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Spatio-Temporal Evolution Characteristics, Development Patterns, and Ecological Effects of "Production-Living-Ecological Space" at the City Level in China

Yukun Cao [1,2], Xianqiao Huang [1,2,*], Xiangyue Liu [1,2] and Bo Cao [1,2]

[1] College of Economics and Management, Northeast Forestry University, Harbin 150040, China
[2] Center for Forestry Economics and Management, Northeast Forestry University, Harbin 150000, China
* Correspondence: hxq@nefu.edu.cn; Tel.: +86-451-8219-2205

Abstract: Effective production, living, and ecological space allocation is essential for advancing territorial policy optimization and improving the sustainability of land resource use. Based on the theory of the "production-living-ecological" space (PLES), the present study uses the spatial transfer matrix model, the coupling degree model, and ecosystem service value measurement to analyze the changes in the number and structural characteristics of the PLES and the evolution pattern of development in 336 cities in China from 2000 to 2020 and to evaluate the resulting ecological effects. The results are as follows: the living space is growing; the agricultural production space is decreasing; and the ecological space has been decreasing and then increasing. The evolution of the city space structure has five distinct patterns of development. Cities in the southeast with high urbanization rates have shifted from the pure economic expansion development pattern to the coordinated diversified development pattern. In contrast, the cities in the northeast and northwest, where ecological space accounts for an absolute proportion, still prefer the economic expansion development pattern. There is still a struggle between the "impulse of local development" and the "objective of central coordination". The development patterns of ecological protection and the coordinated diversified development patterns have higher ecological effects among the five development approaches, confirming the effectiveness of the territorial spatial planning policy under the coordinated development objective. Meanwhile, the optimization of future spatial planning policies should consider not only the rational allocation of space but also the quality development of space.

Keywords: land use allocation; the "production-living-ecological" space (PLES); development pattern; ecological effects; spatial optimization

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1. Introduction

China's land use has a long history of spatial evolution; its development priority has shifted from economic development to urban and rural construction to ecological conservation, and the "production-living-ecological" space (PLES) structure has undergone significant change [1,2]. With the development of urbanization, the contradiction of an imbalance in the structural configuration of land for production space (PS), living space (LS), and ecological space (ES) has become prominent, resulting in the continuous deterioration of the ecological environment [3,4]. Meanwhile, the hierarchical structure of China's spatial planning system and the conflict between the central government's land development allocation model and local development needs make the system vulnerable to spatial mismatch and regional development disorder. Incomplete numbers indicate that there are 83 different types of plans and that there is a severe issue with "many conflicting plans" that hinders the execution of spatial policies [5,6]. The Chinese government has proposed the objective of "building the production space that is intensive and efficient, the living space that is livable and appropriate, and an ecological space that is beautiful and unspoiled" through the thorough construction of an ecological civilization in an effort to address these issues [7]. The Chinese government has also established a unified national territory spatial planning (NTSP) system that incorporates multiple regulations in the hope of achieving efficient and reasonable allocation of national resources [8].

Effective PLES identification is a need for achieving a fair allocation of the PLES. Clarifying the space's definition and classifying it are the first two steps in this process. Chinese scholars developed the PLES concept, which has been used to examine territorial spatial planning. The idea was inspired by the multifunctionality of land notion [9]. The theory of land multifunctionality first appeared in agricultural research, where an interdisciplinary research project was designed to verify the "sustainability" and "multifunctionality" of agriculture [10]. It was later extended to land with multiple social, economic, and environmental functions, and the EU Sixth Framework Project "Sustainability Impact Assessment: Tools for Environmental Social and Economic Effects of Multifunctional Land Use in Europe Regions" (SENSOR) formally proposed a conceptual framework for land multifunctionality [11,12]. There are two main approaches to classifying spaces based on the multiple functions of land. On the one hand, from the perspective of the dominant function of land, the land classification system of the PLES is constructed by refining the land classification criteria [13]. Different study scales classify land use differently in PLES, with the classification of living space and producing space showing the most variation, but they all stress how crucial it is to define ecological space precisely [14,15]. On the other hand, a multi-source data index system was constructed to identify the functions of the PLES by selecting indicators such as total labor productivity, urbanization rate of the resident population, and per capita water ownership [16,17]. Currently, it is common practice to identify the spatial functions of a country's territory using a multi-source data index system; however, due to the difficulty of accessing data sources, this method cannot evaluate the functional evolution of long time series [18], and the evaluation index system of regional main function judgment, although it takes into account natural resource elements and demographic and socio-economic elements, mostly relies on the statistical results of indicators within administrative districts, ignoring the importance of the influence of spatial structure on regional functions [19,20].

The evolutionary process of land space is a spatial mapping of the coupled human–land relationship in the study region. Additionally, the quantitative and spatial redistribution of land resources among functions is a dynamic game involving regional economic, social, and environmental resources [21] that, in the end, reflects linkages such as trade-offs and synergies [22,23]. The convergence of land use types in the PLES has directly resulted in this situation. Policy, in turn, has a significant impact on how land resources are allocated based on function. Government intervention and regulation of resource allocation are typical occurrences in China's institutional system, particularly in the allocation of land resources [5]. For instance, the Chinese government has improved PS and LS expansion in the central and western regions by putting Western Development Strategy into practice; however, this necessitates an increase in the ecological land area through protection projects such as the Grain-for-Green Project and the Natural Forest Protection Project. The compromise and cooperation between the PLES's functions ultimately lead to the development direction of the city.

The current research on the function of the PLES and its trade-offs and synergy in spatial and temporal dimensions is primarily focused on the coupling and coordination relationship between the "space" function within the research unit [24] and the difference in the coupling and coordination levels of different research units [20]. The coupling characteristics, distribution characteristics, spatial and temporal characteristics, and influencing factors among the PLES functions within the study area were investigated by building an evaluation index system for spatial functions using the coupling coordination degree model and the gray correlation degree model [25,26]. However, due to the differences in function definition standards, research scales, and the inconsistency of evaluation index systems, the currently constructed PLES function evaluation index systems are not uniform [17], and the logic behind regional function judgments ignores the current situation of territorial spatial development and protection [27]. At the research scale, provinces [28], cities (urban clusters) [29], and counties [30] are involved, but the larger the administrative unit at the macroscopic scale, the more pronounced the functional differences within the region. The spatial function determination with a single administrative unit of a county often results in functional bias, and it is also difficult to provide support for promoting regional economic development and guiding the efficient development of population clusters [27]. Therefore, there is a lack of different regions at different levels of the research scale and a lack of systematic research on the differential characteristics of spatial-temporal evolution at the local and municipal levels as well as attention to the overall spatial integration and regional land use conflicts.

The ecological environment effect has received more attention as territorial space function has developed. Exploring the impact of urban land use change on ecosystem service value has important practical significance for identifying urban regional ecological environment status and optimizing territorial spatial patterns [28,31]. Current research assesses ecological effects by measuring indicators such as the ecological quality index [32], ecological contribution ratio [33], and ecosystem service value [34]. The first two respond to environmental quality better, while the latter can more accurately reflect the worth of spatial functions. Ecosystem service value assessment is considered a powerful tool to facilitate spatial management and land use optimization [35]. There are many ways to measure the value of ecosystem services, and ecosystem functions and services in China were estimated by using Costanza et al.'s classification and economic parameters [36] based on Gaodi Xie's equivalence factor method [37]. Fewer studies have used the value of ecosystem services as an assessment tool to determine the scope of the ecological effects of various spatial development patterns, despite the fact that there is an expanding body of research on measuring and analyzing the factors that influence the value of ecosystem services. Therefore, this paper analyzes the spatial and temporal evolution characteristics of the PLES at the scale of 336 prefecture-level cities from 2000 to 2020 according to the classification identification of the PLES functions. We first obtain the development patterns of the PLES based on the coupling degree model and then calculate the value of ecosystem services under different urban space development patterns to provide decision-making suggestions for future territorial spatial planning policies in spatial layout and function optimization.

