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TEMPORAL AND SPATIAL EVOLUTION CHARACTERISTICS OF LAND USE AND LANDSCAPE PATTERN IN KEY WETLAND AREAS OF THE WEST LIAO RIVER BASIN, NORTHEAST CHINA

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Highlights

- The wetland resources area in the West Liao River Basin is drastically reduced from 1985 to 2015.
- The CONTAG index of each research area is showing an upward trend, indicating that it is increasingly controlled by the dominant landscape types.
- The main driving force of the landscape pattern evolution in West Liao River Basin are insufficient water resources and intensified human disturbance.

Abstract. The impact of the wetland ecosystem on arid and semi-arid areas is much higher than that in humid areas. It plays a more significant role in regulating climate, conserving water sources, purifying water bodies, and protecting biodiversity. The West Liao River Basin is located in a moderately temperate, semi-arid, and continental monsoon climate-sensitive area, with a fragile ecological environment. Climate warming and drought have gradually caused dry-flow of some river sections in the basin, reduction in the water area, shrinking of wetlands, degradation of vegetation ecological function, and decline of biodiversity. Ultimately, the effect of ecological barriers is significantly weakened. The research of the temporal and spatial evolution of landscape patterns and their relationship with human activities in arid and semi-arid regions is of great significance for the protection and restoration of wetland resources. Based on Landsat remote sensing images in 1985 and 2015, the temporal and spatial evolution of landscape patterns in four key wetland areas in the West Liao River Basin was studied by 3S technology and landscape ecology indexes. Results show that during the 30a years, the wetland resources area in the West Liao River Basin is drastically reduced. Wetland resources of the four study areas, the Dalinor, the Saihanwula, the Hongshan Reservoir, and the West Liao River Estuary, were decreased by 13.80%, 31.06%, 61.10%, and 66.03%, respectively. The reduced wetland resources in the Dalinor and the Saihanwula were mainly converted into grassland, while those of the Hongshan Reservoir and the West Liao River Estuary were mostly converted into farmland. The diversity and evenness indexes of landscape in the Hongshan Reservoir and the West Liao River Estuary are gradually decreasing. The diversity and evenness indexes of the Dalinor and the Saihanwula are not significantly changed but are slightly disturbed by human activities. Changes in the landscape pattern index highlight the decrease in the water area, the increase in the area of dry and paddy fields, and the improvement of sandy land. All these further reflect that insufficient water resources supplementation and increasing human disturbance have a profound impact on the landscape pattern, which has also become the main driving force for the evolution of the landscape pattern in the West Liao River Basin.

Keywords: key wetland areas, land use, landscape pattern, West Liao River Basin.

Introduction

Wetland, known as "the kidney of the Earth", "the cradle of life and civilization", and "the gene pool of species", is listed as one of the three major ecosystems in the World Conservation Strategy, together with forests and oceans (Editorial Committee, 2009; Lü et al., 2018). Wetland is a unique ecosystem formed by the interaction of land and water, and it has the attributes of terrestrial ecosystem and water ecosystem. It offers a variety of resources for human living and production and has functions such as climate

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regulation, water conservation, and purification. And at the same time, it plays a crucial role in biodiversity conservation, which has a great significance in the healthy development of the ecological environment (Zhang et al., 2016a, 2016b; Gong et al., 2012).

The impact of the wetland ecosystem on arid and semi-arid areas is much higher than that in humid areas. Wetlands in this climate zone are scattered, with small patch areas and relatively scarce water resources. Therefore, wetland ecosystems are more vulnerable to external factors (Gao et al., 2009; Yang, 2019). In recent years, due to the dual constraints of the natural environment and human production and living, wetland ecosystems in arid and semi-arid areas have become fragile and sensitive, and wetland structure and ecological functions have been degraded significantly (Song et al., 2017). Therefore, research on the evolution of landscape patterns of wetland ecosystems in arid and semi-arid regions is of far-reaching significance in maintaining the sound development of the wetland ecological environment (Xiao et al., 2010; Wu, 2007). The West Liao River Basin is located in a moderately temperate, semi-arid, and continental monsoon climate-sensitive area, with little precipitation and severe drought. Affected by multiple factors, the current ecological and environmental problems of some river sections such as dry-flow, reduction of water area, shrinking of wetlands, degradation of vegetation ecological function, and decline of biodiversity are becoming more and more prominent. All of these are posing a major threat to the ecological environment and sustainable economic development of the river basin (Zhang et al., 2017).

Land-use change is the main manifestation of changes in terrestrial landscape ecosystems (Li et al., 2012; Wang et al., 2014a), and is also one of the most important responses of global environmental changes and terrestrial ecosystems to global climate change and human activities. It has become one of the core themes of global change research (Liang et al., 2010; Xie, 2008). The landscape pattern can reflect the spatial pattern, size, and shape of the landscape, and the spatial distribution and combination of patches (Du et al., 2018; Wei et al., 2018). The landscape index highly condenses the landscape pattern information and is a simple quantitative index to describe the characteristics of its structural composition and spatial configuration (Gao & Bi, 2010). With the continuous development of landscape ecology, landscape ecology methods have been widely used in land-use change and wetland type succession (Zhou et al., 2020). In this paper, the four most representative wetland ecological key areas in the West Liao River Basin are selected as the research objects, based on the interpretation of high-resolution remote sensing images. This paper analyzes the land-use change and the evolution of wetland landscape patterns in the key wetland areas of the West Liao River Basin, aiming to provide references for the ecological environment protection, utilization, and restoration of the wetlands in this area.

