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PLUS-Model Based Multi-Scenario Land Space Simulation of the Lower Yellow River Region and Its Ecological Effects

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Abstract: The rapid urbanization in recent years as a vehicle for social growth and ecological construction has resulted in a significant transformation of the spatial structure of the land in the lower reaches of the Yellow River. Based on this, the current study used the PLUS model to simulate the future territorial spatial pattern of the lower reaches of the Yellow River in various development scenarios to reveal differences in the ecosystem's spatial distribution and provide a reference for optimizing territorial spatial usage and ecological protection. The results show that the overall accuracy of the Patch-generating Land Use Simulation (PLUS) model's simulation results was 0.748, the Kappa coefficient was 0.812, and the simulation effect was good. The simulation results for each land space in various situations reveal a preferential spatial development trend model. In the territorial and spatial priority scenario, development was reasonably balanced, which is consistent with the status of the quantitative structure of the territorial space of the study area during 2015. From 2015 to 2035, the value of ecosystem services will change in different ways depending on the scenario and the set priorities. The ecosystem service value decreased in the production space and living space priority development scenarios, while it increased in the ecological space and national space priority development scenarios. The PLUS model has a high degree of applicability to the spatial pattern development simulation of the lower Yellow River region, and the results of this multi-scenario simulation and ecological environmental effect study may be used as a reference for future territorial spatial planning and policy formulation in the region.

Keywords: land space; PLUS model; simulation prediction; ecosystem service value; lower Yellow River

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1. Introduction

Land space provides an environment for human survival and is a place for social development and ecological construction. Changes in the land space pattern, as the primary factor driving ecological change, directly affect ecosystem services [1–4]. Ecosystem services are related to ecosystems and human well-being and form an important part of land and spatial planning [5–7]. In the 21st century, China's economy has been in a stage of rapid development. The rapid advancement of urbanization has led to the evolution of land space patterns and imbalances in the development of the economy, society, and the ecological environment. This has also increased the severity of prominent ecological and environmental problems, such as land desertification, soil degradation, and soil erosion, which have seriously affected the stability of the ecosystem [2,8–10]. The 19th Party Congress set "Beautiful China" as the goal of ecological civilian construction, and clearly stated a general requirement for intensive and efficient production space, livable and moderate living space, and beautiful and clear ecological space to better coordinate urban and rural land resources and improve the quality of the ecological environment. The focus of the development of territorial spatial patterns will eventually shift from improving the efficiency of territorial spatial usage to coordinating the development of territorial space [11,12]. Therefore, the prediction of land space usage and the calculation of ecosystem service values by multi-scenario simulation are of great significance to the optimization of land space usage patterns.

Land space patterns have always been the focus of geographical research, and multi-scenario simulation of land space patterns is not only the key means by which to solve problems such as disorderly land development, but also a solid foundation for improving the land spatial development mechanism [13–17]. Scientific and accurate simulation of the future land space pattern is of great practical significance to revealing changes in ecosystem service values [2,13,18–20]. Models such as Conversion of Land Use and its Effects at Small Regional Extent (CLUE-S), Cellular Automata-Markov (CA-Markov), Future Land Use Simulation (FLUS), and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) provide new directions for modeling and estimating the value of ecosystem services as research progresses [21–24]. The Patch-generating Land Use Simulation (PLUS) model simulates changes in land space patterns in the future. The advantage of this model is that it can dynamically simulate the generation and evolution of land use patches with high accuracy by using a land expansion rule analysis strategy and a multi-class seed growth mechanism [13,25–27]. The model compensates for the shortcomings of other models, including CLUE-S, CA-Markov, and FLUS, such as the lack of the ability to simulate the mutual attraction and evolution of open space and urban land under different policies. Currently, multi-scenario simulations from the perspective of land space are rarely used to predict land space patterns. Therefore, the PLUS model was used in this study to simulate future changes in land space patterns in different development scenarios in order to find a reasonable allocation mode for land spatial utilization planning and ecological security management and control.

As one of the most important grain-producing and core agricultural production areas in China, the lower reaches of the Yellow River have come to be representative of dynamic changes in global land and resource usage in recent decades, with frequent human activities, rapid expansion of production and living space, a significant reduction in ecological space, and fierce land space conflicts [9,17]. Therefore, in this study, the lower reaches of the Yellow River were focused on to analyze the land spatial development pattern based on the land spatial classification system obtained by the scoring matrix method. Furthermore, the PLUS model was used to simulate multiple scenarios and dynamically evaluate regional ecosystem services in order to provide a methodological and practical solution for the spatial planning of the lower reaches of the Yellow River.

2. Materials and Methods

2.1. Study Area

The lower Yellow River starts from Taohuayu, Xingyang City, Henan Province and ends in Kenli County, Shandong Province, with a total length of approximately 786 km. Based on previous research, the lower reaches of the Yellow River were divided into 20 prefecture-level cities and 133 counties (including municipal districts) in Henan Province and Shandong Province, covering a total land area of 150,000 km^2 (Figure 1). The lower reaches of the Yellow River have a temperate monsoon climate with simultaneous rain and high temperatures. The annual precipitation is approximately 650 mm, and the topography predominantly consists of plains. The river is gentle, wide, and shallow with many branches, resulting in a large accumulation of sediment and the formation of multiphase alluvial fans in the plain areas. In 2018, the lower Yellow River region accounted for 64% and 61% of the Yellow River basin's GDP and population, respectively, making it the key catchment area for economic and social development. In recent decades, urbanization and agricultural modernization in the region have accelerated, and human activities have frequently interfered with the ecological environment. The interference with the environment has resulted in a variety of problems, such as severe sanding of grain fields and soil erosion, drastic changes in the land space, and uneven land space pattern development.

