land

MDPI

Article

Multi-Scenario Simulation and Assessment of Ecosystem Service Value at the City Level from the Perspective of "Production–Living–Ecological" Spaces: A Case Study of Haikou, China

Jie Chen, Hui Fu * and Shengtian Chen

College of Forestry, Hainan University, Haikou 570228, China; diamond1@163.com (J.C.); omoyatt@163.com (S.C.)
* Correspondence: iflying@126.com

Abstract: Structural changes in land use caused by urban development are one of the most important threats to ecosystem services. An in-depth study of the impacts that different land use patterns have on ecosystem service value (ESV) can provide guidance for sustainable urban planning and ecological conservation. In this research, we sought to explore the response mechanisms of ecosystem services under different urban development scenarios from the perspective of "production–living–ecological" space (PLES). This study combined the Patch-generating Land Use Simulation (PLUS) model and ESV equivalent factor method to simulate the PLES and ESV of Haikou in 2035 under three scenarios of business as usual (BAU), ecological conservation (EC) and economic development (ED), and used the spatial superposition method, transfer matrix, and optimized cross-sensitivity analysis to explore the influence of the PLES on ecosystem services. The ESV of Haikou showed a declining trend from 2010 to 2020 under the influence of PLES changes and was at risk of further decline in the future. The reduction in the value of the water supply service constituted a major part of the loss of ESV. The simulation results demonstrated that the EC scenario had the most rational and ecologically efficient allocation of PLES, with the highest ESV and the lowest sensitivity to PLES changes. The results of this research can serve as an important reference for optimizing the urban land use structure and maintaining the stability of ecosystem services.

Keywords: ecosystem services; PLES; multi-scenario simulation; PLUS model; urban development impact

check for updates

Citation: Chen, J.; Fu, H.; Chen, S. Multi-Scenario Simulation and Assessment of Ecosystem Service Value at the City Level from the Perspective of "Production–Living–Ecological" Spaces: A Case Study of Haikou, China. *Land* **2023**, *12*, 1021. https://doi.org/10.3390/land12051021

Academic Editors: Teodoro Semeraro, Barbara Goličnik Marušić, Vita Žlender, Manfred Schrenk and Kasper Kok

Received: 8 March 2023
Revised: 18 April 2023
Accepted: 29 April 2023
Published: 6 May 2023

1. Introduction

The concept of the ecosystem was introduced by Tansley in 1935, and since then the research framework on the ecosystem has evolved through the efforts of scholars around the world. The definition of ecosystem services has also undergone a series of changes [1], slowly evolving from natural capital [2] to the functions and products of ecosystems today [3]. The current perception of ecosystem services is that humans benefit directly or indirectly from ecosystems, which serve as an essential link between human society and the natural environment [4]. In order to build a systematic framework to quantify global ecosystem services, scholars proposed to use the ecosystem service value (ESV) as a direct assessment indicator [5] and refined it according to the natural and social conditions of different countries and regions [6,7]. ESV has become one of the most important methods for studying ecosystem services and there is a large body of research based on it [8,9]. However, the composition and spatial distribution of ecosystem services are uneven in different regions, as they are influenced by local natural resources, government policies, and development patterns. Therefore, a comprehensive study of the ESV on different regions and scales can help to achieve scientific management of ecosystems and provide path support for sustainable development in certain regions.

Urbanization is an important symbol of modernization and an inevitable process in the development of human societies [10,11]. The drastic transformation between land uses is one of the most distinctive features of urbanization, which is considered the major reason for the reduction of ESV [12–14]. Land uses integrate functions of production, ecology, and life, so China proposed the spatial classification system of "production–living–ecological" space (PLES) based on this in 2012 [15]. Studies have shown that the essence of land use transformation is the dynamic process of quantitative and spatial reallocation of limited land resources among various dominant functions [16,17]. Hence, the ecological environmental issues caused by land use change are essentially attributed to the imbalance of PLES [18–20]. The previous productive function-oriented allocation of land resources has caused a series of environmental problems in China, including air pollution, ecological degradation, and over-exploitation of resources [21,22]. Fortunately, the Chinese government has now established the strategy of coordinated development of PLES in its Territorial Spatial Planning [23,24] and has put more emphasis on the importance of ecological functions [25]. As the main assessment indicator of ecological function capability [9,26], ESV is crucial for ecological compensation decisions [27], ecological zoning [28], environmental assessment, and protection [29]. Therefore, coupling study on the PLES and ESV can link the land use changes with the regional development of land function, and provide a new perspective to study the environmental problem caused by land use transformation.

Currently, the analysis of the potential ecological effect caused by PLES transformation is a hot topic in academic research [30,31]. Most studies focused on the evolution of spatial-temporal patterns and regional differences in ESV triggered by PLES changes. For example, Wang et al. (2021) conducted a comprehensive study on the evolutionary characteristics of PLES and ESV in the Dongliao River Basin from 1990 to 2018 [32]; Jiao et al.(2020) assessed the spatial differentiation characteristics of the PLES and ecological quality in Guizhou Province [33]; Han et al. (2021) analyzed the ecological effect of PLES transformation in the Yellow River Delta from 1998 to 2018 [34]. Some studies established a methodological system for ecological zoning and PLES pattern optimization based on ecosystem service valuation. For example, Zhou et al. (2022) conducted a participatory mapping to integrate ESV into the identification and optimization of regional major functions [35]. However, there are still shortcomings in the current research [17,29,32]. In terms of research scale, existing articles tended to study on the large scale [36], such as provinces [37] and urban agglomerations [38], while only a few studies focused on the city level. The lack of studies on smaller scale areas makes it hard to apply the findings to certain cities' planning. In terms of research content, most of the existing studies were based on static assessments of historical statistics and lacked dynamic assessments of different scenarios and future trends [39]. Thus, the simulation of spatial patterns and ecological impacts of PLES at the city level is an area that remains largely unexplored.

The capital of Hainan Province, Haikou is the frontline of political, economic, cultural, and ecological construction. Since 2010, influenced by the policy of free trade port, the urban construction of Haikou has developed rapidly and environmental issues have become increasingly prominent. However, there is still a lack of basic research on ecosystem service assessment in Haikou, and the research on ecosystem services from multiple perspectives and simulation prediction is in a blank state. As the most urbanized area in Hainan, the development experiences and patterns of Haikou play an important role as a wind vane for the surrounding cities. Accordingly, this research selected Haikou as the case study and proposed a framework with the Markov chain, the PLUS model, and the ESV evaluation method system from a new perspective, which will enable the simulation of the future spatiotemporal patterns of PLES and the analysis of its potential ecological effect. Hence, the aims of this study are: (1) to clarify the PLES and ESV changes of Haikou in different periods from 2010 to 2020; (2) to predict the PLES scenarios of 2035 using the Markov–PLUS model and to analyze the spatiotemporal characteristic of ESV; and (3) to explore the future impact of different PLES allocation on ESV by using spatial superposition method, cross-sensitivity analysis. The findings will serve as an important reference for ecological civilization construction in Haikou and other similar cities.

2. Materials and Methods

2.1. Study Area

Haikou (19°32′~20°05′ N, 110°10′~110°41′ E) is located in the northern coastal region of Hainan Province, with a total area of 2289.09 km^2 (Figure 1). The study area adjoins Chengmai to the west and Wenchang to the east. The Nandu River, the largest river in Hainan, runs through the city and enters the sea, which is named Haikou and makes it rich in water resources, with a total number of 19.07 × 109 m^3. By the end of 2021, Haikou had four districts (at the county level) under its administration, namely Xiuying, Longhua, Qiongshan, and Meilan, with 43 townships and a resident population of 2.25 million. Since the construction of the Free Trade Port began in 2010, Haikou has entered a rapid phase of economic development. The rapid expansion of the city in the short term has accelerated the changes in LULC and also affected the structure and function of ecosystem services. As one of the four pilot ecological civilization zones in China, Hainan Province takes Haikou as the political, economic, and cultural center, which makes the study on Haikou a meaningful reference for the ecological protection and sustainable development of the whole of Hainan Province.

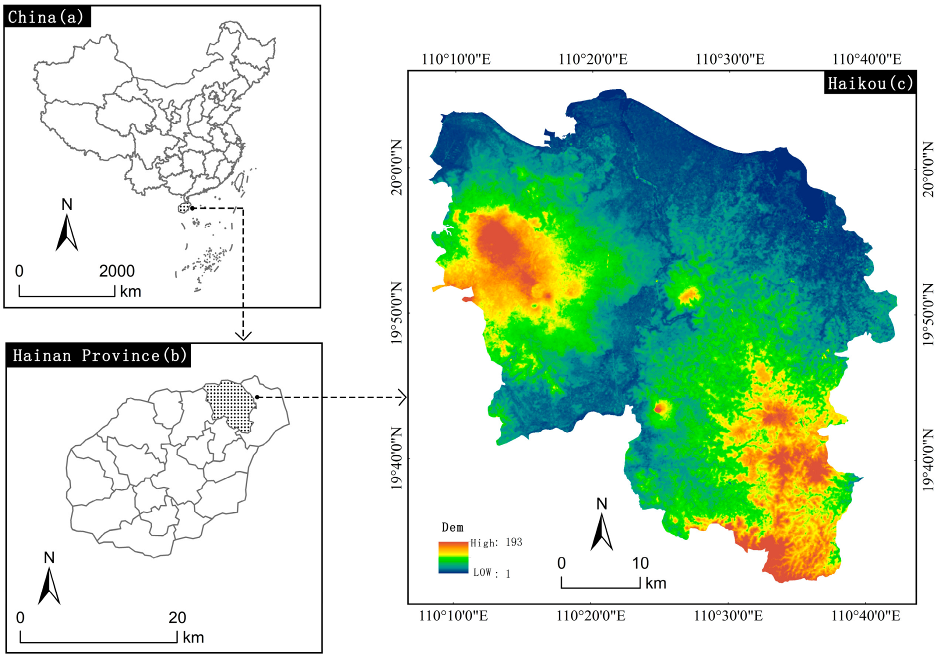

Figure 1. Location of the study area.

2.2. Data Sources

The LULC data in this paper used the spatial distribution data provided by the Resource and Environment Science and Data Center (https://www.resdc.cn, accessed on 20 February 2022) for the years 2010, 2015, and 2020, with a spatial resolution of 30 m. The data contains seven primary classifications including farmland, forest, grassland, water, construction land, bare land, and sea, and 26 secondary classifications. Integrating the classification experience of studies related to ecosystem services and the PLES [32,40,41], the 18 secondary land types in Haikou were classified into five secondary space types, such as agricultural production space, green space, blue space, urban living space, rural living space. Additionally, these five space types were classified into production space, living space, and ecological space in the light of land use function to establish the PLES classification table (Table 1).

Table 1. PLES classification system.

