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Does Rural Production–Living–Ecological Spaces Have a Preference for Regional Endowments? A Case of Beijing-Tianjin-Hebei, China

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Citation: Zeng, P.; Wu, S.; Sun, Z.; Zhu, Y.; Chen, Y.; Qiao, Z.; Cai, L. Does Rural Production–Living–Ecological Spaces Have a Preference for Regional Endowments? A Case of Beijing-Tianjin-Hebei, China. *Land* **2021**, *10*, 1265. https://doi.org/10.3390/land10111265

Academic Editors: Yurui Li, Baojie He, Ayyoob Sharifi, Chi Feng and Jun Yang

Received: 13 October 2021
Accepted: 16 November 2021
Published: 19 November 2021

Abstract: Production–Living–Ecological Space (PLES) is the functional projection of sustainable development in territory spatial planning. Its rational layout has become the most important task for developing countries to enhance ecological awareness and achieve sustainable goals. This study took the rural areas of Beijing-Tianjin-Hebei (BTH) as an example to analyze the relationship by means of quantitative cumulation between regional endowments (natural factors, location and facilities) and PLES to figure out the preference mechanism. The Boosted Regression Tree model (BRT) was used to obtain the contribution rate of factors and the internal marginal effect between 1980~2018. Our conclusions are as follows: Living space (LS) enjoyed the highest advantage of regional endowment level, followed by production space (PS). Except for the distance to water, other indicators were significantly different in the PLES, and the suitable range of various types was expanded from LS to PS and ecological space (ES). During the transfer, elevation had a universal effect. The process of increasing naturalness was affected by the distance of high-level urban areas, which verified the continuous effect of Chinese ecological civilization. This study clarified the selectivity of regional endowments to PLES, which will greatly guide the direction of regional territory spatial planning and the next step of regional sustainable development.

Keywords: rural Production–Living–Ecological Space (PLES); regional endowments; quantitative accumulation curve; Boosted Regression Tree model (BRT); Beijing-Tianjin-Hebei (BTH)

1. Introduction

Sustainable development has been the common goal pursued by all countries in the world [1,2]. Since the "World Outline for Natural Resources Protection" in 1980, economy, society and ecology had been taken as the pillars for applications [3,4]. Chinese Land Use Planning in 2008 proposed a classification system for production land, living land and ecological land, corresponding to the three pillars of sustainable development. Three land types carry economic, social and ecological activities respectively. Later, it was officially revised as Production-Living-Ecological Space (PLES) including production space (PS), living space (LS) and ecological space (ES) in the 18th National Congress of the Communist Party of China in 2012. PS is for providing products, including agricultural production and industrial and mining production. LS is for residents' daily activities, and ES is for providing ecological products and services [5]. So far, territory spatial planning finished the transition to a sustainable structure. PLES planning had become an important part of planning practice, and the rationality and scientific nature of its landscape had become one of the basic principles [6,7].

In the past decade, most studies have cared more about the application of a PLES pattern, such as coupling coordination and conflict evaluation based on current distribution. Yang et al. established an index system to evaluate the PLES function relationship in rural areas of the Beijing-Tianjin-Hebei region [8]. Zou et al. analyzed land-use conflicts in the southeastern coastal areas of China from the perspective of PLES classification [9]. Kong et al. quantitatively evaluated the protection and survival of traditional villages based on the PLES healthy relationship [10]. Jing et al. identified PLES conflicts through a multi-objective suitability evaluation [11]. Other research focused on the functional strength of PLES from land-use versatility. Xie et al. established the PLES zoning method based on the functional symbiosis theory and applied it in Henan Province, China [12]. Duan et al. analyzed the evolution of PLES from the perspective of villagers' behavior [13]. Peng et al. measured the multi-functional value of land use and proposed a spatial classification method [14]. Tao et al. quantitatively identified the evolution process of PLES characteristics in resource-based cities [15]. It was not difficult to find that the application of PLES had formed a complete framework, and a large number of studies had appeared. But what cannot be ignored is that, as a planning item, PLES is the spatial carrier of functional activities. The selection of spatial functions should conform to the basic rules of the regional endowments. Existing studies did not pay attention to it, which resulted in the failure to reflect the practical value of related planning. Therefore, in order to make up for the above-mentioned deficiencies, the endowments preferences of PLES should be investigated to figure out the local rules for scientific territory spatial planning.

Many studies in related fields provided methodological references. In research of soil and water cycles, Pearson's correlation coefficient is often used for potential laws such as land use and carbon emissions, topography and precipitation [16–18]. In land research, the KAPPA index is often used to monitor land-use changes and evaluate the accuracy of remote sensing classification [19–22]. It can also be used to judge the correlation between the sample and the whole. In addition, Spearman's correlation coefficient is used to analyze the significance and applicability of spatial heterogeneity indicators in the study of land-use landscape patterns [18,23–26]. The above studies provide a reliable method set but the methods cannot reflect the correlation differences caused by the changes in index levels. The accumulation curve, which is commonly used in soil science [27], fits the aim of this research well. This method was originally used for the overall change process of soil structure when soil particle size changed gradually. It was later introduced by other disciplines, resulting in the innovative application of the Pareto curve [28]. Besides this, in order to explore the impact mechanism, regression models are also necessary. Traditional regression methods pay too much attention to the explanatory function and strictly reject the correlation between independent variables [29]. Meanwhile, it is difficult to distinguish the importance of independent variables. The Boosted Regression Tree (BRT) model could perfectly solve the above problems. It is a self-learning machine learning method wthathas a high tolerance for the correlation of independent variables and can clearly represent the contribution difference and horizontal marginal effect of independent variables. Therefore, the BRT model can provide methodological support for this study.

The subsequent chapters are as follows: Section 2 describes the data, methods and research area. Section 3 shows the calculation results, including the quantity and pattern characteristics of PLES in the study area, spatial cumulative scale curve of each factor and BRT model results, etc. Section 4 discusses and analyzes the shortcomings based on the results, and Section 5 summarizes the research conclusions.

2. Materials and Methods

2.1. Study Area

The study area (113°11′ E–119°45′ E, 36°05′ N–42°37′ N, Figure 1) includes Beijing, Tianjin, and Hebei province, which consists of thirteen cities. The area is one of the biggest urban agglomerations in China. It covers an area of 216,677.95 km^2, with a permanent population of 11,034,000 by the end of 2018, including 668 subdistricts and 2279 towns and townships (from the 2019 County Statistical Yearbook). In this study, rural area is the collection of towns and townships in the BTH, with a total area of 205,141.89 km^2, accounting for 94.68% of the total. The characteristics of regional endowment in the study area are complex and diverse. It consists of a terrain combination of Taihang Mountain in the northwest and North China Plain in the central and southern region. Additionally, Tianjin is adjacent to the Bohai Sea, connecting inland areas and Marine port resources. Since the reform and opening up, the BTH has been the fastest developing region in north China, with significant territorial space changes. Especially influenced by the capital as center, it is the first to undertake the requirements of national strategies and policies. Moreover, influenced by economic status, there have been hierarchical structures formed in the capital as well as in municipalities, provinces, cities, districts and subdistricts on behalf of the urban grade system. The order has constituted the different radiation to rural space. The attraction from urban systems has become one of the most important endowments in study area.

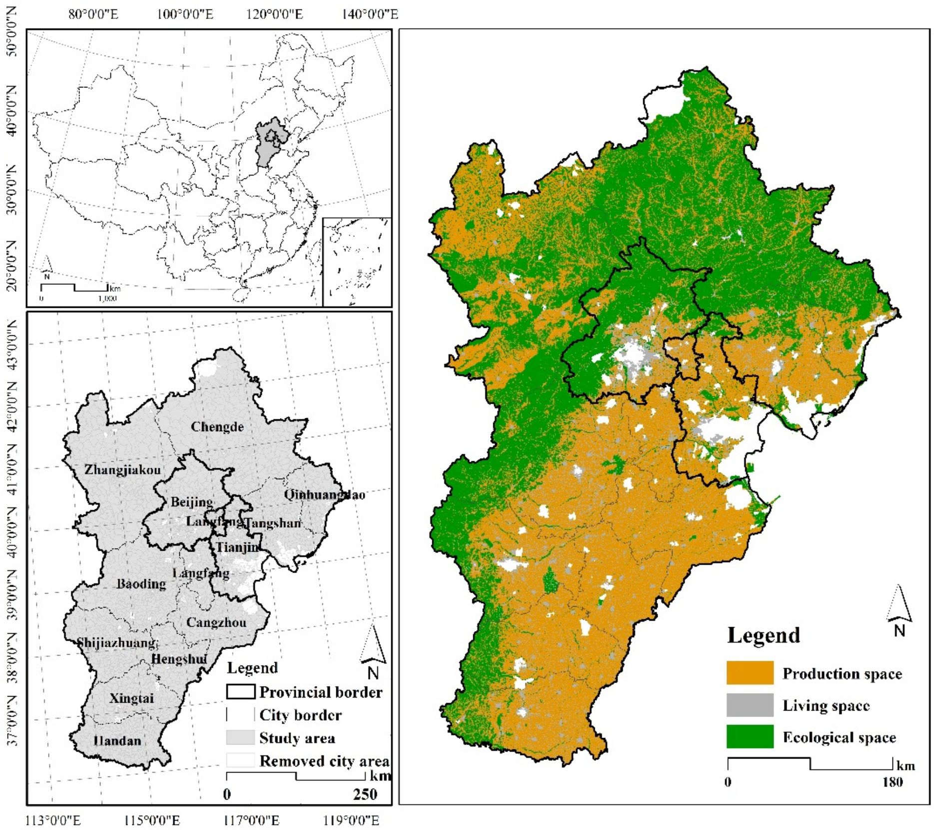


Figure 1. Research area of Beijing-Tianjin-Hebei region.