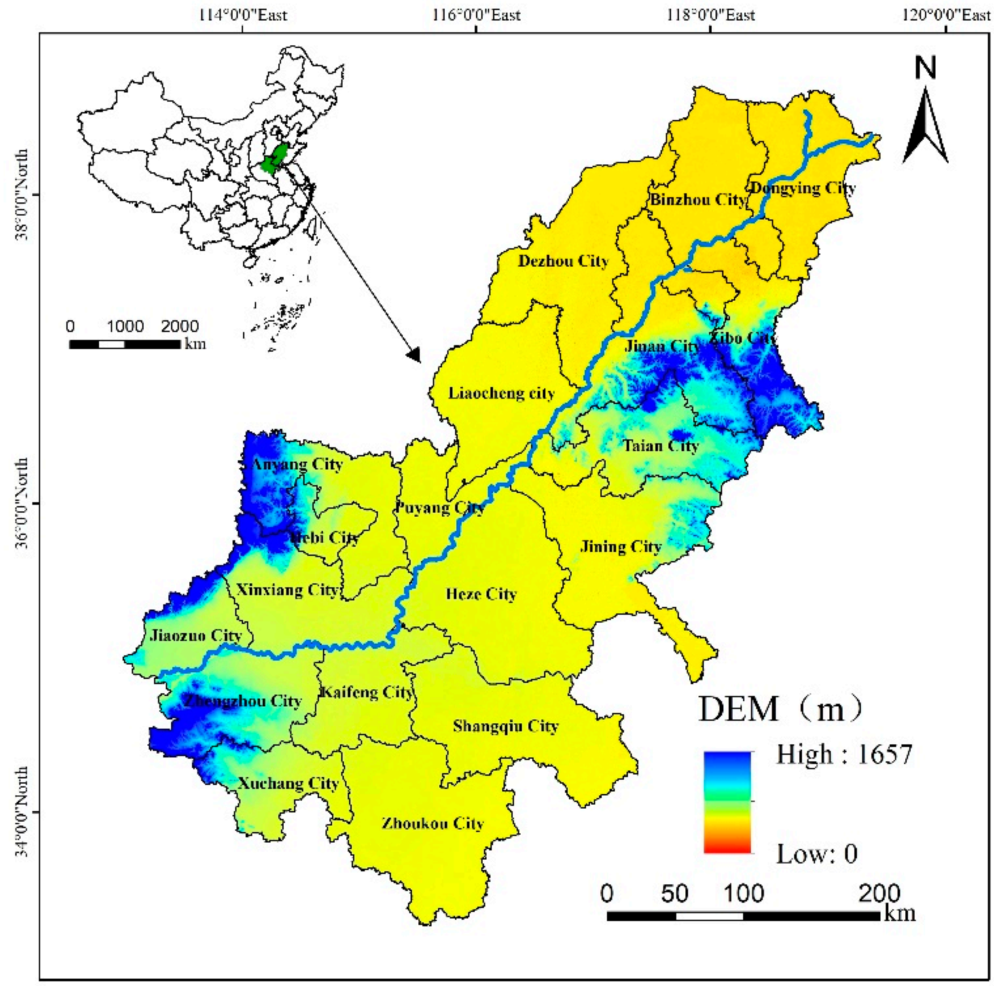


Figure 1. Overview of the lower Yellow River study area.

2.2. Data Sources and Processing

The land use classification data on the lower reaches of the Yellow River for 2005 and 2015 were obtained from the geospatial data cloud platform and had a spatial resolution of 300 m. A use-based national land use spatial classification index system was constructed based on the dominant functions of different spaces in the study area. The study area was divided into three primary land use categories and nine secondary land use categories, with the primary categories being production, living, and ecological spaces. The secondary categories were agricultural production, industrial and mining production, urban living, rural living, forestry ecological, pastoral ecological, water ecological, wetland ecological, and other spaces. The influencing variables of future land resource changes, as well as the different rule methods in the PLUS model, were taken into account during the simulation and prediction process. Natural and societal factors are the primary influences on changes in land spatial patterns. In this study, two driving elements, socio-economic and climatic–environmental factors, were chosen based on the reality of the lower Yellow River region and data availability. Among these, climatic–environmental elements are the primary drivers driving changes in national spatial patterns, whereas socio-economic factors are key contributing elements. All layers in the model were resampled to 300 $\times$ 300 m, and Table 1 lists the individual sources of the relevant data.

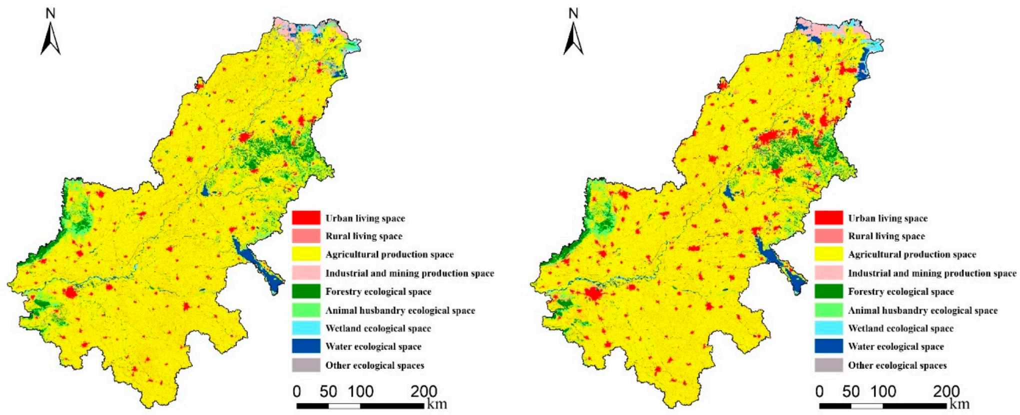
Table 1. Information on data sources.

Data Type	Data Name	Data Description	Data Sources
Land use data	Lower Yellow River 2000 Land Use Classification Data	Land use/cover decomposition data from 2000	Geospatial Data Cloud Platform
	Lower Yellow River 2015 Land Use Classification Data	2015 land use/cover interpretation data	
Restriction on conversion of regional land data	Priority constraints on production space	Production function as a limiting factor	Data Center for Resource and Environmental Sciences, Chinese Academy of Sciences
	Living Space Priority Constraints	Living function as a limiting factor	
	Priority ecological spatial constraints	Ecological function as a limiting factor	
Socio-economic data	Population	National population data obtained in 2015	Shandong Statistical YearbookStatistical Yearbook of Henan Province
	GDP	GDP of the lower Yellow River region in 2015	
	Distance to main road	Distance to National Road	Data Center for Resource and Environmental Sciences, Chinese Academy of Sciences
	Distance to primary road	Distance to Provincial Road	
	Distance to secondary road	Distance to County Road	
	Distance to tertiary roads	Distance to township roads	
	Distance to railway	Distance to railway	
	Distance to motorway	Distance to motorway	
	Distance to High-Speed Rail Station	Distance to HSR transport stations	
	Distance to government	Distance to government premises	
Climate and environmental data	Soil type	Data on the distribution of soil types in 2015	
	Average annual temperature	Average of the temperatures from 2000 to 2015	
	Average annual precipitation	Average of the precipitation values from 2000 to 2015	
	Elevation	The Geo Cloud platform publishes data	Geospatial Data Cloud Platform
	Slope	Calculated from elevation data	Elevation data with a resolution of 300 m
	Distance to water	Distance to water bodies such as rivers, lakes, and reservoirs	Data Centre for Resource and Environmental Sciences, Chinese Academy of Sciences

