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Landscape and avifauna changes as an indicator of Yellow River Delta Wetland restoration

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ABSTRACT

Wetlands are important habitats on biodiversity protection. In this study, the relationship between wetland and avifauna changes in the Yellow River Delta Wetland was studied. Remote sensing and geographic information system provided an advanced platform for the research. After the avifauna survey was performed from 2012 to 2013, the birds' variation and driving factors were analyzed. The results showed that the flow into the wetland increased continuously from 2000, and the increased of artificial wetland prevented the wetland degradation, although at the same time the total wetland area decreased. Medium grassland, tidal flat and pond are the three main landscapes which are beneficial for the habitation of birds. The migrating numbers of red-crowned crane increased significantly from 2005, and the overwintering numbers increased from 2009. The study results show that the key land use types for protecting endangered species of birds are medium grassland, tidal flat and pond landscapes. Wetland changes are sensitive to the birds and significantly affected by the flow. We suggest that the artificial wetland project should enhance the three land use type area to ensure the wetland restoration.

1. Introduction

River delta wetland played an important role in water conservation, biological diversity, environmental purification and food production. Over the past 20 years, the structure and function of wetland system have been studied thoroughly (Waletzko and Mitsch, 2013), a bibliometric approach to quantitatively evaluate global scientific constructed wetlands research, and statistically assess current trends, and future directions using the Science Citation Index Expanded (SCI-EXPANDED) database from 1991 to 2011 were explored (Zhi and Ji, 2012). Wetland health connects natural ecological security to the development of human society, and has been the core study area of the International Geosphere-Biosphere Programme (IGBP) and International Programme of Biodiversity Science (DIVERSITAS). Moreover, in China, wetland health research has been the main key fields and priority support direction of the "Long-term Scientific and Technological Development". The ability of wetlands to adapt to climate change and function as natural filtering areas is reduced by anthropogenic disturbances. Apart from climate change, loss of wetland warrants a serious concern for the long term survival of birds which solely depend on different habitats (Prabhadevi and Reddy, 2012). Despite being known as critical delivery media of ecosystem service, wetlands are suffering great transformations and land use change is a major driving force of wetland degradation (Zorrilla-Miras et al., 2014).

Wetland restoration requires complete functions and structure. Achieving goals of wetland restoration requires new models and indicators of gathering and analyzing information (Ji et al., 2012; Sakalauskas, 2010; Zhi and Ji, 2014). Clear understanding of the links between wetland and biodiversity is needed to assess and predict the true environmental consequences of human activities. Hydrology is one of the most critical factors influencing the function of wetlands especially in drought seasons, as long-term flood or drought can threaten the plants (Yang et al., 2013). Traditional evaluation methods attempt to place monetary figures on use values, and wetland evaluation methods often apply monetary driven approaches which may undermine intrinsic ecosystem values (McDonough et al., 2014). And there has been little discussion of how and when to integrate avifauna into wetland restoration (Gawlik, 2006). Over the past several decades, the remote sensing (RS) and geographical information system (GIS) with high resolution satellite data has been used for wetland degradation research (Ikiel et al., 2013; Sui et al., 2015). The use of RS and GIS creates a powerful tool for landscape as it is a cost-efficient tool for

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0925-8574/

Table 1
List of satellite images used in this study.

Year	Satellite	ID	Path	Row	Acquire date	Resolution (m)
1990	Landsat 5 TM	p121r03419891003	121	34	03/10/1989	30
1995	Landsat 5 TM	p121r03419950918	121	34	18/09/1995	30
2000	Landsat 5 TM	p121r03420000502	121	34	02/05/2000	30
2005	Landsat 5 TM	p121r03420050508	121	34	08/05/2005	30
2010	Landsat 5 TM	p121r03420100911	121	34	11/09/2010	30

identifying and monitoring wetland on a large scale (Piniewski et al., 2012; Prabhadevi and Reddy, 2012). Therefore it is possible to give suggestions for the management plans. Land use changes can be used to identify both the direct and indirect processes of wetland degradation. Mismanagement of wetland lead to land use change and severe environmental problems, which is mainly due to the fact that available data could be used for large-scale management (Ikiel et al., 2013). Analyzing the changes in landscape patterns helps identifying some of the most critical implications of complex interactions between natural environmental changes and anthropogenic activities (YuhaiBao et al., 2011). Combined with birds' investigation, the relationship between hydrological changes, land use changes and birds' changes could be established (Hinojosa-Huerta et al., 2013).

In this paper, we take the Yellow River Delta Wetlands National Reserve (YRDWNR) as a case study and assess the relationship between avifauna and landscape changes. The YRDWNR is one of the most highly representative wetlands in the world, it plays a particularly prominent role in water conservation, bird migration and local biodiversity maintenance (Liu et al., 2014; Peng et al., 2014). It has been 12 years since the implementation of a wetland restoration project in the YRDWNR in 2002. Based on GIS technology and using remote sensing images as the data source, this paper quantitatively analyzes the land use and landscape pattern change characteristics between 1990 and 2010 and their impacts on the habitat.

2. Materials and methods

2.1. Study area

The YRDWNR (118°33′ E–119°20′ E, 37°35′–38°12′ N) is located in northern Shandong Province, on the southern coast of the Bohai Bay. Due to the rich sediment in its water, the delta channel of the Yellow River changed nine times, and the YRDWNR has been divided into two parts (Yu et al., 2013). There are many forms of protected areas in China. Based on their relative importance, each type of protected area can be further graded into two to three levels such as national level, provincial level and prefectural/county level.[1] As a National Nature Reserve built in 1990, national level key protected areas, YRDWNR was a wetland for bird migration, overwintering and breeding. It occupies a very important position in China's biodiversity conservation. Due to the annual decreased runoff of the Yellow River, freshwater diverted to wetlands decreased between 1990 and 2000.

There are currently 296 species of birds in the YRDWNR, 154 of which were listed in the "Agreement between the Government of Japan and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment", and 53 were listed in the "Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment". Passeriformes are the most common at 103 species at 34.8% of all species (Fig. 1).

2.2. Data and analysis

2.2.1. Data processing

In this study we focused on the land use changes using remote sensing methods and techniques. For this purpose, a multi-temporal set of remote sensed data and Landsat 5 TM satellite imagery were analyzed. The study period was from 1990 to 2010 with one image taken every five years (Table 1). Landsat images were downloaded from the USGS GLOVIS website. Specifically, the images selected were mostly acquired from May to November with minimal cloud cover when the vegetation cover in the study area would be dense, and the summer season (June–August) is in the middle of the period. In one exceptional case, we considered the image acquired in 1989 as that of the year 1990.

