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A Study on the Dynamics of Landscape Patterns in the Yellow River Delta Region

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Abstract: The Yellow River Delta region is one of the estuarine deltas with the fastest land building speed, and it is an important region for the study of landscape pattern change due to its diverse variety of landscape types. By analyzing the dynamic degree, landscape type transfer matrix, and landscape indices of landscape types in the Yellow River Delta region in 2005, 2012, and 2018, this paper found that the area of construction land, salt fields, and breeding ponds in the Yellow River Delta region has increased to a large extent, with an increase in the aggregation degree and the utilization rate of this landscape type, and the landscape has developed toward the direction of aggregation and unification. The increase in construction land area mainly comes from the transfer of cropland area, part of which is occupied in order to adapt to urban expansion, and the salt fields and breeding ponds mainly come from the transfer of waters and mudflats, which can be seen as the main utilization direction of the water landscape. Moreover, unused land has increased with the degree of dispersion and fragmentation of development and utilization, so the exploitation and utilization of unused land still needs to be optimized. Through the analysis of the dynamic change in landscape pattern, we can explore the direction and extent of the evolution of landscape types, which has certain guiding significance for the sustainable use of land resources and the sustainable development of economy in the Yellow River Delta region.

Keywords: landscape pattern; dynamic degree; landscape type transfer matrix; landscape pattern index; dynamic change

Citation: Li, L.; Li, X.; Niu, B.; Zhang, Z. A Study on the Dynamics of Landscape Patterns in the Yellow River Delta Region. *Water* **2023**, *15*, 819. https://doi.org/10.3390/w15040819

Academic Editor: Richard Smardon

Received: 19 January 2023
Revised: 16 February 2023
Accepted: 17 February 2023
Published: 20 February 2023

1. Introduction

1.1. Research Progress

The Yellow River Delta region, located at the mouth of the Yellow River, is the youngest wetland ecosystem in the country and the fastest growing area of land resources in the country and the world, making it a key area for ecological research [1,2]. The landscape types in the region are diverse, but with rapid economic development, human activities in the Yellow River Delta region have been enhanced, and the exploitation of land has led to fragmentation of the landscape pattern as well as increased dispersion of the landscape, affecting the ecological pattern, structure and function of the region, leading to a series of ecological problems such as river breakage and vegetation degradation, which pose a threat to ecological security as well as sustainable socioeconomic development [1–3]. Therefore, the dynamic change of landscape patterns has become one of the hot spots of current research. Landscape pattern refers to the arrangement of landscape patches of different sizes, which can characterize the heterogeneity of the landscape and is the result of various ecological processes acting at different scales [4]. The evolution of landscape pattern is closely related to ecological processes, which together drive the changes in landscape types [5]. Li T.Y. et al. used GIS technology and Fragstats software to obtain landscape change patterns in the Fen River Basin over a 25-year period and found that the natural landscape was transformed into an anthropogenic landscape as urbanization accelerated [6]. Wang T. et al. constructed normalized vegetation index timeseries curves to optimize the landscape classification results and analyzed its dynamic changes using the landscape pattern index [7]. Li F. et al. combined landscape pattern evolution with ecosystem service capacity and human stress indicators to analyze the health status and change trends of ecosystems [8]. By studying the dynamic changes and drivers of landscape patterns, Cao L.H. et al. found that socioeconomic development was the main driver of landscape pattern changes, and that economic development and urban and rural population changes were the main driving factors [9].Anthropogenic disturbance indicators can be used to evaluate the degree of influence of human activities on landscape types. The Yellow River Delta region is affected by human activities, so the landscape type clustering is reduced, the overall landscape connectivity is reduced, the shape of patches tends to be regular and simple, the disturbance of human activities such as reclamation, farming, salt tanning, construction, agricultural land reclamation, and so on, although they drive economic development, they also cause serious damage to the ecological environment [3,10,11]. Li M.D. et al. found that the spatial and temporal distribution characteristics of landscape patterns were influenced by the scale of the study, with different scales and development statuses all leading to different landscape patterns [12].Wang D. et al. found that the impact of economic development on the landscape pattern was obvious, with the overall landscape becoming less connected and more fragmented, but the internal stability of the construction land patches increased and the shapes tended to be simpler as a result of urbanization, while other landscape types tended to be more complex and fractured [13]. By studying the evolution of the landscape pattern of Changbai Mountain over a 30-year period, Chen X.Y. et al. found that the landscape changed from small and scattered patches to large and concentrated patches during the restoration process, and the overall connectivity of the landscape decreased and developed toward homogenization [14]. The river networks are also important landscape features, which are obviously influenced by external factors such as climate, and at the same time, the river networks have the role of connectivity, which has a certain influence on the landscape pattern of the surrounding areas. The study of critical nodes of river networks is important for studying the changes in landscape patterns, understanding biodiversity, and maintaining the ecological integrity of the landscape [15,16]. Guo Y. et al. studied the effects of sand transport, sand content, and runoff on landscape changes in the Yellow River Delta region and found a significant correlation between the water and sand factors and landscape patterns [17].

1.2. Importance of Study

The Yellow River Delta region is the last large river delta to be developed in China. It is located at the combination of the Shandong Peninsula and Beijing–Tianjin–Hebei metropolitan area [18], which is the intersection of land and sea, forming a complex ecosystem and has a rich landscape type and a suitable environment for human living, which is important in regulating climate and protecting biodiversity [19]. The region is rich in reserve land resources, and it is an important food production base in China and has abundant natural resources. The development of the Yellow River Delta region began in the 1960s, and from an untouched wasteland to a development hotspot today, the development advantages and potential of the Yellow River Delta region have made it an important force in driving the development of the Bohai Sea Rim. However, with economic development, the ecology of the Yellow River Delta has been damaged by excessive reclamation and the development of salt pans and aquaculture ponds, and the original landscape type and landscape pattern have been changed.

