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Dynamic Changes in the Wetland Landscape Pattern of the Yellow River Delta from 1976 to 2016 Based on Satellite Data

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Abstract: The Yellow River Delta wetland is the youngest wetland ecosystem in China's warm temperate zone. To better understand how its landscape pattern has changed over time and the underlying factors responsible, this study analyzed the dynamic changes of wetlands using five Landsat series of images, namely MSS (Mulri Spectral Scanner), TM (Thematic Mapper), and OLI (Operational Land Imager) sensors in 1976, 1986, 1996, 2006, and 2016. Object-oriented classification and the combination of spatial and spectral features and both the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), as well as brightness characteristic indices, were used to classify the images in eCognition software. Landscape pattern changes in the Yellow River Delta over the past 40 years were then delineated using transition matrix and landscape index methods. Results show that: 1) from 1976 to 2016, the total area of wetlands in the study area decreased from 2594.76 to 2491.79 km^2, while that of natural wetlands decreased by 954.03 km^2 whereas human-made wetlands increased by 851.06 km^2. 2) The transformation of natural wetlands was extensive: 31.34% of those covered by *Suaeda heteropteras* were transformed into reservoirs and ponds, and 24.71% with *Phragmites australis* coverage were transformed into dry farmland. Some human-made wetlands were transformed into non-wetlands types: 1.55% of reservoirs and ponds became construction land, and likewise 21.27% were transformed into dry farmland. 3) From 1976 to 2016, as the intensity of human activities increased, the number of landscape types in the study area continuously increased. Patches were scattered and more fragmented. The whole landscape became more complex. In short, over the past 40 years, the wetlands of the Yellow River Delta have been degraded, with the area of natural wetlands substantially reduced. Human activities were the dominant forces driving these changes in the Yellow River Delta.

Keywords: landscape pattern; object-oriented classification; landsat; wetlands; Yellow River Delta

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1 Introduction

As an important environmental resource, wetlands are a unique ecosystem formed by the interaction between water and land. And they are among the most ecologically diverse in nature. Wetlands provide key functions and services, such as promoting environmental stability, maintaining the genetic diversity of species, and resource utilization (Chen, 1995) and therefore, these systems can greatly affect the human living environment. As we learn more of value that wetlands provide, their quality of protection and management has also improved around the world (Yan et al., 2017). In 2016, the General Office of the State Council of China issued the

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Scheme of Wetland Conservation and Restoration System. It proposes that by 2020, the area of national wetlands will be at least 5.33×10^5 km^2, of which no less than 4.66×10^5 km^2 shall consist of existing natural wetlands and wetland protection rate shall increase to more than 50.00% in China (the General Office of the State Council, 2016). The formulation of this plan marks a new breakthrough in the reform of the 'Ecological Civilization' system in China, and it also reflects the growing awareness of the need to better protect wetlands resources.

Estuarine wetlands are an important ecosystem, in that the interactions between river, sea, and land are characterized by both complexity and variability. The Yellow River Delta wetland is located on the coast of the Bohai Sea, in the northeastern part of Shandong Province, where the land meets this river and sea, giving it important functions of ecological service, resource supply, and efficient environmental production (Chen et al., 2017). Because this wetland not only has unique environmental conditions and economic status, but also has ecological vulnerability, it is a key area of interest for studying the conservation of biodiversity and impact of climate change (Shandong Yellow River Delta National Nature Reserve Administration, 2016). Currently, due to the increase in human activities in the Yellow River Delta, such as excessive land reclamation, coastal engineering, and environmental pollution, the vulnerability of the wetlands has also risen (Fu et al., 2013; Liu et al., 2013). This threat is part of a general trend, of an accelerating impact of human activities and natural factors on the biosphere (Zang et al., 2017), in which wetlands are being degraded and this degradation is irreversible in many cases. Human disturbance such as frequent and excessive land development will inevitably hasten the degradation of wetlands. Therefore, ensuring regional economic development without compromising ecosystem integrity is a major challenge facing humanity. For the protection of wetlands, strengthening their monitoring and analyses of the dynamics and changes in the wetland landscape are of immense practical value.