Primary Classification	**Secondary Classification**	**Including Land Types**	**Production Function**	**Ecological Function**	**Living Function**
Production space	Agricultural production space	dry farmland	5	3	0
		paddy farmland	5	3	0
Ecological space	Green space	forest	0	5	1
		shrubs	0	5	1
		grassland	3	5	0
		bare land	0	3	0
	Blue space	river	1	5	0
		wetland	1	5	0
Living space	Urban living space	urban residential area	0	0	5
	Rural living space	rural residential area	0	0	5

The driver data required for the PLUS model contained both natural and social dimensions, namely: (1) Natural drivers contained terrain data of elevation, slope, and slope direction from the Geospatial Data Cloud (http://www.gscloud.cn/, accessed on 3 February 2022) and climate data of temperature and rainfall from the National Meteorological Science Data Centre (http://data.cma.cn/wa, accessed on 10 February 2022); (2) Social drivers contained data of population density, GDP, urban municipal and public service distribution of facilities. The POI data were obtained from the Baidu Online Map API interface in November 2018. The road network data were sourced from the OSM dataset. Population density and GDP data were aggregated from the statistical bulletins of cities and counties in Hainan Province, statistical yearbooks, and socio-economic data from the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China.

The average price of major grains, sown area, and average grain yield data required for the calculation of ESV equivalents were obtained from the China Agricultural Price Survey Yearbook, the Hainan Provincial Statistical Yearbook, and the National Statistical Yearbook for each year.

2.3. Markov–PLUS Simulations

2.3.1. Quantity Prediction

Markov chains is a forecasting method based on probabilistic analysis of land use change patterns and trends. It uses a transfer probability matrix to predict future demand for land use types as shown in Formula (1).

$$S_{(t+1)} = P_{ab} \cdot S_{(t)} \tag{1}$$

where *St* and *St*+1 are the states of the land at times *t* and *t* + 1, respectively, and *t* is the year; *Pab* is the state transfer probability matrix, which is the probability of transferring land type a to land type *b*.

2.3.2. Conversion Matrix Settings

According to the actual situation of land use in Haikou and the experience of previous studies [42,43], the current social productivity can basically realize the conversion between any LULC type. However, considering that the conversion between some land types, especially built-up areas to water bodies, is costly and rarely happens, this research mainly restricted the transformation of construction land to water and wetlands, and the rest of the land types can be exchanged spatially. The parameter settings are detailed in Table 2 (1 means interconvertible; 0 means not interconvertible).

Table 2. Land use conversion matrix.

LULC	Paddy Field	Dry Farmland	Forest	Shrubs	Grassland	River	Wetland	Urban Residential Area	Rural Residential Area	Bare Land
Paddy field	1	1	1	1	1	1	1	1	1	1
Dry farmland	1	1	1	1	1	1	1	1	1	1
Forest	1	1	1	1	1	1	1	1	1	1
Shrubs	1	1	1	1	1	1	1	1	1	1
Grassland	1	1	1	1	1	1	1	1	1	1
River	1	1	1	1	1	1	1	1	1	1
Wetland	1	1	1	1	1	1	1	1	1	1
Urban Residential area	1	1	1	1	1	0	0	1	1	1
Rural Residential area	1	1	1	1	1	0	0	1	1	1
Bare land	1	1	1	1	1	1	1	1	1	1

2.3.3. Neighborhood Factor Settings

The neighborhood weights indicate the sprawl intensity of different land use types and take values between 0 and 1. The closer the weight value is to 1, the stronger the expansion capability the land has. In this study, the expansion capacity of each land use was calculated based on the data of 2015 and 2020 according to Formula (2), and the resulting parameters are shown in Table 3.

$$X = \frac{X - min}{max - min} \tag{2}$$

where X is the normalized value of the deviation; max is the maximum value of the data; min is the minimum value of the data.

Table 3. Neighborhood factor parameters.

Paddy Field	Dry Farmland	Forest	Shrubs	Grassland	River	Wetland	Urban Residential Area	Rural Residential Area	Bare Land
0.08	0.24	0.28	0.21	0.19	0.00	0.09	1.00	0.27	0.00

2.3.4. Scenario Settings

The basic concept of scenario analysis is to simulate future states based on existing development trends and is widely used for trade-offs between land use and ecosystem services [44]. This study established land use patterns under different scenarios by setting up restriction areas and transfer probability matrices in the PLUS model.

(1) Bussiness as usual scenario (BAU)

This scenario did not consider the binding influence of any planning policies on land use change, and simulated future scenarios based on the land use conversion probability of Haikou from 2010 to 2020.

(2) Ecological Conservation Scenario (EC)

With reference to the guidelines and targets proposed in the 14th Five-Year Plan for Ecological Protection in Haikou, the expansion of construction land and farmland will be strictly controlled. Therefore, this scenario set the ecological space within the planning protection boundary as a restricted conversion area, and the conversion probability of ecological space into production and living space was decreased. Moreover, considering the policies of returning farmland to forests and lakes, the conversion probability of production space to ecological space was increased.

(3) Economic Development Scenario (ED)

In order to maximize economic efficiency, this scenario gives priority to meeting the needs of urban residents for production, housing, and recreation when ecological land conflicts with the need for productive and living land. Therefore, the conversion probability of production and ecological space to living space under the ED scenario was increased and the conversion probability of living space to production and ecological space was decreased.

2.3.5. Model Validation

In order to ensure the accuracy of the simulation by PLUS, the land use data of 2010 and 2015 was selected to simulate the land use situation of Haikou in 2020. Comparing the simulated data with the actual data in 2020, the results showed that the Kappa coefficient was 0.87 and the overall accuracy was 0.92, indicating that the simulation results are scientifically reliable.

2.4. Evaluation Method of ESV

In this research, the improved equivalent factor method proposed by Xie was used to evaluate the regional ESV. Based on the actual land types in the study area and the convenience of calculation, the equivalent table was used for the eight land types except for urban and rural residential areas. Considering the built-up area as an inseparable component of the urban ecosystem, this research referred to the previous studies [40,45–47] to supplement the equivalent factor of urban and rural residential areas.

Despite the variability between regions, this study revised the equivalent factor table of Xie [7] based on the regional food production parameter and made the value table of different ecosystem services in Haikou (Table 4). Studies have shown that the economic value of an equivalent factor is approximately equal to 1/7 of the market value of the average grain output of that year, so the value quantity of the ESV equivalent factor is calculated as Formula (3):

$$D = 1/7A \times Q \times \frac{Q}{Q_0} \tag{3}$$

where D is the economic value of a single equivalent factor in the study area; A is the average local food price; Q and Q_0 are the food production per unit area in the study area and the country, respectively. The final economic value of a single ecological service value equivalent factor was obtained as 1183.11 yuan/ha.

Table 4. Value table of different ecosystem services in Haikou (CNY/ha).

ES Type	Dry Farmland	Paddy Field	Forest	Shrubs	Grassland	Wetland	River	Urban Residential Area	Rural Residential Area	Bare Land
FP	1005.64	1609.03	343.1	224.79	449.58	603.39	946.49	11.83	11.83	0
RMP	473.24	106.48	780.85	508.74	662.54	591.56	272.12	0	0	0
WS	23.66	−3111.58	402.26	260.28	366.76	3064.26	9807.99	−8885.16	−8885.16	0
GR	792.68	1313.25	2567.35	1668.19	2330.73	2247.91	911	−2863.13	−2863.13	23.66
CR	425.92	674.37	7690.22	5004.56	6164.01	4259.2	2709.32	0	0	0
EP	118.31	201.13	2283.4	1514.38	2034.95	4259.2	6566.27	−2910.45	−2910.45	118.31
HR	319.44	3218.06	5607.95	3963.42	4519.48	28666.78	120961.27	0	0	35.49
SC	1218.6	11.83	3135.24	2034.95	2839.47	2732.99	1100.29	23.66	23.66	23.66
NCM	141.97	224.79	236.62	153.8	212.96	212.96	82.82	0	0	0
BM	153.8	248.45	2851.3	1857.48	2579.18	9311.08	3016.93	402.26	402.26	23.66
RC	70.99	106.48	1254.1	816.35	1135.79	5596.12	2236.08	11.83	11.83	11.83

FP: food production; RMP: raw material production; WS: water supply; GR: gas regulation; CR: climate regulation; EP: Environment purification; HR: hydrological regulation; SC: soil conservation; NCM: maintenance of nutrient circulation; BM: Biodiversity; RC: recreation and culture.

Based on Table 4, the regional ESV was calculated according to the following Formula (4):

$$ESV = \sum (A_{(i)} \times VC_{(i)}) \tag{4}$$

where ESV is the total value of ecosystem services; A_i is the area of the ith land type in the study area; and $VC_{(i)}$ is the unit ESV coefficient for the ith land type.

2.5. Coefficient of Improved Cross-Sensitivity

The traditional Coefficient of Cross-Sensitivity (CCS) refers to the impact of area changes on ecosystem service value. However, the conversion of territorial spatial types is usually reciprocal, and the ESV reflects the net value led by the conversion between the different space types. The CCS lacks consideration of the process of interconversion, and the calculated results are difficult to express the practical significance of the elasticity coefficient. Therefore, this paper used the Coefficient of Optimization Cross-Sensitivity (COCS) model to analyze the degree of impact on ESV caused by conversion between different territorial spatial types. The COCS refers to the positive or negative effect on ESV caused by the net conversion within two territorial spatial types [48]. When the COCS is greater than 0, it means that the net transformation of the two types of land classes will promote the ecosystem service functions; otherwise, it will inhibit the ecosystem service functions. As the analysis object of sensitivity, the larger the absolute value of COCS is, the more sensitive ecosystem services are to the land use types of the two transitions, and the less sensitive, otherwise. The formula of COCS is as follows:

$$COCS_{ki} = \frac{\Delta ESV_{ik} / \Delta ESV}{\Delta S_{ki} / \Delta S} \tag{5}$$

where $COCS_{ki}$ is the cross-sensitivity coefficient of the Optimized bidirectional transformation between the k and i space types; ΔESV_{ik} is the change of ESV caused by the transformation between k and i space types; ΔESV is the total change of ESV; ΔS_{ki} is the net transformation area (ha) between k and i space type in the j and $j-1$ year; ΔS is the total transformation area (ha) in the j and $j-1$ year.

3. Results

3.1. Pattern Evolution and Simulation of PLES in Haikou

3.1.1. Spatial-Temporal Characteristics of PLES

The distribution of PLES in Haikou from 2010 to 2020 is shown in Figure 2. Ecological space was the main space type, mainly consisting of green space and occupying over 50% of Haikou's area. Next was the production space, which was mostly block-shaped and scattered. The area of ecological and production space continued to decline from 2010 to 2020. The living space was concentrated in the built-up area of north Haikou, with an obvious clustering effect. As can be seen from Table 5, from 2010 to 2020, the living space in Haikou expanded considerably, with an increase of 59.99%. The large expansion of urban living space is the main reason for the increase in living space, with the share rising from 6% in 2010 to 9.6% in 2020. In contrast, the changes in rural living space were relatively small.