2.2. Data Source

PLES dataset in this study was from 1:100,000 scale land use database of China Academy of Sciences (http://www.resdc.cn/, accessed on 1 September 2021) [30–33]. The dataset was conducted by Resources and Environment Research Center, Institute of Geography, Chinese Academy of Sciences. It was based on Landsat long-time series remote-sensing images as the main data source and generated through human–computer interaction visual remote-sensing interpretation. Land use types include 6 primary types (cultivated land, forest land, grassland, water area, residential land and unused land) and 25 secondary types. Through verification and analysis of a large number of samples, the comprehensive assessment accuracy of first level in China reached over 94.3%, which met the mapping accuracy requirements of 1:100,000 scale users [34]. This data has been widely used in the study of land use, which has advantages in time span and data consistency and can be used for land-use changes in long time series.

Besides this, endowment factors include three types: natural characteristics, location characteristics and facility characteristics. Natural features included elevation, topographic relief and the distance to water. Elevation and relief intensity index were measured by Digital Elevation Model (DEM, GDEM_V2_30 m), which was obtained from geospatial data cloud (http://www.gscloud.cn/, accessed on 3 September 2021). Water surface includes level 1, 3, 4 and 5 rivers and lakes, which was obtained from National Catalogue Service for Geographic Information (https://www.webmap.cn/, accessed on 1 September 2021), 1:250,000 National basic Geographic database. Location characteristics include three indexes: distance to the nearest subdistrict, city and capital. Original data was the border shapefile of towns and subdistricts, which was obtained from the Data Center for Resources and Environmental Sciences, China Academy of Sciences (https://www.resdc.cn/, accessed on 1 September 2021). Rural areas and urban areas can be clearly distinguished by unit types. Three location indexes represented the urban attractiveness from low to high. Facility characteristics were described by the distance to interchanges and roads. The distribution of interchanges and roads were acquired from TiandiMap (https://www.tianditu.gov.cn/, accessed on 5 September 2021) and AMap open platform (https://lbs.amap.com/, accessed on 5 September 2021). All distance indices were manipulated through the path distance tool in ArcGIS 10.3 (https://www.esri.com/en-us/arcgis/products/arcgis-desktop, accessed on 30 June 2021).

2.3. Methods

This study aimed at the preference of PLES selection under different endowments in BTH region. Figure 2 shows the technology roadmap. The cumulative relationship was established first. Endowment factors include nature characteristics, location and facilities, and the scale of PLES in 2018 was taken as current to evaluate the preference of PLES under different endowment levels. Secondly, the year 1980 was defined as the base year, and the process of PLES transferred from 1980 to 2018 was identified. According to the spatial transfer dataset, the contribution rate and internal marginal effect of different transferring orientations were analyzed by BRT model.

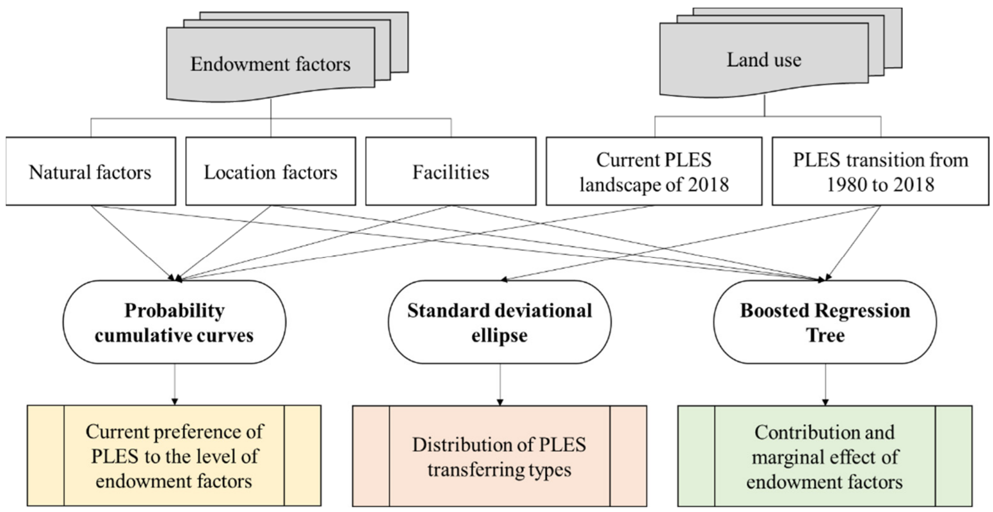


Figure 2. Technology roadmap.

2.3.1. Classification of Production–Living–Ecological Space

In terms of the concept of PLES, it is not only the classification of spatial functions according to human–land relationship, but also the clusters of land use types [5]. PLES types summarize the mechanism of land use differences in the process of regional ecological cycle, such as heat emissions [35–37], carbon emissions [38,39] and other processes with source and sink differences. LS, such as urban areas and rural residential areas, have the highest carbon emission intensity and surface temperature, which constitute the source of regional carbon emission and thermal cycle. Forest land, grassland and other ES types are used to relieve heat and reduce carbon emissions. There are also sinks in the region. PS, such as cultivated land, are consistent in carbon emission and heat release, but the intensity is small and the source-sink characteristics are weak [40,41]. Therefore, PLES simplifies the functional representation of land use characters in territory system by maximizing the differences of action direction and weakening the difference of intensity [6,7]. Current studies on PLES classification include basic classification system of production, living and ecology [38], composite system of production, living and ecology and interaction of three basic types [42], and extended system that divides production space into agricultural production and non-agricultural production [43]. From the practical perspective of territorial spatial planning, this study considered spatial dominant function as the primary principle, chosen to identify the basic system of production, living and ecological space classification (Table 1). According to the land-use types contained in rural spaces and the definition of PLES and the basic classification system established by existing studies [38], PLES dataset of BTH is generated.

Table 1. Classification of PLES.

Primary Land Use Type	Secondary Land Use Type	Classification of PLES
Cultivated land	Paddy field	Production space
	Dry land	Production space
Woodland	Forested land	Ecological space
	Shrubbery	Ecological space
	Other forest land	Ecological space
Grass land	High coverage grassland	Ecological space
	Moderate coverage grasslands	Ecological space
	Low-coverage grassland	Ecological space
Water	Rivers and canals	Ecological space
	Lake	Ecological space
	Reservoir pit	Ecological space
	Permanent glacier snow	Ecological space
	Beaches	Ecological space
	Bench land	Ecological space
Construction land	Urban land	Living space
	Rural residential area	Living space
	Other construction land	Production space
Unused land	Sandy soil	Ecological space
	Gobi	Ecological space
	Salinate field	Ecological space
	Marshland	Ecological space
	Bare land	Ecological space
	Bare rock	Ecological space
	Others	Ecological space
Ocean	Ocean	Ecological space

2.3.2. Regional Endowment Factors

In this study, the regional endowment factors were set in three objective aspects: natural characteristics, location characteristics and facility characteristics. Natural characteristics are the earliest factors that determine the function of space and the most basic environmental characteristics in sustainable development [44]. Natural factors included elevation, relief intensity and distance to water. Among them, elevation and relief intensity determine temperature and climate, as well as whether it was suitable for residents to carry out high-intensity construction [36,45]. The distance to water was taken into account because of the primary demand for agricultural production in rural areas [46]. Location was an important factor that had to be considered in rural development. Urban area was the provider of rural life resources. Different levels of urban areas had different attractiveness, which reshaped the layout of rural spaces [47]. The distance to the nearest subdistrict, distance to city and distance to capitals were selected in this study. Facilities were important catalysts for the evaluation of development potential of rural spaces [48]. Facilities such as interchanges and roads greatly improve the convenience of rural residents and products in and out [49]. This study chose the distance to the interchanges and roads as the facility indexes.