The identification of wetland types and the correct interpretation of the wetland area are crucial research goals (Yang, 2002). With the development of remote sensing technology, satellite-based data now offer the advantage of short revisit time and good accessibility to historical data, which are both helpful for monitoring changes in wetlands (Ozesmi and Bauer, 2002; Dong et al., 2016; Escorihuela and Quintana-Seguí, 2016). In recent years, many studies have investigated the evolving landscape in the Yellow River Delta (Liu et al., 2016). For example, Zong et al. (2009) analyzed the dynamic changes in landscape patterning, by using the methods of supervised classification and visual interpretation from the satellite data of the Yellow River Delta in 1986, 1996, and 2006, to reveal the character of these changes as well as their driving factors. More recently, Hong et al. (2016) described the evolving process and driving force of landscape types in the Yellow River Delta by visual interpretation of satellite data over 9 periods spanning 1973–2013. Han et al. (2017) classified TM (Thematic Mapper) images covering the Yellow River Delta from 1989 to 2014 according to a artificial visual interpretation and calculated the landscape index, while the impact of human activities on the Yellow River wetlands was quantified by the road traffic coverage, residential areas, and other anthropogenic indicators. In sum, most of these studies above used classification methods based on visual interpretations and traditional pixel-based classification; however, the former approach has many limitations to it, such as high costs and heavy workloads, while the latter method often produces a large degree of fragmentation. Conversely, in an object-oriented image analysis, the basic processing units are for objects instead of individual pixels, in that this approach uses the object classification of homogeneous pixels (Mui et al., 2015). Initial image segmentation uses low-level information (i.e., pixel-based features) to create higher-level contiguous image objects (Frohn et al., 2009). Therefore, the object-oriented classification result is less fragmented, and can avoid the typical 'pepper noise' produced by traditional classification methods (Mei et al., 2001; Guo et al., 2007). Finally, in most prior studies, their classification scheme lacked rice paddy fields, an obviously vital type of human-made wetland.

Taking the Yellow River Delta as our study area, we built a wetland classification system and used object-oriented classification methods to obtain the landscape classification results. The landscape index and transition matrix were used to assess the dynamic evolving process of the landscape in the Yellow River Delta. Our aim is to better understand how wetland landscape pattern has changed from 1976 to 2016 and the underlying factors responsible in Yellow River Delta wetland. The results will inform a more comprehensive understanding of the causes and principles underpinning landscape changes in estuary wetlands.

2 Materials and Methods

2.1 Study area

The Yellow River Delta, the second largest estuary delta in China after the Yangtze River Delta (Zhang et al., 2005), is an alluvial plain formed by the Yellow River, with large amounts of sediment deposited in the Bohai Sag. It has a temperate monsoon-type of continental climate, with four distinct seasons and adequate sunshine. The annual total sunshine is 2590–2830 h and total solar radiation is 514.2–543.4 kJ/cm^2; annual average temperature is 11.7–12.6℃; average annual precipitation is 530–630 mm, of which 70.00% is concentrated in the summer; annual evaporation is 1900–2400 mm, and annual average wind speed is 3.1–4.6 m/s (Wang Ying et al., 2013). The Yellow River Delta wetland sustains millions of birds that feed and perch here every year. It serves as an important stopover, habitat, and breeding ground for migratory bird species found inland of northeast Asia, the West Pacific region, east Asia, and Australia. Not surprisingly, it enjoys the reputation of being an 'international airport' for migratory birds.

Vegetation resources are abundant in the general study area. In the Yellow River Delta National Nature Reserve there are 393 species of plants, including 116 species of wild seed plants (Dongying Government, http://www.dongying.gov.cn/). The perennial grass *Phragmites australis* covers a total area of 266.7 km^2 and natural vegetation coverage in the reserve amounts to 55.1% of the total wetlands area. The Reserve protects the largest natural vegetation area within newly formed coastal wetlands in China. In 1994, the Reserve was listed by the state as one of the 16 most important protected wetland ecosystems in the world. Then, in 2013, the Yellow River Delta was added to the list of internationally important wetlands by the Secretariat of the Wetland Convention. More accurately, we used the modern Yellow River Delta for our study area. It corresponds to the area bound by taking Yuwa of Kenli County as the axis point, going north from the Tiaohe estuary, south to the Song Chunrong gully, and east with the –6 m isobath as boundary lines (Fig. 1).

