ORIGINAL RESEARCH

Spatio–Temporal Dynamics of Wetland Landscape Patterns Based on Remote Sensing in Yellow River Delta, China

Guilin Liu · Luocheng Zhang · Qian Zhang · Zipporah Musyimi · Qinghu Jiang

Abstract The wetland landscape patterns of the Yellow River Delta have undergone an extremely significant change due to rapid economic development since 2000. The aim of this paper is to quantitatively analyze spatial and temporal changes of these wetlands in the recent decade. Three sets of wetland maps were acquired using object–oriented classification method based on remotely sensed imageries in 2000, 2005 and 2010. Then landscape indices from class and landscape level using FRAGSTATS 3.3 software were used to quantify the spatial and temporal dynamics of wetlands. The results showed that wetlands coverage decreased by approximately 2.27%. Natural wetlands decreased while constructed wetlands increased, especially prawn pools, which increased by 268.33%. Wetland landscape patches gradually became more complex and decentralized. Wetlands distribution analysis indicated that wetlands were mainly located in the area 45 km from the coastline. The study indicated a relatively high diversity at the estuary of the river and the north of the study area. However, wetlands were highly fragmented in the south of the study area and urban area. Dynamic of wetlands was mainly caused by human–induced factors, especially GDP and urban built–up area.

Keywords Wetland · Landscape dynamic · Object–oriented classification · Yellow River Delta

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Introduction

Since land use and land cover change (LUCC) scientific research program was proposed jointly by the International Geosphere–Biosphere Program (IGBP) and International Human Dimensions Program on Global Environmental Change (IHDP) in 1995(Turner et al. 1995), land use and land cover change has become one of the most important indicators in understanding the interactions between human activities and the environment (Dewan et al. 2012). As an important land cover type, wetlands cover 6% of the Earth's surface and play a critical role in regulating regional climate and preventing or reducing the flood severity (Mitsch and Gosselink 2007). Wetland ecosystem is not only a natural ecological landscape with rich biological diversity but also an environment for human being's existence and development (Holland et al. 1995). However, the quality and quantity of wetlands in developing countries is increasingly affected by human disturbance in the recent decades due to human population growth and economic development (Zedler and Kercher 2005).

The traditional field investigation methods can no longer capture the change trends at the regional scale (Zhang et al. 2009a). However, application of remotely sensed images offers a remedy to monitor wetland landscape changes (Skole et al. 1997) due to their wide range of observation and availability within short time steps. In the recent 20 years, remote

sensing technology has been widely used in wetland resource investigation, identification and change detection (Turner et al. 2003). Landsat imageries have been extensively used for monitoring spatial and temporal dynamics of wetlands at regional and global scale. Their suitability is attributed to huge advantage in data accessibility, long time series and large spatial resolution (Mahmud et al. 2011; Munyati 2000). Therefore, many studies have used Landsat data to detect wetland changes driven by both anthropogenic and natural factors (Xu et al. 2011; Jones et al. 2009; Niu et al. 2009; Gong et al. 2010).

However, change detection is often inadequate to derive detailed landscape properties such as composition and configuration (Narumlani et al. 2004). To fully understand the effects of wetland change at the landscape scale, integration of change detection analysis with landscape pattern analysis has been proposed. Such integrated analysis allows for quantification of spatial structural features, spatial heterogeneity, distribution and configuration of wetlands patches, classes and landscape patterns (O'Neill et al. 1988; Xu et al. 2009; Huang et al. 2012). In the past three decades, a range of landscape indices have been developed to describe the spatial distribution of wetlands characteristically (Forman and Godron 1986; Hargis et al. 1998). In the recent decades, the 3S (GIS, RS, GPS) technique combined with landscape pattern indices analysis have been used to study landscape pattern changes (Tang et al. 2005; Abdullah and Nakagoshi 2006; Seto and Fragkias 2005; Yeh and Huang 2009; Linke and McDermid 2012).

The Yellow River Delta is located in the estuary of the Yellow River, with resource–rich territory of coastal wetlands. The Yellow River Delta has experienced tremendous economic development since the year 2000. Consequently, the dramatic land use changes exacerbated natural wetlands degradation (Wang et al. 2011). As the key economic development area, more industries were established under the economic policies in China. Meanwhile, the development of aquaculture resulted in transformation from natural to constructed wetlands.

What are the detailed dynamics of wetland landscape driven by human factors? This paper hypothesized the influence of human activities on wetlands changes. Rapid economic development, urban expansion, oilfield development and industrialization have resulted in the wetlands degradation. In addition, aquaculture development has also affected the wetlands transformation. Therefore, three specific objectives of this article were to (1) acquire wetland classification from 2000 to 2010 using object–oriented classification method based on Landsat TM/ETM+and HJ/CCD images, (2) analyze spatial and temporal dynamics of wetland landscape patterns based on change detection method, (3) illustrate the relationship between wetland landscape change and the driving factors.

Methods

Study area

The Yellow River Delta is the fastest growing delta in the world (Li et al. 2009). It is located in the northeast of Shandong Province and on the south of Bohai Sea (Fig. 1). Annual mean air temperature is 11.9°C with 196 frostless days in Yellow River Delta. The annual average precipitation is about 640 mm while evaporation is approximately 1962 mm (Cui et al. 2009). Natural vegetation includes *Phragmites australis*, *Suaeda heteroptera*, *Tamarix chinensis*, *Triarrhena sacchariflora*, *Myriophyllum spicatum*, *Limonium sinense* and major crops include winter wheat, corn, soybean and rice (Jiang et al. 2012). There are about 270 kinds of birds, including seven kinds of class I nationally protected birds and 33 kinds of class II nationally protected birds (Jiang et al. 2011).

Shengli Oilfield, the second largest oilfield in China is located at the Yellow River Delta and it is the basis of Dongying City establishment. Due to the state economic strategy, Yellow River Delta has undergone a rapid urbanization and industrialization process. New economic development zones and industry districts were proposed and established by local government. The economic development and population growth accelerate urban expansion. Consequently the road network linking urban and the industry districts became increasingly intense (Liu and Qi 2011).

Remote sensing data

Landsat–7 Enhanced Thematic Mapper Plus (ETM+) in 2000, Landsat–5 Thematic Mapper (TM) in 2004, 2006, 2010 and Chinese HJ/CCD in 2010 were acquired from U.S. Geological Survey, Data Sharing Platform in Earth Observation and Digital Earth Science Center of Chinese Academy of Sciences and China Centre for Resources Satellite Data and Application (CRESDA) respectively. Due to lack of data in 2005, the imageries in 2004 and 2006 were selected and considered as the images in 2005 to acquire wetland classification. Therefore, three sets of remotely sensed imageries with 5–year interval were determined finally.

Chinese HJ satellite (HJ–1A/1B) was launched in 2008 with CCD, Hyper–spectral Imager (HIS) and Infrared Multispectral Camera (IRS). The parameters of HJ CCD Camera are 30m spatial resolution, 2day temporal resolution and 700km swath width. The CCD image has four bands and its spectral range of bands were band 1 (0.43–0.52μm), band 2 (0.52–0.60μm), band3 (0.63–0.69μm) and band 4(0.76–0.90μm) respectively.