Based on the area of landscape types in the Yellow River Delta region during 2005–2018, the transformation of landscape types within the study time period and the spatial distribution characteristics were analyzed. According to the landscape type shift matrix used to analyze the change in landscape types and the transfer direction during the study time period, the change inland use pattern and the trend of the landscape type transfer in the study area can be inferred. Combined with the landscape pattern index, we can analyze the landscape pattern changes in different years, compare the pattern of landscape pattern changes over time from2005 to 2018, and study the change characteristics of its landscape fragmentation degree, dominance, heterogeneity, landscape complexity, landscape density, and other characteristics, which is meaningful for studying the dynamic changes of landscape pattern as well as the evolution and direction of the landscape in the Yellow River Delta region, and provide technical and data support for the changes in the landscape types and rational use of land resources in the Yellow River Delta region. At the same time, it has a positive effect on regulating the conflicts among society, economy, and resources, and promoting the healthy and stable development of the Yellow River Delta region.

2. Study Area Overview and Data Sources

The Yellow River Delta region is where the Yellow River meets the sea, with sediment in the Bohai Sea depressions formed by the alluvial plain. Generally speaking, the "Yellow River Delta" refers to KenliNinghai as the apex, with the north to TaurEstuary as the starting point, and the south to the end of the branch ditch fan-shaped area of about 5400 km^2, most of which is in Dongying City, as shown in Figure 1. It is located in the mid-latitude region, in the warm temperate zone, with cold winters and hot summers, four distinct seasons, and obvious temperature differences. The soil in this area has a high salt content, the natural vegetation is mostly salt vegetation, the distribution of forest trees is limited by the soil topography, forest vegetation is less and more scarce, and herbaceous plant communities are absolutely dominant [20]. The study area is located at 37°16′~38°0′ N, 118°06′~119°18′ E, involving Dongying District, Kenli District, Hekou District, and Lijin County, and the dynamic changes of its landscape pattern were studied.

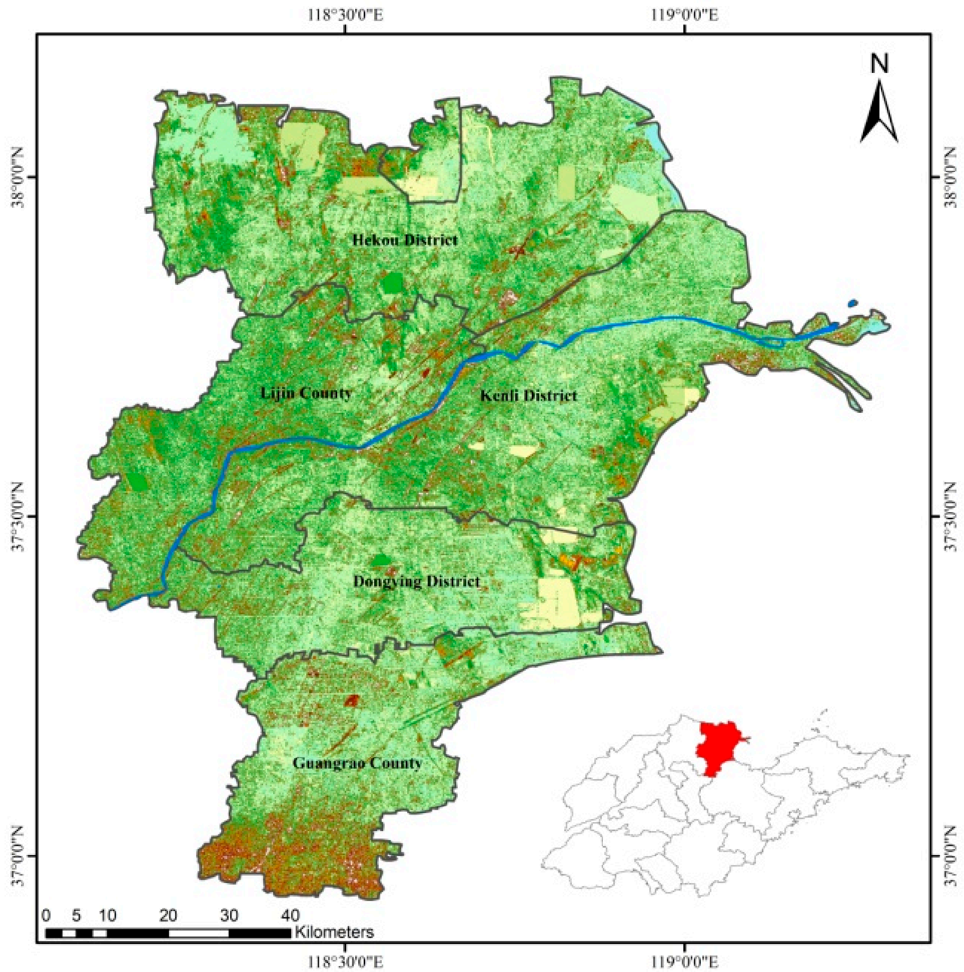

Figure 1. Overview of the study area.

The 2005, 2012, and 2018 Landsat remote sensing image data of the Yellow River Delta region used in this study were downloaded from the Geospatial Data Cloud website (https://www.gscloud.cn/, accessed on 5 December 2022) with a resolution of 30, and the remote sensing effects of similar study months and no clouds were selected to enhance the accuracy of the data. According to the research needs, the Landsat images were pre-processed using ENVI5.31 and the processed Landsat images were supervised and classified into eight major landscape types: grassland, cropland, construction land, woodland, waters, mudflats, salt fields and breeding ponds, and unused land. The textual information was obtained from the Dongying Statistical Yearbook and literature related to the Yellow River Delta region and the changes in landscape patterns.