2.2 Data and processing

Remote sensing data were downloaded from the official website of the United States Geological Survey (http://glovis.usgs.gov/), for later use in our wetland classification (Table 1). In addition, the existing Yellow River Delta classification data on basis of high resolution satellite data (spatial resolution of 2 m) in 2016, along with field survey data obtained in 2017, were used as auxiliary data for cross-validating the results.

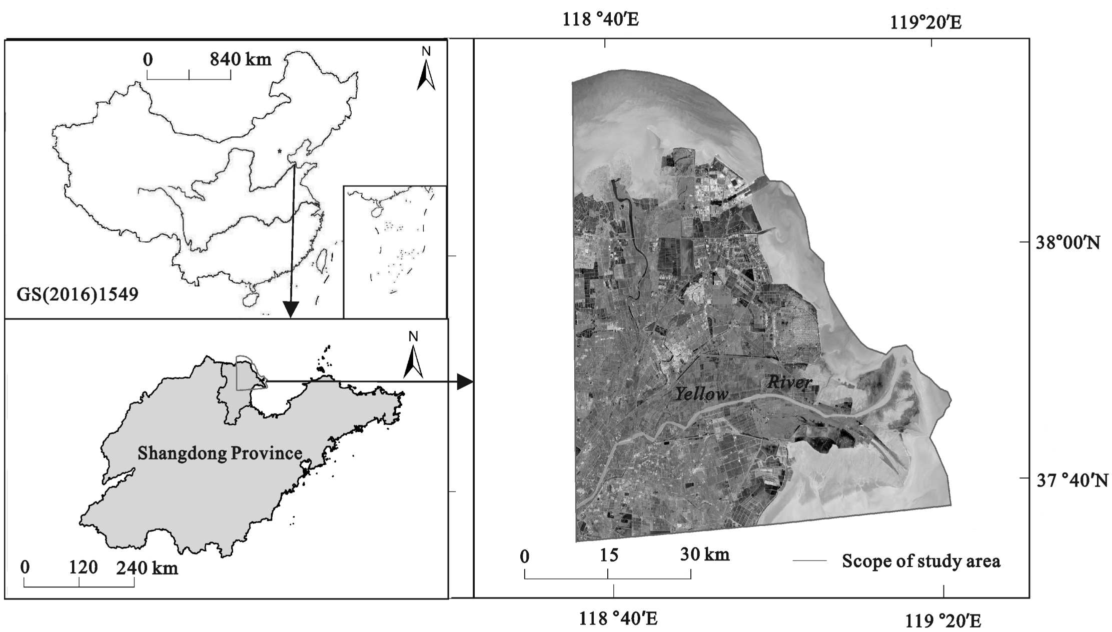

Fig. 1 The location of the Yellow River Delta wetland in Landsat OLI image in 2016

Table 1 Satellite-based data used in this study

File name	Date	Resolution (m)	Cloud amount (%)
Landsat2 MSS	1976-06-02	78	0
Landsat5 TM	1986-05-20	30	0
Landsat5 TM	1996-09-20	30	2.00
Landsat5 TM	2006-10-02	30	20.00[a]
Landsat8 OLI	2016-08-26	30	0.36
ZY3705_464452_160625A0	2016-06-25	2	–
GF3705_752914_160810A0	2016-08-10	2	–
GF3705_542202_160425A0	2016-04-25	1	–
ZY3705_464453_160625A0	2016-06-25	2	–

Notes: [a] no cloud in the study area; MSS: Multi Spectral Scanner, TM: Thematic Mapper, OLI: Operational Land Imager

To ensure consistency in our data classification, Landsat MSS data should generally be resampled to 30 m. But since the downloaded data already underwent geometric correction and radiation correction processing, this step was not necessary. The most commonly used band combination of 5, 4, and 3 (TM) for wetland classification was selected for the image enhancement. Other bands were used for auxiliary recognition. Finally, all the image data were clipped according to the boundary data.

2.3 Wetlands information extraction

2.3.1 Wetlands classification system

Presently, many kinds of wetland landscape classification systems exist in China and abroad (Zhang et al., 2007), especially for landscape types in the Yellow River Delta. In this study, a Yellow River Delta wetland classification system (Table 2) was established on basis of the two pre-existing classification systems: the Ramsar Convention and the National Standards for Wetland Classification introduced in 2009 in China. In short, our classification considered both the characteristics of Yellow River Delta's wetlands as well as the overall influence of human activities.