The single dynamic index of PLES took a turn for the better in 2015, with the loss rate of ecological and production space and the growth rate of living space all slowing down significantly between 2015 and 2020. On the one hand, Haikou began to enter the urbanization deceleration stage, as the urbanization rate of Haikou reached 60% after 2015. On the other hand, the Chinese government started to strongly support ecological civilization construction after 2016, which directly drove the transformation of China's land use pattern from meeting the needs of rapid socio-economic development to the coordinated development of production, living, and ecology [49]. Additionally, the loss rate of production space was mitigated gradually during 2010–2020, which is in line with the current farmland protection policy proposed to replenish farmland reserves and ensure food security.

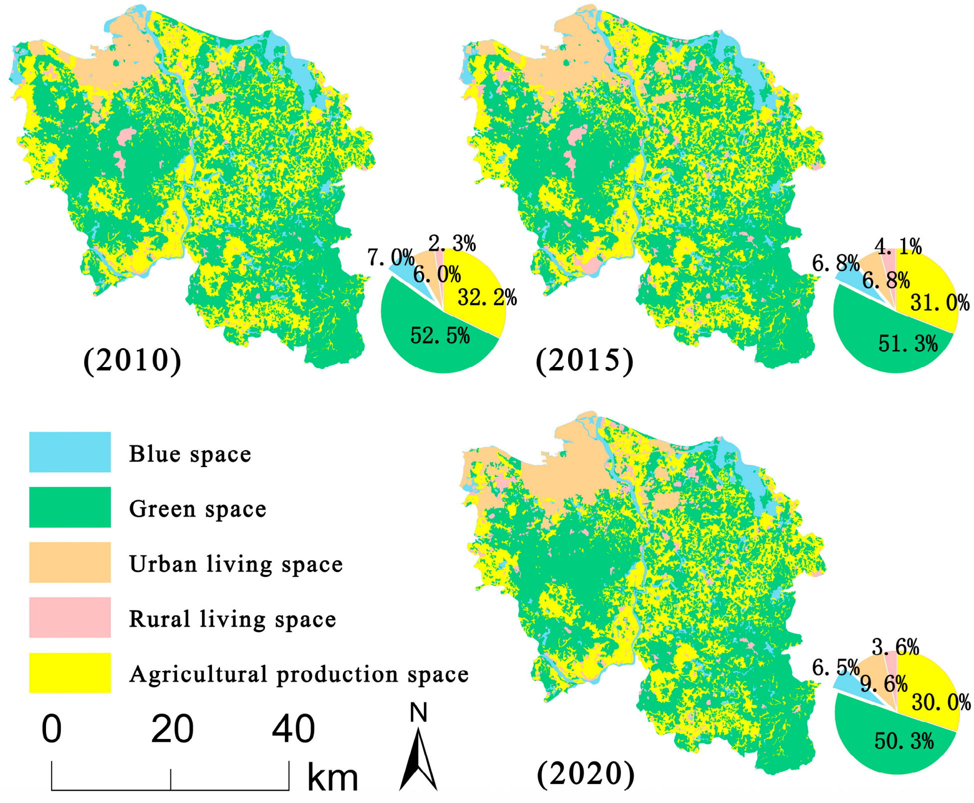

Figure 2. PLES spatial distribution in Haikou from 2010 to 2020.

Table 5. Areas and Single dynamic index of PLES from 2010 to 2020.

Primary Classification	Second Land	Area (ha) 2010	2015	2020	Single Dynamic Index (%) 2010–2015	2015–2020
Production space	Agricultural production space	73,521.81	70,579.26	68,300.73	−0.80%	−0.65%
Ecological space	Green space	119,784.15	117,015.21	114,804	−0.46%	−0.44%
	Blue space	15,923.43	15,543	14,822.64		
Living space	Urban living space	13,588.83	15,510.24	21,841.81	6.47%	4.18%
	Rural living space	5250.69	9421.2	8299.73		

3.1.2. Multi-Scenario Simulation of PLES

The spatial structure and distribution of PLES in Haikou in 2035 under all three scenarios remained similar to the current situation (Figure 3), but there were differences in the amount and rate of changes (Table 6).

(1) Living space. The future growth of living space was still significant, and the growth under the ED scenario was much higher than that of the other two scenarios. The over size of living space under the BAU and EC scenarios were relatively close. Under the three scenarios, the growth of living space mainly came from urban living space, while the contribution of rural living space was small. This widening gap between urban and rural development is most acute in the ED scenario, where the development of rural living space remained nearly stagnant.

(2) Ecological space. Ecological space maintained its downward trend under all three scenarios. The reduction of ecological space escalated in the BAU and ED scenarios, with the loss rate increasing by a third compared to 2010–2020. In contrast, ecological space was effectively protected under the EC scenario. The loss of ecological space under this scenario was in great control and the blue space grew positively, with an increase of 4.6% compared to 2020.

(3) Production space. The variations in production space were different between the three scenarios. Production space began to grow positively under the BAU scenario, rising by 1.13%. Both the ED and EC scenarios showed a downward trend in production space, and the EC scenario had the highest loss of it. The rapidly rising losses on production space under the EC scenario are mainly because current ecological restoration measures are mainly based on returning farmland to forests and lakes, with a higher reliance on farmland. Nevertheless, the area of agricultural production space under this scenario still exceeded the restrictive standard of 62,802 ha proposed for arable land in the 14th Five-Year Plan of Haikou and the deceleration rate of production space was slower than that of 2010–2020.

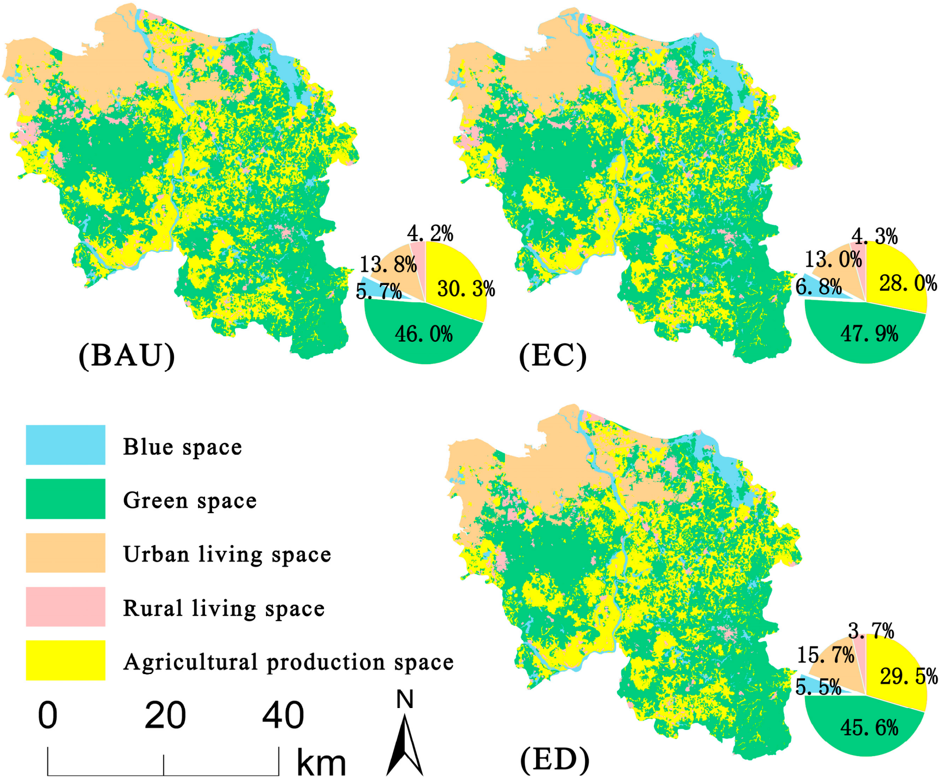

Figure 3. PLES spatial distribution in Haikou under different scenarios in 2035.

Table 6. Areas and Single dynamic index of PLES from 2010 to 2020.

Primary Classification	Second Land	Area (ha)			Single Dynamic Index(%)		
		BAU	EC	ED	2020-BAU	2020-EC	2020-ED
Production space	Agricultural production space	69,089.13	63,862.83	67,120.74	0.08%	−0.43%	−0.21%
Ecological space	Green space	104,762.88	109,062	103,824.9	−0.61%	−0.26%	−0.68%
	Blue space	12,941.1	15,454.62	12,528.63			
Living space	Urban living space	31,467.06	29,696.79	35,912.48	2.42%	2.07%	3.16%
	Rural living space	9627.57	9811.49	8501			

3.1.3. Analysis of the PLES Transformation

Figure 4 shows that the annual PLES conversion area before 2015 was 1645.07 ha, while this number rose to 3079.28 ha after 2015, indicating that disturbance from human activities had a significant effect. As shown in Figure 5, the conversion between land space functions became more intense in the future. The conversion area between production space and ecological space increased considerably. The BAU and ED scenarios showed an overall transformation out of ecological space into production space, while the EC scenario showed a transformation out of production space into ecological space. The future living space kept a net increase in the area throughout the transformation process with other spaces, which was mainly at the expense of the loss of green space and agricultural production space. Furthermore, this study found that the size of urban living space was proportional to the total size of living spaces, while the size of rural living space was inverse to the total size of living spaces. This phenomenon indicated that excessive urban exploitation may crowd out the space for the countryside and aggravate the problem of imbalance between urban and rural development.

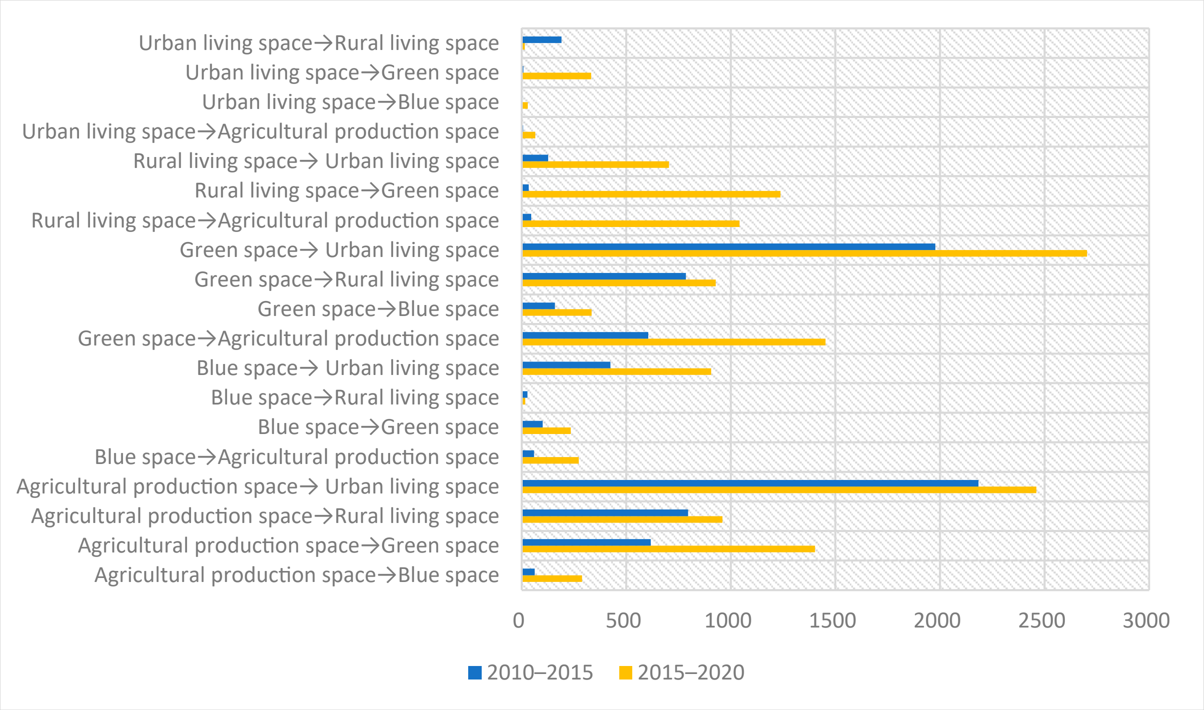

Figure 4. Transformation of PLES in Haikou from 2010 to 2020 (Unit: ha).