3. Research Methodology

(1) Dynamic degree

The dynamic degree can reflect the way of quantitative changes of multiple landscape types such as the spatial changes of different landscape types and the way the landscape is combined over a period of time [21], and is an index that characterizes the dynamic changes of landscape types and can be used to describe the rate of change of landscape types [22]. The expression of the dynamic degree is as follows.

$$\mathrm{Ki} = (\mathrm{Sit1} - \mathrm{Sit2})/\mathrm{Sit1} \times 1/(\mathrm{t2} - \mathrm{t1}) \times 100\%$$

In the expression, Ki is the dynamic degree of type i landscape type in the study period; Sit1 and Sit2 are the area of type i landscape at t1 and t2; t1 and t2 are the beginning of the study period and the end of the study period.

(2) Landscape type transfer matrix

The landscape type transfer matrix can be used to describe the transfer in and out of each landscape type, to calculate the area of interconversion between different landscape types, and to describe the structural characteristics and the direction and degree of the change of landscape type conversion during the study time to express the process of landscape change [23,24]. ArcGIS software was used to intersect the landscape data and calculate the area, and an Excel pivot table was used to produce the landscape type transfer matrix. The expressions are as follows.

$$\mathrm{S_{ij}} = \begin{bmatrix} \mathrm{S_{11}} & \cdots & \mathrm{S_{1n}} \\ \vdots & \ddots & \vdots \\ \mathrm{S_{n1}} & \cdots & \mathrm{S_{nn}} \end{bmatrix}$$

In the expression, S is the area; n is the number of different landscape types; i and j are the landscape types at the beginning and end of the study period.

(3) Landscape pattern index

The landscape index method is a more mature research method in landscape pattern research, which mainly uses the landscape pattern index to describe the pattern of the landscape and its changes [25]. The landscape pattern index reflects the structural composition and spatial pattern of the landscape, and is a high concentration of landscape information [26]. The landscape index was selected to represent the characteristics of all aspects of the landscape, and the index was not redundant to also take the index selection of other related landscapes as a reference [27,28], as shown in Table 1. In this paper, the largest patch index (LPI), edge density (ED), landscape shape index (LSI), perimeter area fractal dimension (PAFRAC), patch cohesion index (COHEOSION), patch density (PD), and aggregation index (AI) were selected as landscape pattern indices to study the landscape pattern characteristics of the study area in combination with the landscape characteristics of the Yellow River Delta region, in order to reflect the landscape pattern characteristics of the study area and studied to reflect the fragmentation, dominance, heterogeneity, connectivity and aggregation of the study area.

Table 1. Landscape index and meaning.

Landscape Index	Abbreviations	Analytical Scale	Meaning
Largest patch index	LPI	Type/landscape	Describe the percentage of the area of the largest patch of a landscape
Edge density	ED	Type/landscape	Describe the extent to which the landscape is divided by boundaries
Landscape shape index	LSI	Type/landscape	Describe the complexity of the plaque shape
Perimeter area fractal dimension	PAFRAC	Type/landscape	Describe landscape shape features
Patch cohesion index	COHESION	Type/landscape	Describe the degree of connectivity between different landscape types
Patch density	PD	Type/landscape	Describe the degree of fragmentation of the landscape
Aggregation index	AI	Type/landscape	Describe the degree of aggregation of the landscape

(4) Relationship between the landscape pattern index and landscape type transfer matrix

The landscape type transfer matrix can provide an in-depth analysis of the changing characteristics of the landscape type structure and the direction of landscape type transfer, and can describe the landscape types at the beginning and end of the study period as well as the changes and directions of the landscape types within the study period and the relationship between the landscape types and each other [12,29]. The landscape pattern index is a general study and quantitative reflection of the characteristics of different aspects of the landscape, condensing the landscape pattern information and reflecting the landscape structure and spatial configuration, being the spatial characteristics of the landscape and the impact of human or natural including disturbances on ecological processes at different scales, being the comprehensive reflection of the impact of human or natural factors interacting in a certain ecological environment [5,29]. Both the landscape pattern index and the landscape transfer matrix describe changes in landscape types, and they are related in some way. The landscape type transfer matrix expresses the landscape transfer area in the form of a matrix to show the transformation of landscape types during the study period, and the landscape pattern index is a summary of the landscape pattern changes by selecting different indices. Both the landscape pattern index and the landscape type transfer matrix are quantitative descriptions of the landscape type changes and quantitative analysis of landscape characteristics, spatial configuration, and structural characteristics, both of which are reflections of the landscape type transformation laws and quantitative descriptions of the state of landscape types and state changes.