2.3.2 Remote sensing classification method of wetlands

A multi-scale segmentation of each image was first carried out, since the selection of scale has a large influence

Table 2 Classification system applied to the wetland landscape of the Yellow River Delta

Level 1	Level 2	Description
Natural wetlands	Natural waters	Inundated all year round, with water depths <6 m (shallow waters) and river estuaries including the sudden increase of exports (river wetlands)
	Intertidal muds	Silt beach with a vegetation coverage of <30%
	Phragmites australis[a]	*Phragmites australis* and alfalfa, vegetation coverage >30%
	Suaeda heteropteras[b]	Pioneer species, growing on both sides of the river
	Spartina alternifloras[c]	Hazardous species, endangered *Phragmites australis* and *Suaeda heteropteras*
Human-made wetlands	Reservoirs and ponds	Reservoir, pit pond, *etc.*
	Aquaculture ponds	Ponds for fish, shrimp, *etc.*
	Salt pans	Salt pans
	Paddy fields	Paddy fields, Lotus pond
Non-wetlands	Forest land	Natural growing trees and shrubs
	Dry farmland	The cultivated land that grows crops all the year round, mainly planting grain, cotton, and vegetables
	Construction land	Artificial buildings such as factories, parks, towns and rural settlements.
	Industrial land	Industrial and mining landoil wells and oil production areas
	Garden plots	Jujube garden, *etc*
	Unused land	Reclaimed but unused area

Notes: a, b and c all belong to the intertidal salt marsh category; here we highlight the different vegetation analyzed in the study on the classification result (Liu, 2017). Because the resolution of the Landsat data was relatively low, the segmentation scale should not be too large. To ensure the comparability of our classification results, the segmentation scale was set to 15 for the 5 remote sensing images. The unsuitable part was manually adjusted (visually). Then, the near-infrared band was taken from the green band to distinguish the water and non-water layers. For the latter, we determined whether the Normalized Difference of Vegetation Index (NDVI) was greater than zero in the vegetation layer and non-vegetation layer. In each layer the threshold values of the NDVI, Normalized Difference of Water Index (NDWI), brightness index were used to extract the relevant information. For those feature types with small threshold differences, samples selected by high spatial resolution data and previous research data were classified by using the nearest neighbor method. Finally, small heterogeneous spots in the classified result were removed, and then the category was adjusted and merged.

The georeferenced points from high spatial resolution imagery from 2016 and the 2017 field survey data were selected for verification. In other years, historical images from Google Earth were used. The selection of the accuracy of the georeferenced point should be evenly distributed in the study area. Each class involved a random selection of 20 accuracy verification points. For the years of 1976, 1986, 1996, 2006, and 2016, their respective overall accuracy was 83.75%, 82.30%, 81.79%, 79.67%, and 81.33%. For the remote sensing images from 1976 to 2016, their spectral information and image quality for the same plants differed due to differences among the shooting years. Hence, in the process of hierarchical classification the 5-stage image selection remained the same, but the value of the specific parameter was set differently.

2.3.3 Wetland landscape index

Landscape pattern analysis typically uses quantitative indices to evaluate and describe a given landscape structure. Such indices can condense much information on landscape spatial patterning and can convey its structural composition and spatial distribution (Wu, 2007). A landscape index consists of a grain size effect and a scale effect. Although these may differ at different scales, they are relatively consistent at the macroscopic level (Zhao, 2005). Considering both the classification result scale (30 m) and the actual land use of the study area, a 30-m scale was selected for the landscape index calculation. To effectively and accurately describe and evaluate the landscape structure (Wang Yanfang, 2013), we selected 10 indices at the landscape level: NP (the number of patches), PD (patch density), LSI (landscape shape index), PAFRAC (perimeter area fractal dimension), CONTAG (contagion index), SPLIT (splitting index), PR (patch richness), SHDI (Shannon's diversity index), SHEI (Shannon's evenness index), and AI (aggregation index). Calculation of these indices was done in Fragstats v4.2 software (McGarigaland Marks, 1995).