Data processing was performed using ERDAS Imagine 2010 and land use interpretation was performed under ArcGIS 10.1 with standard false color RGB432. The satellite imagery underwent geometric correction in order to reduce any displacement errors, the total number of Ground Control Points (GCP) was 32 per image while the correction method was the quadratic polynomial model with the bilinear interpolation method, and the images were also atmospherically corrected in order to remove atmospheric effects.

Supervised classification was performed for land use extraction. The maximum likelihood classification algorithm was chosen due to its successful use in previous studies for detecting land use changes. 27 classes have been defined according to the 2nd "Current Land Use Condition Classification (GBT/21010-2007)", each classes was selected by a group of representative pixels (Table 2), 14 classes were identified and the others were processed according to the China's Land Use Map (1:250,000).

2.2.2. Landscape metrics

We revealed the landscape dynamic changes by analyzing spatial variations of different types of wetland landscape and landscape pattern index variations (YuhaiBao et al., 2011). Considering the actual situation of the research area and landscape type classification system, and analyzing from the landscape type level and landscape pattern level, this paper select six types of index: Area Index, Shape Index, Edge Index, Density Index, Diversity Index and Contagion/Interspersion Index (Table 3). The landscape metrics were calculated with the most popular analysis software designed for this purpose, FRAGSTAS 4.2 (Mcgarigal, 2000).

2.2.3. Avifauna survey

Engineering is sometimes described as the study and practice of solving problems with technological designs, some techniques of ecological engineering that are now widely applied. The common use techniques are avifauna survey, ecological engineering of biodiversity, wetlands ecosystems for receiving wastewaters, wetlands ecosystems for receiving wastewaters, etc. (Odum and Odum, 2003). The functions of ecological engineering methods are to improve the revival ability of ecosystem, improve the protective ability of ecosystem, improve the recoverability of ecosystem, and improve the functions of streams (Wu and Feng, 2006). This research developed avifauna surveys for data collection.

[1] https://en.wikipedia.org/wiki/List_of_protected_areas_of_China.

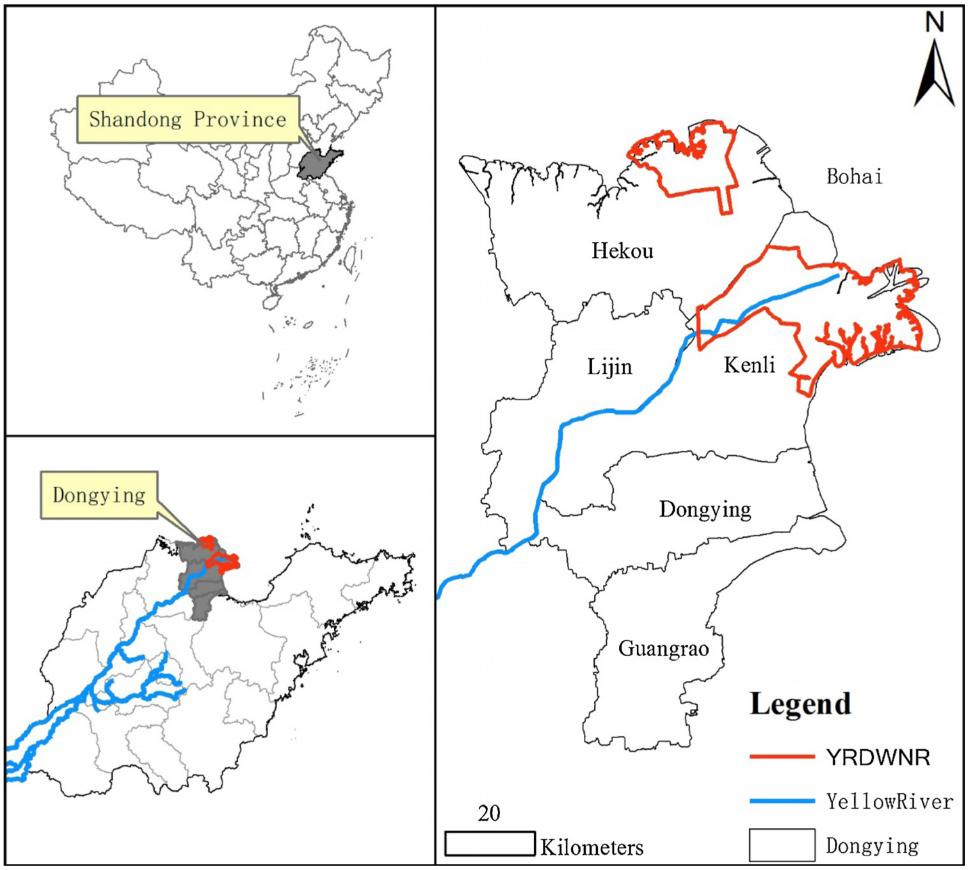


Fig. 1. Location of the study area.

Monthly observations of avifauna were conducted from October 2012 to March 2013. During bird migration, the observation frequency was increased to once every 10 d (from December 2012 to February 2013). The avifauna observation sites included 10, 5, and 6 sections with lengths of 3–5 km respectively. Avian species and abundance birds were determined using both the strip method and direct counting method. The walking speed during data collection was 1–2 km h^{-1}; the strips were 50–100 m wide and 2–5 km long. In most cases, each survey group consisted of at least two individuals using 8X binoculars and a 20-60X77 variable power monocular spotting scope. When birds were flying, feeding or walking, the numbers were estimated using 5, 10, 20, 50 and 100 as the counting units. A single bird species comprising more than 10% of the total number of birds was identified as a dominant species, 1–10% was classified as common species and <1% was rare.