4. Data Analysis

4.1. Spatial Distribution of Landscape Types

Over the study period, the area of all types of landscapes in the Yellow River Delta region has changed with the socio-economic development and environmental changes in its spatial distribution, area and proportion, as shown in Table 2 and Figure 2. In terms of landscape types, the area of cropland was the largest throughout the study period, and cropland was mainly concentrated in the center and southwest of the study area, with a wide spatial distribution, although the change in the area of cropland showed a trend of first increasing and then decreasing. Compared with 2005, the area of cropland decreased in 2018, but it was still the most dominant landscape type in the Yellow River Delta region. The area of three types of landscape types, namely, grassland, construction land, salt fields, and breeding ponds, showed an increasing trend, with the largest increase in the area of salt fields and breeding ponds, which was mainly concentrated in the coastal area, with a zonal distribution and a more concentrated distribution increasing by 536.03 km^2 during the study period. The second was construction land, which is mainly distributed in the southeastern part of the study area and is more concentrated, but there is also a more sporadic distribution in the northern part of the study area, and its area has a trend of gradual expansion, with an increase of 294.83 km^2 during the study period. The landscape type with the smallest increase in area was grassland, which is mainly located in the inlet area, with an increase in area of 13.40 km^2 during the study period, increasing year by year and with an increasing proportion. The area of the four landscape types, namely, woodland, waters, mudflats, and unused land, showed a decreasing trend during the study period. The area that decreased most was unused land, which was mainly distributed in the northern part of the study area, with the development of unused land gradually being exploited and transformed into cropland, construction land, salt fields, and breeding ponds, where the area decreased by 496.22 km^2.The second was mudflats, which are mainly distributed in the northern part of the study area, and the inlet area gradually developed into salt fields and breeding ponds, and the area decreased year by year, with a decrease of 261.91 km^2.The third was waters, the spatial distribution of waters was sporadic, and the area decreased year by year, and the area decreased by 45.44 km^2.The last was woodland, which is mainly distributed in the northeastern part of the study area, with sporadic distribution and a decreasing area year by year, with an area reduction of 14.86 km^2.In general, the two landscape types of salt fields and breeding ponds and unused land changed the most, increasing by 536.03 km^2 and decreasing by 496.22 km^2, respectively; the area of grassland and woodland changed very little and can be regarded as basically unchanged.

Table 2. Area of various landscape types in the Yellow River Delta(km^2) from2005 to 2018.

Year	Grassland	Cropland	Construction Land	Woodland	Waters	Mudflats	Salt Fields and Breeding Ponds	Unused Land
2005	97.48	3020.30	569.50	109.04	345.83	441.40	549.71	829.38
	1.63%	50.65%	9.55%	1.83%	5.81%	7.40%	9.22%	13.91%
2012	105.42	3179.38	652.45	105.89	316.18	330.18	895.74	377.40
	1.77%	53.32%	10.94%	1.78%	5.30%	5.54%	15.02%	6.33%
2018	110.88	2994.69	864.13	94.18	300.39	179.47	1085.74	333.16
	1.86%	50.22%	14.49%	1.58%	5.04%	3.01%	18.21%	5.59%

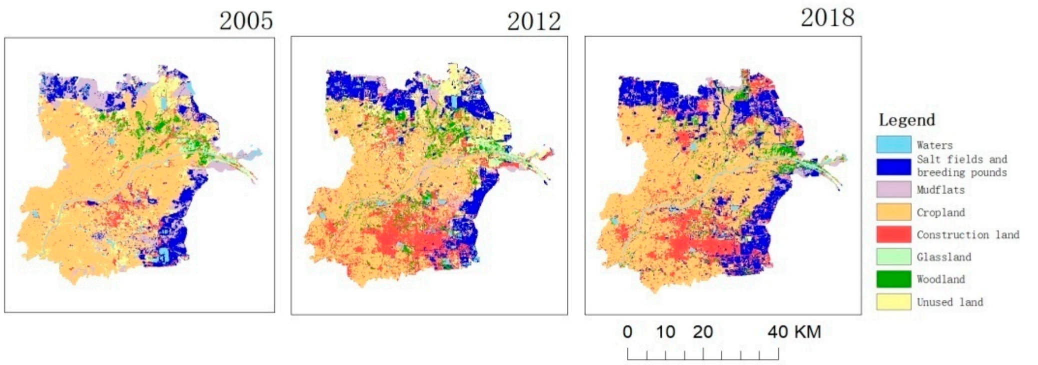

Figure 2. Distribution map of the landscape types.

In terms of year, in 2005, the largest landscape type in the Yellow River Delta region was cropland, and the rest of the landscape types and their proportion were unused land, construction land, salt fields and breeding ponds, mudflats, water, woodland, and grassland; in 2012, the largest landscape type in terms of area and proportion was cropland, and the rest of the landscape types and their proportion were salt fields and breeding ponds, construction land, unused land, mudflats, water, woodland land, and grassland; in 2018, the landscape type with the largest area and proportion was cropland, and the rest of the landscape types and their proportions were, in order, salt fields and breeding ponds, construction land, unused land, water, mudflats, grassland, and woodland. The dynamic degree of each landscape type is shown in Figure 3.During the study period, the proportion of cropland area was above 50%, and its dynamic degree changed less compared with other landscape types at 0.75% and 0.97%, respectively, which shows that cropland is the most dominant landscape type in the Yellow River Delta region. The area of salt fields and breeding ponds also increased greatly during the study period, and the proportion of area reached 18.21% in 2018, almost twice that at the beginning of the study period, which shows that the development and operation of salt fields and breeding have increased in the Yellow River Delta region in recent years; grassland, woodland, and waters showed a small rate of change during the study period, and the dynamic degree was small; the area of grassland showed a trend of expansion, but the expansion rate was slow and the rate of change was slightly reduced, and the dynamic degree changed less, 1.16% and 0.86%, respectively. During the period of 2005–2012, the area of mudflats and unused land decreased significantly, the rate of change of unused land area was faster, with a dynamic degree of 7.79%, the area of salt fields and breeding pounds, cropland, and construction land increased more significantly, and the rate of increase in salt fields and farming ponds area peaked with a dynamic degree of 8.99%, which shows that the development of unused land during this period was more significant, and the development of undeveloped unused land into usable cropland, construction land, etc. During the period of 2012–2018, the area of cropland and mudflats had a large decrease, and the rate of decrease of the area of mudflats accelerated year by year, and the rate of change was the fastest during the period of 2012–2018, with the dynamic degree reaching 7.61%, and the area of construction land, salt fields, and breeding ponds had a relatively large increase, and the area of construction land continued to expand, and the rate of expansion increased year by year, with the dynamic degree during the period of 2012–2018 reached 5.41%,while the area of unused land had a small decrease, which shows that there is still more space for the development of mudflats, which can be used as salt fields and breeding ponds, etc., while the space for the development of unused land is small, with a decrease of only 44.24 km^2, and the area of cropland also had a large reduction. It can be seen that during the period of 2012–2018, the Yellow River Delta region adopted certain fallowing projects to increase the area of woodland and grassland or slow down its area reduction; moreover, due to the social and economic development, the area for construction increased, and the area share increased more.