3 Results

3.1 Landscape pattern and area changes of wetland

The classification maps of wetland landscapes from 1976 to 2016 are shown in Fig. 2. The changes in the wetland areas are shown in Table 3 and Fig. 3. In this 40-year span, the changes to the spatial morphology of the Yellow River estuary were considerable and the swaying of the tail sag is pronounced. In 1976 the Yellow River diverged and a new river estuary was formed. By 1986, this river estuary area had gradually extended to the ocean, reaching in longest extension in 1996. But in 2006, the siltation began to erode and retreat. Finally, from 2006 to 2016, the whole estuary body became stable after the bifurcation, but the tail change of Yellow River had an upward trend.

From 1976 to 2016, the total wetland area in the study area was declining from 2594.76 km^2 in 1976 to 2491.79 km^2 in 2016, of which the natural wetlands decreased by about 954.03 km^2 from 2593.63 km^2 in 1976 (Fig. 3). Those with *Phragmites australis* cover increased slightly at first but then quickly decreased over the 40 years, with a total reduction of 511.47 km^2. The *Phragmites australis* cover increased from 1976 to 1986 as the wetlands extended toward the sea each year. Later, due to excessive land reclamation, *Phragmites australis* coverage declined from 1986 to 2016. *Spartina alternifloras* is a grass species—it undergoes asexual reproduction and has strong reproductive capacity—and its coverage increased from 2006 to 2016. *Suaeda heteropteras* can be greatly affected by the environment,

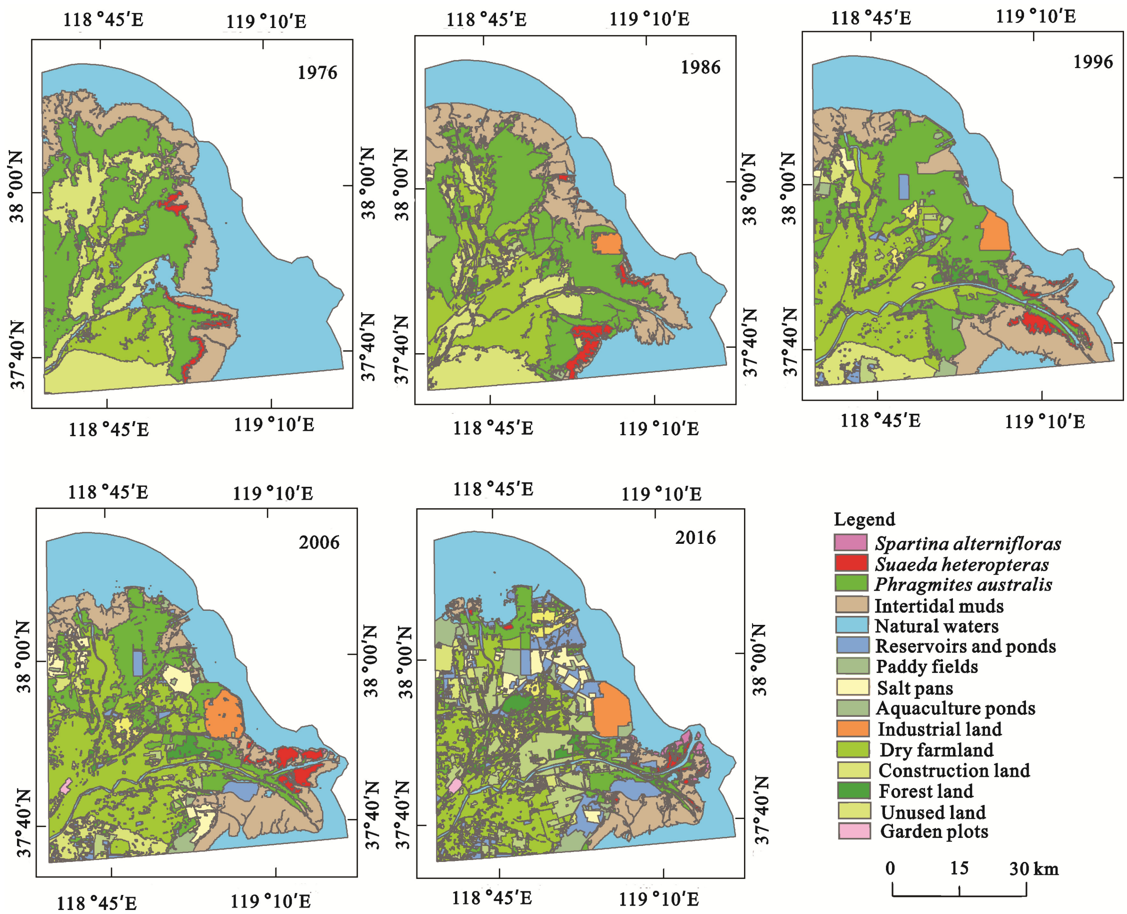

Fig. 2 Classification maps of the Yellow River Delta wetland landscape from 1976 to 2016

