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Simulation of the spatial stresses due to territorial land development on Yellow River Delta Nature Reserve using a GIS-based assessment model

Baolei Zhang · Qiaoyun Zhang · Qingyu Feng · Bohao Cui · Shumin Zhang

Abstract This study aimed at assessing the stresses from land development in or around Yellow River Delta Nature Reserve (YRDNR) and identifying the impacted areas. Major land development types (reservoirs, pond, aquafarm, salt pan, road, residential land, industry land, farming land, and fishing land) in or around the YRDNR from 1995 to 2014 were identified using spatial data sets derived from remote sensing imageries. The spatial stresses were simulated by considering disturbance due to land development activities and accessibility of disturbance using a geographic information system based model. The stresses were then used to identify the impacted area by land development (IALD). The results indicated that main increasing land development types in the study area from 1995 to 2014 were salt pan and construction land. The 98.2% of expanded land development area and 93.7% of increased pump number showed a good control of reserve function zone on land development spread. The spatial stress values and percentages of IALD increased from 1995 to 2014, and IALD percentage exceeded 50% for both parts of YRDNR in 2014. The results of this study also provided the information that detailed planning of the YRDNR (2014–2020) could decrease the spatial stress and IALD percentage of the whole YRDNR on the condition that the area of land development activities increased by 24.4 km^2 from 2014 to 2020. Effective measures should be taken to protect such areas from being further disturbed in order to achieve the goal of a more effective conservation of the YRDNR, and attention should be paid to the disordered land development activities in or around the natural reserves.

Keywords Impact assessment · Spatial stress · Territorial development · GIS model · Yellow River Delta Nature Reserve

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Introduction

Nature reserve is one of major conservation strategies to alleviate ecological degradation and has been considered as an effective measurement to protect endangered species and ecosystems worldwide (Wright 1996; Zeng et al. 2005; Liu et al. 2013; Tomaselli et al. 2012). There are two key goals of building nature reserves. One is to maintain biodiversity. The other is to mitigate negative effects of external pressures on biodiversity in the reserves (Gaston et al. 2008). However, many nature reserves are not achieving these two goals (Shawn and Jeremy 2012) due to external pressures from deforestation

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(Liu et al. 2001), road construction (Dong et al. 2011), tourism development (Liu et al. 2005a, b), urbanization (Wade and Theobald 2010), etc. Thus, it is important and necessary to predict and address these pressures, in order to avoid loss of biodiversity, especially rare species, in protected areas (Hockings et al. 2006). Accurate assessment on threats and stresses of nature reserves has been a serious and basic issue of the World Commission on Protected Areas (WCPA), International Union for Conservation of Nature (IUCN), and World Wildlife Fund (WWF) (Adrian 1998; He et al. 2009).

Territorial land development refers to a variety of long-term or cyclical land use transformation and operations for economic and social purposes (Tang and Sun 2012). The common types of territorial land development are agriculture, urbanization, industrialization, and tourism development etc., which can be expressed as or resulted to the land use/cover changes (LUCC). The main contradiction between nature reserves and territorial land development was conflict of land resources' conservation and utilization (Thorsell and Sigaty 1997; Dengiz and Baskan 2009). At present, the effects of land development on biodiversity are well-known. For example, habitat loss becomes the leading threat to endangered species mainly due to agriculture and urbanization (Kerr and Deguise 2004; Venter et al. 2006; Zhang et al. 2015). Roads and other linear landscape features act as barriers to animal movement and a major source of mortality (Fahrig and Rytwinski 2009). It is urgent and essential to assess and mitigate the effects of land development inside and adjacent to nature reserves by defining land development as human activities that leave lasting, visually detectable infrastructure or footprints on land or waterscapes (Paige et al. 2006).