The distribution of indexes is shown in Figure 3. High elevation was distributed in the northwest, and low elevation was distributed on the North China Plain in the southeast, as shown in Figure 3a. High relief intensity area was distributed in the transition zone of high elevation and low elevation in the north and west (Figure 3b). Only northwest area and south area were far from the water surface (Figure 3c). As for location characteristics, northeast and west area had higher values of distance to the subdistricts (Figure 3d). North area was far from cities (Figure 3d) and capitals (Figure 3f). In Figure 3g, north area was further from interchanges and roads were more evenly distributed in the study area.

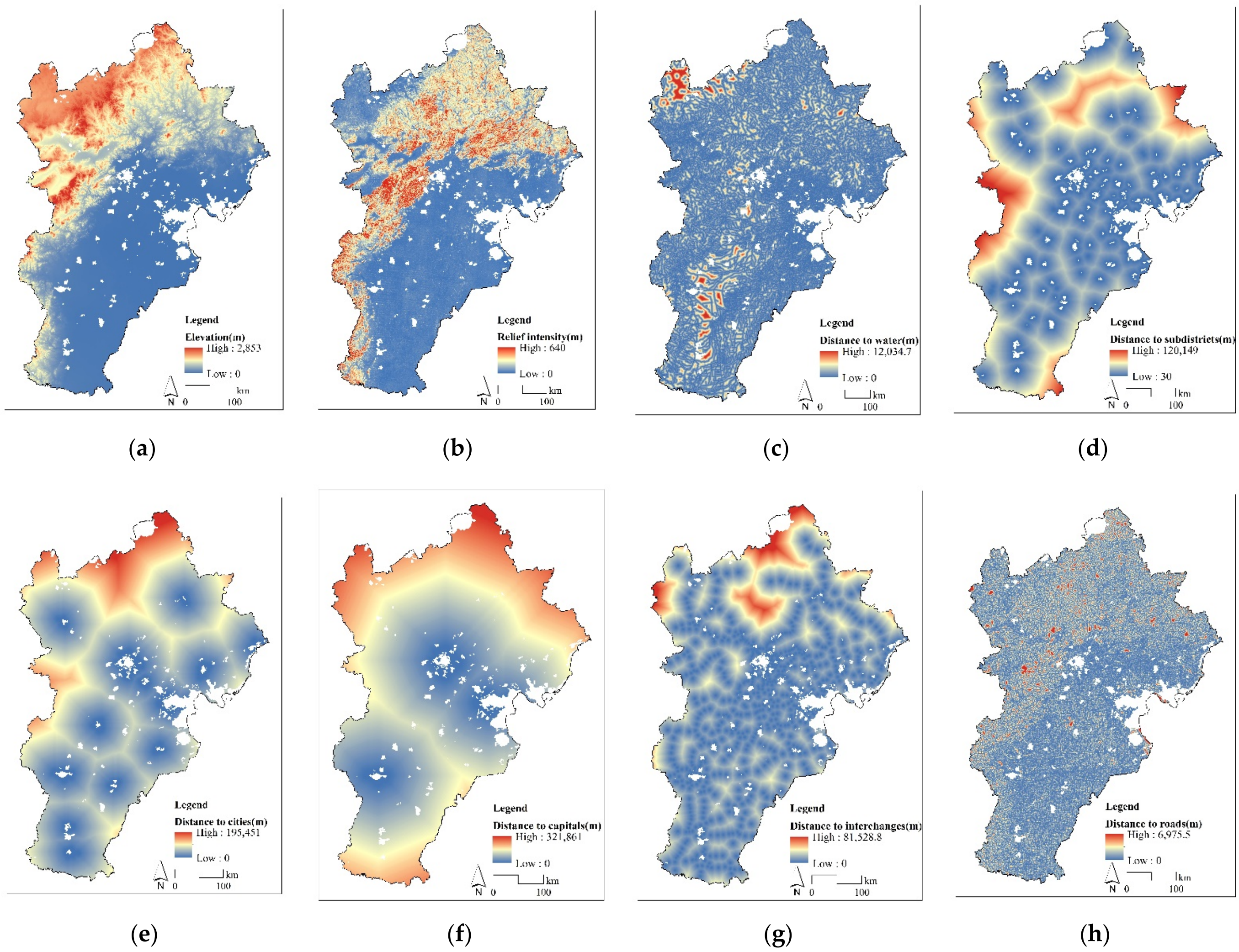


Figure 3. Distributions of factors. (**a**) Elevation distribution, (**b**) distribution of relief intensity, (**c**) distance to water, (**d**) distance to subdistricts, (**e**) distance to cities, (**f**) distance to capitals, (**g**) distance to interchanges, (**h**) distance to roads.

2.3.3. Cumulative Curves of PLES

Cumulative curve, known as frequency accumulative curve, was the first quantitative expression proposed to study the particle size of soil deposition. Object of this method is indicated by the slope change of accumulative curve [50–52]. Later, it was cited by multiple disciplines and has a wide range of values, including the famous Pareto curve [28]. In this study, the cumulative curve was introduced into the research to analyze the difference in regional endowment level of PLES. The factors were divided into 0–100 grades from low to high, and the scale of overall area, PS, LS and ES, were counted and summarized to form four cumulative curves of each factor. The point with slope of 1 was defined as the segmentation point, and the point with accumulation degree of 95% was defined as the critical point to measure the accumulation process.

2.3.4. Standard Deviational Ellipse (SDE)

The standard deviation ellipse (SDE) method is used to analyze the distribution pattern of a point set with spatial coordinates [53]. It was first proposed by Furfey to analyze geographic concentration [54]. This method uses an ellipse to simplify spatial distribution characteristics. The area represents the degree of distribution and concentration, the relationship between the major axis and the minor axis represents the concentrated direction and the center represents the spatial centroid. Many GIS applications allow for its use. In ArcGIS, three-level ellipses can be generated, representing 68%, 95% and 99% of the sample points, respectively [55]. In this study, the PLES transferring patches were extracted as points, and their scale was defined as the weight. The weighted SDE of level 1 in ArcGIS 10.3 was used to identify transferring type distribution.

2.3.5. Boosted Regression Tree Model

Boosted Regression Tree (BRT) model is a machine learning method combining regression tree model and boosted model [56,57]. This method generates data sets by randomly selecting a certain number of samples many times, and the remaining samples constitute test sets to improve the stability and accuracy of regression results [58]. The advantage of the model is that the interaction between independent variables can be ignored. Contributions of independent variables and the marginal effect within the value range are clearly shown in the model results [59,60]. So far, BRT model has been successfully applied in urban heat island factor research [61,62], ecological risk assessment research [57,63] and many other fields, with high value.

BRT model was used in this research to conduct six models. Whether the PLES transferring happened was defined as the dependent variable (transfer types include PS to LS, PS to ES, LS to PS, LS to ES, ES to PS and ES to LS). The indexes of nature, location and facilities were defined as independent variables, and the statistical average value of patch was used as sample to participate in the calculation. The cross coefficients of independent raster data were all less than 0.7. Calculation was carried out through R software and "GBM" package [64]. Existing studies used the consistency measurement of the training data correlation and the cross-validation (CV) correlation to measure the reliability of the BRT model parameters [57]. This study followed the rules to carry out multiple sets of verifications. After several tests, lr = 0.01, TC = 1, BAG Fraction = 0.5 and family = "Bernoulli" were set in consideration of calculation rate and accuracy of results.

3. Results

3.1. Scale of PLES from 1980 to 2018

Figure 4 shows the area of PLES from 1980 to 2018. The results showed that PS occupied the largest proportion in the study area, followed by ES, and LS was the smallest. This is because the study area is an important agricultural area in north China. The agricultural PS represented by cultivated land is the main land use type in the North China Plain. As for the PLES scale, PS decreased significantly since 1980, ES has been basically maintained, and LS expanded significantly. By 2018, a total of a 5326.61 km^2 increment of LS took place or about 30.09%. Based on the analysis of the change process, the period from 1990 to 1995 had the largest expansion stage of LS, with the expansion area exceeding 2000 km^2. From 2015 to 2018, ES expanded, and the area of expansion was 2.6 times the size of LS. Since the reform and opening up, with the improvement of the urbanization level, agricultural technology level and ecological protection awareness, spatial functional needs have changed. The PLES of BTH presented a significant evolution. Influenced by the urbanization process, the study area, as an example, represented the complex relation of a rural functional landscape and regional endowment by showing the interaction between regional development and territorial structure.