Table 3 Changes in the wetland landscape areas in five periods (km^2)

Wetland type	1976–1986	1986–1996	1996–2006	2006–2016	1976–2016
Spartina alternifloras	0.00	3.45	1.05	20.71	25.21
Suaeda heteropteras	10.14	–11.61	5.39	–22.30	–18.38
Phragmites australis	11.51	–115.40	–173.99	–233.60	–511.47
Intertidal muds	–1.00	63.63	–56.46	–240.51	–234.34
Natural waters	–210.04	–125.36	48.71	71.64	–215.05
Reservoirs and ponds	2.57	48.54	44.12	203.01	298.24
Paddy fields	32.23	4.85	2.43	293.74	333.25
Salt pans	1.60	10.37	79.30	1.68	92.95
Aquaculture ponds	4.87	35.13	1.09	85.52	126.61
Industrial land	27.45	20.44	27.25	3.88	79.02
Dry farmland	271.22	225.11	47.54	–187.71	356.15
Construction land	13.42	5.91	19.63	37.83	76.79
Forest land	22.66	12.05	0.43	47.72	82.86
Unused land	–186.64	–177.11	–51.59	–83.98	–499.31
Garden plots	0.00	0.00	5.09	2.37	7.45

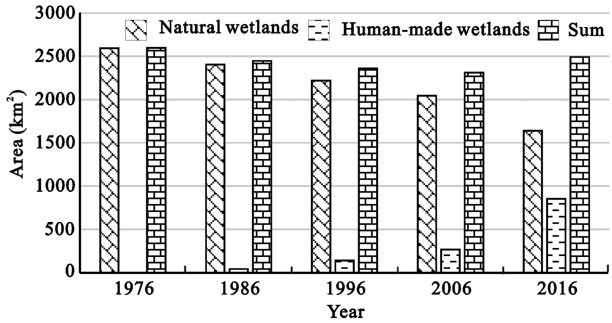

Fig. 3 Changes of Yellow River Delta's wetland areas from 1976 to 2016

and they grow along the river mouth. With the swaying of the tail sag in the Yellow River, the growth environment of *Suaeda heteropteras* was changed, and they were also affected by *Spartina alternifloras*. The number of *Suaeda heteropteras* were greatly reduced from 2006 to 2016.

Overall, the human-made wetlands continued to increase (Fig. 3), with the reservoirs and ponds and paddy fields increasing most, especially from 2006 to 2016 (Table 3). For non-wetlands, dry farmland had the most growth, but the growth rate of dry farmlands began to slow down from 1986 to 1996, mainly due to the establishment of the Yellow River Delta National Nature Reserve in 1992, as well as the government policies focusing on the protection of these wetlands. Finally, the total amounts of construction and industrial land areas also rose over time.

3.2 Dynamic transition matrix of wetland types

To study the conversion among the coastal wetland landscape types in the Yellow River Delta from 1976 to 2016, a transition matrix of wetland types was calculated using the tabulate areas function in ArcGIS spatial analysis. The transition map of Yellow River Delta wetland types is shown in Fig. 4.

As Fig. 4 shows, most of the lost natural wetlands were transformed to human-made wetlands or non-wetlands. For example, 31.34%, 24.70%, and 15.42% of *Suaeda heteropteras* coverage was transformed into reservoir ponds, salt pans, and aquaculture ponds, respectively. Likewise, 4.13%, 6.34%, 13.22%, and 5.96% of intertidal muds areas were respectively converted into salt pans, aquaculture ponds, reservoirs and ponds, and industrial land areas. Sources of dry farmland total were 24.71% of *Phragmites australis* and 2.79% of *Suaeda heteropteras* wetlands. Notably, the human-made wetlands were mainly transformed into non-wetlands: 21.27% of reservoirs and ponds were converted to dry farmland while another 1.55% became construction land.