In addition to spatial and spectral information of remote sensing images, the temporal information is useful for wetlands classification. In order to extract the wetlands information with a high accuracy, temporal information can be used in
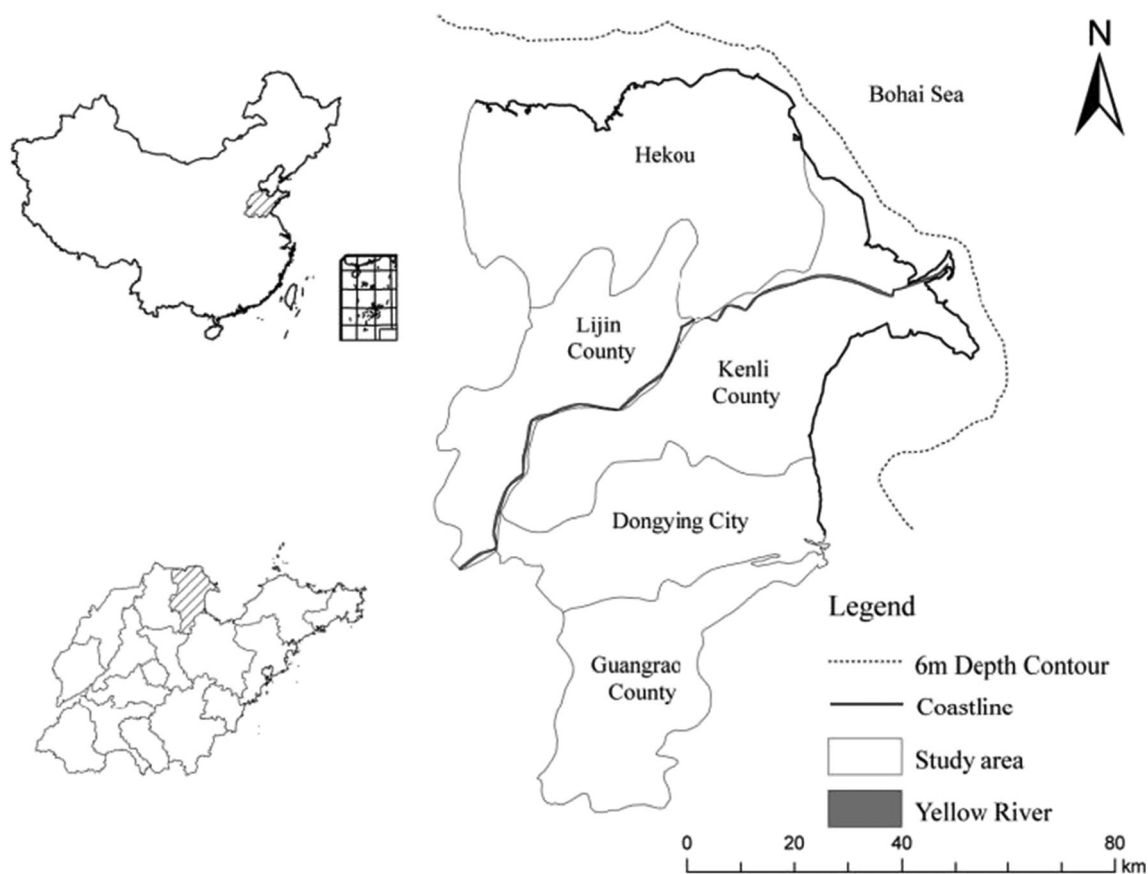
Fig. 1 Sketch map of Yellow River Delta and its location in China

the classification. Therefore, at least 2 different temporal imageries were selected from 2000 to 2010. Meanwhile, the time of tidal in study area was always in January–April period (Wan 2009). Therefore, the proper remotely sensed imageries selected in this paper were not only cloud–free but also during the appropriate period (Table 1).

Ancillary data

The socio–economic data from 1998 to 2011was acquired from Dongying Bureau of Statistics (DBS 2010). The 6m depth contour, vegetation thematic map at the scale of

1,000,000 and the topographic maps at the scale of 1:50,000 were acquired from Ocean Bureau of Dongying. The boundary of Dongying city was obtained from the National Geomatics Center of China (NGCC). A total of 78 reference samples of wetland types were collected using handheld GPS in 2005 and 2010. The hydrological statistics data from Lijin hydrological station (the terminal station of Yellow River) from 2000 to 2009 was obtained from the official website of Yellow River Conservancy Commission of the Ministry of Water Resources (YRCCMWR 2010).

Geometric and Radiometric Rectification

Geometric rectification was performed on all remotely sensed images using 1:50,000 topographic maps based on ENVI 4.7 software. A second order polynomial fit was applied to correct remotely sensed images using 50 ground control points (GCPs) selected from topographic maps, with root mean square error (RMSE) less than 0.5 pixels.

Radiometric calibration was used to transform digital number (DN) values of the image into radiance using gain and offset parameters (Moran et al. 1992). Then FLAASH atmosphere correction model in ENVI 4.7 software was used to convert the radiance to reflectance.

Table 1 Description of satellite remote sensing data

Sensor	Date	Orbit	Resolution	Band No.
Landsat-7 ETM+	28/02/2000	121/34	30	1,2,3,4,5,7
Landsat-7 ETM+	02/05/2000	121/34	30	1,2,3,4,5,7
Landsat-5 TM	10/09/2004	121/34	30	1,2,3,4,5,7
Landsat-5 TM	02/10/2006	121/34	30	1,2,3,4,5,7
Landsat-5 TM	11/09/2010	121/34	30	1,2,3,4,5,7
HJ/CCD	16/08/2010	455/70	30	1,2,3,4
HJ/CCD	28/12/2010	455/70	30	1,2,3,4

Wetlands Classification

Wetlands classification criteria was based on Ramsar Convention and wetlands classification criteria in China (CSFA 2010), wetlands condition and the resolution of remote sensing image available. The shallow sea wetland was defined as area which is the sea water less is than 6 m in depth under low tides (RWCEO 2001). According to this definition, five natural wetlands types and six constructed wetland types were identified (Table 2).

In this paper, the object–oriented classification approach in the eCognition 8.64 software was used for wetland information extraction. This was a two–step process, namely segmentation and classification. (1) Image Segmentation. Two levels of segmentation were applied by adjusting spectral and spatial homogeneity of objects in this paper. Two levels of segmentation process were used, including a scale of 30 for the first level and a scale of 10 for the second level. In both scales a shape and compact index values of 0.1 and 0.5 respectively were used. After segmentation, the objects were finally generated. (2) Image Classification. According to the spectral, temporal and spatial response of land cover types in the objects, the corresponding bands and band combinations were selected and their sensitivity was trained. The thresholds of feature bands of wetland types were determined based on training samples of wetland types. Then the classification rule sets were created using the feature bands and threshold by corresponding hierarchical expert rule–based system.

Finally, wetlands classification was completed based on expert rule–based system. To improve the accuracy of classification results, visual interpretation based on high resolution image from Google Earth and some thematic maps was used for post–classification.