3. Methodology

3.1. Territorial Spatial Function Scoring Matrix

A hierarchical scoring method was used to score the production, living, and ecological functions provided by different land categories according to the principle of top-down hierarchical functions. The Land-Use and Land-Cover Change (LUCC) 2018 classification system was referred to in order to construct a scoring matrix to obtain the initial evaluation results of the production, living, and ecology functions and to identify the dominant functions of the study region along with the corresponding quantitative spatial evaluation [28]. The current status of the study area is shown in Figure 2. The scoring matrix method was used to rate different spaces on a scale of 0 to 5 according to their production, living, and ecological functions, based on multi-source data and the characteristics of different spaces in the study area. A score of 0 represented no relevant function, an increase in a score represented a gradual increase in a function, and a score of 5 indicated the maximum function that could be provided. The national spatial function scoring matrix is presented in Table 2.



(**a**) (**b**)

Figure 2. Current land use status. (**a**) Current situation of land space in 2005; (**b**) Current situation of land space in 2015.

Table 2. Land and Spatial Function Score Matrix.

Class I Land		Class II Land			Production Function	Living Function	Ecology Function
Code	Name	Code	Name	Classification			
1	Production space	a	Industrial and mining production space	Industrial land, mining land, storage land, salt land	3	0	0
		b	Space for agricultural production	Paddy fields, dry land, watered land	4	0	4
2	Living space	c	Urban living space	Urban residential land, transport land, other construction land	4	5	0
		d	Rural living space	Rural residential land, other building land	3	4	0
3	Ecological space	e	Forestry ecological space	Woodland, shrubland, open woodland and other woodland	1	1	5
		f	Pastoral ecological space	High-cover grassland, medium-cover grassland, low-cover grassland Low-cover grassland	2	0	3
		g	Other ecological spaces	Sandy areas, Gobi desert, saline areas, bare ground, bare rocky terrain	0	1	4
		h	Wetland ecological space	Mudflats, mudflats, marshes	0	0	5
		i	Water ecological space	Rivers and canals, lakes, reservoir pits, seas, and permanent glacial snow	2	0	5

3.2. Principle of the PLUS Model, Optimization, Configuration, and Parameter Settings

Qingfeng, et al. improved the PLUS model by using a standard that met cellular automata (CA) [25]. The model integrates a rule-mining framework based on a land expansion analysis strategy (LEAS) and CA based on multi-type random patch seeds (CARS) to dynamically simulate the genesis and evolution of multiple types of land patches based on land use change and driving factor data. This study simulated the change in the land spatial pattern in the lower reaches of the Yellow River through the PLUS model in three steps. First, influenced by the uncertainty in the regional future socio-economic development trend, there is obvious variability in the direction of the territorial space's expansion. Therefore, four scenarios (production space priority, living space priority, ecological space priority, and territorial space priority) were set in this study. Second, based on the earlier land spatial data, the prediction results of the land spatial quantitative structure were obtained using the Markov chain model or the linear regression model, and the expansion probability results of land spatial types were calculated using the LEAS model. Third, specific restricted development areas were set for different scenarios. Combined with the prediction results of the land spatial quantitative structure and the expansion probability results of land spatial types, the prediction results of the land spatial layout in different scenarios were obtained using the CARS model, as shown in Figure 3.

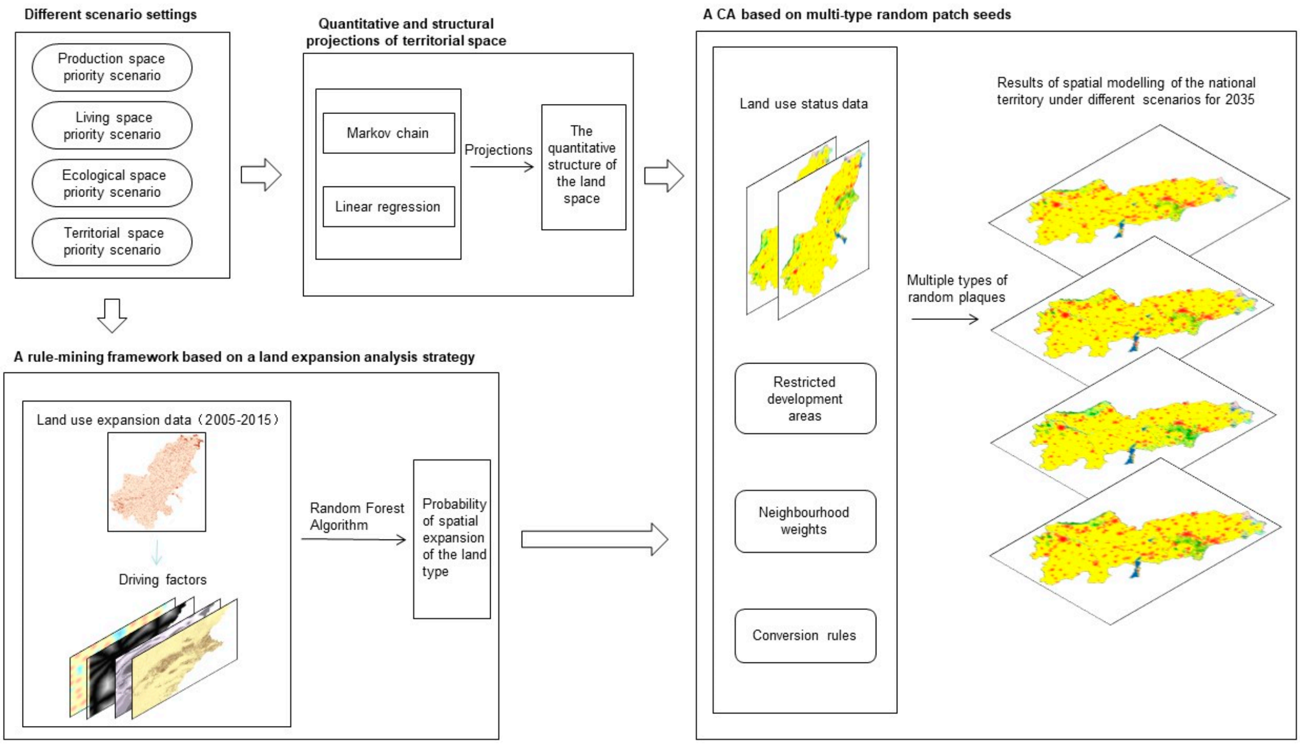


Figure 3. Patch-generating Land Use Simulation framework.