3.3 Analysis of wetland landscape pattern

Table 4 shows the calculated landscape index values over 40 years. That PR followed an increasing trend indicating a greater species diversity in the study area. The rise in PR was also associated with a considerable

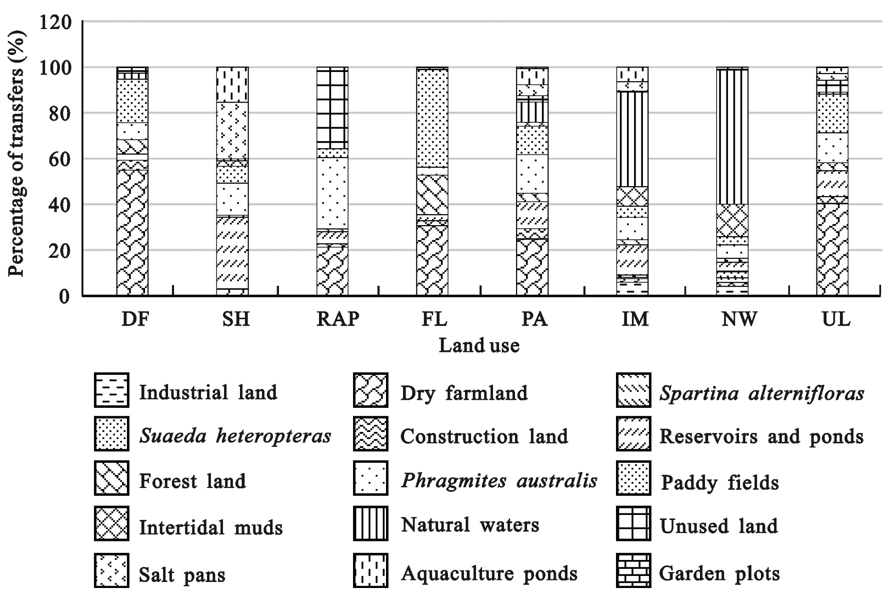

Fig. 4 The transition map of wetland types in Yellow River Delta from 1976 to 2016

Table 4 Landscape-level indices for wetlands of the Yellow River Delta from 1976 to 2016

Year	PR	PD	LSI	PAFRAC	SPLIT	SHDI	SHEI	NP	CONTAG	AI
1976	8.00	0.12	12.25	1.33	7.02	1.58	0.76	417.00	60.20	98.93
1986	13.00	0.21	21.03	1.37	8.19	1.76	0.69	733.00	63.18	98.05
1996	14.00	0.30	18.47	1.27	9.19	1.88	0.71	1028.00	62.27	98.33
2006	15.00	0.42	23.01	1.30	10.13	1.99	0.74	1451.00	60.67	97.87
2016	15.00	0.78	35.03	1.31	11.06	2.19	0.81	2701.00	55.84	96.65

Notes: NP (the number of patches), PD (patch density), LSI (landscape shape index), PAFRAC (perimeter area fractal dimension), CONTAG (contagion index), SPLIT (splitting index), PR (patch richness), SHDI (Shannon's diversity index), SHEI (Shannon's evenness index), and AI (aggregation index)

increase in the NP, and PD also increased. Overall, the LSI tended to rise over time, indicating the landscape shape had become more complex. Both the SHDI and the SHEI generally increased, pointing to more landscape types in the study area. There was no clear dominant landscape type, and the distribution of each was relatively uniform. SPLIT was generally enhanced as well, a change closely related to human activities. Increasingly larger areas of *Phragmites australis* and unused land were developed into small plots of dry farmland, aquaculture ponds, and salt pans. PAFRAC decreased slightly from 1986 to 1996, but increased at other times, suggesting the prevalence of human activities causing disturbance in the area. CONTAG declined, indicating that various types of elements in the landscape were densely distributed and the patches were fragmented. Finally, AI also declined over time, which indicates that patches were scattered and more often fragmented. In general, the whole landscape became more complex than its prior simple state.