Landscape Pattern Indices Selection

In order to reflect the fragmentation, composition and structure, shape, diversity, disaggregated and interspersed of wetland landscape, the indices including Number of Patches and Patch Density, Percent of Landscape, Landscape Shape Index, Landscape Diversity Index and Landscape Evenness Index, and Contagion Index were selected in this paper (Table 3). All these landscape pattern indices were implemented using FRAGSTATS 3.3 software, a public domain spatial indices software developed in the mid–1990s (McGarigal et al. 2002) (Table 4).

Spatial Expression of Landscape Pattern Indices

This study emphasized the spatial variation in diversity and fragmentation changes of wetlands. To reveal the change in diversity spatially, buffers based on the 6m depth contour and two special transects were used. Meanwhile, the moving–window method was adopted to acquire the spatial distribution of wetlands fragmentation.

Table 2 Wetlands classification criteria

I	II	III	Description of wetland classification in study area
Wetlands	Natural wetlands	Riverine wetland	Rivers
		Sea-beach wetland	Coastal tidelands between high and low tide.
		Marsh wetland	Aquatic macrophytes, such as *Phragmites communis*
		Bush wetland	Wetlands dominated by shrubs
		Shallow sea wetland	Areas with sea water less than 6 m depth under low tides
	Constructed wetlands -	Reservoir	Artificial hydraulic engineering buildings used for flood-control storage and water regulation
		Paddy	Farmland used for rice farming
		Pond	Artificial buildings with small water area used for aquaculture
		Salina	Artificial pools used for salt production
		Ditch wetland	Artificial hydraulic engineering buildings used for irrigation
Non-wetland		Prawn pools	Artificial pools used for aquaculture
		Industrial land	Land used for industry
		Residence land	Land used for residents living
		Transport land	Includes roads, railways, airport, etc.
		Saline land	Area with high soil salinity to affect plant growth
		Woodland	Artificial and natural forest
		Dry farmland	Farmlands used for rainfed cultivation

Table 3 Description of landscape indices

Aims	Name	Algorithm	Range	Description
Fragmentation	Number of Patches, NP	$NP = N$	$NP \geq 1$, without limit	NP equals the number of patches in the landscape. NP=1when the landscape contains only 1 patch.
Fragmentation	Patch Density, PD	$PD = N \times A^{-1}$	$PD \geq 0$, without limit	PD equals the number of patches of the corresponding patch type divided by total landscape area (m²), Multiplied by 10,000 and 100 (to convert to 100 hectares), with unit: Number per 100 hectares.
Composition	Percent of Landscape, PLAND	$PLAND = 100 \times A^{-1} \sum_{j=1}^{n} a_{ij}$	$0 < PLAND \leq 100$	PLAND equals the sum of the areas (m²) of all patches of the corresponding patch type, divided by total landscape area (m²), multiplied by 100 (to convert to a percentage).
Patches shape	Landscape Shape Index, LSI	$LSI = N^{-1} \sum_{i=1}^{m} \sum_{j=1}^{n} (0.25 P_{ij} \times a_{ij}^{-1/2})$ -	$LSI \geq 1$, without limit	LSI=1 when the landscape consists of a single square patch; LSI increases without limit as landscape shape becomes more irregular. It provides a standardized measure of total edge or edge density that adjusts for the size of the landscape.
Disaggregated, interspersed degree	Contagion Index, CONTAG	$$CONTAG = 100 + \dfrac{50 \sum\limits_{i=1}^{m} \sum\limits_{j=1}^{n} (P_i) \left(\dfrac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right) \times \ln(P_i) \left(\dfrac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right)}{\ln(m)}$$	$0 \leq CONTAG \leq 100$	CONTAG approaches 0 when the patch types are maximally disaggregated and interspersed; CONTAG=100when all patch types are maximally aggregated.
Diversity	Landscape diversity index, SHDI	$SHDI = -\sum_{i=1}^{m} (P_i)\ln(P_i)$	$SHDI \geq 0$, without limit	SHDI index is a popular measure of diversity in community ecology, applied here to landscapes
Diversity	Landscape evenness index, SHEI	$SHEI = H / H_{max}$	$0 \leq SHEI \leq 1$	SHEI index is expressed such that an even distribution of area among patch types results in maximum evenness. As such, evenness is the complement of dominance.

Note: N is the total number of wetlands patches; A is total landscape area (m²); P_i, probability of the wetland type in the total area; m, total number of wetland types in the area; $H_{max} = \ln (m)$; a_{ij}, area of the jth patch belong to the ith landscape; g_{ik}, number of adjacencies between pixels of patch types (classes) i and k based on the double-count method

Table 4 Transition matrices of wetland types during 2000–2005(a), 2005-2010(b) and 2000–2010(c) (10³ha)

(a)

2000a	Wetland types in 2005												
	Bush wetland	Ditch	Marsh wetland	Non wetland	Paddy	Pond	Prawn	Reservoir	River	Salina	Sea-beach	Shallow sea	Total
Bush wetland	**20.66**		0.28	0.04	-	0.88	0.24	-	0.02	0.39	0.43	-	22.94
Ditch	0.01	**0.29**	0.01	0.82	-	-	0.01	-	0.47	-	0.01		1.62
Marsh wetland	0.44		**38.95**	2.09		0.54	5.06	0.03	0.07	0.12	0.24		47.54
Non wetland	14.96	0.17	0.12	**506.75**		2.25	0.42	0.04	2.03	1.27	0.01		528.02
Paddy				0.01	**0.63**	0.01							0.65
Pond	0.02		0.03	0.6		**18.03**	7.07	0.16	0.01	1.34	0.98		28.08
Prawn pools			0.02	0.02		0.28	**14.23**		0.01	0.52	0.06		15.3
Reservoir				0.02				**4.14**	0.09				4.25
River	0.03	0.11	0.06	0.31		0.01	0.01		**7.83**		0.05		8.41
Salina		0.01	0.02	0.02		1.16	3.19			**5.81**	0.84		11.05
Sea-beach	0.01		0.84	1.92		2.5	6.89		0.16	6.92	**65.07**	17.87	102.18
Shallow Sea											2.48	**158.14**	160.62
Total	36.13	0.58	40.33	512.6	0.63	25.66	37.12	4.37	10.69	16.37	70.17	176.01	**930.66**

(b)

2005a	Wetland types in 2010												
	Bush wetland	Ditch	Marsh wetland	Non wetland	Paddy	Pond	Prawn	Reservoir	River	Salina	Sea-beach	Shallow sea	Total
Bush wetland	**3.98**	0.08	2.6	28.03		0.49	0.12		0.27	0.56	0.01		36.14
Ditch		**0.14**		0.37		0.01	0.01		0.04				0.57
Marsh wetland	0.08	0.06	**20.21**	6.36		2.05	6.23	0.01	0.99	4.09	0.24		40.32
Non wetland	0.02	1.42	1.15	**496.46**	0.01	6.71	2.35	0.04	1.94	2.25	0.24		512.59
Paddy				0.01	**0.62**	0.01							0.65
Pond	0.4	0.04	0.11	3.04		**17.39**	2.71		0.1	1.83	0.02		25.64
Prawn pools		0.03	0.13	0.18		2.77	**26.56**		0.05	7.3	0.11		37.13
Reservoir		0.01	0.01	0.06		0.02		**4.28**					4.38
River	0.09	0.75	0.37	2.16		0.05	0.07	0.17	**6.9**	0.02	0.11		10.69
Salina			0.09	0.04		0.87	9.42		0.02	**5.39**	0.54		16.37
Sea-beach	0.02	0.03	22.16	0.44		0.6	8.84		1.85	1.92	**33.57**	0.75	70.18
Shallow Sea											1.41	**174.59**	176
Total	4.59	2.56	46.84	537.15	0.63	30.97	56.31	4.5	12.16	23.36	36.25	175.34	**930.66**

