation services show a tradeoff relationship [58,59]. This paper finds that most of the relationships among various ecosystem services in Fujian are synergistic, which also provides benefits for the formulation of ecological restoration and protection policies in the region. Forest and grassland have high vegetation coverage, strong soil fixation ability, less soil erosion, high soil conservation and high carbon storage. In contrast, the surface vegetation coverage of cultivated land and construction land is low, soil fixation ability is weak, and soil erosion is serious. Therefore, soil conservation is low, and carbon storage is low. Forest is the dominant land use type to maintain soil conservation and carbon storage in the study area. The soil conservation and carbon storage capacity of the study area can be improved by increasing the area of forest and grassland. The habitat quality of each land use type is high or low, and the habitat quality can be improved by giving priority to increasing the area of forest, grassland and water. The changes in construction land and unused land had little effect on habitat quality. Fujian can make relevant policies to restrict the conversion of large areas of cultivated land to other land uses and increase unit yield to improve grain production services, such as water and fertilizer management and agricultural measures.

4.3. Research Deficiencies and Prospects

In this paper, two methods, the correlation coefficient method and ESTD model, are used to identify the numerical relationships of ecosystem service tradeoff/synergy. The results demonstrate that the two methods can identify the relationships among ecosystem services and the results are consistent. Owing to different calculation methods and data requirements, there are differences in the size of relevant values. Bivariate local spatial autocorrelation analysis was designed to reveal spatial heterogeneity of ecosystem service trade-offs/synergies. However, these three methods still cannot fully reflect the internal mechanisms and action mechanisms of ecosystem services. Further discussion and in-depth analysis are required in the future with the help of other methods and means.

This paper is restricted to the analysis of the spatial-temporal evolution of ecosystem services and the tradeoffs among different ecosystem services. There is a lack of studies on the tradeoffs between supplying and demand for ecosystem services. The balance between supply and demand for ecosystem services is the key to whether an ecosystem can support human well-being. This issue has to be addressed in more depth in future research, enabling Fujian Province to formulate a more comprehensive and specific regional development and ecological protection strategy. At present, the research on the internal mechanism of ecosystem service interaction is far from sufficient. Feng [60] examined the global relationship between five environmental factors (vegetation coverage, vegetation type, elevation, silt, and sand composition) and ESs in 151 sample sites. Qiu and Turner [61] by using logistic regression found several potential explanatory variables, used to explore the local scale and the global relationship between the landscape types of ESs, including slope, soil physical properties, population density, the distance to the river, to the most recent wetland, and to the forest, within a radius of 560 m including the total landscape forest, farmland, and the percentage of the wetlands, and so on. However, these studies are mainly based on global regression models. In the selection of factors, ecological factors are mostly considered, and urbanization factors are seldom considered. This results in the potential correlation between urbanization and the trade-offs/synergies between ESs being completely ignored. Previous studies have shown that ecosystem services are significantly affected by urbanization [49,60,62], and so ignoring human influence may lead to misleading judgments. Therefore, the study of the correlation between ecosystem services and nature and social economy will be an important part of future research.

5. Conclusions

This paper takes Fujian Province as the research area under the background of rapid urbanization and ecological civilization construction. Four typical ecosystem services, namely soil conservation services, carbon storage services, habitat quality, and food supply services, were estimated using applicable models. The spatial and temporal dynamics and the tradeoff/coordination relationship among them were tested by using the polar coordinate rose diagram, correlation analysis, ESTD model, spatial autocorrelation analysis, and spatial mapping.