1. Overview of the study areas

The main body of the West Liao River Basin is located in Chifeng City and Tongliao City in the southeast of Inner Mongolia and covers Pingquan and Weichang of Hebei Province, Horqin Right Wing Middle Banner of Inner Mongolia, Jianping of Liaoning Province, part of Tongyu, and Shuangliao of Jilin Province, China (Figure 1). The West Liao River Basin is located in the inland and due to the limitation of precipitation, its wetland ecosystem is very fragile. In this study, four representative key wetland areas with the most abundant wetland resources were selected as the study areas, covering the upper, middle, and lower reaches of the West Liao River Basin. They are as follows: 1. The Dalinor National Nature Reserve (1182.98 km^2): a comprehensive nature reserve with rare birds and diverse landscapes such as lakes, wetlands, sand, grasslands, and

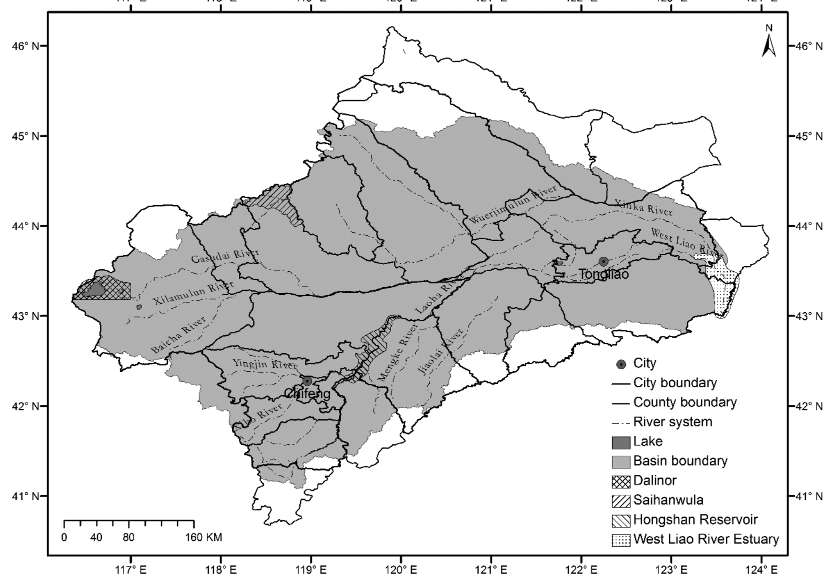

Figure 1. The location of the study areas

woodlands; 2. The Saihanwula National Natural Reserve (1005.68 km^2): a comprehensive nature reserve with rare and endangered wild animals and plants and diverse landscapes such as forests, grasslands, sandy lands, and wetlands; 3. Hongshan Reservoir (1148.31 km^2): is the largest reservoir in the West Liao River Basin. The "Xiaoheyan wetland bird nature reserve" is located in this area, mainly composed of birds and wetlands; 4. The reach area of the West Liao River Basin before it flows into Liao River (1548.27 km^2).

2. Data and research method

2.1. Data source and preprocessing

2.1.1. Data source

The research data in this paper is the remote sensing image data taken by the American land satellite Landsat-5 TM and Landsat-8 OLI in two phases (July-August in 1985 and 2015), with a spatial resolution of 30 m. The image data is downloaded from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/) and the geospatial data cloud website (http://www.gsloud.cn/). The field survey data mainly takes the research wetland type areas as the main survey objects. Google Earth satellite imagery is also used.

2.1.2. Remote sensing data preprocessing

The division of landscape types is the primary link in the evolution and dynamic analysis of landscape patterns, and determining the appropriate basic taxonomic unit is critical for landscape ecological research (Zhang et al., 2003; Chen et al., 2010). The land use classification system has a clear classification significance in geoscience research, and its dynamic changes can directly reflect the evolution of landscape patterns. First, the remote sensing image is segmented at multiple scales, and then the object-oriented classification method is used to interpret the land use types. The interpretation includes wetlands (swamps: grass wetland, shrub wetland, forest wetland), beach land, water