2. Materials and Methods

2.1. Data Source and Processing

2.1.1. Data Source and Study Area

The study area was the major cities in mainland China, with prefecture-level cities as the study unit, including 336 prefecture-level cities, regions, autonomous regions, and municipalities directly under the central government (Figure 1). Due to data acquisition reasons, Taiwan, Hong Kong, Macao, and Sansha City in Hainan Province were not included in the study.

The data for the natural resources category included city boundary data and land use data of mainland China. City boundary data were downloaded from the National Geographic Information Center of China (http://ngcc.sbsm.gov.cn, accessed on 18 January 2022). Land use/cover data were obtained from the European Space Agency's (ESA) CCI-LC project (http://maps.elie.ucl.ac.be/CCI/viewer/index.php, accessed on 10 June 2021) [38] that uses the CCI-LC dataset containing two versions due to the long-term continuous time-series nature of the sample. The land use data atlas (2000–2015) uses version 2.0.7, and the land use data atlas (2016–2020) uses version 2.1.1. Both versions were produced with the same processing chain, with a spatial resolution of 300 m and a temporal resolution of 1 year.

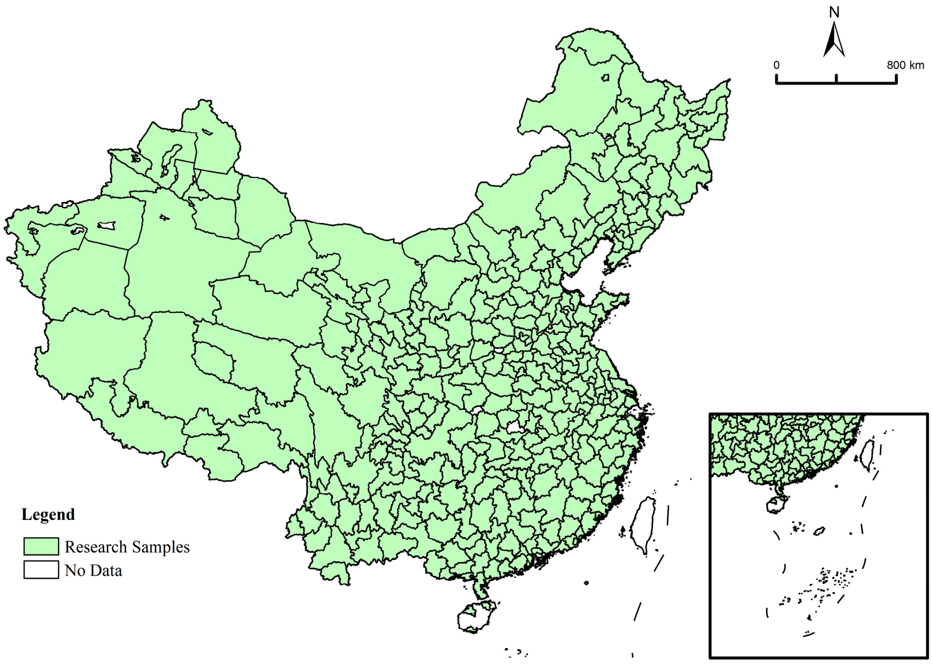

Figure 1. Distribution of the sample cities.

The economic and social data were obtained from the China Statistical Yearbook, the National compilation of agricultural cost-benefit information, provincial statistical yearbooks, and the official website of the National Bureau of Statistics (https://data.stats.gov.cn, accessed on 18 January 2022). The main sown areas and unit area production of rice, wheat, and corn for each year nationwide and by the province as well as the consumer price index for residents were obtained from the China Statistical Yearbook (2001–2021), and the average prices of rice, wheat, and corn for each year in each region nationwide were obtained from the National Compilation of Costs and Benefits of Agricultural Products (2001–2021).

2.1.2. Data Processing

Reclassification of land use types was performed under the definition of the PLES. Seven land cover types, including arable land, urban land, and forest land, were reclassified in terms of their functional dominance. The ES refers to the national land space with natural attributes and the main function of providing ecological services or ecological products, including various ecological elements such as forests, grasslands, and wetlands. The LS is the space used for people's daily life activities, and the PS is the specific functional area where people carry out production activities [15]. In the further classification criteria of secondary space, we refer to the study of Ziyan Ling et al. [15,29]. We further divided the PLES index system into agricultural PS, urban LS, and ES. It was improved according to the "three zones and three lines" (ecological red line, urban development boundary, and basic farmland protection red line) proposed by the Chinese government, and the division of agricultural space, urban space, and ecological space in this system can fit well with ESA's land classification standards. The spatially specific land use types are based on the classification of land cover data provided by ESA [39] (Table 1). In addition, although the CAS statistics cover industrial and mining construction land and rural living land, it is difficult to analyze the spatial evolution pattern under long time series due to the limited time-series data. In the work of spatial classification corresponding to land cover data, urban space and rural settlements were included in the LS according to ESA's land classification standards [39,40].

Table 1. The production–living–ecological space classification of Chinese cities corresponding to the land cover categories.

Classification of PLES	Space Secondary Classification	The Number of PLES	Land Cover Type	Specific Categories	Land Data Code
Production space (PS)	Agricultural production space	1	Cropland	Rain-fed cropland (dry land)	10
				Irrigated or post-flooding cropland (paddy field)	20
				Mosaic cropland and natural vegetation	30, 40
Living Space (LS)	Living Space	2	Built-up land	Urban	190
Ecological Space (ES)	Forestry Ecological Space	3	Forest land	Coniferous Forest	70, 80
				Mixed Coniferous Forest	90
				Broadleaf Forest	50, 60
				Shrubland	120
				Mixed forest land	100
				Mangrove Forest	160, 170
	Grassland Ecological Space	4	Grassland	Grassland	130
				Mosaic herbaceous cover (>50%) Land	110
				Lichens and mosses	140
	Wetland Ecological Space	5	Wetland	Wetland	180
	Other Ecological Spaces	6	Desert	Sparse vegetation	150
				Bare areas	200
	Water ecological space	7	Water area	Water bodies	210
				Permanent snow and ice	220

2.2. Methods

2.2.1. PLES Transfer Matrix Model

The PLES transfer matrix model refers to the land use transfer matrix model based on the functions of the PS, LS, and ES, and the model portrays the quantitative relationship between the three spatial types of conversion. The net conversion area is the difference between the area of two different types of spaces that are interconverted, and the positive or negative value of the difference reflects the final direction of transformation between two of the three types of PS, LS, and ES within the study area. For the PLES, this means that the direction of transformation can be unidirectional or multidirectional. The PLES transfer matrix and the net conversion area can reveal the characteristics of the changing spatial pattern of each city in a given period [28,41]. The logical diagram of the PLES transfer matrix model is shown in Figure 2.

The PLES transfer matrix is given by

$$F_{ij} = \begin{bmatrix} f_{11} & f_{12} & \dots & f_{1n} \\ f_{21} & f_{22} & \dots & f_{2n} \\ \dots & \dots & \dots & \dots \\ f_{n1} & f_{n2} & \dots & f_{nn} \end{bmatrix} \quad (1)$$

where F_{ij} is the area of the space type i at the beginning of the period that is transformed into the space type j at the end of the period; n is the number of space types, and according to the number of space types in PLES, the value of n is taken as 3.