3.2.1. Different Scenario Settings (DSSs)

Four priority scenarios were set (a production space priority scenario, a living space priority scenario, an ecological space priority scenario, and a land space priority scenario). In the production space priority scenario, industrial, mining, and agricultural production spaces are given priority to meet the needs of human production and operation activities for production factors. In the living space priority scenario, the production function is limited while taking into account the ecological function, and priority is given to the development of living functions and meeting the expansion needs of urban and rural living spaces. In the ecological space priority scenario, the importance of all kinds of ecological spaces is emphasized for ecological protection, strictly restricting the occupation of ecological space for production and living space development and encouraging the outward expansion of ecological space. In the land and space priority scenario, the coordinated development of land and space is the goal in order to find the optimal allocation of land and space and realize the ecological protection and high-quality development priorities of the regional economy.

3.2.2. Quantitative and Structural Projections of Territorial Space (QSP)

A Markov chain model or a linear regression model can be used to predict a structure quantitatively. Linear regression models are numerical regression models that represent the interdependence of the variables. They are useful for solving most land use structural optimization problems but are ineffective when the multi-objective choice is based on the Pareto criterion. With discrete stochastic processes of movement in time and space, Markov chains are used to predict the future spatial structure of a country based on past patterns or interactions with related factors [21,22]. The Markov chain model was used to predict the quantitative geographical structure of the land in the lower Yellow River region based on spatial data on the land in the past in an integrated way, considering the drivers in various scenarios.

3.2.3. A Rule-Mining Framework Based on a Land Expansion Analysis Strategy (LEAS)

To extract the country's spatial expansion statistics during this era, land spatial data from 2005 and 2015 were superimposed. The increase was combined with the corresponding climatic and environmental factors (soil type, average annual temperature, average annual precipitation, elevation, slope, etc.) and socio-economic factors (population, GDP, road distance, etc.). The spatial expansion and drivers were then examined individually using the random forest classification (RFC) [25] algorithm to investigate the relationship between each type of spatial growth and multiple drivers in order to determine the likelihood of the expansion of the territorial spatial type in the Yellow River's lower reaches.

3.2.4. CA Based on Multi-Type Random Patch Seeds (CARS)

The restricted-development areas in the lower reaches of the Yellow River region for the production space, living space, ecological space, and land space priority scenarios were taken to be the agricultural production, urban living, forestry ecological, urban living, and forestry ecological spaces, respectively, based on differences in the development needs of different land space scenarios. Based on the 2015 territorial spatial data, the CARS model with the threshold-decreasing mechanism was adopted according to the weights of the territorial spatial types and the conversion rules to obtain the results of the territorial spatial simulation in different scenarios. The model combined the probability of the expansion of the territorial spatial type obtained from the LEAS model and the prediction results of the quantitative structure of the territorial space obtained using the Markov chain model [21,22].

The conversion rule specifies whether certain forms of space can be converted into another type of space. If one type of space can be converted into another, the value is 1. The value is 0 if the two types of spaces cannot be transitioned into one another [29]. Based on the land-class ranking shown in Table 2, four prediction scenarios were simulated, each corresponding to four distinct conversion rules, as shown in Table 3. Within a neighborhood, the weights indicate the relationships between distinct spaces and land–space types. The neighborhood weights of different spaces were assigned using the expert scoring method based on the spatial characteristics of the study area, and corrections were made based on the calculated data on the expansion area share of each spatial type. The parameters were set as shown in Table 4 after several simulations and debugging.

Table 3. Rules for the conversion of land and space types.

	Production Space Priority Scenario									Living Space Priority Scenario									Eco-Spatial Priority Scenario									Homeland Space Priority Scenario								
Code	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	i
a	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1	1	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0
b	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	1	0	0	1	0	0	0	0
c	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
d	1	1	1	1	1	0	0	1	1	0	0	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	1	1	1	0	0	0
e	1	1	1	0	1	0	0	1	1	0	1	1	1	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
f	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	0	1	1	0	0	1	0	1	1	0	1	1	0	1	1	0	1	1	0	1	1
g	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
i	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Table 4. Neighborhood weight parameters.

Homeland Space Type	Town Living Space	Industrial and Mining Production Space	Forestry Ecology Space	Pastoral Ecology Space	Rural Living Space	Agricultural Production Space	Other Ecological Space	Wetland Ecology Space	Watershed Ecology Space
Neighborhood weights	0.35	0.08	0.07	0.11	0.05	0.22	0.02	0.02	0.08

3.3. Measurement of the Ecosystem Service Value

The equivalent factor method was used to calculate the ecosystem service value of the lower reaches of the Yellow River. By consulting the Chinese Statistical Yearbook, the Shandong Statistical Yearbook, the Henan Statistical Yearbook, and other relevant materials to obtain data on grain production for each year, grain production was calculated according to the rule of the 1/7 average grain yield market economic value within a unit area. The final grain yield per unit area in the lower reaches of the Yellow River from 1990 to 2015 was 4863.76 kg/hm^2. Taking the average price of wheat, corn, and rice in the study area in 2015 as the actual price of grain, the average unit price of grain was CNY 2.44/kg. Based on the coefficient table of Gaodi et al. [30], and according to the correction coefficient of Formula (1), the economic value of a single equivalent factor was CNY 1692.47/hm^2. According to Equations (2) and (3), the ecological service value coefficient (Table 5) and the ecosystem service value in the lower Yellow River region were calculated.

Table 5. Ecosystem service value coefficient per unit area in the lower reaches of the Yellow River.