Large amount of studies have been conducted to analyze impacts on the effectiveness of protected areas for preserving biodiversity from territorial land development, which may affect the water, soil or air in the protected area (Martínez-Graña et al. 2014; Kamwi et al. 2017). These studies can be categorized into two groups. One group is the assessment of impacts from a certain land development activity by directly measuring the characteristics using various environmental indicators such as hydrological attributes, vegetation types and structure, biodiversity, and landscape integrity. These land development activities include urban expansion (Borgstr et al. 2013; Liu et al. 2014), road construction (Song and Li 2012), agriculture development (Yang et al., 2013; Leng et al. 2011), tourism development

(Liu and Lv 2008), and water diversion project (Li and Jiang 2001), etc. The other group is the rapid questionnaire assessment based on the method of rapid assessment and prioritization of protected area management (RAPPAM) promoted under the WCPA frame of WWF (Luan et al. 2011). The RAPPAM method is designed for the comparisons of nature reserves. This method has been tested and used in 22 counties worldwide such as France, Cameroon, Gabon, China, and Algeria, etc. (Ervin 2003). The acquisition of field data for nature reserves depends on labor availability (He et al. 2011) and natural conditions. Besides, the questionnaire may be affected by the subjective views of respondents. Thus, the efficiency of these two method groups may be reduced. Remote sensing (RS) data play an important role in deriving and mapping environmental indicators of an ecosystem. Patterns and trends embedded in the RS data (e.g., land use) can be captured by spatial analysis using GIS software (Cedfeldt et al. 2000). The simultaneous use of RS and GIS makes it possible to assess the spatial stresses from land development in a timely manner (Rebelo et al. 2008). However, it should be pointed out that research of this field is still in its early stage, and more effective models are needed for the assessment.

The Yellow River Delta Nature Reserve (YRDNR) was established in 1992 with the aim of protecting the coastal wetland ecosystem and endangered birds. As one of the most active regions of land ocean interaction in the world, the YRDNR is home to several bird species receiving the topmost priority for conservation (Xu et al. 2002; Wang et al. 2014; Zhang 2011). At the same time, the YRDNR is subjecting to increasing human disturbance (e.g., petroleum exploitation and production) in or around its boundaries since the early 1960s. After the Yellow River Delta (YRD) development was incorporated into a national strategy of construction for the efficient ecological economic zone of YRD in 2009, the regional land development activities according to national strategy have been booming all over the delta toward multipolar development direction, which inevitably brings long-lasting stresses to the YRDNR. Therefore, it is especially important to identify the threats and pressures from regional land development for the merit-based selection policy and related interventions to improve management level of the YRDNR (Zhou et al. 2008; Deng et al. 2010; Zhang 2011). In this paper, the authors aim to: (1) investigate land development activities in or around the YRDNR from 1995 to 2014 using

spatial data sets derived from remotely sensed imageries; (2) simulate the spatial stress on YRDNR due to land development and identify the impacted area by land development (IALD) using a geographic information system (GIS)-based model.

Materials and methods

Study site

The YRD is a newly formed estuarine delta of Yellow River situated in the estuary of the Yellow River in Dongying City, Shandong Province of East China. The YRD is one of the most beautiful six wetlands in China and an important energy base holding more than 50×10^8 t petroleum and 2300×10^8 m^3 natural gas (Bi, et al. 2011; Kuenzer et al. 2014). The YRDNR (37° 35' - 38°' 12′ N, 118° 33

–119° 20′ E) is located at the estuaries of Yellow River within the YRD and comprises two parts: the floodplain of the former river mouth of the Yellow River in the north which is called "Yiqianer" or "Northern Reserve" (NR), and the floodplain of the current river mouth in the east which is called "Yellow River Estuary" or "Eastern Reserve" (ER). The total area of the YRDNR is 1530 km^2, with the core area of 590 km^2, the buffer area of 112 km^2, and the experiment area of 824 km^2 (Fig. 1). The YRDNR belongs to a warm temperate continental monsoon climate with four distinctive seasons. The annual temperature ranges 11.7~12.6 °C and mean annual precipitation ranges 530~630 mm. However, average annual evaporation is about 1900 mm which is almost three times of the average annual precipitation. Every year, approximately 10.5 million tons of sediment is carried by the Yellow River and deposited in the delta where the flow rate slows down resulting in large floodplain area and special wetland landscape (Xu 2002).