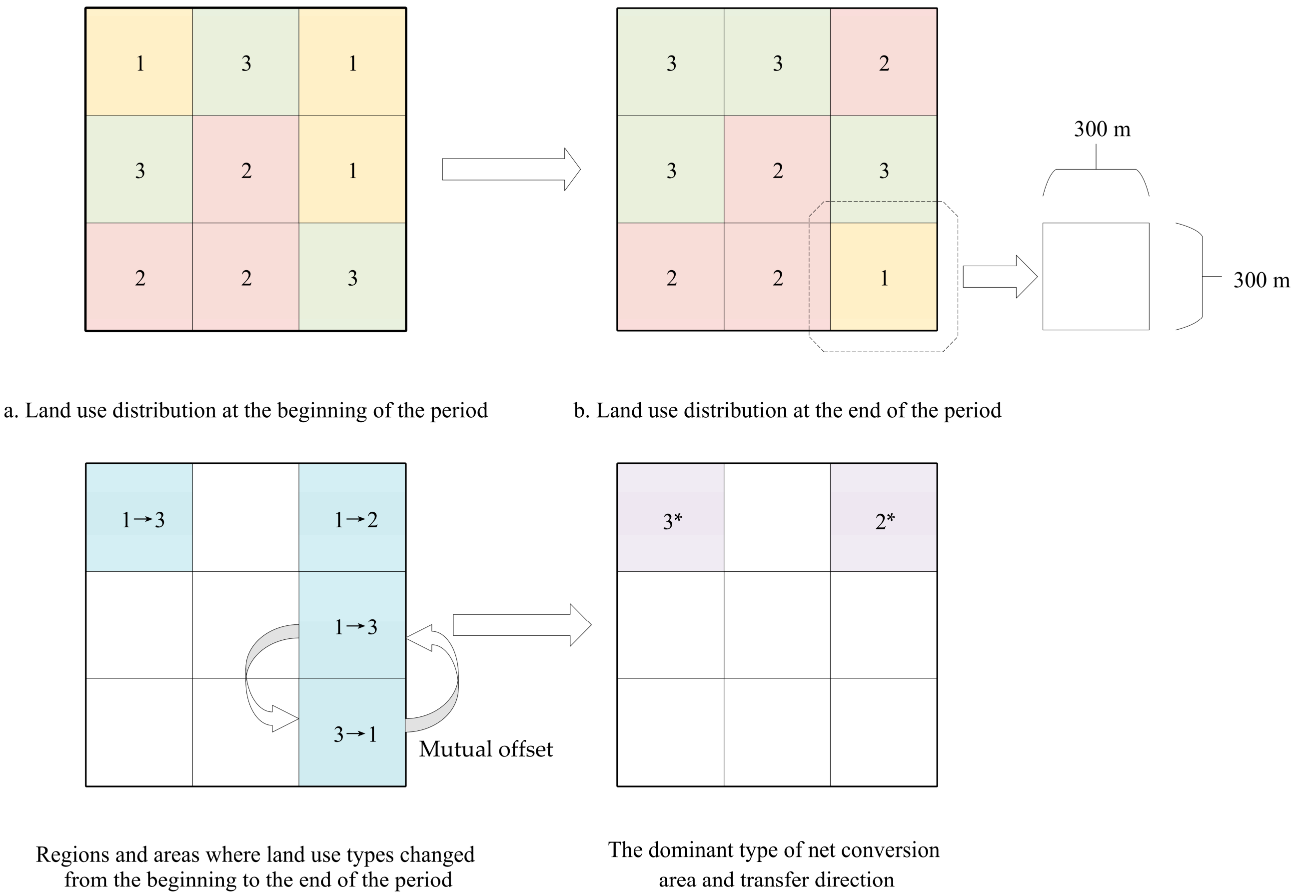

Figure 2. Logical diagram of the PLES transfer matrix model. Note: 1, 2, and 3 denote three different types of land. The"→" shows that the land's land type has changed. The"1→2" denotes that the land type changed from 1 to 2 at the end of the period. The "*" denotes the conversion area, and the number denotes the final conversion direction of the land type.

The equations of the net conversion area of the PLES are as follows:

$$F_{i.j} = f_{ji} - f_{ij} \tag{2}$$

$$F_i = \begin{cases} 0, F_{i.j} < 0 \\ F_{i.j}, F_{i.j} \geq 0 \end{cases} \tag{3}$$

$$F_j = \begin{cases} |\ F_{i.j}\ |, F_{i.j} < 0 \\ 0, F_{i.j} \geq 0 \end{cases} \tag{4}$$

where f_{ji} is the area transferred from spatial type j to spatial type i; f_{ij} is the area transferred from spatial type i to spatial type j; and $F_{i.j}$ is the difference of the converted area between spatial type i and j, which is the net converted area of spatial type i and j. When $F_{i.j} > 0$, this means that the conversion result between spatial type i and j in the study area is a larger area converted from j to i. The direction of spatial structure development in this area is dominated by type i. At this time, the net conversion area between spatial type i and j is F_i, and F_i refers to the net conversion area converted to type i. When $F_{i.j} < 0$, the conversion between spatial types i and j is larger than for conversion to j. The direction of spatial structure development in the region is dominated by type j, and the net spatial conversion area is F_j.

2.2.2. PLES Coupling Degree Model

The PLES coupling degree model is based on the concept of coupling degree in physics and is chosen to quantitatively analyze the coupling interaction between the functions of the PLES in the city. The process of spatial redistribution of the functions of the PLES (in terms of the net conversion area between spaces in spatial structure) and the strength of the interconversion relationship can further reflect the trade-offs and decision-making results of cities in terms of economic development and ecological conservation-oriented development and thus summarize the similarities and differences of urban spatial development approaches [24]. Since this study focuses more on analyzing the interaction between economic functions dominated by the PS and the LS ($F_1 + F_2$) and ecological functions dominated by the ES (F_3) in regional development, the following coupled coordination model was constructed based on the above principles, and different development patterns and characteristics are classified according to the value of the coupling coordination degree S.

The PLES coupling degree model can be expressed as follows:

$$S = 2 \times \sqrt[2]{(F_1+F_2) \times F_3} \; / \; [(F_1+F_2)+F_3] \quad (5)$$

where F_1 represents the net transfer area of the PS in the PLES of the city during the study period; F_2 represents the net transfer area of the LS; and F_3 represents the net transfer area of the ES. S is the coupling degree, a value between 0 and 1. When S = 1, the coupling degree is maximal; the system reaches a high level of coordinated development between the elements within the system, and the system tends to develop in a coordinated manner. In contrast, when S = 0, the system will tend to develop in an uncoordinated manner [42].

The urban development patterns characterized by different coupling degree values are shown in Table 2.

Table 2. Characteristics of development patterns under different coupling degree values.

The PLES Coupling Degree	Assessment	Patterns of Development	Characteristics
S = 0	$F_1 + F_2 \neq 0, F_3 = 0$	Pure economic expansion (S1)	The city is in the development mode of economic and urban construction with the reduction of ecological space.
	$F_1 + F_2 = 0, F_3 \neq 0$	Pure ecological protection (S2)	The city has a spatial structure aimed at slowing down the economy and has taken a development approach to ecological restoration and protection with expanded ecological space.
$S \in (0,0.5]$	$(F_1 + F_2) > F_3$	Unbalanced, biased economic expansion (S3)	A diversified approach has been used for the spatial development of the city, where the choice of spatial function is in a dynamic game state, with the economic development function dominating and the ecological function playing a smaller role.
	$(F_1 + F_2) < F_3$	Unbalanced, biased ecological protection (S4)	A diversified approach has been used for the spatial development of the city, where the choice of spatial function is in a dynamic game state, with a greater preference for ecological protection functions and a smaller role for production and living functions.
$S \in (0.5,1]$	-	Coordinated and diversified development pattern (S5)	The three spatial structures of the city are transformed into each other in a more orderly manner and are in a coordinated development pattern that can meet the needs of different subjects.