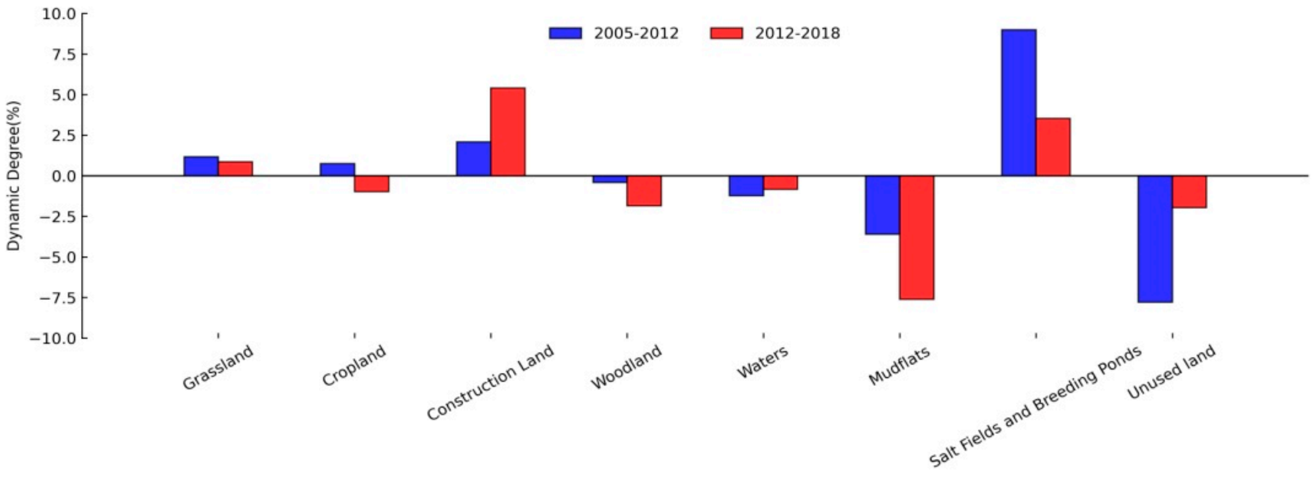

Figure 3. Dynamic degree of landscape type.

4.2. Landscape Type Transfer Matrix

The landscape type transfer between 2005 and 2012 is shown in Table 3.During the period of 2002–2012, the largest increase in the area of salt fields and breeding ponds was 346.03 km^2, whose transferred-in and transferred-out areas were 257.80 km^2 and 40.63 km^2, respectively, and their increase mainly came from mudflats, which reached 152.42 km^2. The next largest increase in the area of cropland was 159.08 km^2, whose transferred-in and transferred-out areas were 187.93 km^2 and 340.95 m^2, and the increase in cropland area was mainly from unused land and construction land. The area of construction land increased by 78.92 km^2, and the area transferred-in and -out was 292.84 km^2 and 67.53 km^2, respectively, while the increase in its area mainly came from cropland, whose area was 241.83 km^2, and unused land was also partly transferred to construction land, but the area was smaller (28.09 km^2), which shows that with the development and expansion of cities, the demand for construction land increases. Therefore, it can be seen that with development and urban expansion, the demand for construction land became greater and greater, and part of the cropland was transformed into construction land to meet the expansion of urban development. The area of mudflats decreased, its turn-out area was 186.36 km^2, and its main turn-out direction was salt fields and breeding ponds, with an area of 152.42 km^2, so it can be seen that the difficult-to-use mudflats can be utilized through the development of salt fields and breeding industry. The decrease in unused land was the greatest at 451.98 km^2, and its transferred area was 156.51 km^2 and its main transfer direction was cropland, construction land, salt fields and breeding ponds, with areas of 83.62 km^2, 28.09 km^2, and 33.19 km^2, respectively, which shows that the main development direction of unused land between 2005 and 2012 was cropland. The turn-out area of the waters was 85.03 km^2, and the main turn-out direction was salt fields and breeding ponds, whose area was 48.91 km^2, and the salt fields and breeding ponds were the main development and utilization directions of the waters. The area of grassland slightly increased and the area of woodland slightly decreased, but the area of grassland and woodland changed less, and their transferred-in and transferred-out areas were 39.59 km^2 and 47.48 km^2, 40.62 km^2, and 37.51 km^2, respectively, and the transferred-in and transferred-out areas basically remained balanced. In general, the area of salt fields and breeding ponds increased more and changed at a faster rate, mainly transformed from waters and mudflats. The current direction of unused land development is mainly cropland, but the construction land needed for development mainly originates from cropland, and the future direction of unused land development can be inclined to construction land.

Table 3. The Yellow River Delta landscape type transfer matrix for2005–2012.