### Land use data source and pattern identification

The consequence of territorial land development activities are changes of land use type, so the land use types were used to represent land development. The YRDNR became provincial nature reserve in 1991, and was upgraded to national nature reserve in 1992. In this research, the land use map of 1995 was used as the basic condition, and the time lag about 10 years was used to analyze the impacts of land development activities on the nature reserve.

Landsat images and preprocessing

Landsat image data have been providing repetitive, synoptic, and global coverage of multispectral moderate resolution images with relatively high frequency for over 30 years, and have been widely used to detect LUCC (Wang et al. 2014). The observed rates of LUCC suggest that Landsat data with 30 m spatial resolution can be used to quantitatively determine land development types on 20 year time scales (Mars and Houseknecht 2007; Zhang 2011). According to historical evolution characters of land development in YRD, this study analyzed the changes of land development type for 1995, 2006, and 2014 based on LUCC. Images of the latest Landsat platforms in each session (shown in Table 1) were purchased from the China Remote Sensing Satellite Ground Station. Purchased images included Landsat Thematic Mapper (TM) and Landsat Operational Land Imager (OLI) images with 30 m resolution, and Landsat Enhanced Thematic Mapper (ETM) imagery with a 15 m resolution. Landsat OLI data had a blue band, which was especially suitable for coastal observation. Ancillary data include 1: 50,000 digital topographical maps, aerial photographs, land use maps, administrative maps, and social-economic statistical data from local authorities. The YRDNR boundary was delineated based on administrative maps. The aerial photos and land use maps from local governments were used as references for interpreting satellite images and land use mapping.

The raw images used for this study were geo-referenced based on the digital topographical maps. After geo-referencing, the images was projected to the Gaussian–Krueger projection and had a Root Mean Squared Error (RMS error) of less than one pixel. The empirical "radiometric rectification" method referred by Hall et al. (1991) was used for radiometric correction. Image enhancement techniques (Bajjouk et al. 1998) were applied to the data in order to optimize the information for visual interpretation and digitalization. At last, image statistics and histograms from the three periods were similar and comparable for the study area.
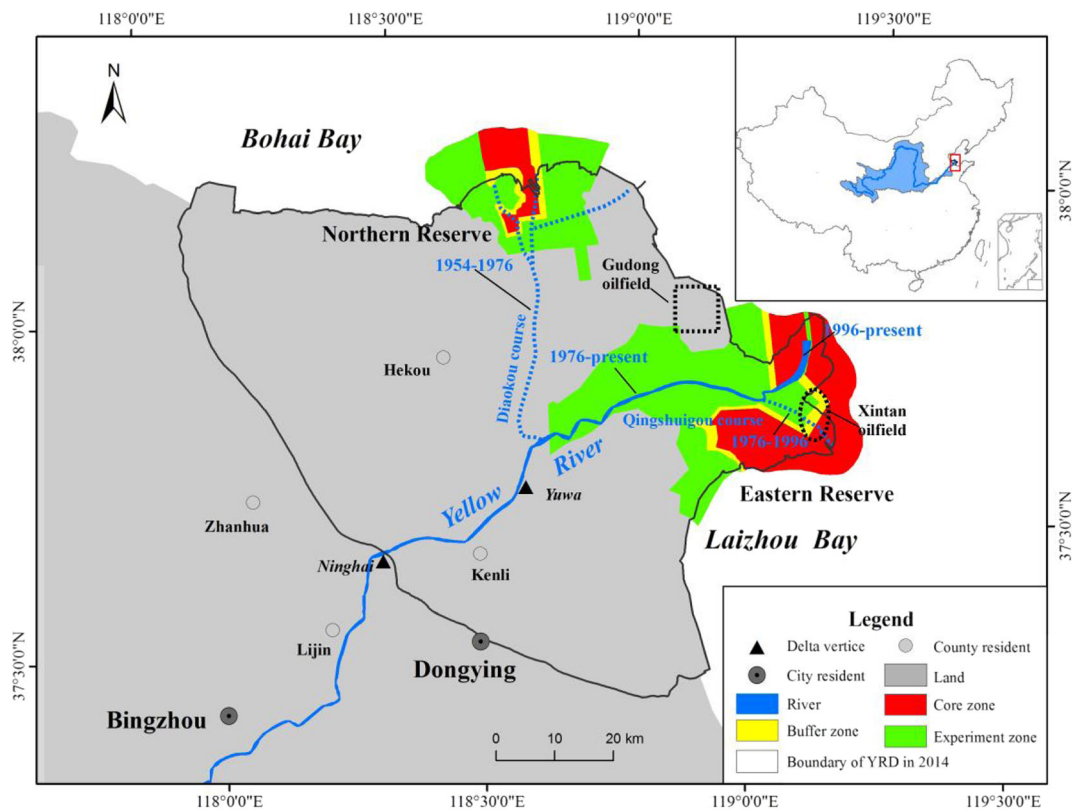
Fig. 1 Location of study area