3. Results

3.1. Land use change

The land use map is shown in Fig. 2. The change process of land use from 1990 to 2010 is shown in Table 4. The land use changed from 1990 to 2010 mainly due to erosion and deposition; the maximum total area of the Yellow River Delta Wetland was 1140.76 km^2 in 1995, while the minimum was 1031.13 km^2 in 2005. The total area of wetland increase from 1990 to 1995, but shrunk heavily from 1995 to 2010. From 1995 to 2010, the wetland decreased by 91.55 km^2, and most decreased by 109.63 from 1995 to 2005. The primary land use types were grassland, dry land and beach land which together covered over 100 km^2. Grassland increased slowly in the range between 38.67% and 48.42%. Opposite to the total area of wetland, the largest area of grassland appears in 2005. High coverage grassland was the largest percentage of grassland, but the percentage of grassland decreased from 20.21% to 17.73%. Dry land ranged from 107.14 km^2 to 137.66 km^2. From 1990 to 2010, dry land increased by 8.34 km^2. And beach land decreased from 235.56 km^2 to 192.63 km^2. Similar to that of the total wetland area, the largest percentage was 29.27% in 1995.

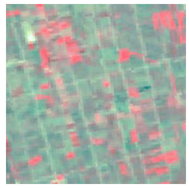
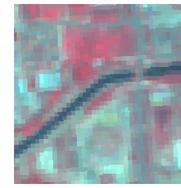
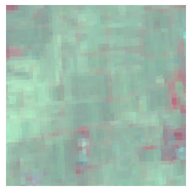
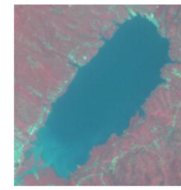
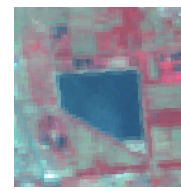
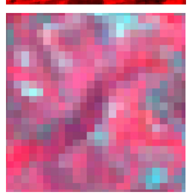
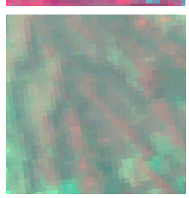
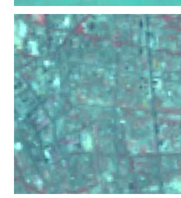
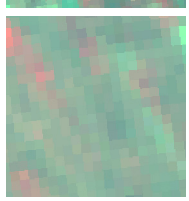
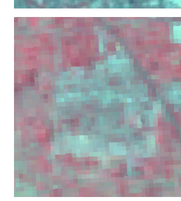
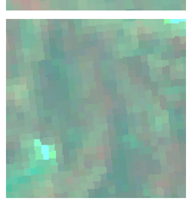
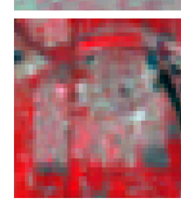
We may conclude from the land use transfer matrix map (Fig. 3) that the reservoir, beach land, high and low coverage land changed most. The reservoir area increased 45.32 km^2 over 20 years, and the increased areas were mainly from other construction land (22.33%), beach land (29.64%), high coverage grassland (10.34%) and low coverage grassland (7.24%) in 1990. Beach land decreased only slightly, and the 42.93 km^2 decreased beach land from 1990 was mainly transferred to grassland (7.79% high coverage grassland, 7.79% moderate coverage grassland and 7.74% low coverage grassland) in 2010. High coverage grassland decreased by 25.88 km^2, while of the remaining 71.31% of the grassland in 1990, the respective transferred percentages to reservoir, low coverage grassland and moderate coverage grassland were 10.34%, 6.14% and 5.77%. Low coverage grassland increased by 35.45 km^2, the low coverage grassland in 2010 was mainly from 1990, at 88.18%. The transferred low coverage grassland was from moderate coverage grassland (14.37%), beach land (7.79%) and high coverage grassland (6.14%) in 1990.

3.2. Landscape pattern

3.2.1. Landscape metrics

The landscape index of the YRDWNR on the landscape pattern levels is shown in Table 5. During the study period, the CONTAG was between 51 and 55, which indicated that the aggregation of the area

Table 2
Representative pixels of land use classification.

Land use type		Pixels	Land use type		Pixels
Farmland	Paddy Field		Waters	River	
	Dry Field			Lake	
Forestland	Forested			Reservoir and Pond	
	Shrub			Beach Landscape	
Grassland	High Cover Grassland		Urban and Rural, Industrial, Residential Land	Urban Land	
	Medium Cover Grassland			Rural Residential Land	
	Low Cover Grassland			Other Construction Land	

landscape was moderate. DIVISION was between 0.94 and 0.96, and IJI was between 77 and 81. MESH changed greatly, the minimum is being 4722.91 in 2000 and maximum 6733.12 in 1995. The PLADJ was between 92 and 93. The SPLIT was low in 1995 and 2005, the values of which were 16.94 and 17.57. The SPLIT was high in 1990, 2000 and 2010, ranging between 20 and 25.

From 1990 to 2010, the density index was slightly changed. The PD increased from 1990 to 2000 and decreased from 2000 to 2010, indicating that the fragmentation degree changed according to the same trend. The LPI was between 11 and 12 in 1990, 1995 and 2005, and between 9 and 10 in 2000 and 2010. The NP reached 296 in 2000, while ranging between 250 and 270 in the other periods. The SHDI and SHEI in five years were dynamically changed. The minimum values appeared in 1995, while the maximum ones appeared in 2000. The values in 2010 were increased in comparison to 2000, which may have been due to the decrease of river land, bottom land and alkaline land and the increase of salt marsh land and dry land.

The diversity index did not changed significantly. The PR was 14 in all periods except for 2005. The SHDI was about 2.1 and SHEI was about 0.8, and the SIDI and SIEI were 0.85 and 0.9. The MSIDI and MSIEI respectively changed between the ranges of 1.82–2.0, and 0.69–0.77. The ED was between 11 and 15, and the maximum of ED and TE all appeared in 2000. The LSI was between 13 and 15, and PAFRAC was between 1.31 and 1.37.

Table 3
Landscape pattern metrics description.

Level	Index	Index name	Unit	Range
Area	TA	Total Area	ha	
	CA	Class Area	ha	
	PLAND	Percent of Landscape	%	
Contagion/Interspersion	AI	Aggregation Index	%	(0,100]
	CONTAG	Contagion Index	%	
	DIVISION	Landscape Division Index	%	
	IJI	Interspersion Juxtaposition Index	%	
	MESH	Effective Mesh Size	%	
	PLADJ	Proportion of Like Adjacency	%	
	SPLIT	Splitting Index	%	
Density	LPI	Largest Patch Index	%	$n \geq 1$
	NP	Number of Patches	n	
	PD	Patch Density	n/100 ha	
Diversity	MSIDI	Modified Simpson's Diversity Index	–	$n \geq 1$
	MSIEI	Modified Simpson's Evenness Index	–	
	PR	Patch Richness	n	
	SHDI	Shannon's Diversity Index	–	
	SHEI	Shannon's Evenness Index	–	
	SIDI	Simpson's Diversity Index	–	
	SIEI	Simpson's Evenness Index	–	
Edge	ED	Edge Density	m/ha	
	TE	Total Edge	m	
Shape	LSI	Landscape Shape Index	–	
	PAFRAC	Perimeter Area Fractal Dimension	–	

Table 4
Land use area in different period of study.