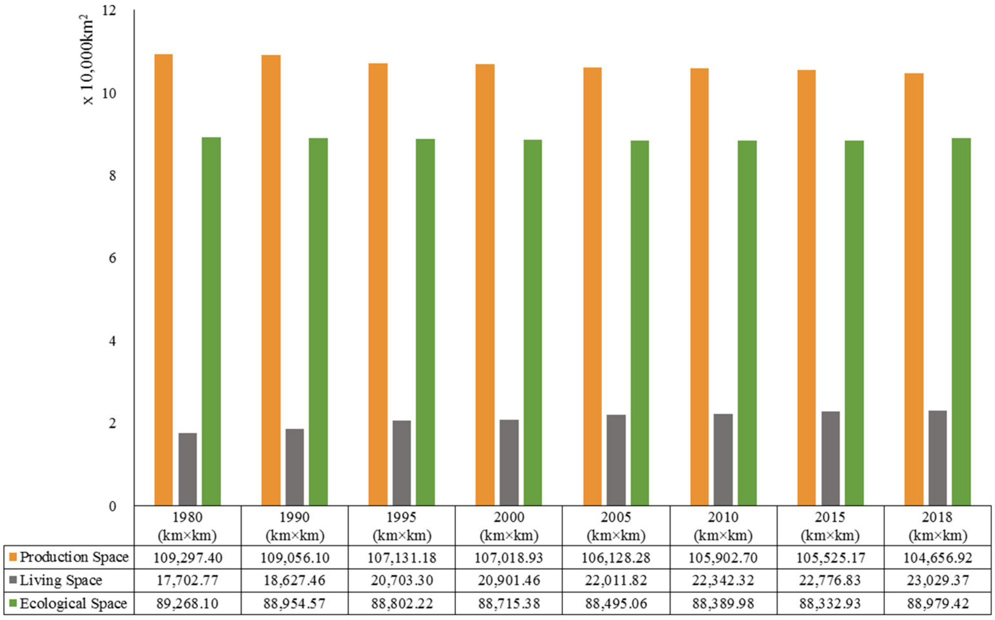


Figure 4. Area of PLES from 1980 to 2018.

3.2. Basic Descriptive Endowment Characteristics of PLES Types

The PLES pattern of the study area changed a little in the past decades. The current PLES distribution and endowment characteristics were combined for further analysis. Table 2 shows the mean value and standard deviation of the indicators of each type.

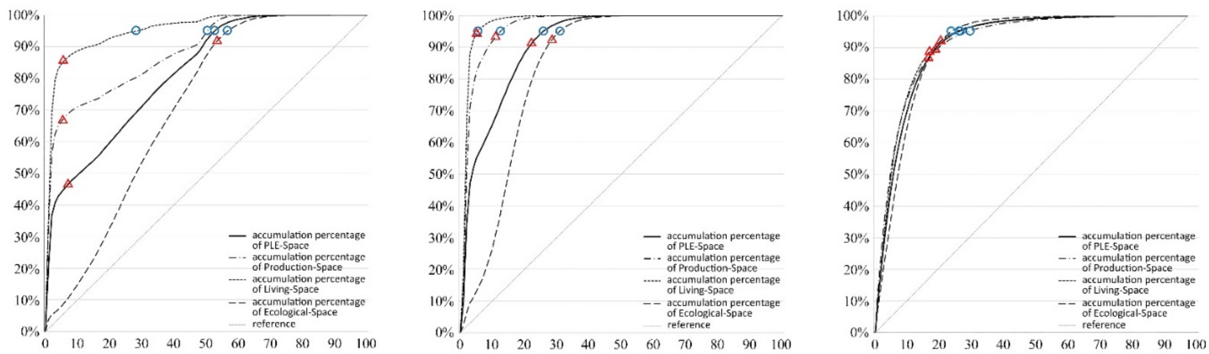
Table 2. Mean value and STD of factors of PLES (EL—elevation; RI—relief intensity; DW—distance to water; DS—distance to subdistricts; DCI—distance to cities; DCA—distance to capitals; DI—distance to interchanges; DR—distance to roads).

	Natural Factors			**Location Factors**			**Facility Factors**	
	EL (m) MEAN	**RI (m) MEAN**	**DW (m) MEAN**	**DS (m) MEAN**	**DCI (m) MEAN**	**DCA (m) MEAN**	**DI (m) MEAN**	**DR (m) MEAN**
PS	327	22	1021	20,713	45,431	109,863	11,181	386
LS	130	13	974	14,842	32,827	85,977	8095	207
ES	834	99	1113	34,862	66,259	132,104	18,505	698
	STD	**STD**	**STD**	**STD**	**STD**	**STD**	**STD**	**STD**
PS	493	26	1291	18,690	30,532	62,463	9825	340
LS	278	14	1108	15,246	24,603	59,160	6728	218
ES	483	56	997	22,520	35,934	64,910	14,052	577

There is a great difference among PLES types. From the natural factor index, LS occupies the position with a lower elevation and less fluctuation, while ES is relatively distributed in the region with a higher elevation and steep terrain, and PS is between them. Compared with the STD of elevation and relief intensity of the other types, the values of LS are all small, indicating that LS has more stringent requirements on terrain and a smaller suitable range than PS and ES. The distance from water has little difference among them. After their differences were magnified, we found that the average distance to water in ES is the biggest and the STD is the smallest. Considering that ecological space includes rivers and lakes, it further shows that PS and LS had a strong demand for water. The location factor results show consistency in all indicators, and indexes of LS are smaller than PS and ES. It can be considered that the LS in rural areas was inherited from the urban spatial hierarchy. Additionally, the gap among PLES types shown in the distance to the capital is bigger than in the distance to subdistricts. A higher level of urban area has more attraction to rural LS. PS and ES are distributed around the LS patches, which made ES have a maximum distance to the urban area at every level. The facility factor indexes results show that the expressway is an important factor to change spatiotemporal distance, as it connects large cities, towns and the wide rural space. Interchanges are also the spatial trigger of rural development. The distance to roads is similar. It is noteworthy that LS is closer to the area with convenient facilities, and the preference level of LS and ES for facility indicators is very different. We guessed that by considering the elevation and relief intensity index results of ES, there is a bigger cost for building interchanges and roads in ecological areas. It also contributed to the distance from ES to the infrastructure elements.

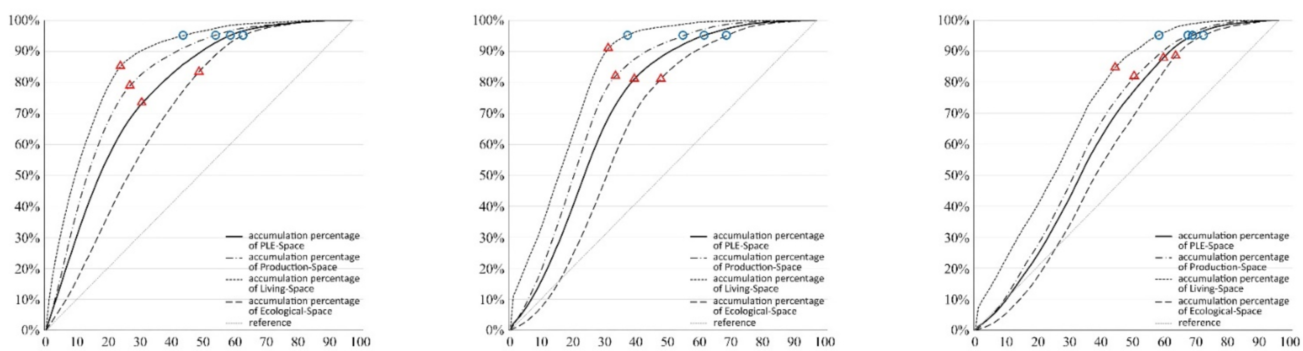
3.3. Cumulative Relationship of PLES and Endowment Factors Level

There was a significant adaptation relationship between PLES and the levels of various endowment factors. In order to explore such preferences, the PLES landscape and the endowment factors level of BTH in 2018 are overlapped, and the cumulative curves from low to high of the overall type and each type are plotted in Figures 5–8.



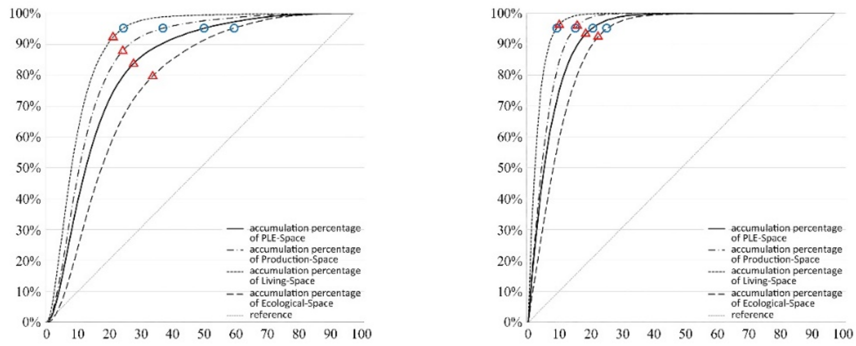
(**a**) (**b**) (**c**)

Figure 5. PLES cumulative curves of natural factors. (**a**) Elevation; (**b**) relief intensity; (**c**) distance to water.