(c)

2000a	Wetland types in 2010												
	Bush wetland	Ditch	Marsh wetland	Non wetland	Paddy	Pond	Prawn	Reservoir	River	Salina	Sea-beach	Shallow sea	Total
Bush wetland	**4.38**	0.05	2.11	13.52		0.23	0.78		0.24	1.64	0.01		22.95
Ditch	0.09	**0.57**	0.01	0.79		0.01	0.01		0.23				1.62
Marsh wetland	0.09	0.05	**20.78**	6.66		3.8	10.17	0.01	0.98	4.76	0.23		47.53
Non wetland	0.02	1.18	0.58	**511.04**	0.01	5.84	3.89	0.11	2.83	2.31	0.22		528.03
Paddy					**0.63**	0.01							0.64

Table 4 (continued)

Pond		0.05	0.03	2.03		**16.6**			0.05	3.09	0.02		28.08
Prawn pools		0.01	0.01	0.01		1.33	6.21	0.16	0.01	2.77	0.01		15.29
Reservoir		0.01		0.01		0.01	**10.98**	**4.22**					4.25
River	0.09	0.53	0.32	1.37		0.04	0.04	0.01	**5.92**	0.02	0.07		8.41
Salina			0.02	0.06		2.3	5.3		0.01	**2.76**	0.61		11.06
Sea-beach	0.01	0.1	22.97	1.65		0.79	18.93		1.9	6.02	**32.63**	17.18	102.18
Shallow Sea											2.45	**158.17**	160.62
Total	4.59	2.55	46.83	537.14	0.64	30.96	56.3	4.51	12.17	23.37	36.25	175.35	**930.66**

(1) *Synoptic analysis of wetland landscape patterns for different buffers*

Nine buffers based on 6m depth contour, with the range of 0–10km, 10–15km, 15–20km, 25–30km, 30–45km, 45–55km, 55–66, 66–100km were developed using ArcGIS 9.3 software of ESRI. The landscape datasets in grid format were extracted by different buffers. Variance of landscape dynamics in different buffers was analyzed to reveal spatial pattern of wetland landscape.

(2) *Transect analysis along Yellow River and urban–to–shoreline*

A transect along urban–to–shoreline to was used to reveal the gradients of wetland changes caused by population growth and economic development. In addition, transect along the Yellow River was selected to reflect gradients variation caused by runoff and sediment of Yellow River. Two transects with the size of 5 km were generated using ArcGIS 9.3 fishnet tool (Fig. 5). The corresponding landscape data in grid extracted using these blocks was analyzed based on landscape indices in FRAGSTATS 3.3.

(3) *Identifying spatial pattern of wetlands using Moving–window analysis*

This study used 1×1km squares as basic unit for moving–window analysis. The grid maps produced based on moving–window analysis represented the spatial distribution of indices. Then spatial variation of indices was analyzed detailed.

Results and discussion

The spatiotemporal changes of wetlands analysis

Figure 2 illustrates the wetlands classification results from 2000 to 2010. The overall classifications accuracies were 85.20% (Kappa coefficient–0.895), 81.36% (Kappa coefficient–0.891), 87.60% (Kappa coefficient–0.884), for the year 2000, 2005 and 2010 respectively.

In general, wetlands coverage decreased by approximately 2.27% from 4.02×10^5 ha in 2000 to 3.94×10^5 ha in 2010. Natural wetlands area decreased by 2.45% during the period 2000-2005, 17.44% during 2005-2010. In contrast, constructed wetlands increased by 94.15% from 2000 to 2010. The prawn pools and the Salina wetlands expanded drastically with increase of 268.33% and 111.28% respectively between 2000 and 2010. Constructed wetlands driven by economic development increased more rapidly compared with the other wetlands. A break down analysis of the dynamics of the natural wetlands indicated that bush wetland had the highest coverage decrease (79.96%) from 2000 to 2010, followed by
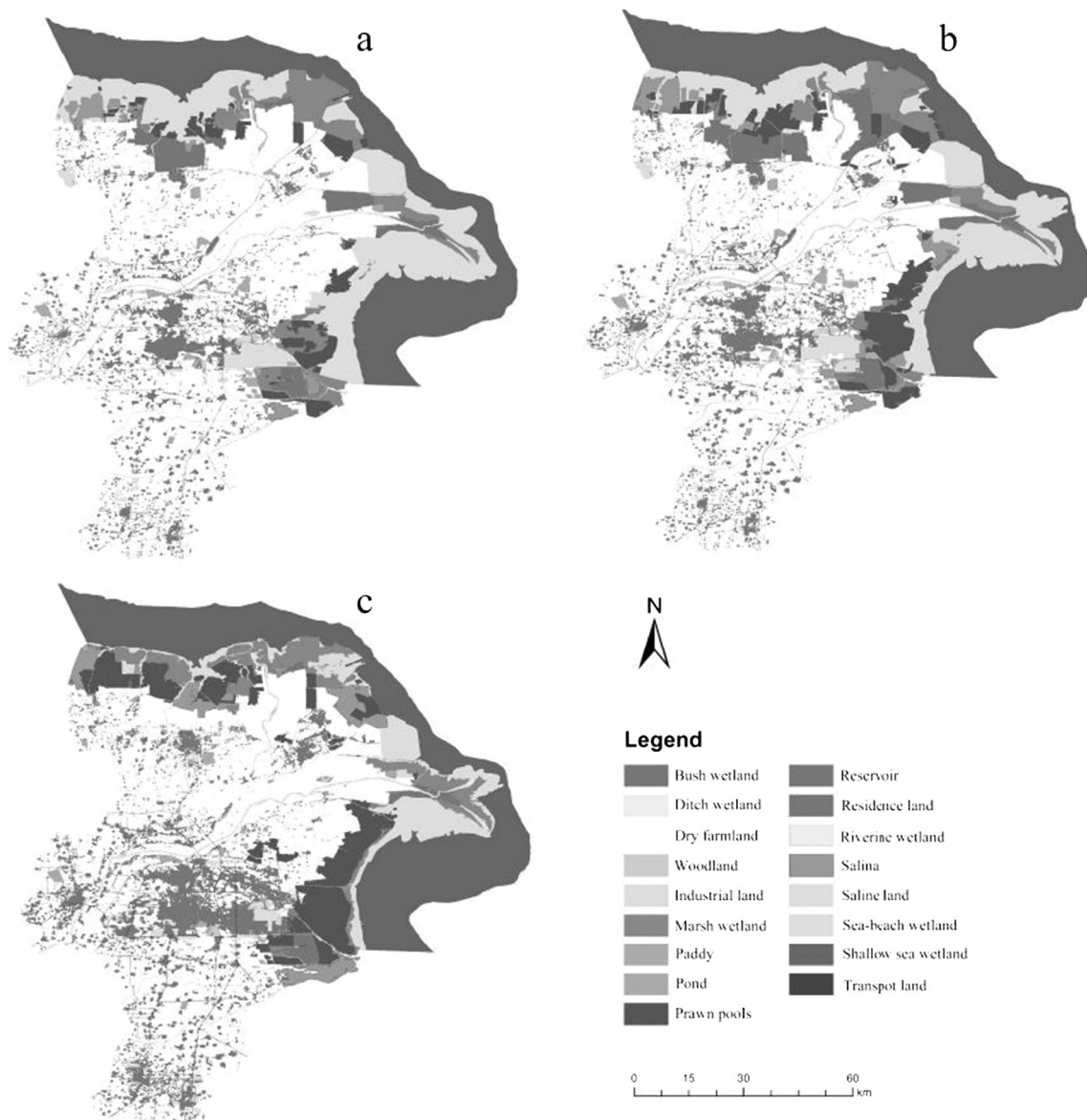
Fig. 2 Classification of wetlands: **a** 2000, **b** 2005, **c** 2010