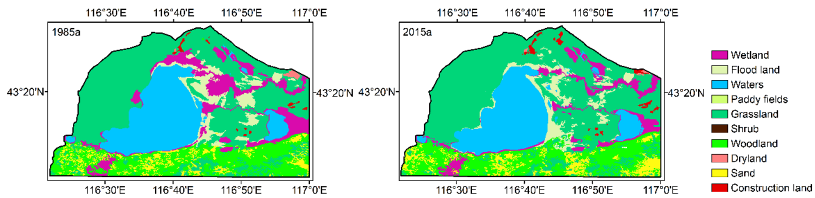

Figure 2. Temporal and spatial evolution of the land use in Dalinor

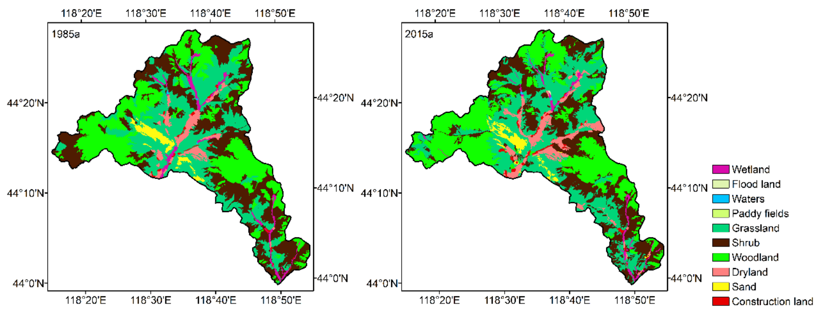

Figure 3. Temporal and spatial evolution of the land use in Saihanwula

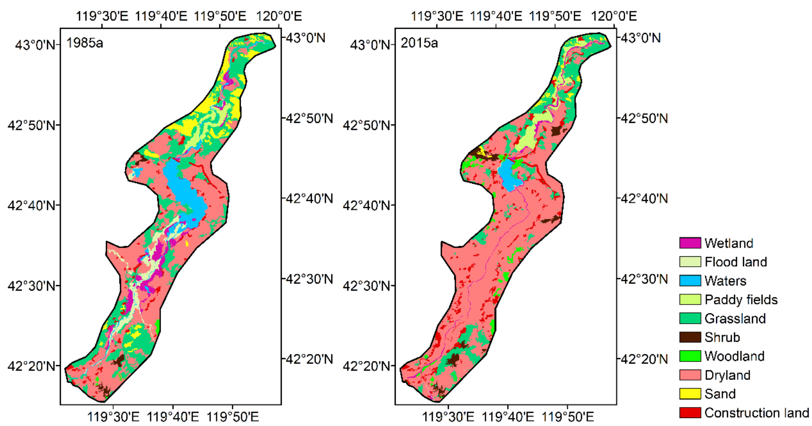

Figure 4. Temporal and spatial evolution of the land use in Hongshan Reservoir

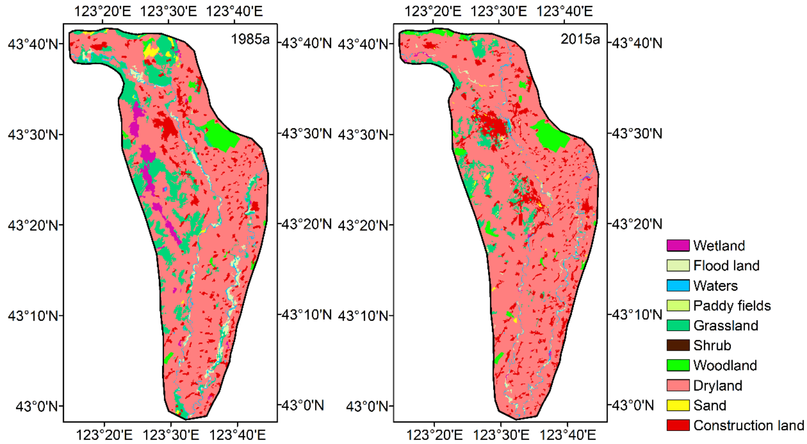

Figure 5. Temporal and spatial evolution of the land use in West Liao River Estuary

area (river, lake, pond), grassland, shrubland, woodland, dry land, paddy field, sandy land, construction land (residential area), Factories, highways, dams, etc.) 10 types, of which wetland includes 4 types of wetland, beach land, water area, and paddy field. Finally, field survey data and drones are used to take aerial images, Google Earth high-resolution images are used to select points, and a confusion matrix is used to evaluate the classification effect, for the purpose of obtaining the total classification accuracy and Kappa coefficient for each year. The result shows that the classification accuracy is greater than 85%, which meets the research requirements. The interpretation results are shown in Figure 2–Figure 5.

2.2. Research methods

2.2.1. Transition matrix method

The land use transfer matrix can describe the mutual transformation of various types and can reflect the structural characteristics of land types and the direction of transfer between types (Shi et al., 2012; Wang et al., 2014b). This paper rasterizes the interpreted vector data of land use types, uses the spatial analysis function of GIS to perform statistical analysis on the area of each land-use type in different periods in the study areas, and constructs the transition probability matrix between different regions. Ultimately, the temporal change characteristics and spatial pattern evolution trend of wetland types in a certain period are analyzed.

2.2.2. Landscape pattern index

The landscape pattern index is a high-level summary of landscape pattern information, reflecting the composition of landscape structure and spatial configuration characteristics, and is one of the important indexes for landscape pattern research (Wu, 2007; Ahlqvist & Shortridge, 2010). Fragstats software includes all commonly used calculation methods of landscape pattern index, which can be analyzed from three levels of patch, type, and landscape. This paper selects the Number of Patches (NP), the Largest Patch Index (LPI), and the Mean Fractal Dimension Index (FRAC_MN) based on the type level. Based on the landscape level, this paper selects the Shannon's Diversity Index (SHDI), Shannon's Evenness Index (SHEI), Contagion Index (CONTAG) to analyze the shape, fragmentation, spatial configuration, and diversity of the landscape in the study area for research. The calculation formula of the landscape index can be found in the literature (Herzog et al., 2001; Hulshoff, 1995).