Ecosystem Type		Ecosystem Service Value Factor/(CNY·hm^{-2}·a^{-1})		
		Production Space	Living Space	Ecological Space
Supply Services	Food production	3746.76	33.91	5136.96
	Raw material production	830.73	101.72	6967.96
	Water supply	−5865.97	−1339.34	25,142.30
	Subtotal	−1288.48	−1203.71	37,247.23
Reconciliation Services	Gas regulation	3051.66	372.98	24,125.08
	Climate regulation	1576.69	339.07	55,913.23
	Hydrological regulation	5238.69	712.05	264,121.35
	Waste reconciliation	508.61	1051.13	33,178.35
	Subtotal	10,375.65	2475.24	377,338.00
Support Services	Maintaining the soil	1797.09	440.80	28,973.84
	Maintaining biodiversity	610.33	406.89	39,061.27
	Maintaining nutrient circulation	525.56	33.91	2220.93
	Subtotal	2932.99	881.59	70,256.04
Cultural Services	Aesthetic landscape	271.26	169.54	20,768.26
	Subtotal	271.26	169.54	20,768.26
Total		12,291.42	2322.65	505,609.53

The equations are as follows:

$$E_a = 1/7A \times Q \times \frac{Q}{Q_0}, \quad (1)$$

$$VC_i = \sum_{f=1}^{k} EC_{if} \times E_a, \quad (2)$$

$$ESV = \sum_{i=1}^{n} VC_i \times A_i, \quad (3)$$

where E_a is the economic value of a single equivalent factor in the study area (CNY/hm^2), A is the average local food price, Q and Q_0 are the food production per unit area in the study area and nationwide (kg/hm^2), respectively, VC_i is the ecosystem service value per unit area of the ith country space (CNY/hm^2), EC_{if} is the fth ecosystem service value equivalent to the ith country space, A_i is the area of the ith country space (km^2), and ESV is the ecosystem service value of the study area (in billion CNY).

4. Results and Analysis

4.1. Verification of the Accuracy of the Simulation Results

We simulated the geographical data on the area for 2035 under the priority land use scenario using the Kappa coefficient to test the simulation results obtained using the PLUS model and merged existing land use data from 2005 and 2015. The simulation results were compared with the status of the land space during 2015, and the Kappa coefficients and overall accuracy were calculated. The simulation effect of the PLUS model improves when the Kappa coefficient and overall accuracy approach the value 1.0; if the Kappa coefficient is greater than 0.8, the simulation effect is good. The results show that when the sampling rate of the simulation results was 10%, the Kappa coefficient was 0.812 and the overall accuracy was 0.748. The experimental simulation results were satisfactory. To further verify the simulation accuracy of the model, the figure of merit (FoM) [31] coefficient was introduced to compare the accuracy of the PLUS and FLUS models, and the results were 0.2642 and 0.1895, respectively, which shows that the PLUS model can perform better than the FLUS model in simulating land and space changes over a long period of time.

4.2. Analysis of Overall Change Trends

The land spatial prediction results of different scenarios for 2035 were obtained using the PLUS model (see Table 6), and the change in the ecosystem service value in the lower Yellow River from 2005 to 2035 was calculated according to the land spatial data (see Table 7). Compared with the land space situation during 2015, in terms of quantity, in the production space priority scenario, both production space and living space showed a diffusion trend, and the ecological space decreased, with a low growth value of 0.78% in the production space. In the living space priority scenario, the living space showed a large-scale expansion trend, with an increase of 30,471.70 km^2, and the remaining spaces showed a decreasing trend. In the ecological space priority scenario, the ecological space was fully protected, the production space was reduced by 6531.60 km^2, and the expansion of living space was small. The land and space priority scenario presented a relatively balanced situation, where the living space only increased by 1.29%, and the ecological and production space did not fluctuate significantly. The distribution of the various spatial types in the study area changed significantly (Figures 4–7), and the development trend of each space was consistent with the priority conditions of the different scenarios. Living and production spaces were concentrated in the Haihe Plain, Huanghuai Plain, and Shandong hilly areas. Among them, the living space developed in an extended manner based on the 2015 figures, while the production space increased only in the production space priority scenario, and the expansion range was narrow. The ecological space was located in the Taihang Mountains in the west and the Taishan Mountains in the east, which are greatly affected by the surrounding Zhengzhou metropolitan area and the Jinan metropolitan area.

Table 6. Spatial land area changes in the study area for the period 2005–2035.

Year	Scenario	Production Space		Living Space		Ecological Space	
		Area/km^2	Percentage/%	Area/km^2	Percentage/%	Area/km^2	Percentage/%
2005	State of the land space	109,854.20	73.14	20,516.10	13.66	19,835.80	13.21
2015	State of the land space	108,943.20	72.53	24,279.30	16.16	16,983.60	11.31
2035	Production space priority scenario	110,112.90	73.31	27,466.90	18.29	12,626.30	8.41
	Living space priority scenario	106,986.00	71.23	30,471.70	20.29	12,748.40	8.49
	Eco-spatial priority scenario	102,411.60	68.18	25,419.40	16.92	22,375.10	14.90
	Homeland space priority scenario	108,252.30	72.07	26,217.90	17.45	15,735.90	10.48

Table 7. Ecosystem service values by spatial type in the study area for the period 2005–2035.

Year	Scenario	Production Space/Billion	Living Space/Billion	Ecological Space/Billion	Total/Billion
2005	State of the land space	45.01	2.38	83.58	130.97
2015	State of the land space	44.64	2.82	71.55	119.01
2035	Production space priority scenario	45.11	3.19	53.2	101.5
	Living space priority scenario	43.83	3.54	53.71	101.09
	Eco-spatial priority scenario	41.96	2.95	94.28	139.19
	Homeland space priority scenario	44.35	3.04	66.3	113.7