sea-beach wetlands (64.52%). Overall, there has been a remarkable boom for the constructed wetlands while natural wetlands have receded in the past decade.

Landscape analysis on the class level index

The shallow sea was the dominate wetland type with the percentage higher than 16% of the Yellow River Delta, followed by sea-beach wetland while the smallest proportion of wetland landscape was paddy (Fig. 3). The percentage of prawn pools, sea-beach and bush wetland landscape changed more dramatically compared with the other wetlands from 2000 to 2010. Sea-beach wetland landscape comprised 10.98% of the study area in 2000 but decreased to 7.54% and 3.89% in 2005 and 2010 respectively. Bush wetland

landscape covered 2.47% of the Yellow River Delta in 2000. It increased to 3.88% in 2005 and dramatically decreased to 0.49% in 2010. Prawn pools covered only 1.64% of the delta in 2000 but increased to 3.99% and 6.05% in 2005 and 2010 respectively. Synoptic analysis of PLAND index change indicated that the natural wetland landscape decreased while the constructed wetland landscape increased during the period 2000-2010.

LSI index of pond, sea-beach, bush and marsh wetlands decreased from 2000 to 2010, which implied that the shape of patches had a regular and simple trend of change. However, the LSI index of river and ditch wetlands increased by 5.85% and 17.23% respectively illustrating that the shapes had irregular and complex trends. Percentage analysis of the of various wetlands types indicated that river, ditch and pond had higher LSI value. Overall, the patch shape of natural wetlands was
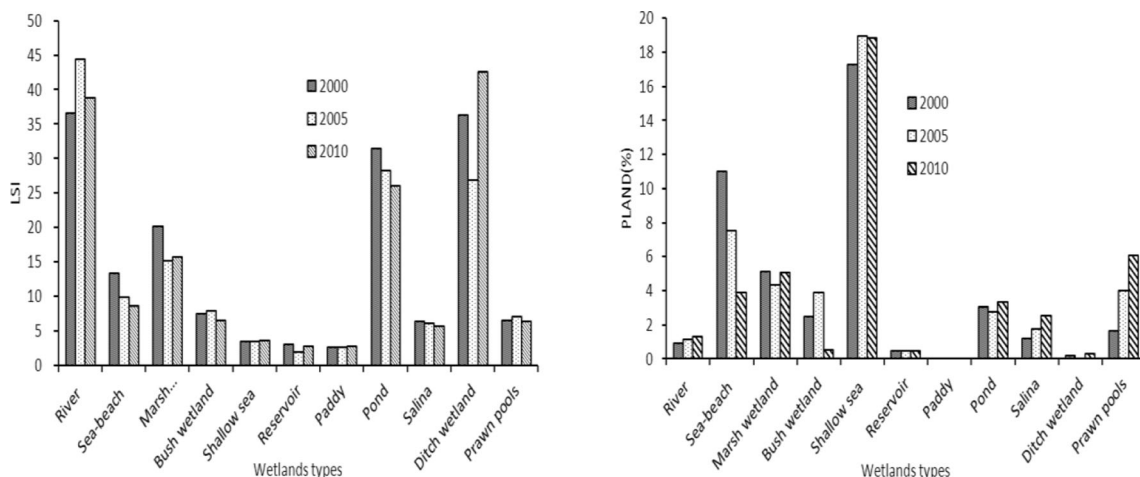
Fig. 3 The PLAND and LSI index of wetland types in Yellow River Delta, 2000-2010

relatively regular and simple. In contrast, the patch shape of the constructed wetlands was irregular and complex due to anthropogenic activities.

Landscape analysis on the landscape-level index

The PD index of wetland landscape increased by 26.07% between 2000 and 2010, which revealed that fragmentation of landscape patches increased (Table 5). Meanwhile, LSI index of wetland landscape increased by 19.33%, which indicated the increase in their patch shape variation. Increased PD and LSI indices demonstrated that the fragmentation, shape complexity and heterogeneity of wetlands had increased due to intense human activities. The CONTAG index of wetland landscape was 67.16 in 2000 and decreased to 65.29 in 2010. Such a decrease indicated that wetland landscape types disaggregated from 2000 to 2010. Although the landscape diversity index increased by 5.17% from 2000 to 2010, it decreased by 4.75% during the period 2005-2010, which revealed that landscape diversity decreased slightly and reflected the non-equalization trend of landscape patterns. SHEI index reflects landscape diversity affected by the dominated landscape, which has a positive correction with dominance index. SHEI index of wetland landscape increased by only 4.76% during the period 2000-2010, which illustrated that the dominance of wetland landscape had almost no change in the study area.

Table 5 Variations of landscape indices at landscape level

| PD		LSI	SHDI	SHEI	CONTAG
2000	0.36	35.62	1.74	0.62	67.16
2005	0.38	38.10	1.84	0.65	65.29
2010	0.46	42.50	1.83	0.65	65.29

Landscape pattern index spatial analysis

### Synoptic analysis of SHDI index change in various buffers

Buffers were used to illustrate the distribution and dynamics of wetland landscape diversity from shoreline. Landscape diversity had maximum value within 45km buffer from shoreline and then leveled off (Fig. 4). The SHDI index increased with the size of buffer and peaked within the 45km buffer, which showed that wetlands were mainly located within 45 km from coastline.