(1) From 2000 to 2020, soil conservation services in Fujian Province first increased and then decreased, with an overall decrease of 137.89 t/hm^2. Carbon storage services showed a decreasing trend, with the annual average reducing from 2362.24 kg/m^2 in 2000 to 2324.60 kg/m^2 in 2020. The habitat quality in Fujian Province was good. Food supply services are increasing, and the annual mean has increased from 56.95 in 2000 to 270.14 billion yuan/km^2 in 2020. As can be seen from the polar coordinate rose chart, soil conservation services in Nanping and Ningde are the largest, while those in Xiamen are the smallest. Nanping city has the largest carbon storage service, while Xiamen city has the smallest carbon storage service. Nanping had the highest habitat quality, while Xiamen and Quanzhou had the lowest. Xiamen city has the largest food supply service, while Longyan city has the smallest food supply service.
(2) The spatial distribution of the four typical ecosystem services in Fujian Province showed specific aggregation patterns. Positive correlation type cluster distribution is characterized by high-high aggregation and low-low aggregation. The negative correlation types, characterized by high-low aggregation and low-high aggregation, are dispersed and weakly concentrated.
(3) The tradeoffs/synergies analysis showed that there was a synergistic relationship between soil conservation services, carbon storage services and habitat quality at the provincial scale. There are tradeoffs between food supply services and soil conservation services, carbon storage services, and habitat quality. The synergetic relationship is the dominant relationship among ecosystem services in Fujian Province. At the prefecture-level scale, the tradeoffs/synergies among ecosystem services vary among prefecture-level cities. The Moran's I index of bivariate spatial autocorrelation at the county scale is consistent with the correlation coefficient. The tradeoffs/synergies among ecosystem services are spatially heterogeneous.
(4) This study used the correlation analysis method, tradeoff synergy model and bivariate spatial autocorrelation analysis to study the tradeoffs/synergies relationship of ecosystem services in Fujian Province at diverse scales. The results demonstrate that the three methods can clearly show the relationship between various ecosystem services, and the research results are highly consistent. These results indicate that the synergetic relationship is the dominant relationship among ecosystem services in Fujian Province. Tradeoffs between food supply and soil conservation, carbon storage, and habitat quality are most common.
(5) This paper measured four ecosystem services, soil conservation, carbon storage, habitat quality, and food supply, analyzed the temporal and spatial evolution of ecosystem services, and analyzed their trade-offs and synergies. More efforts are needed in the future to explore the use of biomass to measure food supply services. In addition, the influencing factors of trade-offs and synergies between ecosystem services have great research significance, and attention to this issue needs to be enhanced and deepened in the following research. The balance of supply and demand for ecosystem services is key to whether ecosystems can support human well-being. We will also explore this question in future research. It is hoped that this study can provide more comprehensive and specific regional development and ecological protection strategies for Fujian Province.