Land use type	Area (km^2)				
	1990	1995	2000	2005	2010
Low cover grassland	115.19	106.01	104.80	120.57	150.64
Medium cover grassland	137.08	143.39	127.59	192.16	148.10
High cover grassland	211.91	191.73	215.22	184.69	186.03
River	55.97	59.98	27.23	25.85	44.31
Lake	0.10	0.91	0.70	0.57	0.25
Rural residential area	2.00	1.85	1.75	1.75	1.81
Plain dry land	125.48	137.66	135.59	107.14	133.82
Other	11.97	10.22	12.01	7.87	11.56
Other built-up area	54.66	54.88	37.41	44.17	44.76
Reservoir and pond	7.03	8.22	31.07	21.49	52.35
Swamp	14.64	13.40	36.13	30.63	1.96
Beach landscape	235.56	333.90	214.88	219.53	192.63
Tidal flat	66.43	68.44	88.06	64.31	68.73
Salt marsh	10.40	10.18	10.40	10.40	12.27
Total area	1048.41	1140.76	1042.83	1031.13	1049.21

3.2.2. Class metrics

The landscape types of the CA and PLAND were different, the CA of tidal flat was the largest, and the maximum value appeared in 1995. The LSI changes of river and beach landscape were larger. The PAFRAC changes of reservoir and pond were also larger. Swamp, lake and other landscape types were nearly zero. The ED changed significantly, especially for the beach landscape types. The ED of beach landscape increased significantly in 2000 and 2005, then decreased to its minimum value in 2010. The ED of reservoir and pond increased every period since 1990. The TE changed in a manner similar to ED. The Density Index is shown in Fig. 4. The PD of river, beach landscape, rural residential area and plain dry field were larger, among which river landscape is the largest. The PD of the river increased, which indicated that the river landscape fragmentation degree gradually increased. This is followed by the value of the maximum PD reaching about 0.09 in 2005.

The LPI of grassland, tidal flat and plain dry field were larger, which indicates that these three landscape types have the advantages of landscape types in the entire study area and that grassland landscape is the most dominant landscape type. Overall, from 1990 to 2010, the LPI of the main landscape types in the study area underwent rapid change. The LPI of medium cover grassland in 2005 and tidal flat in 1995 was nearly 12. The LPI of reservoir and pond increase from nearly 0 to 3, which indicated that its dominance became gradually stronger. The NP of river increased from 36 in 1990 to 88 in 2005, and decreased to 56 in 2010. River, beach landscape, rural residential area and plain dry field were the higher variable landscape patch type, i.e. the NP values were high.

From 1990 to 2010, the AI variation of river, lake, reservoir and pond were relatively large, which indicated that these types reunited by means of a few large plaque, and the fragmentation degree was relatively high. From the landscape types of AI changes, the river and lakes changed significantly. From 1990 to 2010, the AI of river reduced significantly, and increased between 2000 and 2010. The IJI of the landscape types greatly affected by human activities were smaller, except lake.

From the landscape types of the MESH changes, medium cover grassland and tidal flat changed significantly. The MESH of medium cover grassland increased significantly in 2005, and the tidal flat increased significantly in 1995. The PLADJ of all the types changed