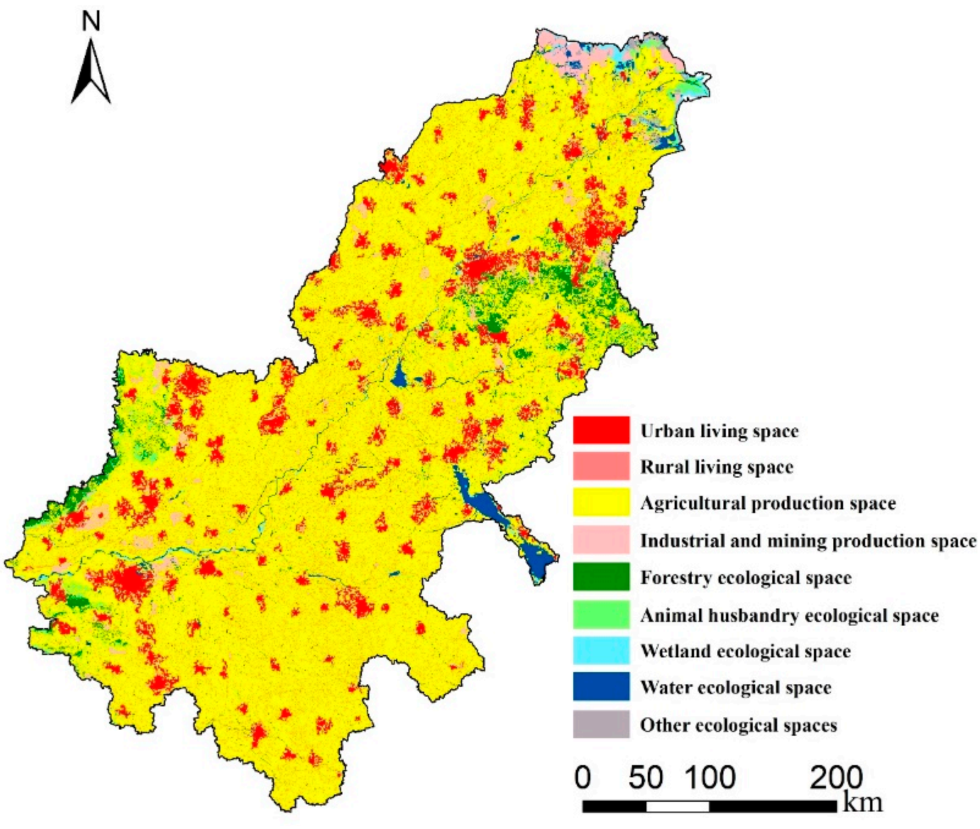


Figure 4. Spatial layout of the production space in 2035.

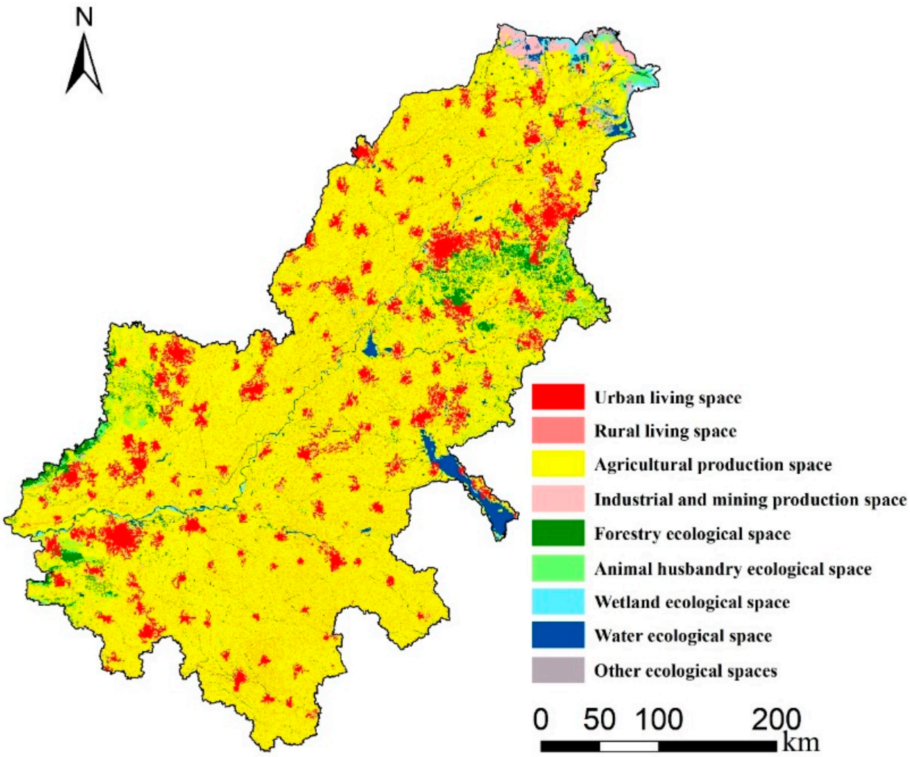


Figure 5. Spatial layout of the living space in 2035.

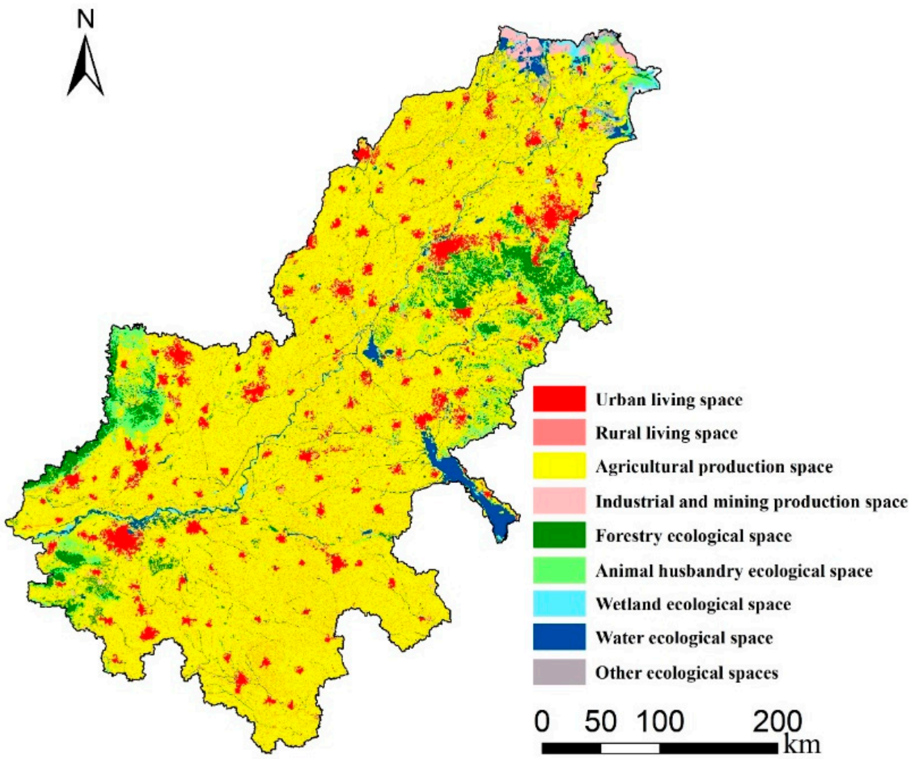


Figure 6. Spatial layout of the ecological space in 2035.