Author Contributions: P.Z. designed the overall ideas for this study. M.L., P.Z. and W.P. performed data analysis. M.L., P.Z. wrote this manuscript, and all the authors were involved in improving the quality of this manuscript. P.Z. was also responsible for the academic merit of this manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: We are sincerely grateful to U.S. Geological Survey for Landsat image and data processing, to Chinese Academy of Sciences for reference data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shoyama, K.; Kamiyama, C.; Morimoto, J.; Ooba, M.; Okuro, T. A review of modeling approaches for ecosystem services assessment in the Asian region. *Ecosyst. Serv.* **2017**, *26*, 316–328. [CrossRef]
2. Daily, G.C. *Nature's Services: Societal Dependence on Natural Ecosystems*; Island Press: Washington, DC, USA, 1997.
3. Wong, C.P.; Jiang, B.; Kinzig, A.P.; Lee, K.N.; Ouyang, Z. Linking ecosystem characteristics to final ecosystem services for public policy. *Ecol. Lett.* **2015**, *18*, 108–118. [CrossRef] [PubMed]
4. Liu, D.; Chang, Q. Ecological security research progress in China. *Acta Ecol. Sin.* **2015**, *35*, 111–121. [CrossRef]
5. Millennium, E.A. *Ecosystems and Human Well-Being, Encyclopedia of the Anthropocene*; Island Press: Washington, DC, USA, 2005.
6. Wang, B.; Tang, H.; Xu, Y. Integrating ecosystem services and human well-being into management practices: Insights from a mountain-basin area, China. *Ecosyst. Serv.* **2017**, *27*, 58–69. [CrossRef]
7. Hao, R.; Yu, D.; Sun, Y.; Shi, M. The features and influential factors of interactions among ecosystem services. *Ecol. Indic.* **2019**, *101*, 770–779. [CrossRef]
8. Spyra, M.; La Rosa, D.; Zasada, I.; Sylla, M.; Shkaruba, A. Governance of ecosystem services trade-offs in peri-urban landscapes. *Land Use Policy* **2020**, *95*, 104617. [CrossRef]
9. Zhang, Z.; Liu, Y.; Wang, Y.; Liu, Y.; Zhang, Y.; Zhang, Y. What factors affect the synergy and tradeoff between ecosystem services, and how, from a geospatial perspective? *J. Clean. Prod.* **2020**, *257*, 120454. [CrossRef]
10. Meng, M.; Yun, Z.; Junjun, Z.; Yue, D.; Aifang, W.; Hao, S. Spatial-temporal Evolution of Ecosystem Service Value Under Rapid Urbanization—A Case Study of Nanjing City. *Bull. Soil Water Conserv.* **2021**, *41*, 296–304.
11. Grasso, M. Ecological—Economic model for optimal mangrove trade off between forestry and fishery production: Comparing a dynamic optimization and a simulation model. *Ecol. Model.* **1998**, *112*, 131–150. [CrossRef]
12. Rodríguez, J.P.; Beard, T.D., Jr.; Bennett, E.M.; Cumming, G.S.; Cork, S.J.; Agard, J.; Dobson, A.P.; Peterson, G.D. Trade-offs across Space, Time, and Ecosystem Services. *Ecol. Soc.* **2006**, *11*, 709–723. [CrossRef]
13. Bennett, E.M.; Peterson, G.D.; Gordon, L.J. Understanding relationships among multiple ecosystem services. *Ecol. Lett.* **2009**, *12*, 1394–1404. [CrossRef] [PubMed]
14. Carreño, L.; Frank, F.C.; Viglizzo, E.F. Tradeoffs between economic and ecosystem services in Argentina during 50 years of land-use change. *Agric. Ecosyst. Environ.* **2012**, *154*, 68–77. [CrossRef]
15. Martín-López, B.; Gómez-Baggethun, E.; García-Llorente, M.; Montes, C. Trade-offs across value-domains in ecosystem services assessment. *Ecol. Indic.* **2014**, *37*, 220–228. [CrossRef]
16. Bai, Y.; Chen, Y.; Alatalo, J.M.; Yang, Z.; Jiang, B. Scale effects on the relationships between land characteristics and ecosystem services—A case study in Taihu Lake Basin, China. *Sci. Total Environ.* **2020**, *716*, 137083. [CrossRef]
17. Qi, Y.; Lian, X.; Wang, H.; Zhang, J.; Yang, R. Dynamic mechanism between human activities and ecosystem services: A case study of Qinghai lake watershed, China. *Ecol. Indic.* **2020**, *117*, 106528. [CrossRef]
18. Turner, K.G.; Odgaard, M.V.; Bøcher, P.K.; Dalgaard, T.; Svenning, J. Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. *Landsc. Urban. Plan.* **2014**, *125*, 89–104. [CrossRef]
19. Caiyun, Q.; Jie, G.; Jinxi, Z. Change and tradeoffs-synergies analysis on watershed ecosystem services: A case study of Bailongjiang Watershed, Gansu. *Acta Geogr. Sin.* **2018**, *73*, 868–879.
20. Xie, W.; Huang, Q.; He, C.; Zhao, X. Projecting the impacts of urban expansion on simultaneous losses of ecosystem services: A case study in Beijing, China. *Ecol. Indic.* **2018**, *84*, 183–193. [CrossRef]
21. ZiCheng, L.; Lan, J.; Yu, C. The ecosystem services evaluation and trade-off synergy in Min River Basin. *Acta Ecol. Sin.* **2020**, *40*, 3909–3920.
22. Armatas, C.A.; Campbell, R.M.; Watson, A.E.; Borrie, W.T.; Christensen, N.; Venn, T.J. An integrated approach to valuation and tradeoff analysis of ecosystem services for national forest decision-making. *Ecosyst. Serv.* **2018**, *33*, 1–18. [CrossRef]
23. Mengya, H.; Zhiyuan, R.; Yijie, S.; Shengnan, Z. The dynamic analysis of trade-off and synergy of ecosystem services in the Guanzhong Basin. *Geogr. Res. Aust.* **2017**, *36*, 592–602.
24. Zheng, Z.; Fu, B.; Feng, X. GIS-based analysis for hotspot identification of tradeoff between ecosystem services: A case study in Yanhe Basin, China. *Chin. Geogr. Sci.* **2016**, *26*, 466–477. [CrossRef]
25. Cao, Y.; Li, G.; Tian, Y.; Fang, X.; Li, Y.; Tan, Y. Linking ecosystem services trade-offs, bundles and hotspot identification with cropland management in the coastal Hangzhou Bay area of China. *Land Use Policy* **2020**, *97*, 104689. [CrossRef]
26. Zhong, L.; Wang, J.; Zhang, X.; Ying, L. Effects of agricultural land consolidation on ecosystem services: Trade-offs and synergies. *J. Clean. Prod.* **2020**, *264*, 121412. [CrossRef]