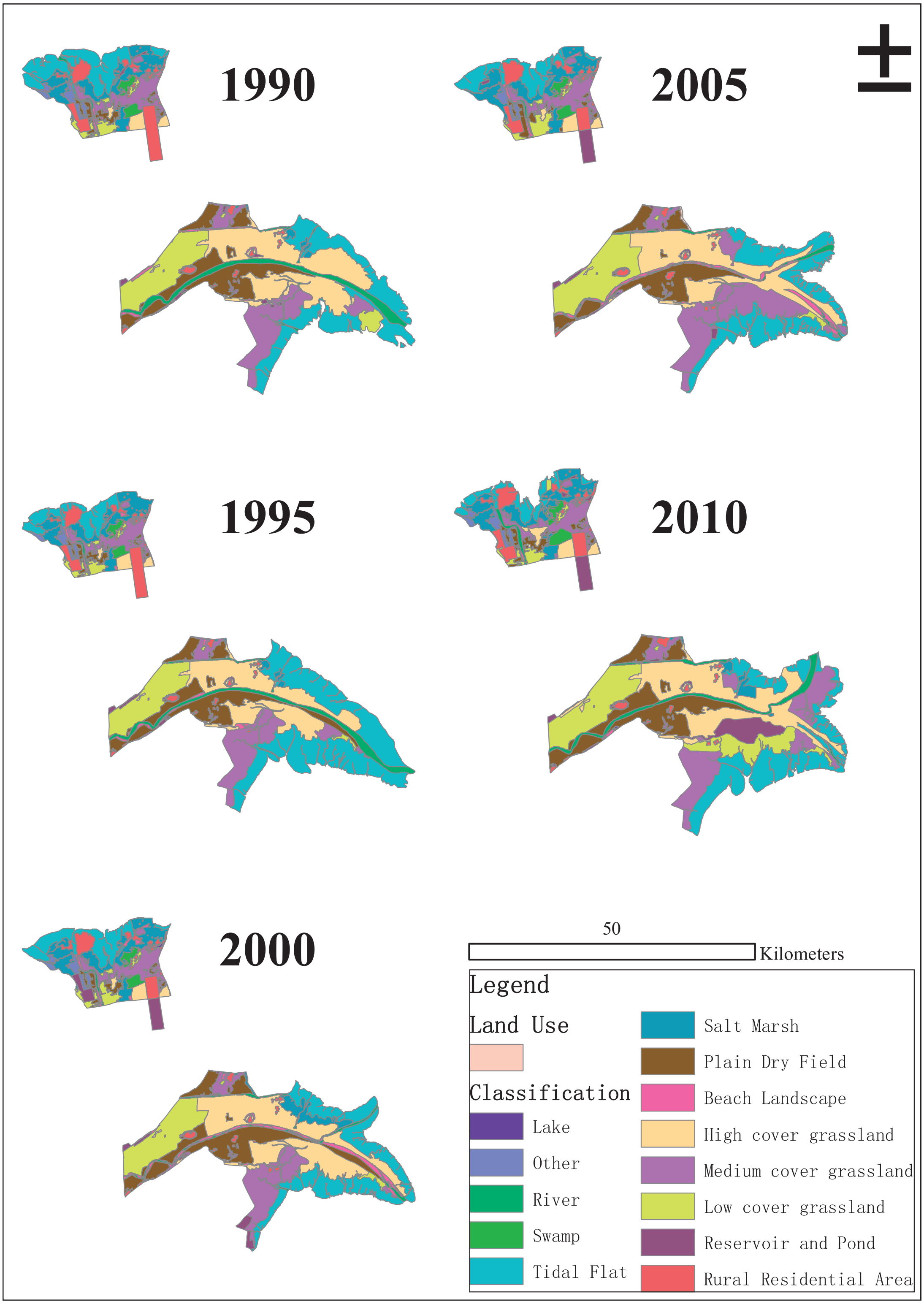


Fig. 2. Land use map in this study.

slightly. The PLADJ of river decreased in 2000 and increased in 2010.

3.3. Avifauna data

The wetland is located in the Palearctic region of northern China, which is often described as a hilly plain sub-region of the east Oriental realm, and features transition characteristic of the two regions. According to the investigation performed in 2012–2013, the majority was migratory birds, at 50.75%, with resident breeding birds and summer migrant birds at 37.2%. The major type of birds present was Palearctic, with a total of 206 types or 69.6%. Most of the birds were migratory such as white crane, red-crowned crane, and mandarin duck. Wide-distributed constituted 62(20.9%) and

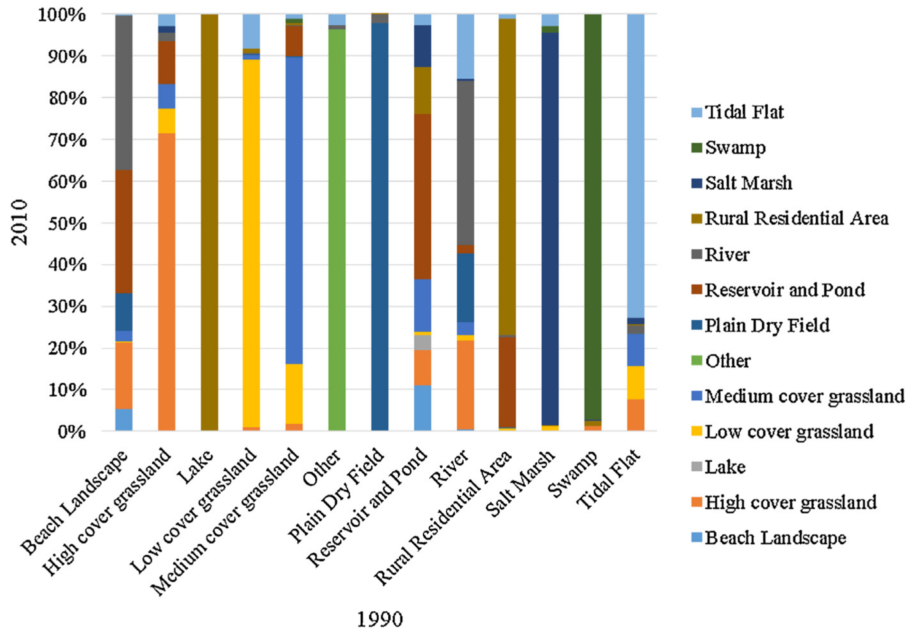


Fig. 3. Land use transfer matrix map.

Table 5
Landscape metrics in different period.

		1990	1995	2000	2005	2010
Contagion/Interspersion	AI	93.53	93.77	92.66	92.93	93.41
	CONTAG	53.41	54.83	51.89	54.11	52.51
	DIVISION	0.95	0.94	0.95	0.94	0.96
	IJI	80.44	80.27	80.16	77.26	79.81
	MESH	5023.72	6733.12	4722.91	5877.96	4201.27
	PLADJ	92.64	92.93	91.75	92.02	92.50
	SPLIT	20.87	16.94	22.08	17.57	24.97
Density	LPI	11.58	11.61	9.92	11.92	9.49
	NP	265	257	296	266	251
	PD	0.25	0.23	0.28	0.26	0.24
Diversity	MSIDI	1.93	1.82	1.98	1.94	2.02
	MSIEI	0.73	0.69	0.75	0.72	0.77
	PR	14	14	14	15	14
	SHDI	2.11	2.05	2.16	2.13	2.16
	SHEI	0.80	0.78	0.82	0.79	0.82
	SIDI	0.86	0.84	0.86	0.86	0.87
	SIEI	0.92	0.90	0.93	0.92	0.93
Edge	ED	12.59	11.97	14.22	13.41	12.28
	TE	1,320,200	1,365,400	1,483,000	1,385,300	1,288,700
Shape	LSI	13.62	13.78	15.15	14.87	14.33
	PAFRAC	1.33	1.34	1.36	1.37	1.31

Table 6
Avifauna survey data in 2012–2013.

Species	Resident (breeding birds)	Summer migrant (breeding birds)	Migratory	Winter migrant	Total
Palearctic	22	24	130	30	206
Oriental	5	16	7	0	28
Wide-distributed	20	23	13	6	62
Total	47	63	150	36	296

Oriental only 28(9.5%), most of which were breeding birds such as *Butorides striatus* and *Dicrurus macrocercus* (Table 6).

There are some very important birds found in the Yellow River Delta Wetland, such as Red-crowned crane, Whooper swan, Larus saundersi and *Ciconia boyciana*. In this investigation, the migrating and overwintering numbers of Red-crowned crane are 900 and 200 (Table 7). Compared with the number of bird species in 1990, the number increased by 35 in the investigation in 1995, when there were 21 migratory, 4 winter migrant, 3 summer migrant and 7 resident.