2.2.3. Ecosystem Service Value (ESV)

The ecological and environmental effects of the PLES can be characterized as the differences in ecosystem services under different coupled and coordinated development approaches, and the rationality of the layout of the PLES can be judged by comparing the differences in ESV growth and growth rates under different patterns for the reference of spatial layout optimization and sustainable use of resources under the construction of an ecological civilization [43,44]. Reviewing the results of Costanza's study [45], Chinese ecologist Gaodi Xie et al. [46,47] developed a table of equivalent weighting factors to measure the value of ecosystem services in China. Compared with the InVEST model and ARIES model, which measure the quality of things [48], the equivalent factor method is more applicable to assessing the value of ecosystem services at regional and global scales [49]. This study used these equivalence factor measures to calculate the value of ecosystem services for 336 cities in China from 2000 to 2020. A standard unit ESV equivalent factor was defined as the ecological service value of 1 hm^2 of farmland food production with an equivalent value of 1. The equivalent factors of other ecosystem types of ecological service values were the magnitude of their contribution relative to the service function of farmland food production [50]. Also, for the value of the standard unit ESV equivalent factor, the magnitude of the factor depends on its location in space, and the value of the unit varies from region to region [37]. The impact of the correction and determination of the equivalent factor on the value of ecosystem services is significant [51]. Therefore, this study revised the ESV coefficients per unit area in different regions by counting the annual grain prices in each province.

The equation for the value of one standard unit of ESV equivalent factor is as follows:

$$C = 1/7 \times P \times Q \tag{6}$$

where C is the value of one standard unit of ESV equivalent factor (CNY/hm^2); P is the average price of grain in each province (CNY/kg); and Q is the yield per unit area of grain in each province (kg/hm^2). The average prices and unit area yields of the three-grain crops of wheat, corn, and rice from 2000 to 2020 can be obtained based on the National Compilation of Costs and Benefits of Agricultural Products (2000–2020). Wheat, corn, and rice are the three major grains in China, and their cultivation areas are distributed in all provinces [52]. Therefore, these three grain crops were chosen as representatives to calculate the value of one standard unit of ESV equivalent factor. To eliminate the impact of price fluctuations on value changes, this study introduced the consumer price index to adjust the average grain price data of each year to the price level of 2000, and the value of one standard unit of ESV equivalent factor in each province of the country in each year was calculated.

The equation of the ESV coefficient per unit area is as follows:

$$C_i = EC_i \times C, i = 1, 2, \ldots, 18 \tag{7}$$

where C_i is the ESV of land use type i per unit area (CNY/hm^2); C is the value of one standard unit of ESV equivalent factor (CNY/hm^2); EC_i is the equivalent value of ecosystem services per unit area, which can be obtained from the equivalence factor table in the research results of Gaodi Xie et al. [46]; and i is the type of land cover, including seven indicators, namely, cropland, urban, forest land, grassland, wetland, desert, and water area. The secondary index contains 18 types of rain-fed cropland, irrigated or post-flooding mosaic cropland, urban area, coniferous forest land, mixed coniferous forest land, broadleaf forest land, shrubland, mixed forest land, mangrove forest land, grassland, mosaic herbaceous cover (>50%) land, lichens and mosses land, wetland, sparse vegetation land, bare areas, water bodies, and permanent snow and ice.

The ESV is given by

$$ESV = \sum_{i=1}^{18} A_i \times Ci,\ i = 1, 2, \ldots, 18 \quad (8)$$

where ESV is the total ecosystem service value (CNY); A_i is the area of land cover type I; C_i is the ESV per unit area of land cover type I (CNY/hm^2); and I is the land cover type.

3. Results

3.1. Evolutionary Characteristics of the PLES

3.1.1. Spatio-Temporal Variation Characteristics of the PLES

After reclassifying the land use types according to the criteria for defining the PLES, the distribution of the PLES in Chinese cities from 2000 to 2020 was assessed (Figure 3) using ArcGIS 10.7, and the ratio of the area of each type of space from 2000 to 2020 was calculated by extracting the data (Table 3).

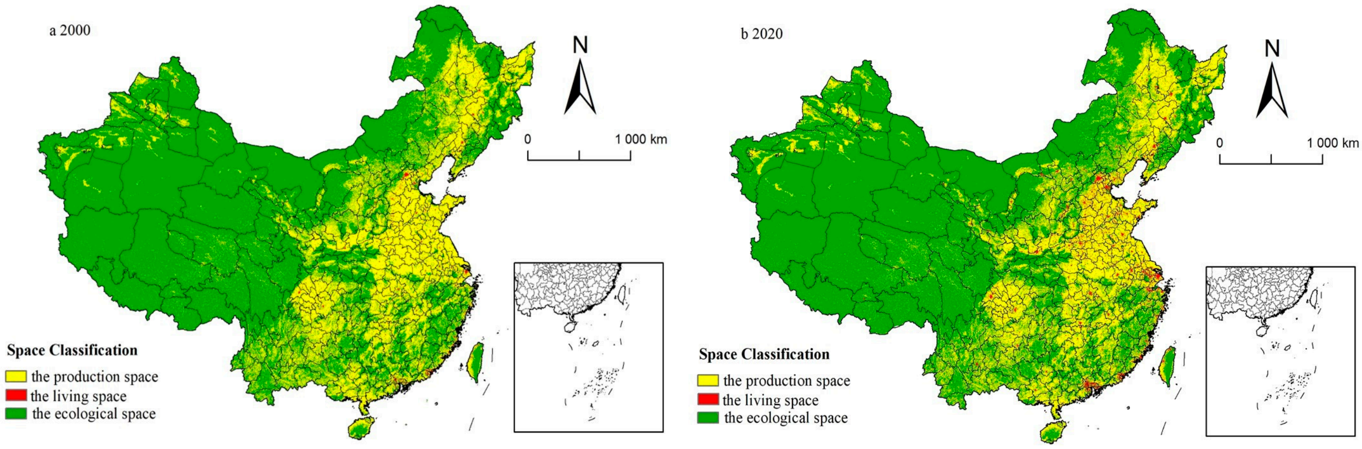

Figure 3. Spatial distribution of PLES from 2000 to 2020.

Table 3. The ratio and shift in each sort of space area in China from 2000 to 2020.

Year	Share of the PS Area (%)	Share of the LS Area (%)	Share of the ES Area (%)
2000	29.031	0.464	70.504
2005	28.905	0.744	70.351
2010	28.879	1.023	70.098
2015	28.697	1.314	69.989
2020	28.298	1.561	70.141
2000–2005	−0.126	0.279	−0.153
2005–2010	−0.026	0.284	−0.253
2010–2015	−0.181	0.287	−0.109
2015–2020	−0.399	0.290	0.152
2000–2020	−0.733	1.097	−0.364

According to time characteristics, from 2000 to 2020, the ES made up the majority of the PLES in China from 2000 to 2020, with the LS making up the smallest portion. The LS was growing as the PS was shrinking. Initial declines in the ES were followed by increases. Additionally, the ES distribution pattern of "high in the west and low in the east" continues to exist. According to the process of national urbanization and industrialization, the LS, particularly the urban LS, is growing; from 0.464% in 2000 to 1.561% in 2020, the area proportion has increased. Between 2000 and 2015, the ES fell, with a 0.515% drop in the proportion. Under the policies of a complete prohibition on commercial cutting of natural forests in 2014 and the creation of China's ecological redline (ER) policy of the NTSP, the proportion increased by 0.152% between 2015 and 2020, and the area of ES was effectively increased. In contrast, the LS has been gradually annexing the PS as a result of urbanization and environmental conservation initiatives such as the Grain-for-Green Project. As a result, the PS's agricultural PS has decreased from 29.031% in 2000 to 28.298% in 2020, a drop of 0.733%.