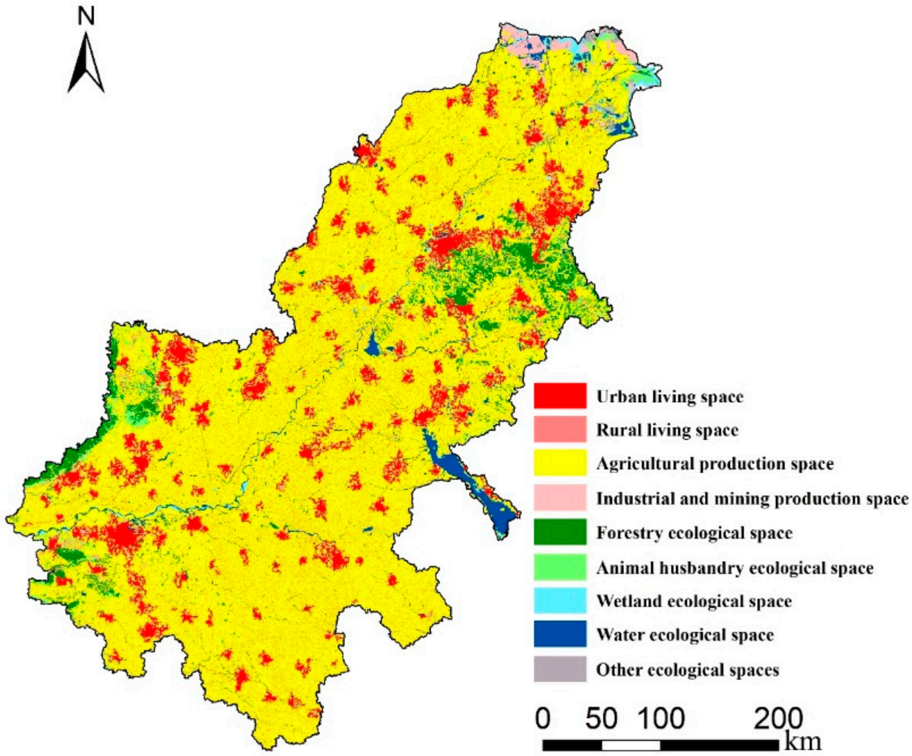


Figure 7. Spatial layout of the territorial space in 2035.

The ecosystem service value (ESV) of the lower Yellow River region decreased by a total of CNY 196 million between 2005 and 2015, according to the data in Table 7. The trend of the change in the value of the ecosystem services from 2015 to 2035 is not the same, with only an approximate increase of CNY 822 million in the ecological space priority scenario and decreases of CNY 2.946, CNY 2.988, and CNY 1.727 billion in the other three types of scenarios, which are projected to become CNY 10.150, CNY 10.109, and CNY 11.370 billion by 2035, respectively, all of which are significantly different from 2005. Simultaneously, as the regional economy develops, the share of living space in the ESV gradually increases, whereas the ESV of the production space and the ecological space only increases in the corresponding priority scenarios and tends to decrease in all other scenarios, with a more balanced result obtained only in the territorial space priority scenario. Comparing the ecosystem service values of different land spatial types, it can be observed that ecological space is the primary pillar of the ecosystem service value in the lower reaches of the Yellow River, followed by production space. These findings echo the important production and ecological functions of the study area. With a reduction in the proportion of production space and ecological space, the overall ESV in the lower reaches of the Yellow River tends to decline and only increases when the expansion of the ecological space is obvious.

4.3. Analysis of Simulation Results for Different Scenarios

4.3.1. Production Space Priority Scenario

To achieve the development of production space, the production space priority scenario is constrained by the protection of industrial, mining, and agricultural production spaces by lowering the cost of converting other spaces into production space and by strictly limiting the conversion of production space into other spaces. Compared with 2015, the study area has grown by 1169.70 km^2 of production space, 3187.60 km^2 of living space, and 4357.30 km^2 of ecological space. With a clear growth trend in the scale of production and living space, the forestry and pastoral ecological space around the Taihang Mountains and the Taishan Mountains in the study area and the ecological space in the waters of Nanyang Lake should be prioritized as the demand for production space increases. Simultaneously, some production spaces around towns have been converted into living spaces to meet the demand for the expansion of living space brought on by economic development (Figure 4). The simulation results suggest that a high level of demand for production space, based on the idea of prioritizing production space, will result in a reduction in ecological space, which is incompatible with the balanced development of the spatial pattern of the national territory.

4.3.2. Living Space Priority Scenario

The living space priority scenario prioritizes meeting human requirements, restricting the transformation of living space into other spaces, and prioritizing the development of living space to ensure that the quality of life of residents is high. In terms of the quantitative structure, the living space in the study area increased from 24,279.30 km^2 to 30,471.70 km^2 while the production space and ecological space decreased by 1957.20 km^2 and 4235.20 km^2, respectively. In terms of the spatial structure, the living space expanded based on the original mosaic layout by the conversion of some of the production space and a large number of ecological spaces. The expansion is more obvious in the plain areas with flat terrain, sufficient water resources, and lush vegetation, especially around the Taihang Mountains and the Taishan Mountains. Simultaneously, to satisfy the growing demand for living space, some of the forestry and pastoral ecological space has been converted to production space, resulting in a decline in both production and ecological space (Figure 5). Overprotection of living space will result in urban limits that do not need to be expanded, an increase in underutilized and low-utility land, damage to the environments that inhabitants live in, a decline in the quality of life of inhabitants, and a negative influence on the region's long-term development.