4. Discussion

The wetland changes have occurred as a result of interactions of numerous human forces. The diversity of wetland ecosystems is affected by the geographical environment and geomorphology

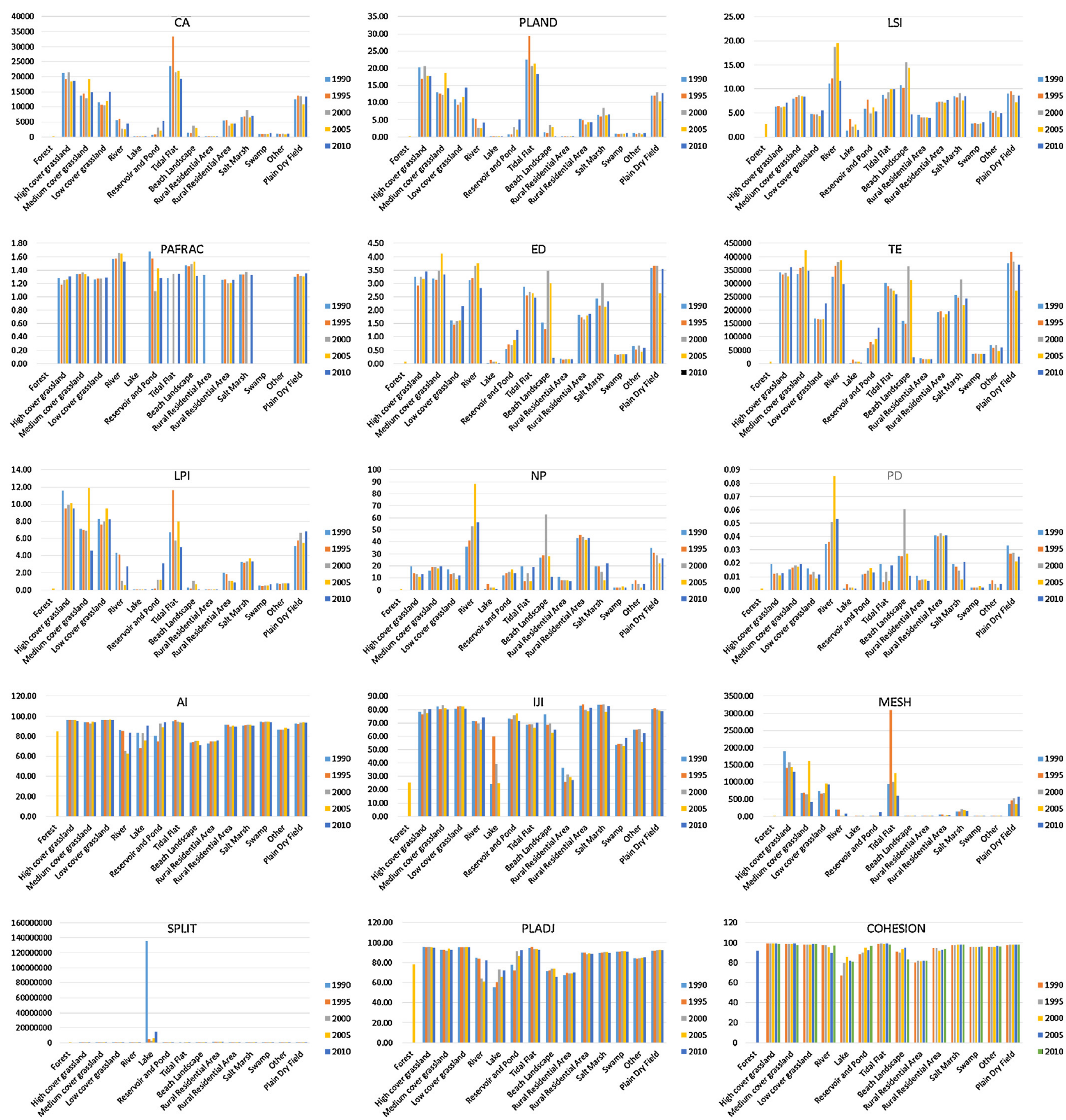


Fig. 4. Class metrics of wetland landscape types in this study area.

Table 7
Migrate and overwintering numbers.

Species	Kind	Migrate numbers	Overwintering numbers
Red-crowned crane	Endangered species	800	200
Whooper swan	Rare species	400	1200–2100
Larus saundersi	Endangered species	1500	–
Ciconia boyciana	Endangered rare species	–	–

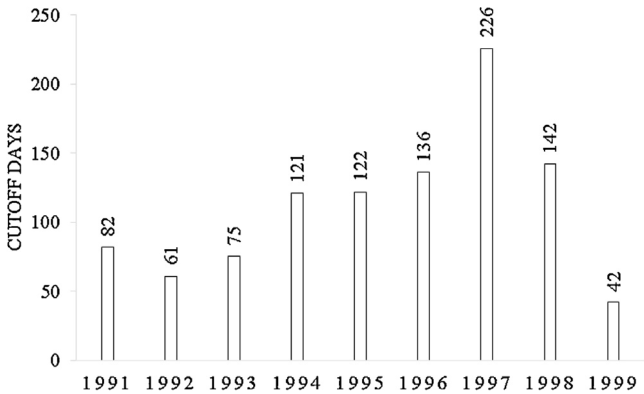


Fig. 5. Cutoff days of the Yellow River in the 1990s.

condition or soils (Zhang et al., 2013). Many studies have indicated that flow variation is an important driving force of wetland change. Artificial wetland growth is also one of the main factors in landscape change. Thus, avifauna changes due to the wetland restoration.

4.1. Flow variation and water transferring to the wetland

Water availability is a crucial factor determining the health of wetland. Researchers have suggested that more efforts should be devoted to water conservation in and around wetlands (Yang et al., 2013). The flow data of the Yellow River was supplied by (the Yellow River Conservancy Commission of the Ministry of Water Resources, YRCC-MWR). In the 1990s, the discharge of the Yellow River decreased greatly. Researches has shown that water and sediment discharge are the dominant variable factors of the wetland, and human activities also have an important influence on the transformation of wetland types and wetland degradation (Li et al., 2009). The areas of Yellow River and adjacent ponds have decreased due to the lack of water from upstream (He et al., 2011). There have been several days of cutoff in the downstream of the Yellow River almost every year. As the day of cutoff has advanced and extended, the maximum cutoff 226 days was raised in 1997 (Figs. 5 and 6).