The PLES's spatial characteristics (Figure 3) demonstrate that there was little change in the PLES's distribution pattern between 2000 and 2020. The principal line separating China's east and west in terms of population density and natural resources is the Hu Line (HL, also known as the Heihe-Tengchong Line). The PS and the LS are mainly situated to the east of the line. The majority of the ES are located west of the line. The LS moves from the focal point outward to the surrounding area over time.

The particular characteristics are as follows: first, the PS (agricultural PS) is consistent with the "seven regions and 23 belts" as the primary agricultural strategy in the functional area planning policy, which is distributed primarily in the cities where the main agricultural production areas are located, such as the Northeast Plain, the Yellow Huaihai Plain, the Yangtze River Basin, the Fenwei Plain, the Hetao Irrigation Area, South China, and Xinjiang. Second, the LS is primarily distributed in the Bohai Rim, the Yangtze River Delta, and the Pearl River Delta regions centered in Beijing, Shanghai, and Guangzhou. The proportion of urban LS is rising in these regions, and it is followed by a dotted distribution in the densely populated areas and provincial capitals. Third, the ES is largely distributed in the major cities in the Qinghai–Tibet Plateau, the Loess Plateau, Northeast China, Southwest China, and the southern hilly region.

3.1.2. Structural Transformation Characteristics of the PLES

The structural transformation of the PLES is reflected in the transformation between the types of PLES, including the quantitative transfer and the final transfer direction. According to Equations (1)–(4) of the transfer matrix model of the PLES in the research methodology, the area of inter-transformation (i.e., the transformation of production space to ecological space and vice versa) and the net transformed area between the three spaces of the national territory in different periods were obtained (Table 4), and a graph was drawn using ArcGIS 10.7 that depicts the transformation between the three functional spaces of Chinese cities from 2000 to 2020 (Figure 4).

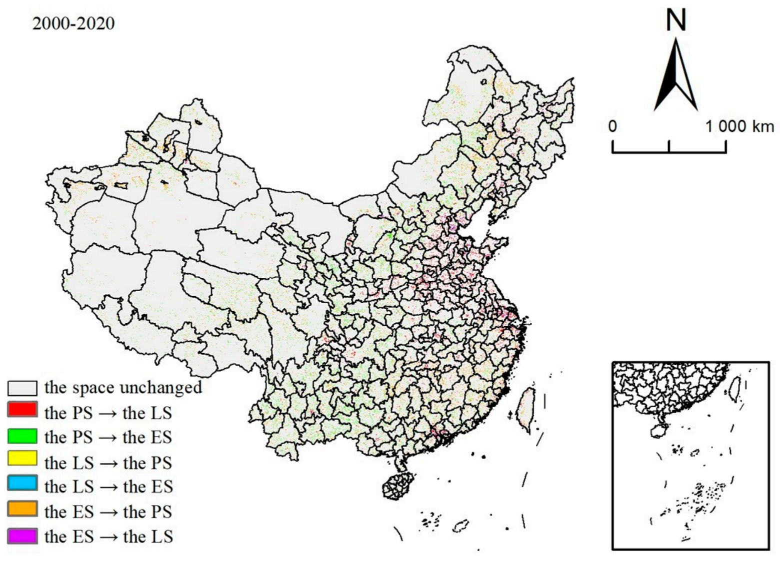

Figure 4. The transformation between the three functional spaces of Chinese cities from 2000 to 2020.

Table 4. Table of the interconversion of the area of the PLES in China.

Period	Type	PS–LS (km^2)	PS–ES (km^2)	LS–ES (km^2)
2000–2020	The former → the latter conversion area (f_{ij})	86,753	206,347	417
	The latter → the former conversion area (f_{ji})	2022	213,164	19,899
	The net conversion area ($F_{i.j}$)	84,731	−6817	−19,482
	Dominant Type	The PS → the LS	The ES → the PS	The ES → the LS
2000–2005	The former → the latter conversion area (f_{ij})	20,588	25,149	0
	The latter → the former conversion area (f_{ji})	0	33,709	6033
	The net conversion area ($F_{i.j}$)	20,588	−8560	−6033
	Dominant Type	The PS → the LS	The ES → the PS	The ES → the LS
2005–2010	The former → the latter conversion area (f_{ij})	22,478	10,444	0
	The latter → the former conversion area (f_{ji})	0	30,407	4187
	The net conversion area ($F_{i.j}$)	22,478	−19,963	−4187
	Dominant Type	The PS → the LS	The ES → the PS	The ES → the LS
2010–2015	The former → the latter conversion area (f_{ij})	24,322	7165	0
	The latter → the former conversion area (f_{ji})	0	14,199	3331
	The net conversion area ($F_{i.j}$)	24,322	−7034	−3331
	Dominant Type	The PS → the LS	The ES → the PS	The ES → the LS
2015–2020	The former → the latter conversion area (f_{ij})	31,480	174,268	1568
	The latter → the former conversion area (f_{ji})	14,023	145,618	7524
	The net conversion area ($F_{i.j}$)	17,457	28,650	−5956
	Dominant Type	The PS → the LS	The PS → the ES	The ES → the LS

In terms of temporal characteristics, the PLES can be quantitatively transformed from one type to another at macroscopic study scales, and the end direction of the spatial structure was from the PS and the ES to the LS. Between the ES and the PS, the ES was more frequently transformed into the PS. Specifically, from 2000 to 2015, the PS and ES were continuously transferred to the LS whereas the LS was not transferred out. The PS occupied a larger portion of the ES. From 2015 to 2020, the PLES types were transferred among each other, but finally, the PS was shrunk and transformed into the ES and LS.

In terms of spatial characteristics, the transition from the PS and the ES to the LS most frequently occurred in the eastern region, while the PS and the ES were interchanged in the central and northwestern regions. First, there has been an increase in the area of urban LS in important cities and provincial capitals such as Beijing, Shanghai, and Guangzhou as well as in the more prosperous provinces of Hebei, Shandong, Jiangsu, and Zhejiang. The top five cities with the highest area of PS converted to LS are Baoding, Hebei (1396 km^2), Shanghai (1330 km^2), Suzhou, Jiangsu (1320 km^2), Linyi, Shandong (1282 km^2), and Cangzhou, Hebei (1216 km^2). The cities with the largest area of ES converted to LS are Tianjin (1014 km^2), Tangshan, Hebei (562 km^2), Baotou, Inner Mongolia (391 km^2), Suzhou, Jiangsu (361 km^2), and Beijing (342 km^2). Second, there is spatial exchange between PS and ES in the same area, meaning that the region that was production space at the beginning of the period transforms into ecological space at its conclusion, while the area that was ecological space at the beginning of the period becomes production space. This spatial shift is focused in less developed and populous regions such as Inner Mongolia, Qinghai Province, Tibet, and Xinjiang Province. The top five cities in the conversion of PS to ES are Hulunbeier City, Inner Mongolia (4712 km^2), Yushu City, Qinghai (4636 km^2), Chifeng, Inner Mongolia (3919 km^2), Naqu City, Tibet (3632 km^2), and Xi'an League, Inner Mongolia (3613 km^2). The top five cities in terms of area converted from ES to PS in descending order are Hulunbeier City, Inner Mongolia (6155 km^2), Chifeng City, Inner Mongolia (4781 km^2), Tongliao City, Inner Mongolia (4727 km^2), Yushu City, Qinghai (4362 km^2), and Xilinguole City, Inner Mongolia (3890 km^2). These cities have a rich resource base, large administrative areas, and most of them are located in ecological function areas. Third, the majority of the cities that have switched from PS to ES are located within the Grain-for-Green Project's application region, including significant cities in the Guangxi, Yunnan, and Shaanxi Provinces.