Transect analysis along Yellow River and urban-to-shoreline

The SHDI index changed dramatically from unit 23 to 28 in areas located near Bohai Sea while landscape heterogeneity in southern study area was weak (Fig. 5a). SDHI index in unit 12, 13 and 14 which was located in the city center was relatively lower. The SHDI index in unit 19 was the lowest in the past decade because the main composition was dry
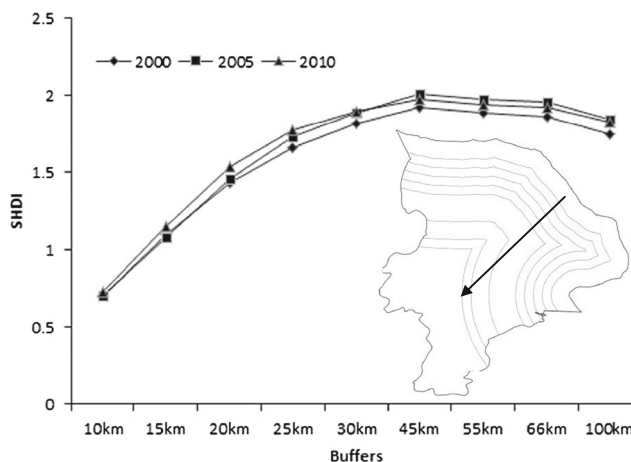
**Fig. 4** Landscape Diversity changes in response to the size the buffers

(a)

(b)
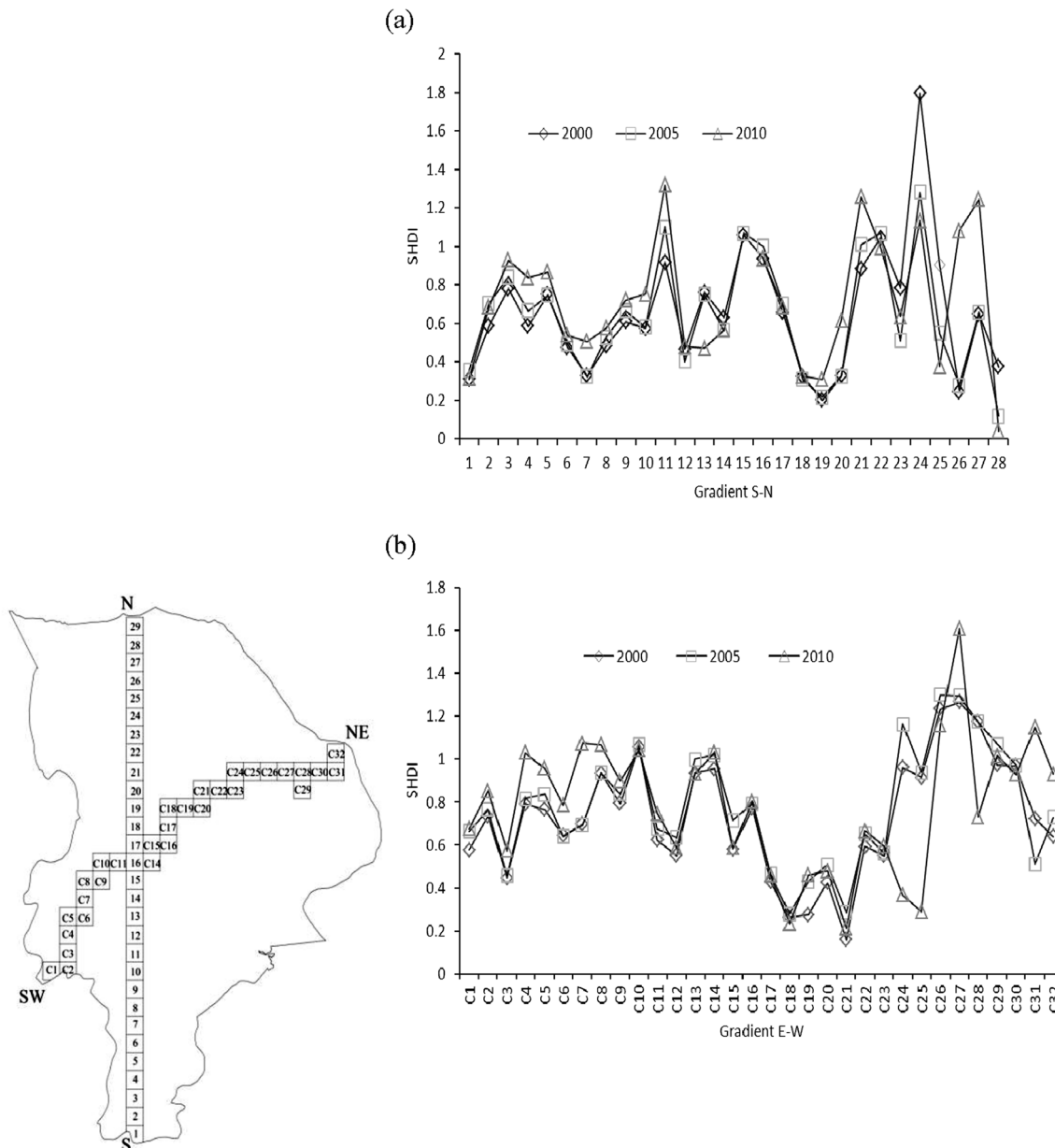
Fig. 5 Wetland landscape diversity varies along the urban-to-shoreline (**a**) and Yellow River (**b**)

farmland with lower heterogeneity. Fig. 5b illustrates gradient of wetland landscape diversity change along the Yellow River. The SHDI index value in the northeast of study area was higher than southwest area. Unit 21 and 27 had the lowest and the highest SHDI values respectively. The SHDI of wetland landscape pattern from unit 24 to 28 changed dramatically during the period 2000-2010.

Identifying spatial pattern of NP using Moving-window analysis

From 2000 to 2010, the landscape heterogeneity increased dramatically, especially in the urban area and the south of