When the goal is to allocate water resources to wetland restoration, the availability of water in a given river basin should also be considered, and the flows allocated to the artificially restored wetlands is a complex problem (Yang, 2011). An ecological and hydrologic restoration of the Mississippi–Ohio–Missouri (MOM) Basin in the United States showed that the land has been artificially drained and 80–90% of the original wetlands have been lost (Mitsch and Day, 2006). The flow range at Lijin Station was very high before the optimal allocation, and the flow was very

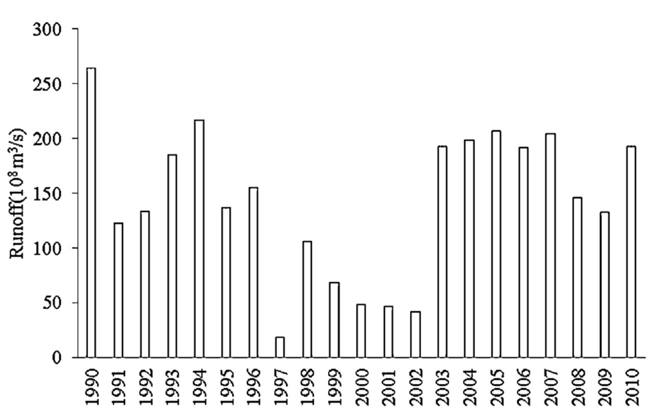


Fig. 6. Average annual runoff of Lijin in 1990–2010.

low from 1997 to 2002. The minimum flow was 18.6×10^8 m^3/s in 1997, and in 2002 the flow remained at 41.9×10^8 m^3/s. The Yellow River began optimal allocation in 2003, when the flow began to recover. From 2002 to 2007, the supply for the wetland was mainly provided by groundwater seepage. The influence range was about 2.5 km along the both sides of the stream. Increasing water demand for agricultural, industrial and domestic use leads to a decreased mean annual water discharge (Ottinger et al., 2013) (Fig. 7).

The ecological water supplements from 2008 to 2011 were 0.14×10^8 m^3, 0.15×10^8 m^3, 0.43×10^8 m^3 and 0.59×10^8 m^3. The water supplement kept the wetland degradation within reasonable limits, and prevented the reverse evolution of wetland plants. The reeds for birds were initially formed.

The main factors of wetland change were runoff changes resulting in reduced wetland flow. From the annual runoff of Lijin, we can see that the annual total amount of runoff was 264.4 and 195.3 million m^3 (BCM) in 1990 and 2010. The annual total amount of runoff in 2010 was 0.74 times that in 1990. Therefore, the wetland restoration driven force was mainly due to the runoff variation, especially the water transfer for ecological use in 2008–2010. In 2010, the Diaokou River once again began flowing after 34 years of cutoff, the main purpose of which was to transfer water the core region of the wetland in order to improve the wetland ecosystem.

4.2. Impacts of flow variation on wetland restoration

Although there have been some researches performed on Dongying City or Yellow River Delta Wetland (Ottinger et al., 2013), this study examine and quantifies the land use changes in the Yellow River Delta Wetland in an attempt to determine the factors affecting these changes.

Wetlands may be classified as one of two types, natural wetlands and artificial wetlands. The natural wetland area decreased by 541.66 km^2 from 1976 to 2010, decrease of 41.9%. The artificial wetland increased 336.06 km^2 over 34 years, and the increase rate was especially high from 1990 to 2010. The natural wetland and artificial wetland variation were different, the general trend being that the natural wetland decreased each year, while the artificial wetland increased rapidly. Landscape types changed with open water areas expanding and the tidal flats decreasing in the years following restoration (Hua et al., 2012). The degradation of marsh land and freshwater wetland was seriously, but the shrinking trend and function degradation trend decelerated after 2000 (Fig. 8).

The transition of the Yellow River Delta Wetland structure was mainly caused by human activities and the runoff and sediment changes in the estuary. These human activities concluded constructions, land resources exploration and water projects constructions. In addition, the oil exploitation on protected wetlands is another important influence (Bi et al., 2011). The human activities resulted in artificial wetland area increasing rapidly and natural wetland area decreasing, and at the same time the fragmentation index increased and habitat suitability decreased. The water and sand resources of the Yellow River were the driven forces of new wetland formation, growth and evolution. The water area increased in 2010 compared with 1990, while the total area of wetland increased but beach land and marsh land decreased. From 1990 to 1999, the water and sand that flowed into the estuary reduced heavily exacerbating the shrinking of the YRDWNR especially the freshwater wetlands, which indirectly caused the degradation of wetland functions. Since the optimal allocation of Yellow River from 1999, wetland recovery has been supported by appropriate water resources. Since this time, the freshwater wetland area has increased and the quality of wetland has improved.

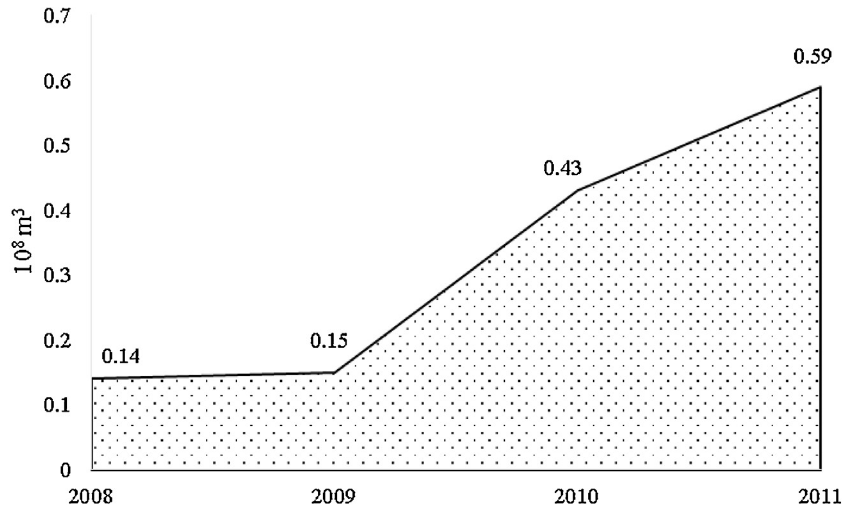


Fig. 7. The operation for Yellow River Delta Wetland and water transfer for wetland recovery from 2008.

4.3. Evaluation of wetland restoration success on birds

Birds are an indicator species for wetland environments, studies of relationship between bird species and environmental variables were mainly concentrated on landscape-level, habitat level and human-level (Ke et al., 2010; Yuan et al., 2014). Based on the birds' growth and reproduction necessities, water area, marsh land and beach land were the most important habitat areas. Reeds were the most important plants in the wetland, and the limit factor of reeds was water. As research results, salt marshes can be restored most easily when natural hydrologic conditions are restored (Hinkle and Mitsch, 2005). Following the completion of the hydrologic portion of wetland restoration, the most suitable water depth of reeds in the YRDWNR was 0.05–0.6 m. Wetlands with more vegetation species and shallow water tend to attract more birds. The habitats of swimming birds and wading birds were mainly stream course and marsh land. After restoration, the improvement of ecological conditions provided favorable habitats for a variety of birds. More and more migrating and breeding birds including some rare species appeared and bred in the study area.