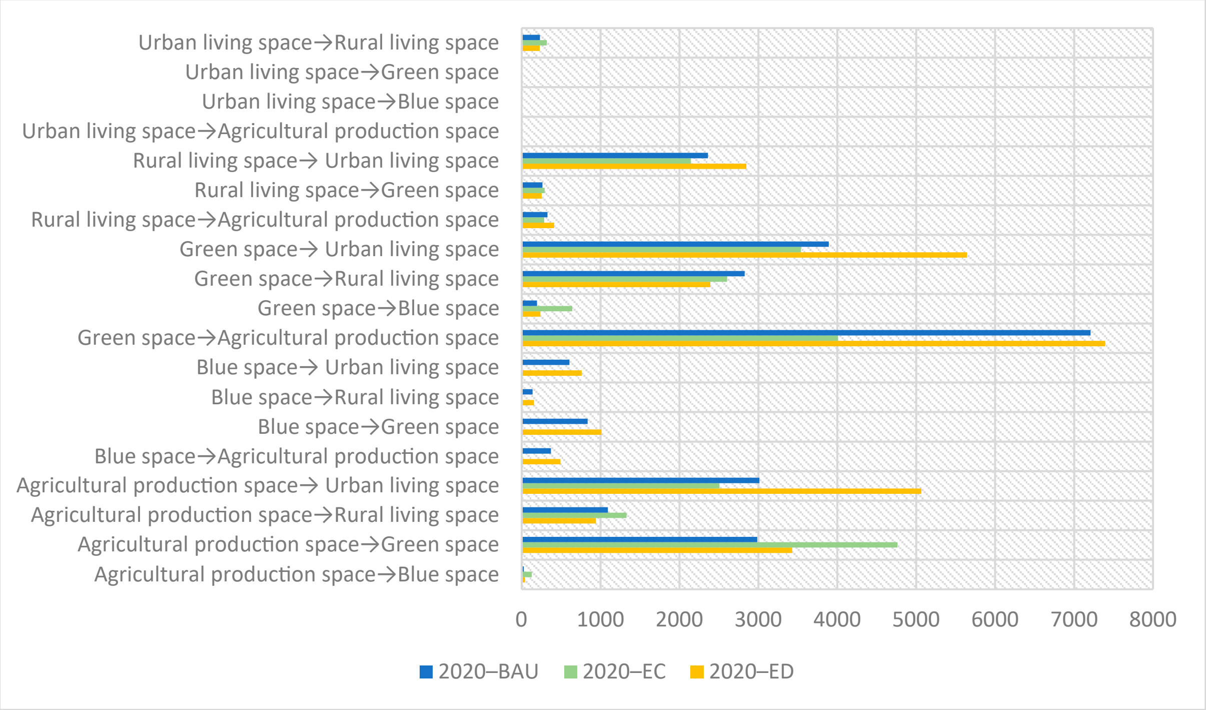

Figure 5. Transformation area of PLES in Haikou under different scenarios in 2035 (Unit: ha).

As is shown in Figure 6, the range of spatial variation of PLES in Haikou from 2010 to 2020 was small and mainly concentrated in the northern urban areas of Haikou. Under the simulated scenarios, the changes of PLES became broader and more heterogeneous spatially in the future. Additionally, the PLES of Haikou showed an overall stratified distribution tendency along the northwest to southeast direction. The clustering of living space in the north further enhanced in the future. Production space and ecological space converged in the central and southeastern parts of Haikou sequentially, with a great spatial exchange occurring between them. This distribution method will enlarge the separation distance between PLES, especially for the living and ecological space, which could further damage the fragile environment of built-up areas.

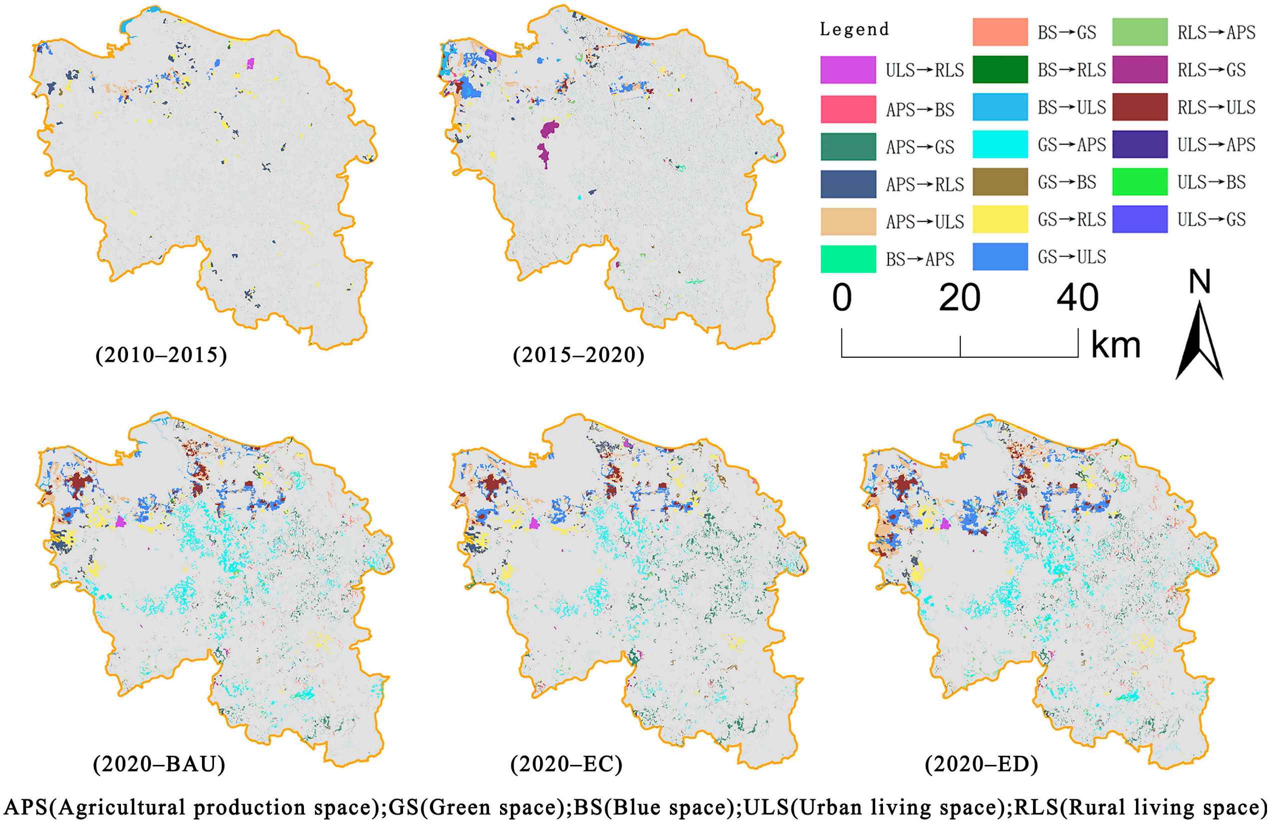

Figure 6. Spatial transformation of PLES in Haikou.

3.2. Analysis of ESV Changes in Haikou

To prevent the spatial unit of the study area from being too fragmented, the area was divided into 500 m × 500 m spatial grid cells with reference to previous cases of similar studies. This study used the ArcGIS fishnet tool to create the square grid, calculate the ESV within each grid, and classify the ESV in Haikou into seven classes according to the geometric breakpoint method (Figure 7). The total ESV loss in Haikou from 2010 to 2020 was 465.75 million yuan, of which 225.85 million yuan was lost in 2010–2015 and 239.90 million yuan in 2015–2020 (Table 7). All ecosystem services showed a clear downward trend from 2010 to 2020, but the overall structure was relatively stable. Regulating service was the most prominent service type, with a share of ESV ranging from 77.51% to 80.08%. Support service was the secondary important service type, with a share between 16.22% and 17.20%. Supply service and culture service accounted for a small proportion, together accounting for less than 5% of the total ESV.

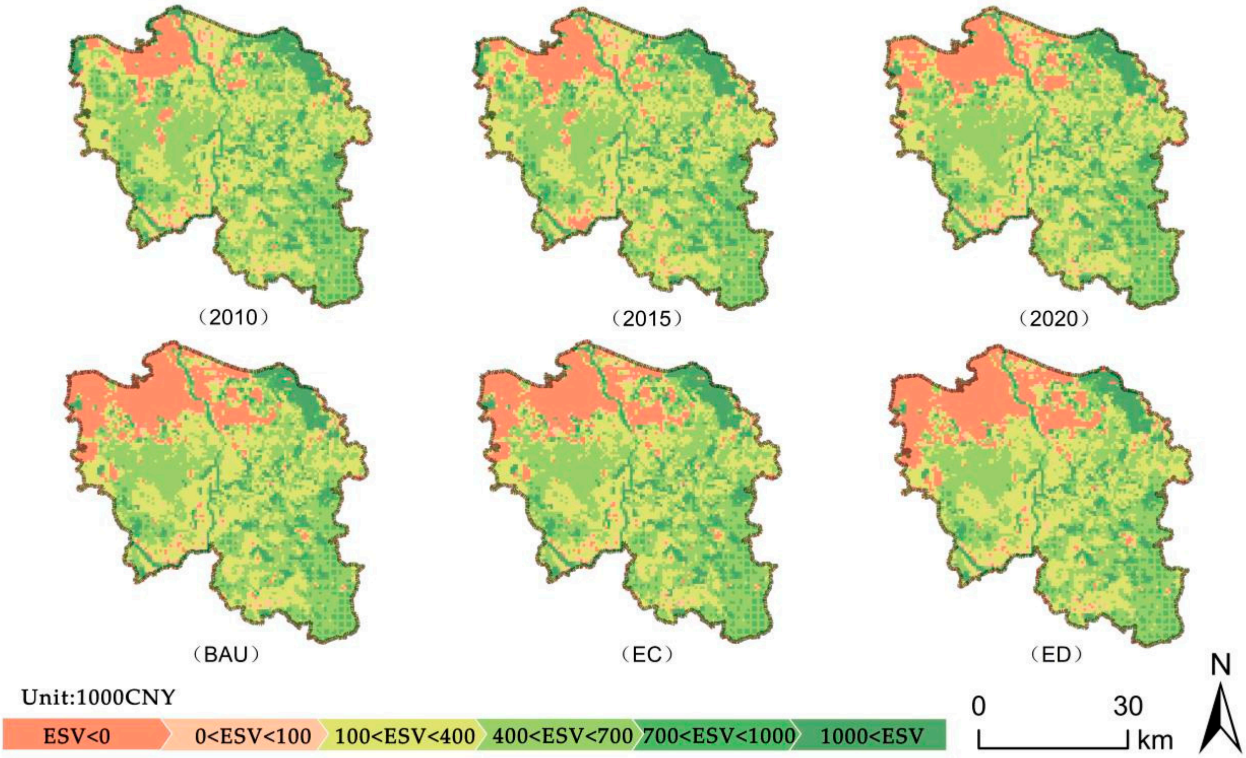

Figure 7. The spatial distribution of ESV in Haikou from 2010 to 2035 under different scenarios.