3. Results and analysis

3.1. Spatio-temporal changes of land use in each study area

3.1.1. Present situation of land use

From the land use of each study areas (see Table 1 and Figure 6), the Dalinor is mainly composed of grassland, which is mainly distributed in the north of the south edge of the Dalinor Lake, with an area of 548.17 km^2 (the data in 2015, the same below), accounting for more than 40%. The waters are mainly composed of the Dalinor Lake, the Ganggengnuo'er Lake, and the Duonuonuo'er Lake, with a total area of 220.97 km^2. The forest land (sparse sand forest) and the sandy land are mainly distributed in the Hunshandake Sandy Land in the south, with an area of 181.60 km^2 and 66.42 km^2, respectively. The wetland and the flood land are mainly distributed around two large lakes, accounting for 6.97% and 6.06%, respectively. The proportion of the farmland and the construction land is very small.

The Saihanwula is mainly composed of forest, shrub, and grass, with a total area of 895.69 km^2, accounting for 89.07%. The farmland, residential area, and wetland are mainly distributed in the river valley, accounting for 5.96%, 1.04%, and 1.78%, respectively. Some flood land and sandy land are scattered.

The Hongshan Reservoir is mainly composed of dryland and grassland, with an area of 722.79 km^2 and 176.85 km^2, totally accounting for 78.34%. The paddy field is mainly distributed in the flood discharge area of the reservoir, accounting for about 4%. Waters (reservoir) and

Table 1. Changes in land use in each study area (km^2)

Land use	Dalinor		Saihanwula		Hongshan Reservoir		West Liao River Estuary	
	1985a	2015a	1985a	2015a	1985a	2015a	1985a	2015a
Wetland	126.07	82.44	26.64	17.90	52.26	21.90	40.57	2.95
Flood land	73.15	71.64	0.00	0.30	54.98	1.80	33.71	13.32
Waters	235.87	220.97	0.50	0.51	91.18	21.24	26.96	18.12
Paddy fields	–	–	–	–	28.17	43.21	–	–
Grassland	495.16	548.17	312.79	322.40	301.29	176.85	213.18	86.65
Shrub	–	–	314.09	265.36	11.58	30.41	–	–
Woodland	189.15	181.60	287.69	307.93	5.53	33.94	38.97	53.78
Dryland	3.62	1.48	36.37	59.94	479.18	722.79	1074.77	1218.27
Sand	55.18	66.42	21.25	20.85	89.87	16.42	11.60	6.23
Construction land	4.78	10.26	6.35	10.49	34.28	79.75	108.51	148.95

Note: – means no such land use, the same below.

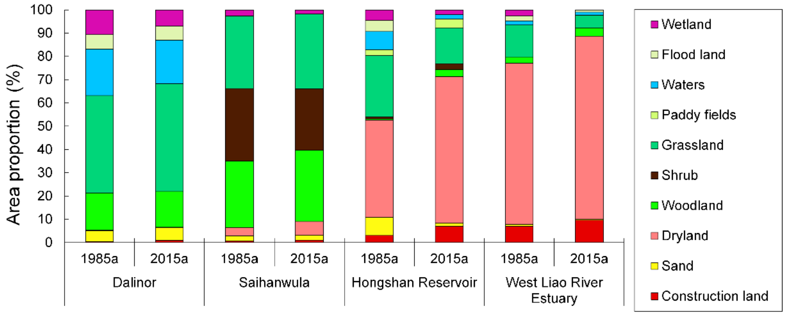

Figure 6. Changes in the proportion of land use in each study area

wetlands account for 1.85% and 1.91%, respectively. The Horqin Sandy Land is on both sides of the flood discharge area, which has been greatly reduced in recent years, accounting for only 1.43%.

The West Liao River Estuary is dominated by farmland, with a total area of 1218.27 km^2 in 2015, accounting for 78.69%. Most towns and villages are built near the river, with a large population density. There are also many residential areas and factories. The construction land accounts for a relatively high proportion of approximately 10%.

3.1.2. Temporal change characteristics of land use

From the perspective of temporal change, the wetland area of each study area showed a significant downward trend in the past 30a years. The wetland of the Dalinor decreased by 43.63 km^2, the Saihanwula by 8.74 km^2, the Hongshan Reservoir by 30.36 km^2, and the West Liao River Estuary by 37.62 km^2. Except for the Saihanwula, the waters of the other three study areas also decreased significantly. Compared with that in the 1980s, it has decreased by 6.32% (Dalinor), 76.71% (Hongshan Reservoir), and 32.79% (West Liao River Estuary) respectively. The area of the paddy field of the Hongshan Reservoir has increased from 28.17 km^2 to 43.21 km^2. A comprehensive analysis of natural wetland and constructed wetland shows that the area of wetland is still shrinking. Except for the Dalinor, which is dominated by animal husbandry, the proportion of farmland (dryland) in other study areas continued to rise. The dryland of the Hongshan Reservoir increased by 243.61 km^2, followed by the West Liao River Estuary, which increased by 143.50 km^2. The forest land changes in each area are relatively stable. The grassland changes are divided into three levels. The grassland area in the forest area (Saihanwula) has basically remained stable, the grassland area in the pastoral area (Dalinor) tends to increase, and the grassland area in the agricultural area (Hongshan Reservoir, West Liao River Estuary) has dropped significantly.