4 Discussion

In this study, vegetation extraction relies primarily on the NDVI index in the process of wetland type extraction. But small variations in the NDVI index can easily lead to a misclassification. Therefore, the distinction between paddy fields and dry farmland mainly depended on the water demand characteristics of rice planting. The auxiliary images from April to August within the same year were used to accurately distinguish these two different land use types. Additionally, our results for the beach and shallow water areas were somewhat affected by the shooting time of remote sensing images. We suggest that the next step is to select aerial photographs or high spatial resolution data at low tide periods to distinguish beach and shallow water areas more accurately. The extraction of *Suaeda heteropteras* cover is limited by the number of bands, radiation resolution, and the shooting time of the early Landsat data sources. However, by combining the spatial features of ground objects and the niche characteristics of this species, as well as using historical images from Google Earth and previous research, the accuracy of our classification results was improved.

According to our results, the landscape types have changed drastically in the past 40 years. Not only have the wetlands mostly become degraded, but also those existing wetland patches tend to be fragmented. The discerned changes in landscape types are mainly influenced by both natural and human factors. 1) Changes in the climate (e.g., temperature) in the study area play a key role in the formation of new wetlands. Long-term increasing temperature and declining precipitation will likely lead to wetlands' degradation. Studies have shown that the annual average temperature in the region continues to increase while annual precipitation has decreased from 1961 to 2010 (Song et al., 2016). Importantly, the cut-off and diversion of the Yellow River have also changed the types of landscape characterizing the Yellow River Delta (Han et al., 2017). 2) According to our results, the dominant factor underpinning landscape change in the Yellow River Delta has been interference from human activities. The increase in human land use, such as farmland reclamation, beach development, and construction work in the region, have all led to wetland degradation. Other studies have reached the same conclusion (Gai, 2011; Zhang, 2016; Chen et al., 2017). Generally speaking, anthropogenic factors were the dominant forces causing landscape types in the Yellow River Delta to change over time and in extent. From 1976 and 2006, it is clear these changes were mainly due to farmland reclamation. Nonetheless, from 2006 to 2016, the development of reservoirs and ponds was the main driver of change.

On the basis of these research results, we suggest that in order to prevent wetland degradation and to protect and make rational use of wetlands, we should carry several key tasks. First, ensure a fresh water supply of wetlands in the Yellow River Delta through water and sediment regulation of the Yellow River. Second, stop the reclamation of wetlands, and return farmlands to wetlands in critical areas. Third, implement biodiversity protection in ecologically valued areas, such as bird habitats, natural beaches, *Suaeda heteropteras* communities and emerging wetlands. Fourth, strictly abide by the ecological conservation redline (ECR) and strengthen the management and capacity-building of the nature reserve. The ECR refers to the area demarcated for special protection according to the protection needs of ecosystem integrity and connectivity in order to maintain national or regional ecological security and sustainable development. Fifth, combine natural recovery with artificial restoration efforts and gradually restore the ecological functions of wetlands. Sixth, make full use of unique estuary wetlands to develop wetland eco-tourism, promote local economic development, and enhance people's awareness of wetland protection to ensure the sustainable development of wetlands into the future.

5 Conclusions

This study used series of Landsat images to explore the changes in landscape types in the Yellow River Delta wetland from 1976 to 2016 and the underlying factors responsible. Results showed that medium-and low-resolution data can meet the need for dynamic monitoring of long-term sequence of estuary wetlands. In the changes of wetland landscape pattern, over the past 40 years, the total wetland area in the study area declined from 2594.76 km^2 in 1976 to 2491.79 km^2 in 2016. During the dynamic evolving of wetlands, the transformation of natural wetlands was relatively large. It decreased about 954.03 km^2 from 2593.63 km^2 in 1976. Most of the lost natural wetlands were transformed to human-made wetlands or non-wetlands. From 1976 and 2006, these changes were mainly due to farmland reclamation. Nonetheless, from 2006 to 2016, the development of reservoirs and ponds was the main driver of changes. With the expansion of human activities, more landscape types occurred in the study area. The heterogeneity of the landscape space increased and its patterning tended to be more complex in contrast to its prior simplicity. Overall, wetland patches tend to be fragmented, complicated, and reduced in connectivity. The wetland degradation is affected by both natural and anthropogenic processes. Among the two, the anthropogenic factor has been the dominant one causing changes in the landscape types of the Yellow River. With rapid economic development and increase in human population density, the demand for agricultural land and construction land has increased in tandem. Insufficient awareness of wetland protection, excessive land reclamation, and construction have undoubtedly contributed to this documented degradation of wetlands.In the future research, we plan to quantify the impact of human activity on the wetland degradation.

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