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

Figure 6. PLES cumulative curves of location factors. (**a**) Distance to subdistricts; (**b**) distance to cities; (**c**) distance to capitals.



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

Figure 7. PLES cumulative curves of facilities. (**a**) Distance to interchanges; (**b**) distance to roads.

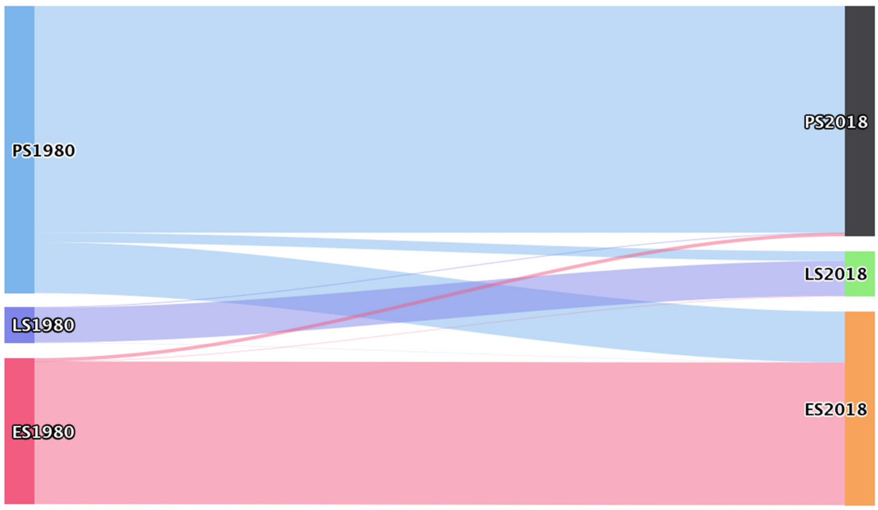


Figure 8. Sankey diagram of PLES area from 1980 to 2018.

3.3.1. Cumulative Relationship of PLES and Natural Factors Level

Figure 5a–c represents the cumulative curve of the elevation, relief intensity and distance to water in the overall and PLES types, respectively. Among the dispersion of curves, the difference among the four curves in Figure 5a is the largest. In particular, there is almost no difference in the distance to water in Figure 5c. In Figure 5a, the LS curve was higher than the other three. The tangent point of the curve with slope one was defined as the segmentation point. Before the segmentation point, the rate of area accumulation was faster than 1%, and after, it was the opposite. When the accumulation level reached 95%, the critical point was defined, based on the thought that 95% of the space of each type could represent most of the characteristics of that type. When the elevation level reaches only 6%, the LS curve reaches the segmentation point, and the accumulation is completed at 85.81%. The segmentation point of PS appears when the elevation index is 6%, but only 67.75% is accumulated. For the same elevation suitability, the accumulation ratio of PS was lower than that of LS, because the living function was in a leading position in rural areas, which caused a higher priority in functional selection. Due to the effect of PS and LS, the segmentation point of the study region appears at the level of an 8% elevation, and the total accumulation is less than 48%. In sharp contrast, the segmentation point of ES appeared at the 53% elevation level, which accumulated more than 90%. The critical points of the four curves in Figure 5a appeared at 28%, 50%, 52% and 57%, respectively. This suggests that LS and PS are appropriately distributed below 6% of the regional elevation level. When the elevation exceeds 28% and 50%, there is almost no LS and PS. The space between the segmentation point and critical point is of suitable scope. The scope of the ES suitability was minimum, and changes in the elevation had little influence. The ES is distributed over a space that is hard to use, so it deserved a relatively lower position. Figure 5b showed that the accumulation performance of relief intensity was different from that of elevation. The segmentation levels of LS, ES, study region and PS are located at 6%, 12%, 24% and 30%, respectively. LS has the greatest dependence on lower relief. The accumulation of the four lines at the segmentation point is over 90%. The critical points were close to the segmentation points. This was because the relief intensity was mainly distributed in the low-level range, and the high relief area was small. The cumulative level of LS was 95.79%, and the critical point was lower than the segmentation point. In addition, the curves of LS and PS were closer to the Y-axis below the segmentation level, and the ES curve was farther from the Y-axis. It can be seen that the space with low relief intensity was mainly occupied by LS and PS, which is similar to the results of the elevation curves. Figure 5c shows the accumulation of the distance to water. The segmentation points of the four curves are in the horizontal range of 18–21%. The accumulation of PS was higher than that of LS and ES before 7%. When it exceeded 22%, ES became the highest accumulation type. Although the difference among the curves is small, there are still differences in different horizontal stages.

3.3.2. Cumulative Relationship of PLES and Location Factors Level

Figure 6a–c shows the cumulative characteristics of the distance to subdistricts, cities and the capital, respectively. After comparing the distance of the curves to the y axis among the three indicators, it was found the curve of the distance to the subdistricts was closer. The closer to subdistricts, the faster the accumulation grew. The curve of distance to the capital was closer to the reference line. In Figure 6b,c, when the distance level is lower than 16% and 27%, the accumulation of ES is lower than the reference level. In Figure 6c, the PS is also lower than the reference level when the distance level is lower than 8%. It can be considered that within this range, ES and PS are greatly compressed by LS. Rural areas outside the high-grade urban area have taken on the characteristics of towns, and the area is mainly dominated by living functions. By summarizing the segmentation points, it can be found that the segmentation points and critical points of LS appear first. When the segmentation points appear, the accumulation level is also the highest, which has the most urgent demand for location. The index level of the ES segmentation point is the latest, the PS segmentation point appears earlier than the segmentation point of the study area, and the accumulation level is basically the same.

3.3.3. Cumulative Relationship of PLES and Facilities Factors Level

Figure 7a,b, respectively, plot the PLES accumulation of the distance to interchanges and roads. In Figure 7a, the curves of LS, PS, overall study area and ES are distributed from top to bottom. The segmentation points appear at 21%, 25%, 28% and 34%, respectively. The demand for interchanges is most significant in LS. The accumulative levels are 91.74%, 88.19%, 83.52% and 79.22%, respectively, which also shows a decreasing trend. This is because the configuration of interchanges not only needs to consider the coverage of LS but also needs to bear the terrain cost of the construction of high-speed roads. Figure 7b shows the cumulative process of road accessibility. Similar to Figure 7a, the areas with the highest road accessibility are LS, PS and ES. It is obvious, as for the distance to road index, that the segmentation point of LS and PS is located on the right side of the critical point. When the accumulation level reaches 95%, the accumulation rate is still higher than 1%, and the correlation between the living function and production function and road accessibility is high. However, considering the sequence relationship between road element construction and the formation of PLES, road accessibility is one of the main factors in the choice of LS. Planning roads needed to take the minimum cost into account. The cost of occupying agricultural production space is smaller, thus resulting in a close relationship between PS and road accessibility.

According to the above findings, LS has the minimum suitable range and the fastest accumulation speed in natural characteristics, location characteristics and facility characteristics. ES is the opposite. The accumulation process of PS is faster than that of the overall study area. According to the overall curve, LS and PS can be defined as the type with a clear need for endowment, while ES is in a weak position in the choice of endowment by functional types.

3.4. Transferring Characteristics of PLES from 1980 to 2018

PLES is an important expression of the man–land relationship. As the man–land relationship is influenced by people's cognitive evolution, technological updates and resource awareness, PLES shows phased characteristics in a long time series. This leads to changes in the functional demand pattern of the territory. Thus, it changes the distribution pattern of the PLES pattern. 1980 was defined as the base year, and the total amount of PLES changed by 2018 was 28,458.3 km^2, accounting for only 13.9% of the study area (Figure 8). The largest transferring type scale was PS-ES. The transferring area was more than 20,000 km^2, accounting for 77.81% of all types of the transferring area (Table 3). This is because the normal production space could not satisfy the huge demand for agricultural products before the reform and opening up, a lot of unsuitable land was reclaimed into arable land. After 1990, the supply and demand of agricultural products tended to be stable, and the BTH region suffered from serious dust weather. The government issued the policy of returning farmland to forest, which restored a large amount of agricultural space to ES, and reconstructed the pattern of rural PLES.

Table 3. PLES transfer matrix from 1980 to 2018.