4.3.3. Ecological Space Priority Scenario

The ecological environment is protected as a constraint in the ecological space priority scenario, and ecological space that has been encroached upon by production and living space is restored to maintain the scale of the ecological reserve, with the conversion of ecological space to other spaces being strictly limited. In terms of the quantitative structure, the production, living, and ecological spaces account for 68.18%, 16.92%, and 14.90%, respectively. Compared with 2015, ecological spaces increase by 3.59%, while production spaces decrease by 4.35%. The ecological space in the study region exhibits an expansion trend in terms of spatial organization. The production space in areas with sufficient water resources around the Taihang Mountains and the Taishan Mountains continues to be converted to ecological space after the needs of living space are met. The ecological space for forestry and animal husbandry is protected, and the ecological space in areas such as Binzhou City and Dongying City develops more rapidly as a result of the implementation of protective policies, such as returning farmland to forest and grassland. The ecological space in the lower reaches of the Yellow River expands greatly in this scenario, while the production space shrinks the most compared with the other three scenarios, and the living space expands the least (Figure 6). As a result, living spaces should be created appropriately on the basis of the development of ecological space, the construction of public service facilities should be enhanced, and national land space planning should be carried out scientifically and reasonably.

4.3.4. Territorial Space Priority Scenario

In the national spatial priority scenario, a dynamic balance between production, living, and ecological space is sought with the objective of the rational use of national space. The coordinated development of national space is achieved by increasing the probability of converting production space, appropriately favoring the development of ecological space, and strengthening the constraints on the development of living space. In terms of the quantitative structure, production space decreases by 690.90 km^2 compared with 2015, living space increases by 1938.60 km^2, and ecological space decreases by 1247.70 km^2, which is basically consistent with the 7:2:1 quantitative structure of the production, living, and ecological spaces that was prevalent in the study area during 2015. In terms of the spatial structure, the territorial spatial priority scenario showed a small reduction in production space and a more efficient layout of living space, with a scale of expansion only higher than that of the ecological spatial priority scenario. Compared with the production space priority scenario and the living space priority scenario, the ecological space near the Taihang Mountains and the Taishan Mountains is reduced to a smaller scale (Figure 7). In terms of the overall pattern, the development of the various spaces in the territorial spatial priority scenario is relatively balanced, but the Zhengzhou and Jinan metropolitan areas and the surrounding living spaces are expanding at a significantly faster rate than other areas, and attention should be paid to the impact of the economic development of the two major urban agglomerations on the surrounding ecological environment to ensure that the development of the territorial spatial pattern has a high level of quality.

5. Discussion

In this study, the PLUS model was used to simulate future territorial spatial development patterns in a territorial spatial priority scenario, taking into account ecological civil construction, arable land conservation, and regional economic development [25–27]. The model not only comprehensively considers the driving factors, such as socio-economic and climatic–environmental factors, but also ensures the multi-objective development of land-use benefits. It has a high degree of applicability for the simulation and prediction of the land space usage distribution in this region, which can help decision-makers coordinate the interests of various parties within the territorial space to ensure sustainable urban economic development [16,19]. The results of this study are basically consistent with those of related studies, which found that the land use pattern of the Yellow River's lower reaches was dominated by arable land with a clearly decreasing trend from 2005 to 2015, and the ESV also exhibited a decreasing trend [32,33]. The simulation results not only show a balance between the demand for economic development and the overall awareness of ecosystem services and arable land conservation strategies, but also correspond better to the current economic development and spatial pattern of the country. Meanwhile, the value of ecosystem services in this scenario, although reduced compared with 2005, shows a more reasonable increase in economic benefits than the other scenarios. Based on the simulation results, and because of the unrecoverable nature of production and ecological spaces, the lower Yellow River region should focus on the hotspots and vulnerable areas of territorial spatial change in the future, strengthen the establishment of measures for the ecological protection of forests around the Taihang Mountains and the Taishan Mountains, establish measures for the ecological protection of the waters of Weishan Lake in the urban cluster of Jining City, focus on the protection and construction of wetlands and other ecological spaces in Binzhou City and Dongying City, integrate ecological concepts into the territorial spatial pattern, and prevent ecological and environmental damage and spatial conflicts caused by the disorderly expansion of living spaces.

Based on different perspectives of land space development, the PLUS model can be used to dynamically simulate the generation and evolution of multiple types of land patches in the future, express and explore the value of ecosystem services in multiple scenarios to identify potential new directions for optimizing the spatial pattern of land usage in the lower reaches of the Yellow River, and consider the future evolution of production, living, and ecological space. In this study, the drivers were selected without considering biological and geological factors, and the conversion rules were based mainly on expert experience, so the differences in drivers and conversion rules may produce some uncertainty in the results. Therefore, in future studies, researchers should comprehensively consider the influence of the natural, geological, and location factors of the study area, predict the spatial development of the study area in a more detailed fashion, improve the accuracy of the model, optimize the evaluation methods to further improve the analysis of ecosystem services, and weigh the relationship between the development and protection of the study area.

6. Conclusions

In this study, we used the PLUS model to forecast the spatial pattern of land usage in 2035 and its impact on the value of ecosystem services from a spatial perspective. The overall accuracy of the simulation was 0.748, indicating that the PLUS model may be used to anticipate the future pattern of land space usage in the lower reaches of the Yellow River.

In terms of the quantitative structure of the simulation results, the production space dominated all spatial types in the lower Yellow River area in the various development scenarios, with a small increase in production space of 0.78% in the production space priority scenario. The largest expansion of production space in the living space priority scenario showed outward development based on a mosaic layout, while the proportion of the other types of space decreased. The national land space priority scenario showed a relatively balanced situation, with a large-scale reduction seen only in production space and the protection of ecological space given priority, resulting in an increase of 3.59 percentage points, totaling 22,375.10 km^2, compared with 2015. The ecological zones around the Taihang Mountains and the Taishan Mountains changed the most in terms of the spatial arrangement and were ecologically the most sensitive. The ecological space around the two metropolitan areas changed significantly because of the rapid expansion of the Zhengzhou metropolitan cluster and the Jinan metropolitan area, which are the core areas of the study area, and all spatial types showed spatial convergence in the various scenarios. Furthermore, from 2005 to 2015, the ESV of all spaces except living spaces decreased, indicating a downward trend. The total ESV increased adequately only in the ecological space priority scenario in the 2035 multi-scenario national spatial simulation, whereas the ESVs of the other three scenarios were all slightly different from the 2005 ESV value. The share of living space in the ESV gradually increased as the regional economy developed, whereas the ESV of the production space and the ecological space only increased in the corresponding priority scenarios and decreased in all other scenarios, resulting in a small but balanced overall state in the territorial space priority scenario. In conclusion, the results of the PLUS model simulation are accurate and can be used to guide future spatial planning and policy formulation in the lower Yellow River region.

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