2005 / 2012	Grassland	Cropland	Construction Land	Woodland	Waters	Mudflats	Salt Fields and Breeding Ponds	Unused Land
Grassland	0	4.55	0.13	21.25	5.64	7.25	0.13	0.64
Cropland	22.38	0	56.8	12.89	2.96	7	2.27	83.63
Construction land	1.06	241.83	0	0.32	8.12	5.55	7.87	28.09
Woodland	7.92	25.8	0.54	0	0.47	0.26	0.07	5.56
Waters	3.77	40.22	5.49	1.08	0	7.48	13.15	0.81
Mudflats	10.05	3.41	0.21	1.45	12.74	0	14.85	4.59
Salt fields and breeding ponds	1.44	18.56	2.95	0.33	48.91	152.42	0	33.19
Unused land	0.86	6.58	1.41	0.19	6.19	6.4	2.29	0

The landscape type transfer between 2005 and 2012 is shown in Table 4. During the period 2012–2018, the largest increase in the area of land for construction was recorded, with an area increase of 221.68 km^2, whose transferred-in and transferred-out areas were 341.95 km^2 and 81.07 km^2, respectively, and whose increase mainly originated from cropland, whose area was 299.41 km^2, accounting for 87.56% of the transferred-in area. This was followed by salt fields and breeding ponds, which increased by 190.00 km^2, with their transferred-in and transferred-out areas of 201.28 km^2 and 67.78 km^2, respectively, and the increase in their areas mainly came from mudflats, with an area of 121.66 km^2, and the area of mudflats converted to salt fields and breeding ponds decreased compared to the period 2005–2018. The area of cropland decreased the most (184.69 km^2), and the area of cropland transferred-out was the largest (372.63 km^2), with the main transfer direction being construction land. The area of mudflats transferred-out was197.82 km^2, mainly in the direction of salt fields and breeding ponds, accounting for 61.50% of the transferred area, and the remaining part was mainly converted into water, with an area of 33.33 km^2. The area of unused land transferred-out was68.17 km^2, and its main transfer directions were construction land, water, salt fields, and breeding ponds. The area of waters decreased, but the reduction decreased, and the area transferred-in and-out of waters was 124.31 km^2 and 87.7 km^2, respectively, and the main sources of the transferred area were cropland, mudflats, salt fields, and breeding ponds. The difference between the transferred-in and transferred-out area of grassland was relatively small, and the transferred-in area mainly came from woodland; the transferred-in and transferred-out area of woodland were 23.30 km^2 and 52.23 km^2, respectively, and the main transferred-out direction was grassland and cropland.

Table 4. The Yellow River Delta landscape type transfer matrix for 2012–2018.

2012 / 2018	Grassland	Cropland	Construction Land	Woodland	Waters	Mudflats	Salt Fields and Breeding Ponds	Unused Land
Grassland	0	11.42	0.93	24.84	0.74	13.84	0.46	1.48
Cropland	13.49	0	59.58	21.71	23.13	10.97	1.39	11.57
Construction land	0.74	299.41	0	2.52	9.84	8.81	6.09	14.54
Woodland	7.37	12.34	0.56	0	0.59	0.77	1.26	0.41
Waters	3.17	26.97	8.34	1.15	0	33.33	36.12	15.23
Mudflats	7.06	8.77	1.6	1.62	7.03	0	19.37	10.34
Salt fields and breeding ponds	1.41	12.54	8.61	0.37	42.09	121.66	0	14.6
Unused land	0.77	1.18	1.45	0.02	4.28	8.44	3.09	0

In summary, the transfer in and out of landscape types during the study period is shown in Figure 4, the largest areas of cropland, mudflats, and unused land were transferred-out during the study period, with 713.58 km^2, 384.18 km^2, and 224.68 km^2, respectively. Salt fields and breeding ponds and construction land increased the most, and the increase in the area of salt fields and breeding ponds mainly came from mudflats and waters, which shows that salt fields and breeding ponds can be an important way to develop waters and mudflats. the increase in the area of construction land mainly comes from cropland, so urban development will sacrifice some cropland; the main conversion direction of unused land is cropland and construction land, but the area of unused land transferred out during 2012–2018 is smaller than that during 2005–2012, and the development and utilization of unused land still needs to be improved; grassland and woodland were basically balanced between 2005 and 2012, while during 2012–2018, the area transferred from grassland was higher and the area transferred from woodland was greater, and the main transfer direction of woodland was grassland, and the area of grassland increased year by year and the area of woodland decreased year by year, which shows that the Yellow River Delta region is more suitable for herbaceous plants.

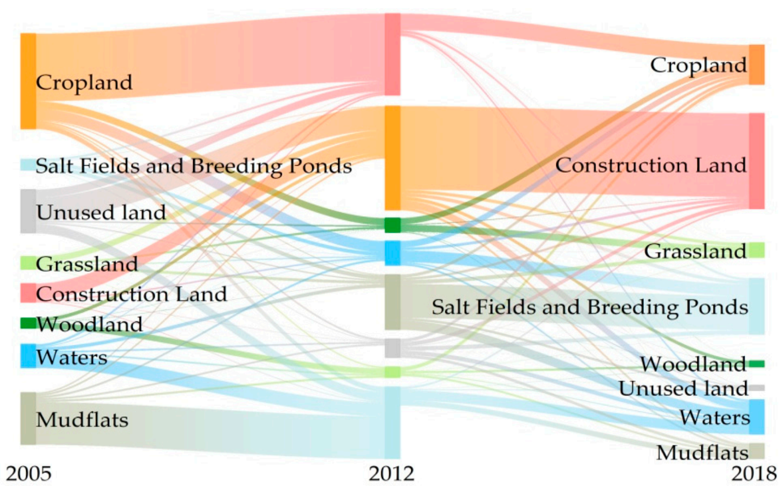

Figure 4. Separate mulberry map of the landscape type transfer matrix.