3.2. Transformation of the City-Level Development Pattern of the PLES

To judge the choice between economic development and ecological protection made by cities under the policy guidance of the NTSP, the spatial distribution and transformation characteristics of the spatial development patterns of cities in different periods were determined according to the coupling degree model. According to Equation (5), the number of cities under different development patterns of the PLES from 2000 to 2020 (Table 5) and the spatial distribution of different development patterns in the four periods (Figure 5) were obtained.

Table 5. Number of cities under different development patterns in the PLES from 2000 to 2020.

Pattern	2000–2005	2005–2010	2010–2015	2015–2020
The pure economic expansion development pattern (S1)	204	217	201	87
The pure ecological protection development pattern (S2)	2	0	1	1
The unbalanced, biased economic expansion development pattern (S3)	29	29	38	35
The unbalanced, biased ecological protection development pattern (S4)	20	4	8	31
The coordinated and diversified development pattern (S5)	81	86	88	182
Total number of cities	336			

In terms of temporal characteristics, the PLES's development pattern changed from the pure economic expansion to the coordinated and diversified pattern between 2000 and 2020. The number of cities with the pure ecological protection development pattern was the lowest, with a maximum of two cities every period. There were only a small number of cities with two imbalanced development patterns—a minimum of 4 and a maximum of 38—and there was little variation in the total number. Prior to 2010, there were 2.5 times as many cities with the pure economic expansion development pattern as there were cities with the coordinated and diversified development pattern. More cities began to follow the coordinated and diversified development pattern after 2010, and the number of cities following this pattern quickly expanded from 88 in the years 2010–2015 to 182 in the years 2015–2020. This marked a substantial shift in the development pattern. This partially reflects the efficacy of the State Council's 2010 policy known as "the Main Function Area Plan".

In terms of spatial characteristics, from 2000 to 2020, the coordinated and diversified development pattern spread and relocated from major cities in the center to the more economically developed regions in the east, while the pure economic expansion development pattern shifted from the east to the central and northwestern regions. The pure ecological protection development pattern and the unbalanced, biased ecological protection development pattern were located in the western regions with larger ES.

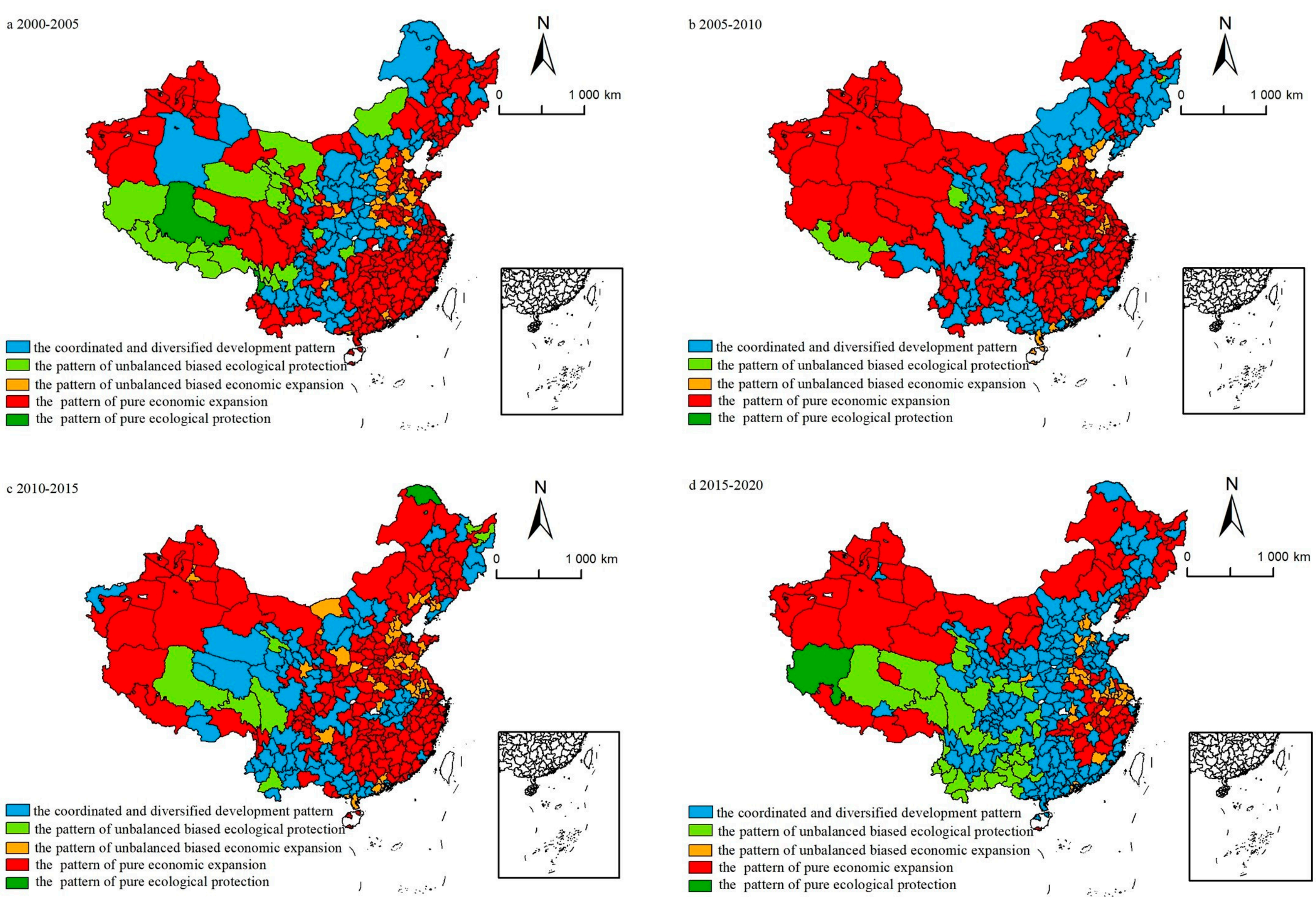

Figure 5. Development patterns of the PLES in different cities from 2000 to 2020.

Specifically, from 2000 to 2005, cities with the pure economic expansion development pattern were more scattered, being concentrated in economically developed cities along the east coast, major cities south of the Yangtze River basin, provincial capitals in the northeast and northwest China, and major cities with high agricultural production. The major cities with the unbalanced, biased economic expansion development pattern were concentrated in four provinces, namely, Hebei, Henan, Shandong, and Xi'an, with the representative cities being Shijiazhuang, Jinan, Zhengzhou, and Xi'an. Most of the cities with the coordinated and diversified development pattern overlap with the "Hu Line". Most of the cities with ecological protection development pattern are concentrated in Inner Mongolia, Gansu, Qinghai, Tibet, and Guangxi Province. The representative cities are Alashan, Zhangye, and Linzhi.