Table 7. Haikou ESV under different periods (million yuan).

Categories	Sub-Categories	2010	2015	2020	BAU	ED	EC
Supply service	Food Production	152.30	146.96	142.61	139.74	136.32	135.00
	Raw Material Production	107.39	104.78	102.68	95.28	94.23	98.70
	Water Supply	−125.00	−177.69	−226.32	−350.22	−379.60	−293.46
Regulating service	Gas Regulation	321.20	293.87	271.04	217.45	203.54	228.01
	Climate Regulation	913.62	892.41	874.31	804.57	797.17	839.69
	Environment Purification	301.65	275.28	250.90	187.40	173.17	216.79
	Hydrological Regulation	2433.15	2362.79	2261.07	1994.15	1936.80	2299.70
Support service	Soil Conservation	394.53	385.67	378.70	349.07	345.86	364.92
	Maintenance of Nutrient Circulation	411.95	40.01	39.06	37.13	36.54	37.13
	Biodiversity	394.72	388.75	382.96	357.28	354.95	375.00
Culture service	Recreation and Culture	186.58	182.63	178.56	163.71	161.76	174.10
Total		5492.07	4895.47	4655.57	3995.56	3860.74	4475.59

Compared to 2020, the ESV under different scenarios showed different trends. The loss rate of ESV under the BAU and ED scenarios accelerated, while the rate under the EC scenario slowed down (Table 8). In 2035, ESV under the BAU, ED, and EC scenarios decreased by 660.05 million yuan, 794.83 million yuan, and 179.98 million yuan, respectively, from 2020. The low level of losses in the regulating service is the main reason why the ESV of the EC scenario is much higher than that of the other two scenarios. Furthermore, among the four ecosystem service types, the ESV of supply service had the highest percentage of loss, which turned from positive to negative. This is mainly attributed to the large reduction in water supply service. While there was an improvement in production space under both the BAU and ED scenario, the large growth in living space not only reduced the water supply capacity of ecological and production space but also brought about a huge consumption of water resources, which finally caused the deterioration of supply service.

Table 8. Single dynamic index of ESV under different periods.

Categories	2010–2015	2015–2020	2010–2020	2020–BAU	2020–ED	2020–EC
Supply service	−9.00%	−14.88%	−8.59%	−47.14%	−59.04%	−27.66%
Regulating service	−0.73%	−0.87%	−0.79%	−0.83%	−1.00%	−0.13%
Support service	−0.39%	−0.34%	−0.36%	−0.48%	−0.53%	−0.20%
Culture service	−0.42%	−0.45%	−0.43%	−0.55%	−0.63%	−0.17%

3.3. Quantitative Analysis of Cross Sensitivity of ESV

The cross-sensitivity of the simulated scenarios between PLES is shown in Figure 8. Since the net transformation area between each two PLES types is bidirectionally symmetrical, only the unidirectional sensitivity coefficients were shown in this paper. For comparison purposes, the sensitivity coefficients were divided into five levels according to their absolute magnitude (non-sensitivity: 0.0–0.1, weak sensitivity: 0.1–0.2, moderate sensitivity: 0.2–0.3, strong sensitivity: 0.3–0.4, extreme sensitivity: above 0.4).

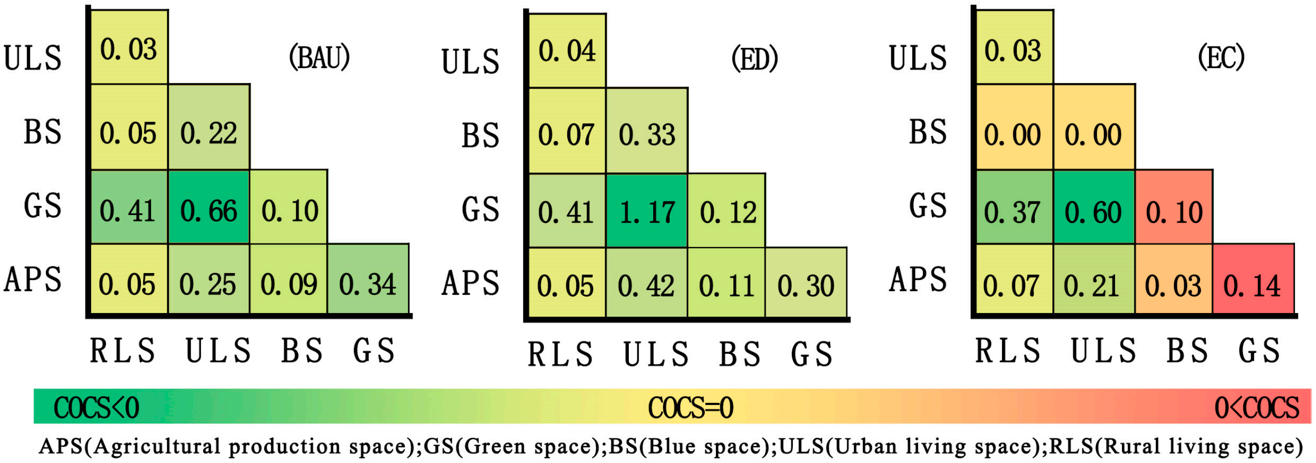

Figure 8. Heatmap of ESV COCS in Haikou under simulation scenarios.

(1) Cross-sensitivity between ecological space and living space

The sensitivity of ESV to the transformation between ecological space and living space was the highest in all three scenarios. This extreme sensitivity is mainly in response to the transformation of green space into urban living space. The COCS of this transformation under BAU, ED, and EC were −0.66, −1.17, and −0.6, respectively. The transformation had a suppressive effect on ESV and this side effect is expected to increase sharply with the rising size of the economy. Next, the COCS of the transformation of green space to rural living space was high, with BAU and ED being extremely sensitive and EC being strongly sensitive. The COCS of this transformation was less than 0, so this transformation had an inhibitory effect on ESV. However, the COCS of this transformation under the BAU and ED scenarios were equal, which indicated that the impact of this transformation on ESV does not increase significantly with the expansion of living space, but tends to stabilize gradually. Thirdly, the sensitivity of the transformation from blue space to urban living space varied considerably with the development patterns. The EC, BAU and ED scenarios showed that the response of ESV to this transformation was non-sensitive, moderately sensitive, and strongly sensitive separately. Lastly, The COCS for the transformation of blue space to rural living space under all scenarios was less than 0.1, which indicated that ESV lacks sensitivity to this transformation.

(2) Cross-sensitivity between ecological space and production space

The transformation between ecological and production space in the BAU and ED scenarios showed an overall net output of ecological space, which had a suppressive effect on ESV. This sensitivity was mainly in response to the transfer of green space to agricultural production space. The low COCS for the transformation of blue space to agricultural production space indicated that ESV lacks sensitivity to this transformation. In the EC scenario, due to the promotion of the green development model, ecological restoration projects such as the return of farmland to forest and water had expanded the replenishment of farmland to forest and water, so the transformation of ecological space and production space had a positive role on ESV. The COCS for the transformation from green space and blue space to agricultural production space was 0.14 and 0.03, respectively, which indicated that Haikou relies mainly on the means of returning farmland to forest to achieve the optimization of ecological functions.

(3) Cross-sensitivity between production space to living space

The transformation of production space to living space in all three scenarios was shown as a net transfer out. The COCS for the transformation of production space to living space was all less than 0, which had an inhibitory effect on ESV. The sensitivity was mostly reflected in the transformation of agricultural production space to urban living space. The COCS of this transformation under the BAU and EC scenarios were 0.25 and 0.21, respectively, which were moderately sensitive. However, the COCS of this transformation increased significantly and reached an extremely sensitive level under the ED scenario, which was mainly due to the large flow of peri-urban farmland to construction land derived from the tremendous increase in demand for urban space.

4. Discussion

4.1. Spatial-Temporal Changes of PLES

The study result showed that the land space function structure of Haikou is unstable, which is manifested in the increasing changing number and scale of PLES during the study period. As a typical coastal mono-core city, Haikou expanded its living space outwards as a concentric circle from 2010 to 2020 [50]. The PLES changes at this point are mainly concentrated around the built-up areas. Under the simulation scenarios, the spatial pattern of PLES in Haikou changed significantly, showing a stratified distribution tendency along the northwest-to-southeast direction. The city layout shifted from a mono-core structure to a multi-core structure. The living space expanded mainly along the east and west flanks of the city, forming new urban expansion centers in the New Port and Jiangdong New District. This phenomenon is the same as the findings of Wang et al. and Li et al. [51], and conforms to the overall development strategy of "one main city and three subsidiary cities" proposed in the 14th Five-Year Plan of Haikou. Large-scale geographical replacement between ecological and production space occurred in the central and south-eastern parts of Haikou. Production space converged on the central part of Haikou, while ecological space had a shift to the agricultural and forestry production guarantee area in the southeast. This distribution scheme of PLES will aggravate the separation between living space and ecological space, which could easily damage the fragile eco-resilience of urban areas [32], and exacerbate ecological problems such as urban flooding, heat island effect, and loss of biodiversity [52].