4.3. Landscape Pattern Index

Landscape pattern index is the change and summary of the landscape pattern, select different landscape pattern index can be summarized on different sides of the landscape characteristics, in order to reflect the landscape pattern change pattern, the selection and analysis of the landscape pattern index as shown in Table 5.

Table 5. Landscape pattern index.

Landscape Type	Year	LPI	ED	LSI	PAFRAC	COHESION	PD	AI
Grassland	2005	0.48	0.43	10.66	1.41	93.6	0.01	78.63
	2012	0.54	0.95	13.65	1.46	92.15	0.02	72.88
	2018	0.39	0.45	10.66	1.41	93.23	0.01	79.7
Cropland	2005	29.98	5.78	27.21	1.48	99.85	0.02	89.49
	2012	53.34	9.91	27.02	1.48	99.86	0.04	89.88
	2018	28.65	5.9	27.83	1.43	99.82	0.03	89.24
Construction Land	2005	1.72	3.07	35.92	1.42	93.67	0.11	63.7
	2012	3.39	6.65	40.16	1.49	92.5	0.22	65.13
	2018	3.35	4.12	36.21	1.44	95.44	0.12	72.76
Woodland	2005	0.42	0.63	13.88	1.48	91.98	0.01	74.43
	2012	0.37	1.07	15.77	1.5	91.37	0.02	66.74
	2018	0.15	0.43	12.99	1.42	88.7	0.01	66.25
Waters	2005	0.62	2.35	31.9	1.45	85.74	0.09	63.8
	2012	0.85	3.29	28.61	1.42	86.53	0.12	65.02
	2018	0.34	2.08	31.21	1.42	86.43	0.12	59.99
Mudflats	2005	1.49	1.31	17.2	1.41	96.04	0.03	83.39
	2012	1.66	1.66	15.89	1.42	95.56	0.05	81.66
	2018	0.65	0.86	18.2	1.45	92.66	0.04	71.57
Salt Fields and Breeding Ponds	2005	2.23	1.07	12.42	1.34	97.57	0.02	89.04
	2012	6.99	1.98	10.89	1.33	98.3	0.03	92.61
	2018	4.95	1.08	9.37	1.32	98.53	0.02	94.36
Unused land	2005	2.31	2.92	25.33	1.45	96.21	0.06	81.43
	2012	1.01	2.6	20.59	1.43	92.98	0.06	77.08
	2018	0.51	1.97	26.16	1.43	89.7	0.07	70.26

LPI(largest patch index) denotes the percentage of the largest patch area in a certain landscape. During the study period, the LPI value of cropland was the largest, which shows that the dominance of cropland was the most obvious among all landscape types in the Yellow River Delta region, but the dominance of cropland showed a trend of increasing and then decreasing between 2005 and 2018, and the magnitude of change was large. The LPI of construction land increased year by year, which shows that the dominance of construction land increased due to economic development; the LPI of the salt fields and breeding ponds increased significantly in 2012from 2.23 to 6.99, and then decreased in 2018, presumably because salt fields and breeding ponds were the focus of development and utilization from 2005 to 2012.The LPI of woodland and unused land decreased year by year, and with the development of unused land, the proportion of their patch area decreased, and the dominance decreased, while the LPI of grassland, water, and mudflats showed a trend of first increasing and then decreasing. The LPI of grassland, watershed, and mudflats showed a trend of increasing and then decreasing, and the overall dominance was decreased during the study period.

ED (edge density) denotes the extent to which the landscape is fragmented by boundaries [30], and larger ED values indicate more complex patch shapes and a higher degree of fragmentation. During the study period, the ED value of cropland was the largest, and its landscape fragmentation was the largest, and its spatial heterogeneity was also the largest, with the most well-preserved internal features and less influenced by the outside world [21].The ED of the unused land decreased year by year, which shows that it is disturbed by human activities and its heterogeneity decreases, and it is more disturbed by the outside world. Except for unused land, the edge density of all landscape types showed a trend of first increasing and then decreasing.

The LSI (landscape shape index) denotes the complexity of the patch shape; the higher the LSI value, the more complex the landscape shape, and the lower the LSI value, the more simplistic the landscape tends to be [31]. The LSI of construction land was the highest and the landscape shape was the most complex. Although the LSI value first increased and then decreased, the LSI of construction land was higher than other landscape types during the study period. The LSI of the salt fields and breeding ponds decreased year by year, which shows that the complexity of their patch shape decreased and tended to be more holistic and large-scale, while the LSI of grassland and woodland first increased and then decreased, and the LSI of water, mudflats, and unused land first decreased and then increased, so the overall complexity tended to be simpler [31]. The LSI of grassland and woodland increased and then decreased, while the LSI of water, beach, and unused land decreased and then increased and the overall complexity changed less. In contrast, the LSI of cropland changed very little, ranging from 27.02 to 27.83, and the complexity of the landscape remained almost unchanged.

The more PAFRAC (perimeter area fractal dimension) converges to 1, the more homogeneous the landscape form and the greater the degree of human interference [21]. The PAFRAC of salt fields and breeding ponds tended to be the closest to 1 among all landscape types and decreased year by year, which shows that they are developing toward homogeneity year by year. The PAFRAC of cropland, water, mudflats, and unused land also decreased year by year, and the greater the degree of human interference, the PAFRAC of grassland, construction land, and woodland showed a trend of first increasing and then decreasing, and the degree of the landscape homogeneity decreased and then increased, and the PAFRAC of woodland was larger, reaching the maximum of 1.50 in 2012, and the landscape morphological patches were also the most complex and the least disturbed by human beings.