3.1.3. Spatial change characteristics of land use

This paper uses the area transfer matrix to analyze the spatial evolution characteristics of various land use. Table 2 shows the land-use area transfer matrix of the Dalinor. From 1985 to 2015, 36.66% of the wetlands were converted into grassland. 13.03 km^2 of waters turned into flood land and 5.57 km^2 of those turned into wetlands. However, the area converted into waters is only 5.63 km^2, and the waters are reduced as a whole. Forest-grass and forest-sand conversion to each other, and the areas are the same as before. Other land uses have little mutual transformation.

Table 2. Area transfer matrix of Dalinor land use from 1985 to 2015 (km^2)

	Wetland	Flood land	Waters	Grassland	Woodland	Dryland	Sand	Construction land	Total
Wetland	64.43	5.38	3.78	46.22	5.76	0	0.09	0.36	126.02
Flood land	2.31	43.33	1.35	24	2.08	0	0.08	0.04	73.19
Waters	5.57	13.03	215.34	1.9	0.03	0	0.01	0	235.88
Grassland	7.87	7.7	0.5	461.32	10.92	0.22	1.4	5.06	494.99
Woodland	2.17	1.2	0	10.34	147.31	0	28.08	0.16	189.26
Dryland	0	0	0	1.86	0	1.26	0	0.4	3.52
Sand	0.07	1.01	0	1.53	15.99	0	36.74	0	55.34
Construction land	0	0	0	0.55	0	0	0	4.23	4.78
Total	82.42	71.65	220.97	547.72	182.09	1.48	66.4	10.25	1182.98

Note: the matrix element A_{ij} represents the area converted from land-use *i* to *j* from 1985 to 2015.

Table 3. Area transfer matrix of Saihanwula land use from 1985 to 2015 (km^2)

	Wetland	Flood land	Waters	Grassland	Shrub	Woodland	Dryland	Sand	Construction land	Total
Wetland	14.38	0.28	0.14	5.87	0.89	0.14	4.6	0	0.34	26.64
Flood land	0	0	0	0	0	0	0	0	0	0
Waters	0.04	0	0.34	0.07	0.02	0	0.03	0	0	0.5
Grassland	1.64	0.02	0.03	214.49	43.43	20.39	21.73	7.2	3.83	312.76
Shrub	1.34	0	0	72.95	194.08	42.06	2.97	0.34	0.34	314.08
Woodland	0.28	0	0	17.86	25.07	244.50	0.02	0	0	287.73
Dryland	0.23	0	0	3.31	1.58	0.42	30.11	0.05	0.66	36.36
Sand	0	0	0	7.39	0.19	0.42	0	13.26	0	21.26
Construction land	0	0	0	0.45	0.03	0.07	0.48	0	5.32	6.35
Total	17.91	0.3	0.51	322.39	265.29	308	59.94	20.85	10.49	1005.68

The Saihanwula mainly has three types of land use: forest, shrub and grass. From 1985 to 2015, the area transfer was mainly concentrated among these three types of land use, with shrubs transferring the most, followed by grassland, and forest land the least (Table 3). From the perspective of income and expenditure, shrubs have negative incomes, and grasslands and woodlands have positive incomes. 5.87 km^2 of wetland was converted into grassland, while only an small area of other land use types were converted into wetland. In general, wetlands are gradually shrinking. The increase in construction land (mainly residential areas) was mainly transformed from grassland, indicating that villages were mainly expanding on grassland.

From the Area transfer matrix of Hongshan Reservoir land use from 1985 to 2015 (Table 4), it can be seen that from 1985 to 2015, the area of dry land increased rapidly, mainly transferred from wetlands along the river, beach land, grassland and reservoir areas. Since the 1980s, the waters of the reservoir have been continuously reduced and have been in the state of dead storage capacity. As the reservoir area shrinks, the wetlands and flood lands along the river gradually move with the reservoir. The exposed reservoir, wetland, and flood land far away from the reservoir were transferred into farmland. The increase in the area of the paddy field is mainly concentrated in the flood discharge area of the reservoir. With the decrease of discharge water, the flood discharge area has been transferred into paddy fields. Both sides of the flood discharge area are the Horqin Sandy Land. In recent years, with the vigorous advancement of sandy land protection and greening, sandy land vegetation has recovered rapidly, and most of the sandy land has been transformed into grassland.

The West Liao River Estuary is dominated by farmland. During the 30a years, the area of dry farmland has increased by 143.50 km^2, of which 108.67 km^2 was transformed from grassland, and the rest are from the wetland, flood land, construction land, and waters. Another type of transfer is the transfer from dryland to construction land with an area of 62.55 km^2. This is mainly due to a large number of villages and towns on both sides of the estuary. With the increase in population and industrial development, construction land has increased greatly (Table 5).