From 2005 to 2010, cities with the pure ecological protection development pattern and those with the unbalanced, biased ecological protection development pattern have been replaced, and the number of cities with the pure economic expansion development pattern has been rising, with a clear trend of increase in the northwest region. The representative cities are Xilinguole, Alashan, Zhangye, and Naqu City. The majority of the cities with the coordinated, diversified development pattern may be found in the provinces of Shanxi, Heilongjiang, Sichuan, Yunnan, and Guangxi. Baise City, Yulin, Xinanmeng, Yichun, and Yuxi are the representative cities. These cities are located in the construction zones for ecological protection projects, and the policy's effect over their development has compelled them to diversify throughout this time.

From 2010 to 2015, cities with the coordinated diversified development pattern began to expand to the southeast, and the coordinated diversified development pattern began to emerge in Jiangxi, Hubei, Anhui, Jiangsu, and Chongqing, represented by cities such as Nanchang, Wuhan, Hefei, and Zhenjiang. Most cities in Yunnan and Guangxi provinces also belong to this development pattern. Several cities in Northeast China where state-owned forest areas are located have shifted to the ecological protection development pattern, and some cities in Yunnan, Sichuan, and Tibet have reverted to the ecological protection development pattern.

From 2015–2020, most of the more economically developed cities in the eastern region began to shift to a coordinated and diversified development pattern, except for some cities in the southeast; most of the northwest and northeast regions remain in the pure economic expansion development pattern, with economic development as the main goal. The number of cities with the pure ecological protection development pattern and the unbalanced, biased economic ecological protection development pattern has increased, becoming concentrated in several provinces such as Guizhou, Guangxi, Yunnan, Tibet, Sichuan, and Qinghai, with representative cities being Zunyi, Baise, Pu'er, Naqu, and the Ali region.

3.3. Evolution Law of Ecological Effects under the Development Pattern of the PLES

Based on the ecological effect of ecosystem service value measurement, the ecosystem service value of each city in each year was calculated using Equations (6)–(8). Based on the different development patterns of the PLES, the average annual growth of ecosystem service value and the average annual growth rate were calculated for all cities under each pattern, and the average annual growth and average annual growth rate of each development pattern in different periods were obtained (Table 6).

Table 6. Mean values of ESV growth and growth rates under different development patterns.

Pattern	Average Annual Growth of ESV (Billion, CNY)				The Average Annual Growth Rate of ESV (%)			
	2000–2005	2005–2010	2010–2015	2015–2020	2000–2005	2005–2010	2010–2015	2015–2020
National average value	13.14	11.15	2.61	–2.78	7.38	7.31	0.89	–0.94
(S1)	12.07	19.38	2.21	–3.21	8.29	7.70	0.80	–0.93
(S2)	109.02	–	12.20	–71.40	8.48	–	0.74	–2.20
(S3)	4.16	7.38	0.60	–3.18	8.03	7.63	0.28	–1.57
(S4)	36.40	41.08	–3.09	–4.74	10.23	8.33	0.62	0.39
(S5)	14.90	21.60	4.78	–1.78	9.32	8.00	1.59	–0.56

To assess their ecological effects, the average annual growth rates for each development pattern and the average annual ESV growth were rated from highest to lowest. Over multiple periods, it was discovered that the unbalanced, biased ecological protection development pattern had the maximum ecological value effect. The coordinated, varied development pattern came next. The lowest positive impact on ecological value was caused by the uneven, biased economic expansion development model. The specific characteristics are as follows.

First, the ecologically constrained development approach and the coordinated diversified development pattern have higher ecological effects among the five development patterns. A comprehensive ranking of the values of ecosystem service value growth and growth rate shows that the coordinated diversified development pattern ranked steadily in the top three for several periods. Among the uncoordinated development patterns, the unbalanced, biased ecological protection development pattern was more often ranked first in ecological effects, and the unbalanced, biased economic expansion development pattern was ranked lowest in several periods. Combined with the evolution pattern of the PLES development patterns of cities from 2000 to 2020 (Table 5), the number of cities under the coordinated diversified development pattern has been increasing to the highest proportion, and the ecological effects provided have had the greatest comprehensive value, reflecting the rationality of the evolutionary direction of the PLES under the NTSP.

Second, there are temporal fluctuations in the ecological effects of different development patterns. Before 2010, the mean ESV growth and growth rates under the two development patterns with ecological protection were ranked in the top two, with the pure economic expansion development pattern ranked next. After 2010, however, the pure economic expansion development pattern ranked second for the period 2010–2015, and the pure ecological protection development pattern ranked fifth for the period 2015–2020, contrary to expectation. The reason for this was that the composition of cities belonging to different development approaches has changed over time. Combining the spatial evolution characteristics of the development patterns of the PLES from 2000 to 2020 (Table 5), before 2010, cities with the pure economic expansion development pattern were mostly in economically developed regions such as Beijing, Shanghai, and Guangzhou. After 2010, the cities that belonged to the pure economic expansion development pattern changed to places such as Yichun City in Heilongjiang Province, Hulunbeier City in Inner Mongolia, and Hami City in Xinjiang that were rich in natural resources but less economically developed.

Third, there are breakpoints in the temporal evolution of ecological effects. Before 2015, the average value of ESV growth volume and growth rate under the five development patterns was positive. In contrast, the average values of ESV growth volume and growth rate were negative for all patterns except for the unbalanced, biased ecological protection development pattern during the period 2015–2020. The national average ESV growth volume decreased from CNY 13.14 billion (2000–2005) to CNY –2.78 million (2015–2020) and the average annual growth rate decreased from 7.38% (2000–2005) to −0.94% (2015–2020). In addition, ES is internally subdivided into several types, including woodland ES, grassland ES, and wetland ES. The amount of ecological effect value that can be assigned to different land types also varies, and the conversion between ESs can lead to fluctuations in ecological effects; for example, during 2015–2020, the city with a single purely ecologically bound development approach was the Ali region of Tibet, where the total ES area increased, but within the ES, grassland ES decreased (by an area of 62,563 km^2), which was converted to other ESs such as a desert (where the area increased by 61,268 km^2), resulting in the loss of ecological effects.

4. Discussion

4.1. Scientific Optimization of Spatial Structure

This study analyzed the spatio-temporal evolutionary characteristics of the layout of the PLES in China under the improved classification system of the PLES. It concluded that LS in China has been expanding from 2000 to 2020, and these findings are consistent with the findings of the existing study by Dongyan Kong et al. [28]. Ecological space shows a trend of first decreasing and then increasing; specifically, after 2015, ES continued to expand, and the ecological attributes of national space were given more attention. Moreover, this study found an overlooked problem, which is the continuous decrease in agricultural PS. China has been in the process of rapid urbanization for the past 20 years, and the living space has been expanding as a result of China’s past economic development. But ensuring urbanization through the continuous expansion of urban living space is an unsustainable approach [53,54]. Environmental protection and food supply are equally important. Arable land resources are related to a country’s food security, especially for developing countries with large populations. In general, China’s agricultural PS faces shrinkage due to the demand for land for urban development and construction and the impact of the environmental protection policy of returning farmland to the forest [55], a result that was effectively verified in this study. Economical and concentrated utilization of land resources is the fundamental strategy for realizing the common development of the social economy and ecosystem service value [53]. While the future territorial spatial planning policy optimizes the goal of promoting the expansion of ES, it should more strictly control the red line of basic farmland protection while paying more attention to the intensive and efficient agricultural land production model and being aware of the country's food security problems.