	PS2018 (km^2)	**LS2018 (km^2)**	**ES2018 (km^2)**
PS1980	98,807.90	4196.57	22,144.28
LS1980	335.50	15,203.01	81.31
ES1980	1516.29	184.34	62,196.70

The spatial distribution of PLES types in 1980 and 2018 was overlayed to obtain the spatial pattern of the PLES shifting type. According to the naturalness of PLES types, the transferring process can be divided into two orientations: the process of increasing nature and the process of decreasing nature. The decreasing nature process includes the transfer of PS to LS, ES to PS and ES to LS. The other three transfer types were included in the process of increasing nature. The result of the standard deviation ellipse is shown in Figure 9a,b. It was shown that the distribution of different transfer directions and types of space in the study area is different. Significantly, in the process of decreasing nature, which used to be ES, the patches forming PS are widely distributed and mainly located in the central area, while the patches forming LS are mostly distributed in the periphery of Beijing and Tianjin, extending to the south of the North China Plain. The patches from PS to LS are mainly distributed in the North China Plain. In the process of increasing nature, the production space patches, which were LS, are distributed on the north and south sides of Beijing and Tianjin, while the ES patches are gathered around Beijing and Tianjin. The PS patches from ES are distributed in the Taihang Mountain area. In the study area, the three transferring types of decreasing nature are highly overlapped, which are centered in the urban areas of Beijing and Tianjin and extended to the north of the North China Plain. It can be seen that the expansion of high-level urban areas led to the transformation of territorial space to decreasing nature in a certain range around the area. In contrast, the distribution of increasing nature types presents a pattern of parallel movement from the northwest to the southeast. The overlap occurs only in part of the transition zone, from the shallow mountainous area to the North China Plain in the northwest of Beijing. With the process of parallel movement, the difficulty of transferring gradually increased. The LS–ES ellipse is almost distributed on the North China Plain. The huge difference in the distribution of transferring types shows the re-optimization of regional endowment on the choice of spatial functions. It was necessary to analyze its internal mechanism by type.

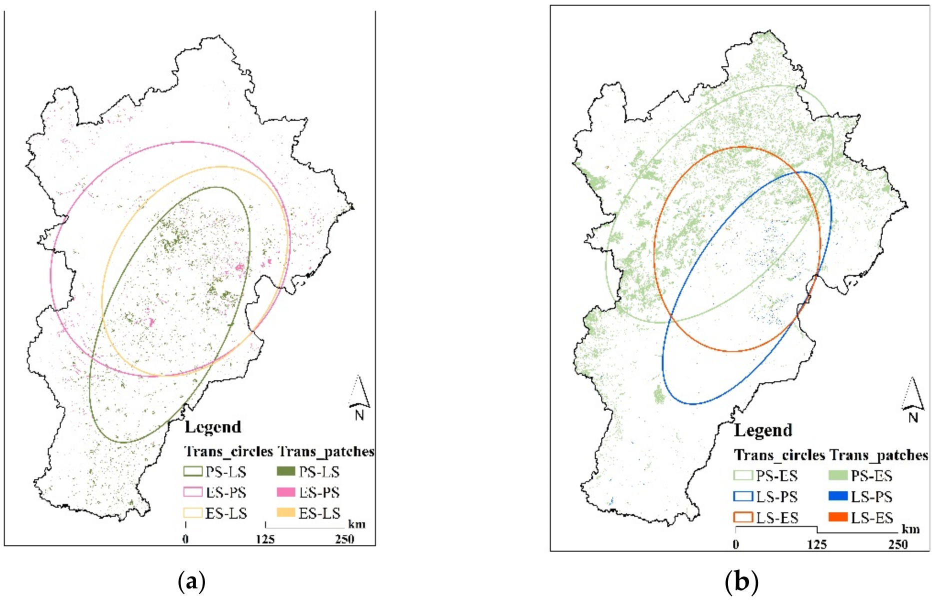


Figure 9. Distribution and standard deviational ellipse of PLES transfer. (**a**) Decreasing nature type; (**b**) increasing nature type.

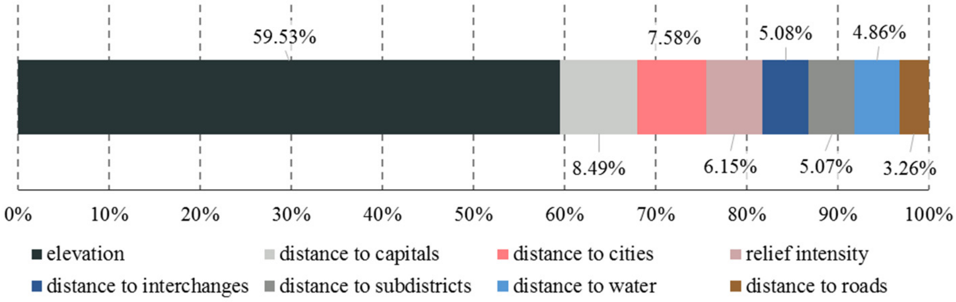
3.5. The Preference of Endowment Factors during PLES Transfer

In order to figure out how the functional types were selected and transferred in the BTH region, the BRT model was used to analyze the relationship between the PLES transfer process and endowment factors of each.

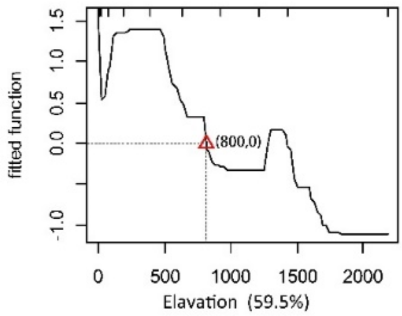
3.5.1. Decreasing Nature Process Results

The transfer of ES–PS is mainly affected by elevation. Figure 10a shows the results. The contribution of elevation accounted for 59.53%, the contribution of the others was relatively average, and each of them accounted for less than 10%. When the elevation was lower than 800 m, the factors had a positive effect. In Figure 10b, after 500 m, the influence intensity gradually decreased with the increase of the elevation index. When it exceeded 800 m, the influence changed to negative. After 1250 m, the negative influence intensified. The ES was transformed into PS because the expansion of agricultural planting varieties had different demands for different climate and altitude conditions. As a result, it was difficult for a part of the original space for food cultivation to become the planting area for new crops due to climate reasons. In addition to this, the space of this type was mainly in the transition zone from the mountainous area to the plain area, which was closer to the concentrated area of LS. It could also meet the urban demand for agricultural products better.

The process of ES–LS was mainly influenced by elevation, the distance to cities and the distance to roads (Figure 11a). The contribution rate of elevation was higher than 30%. The other two factors were higher than 20%. It is shown in Figure 11b that positive effects were observed in areas below 750 m, within 5 km of urban areas and 250 m of roads. Negative effects were observed in areas 250–3080 m from roads. ES–LS patches are mainly distributed next to the coastal line and around the mountain city. The ES area was abundant in the coastal region, but the usage of harbor resources accelerated the transformation process. Besides this, urbanization inspired ecological tourism demand from citizens, and ES around the mountains was developed. It formed many resorts combining ecology and life, which became one of the important sources of the ES–LS patches.

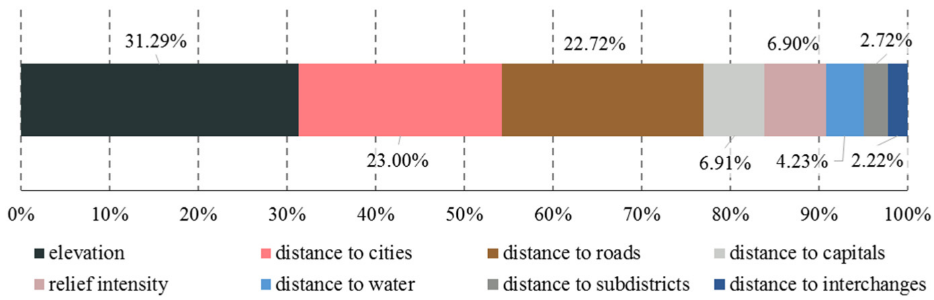


(**a**)

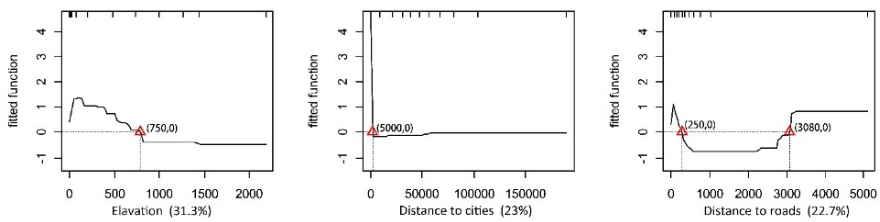


(**b**)

Figure 10. Factor contribution ranking and marginal effect of ES–PS. (**a**) Contribution degree of factors; (**b**) marginal effect of factor which contribution degree over 10%.



(**a**)



(**b**)

Figure 11. Factor contribution ranking and marginal effect of ES–LS. (**a**) Contribution degree of factors; (**b**) marginal effect of factor with a contribution degree over 10%.