27. Jing, L.H.L.L. Ecosystem service trade-offs in the Guanzhong-Tianshui economic region of China. *Acta Ecol. Sin.* **2016**, *36*, 3053–3062.
28. Egoh, B.; Reyers, B.; Rouget, M.; Richardson, D.M.; Le Maitre, D.C.; van Jaarsveld, A.S. Mapping ecosystem services for planning and management. *Agric. Ecosyst. Environ.* **2008**, *127*, 135–140. [CrossRef]
29. Carter Berry, Z.; Jones, K.W.; Gomez Aguilar, L.R.; Congalton, R.G.; Holwerda, F.; Kolka, R.; Looker, N.; Lopez Ramirez, S.M.; Manson, R.; Mayer, A.; et al. Evaluating ecosystem service trade-offs along a land-use intensification gradient in central Veracruz, Mexico. *Ecosyst. Serv.* **2020**, *45*, 101181. [CrossRef]
30. Willemen, L.; Hein, L.; van Mensvoort, M.E.F.; Verburg, P.H. Space for people, plants, and livestock? Quantifying interactions among multiple landscape functions in a Dutch rural region. *Ecol. Indic.* **2010**, *10*, 62–73. [CrossRef]
31. Renard, D.; Rhemtulla, J.M.; Bennett, E.M. Historical dynamics in ecosystem service bundles. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 13411–13416. [CrossRef]
32. Jinghu, P.; Zhen, L. Analysis on trade-offs and synergies of ecosystem services in arid inland river basin. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 280–289.
33. Shui, W.; Sun, X.R.; Yang, H.F.; Zheng, J.Y. Scenario simulation of ecosystem service trade-offs in bay cities: A case study in Quanzhou, Fujian Province, China. *Acta Ecol. Sin.* **2019**, *30*, 4293–4302.
34. Liu, Z.F.; Tang, L.N.; Qiu, Q.Y.; Xiao, L.; Xu, T.; Yang, L. Temporal and spatial changes in habitat quality based on land-use change in Fujian Province. *Acta Ecol. Sin.* **2017**, *37*, 4538–4548.
35. Fu, G.; Chen, S.; McCool, D.K. Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. *Soil Tillage Res.* **2006**, *85*, 38–49. [CrossRef]
36. Onori, F.; De Bonis, P.; Grauso, S. Soil erosion prediction at the basin scale using the revised universal soil loss equation (RUSLE) in a catchment of Sicily (southern Italy). *Environ. Geol.* **2006**, *50*, 1129–1140. [CrossRef]
37. Nie, X.; Lu, B.; Chen, Z.; Yang, Y.; Chen, S.; Chen, Z.; Wang, H. Increase or decrease? Integrating the CLUMondo and InVEST models to assess the impact of the implementation of the Major Function Oriented Zone planning on carbon storage. *Ecol. Indic.* **2020**, *118*, 106708. [CrossRef]
38. Lyu, R.; Mi, L.; Zhang, J.; Xu, M.; Li, J. Modeling the effects of urban expansion on regional carbon storage by coupling SLEUTH-3r model and InVEST model. *Ecol. Res.* **2019**, *34*, 380–393. [CrossRef]
39. Peng, J.; Pan, Y.; Liu, Y.; Zhao, H.; Wang, Y. Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. *Habitat Int.* **2018**, *71*, 110–124. [CrossRef]
40. Caro, C.; Marques, J.C.; Cunha, P.P.; Teixeira, Z. Ecosystem services as a resilience descriptor in habitat risk assessment using the InVEST model. *Ecol. Indic.* **2020**, *115*, 106426. [CrossRef]
41. Ding, Q.; Chen, Y.; Bu, L.; Ye, Y. Multi-Scenario Analysis of Habitat Quality in the Yellow River Delta by Coupling FLUS with InVEST Model. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2389. [CrossRef]
42. Wang, Z.; Mao, D.; Li, L.; Jia, M.; Dong, Z.; Miao, Z.; Ren, C.; Song, C. Quantifying changes in multiple ecosystem services during 1992–2012 in the Sanjiang Plain of China. *Sci. Total Environ.* **2015**, *514*, 119–130. [CrossRef]
43. Liu, H.; Wu, J.; Chen, X.L. Study on spatial-temporal change andtrade-off/synergy relationships of ecosystem services in the Danjiangkou water source area. *Acta Ecol. Sin.* **2018**, *38*, 4609–4624.
44. Wartenberg, D. Multivariate Spatial Correlation: A Method for Exploratory Geographical Analysis. *Geogr. Anal.* **1985**, *17*, 263–283. [CrossRef]
45. Martínez Batlle, J.R.; van der Hoek, Y. Clusters of high abundance of plants detected from local indicators of spatial association (LISA) in a semi-deciduous tropical forest. *PLoS ONE* **2018**, *13*, e208780. [CrossRef]
46. Anselin, L. Local Indicators of Spatial Association-LISA. *Geogr. Anal.* **1995**, *27*, 93–115. [CrossRef]
47. Zheng, D.; Wang, Y.; Hao, S.; Xu, W.; Lv, L.; Yu, S. Spatial-temporal variation and tradeoffs/synergies analysis on multiple ecosystem services: A case study in the Three-River Headwaters region of China. *Ecol. Indic.* **2020**, *116*, 106494. [CrossRef]
48. Xu, S.; Liu, Y.; Wang, X.; Zhang, G. Scale effect on spatial patterns of ecosystem services and associations among them in semi-arid area: A case study in Ningxia Hui Autonomous Region, China. *Sci. Total Environ.* **2017**, *598*, 297–306. [CrossRef]
49. Zhang, Y.; Liu, Y.; Zhang, Y.; Liu, Y.; Zhang, G.; Chen, Y. On the spatial relationship between ecosystem services and urbanization: A case study in Wuhan, China. *Sci. Total Environ.* **2018**, *637–638*, 780–790. [CrossRef]
50. Zhu, W.; Pan, Y.; He, H.; Yu, D.; Hu, H. Simulation of maximum light use efficiency for some typical vegetation types in China. *Chin. Sci. Bull.* **2006**, *51*, 457–463. [CrossRef]
51. Zhao, M.; Zhou, G. Carbon Storage of Forest Vegetation in China and its Relationship with Climatic Factors. *Clim. Chang.* **2006**, *74*, 175–189. [CrossRef]
52. Shui, W.; Du, Y.; Wang, Y.; Yang, H.; Fu, Y.; Fang, B.; Huang, M. Spatio-temporal dynamics and scenarios simulation of trade-offs between ecosystem services in Min Delta urban agglomeration. *Acta Ecol. Sin.* **2019**, *39*, 5188–5197.
53. Yang, G.; Ge, Y.; Xue, H.; Yang, W.; Shi, Y.; Peng, C.; Du, Y.; Fan, X.; Ren, Y.; Chang, J. Using ecosystem service bundles to detect trade-offs and synergies across urban–rural complexes. *Landsc. Urban Plan.* **2015**, *136*, 110–121. [CrossRef]
54. Zhang, Y.; Long, H.; Tu, S.; Ge, D.; Ma, L.; Wang, L. Spatial identification of land use functions and their tradeoffs/synergies in China: Implications for sustainable land management. *Ecol. Indic.* **2019**, *107*, 105550. [CrossRef]