Coastal areas with tidal salt marshes are valuable habitat for many species of plants and birds, but they have been significantly altered (Ottinger et al., 2013). The species diversity and evenness indices were generally increased from 1990 to 2010, during which time all types of landscape pattern developed equalization, but the average area of patches decreased, which affected the birds' habitats. Large amounts of wetlands changed due to the artificial wetlands, and the ratio of natural and artificial wetland decreased by 72.5%. Marsh land increased to provide high quality habitats for the red-crowned crane and whooper swan. In the process of adapting to the changed environment, the red-crowned crane may also choose artificial wetlands as an alternative to complementary habitats (Wang et al., 2012). The species number increased, and some breeding of red-crowned crane took place. The reeds were mainly located in high coverage grassland, the reeds improved the habitat of the whooper swan, red-crowned crane and *Ciconia boyciana*.

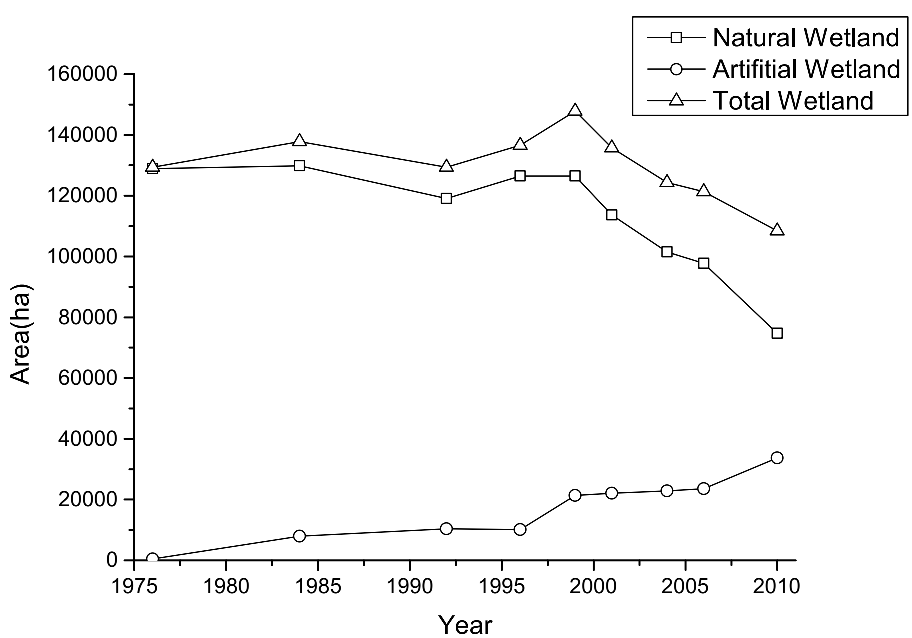


Fig. 8. Wetland area changes since 1976.

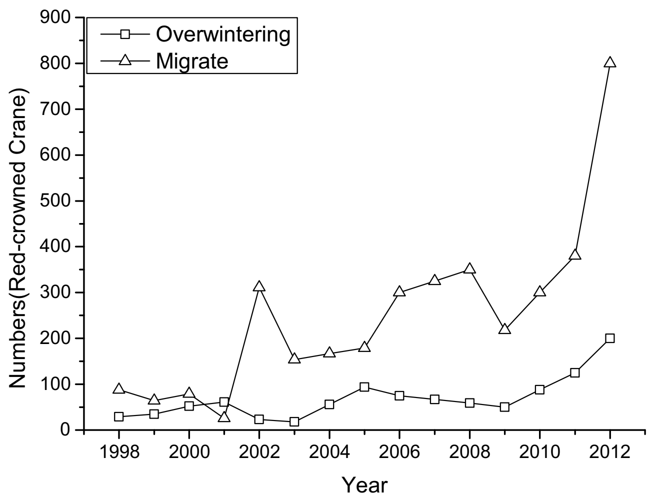


Fig. 9. Overwintering and migrate number changes of Red-Crowned Crane.

From 2000 to 2010, the overwintering numbers of red-crowned crane increased from 52 to 200 and the migrate numbers increased from 79 to 800. In the first 5 years following the restoration, the overwintering numbers increased and then decreased, then after 4 years increased again (Fig. 9). There have also been researches which indicate that the potential habitat of the red-crowned crane increased 22.4% from 1992 to 2008 (Wang et al., 2011). Certainly, the habitat changes have positive impacts on the global biodiversity because the Yellow River Delta Wetland is important to the population of red-crowned cranes and other migratory birds.

5. Conclusion

According to the dynamic analysis of landscape pattern over the past 20 years and avifauna survey, water transferred to the wetland was an important reason for maintaining the wetland. By means of scheduled water management and water transferring measures, the artificial wetland increased and prevented the wetland degradation. The artificial wetland increased continuously, while the total wetland area decreased. The natural wetland decreased significantly since 2000, thus affecting the ecosystem service. Grassland, plain dry land and beach landscape were the main types in 2010. These treads explained the shrinking of wet area in the Yellow River Wetland and deterioration trend of the local ecological environment. The MESH, LPI, NP and TE of landscape metrics continued to decrease. The overall landscape types did not change much throughout the five periods.

It is expected that the land use change discerned by remote sensing analysis will have an impact on the diversity and population of birds, in particular endangered water birds. Medium grassland, tidal flat and pond are the three main landscapes which are beneficial for the habitation of birds. The red-crowned crane migrate to this area, and overwintering numbers have increased. Although the total wetland area decreased, the grassland mainly the medium cover grassland and tidal flat, did not change significantly, the reservoir and pond landscape increased by more than six times the sizes in 1990. The wetland recovery and protection should enhance the habitat management and the construction of artificial wetland should focus on the total landscape balance. Medium grassland, tidal flat and pond landscapes were shown to be the key land use types to protect the endangered species birds. The components of bird species are subject to the process of wetland restoration. The restoration of hydrologic links between the Yellow River and the wetlands is an effective way to restore wetland landscape.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoleng.2015.11.017. These data include Google map of the most important areas described in this article.

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