COHESION (patch cohesion index) denotes the degree of connectivity between different landscape types and indicates the physical connectivity of landscape patches, where the larger the value, the stronger the landscape connectivity [31]. The highest connectivity index was found for cropland, up to 99.86, which showed the best natural connectivity of cropland; the connectivity index of woodland, mudflats, and unused land decreased year by year, and the connectivity decreased due to the cut of the developed and used landscape [21].The connectivity index of grassland and construction land showed a trend of increasing and then decreasing, and the connectivity index of water, salt fields and breeding ponds increased year by year, but the change was smaller.

PD (patch density) denotes the degree of fragmentation of the landscape; the higher the patch density, the greater the fragmentation of that landscape type [32]. The PD of construction land was the largest, with a maximum patch density of 0.22 in 2012, and there was a significant decrease in the PD of construction land between 2012 and 2018, indicating that the utilization rate of construction land had climbed [33].The PD of water and unused land showed an increasing trend and the degree of fragmentation increased; cropland, construction land, forest land, mudflats, salt fields, and breeding ponds all decreased in PD between 2012 and 2018, with less fragmentation, a tendency to complete the landscape, and an increase in utilization.

AI (aggregation index) denotes the degree of aggregation of the landscape and reflects the interconnectedness of each landscape; the higher the AI, the denser the landscape, and vice versa, when it is more dispersed [22]. The AI of cropland was the highest and hardly changed during the study period, which shows that the degree of aggregation of cropland is high and stable. In contrast, the AI of woodland, water, mudflats, and unused land decreased year by year, which shows that the degree of aggregation of the landscape decreased and became more and more scattered, among which the AI of water was the lowest and also decreased continuously. For construction land, salt fields, and breeding ponds, the AI increased year by year, which shows that the plots needed for development gradually gathered and facilitated centralized development. For grassland, the degree of aggregation first decreased and then increased, and the landscape density of grassland did not change significantly at the beginning and end of the study period.

5. Conclusions and Discussion

(1) Cropland is the most dominant landscape type in the Yellow River Delta region, with a relatively concentrated distribution, reaching more than 50% of the total area. The landscape types with the largest increase in area during the study period were salt fields and breeding ponds and construction land, with an increase of 536.03 km^2 and 294.83 km^2, respectively; the area share of salt fields and breeding ponds was second only to that of cropland since 2012 and widely concentrated in coastal areas, while the area for construction has increased more steadily, with the third largest area share, and its dynamic degree has continued to grow and expand at a higher rate. Furthermore, the area of unused land decreased significantly, reduced to 40.17% of the area at the beginning of the study period, which shows that the unused land had been developed and used for development and construction during 2005–2018, but the dynamic degree of unused land decreased, the rate of less area slowed down, and the rate of development of unused land decreased. The area of mudflats decreased by 291.91 km^2 during the study period, and the dynamic degree of mudflats continued to increase with a faster rate of change and a higher potential for development and utilization. The dynamic degree of construction land also continued to grow and expand at a higher rate, while the dynamic degree of salt fields and breeding ponds and unused land was the highest from 2005 to 2012, which shows that the development of unused land was more concentrated.

(2) During the study period, the landscape of cropland, mudflats, and unused land had the largest area of turn-out, with more obvious dynamic changes, and the main transfer-out of cropland was in the direction of construction land, which shows that the expansion of the city has taken up some of the cropland, and the area of cropland converted to grassland increased between 2012 and 2018, which has strengthened ecological restoration measures such as returning cropland to grass to a certain extent. The main direction of the turning out of unused land was from cropland to construction land, and the area turned into grassland and waters increased more. It was presumed that the area of unused land suitable for reclamation into cropland was reduced, and more unused land was used for urban construction and ecological construction. The area of salt fields and breeding ponds increased mainly from mudflats and waters, which were expanded and concentrated, and the development of salt fields and breeding industry can be regarded as the main development direction of waters in the Yellow River Delta region. During the study period, the landscape types constantly changed and there were complex interconversions between the landscapes as urbanization progressed.

(3) The connectivity index of each landscape type in the Yellow River Delta region was high and the difference between different landscape types was small, which shows that the connectivity between landscapes is good. Cropland in the study time period foreach landscape index was stable, with a small change; the LPI of construction land increased year by year, its dominance increased, and during 2012–2018, the construction land tended to be a simple landscape, and the utilization rate improved, the degree of aggregation increased, it can be seen that urban development was greater and more concentrated. The salt fields and breeding ponds also developed in the direction of homogenization and aggregation, and mudflats and unused land after development and utilization, the heterogeneity of mudflats, unused land were reduced after development and utilization,, and the degree of external influence became bigger, and the landscape form developed in the direction of complexity, fragmentation, and dispersion For the area of woodland, this decreased year by year and the maximum patch area also decreased, while the heterogeneity and complexity

of the landscape first increased and then decreased, but the overall trend was one of decrease, and the landscape dispersion of woodland also became higher, which shows that the Yellow River Delta region is not suitable for forestry development, but also to pay attention to the protection of existing woodland.

Author Contributions: Conceptualization, L.L. and X.L.; Data curation, L.L. and Z.Z.; Funding acquisition, X.L. and B.N.; Investigation, B.N. and Z.Z.; Methodology, Z.Z. and L.L.; Software, Z.Z.; Validation, B.N. and X.L.; Writing—original draft, L.L.; Writing—review and editing, X.L. and L.L. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was supported by the National Natural Science Foundation of China (No. 41807004 and No. 42077446).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in this article.

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

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