study area due to expansion of construction land (Fig. 6). In addition, the number of patches increased in the east and north of study area, which indicated that wetlands became more fragmented due to human activities. NP index profiles extracted from the South to North direction (the same as Fig. 5) using ArcGIS 9.3 3D analysis tool indicated that the profiles remained similar between 2005 and 2010. This implied that fragmentation in this direction remained unchanged, an indication that human activities were not intense during 2005-2010. Three curves remained the similar change trend, which peaked at the urban area, followed by southern area. However, the wetlands in northern study area had the lowest NP value.
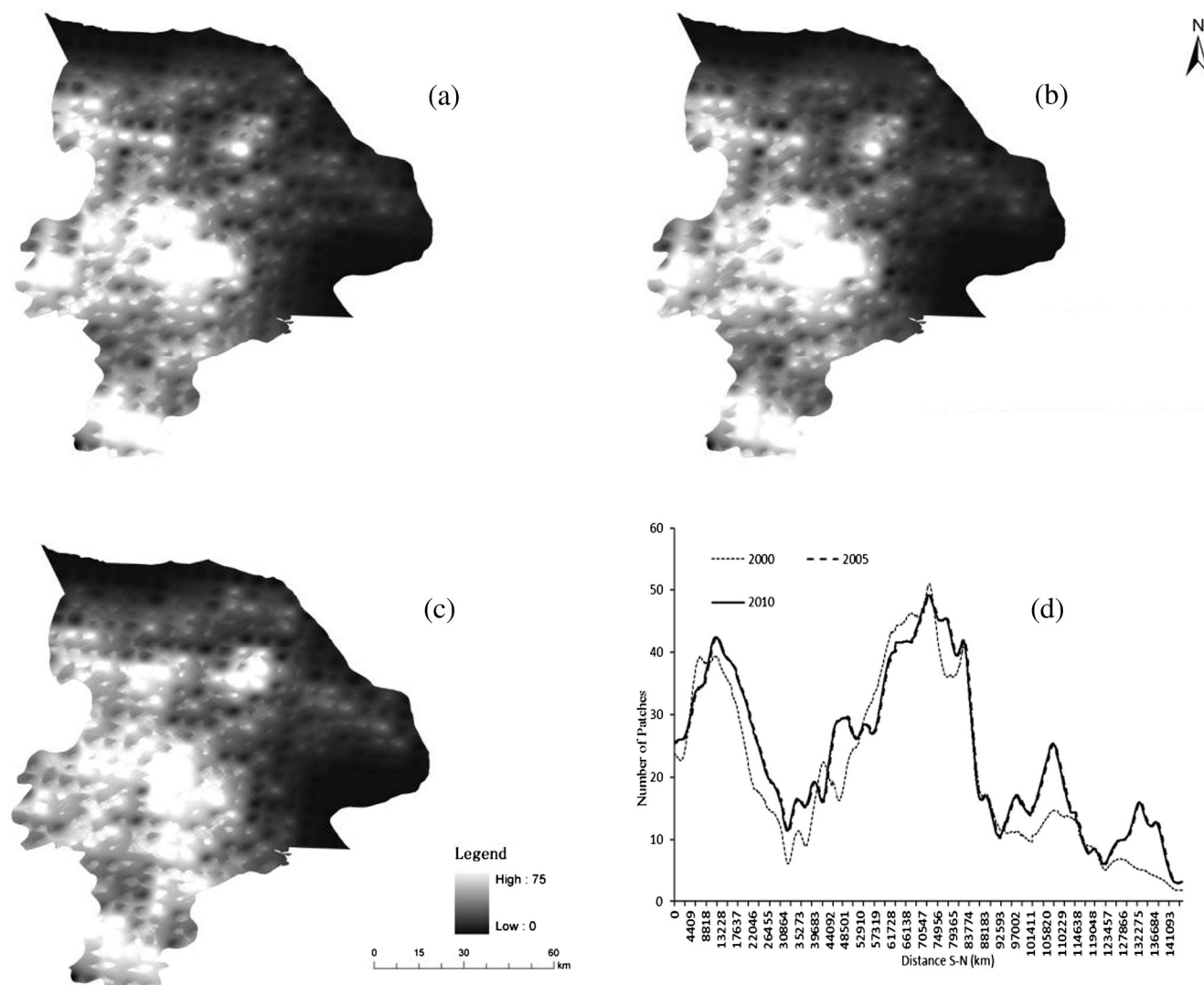
Fig. 6 The NP spatial distribution of Yellow River Delta: **a** in 2000, **b** in 2005, **c** in 2010, **d** the profile

Driving forces analysis of wetlands changes

In the area nearby the coastline, the driving forces mainly included runoff and sediment deposition from the upper reaches of Yellow River, industrialization, ocean erosion, oilfields development and aquaculture development. Due to lack of ocean erosion data, the influence of ocean erosion on wetlands dynamics was not quantitatively analyzed. The aquaculture activities resulted in the conversion of natural wetlands into constructed wetlands, such as Salina and prawn pools. The average annual runoff and sediment discharge from 1950s to1960s were approximately $5.0 \times 10^{10} m^3$ and more than 1.0×10^{12} kg respectively. From 1970s to1980s, the average annual runoff and sediment discharge dropped to about $3.0 \times 10^{10} m^3$ and less than 1.0×10^{12} kg. This further dropped to about $1.41 \times 10^{10} m^3$ and less than 3.9×10^{11} kg in the 1990s (Zhang and Li 2008). According to hydrological statistics data of Lijin hydrological station, the average runoff decreased to $1.36 \times 10^{10} m^3$ and

sediment amount decreased to 1.34×10^{11} kg from 2000 to 2009. The decline in runoff and sediment was associated to reduction of natural wetlands because the runoff and sediment were both the basis of natural wetlands formation. The only natural factor associated with wetlands decline was the ocean erosion which led to change in wetlands composition near the coastline, a factor that led to reduction of sea-beach and an increase of the shallow sea wetlands (Chen et al. 2005).

Dynamic of wetlands in the other area was mainly affected by oilfields development, urbanization and industrialization, human population growth, economic development. The constructed wetlands such as reservoirs, ditch increased by 20.39% from 2000 to 2010 and this was associated to the increase of reservoirs and the other water conservancy projects. The discovery and exploitation of oilfield has led to the gradual formation and expansion of urban, oil and gas exploration (Zhang et al. 2009b). Then the petroleum-related industries and a large number of industrial parks surged due to the

economic development in Yellow River Delta. The state economic strategy caused intense expansion of urban and infrastructure construction. Consequently, the road network linking the main urban and economic development zones became increasingly intense.

Compared with runoff and sediment from Yellow River, the effects of human activities were more pronounced and likely to be the major causes of wetland changes. Therefore, the Gross Domestic Product (GDP), aquaculture production, population and urban built-up area were selected to analyze the conversion of natural and constructed wetlands (Fig. 7 a, b, c and d). The analysis indicated that natural wetlands decreased while constructed wetlands increased with the increase of GDP, aquaculture production, population and urban built-up area during the period 2000-2010. This was a clear

indication that wetlands change was attributed to human activities. The rapid economic development and increase in aquaculture production led conversion of natural wetlands into Salina and prawn pools.

The relationship between wetlands and the four driving factors, allowed for development of qualitative relationships. Then a correlation analysis was used to analyze the correlation between wetlands and driving factors based on SPSS 17 software. As an indicator to describe the human activities, GDP was the significant correction factor of construction wetlands, with the positive correlation coefficient 0.998 ($P<0.05$, two-tailed) and urban built-up area was the main significant correction factor of natural wetlands with negative correlation coefficient 0.999 ($P<0.05$, two-tailed).

(a)

(b)

(c)