Table 4. Area transfer matrix of Hongshan Reservoir land use from 1985 to 2015 (km^2)

	Wetland	Flood land	Waters	Paddy fields	Grass-land	Shrub	Wood-land	Dryland	Sand	Construc-tion land	Total
Wetland	2.01	0	0.02	4.62	0.32	0	0.01	44.37	0	0.92	52.27
Flood land	3.07	0	0	0.15	1.07	0	0.28	49.91	0	0.50	54.98
Waters	8.11	0.71	21.02	2.38	0.84	0.01	0.63	56.79	0.01	0.70	91.20
Paddy fields	0.61	0	0	12.84	0.66	0.01	13.63	0	0	0.42	28.17
Grassland	4.51	0.45	0.15	15.75	90.68	11.99	12.26	140.29	2.99	22.2	301.27
Shrub	0	0	0	0	0.14	9.18	0.75	1.50	0.01	0	11.58
Woodland	0	0	0	0	0.08	0	5.45	0	0	0	5.53
Dryland	3.38	0.64	0.06	6.05	31.46	4.98	14.37	396.66	0.13	21.43	479.16
Sand	0.21	0	0	1.34	51.20	4.23	0	15.20	13.28	4.40	89.86
Construction land	0.01	0	0	0.09	0.38	0	0.17	4.45	0	29.19	34.29
Total	21.90	1.80	21.25	43.22	176.83	30.40	47.55	709.17	16.42	79.76	1148.31

Table 5. Area transfer matrix of West Liao River Estuary land use from 1985 to 2015 (km^2)

	Wetland	Flood land	Waters	Grassland	Woodland	Dryland	Sand	Construction land	Total
Wetland	0.12	0.01	0.47	1.24	0.26	37.69	0.14	0.64	40.57
Flood land	0.60	1.83	2.46	0.16	0	27.84	0.18	0.64	33.71
Waters	0.41	2.28	4.85	0.43	0	17.91	0.1	0.99	26.97
Grassland	0.84	1.86	1.96	39.68	10.72	148.35	1.00	8.78	213.19
Woodland	0	0	0	1.84	36.25	0.41	0.34	0.09	38.93
Dryland	0.85	6.87	8.1	36.22	5.86	950.26	4.06	62.55	1074.77
Sand	0.09	0.07	0.1	5.22	0.55	4.37	0.27	0.94	11.61
Construction land	0.04	0.41	0.18	1.87	0.1	31.44	0.14	74.34	108.52
Total	2.95	13.33	18.12	86.66	53.74	1218.27	6.23	148.97	1548.27

3.2. Analysis of landscape pattern changes in each study area

3.2.1. Structural characteristics of landscape patches

From changes in the number of landscape patches in each study area (see Table 6), the number of grasslands, woodland, and sand patches in the Dalinor is the majority, while the number of wetland and water patches is the minority. The Saihanwula is dominated by grassland, shrub, and woodland patches, accounting for more than 80%. The number of patches of grassland, dryland, and construction land in the Hongshan Reservoir is the majority. The number of patches of grassland and construction land occupied the majority in the West Liao River Estuary. Comprehensive analysis of patch number change and largest patch index (Table 7) shows that the number of grassland patches in the Dalinor has little change, but the largest patch index increases, indicating that the grassland uniformity is getting worse. The number of patches in the sandy sparse forest and the sandy landscape is decreasing, the woodland area changes little, and the sandy land area increases slightly, all of which demonstrating that the small area of woodland shows a trend of being connected into patches. The two lakes and the waters connecting them are separated due to the drop in water level, which leads to an increase in the number of patches in the waters, and thus reducing the maximum patch index of the waters. The number of forest, shrub, and grass landscape patches increased in the Saihanwula, but the largest patch index either increased or decreased differently, resulting from human disturbance. The increase of grassland patches in the Hongshan Reservoir originated from the transfer of sandy land in the lower reaches of the reservoir. The decrease of dryland and wetland patches is due to the transfer of part of the wetland into dryland and part of the reservoir area into dryland, which makes the dryland connected into a piece, and the largest patch index of dryland increases from 10.86% to 56.53%. The increase in the number of construction land patches is closely related to population growth and economic development. The results show that

Table 6. Changes in the number of landscape patches in each study area

Landscape type	Dalinor		Saihanwula		Hongshan Reservoir		West Liao River Estuary	
	1985a	2015a	1985a	2015a	1985a	2015a	1985a	2015a
Wetland	30	29	42	41	28	19	25	12
Flood land	18	35	–	2	25	9	78	115
Waters	9	19	3	2	13	3	23	73
Paddy fields	–	–	–	–	3	8	–	–
Grassland	228	237	179	220	122	209	113	217
Shrub	–	–	182	344	8	16	–	–
Woodland	289	164	94	106	7	35	20	41
Dryland	4	4	23	49	111	82	73	102
Sand	285	181	7	20	47	46	17	55
Construction land	11	15	23	30	76	139	243	326

Table 7. Changes in landscape largest patch index in each study area (%)