In Figure 12a, relief intensity and elevation are the main contributing factors for the transformation of PS–LS, with contributions of 57.21% and 33.21%, respectively. It can be seen that natural factors, especially topographic features, are the main reasons for the transferring process. The visualized marginal effect shows that the two factors played a positive role in the transformation process when the relief intensity was less than 70 m and the elevation was less than 1050 m (Figure 12b). The effect intensity peaked when the index level was lower. Living functions are distributed at the flat and low-altitude area, and the priority of LS is higher than that of PS, so the PS at the edge of the living space is invaded.

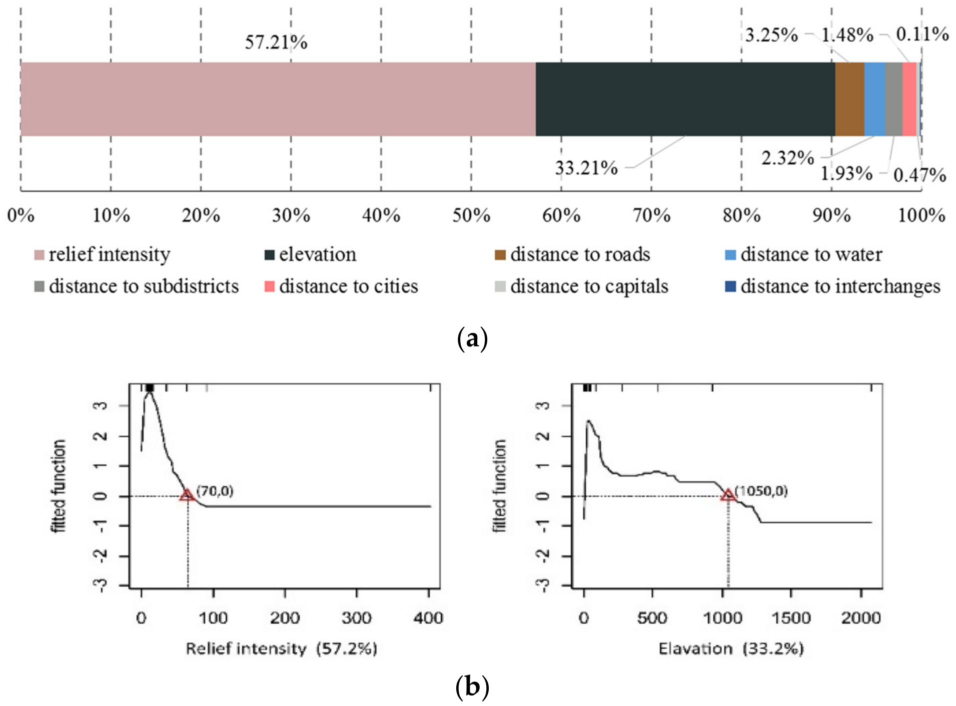


Figure 12. Factor contribution ranking and marginal effect of PS–LS. (**a**) Contribution degree of factors; (**b**) marginal effect of factor with a contribution degree over 10%.

3.5.2. Increasing Nature Transfer Results

In the process of PS–ES (Figure 13a), elevation, relief intensity, distance to capital and distance to roads were the main influencing factors. All contributing rates were over 10%. Elevation contributed the most, 30.16%. The marginal impact process of each index was analyzed. When the elevation was less than 200 m, it had a positive effect on the transferring process, and when it was more than 1750 m, it had a negative effect. When the relief was less than 100 m, the impact was negative, and when it was more than 100 m, the impact can be ignored. Within 72 km of capitals, the effect was positive. As to the distance to roads, it was negative within less than 350 m and positive within 350–1350 m. The transfer of PS–ES, on the one hand, came from the ecological restoration of agricultural space unsuitable for cultivation through the policy of returning farmland to forest. On the other hand, it came from the demand for ES in the process of high-level urban area expansion.

The transfer from LS to PS was affected by elevation and distance to capitals, contributing 59.76% and 25.26%, respectively (Figure 14a). The positive influence process mainly occurred within an elevation of 150 m and 70 km to capitals. When the distance to capitals was more than 70 km, the positive influence was changed into the negative and it disappeared when the distance was over 260 km (Figure 14b).

In addition to the above two indexes, the distance to water surface played a significant role in the transition of LS–ES, which contributes more than 20% (Figure 15a). The contribution rates of elevation and distance to capitals are 34.33% and 24.73%, respectively. The marginal effect is also different, a positive effect was found in elevation below 150 m, within 63 km of capitals and 400 m to water surface (Figure 15b).

The transfer of LS to PS and ES is caused by the adjustment of spatial layout and the control of ES protection. The original LS is gradually hollowing out due to the migration of residents to cities and the decline of natural fertility, which seems to show the need for cancellation. As for inefficient LS, most of the patches will be restored to agricultural PS to ensure the country's bottom-line requirement of 1.2 million km^2 of farmland scale. The other kind of LS close to ecological elements (such as rivers) was forced to withdraw due to ecological risks caused by ecological encroachment to protect ecological integrity.

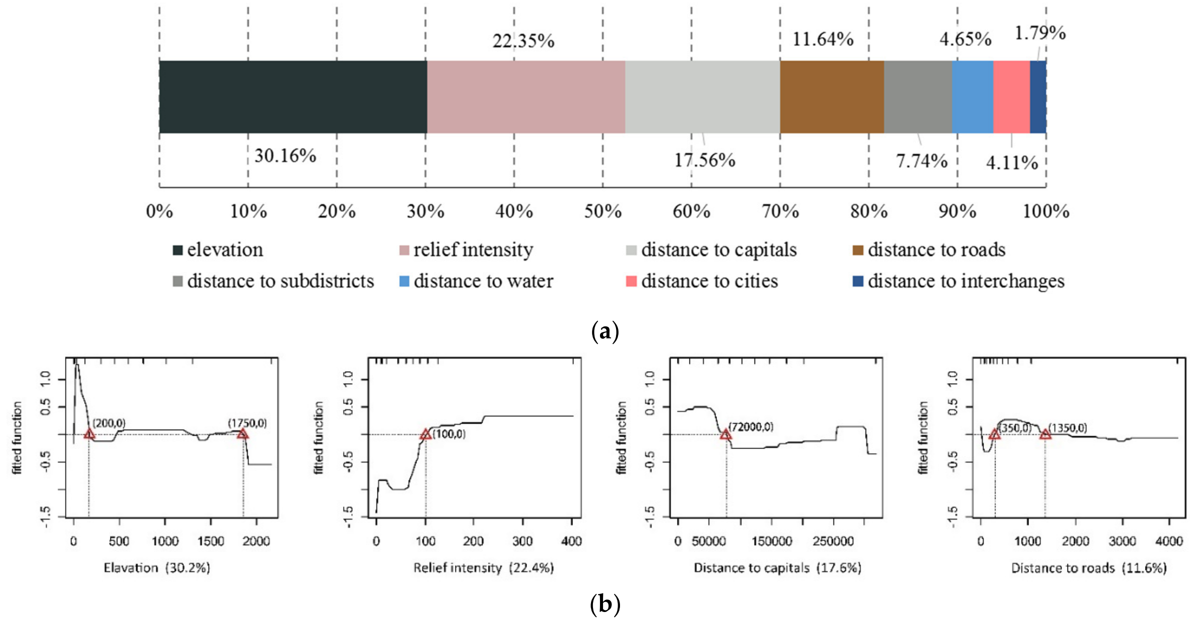


Figure 13. Factor contribution ranking and marginal effect of PS–ES. (**a**) Contribution degree of factors; (**b**) marginal effect of factor with a contribution degree over 10%.