In common with most economically developed regions, the highest proportion of the total area of PLES changes was occupied by the transformation between ecological and living space in Haikou [53,54]. Under the BAU scenario continuing the current development trend, the proportion of ecological space in Haikou dropped from 56.8% in 2020 to 51.7% in 2035, and the loss rate was higher than that of 2010–2020. These changes suggested that without any intervention, the current model of land and space development in Haikou is still insufficient to balance economic development and ecological conservation, and a reallocation of land resources is needed to promote the harmonious development of ecology and economy. The ED scenario simulated the territorial spatial structure of Haikou under high economic growth. Studies showed that the change in living space in Haikou is mainly motivated by economic factors and that living space realizes the maximization of area and growth rate through the massive encroachment of production and ecological space [55]. This human-driven allocation of land resources, which sacrifices ecological and productive space for economic benefits, can boost the economy in the short term, but it will upset the balance between human economic activities and the natural environment in the long term [56,57]. In addition, this scenario also suffered from uneven development between urban and rural areas. The rapid growth of urban living space stood in sharp contrast to the stagnant conditions of rural living space. The widening gap between the city and the countryside will seriously hinder the synergistic and quality development of urban and rural areas [58], which is detrimental to the long-term stability of the national economy [59]. The simulation process of the EC scenario took the present ecological control indicators and ecological restoration measures into account. The simulation outcomes simultaneously achieved the objectives of restraining urban expansion, protecting the ecological environment, and securing the demand for farmland. The incremental increase in living space under the EC scenario was the lowest, but the growth of rural living space was higher than in other scenarios. Agricultural production space diminished a lot due to the increased efforts to return farmland to forest and grass, but still meets Haikou's demand for farmland planned for the next 15 years. Benefiting from a substantial replenishment of agricultural production space, the loss of ecological space reduced to a fraction and the blue space experienced a positive increase at the Dongzhai Port wetland area. Therefore, effective land use policies are the essential key to achieving the coordinated development of PLES, and an important guarantee for fulfilling the sustainable development goals of China's ecological civilization [49,60].

4.2. Response of ESV to Changes in PLES Transformation

Research has shown that changes in ESV are influenced by the physical geography, local culture, and urban development strategies of the study area [32,61], and this phenomenon is evident throughout this study, as shown by the large differences in the impact of PLES changes on ESV under different urban development patterns. The natural resource and its internal structure defines the context of regional ecological quality and the direction of PLES transformation determines its contribution to the improvement of regional ecological quality [49]. Haikou is blessed with rich ecological and environmental resources, owning a large scale of forests and many natural and artificial wetlands [62]. The area of ecological space was consistently maintained at 55% or more between 2010 and 2020. Thus ecological space is the main contributor to ESV, and the corresponding regulatory and support services serve as the prevailing ecosystem services. With the introduction of various green policies in 2015, such as the ecological red line and agricultural planning [63], the expansion rate of living space in Haikou slowed down to some extent. However, the ESV remained in a state of continuous decline during the study period. Of all types of PLES transformation, the sensitivity of ESV to the transformation of ecological space to living space was highest throughout the study. In areas where agriculture is the main source of income, ESV is mainly influenced by the interaction between production and ecological space [64,65]. The economy of Haikou is primarily service-oriented [51], with associated industries highly reliant on urban living space [55]. The scale and aggregation effect of the service sector could lead to a massive expansion of living space, which will further exacerbate the conflict between land space functions and the decline of ecological functions in the region [66]. Thus, the overall fluctuation of ESV in areas with a developed service sector is determined by the transformation between ecological space and living space. Furthermore, the structural changes showed that in the process of promoting intensive urban development, the PLES around the highly urbanized areas are more vulnerable to human disturbance [60], which could explain why ESV losses in Haikou are concentrated around the built-up area in the north.

Regarding the driving mechanism and the effect of land space function transformation, some researchers have found that returning farmland to forestry and grass may not significantly alter land space function and ecological quality [67], which is in contrast to the findings of this paper. Despite the large discrepancies in the growth rate of living space between the BAU and ED scenarios, the ESV losses for both were close, declining by 660.01 million yuan and 794.83 million yuan, respectively, from 2020. From this, it can be assumed that simply controlling the extent of urban growth does not achieve significant improvements in regional ecosystem services. By contrast, the EC scenario with a similar growth rate of living space to BAU resulted in a loss of ESV with only a decrease of 179.98 million yuan from 2020, which suggested that the urban development pattern of the EC scenario is able to propel urbanization while managing the depletion of ecosystem services at a low level. The impressive promotion of ESV under the EC scenario is mainly attributed to the reinforced ecological restoration efforts such as the return of farmland to forests and lakes and the strict restrictions on the exploitation of ecological space. Long-term ecological restoration is thus an important policy for the harmonious development of the natural environment and the social economy. [68,69].

4.3. Implications and Suggestions

In general, the dilemma of economic and environmental conflicts faced by Haikou in its development process is also widely occurring in other coastal cities at home and abroad. Currently, the global coastline hosts nearly half of the world's population and two-thirds of the world's megacities [70]. Coastal cities have become a major carrier of national and global economic development [71]. However, coastal areas usually have abundant rainfall, high vegetation cover, and rich wetland resources, which makes them an important barrier to protecting regional biodiversity and ecological functions [72–74]. This has ultimately led to the rapid development of coastal cities accompanied by a dense population, massive consumption of resources, and environmental degradation [70,75]. We, therefore, proposed the following suggestion:

(1) Coastal zones of coastal cities are usually the areas with the most frequent changes in LULC and suffer from the most severe declines in ecosystem services [76,77], which is consistent with this research. Water supply and hydrological condition services are typically most severely damaged during shoreline development [78,79]. Therefore, it is necessary for coastal cities not only to strengthen the management and protection of the coastal zone and its buffer zone but also to classify and grade the development activities according to their dependence on water resources in the process of laying out regional functions and industries [80], so as to avoid further deterioration of the water resources environment caused by unreasonable planning.

(2) Early layout planning of urban groups and establishment of a long-term mechanism to balance ESV. At the city scale, the functional zoning of PLES is more clearly defined [81] and beneficial for cities of small and medium size, which is not only convenient for production and living, but also contains the impact on the environment within a relatively reasonable range [82,83]. However, studies have shown that when cities exceed medium or above scale, the concentrated distribution of large urban spatial functions will bring problems such as single ecosystem structure [84], PLES disproportion [85], and more serious urban disease phenomena [82]. According to the city size classification criteria introduced by the Chinese State Council in 2014, cities with a resident population of more than one million are considered large cities, and those with more than five million are mega-cities. Up to 2020, Haikou had been ranked as a large city with a 2.9 million population and is expected to approach the level of a mega-city in 2035. In the face of the rapidly expanding urban scale in the future, cities need to lay out urban clusters earlier to shift some industries and populations, so as to relieve the functions of major cities and reduce ecological pressure. This multi-group model can not only reduce the city scale and balance the demand for ecological quality and regional economic growth, but also provide space for the surrounding small cities or towns to thrive and narrow the development gap [82,86].

(3) Further strengthen the efforts of ecological restoration and protection. In this research, the comparison of scenarios revealed that limiting city size at the expense of economic development alone cannot fundamentally alleviate the huge loss of ESV brought about by urbanization. It is necessary to consolidate ecological restoration projects in

order to achieve the overall stability of regional ecological quality. The government should pay attention to the protection and recovery of ecological high-pressure areas such as wetlands, rivers, and forests, and carry out the redevelopment and reuse of inefficient or unused land according to the conditions of local land resources. At the same time, the urban ecological problems caused by a monolithic living space need to be alleviated and the quality of ecological services in built-up areas needs to be upgraded by means of optimizing the layout of green spaces and bringing up the total amount and quality of green spaces in built-up areas.

4.4. Applicability and Limitations

PLES is a new concept that has been proposed in China in recent years in response to sustainable development needs and functional zoning of territorial space. This concept aims to establish sustainable urban spatial systems and shares similarities with some of the concepts in modern Western urban spatial planning [15,37]. This study conducted a dynamic assessment of ESV from a PLES perspective and proposed a research framework based on the Markov chain, the PLUS model, and the equivalent factor method, which can help decision-makers to develop land reform programs from a macro perspective and provide a new direction to support sustainable land resource management. The spatial mapping and transfer matrix were first used to clarify the spatial and temporal variation characteristics of PLES in Haikou over the past decade. Then, corresponding scenario simulations based on different economic and ecological objectives were carried out to compare the similarities and differences of PLES development trends under different scenarios. Finally, the equivalent factor method was used to achieve the quantification of ecosystem services at different stages and clarify the ecological resource conditions of the region, which was used as a reference for the optimal spatial allocation of the city. Compared with existing studies, the regional land resource simulation and optimization method combining PLES and ESV on the one hand can analyze the impact of spatial functional imbalance on the ecological environment from a macroscopic perspective, and on the other hand can provide a basis for spatial planning for the land department, which has practical application value.

Certainly, there are limitations to this research. Although relevant studies have shown that the accuracy of the equivalent factor approach is essentially the same as that of the physical quantity-based assessment method [87], the equivalent factor approach still lacks the content of assessing the non-market value of ecosystem services, making it difficult to uncover the ecological processes behind each ecosystem service changes [88,89]. In addition, the functions of each land use are diverse, such as agricultural land having certain ecological functions as well as productive ones [32,90,91]. This research only classified land use types using the basic PLES classification, which is not comprehensive enough to consider all the functions of land use. So subsequent studies can further investigate ecosystem services based on a refined PLES classification.

5. Conclusions

This study explored the effects that different changes and configuration methods in land use functions have on ecosystem services from a PLES perspective. The results showed that the PLES pattern in Haikou tended to be unstable, and changes were concentrated in the northern coastal zone. These changes presented an overall inhibitory effect on ESV, which continued to decline in Haikou during the study period. Water supply was the ecosystem service type with the most severe decline in value, mainly influenced by the expansion of living space and urban population density. The loss of ESV varied widely among future scenarios due to different allocation of PLES. Among these scenarios, the EC scenario with ecological priority as the goal was the optimal simulation choice. This scenario had the lowest ESV sensitivity to PLES transformation, indicating that the PLES allocation pattern was more friendly to ecosystem services, and thus the ESV was much higher than the other two scenarios. Although the ESV under the EC scenario was much higher than the other two, the ecosystem services were still in negative growth. Therefore, to achieve a balanced regional ESV occupation, it is still necessary to continue to strengthen ecological restoration efforts on the basis of this scenario. With the global demand for ecological sustainability, a quantitative assessment of the dynamic changes in ESV from multiple perspectives can help to better understand the relationship between land use and ecosystem services, which is important for guiding regional sustainable development and the effective use of land resources.

Author Contributions: Project administration, funding acquisition, H.F.; writing—review and editing, J.C.; writing—original draft and methodology, J.C and S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Hainan Provincial Natural Science Foundation of China "Multi-scale Study on Spatial and Temporal Evolution and Optimization of Wetland Landscape Pattern in Haikou City". Grant number:421MS015.

Data Availability Statement: Not applicable.