Landscape type	Dalinor		Saihanwula		Hongshan Reservoir		West Liao River Estuary	
	1985a	2015a	1985a	2015a	1985a	2015a	1985a	2015a
Wetland	4.49	2.12	0.60	0.22	1.30	0.62	0.60	0.06
Flood land	1.80	2.18	–	0.03	1.65	0.06	0.17	0.06
Waters	17.96	16.18	0.03	0.03	6.02	1.84	0.40	0.14
Paddy fields	–	–	–	–	1.30	2.25	–	–
Grassland	26.07	38.91	16.89	9.03	5.68	4.18	2.38	0.74
Shrub	–	–	5.24	5.68	0.35	0.85	–	–
Woodland	12.10	8.68	11.40	12.20	0.30	0.54	1.77	1.78
Dryland	0.28	0.04	1.10	1.12	10.86	56.53	61.10	77.29
Sand	0.60	1.32	1.55	1.40	1.35	0.19	0.31	0.05
Construction land	0.15	0.22	0.07	0.13	0.33	0.44	0.93	1.50

the number of patches increased significantly, but the total area and the largest patch index of grassland decreased significantly, revealing that the grassland is severely fragmented after being divided. The reason for the change of patch number of construction land was the same as that of the Hongshan Reservoir.

3.2.2. Shape characteristics of landscape patches

The mean fractal dimension index of patches can be used to judge the complexity of the landscape. The mean fractal dimension index change of each study area is shown in Figure 7. It can be seen from the figure that the mean fractal dimension index of each wetland has increased to varying degrees, which shows that although the area of the wetland has decreased, the shape of the wetland has become more complicated.

Among them, the mean fractal dimension index of the Hongshan Reservoir has the largest increase from 1.1064 to 1.1912. The Saihanwula's rise was not significant. The mean fractal dimension of the grassland in the Dalinor, the Hongshan Reservoir, and the West Liao River Estuary decreased, revealing that the shape of grassland patches tends to be simple. The mean fractal dimension index of the Dalinor grassland has not decreased much. And that of the Hongshan Reservoir and the West Liao River Estuary has decreased due to the fact that most of the grassland has been transferred into farmland, and the outline has become simple, which is consistent with the simultaneous decrease of the mean fractal dimension index of the dry fields in the two areas. While the mean fractal dimension index of the Saihanwula grassland has become larger, and the number of patches has also increased, indicating that the grassland is divided by human intervention. The changing trend of the mean fractal dimension index of the waters is exactly the opposite of that of the wetland, which shows that the shape of the waters becomes simple while shrinking. The mean fractal dimension index of other landscape types does not change significantly.

3.2.3. Overall changes in landscape pattern

This research selects the Shannon's diversity index and the evenness index to measure the characteristics of the

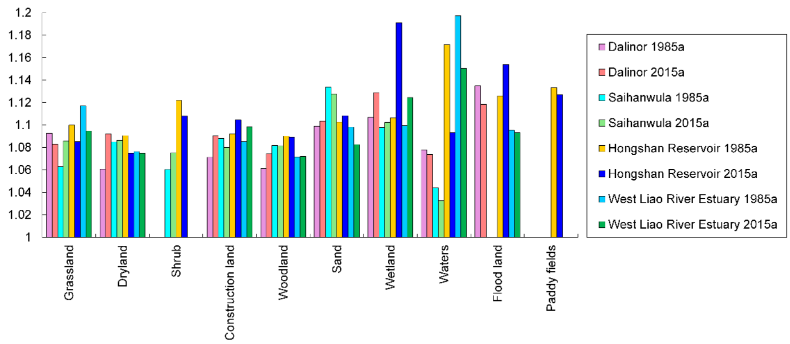

Figure 7. The mean fractal dimension index of landscape types in each study area

landscape. From 1985 to 2015, the diversity index and the evenness index of the Hongshan Reservoir and the West Liao River Estuary showed a significant decreasing trend, which indicates that the diversity and uniformity of patches are gradually decreasing (Table 8). This was because the waters of the Hongshan reservoir were transformed into farmland, and the grassland of the West Liao River Estuary was transformed into farmland, and farmland became the dominant landscape. Generally speaking, the disparity between the proportions of all kinds of landscapes is getting wider and wider. The diversity index and evenness index of the Dalinor and the Saihanwula did not change significantly, indicating that the proportion of each landscape has not changed much, which also shows that the two study areas have been effectively protected after the establishment of nature reserves.

Analyzing the CONTAG index, we can see that the CONTAG index of each area is showing an increasing trend (Table 8), indicating that each area is increasingly controlled by dominant landscape types. The most prominent change is the Hongshan Reservoir, where the CONTAG index increased from 59.5607 to 67.7229, mainly due to the sharp decrease in the waters and the sharp increase in the area of farmland. The main reason for the change in the CONTAG index of the West Liao River Estuary was that grassland gradually transformed into farmland, and the proportion of farmland increased to 78.69%.