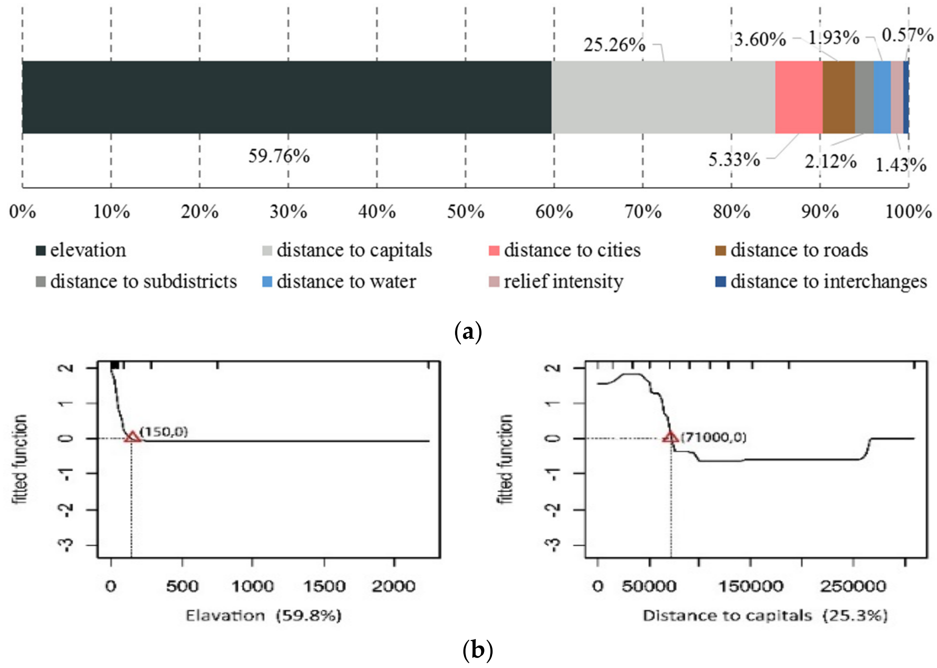
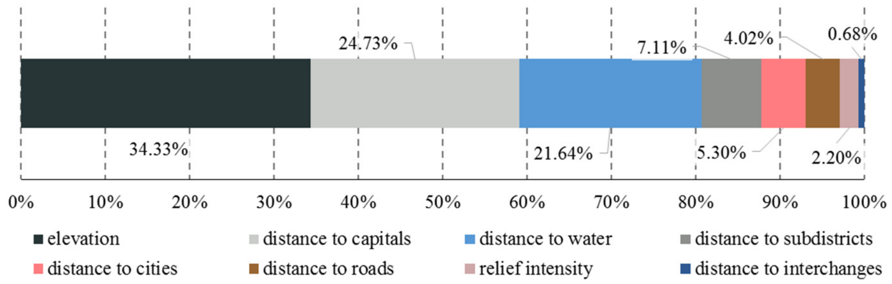
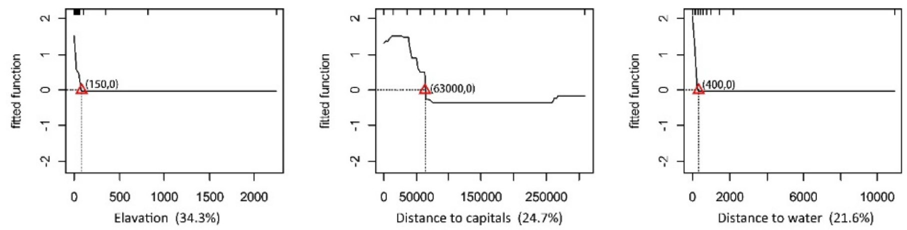


Figure 14. Factor contribution ranking and marginal effect of LS–PS. (**a**) Contribution degree of factors; (**b**) marginal effect of factor with a contribution degree over 10%.



(**a**)



(**b**)

Figure 15. Factor contribution ranking and marginal effect of LS–ES. (**a**) Contribution degree of factors; (**b**) marginal effect of factor with a contribution degree over 10%.

4. Discussion

4.1. The Dual Selection between PLES and Regional Endowment

Based on the above results, it was not difficult to find that LS in the study area enjoyed the optimal endowment level, which is concentrated in the region with flat terrain, superior location conditions and high facility popularity, followed by PS. LS and PS were higher than the regional endowment level. ES was in a weak position in the functional competition. The terrain fluctuation was too large. Some ES patches cannot be used for production or living functions, so they retained certain natural attributes and became ES. It can be considered that the living function is the foundation of rural spatial organization, and the safety and comfort of the living environment is the primary rule to construct the relationship between residents and land. Production function was derived from the guaranteed LS. The study area was the main agricultural farming space in China. The spatial configuration of the traditional farming mode was mainly concentric, which was formed by rural settlements and cultivated land within the farming radius. It explained the endowment advantage of production space.

From the perspective of endowment types, the endowment of natural elements limited the space in the choice of functions, especially in the natural endowment of sensitive LS and the PS. This sensitivity limited the infinite expansion of production and living demand and kept some ES as an important role for the sustainable development of regional balance. Location factors demonstrated the attraction in moving from an urban area to a rural area, especially with the rural living demand for high-grade town nodes. It constituted the dual flow pattern and regional spatial connection. In the urban–rural system, urban areas can be regarded as higher-level LS. More advanced urban areas can provide better living services and greater ecological demand, which explains why the distance to capital had a great impact on the naturally rising transformation types. Facility was an artificial element type in regional endowment and was also a new element constantly updated during the man–land relationship evolution. Facility elements were double-sided. On the one hand, they were dependent on rural development and beneficial to living and production functions. However, on the other hand, new facilities occupy land, which was easy to have a negative impact of cutting patches while reducing the mitigation effect of ES and increasing the risk of ES decreasing.

4.2. Mechanism in the PLES Transferring Process

In the interaction between regional endowment and PLES pattern, firstly, there was no doubt that regional endowment determines the type of PLES. In particular, natural features such as elevation and topographic relief determine the cost of space utilization. At the earliest, people preferred to develop areas with lower development costs. When people obtained enough LS and PS to support basic life, other spaces in the region retained their natural properties and formed ES. At that time, the basic pattern of PLES was formed, which was adapted to the population size, productivity level and science and technology. Then, with social development, including cognitive progress in politics and the scientific and cultural level, changes in the population scale, tools and techniques, agricultural product demand and other aspects were reflected in the demand for the scale of PLES. This led to the deviation of the segment level of regional endowment factors among PLES types. This deviation did not touch on the decisive fundamental role of endowment on PLES but only resulted in a small-scale shift of functional space type. It also formed a new appropriate relationship between regional endowment and PLES. The evolution of this suitable relationship was the dynamic performance of the human–land relationship system, and the continuous modification in shifting made the coordination between human cognition, resources and environment and PLES landscape. Then, it reached the goal of sustainable development. So far, it can be considered that the relationship between PLES and regional endowment is a dynamic combination of natural dominance and non-natural change.

4.3. Implications for Territory Spatial Planning

PLES is an important concept of sustainable development in territory spatial layout. China put the concept that provided a template planning of sustainability to the world. It represented the evolution from the attention of economic development to the coordination of social, economic and ecological functions. In the BTH region, the endowment priority of LS and PS showed that the development of past decades has ignored the importance of ecology. Preferential spatial resources were allocated to the expansion of settlements and agricultural production. Although there had been a positive ecological trend around high-grade urban areas, there was no significant improvement in other rural areas, which indicated that the protection and optimization of ES still need to be extended to a broader region and the importance of ecological protection needs to be further emphasized. Extending this framework to other regions and countries, the cumulative curve can be used to evaluate the suitability of functional landscape, and the BRT model could identify the importance among regional endowments. In general, this study can be used as a means to evaluate the performance of territorial spatial planning and the optimization results of PLES periodically in the future. It could help realize the real-time adjustment of territorial spatial planning schemes and the periodic review of local government actions.

4.4. Research Deficiency and Limitation

By analyzing the relationship between rural PLES and the level of regional endowment factors, this study analyzed the characteristics and mechanisms of rural PLES patterns. However, there are still some deficiencies in the research. Firstly, there are several classification methods of PLES in past studies. This study chose the basic method by reclassifying the land use types for further analysis. This is a common method, but it ignored some features of land versatility and needs to be improved in the follow-up research. Secondly, the suitability level of PLES for regional endowment selection overlaps in the research results, so it is necessary to refine the overlapped part and accurately locate the type threshold. Although the cumulative curve and the BRT model can meet the technical needs of this research, the results obtained are too simple to show the analysis process. Therefore, it is difficult to present deeper rules. In the future, more appropriate methods and accurate results should be the goal of the next step.

5. Conclusions

In this study, the preference of PLES for regional endowments in BTH was identified. Firstly, LS enjoyed the priority of endowment selection, occupying the space with the best regional characteristics in the study area. PS was next and higher than the overall level of the research area. ES had the lowest priority. Secondly, PLES transfer occurred in a small area, mainly from PS to ES. Elevation is the main influencing factor in all shifting processes. After dividing transferring types into a decreasing nature set and increasing nature set, we found that natural decreasing transfer was influenced mainly by terrain features and that the distance to capitals was involved in all processes of increasing nature transfer. For the BTH region, the importance of ecology needs to be emphasized, especially in the vast rural areas far from the provincial capital. The preference law of PLES for regional endowment characteristics should be reasonably used in sustainable development planning in the future so as to accomplish the coordination of production, living and ecology.

Author Contributions: P.Z., S.W. and Z.S. developed the research idea and wrote the manuscript. Y.Z. collected and pre-processed PLES distribution and factors. Y.C. and Z.Q. checked out the statistical analysis. L.C. revised the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the National Natural Science Foundation of China (Grant Numbers 51978447). Scientific and Technological Major Project of Tianjin, China (18ZXSZSF00240). Major Projects of High Resolution Earth Observation Systems of National Science and Technology (05-Y30B01-9001-19/20-4).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare that there is no conflict of interest.

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