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

References

1. Deng, X.; Li, Z.; Gibson, J. A review on trade-off analysis of ecosystem services for sustainable land-use management. *J. Geogr. Sci.* **2016**, *26*, 953–968. [CrossRef]
2. Feldberg, W.; Vogt, M. Acetylcholine synthesis in different regions of the central nervous system. *J. Physiol.* **1948**, *107*, 372. [CrossRef] [PubMed]
3. Mea, M.E.A. *Ecosystems and Human Well-Being: The Assessment Series*; (Four Volumes And Summary); Island Press: Washington, DC, USA, 2005.
4. Costanza, R.; De Groot, R.; Braat, L.; Kubiszewski, I.; Fioramonti, L.; Sutton, P.; Grasso, M. Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosyst. Serv.* **2017**, *28*, 1–16. [CrossRef]
5. Starrett, D.; Tilman, D.; Walker, B. Ecology: The value of nature and the nature of value. *Science* **2000**, *289*, 395–396.
6. Xie, G.D.; Zhang, C.X.; Zhang, C.S.; Xiao, Y.; Lu, C.X. The value of ecosystem services in China. *Resour. Sci.* **2015**, *37*, 1740–1746.
7. Xie, G.D.; Zhang, C.X.; Zhang, L.M.; Chen, W.H.; Li, S.M. Improvement of the evaluation method for ecosystem services value based on per unit area. *J. Nat. Resour.* **2015**, *30*, 1243–1254.
8. Daily, G.C.; Polasky, S.; Goldstein, J.; Kareiva, P.M.; Mooney, H.A.; Pejchar, L.; Ricketts, T.H.; Salzman, J.; Shallenberger, R. Ecosystem services in decision making: Time to deliver. *Front. Ecol. Environ.* **2009**, *7*, 21–28. [CrossRef]
9. Zhang, Z.; Gao, J.; Fan, X.; Lan, Y.; Zhao, M. Response of ecosystem services to socioeconomic development in the Yangtze river basin, China. *Ecol. Indic.* **2017**, *72*, 481–493. [CrossRef]
10. Ahmed, Z.; Asghar, M.M.; Malik, M.N.; Nawaz, K. Moving towards a sustainable environment: The dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. *Resour. Policy* **2020**, *67*, 101677. [CrossRef]
11. Kindu, M.; Schneider, T.; Teketay, D.; Knoke, T. Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the ethiopian highlands. *Sci. Total Environ.* **2016**, *547*, 137–147. [CrossRef]
12. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global change and the ecology of cities. *Science* **2008**, *319*, 756–760. [CrossRef]
13. Schneider, A.; Loganm, K.E.; Kucharikm, C.J. Impacts of urbanization on ecosystem goods and services in the US corn belt. *Ecosystems* **2012**, *15*, 519–541. [CrossRef]
14. Yao, X.; Chen, Y.; Zhang, Q.; Mou, Z.; Yao, X.; Ou, C. Assessment of the urban expansion and its impact on the eco-environment—A case study of Hefei municipal area. *Sustainability* **2022**, *14*, 10613. [CrossRef]
15. Zhang, H.Q.; Xu, E.Q.; Zhu, H.Y. An ecological-living-industrial land classification system and its spatial distribution in China. *Resour. Sci.* **2015**, *37*, 1332–1338.
16. Guan, Q.C.; Hao, J.M.; Shi, X.J.; Gao, Y.; Wang, H.L.; Li, M. Study on the Changes of Ecological Land and Ecosystem Service Value in China. *J. Nat. Resour.* **2018**, *33*, 195–207.
17. Dai, W.Y.; Jiang, F.Q.; Huang, W.L.; Liao, L.H.; Jiang, K. Study on transition of land use function and ecosystem service value based on the conception of production, living and ecological space: A case study of the Fuzhou New Area. *J. Nat. Resour.* **2018**, *33*, 2098–2109.
18. Gou, M.M.; Liu, C.F.; Li, L.; Xiao, W.F.; Wang, N.; Hu, J.W. Ecosystem service value effects of three gorges reservoir area land use transformation under the perspective of "production–living–ecological" spaces. *Chin. J. Appl. Ecol.* **2021**, *32*, 3933–3941.
19. Liu, C.; Deng, C.; Li, Z.; Li, Y. Response characteristics of Soil Erosion to Spatial Conflict in the Production-Living-Ecological Space and Their Drivingmechanism: A Case Study of Dongting Lake Basin in China. *Land* **2022**, *11*, 1794. [CrossRef]

20. Zhang, L.; Hu, B.; Zhang, Z.; Liang, G. Research on the spatiotemporal evolution and mechanism of ecosystem service value in the mountain-river-sea transition zone based on "production-living-ecological space"—Taking the Karst-Beibu gulf in southwest Guangxi, China as an example. *Ecol. Indic.* **2023**, *148*, 109889. [CrossRef]
21. Huang, J.C.; Lin, H.X.; Qi, X.X. A literature review on optimization of spatial development pattern based on ecological-production-living space. *Prog. Geogr.* **2017**, *36*, 378–391.
22. Dong, J.; Zhang, Z.; Da, X.; Zhang, W.; Feng, X. Eco-Environmental effects of land use transformation and its driving forces from the perspective of "production-living-ecological" spaces: A case study of Gansu province. *Acta Ecol. Sin.* **2021**, *41*, 5919–5928.
23. Hu, F.; An, Y.; Zhao, H. Research on characteristics of ecological environment effect on a "semi-Karst" region based on land use transition: A case in central Guizhou province, China. *Earth Env.* **2016**, *44*, 447–454.
24. Hu, W.; Wang, L.; Shu, M. Reflections on delimiting the three basic spaces in the compilation of urban and rural plans. *City Plan. Rev.* **2016**, *40*, 21–26.
25. Yang, X.; Chen, X.; Qiao, F.; Che, L.; Pu, L. Layout optimization and multi-scenarios for land use: An empirical study of production-living-ecological space in the Lanzhou-Xining city cluster, China. *Ecol. Indic.* **2022**, *145*, 109577. [CrossRef]
26. Shi, M.; Wu, H.; Fan, X.; Jia, H.; Dong, T.; He, P.; Baqa, M.F.; Jiang, P. Trade-Offs and synergies of multiple ecosystem services for different land use scenarios in the Yili river valley, China. *Sustainability* **2021**, *13*, 1577. [CrossRef]
27. Guo, R.Z.; Shen, H.J. Studies on ecological compensation standard based on ecosystem service in Lishui river basin. *Ecol. Sci.* **2021**, *40*, 147–154.
28. Qiao, B.; Cao, X.Y.; Sun, W.J.; Gao, Y.Y.; Chen, Q.; Yu, H.Y.; Wang, Z.; Wang, N.A.; Cheng, H.Y.; Wang, Y.P.; et al. Ecological zoning identification and optimization strategies based on ecosystem service value and landscape ecological risk: Taking Qinghai area of Qilian mountain national park as an example. *Acta Ecol. Sin.* **2023**, *43*, 986–1004.
29. Mai, R.R.G.; Gao, M.H.; Ma, L.G. Dynamic changes of land use and ecosystem service value of production-living-ecological space in desert-Oasis area. *J. Anhui Agric. Sci.* **2023**, *51*, 60–67.
30. Kang, J.; Zhang, X.; Zhu, X.; Zhang, B. Ecological security pattern: A new idea for balancing regional development and ecological protection. A case study of the Jiaodong peninsula, China. *Glob. Ecol. Conserv.* **2021**, *26*, E01472. [CrossRef]
31. Yang, Y.; Bao, W.; Li, Y.; Wang, Y.; Chen, Z. Land use transition and its eco-environmental effects in the Beijing–Tianjin–Hebei urban agglomeration: A production–living–ecological perspective. *Land* **2020**, *9*, 285. [CrossRef]
32. Wang, A.; Liao, X.; Tong, Z.; Du, W.; Zhang, J.; Liu, X.; Liu, M. Spatial-Temporal dynamic evaluation of the ecosystem service value from the perspective of "production-living-ecological" spaces: A case study in Dongliao river basin, China. *J. Clean. Prod.* **2022**, *333*, 130218. [CrossRef]
33. Jiao, L.; Xue, Z.J.; Yin, J.; Yin, J.; Zhu, S.L. Eco-Environmental effects of land use transition in Karst area based on the view of "ecological-production-living spaces": Taking Guizhou province as an example. *Ecol. Econ.* **2020**, *36*, 206–212.
34. Han, M.; Kong, X.; Li, Y.; Wei, F.; Kong, F.B.; Huang, S.P. Eco-Environmental effects and its spatial heterogeneity of 'ecological-production-living'land use transformation in the yellow river delta. *Sci. Geogr. Sin.* **2021**, *41*, 1009–1018.
35. Zhou, Y.C.; Yin, D.; Huang, Q.X.; Zhang, L.; Bai, Y.S. Spatial optimization based on ecosystem services and the participatory mapping: A case study in Baiyangdian watershed. *J. Nat. Resour.* **2022**, *37*, 1988–2003. [CrossRef]
36. Jiao, G.; Yang, X.; Huang, Z.; Zhang, X.; Lu, L. Evolution characteristics and possible impact factors for the Changing pattern and function of production-living-ecological space in Wuyuan county. *J. Nat. Resour.* **2021**, *36*, 1252–1267. [CrossRef]
37. Wen, X.; Chen, C. Study on the spatial-temporal evolution of ecosystem service value in Chongqing section of the Yangtze river basin based on ecological-production-living spaces. *J. Chongqing Norm. Univ. (Nat. Sci.)* **2022**, *39*, 128–140.
38. Fu, X.; Wang, X.; Zhou, J.; Ma, J. Optimizing the production-living-ecological space for reducing the ecosystem services deficit. *Land* **2021**, *10*, 1001. [CrossRef]
39. Bai, Y.P.; Wang, J.B.; Liu, L.; Du, Y.D.; Deng, X.Z.; Chen, J.C. Prediction and trade-off analysis of ecosystem service value in Heihe river basin—A case study in Zhangye city. *Acta Ecol. Sin.* **2022**, *13*, 1–13.
40. Fu, J.; Zhang, Q.; Wang, P.; Zhang, L.; Tian, Y.; Li, X. Spatio-Temporal changes in ecosystem service value and its coordinated development with economy: A case study in Hainan province, China. *Remote Sens.* **2022**, *14*, 970. [CrossRef]
41. Xue, Z.Y. Anecological-Living-Industrial Land classification system and its spatial distribution in China. *Resour. Sci.* **2015**, *37*, 1332–1338.
42. Ouyang, X.; He, Q.; Xiang, Z. Simulation of impacts of urban agglomeration land use change on ecosystem services value under multi-scenarios: Case study in Changsha-Zhuzhou-Xiangtan urban agglomeration. *Econ. Geogr.* **2020**, *40*, 93–102.
43. Zhang, X.Y.; Zhang, X.; Li, D.H.; Lu, L.; Yu, H. Multi-Scenario simulation of the impact of urban land use change on ecosystem service value in Shenzhen. *Acta Ecol. Sin.* **2022**, *42*, 2086–2097.
44. Zhang, Z.; Nie, T.; Gao, Y.; Sun, S.M.; Gao, J. Study on temporal and spatial characteristics of coupling coordination correlation between ecosystem services and economic—Social development in the Yangtze river economic belt. *Resour Env. Yangtze Basin* **2022**, *31*, 1086–1100.
45. Dai, X.; Johnson, B.A.; Luo, P.; Yang, K.; Dong, L.; Wang, Q.; Liu, C.; Li, N.; Lu, H.; Ma, L.; et al. Estimation of urban ecosystem services value: A case study of Chengdu, southwestern China. *Remote Sens.* **2021**, *13*, 207. [CrossRef]
46. Ye, Y.; Bryan, B.A.; Connor, J.D.; Chen, L.; Qin, Z.; He, M. Changes in land-use and ecosystem services in the Guangzhou-Foshan metropolitan area, China from 1990 to 2010: Implications for sustainability under rapid urbanization. *Ecol. Indic.* **2018**, *93*, 930–941. [CrossRef]