Table 8. Overall landscape pattern index of each study area

Study area	Year	SHDI	SHEI	CONTAG
Dalinor	1985	1.5733	0.7566	58.0366
	2015	1.5244	0.7331	58.9760
Saihanwula	1985	1.4182	0.6820	61.8170
	2015	1.4527	0.6612	62.2221
Hongshan Reservoir	1985	1.6703	0.7254	59.5607
	2015	1.3086	0.5683	67.7229
West Liao River Estuary	1985	1.0912	0.5248	69.6904
	2015	0.8189	0.3938	76.1954

4. Discussion

The patch characteristics of different landscape types in different study areas show irregular changes, and a certain index alone cannot objectively analyze the evolution trend of the landscape. For example, the number of grassland landscape patches in each study area is increasing, but it does not necessarily mean that the grassland landscape is seriously fragmented. A comprehensive analysis of the area change and the largest patch index shows that both the area of the Dalinor grassland and the largest patch index has increased, which does not mean that the fragmentation of grassland landscape is serious, but the grassland area and grassland patches increase due to the conversion of other landscape types into grassland. It is not possible to use a single landscape index to measure the trend of landscape feature changes. Multiple interrelated indexes should be analyzed comprehensively so that the conclusions will be more objective.

The diversity index and evenness index of the Dalinor and the Saihanwula did not change significantly and were less disturbed by human activities, which is consistent with the analysis conclusion of Su Longgaowa (Su, 2010)'s analysis of the landscape pattern of the Saihanwula Nature Reserve. However, according to Guan Ruihua (Guan, 2011), the impact of human activities on the Dalinor is increasing, which is not completely consistent with the conclusion of this paper. The Hongshan Reservoir wetland has transformed into farmland in a large amount, showing a serious shrinking trend, which is similar to Wu Menghong (Wu, 2018)'s analysis of the wetland in the West Liao River Basin. Due to the shrinking of wetlands, the drastic reduction of water area, the expansion and connection of farmland, the diversity of wetland landscapes in the Hongshan Reservoir and the West Liao River Estuary has decreased, farmland has become a dominant landscape, and the proportion of landscape structure has become increasingly disparity. This is contrary to the evolution characteristics of urban wetland landscapes along the Yellow River in Ningxia, which belong to the same semi-arid region (Gao et al., 2020). All of these may result from the composition and structure of land-use types and local policies in the urban belt along the Yellow River.

From the temporal evolution of wetland landscapes in each study area, the wetland resources in the West Liao River Basin tend to deteriorate, especially the water landscape has the largest decrease. From the analysis results of the precipitation change of the West Liao River Basin (Wang et al., 2020), the precipitation in the basin has a slight downward trend, and the decline is not large. This shows that the natural precipitation in the basin has not changed significantly. Therefore, the decrease in the amount of water in the major waters (river, lake, reservoir) and the interference of human activities have become the main reasons for the shrinkage of wetland in the basin.

The abundance of water resources is directly related to the stability and health of wetland resources. For the Hongshan Reservoir and the West Liao River Estuary, which are dominated by agriculture, as the area of farmland continues to increase, the demand for water resources will inevitably increase. It will cause water shortages and impair the watershed, and thus leading to a great threat to wetland resources. Therefore, wetland protection is a systematic project. We should focus on the wetland area and make scientific judgments from a wider range and deeper level before putting forward systematic and scientific protection measures and plans.

Conclusions

Based on Landsat remote sensing image data and landscape ecology principles, this study analyzed the temporal and spatial evolution characteristics of landscape patterns in four key wetland areas in the West Liao River Basin, and reached the following conclusions:

From 1985 to 2015, the area of wetland in each study area was significantly reduced. The area of the Dalinor wetland has been reduced by 13.80%, among which the area of wetland along the lake has been reduced by 43.63 km^2, and the area of the three main lakes has been reduced by 14.90 km^2. Although the flood discharge area of the Hongshan Reservoir has increased its paddy field area since 2000, the overall wetland area has decreased by 61.10% (138.44 km^2) due to the substantial decrease in the water area of the reservoir area. After the degradation of the wetland resources in the West Liao River Estuary, most of them were developed into farmland (a decrease of 66.85 km^2). The Saihanwula has very few waters and accounts for a not large proportion of wetland, which has been reduced by 8.43 km^2 in 30a years.

In the past 30a years, the diversity index and evenness index of the Hongshan Reservoir and the West Liao River Estuary has shown a significant downward trend, which indicates that the diversification and uniformity of patches are gradually decreasing. The diversity index and evenness index of the Dalinor and the Saihanwula did not change significantly. The CONTAG index of each study area is showing an upward trend, indicating that it is increasingly controlled by the dominant landscape types.

With the gradual increase in ecological restoration and protection, the Horqin Sandy Land on both sides of the Hongshan Reservoir's flood discharge area was transferred into grassland after 2000, and the ecological environment has been greatly improved. As the flood discharge and drainage of the Hongshan Reservoir have been reduced, most of the flood discharge areas have been transformed into paddy fields. As a result, the area of constructed wetlands has increased to a certain extent.

Ethical approval

– Consent to Participate: agree.
– Consent to Publish: agree.
– Authors Contributions: Zhichun Wang: analysis; Huiying Zhao: supervision, Chunliang Zhao: analysis.
– Availability of data and materials: N/A.
– Clinical Trials Registration: N/A.

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Disclosure statement

We declare that we have no conflict of interest.

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