4.2. Spatial Differences in Development Patterns and Policy Orientation

Exploring development patterns of the city that can promote sustainable development has been a topic of interest in the field of spatial planning, and the last two decades have been a period of development transition and large changes in spatial patterns in China, where the endogenous dynamics of economic development and the external constraints of ecological protection have jointly influenced the spatial development of a city [56,57]. There are clear characteristics of regional differences in urban development patterns, and our results are consistent with the above theoretical expectations. Before the promulgation of China's National Functional Area Plan policy in 2010, most cities in China chose a single development pattern of pure economic expansion, and the transfer of space basically followed the principle of maximum benefit or minimum cost in economics; regardless of the presence or absence of environmental policy intervention, agricultural PS and ES would be transferred to LS with higher economic value, while the probability of transferring LS to other spaces was less [58]. Only under strong environmental protection policy constraints will cities choose to convert agricultural PS to ES; for example, there are more coordinated and diversified development patterns of ecological protection in the cities belonging to the Grain-for-Green Project and the Natural Forest Protection Project areas. Since 2010, the Chinese government has proposed a development strategy of zoning the main functions, delineated a stricter spatial control of the PLES, and put forward the development goals of coordinated spatial development and regional balance. Under this policy guidance, most cities have shifted from the pure/unbalanced biased economic expansion development pattern to the diversified and coordinated development pattern, and the urbanization process in the more developed regions of China has begun to slow down, taking the lead in completing this paradigm shift. However, the game between the "goal of central coordination" and the "impulse of local development" still exists [59]. Under the national macro planning, each region's development and protection are prioritized according to its primary role and resource endowment, while the cities continue to take into account the practical requirements of urban growth while making decisions, a circumstance in which the more economically developed eastern regions begin to raise the ES more as a result of an uptick in public demand for the environment. In the contrast, cities in the ecologically abundant but economically underdeveloped ecological function regions of the northeast and west continue to adopt a shoddy economic expansion model that depends on growing LS and PS because there is insufficient endogenous development momentum in these regions. Therefore, to fundamentally improve the ecological environment, the best path is to complete the upgrade of the development stage as fast as possible to achieve the transformation from resource-driven growth to environmentally friendly quality- and innovation-driven growth [13] and actively explore the asset value of ecological resources and the diversified models of payment for ecosystem services [60]. Promoting the realization of the value of ecological products is an effective path to truly realize a coordinated and diversified development approach.

4.3. Better Increase of Ecological Effects

The issue of concern in the field of spatial planning revolves around the ecological and environmental effects arising from the urban land use process, and it has become an academic consensus to use ESV as a measure of ecological and environmental effects [61,62]. Compared to the existing literature on measuring the value of ecosystem services within cities and between regions and the influencing factors, this paper focuses more on the assessment of the advantages and disadvantages of the ecological effects measured by ecosystem values under different development patterns. Given that the magnitude of ESV is primarily driven by land use cover change and the value per unit area coefficient, the resulting ecological effects reveal some beneficial findings. According to our comparison of the mean values of ESV growth volume and growth rate under the five development patterns, first, the ecological effects of the city under the coordinated and diversified development pattern were able to stabilize at a high level. Moreover, the continuous rapid urban expansion negatively affected the value of ecosystem services [61], and the average annual growth volume and growth rate of ESV under the unbalanced biased economic expansion development pattern in each period were at a low level, as confirmed by our study. Second, we also found that some cities have maintained a high ESV growth and growth rate, despite the purely economic expansion pattern of development over a certain period, i.e., a constant expansion of production and living areas, due to the rich resource base of the city that can guarantee a stable growth of ESVs over a short period, masking to some extent the drawbacks of this pattern. Finally, the pure/unbalanced biased ecological protection development pattern is at a high level most of the time, consistent with the academic consensus that the expansion of ES can have an effective ecological improvement effect. However, our study also found that most of the cities that chose this development pattern had a dominant role in the spatial allocation of ES and the value of ecosystem services does not increase infinitely with the expansion of ES. The marginal ecological benefits generated by the expansion of ES show a law of diminishing returns; this is also related to the scarcity value of ES [63,64]. The process of improving territorial spatial planning policy should not only stay at the level of "restriction and control" but should also play the role of "leading and guiding" via formulating refined development plans according to the differences of regional development, considering the threshold value of ecological effects of regional development, and allowing the reasonable transformation of the internal structure of the PLES within a scientific scope. Furthermore, it is necessary to pay more attention to the improvement of ES quality and enhancement of the ecological effect by increasing the value of ecosystem services per unit area and enhancing the synergy with LS. Furthermore, in contrast to the conclusion that the value of ecosystem services in China is decreasing, as concluded by an existing study [38], our study through the revision of the equivalent factor coefficients concluded that the value of ecosystem services as a whole has shown an increase, despite the decreasing growth rate of ESV.

4.4. Limitations and Further Work

Our study also has some limitations. This is reflected in the following two aspects. First, this study focuses more on the configuration of the primary classification of land functions in the PLES, while the more detailed secondary classifications, such as ES, are also transformed into forest ES and grassland ES, and the layout and transformation between these types also have an impact on the value of ecosystem services. However, for the sake of brevity, this study only provides some descriptive statistical analysis of the interconversion of land functions of secondary classifications in some chapters, and the analysis of the spatial transformation mechanisms between secondary indicators, especially forest ES and other ESs within the ES, and their influencing factors need to be studied more thoroughly in the future. Second, the value of ecosystem services is closely related to biodiversity and ecosystem functions, and it is not easy to quantify and assess the value of ecosystem services accurately. Although this study also revised the equivalence factor coefficients, there are various ways to revise the equivalence factor coefficients in China, and no unified standard has been formed, suggesting that the accuracy of the results needs to be further improved in the future.

5. Conclusions

Spatial development patterns at the city level in China have evolved, with great variance, driven by both the development goal of maximizing benefits and ecological protection policies. The PLESs of cities are progressing toward sustainable development under the direction of territorial spatial planning strategies, but there are still some areas that need to be optimized. The following are the study's main findings.

(1) The area occupied by ES is the greatest and the area occupied by LS is the smallest percentage in terms of the spatial composition and distribution of the PLES. While the ES is concentrated in the western hilly regions, the LS and PS are clustered in the eastern plains. The LS has been growing, the agricultural PS has been declining, and the ES has demonstrated a trend of first dropping and then increasing over the evolution of spatial layout during the previous 20 years. The LS spreads out and encroaches on the PS and ES in the eastern region. Between the PS and the ES, they are switched around spatially in the central and northwest regions.

(2) The regional distribution of the PLES's structural change over time varies greatly. The pure economic growth development pattern is giving way to the coordinated, diversified development pattern in China, and an increasing number of cities are adopting the ecological protection development pattern. The more economically developed eastern cities, particularly the coastal cities in the southeast, take the lead in changing from the pattern of economic expansion to the coordinated diversified development pattern. The economically underdeveloped but environmentally rich cities in the northeast and northwest still support the economic expansion development pattern, despite the fact that they are recognized by national policy guidelines as ecological functioning zones.

(3) There are differences in the ecological effects of different development patterns, with the biased ecological protection development pattern and the coordinated diversified development pattern exerting higher ecological effects among the five development patterns. There are temporal fluctuations in the ecological effects of different development approaches. The mean values of ESV growth and growth rate under all development modes showed decreasing trends, and the ecological effects are influenced not only by the ecological area but also by the quality of ES.

Thus, the protection policies of the red line of basic farmland protection and the red line of ecological protection established by the Chinese government in 2019 should be strictly implemented. Particular attention should be given to the question of decreasing arable land in the future, particularly the further reduction of arable land caused by the expansion of urban boundaries, and concentrating on high-quality urban construction. Cities should focus on the guiding principles of spatial planning policies, support research into methods for recognizing the value of ecological products in resource-rich regions, and advocate for the inherent strength of sustainable development. Policies should not only optimize the allocation among PLESs but also pay more attention to the intensive management of land resources to bring about positive outcomes.

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