47. Ran, Y.J.; Lei, D.M.; Liu, L.; Gao, L.P. Impact of land use change on ecosystem service value in urban agglomeration of central Yunnan province during 2000–2020. *Bull. Soil Water Conserv.* **2021**, *41*, 310–322.
48. Lu, C.; Zhang, Y.H.; Zeng, R.; Qiu, X.H.; Dong, G.L. Land space dynamic changes and cross-sensitivity of ecological service function in the lower yellow river reaches. *J. Agric. Resour. Environ.* **2023**. [CrossRef]
49. Du, W.; Wang, Y.; Qian, D.; Lyu, X. Process and eco-environment impact of land use function transition under the perspective of "production-living-ecological" spaces—Case of Haikou city, China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 16902. [CrossRef]
50. Wang, H.; Zhang, L.; Bi, S.; Han, R.D. Remote sensing monitoring and simulation of city development for Hainan province. *J. Appl. Sci.* **2018**, *36*, 798–807.
51. Wang, P.; Zheng, D.; Huang, S. The influence factors of urban land expansion and calculation of its utmost scale —A case study of Haikou city. *J. Shanxi Agric. Univ. (Soc. Sci. Ed.)* **2018**, *17*, 44–50.
52. Nor, A.N.M.; Corstanje, R.; Harris, J.A.; Brewer, T. Impact of rapid urban expansion on green space structure. *Ecol. Indic.* **2017**, *81*, 274–284. [CrossRef]
53. Gong, Q.; Guo, G.; Li, S.; Liang, X. Decoupling of urban economic growth and water consumption in Chongqing and Chengdu from the "production-living-ecological" perspective. *Sustain. Cities Soc.* **2021**, *75*, 103395. [CrossRef]
54. Wu, J.; Zhang, D.; Wang, H.; Li, X. What is the future for production-living-ecological spaces in the greater bay area? A multi-scenario perspective based on DEE. *Ecol. Indic.* **2021**, *131*, 108171. [CrossRef]
55. Wang, T.; Wei, S.C. Characteristics and influencing factors of land use transition in Haikou city during 2009–2018. *Bull. Soil Water Conserv.* **2022**, *42*, 344–352.
56. Lu, D.; Chen, M. Several viewpoints on the background of compiling the "national new urbanization planning (2014–2020)". *Acta Geogr. Sin.* **2015**, *70*, 179–185.
57. Shi, Z.; Deng, W.; Zhang, S. Spatial pattern and spatio-temporal change of territory space in Hengduan mountains region in recent 25 years. *Geogr. Res.* **2018**, *37*, 607–621.
58. Du, W.X.; Hu, P.P. Analysis of the interaction mechanism between the urban-rural coordinated development and the urban-rural income gap. *J. Northwest AF Univ. (Soc. Sci. Ed.)* **2010**, *10*, 42–60.
59. Sun, B.W. Adhere to the integrated development of urban and rural areas, and continue to narrow the gap between urban and rural areas, and promoting common prosperity: Studying and explaining the spirit of the 20th CPC congress of the communist party of China. *Ecol. Econ.* **2023**, *39*, 13–25.
60. Guan, M.; Zhang, W.X.; Jiang, H.M.; Lu, C.; Ge, Y.; Dong, G. Cross-Sensitivity evaluation of ecosystem services based on land use changes in Shandong province. *J. China Agric. Univ.* **2022**, *27*, 192–203.
61. Huang, C.; Teng, M.; Zeng, L. Long-Term changes of land use/cover in the Three Gorges reservoir area of the Yangtze river, China. *Chin. J. Appl. Ecol.* **2018**, *29*, 1585–2596.
62. Zhong, Z.; Qiu, H.; Yang, X. Analysis of wetland changes and driving forces in Haikou in the last 30 years. *J. Hainan Norm. Univ. (Nat. Sci.)* **2021**, *34*, 215–226.
63. Lei, J.; Chen, Z.; Wu, T.; Li, X.; Yang, Q.; Chen, X. Spatial autocorrelation pattern analysis of land use and the value of ecosystem service in northeast Hainan island. *Acta Ecol. Sin.* **2019**, *39*, 2366–2377.
64. Abulizi, A.; Yang, Y.; Mamat, Z.; Luo, J.; Abdulslam, D.; Xu, Z.; Zayiti, A.; Ahat, A.; Halik, W. Land-Use change and its effects in Charchan oasis, Xinjiang, China. *Land Degrad. Dev.* **2017**, *28*, 106–115. [CrossRef]
65. Pan, N.; Guan, Q.; Wang, Q.; Sun, Y.; Li, H.; Ma, Y. Spatial differentiation and driving mechanisms in ecosystem service value of arid region: A case study in the middle and lower reaches of Shule river basin, NW China. *J. Clean. Prod.* **2021**, *319*, 128718. [CrossRef]
66. Li, S.T.; Li, H.X. Study on the characteristics and evolution trends of the distribution pattern of service industry. *Ind. Econ. Res.* **2014**, *05*, 1–10.
67. Ji, Z.; Liu, C.; Xu, Y.; Huang, A.; Lu, L.; Duan, Y. Identification and optimal regulation of the production-living-ecological space based on quantitative land use functions. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 222–231.
68. Carvalho-Santos, C.; Monteiro, A.T.; Arenas-Castro, S.; Greifeneder, F.; Marcos, B.; Portela, A.P.; Honrado, J.P. Ecosystem services in a protected mountain range of Portugal: Satellite-based products for state and trend analysis. *Remote Sens.* **2018**, *10*, 1573. [CrossRef]
69. Li, S.; Sun, Z.; Tan, M.; Guo, L.; Zhang, X. Changing patterns in farming–pastoral ecotones in China between 1990 and 2010. *Ecol. Indic.* **2018**, *89*, 110–117. [CrossRef]
70. Burt, J.A.; Killilea, M.E.; Ciprut, S. Coastal urbanization and environmental change: Opportunities for collaborative education across a global network university. *Reg. Stud. Mar. Sci.* **2019**, *26*, 100501. [CrossRef]
71. Xu, C.; Jiang, W.; Huang, Q.; Wang, Y. Ecosystem services response to rural-urban transitions in coastal and island cities: A comparison between Shenzhen and Hong Kong, China. *J. Clean. Prod.* **2020**, *260*, 121033. [CrossRef]
72. Chi, Y.; Zhang, Z.; Xie, Z.; Wang, J. How human activities influence the island ecosystem through damaging the natural ecosystem and supporting the social ecosystem? *J. Clean. Prod.* **2020**, *248*, 119203. [CrossRef]
73. Li, C.; Fang, S.; Geng, X.; Yuan, Y.; Zheng, X.; Zhang, D.; Li, R.; Sun, W.; Wang, X. Coastal ecosystem service in response to past and future land use and land cover change dynamics in the Yangtze river estuary. *J. Clean. Prod.* **2023**, *385*, 135601. [CrossRef]
74. Aktürk, E.; Güneroğlu, N. Degradation of coastal ecosystem services in southern Black Sea: A case study of Trabzon city. *Ocean. Coast. Manag.* **2021**, *213*, 105837. [CrossRef]

75. Lin, T.; Xue, X.; Shi, L.; Gao, L. Urban spatial expansion and its impacts on island ecosystem services and landscape pattern: A case study of the island city of Xiamen, southeast China. *Ocean. Coast. Manag.* **2013**, *81*, 90–96. [CrossRef]
76. O'higgins, T.G.; O'dwyer, B. A vulnerability framework to protect coastal social ecological systems. *Anthr. Coasts* **2019**, *2*, 279–292. [CrossRef]
77. Politi, E.; Paterson, S.K.; Scarrott, R.; Tuohy, E.; O'Mahony, C.; Cámaro-García, W.C. Earth observation applications for coastal sustainability: Potential and challenges for implementation. *Anthr. Coasts* **2019**, *2*, 306–329. [CrossRef]
78. Le Maitre, D.C.; Kotzee, I.M.; O'farrell, P.J. Impacts of land-cover change on the water flow regulation ecosystem service: Invasive alien plants, fire and their policy implications. *Land Use Policy* **2014**, *36*, 171–181. [CrossRef]
79. Vigerstol, K.L.; Aukema, J.E. A comparison of tools for modeling freshwater ecosystem services. *J. Environ. Manag.* **2011**, *92*, 2403–2409. [CrossRef]
80. Xing, W.X.; Yang, X.Y.; Liu, D.H. Study on the definition and management of the spatial use of coastal zones based on the degree of water dependence: Experiences from the United States. *Urban Plan. Int.* **2021**, *36*, 31–42.
81. Wang, Y.; Liu, X.L.; Wei, X.H.; Yu, H.W. Preliminary study on the method and practice of regional spatial planning—From "Sansheng space" to "three districts and three lines". *Urban Plan. Forum* **2018**, *04*, 65–74.
82. Xiao, J.C. "Multi-Center Group" Model To Deal With "Urban Diseases". *China Soc. Sci. J.* **2012**, *07*, 11–0274.
83. Wang, S.L. *The Study on Urban Problems and Its Control in China under the Background of Urban-Rural Integration*; Wuhan University: Wuhan, China, 2019.
84. Wu, Z.Y.; Shan, J.J. Research On the evolution patterns and optimization countermeasures of urban production-ecological-living space in China. *City* **2019**, *10*, 15–26.
85. Lu, D.F.; Jiang, M.Q. Characteristics, logical relations and optimization strategies of urban Sansheng space. *Hebei Acad. J.* **2019**, *39*, 149–159.
86. Shi, N.J.; Duan, P.J. Prescription for urban diseases treatment from the strategic philosophy. *Think Tank Theory Pract.* **2021**, *6*, 45–54.
87. Kang, N.; Hou, L.; Huang, J.; Liu, H. Ecosystem services valuation in China: A meta-analysis. *Sci. Total Environ.* **2022**, *809*, 151122. [CrossRef]
88. Xie, G.; Zhang, C.; Zhen, L.; Zhang, L. Dynamic changes in the value of China's ecosystem services. *Ecosyst. Serv.* **2017**, *26*, 146–154. [CrossRef]
89. Seppelt, R.; Dormann, C.F.; Eppink, F.V.; Lautenbach, S.; Schmidt, S. A quantitative review of ecosystem service studies: Approaches, shortcomings and the road ahead. *J. Appl. Ecol.* **2011**, *48*, 630–636. [CrossRef]
90. Zhou, D.; Xu, J.; Lin, Z. Conflict or coordination? assessing land use multi-functionalization using production-living-ecology analysis. *Sci. Total Environ.* **2017**, *577*, 136–147. [CrossRef]
91. Duan, Y.; Wang, H.; Huang, A.; Xu, Y.; Lu, L.; Ji, Z. Identification and spatial-temporal evolution of rural "production-living-ecological" space from the perspective of villagers' behavior–a case study of Ertai town, Zhangjiakou city. *Land Use Policy* **2021**, *106*, 105457. [CrossRef]