(d)
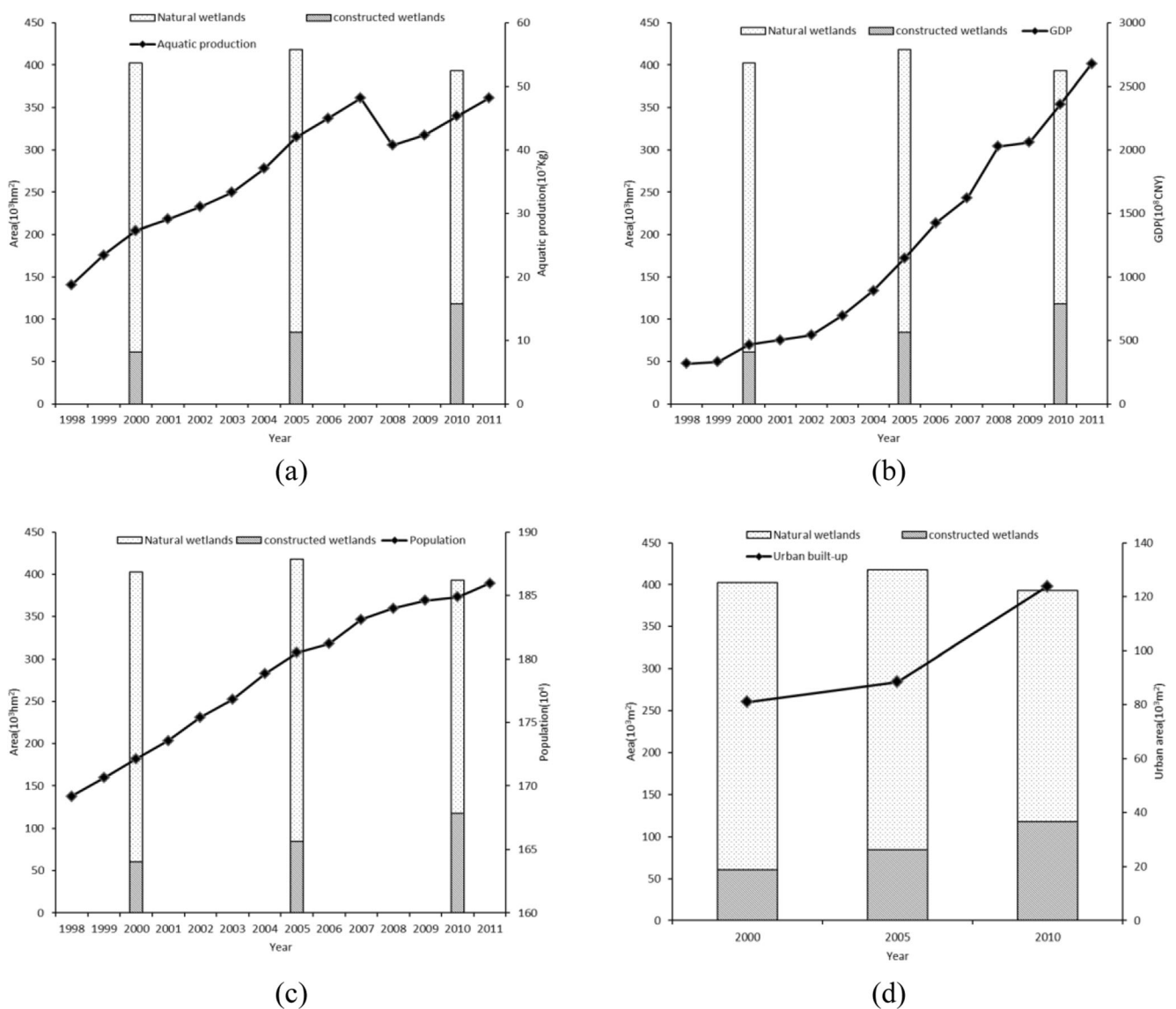
Fig. 7 **a** Relationship between wetlands area and aquaculture production, **b** between wetlands area and GDP, **c** between wetlands area and population, **d** between wetlands area and urban built-up

Discussion

According to the quantitative and qualitative analysis between wetlands and driving factors, the anticipated results described above were explicitly confirmed. The results revealed that the spatiotemporal dynamics of wetland landscape patterns were mainly caused by human activities, including economic development, urbanization, population growth, oilfields and aquaculture development. The natural wetlands degradation became increasingly serious, which was consistent with one previous research (Zhang and Sun 2005). The increase of constructed wetlands from natural wetlands caused by aquaculture activities was also consistent with the results from Liu et al. (2008). The main driving factors causing changes in wetland were consistent with the relative research in Yellow River Delta using the field data (Wang et al. 2011). Therefore, the method using remote sensing and landscape indices can acquire the truth of spatiotemporal dynamics of wetlands in Yellow River Delta. Land use change driven by natural or human factors has direct or indirect implications on the structure and functional integrity and hence the ecosystem's resilience. These implications manifested at the landscape level by affecting the landscape processes (Cui et al. 2012). Landscape pattern is a manifestation of the spatial heterogeneity of land use pattern and as such, landscape pattern change is the most intuitive sign of land use change (Wu et al. 2013). The results of this study clearly indicated the explicit link between the land use change and the observed landscape fragmentation patterns. Due to rapid economic and aquaculture development, land-use change degree increased dramatically and this was linked to the observed landscape fragmentation patterns. The observed land use changes and landscape fragmentation patterns confirmed the wetlands disturbance intensity induced by human activities. Therefore, this paper provided scientific evidence for informed policy formulating and decision making on wetlands management and conservation. Firstly, the spatial distribution of wetland types can be easily known by readers and wetland management sectors. Secondly, spatiotemporal dynamics of wetland landscape patterns during 2000-2010 can be presented in a simplified manner. Finally, the driving mechanism of wetland changes was revealed detailedly.

Many researchers analyzed spatial and temporal dynamics of wetland landscape patterns using remotely sensed imageries and landscape indicators but the spatial distribution of landscape patterns were rarely referred (Wang et al. 2008; Cao 2008; Qiu et al. 2009). These papers only considered the entire study area as a unit to discuss the temporal dynamics of wetland landscape patterns while the spatial variation was not revealed. Compared with these researches, this paper used spatial repression and gradient analysis to obtain the spatial distribution of wetland landscape patterns. The spatial variation analysis not only made this paper more intuitive for readers and more advanced than the previous researches, but also made the results more useful to protecting wetland than the previous researches. The method of wetlands classification based on expert rule sets from spectral, spatial and temporal information of remote sensing data and ancillary data provided more detailed wetland types than the previous studies (Hui et al. 2008; Zhang et al. 2011).

However, many researchers focused on the impacts of wetlands dynamics on species habitat (Ward et al. 2010; Jordan and Jelks 1997; Webb et al. 2010), which provided some evidence for biodiversity protection in the wetland areas. The wetland in Yellow River Delta is an important habitat for birds. Thus, the response of bird's habitat to the dynamics of wetland landscape patterns can provide lines of evidence to protecting wetlands. As an important factor, climate change can affect the dynamics of wetlands. Climate changes such as rainfall, evaporation variation are all key factors to affect the dynamics of natural wetland. Thus, the coupling relationship between climate change and wetlands dynamics was discussed by many researchers (Withey and van Kooten 2011; Johnson et al. 2010; Mitsch and Hernandez 2013; Burley et al. 2012).

The analysis between climate change, species habitat and wetland landscape patterns changes can both provide more powerful scientific evidence to support the wetlands management. Ecosystem services, including the goods and services produced by wetlands ecosystems, provide a useful view to understand the nonmarket value of wetlands for citizens and wetlands managers, which has been highlighted as a pathfinder role for a new paradigm (Maltby and Acreman 2011). The research about ecosystem services of wetlands can reveal the meaning of it on the wetlands management (Jenkins et al. 2010).

These were all the limitations of my research. Therefore, the further research will refer to these aspects, especially the response of ecosystem service and climate change to wetland landscape patterns changes. The integrating ecosystem services of wetlands with wetland landscape patterns dynamics could put this case study in a broader context and make the implications more explicit particularly to wetlands managers and policy makers.

Conclusions

The object-oriented method using multi-temporal remotely sensed imageries was employed to obtain wetlands classification. A post classification method and a series of landscape indices were then used to describe the spatiotemporal dynamics of wetlands from 2000 to 2010. The results showed that constructed wetlands boomed while natural wetlands receded. The diversity in the city center and southern study area was

relatively lower while the area nearby the coastline had rich landscape composition and diversity. The results clearly indicated that the wetlands fragmentation was caused by anthropogenic activities in the study area.

The robustness of this approach lies in its ability to reflect wetland changes at a regional scale and can be replicated and reproduced in other areas of the world. In addition, this method has huge advantage in expressing the spatial distribution and changes of wetland landscape.

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