55. Ricketts, T.H.; Regetz, J.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Bogdanski, A.; Gemmill-Herren, B.; Greenleaf, S.S.; Klein, A.M.; Mayfield, M.M.; et al. Landscape effects on crop pollination services: Are there general patterns? *Ecol. Lett.* **2008**, *11*, 499–515. [CrossRef] [PubMed]
56. Morandin, L.A.; Winston, M.L. Pollinators provide economic incentive to preserve natural land in agroecosystems. *Agric. Ecosyst. Environ.* **2006**, *116*, 289–292. [CrossRef]
57. Tallis, H.; Kareiva, P.; Marvier, M.; Chang, A. An ecosystem services framework to support both practical conservation and economic development. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9457–9464. [CrossRef]
58. Bitian, Z.; Qingwen, M.; Wenjun, J.; Siyuan, H.; Moucheng, L.; Lun, Y. Research progress and perspective on ecosystem services trade-offs. *Acta Ecol. Sin.* **2021**, *41*, 5517–5532.
59. Hao, R.; Yu, D.; Wu, J. Relationship between paired ecosystem services in the grassland and agro-pastoral transitional zone of China using the constraint line method. *Agric. Ecosyst. Environ.* **2017**, *240*, 171–181. [CrossRef]
60. Feng, Q.; Zhao, W.; Fu, B.; Ding, J.; Wang, S. Ecosystem service trade-offs and their influencing factors: A case study in the Loess Plateau of China. *Sci. Total Environ.* **2017**, *607–608*, 1250–1263. [CrossRef]
61. Qiu, J.; Turner, M.G. Spatial interactions among ecosystem services in an urbanizing agricultural watershed. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 12149–12154. [CrossRef]
62. Seto, K.C.; Guneralp, B.; Hutyra, L.R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 16083–16088. [CrossRef]