Identification of land development type

Generally, artificial land use types are used to represent the types of land development activities (Zhang et al. 2016). The artificial land use types in YRD included reservoirs, pond, aquafarm, salt pan, road, residential land, industry land, farming land, fishing land, and oil industry activities (oil pumps). Although the land use types of artificial ecosystem are all the results of human activities, reservoirs and ponds have relatively less impacts on the daily life of birds. In this research, agriculture land, salt pans, aquafarm, construction land, and oil pumps are selected as major land development activities considered. Agriculture land included land that had plowing, sowing, and raising operations on both paddy and dry farming land. Salt pans are artificial ponds designed to extract salts from sea water or other brines, and are commonly separated by levees. Aquafarm includes fishing ponds, shrimp ponds, crab ponds, and other aquatic pond, etc. Construction land includes urban areas, rural settlements, factories, and others areas such as oil fields and roads. An oil pump shows more like a point on Landsat images with resolution of 30 m.

So, oil pumps were taken as point file based on manual digitization of oil pumps from the available Landsat data. One source of uncertainty is that more than one pump locates in some of the square sites when digitizing oil pumps based on 30 m Landsat data, whereas some other sites might not yet have pumps but are being prepared for a pump set up. As oil pumps operate for several years up to decades, pumps that are detected in 1995 data also include pumps set up in the late 1980s.

Table 1 List of satellite images used in this study

Platform	Sensor	Path/row	Resolution (m)	Acquisition date
Landsat 5	Thematic Mapper	121–34	30	September 18, 1995
Landsat 5	Enhanced Thematic Mapper	121–34	15	November 2, 2006
Landsat 8	Operational Land Imager	121–34	30	May 11, 2014

Land use mapping

Visual interpretation of land use types based on multi-spectral or multitemporal remote sensing images has been the main approach for identifying land use changes (Ke et al. 2011). Although visual interpretation is time-consuming, it can more accurately provide land use maps compared with automatic classification (Liu et al. 2005a, b). Therefore, it is particularly suitable for the YRD. In order to obtain high quality land use change information based on the Landsat TM images in 2014, we developed a land use database at a spatial scale of 1: 100,000 through visual interpretation and digitalization with technical support from ArcGIS software (ESRI 1999). Before the interpretation began, fieldwork was conducted in October 2014 covering the entire study area.

Interpreters used ArcGIS software to identify land use types based on their understanding on the object's spectral reflectance, structure, and other ancillary information. Then, they drew boundaries and added the attribute labels to the polygons to produce the digital map. In order to meet the requirement of the land use database at the spatial scale of 1: 100,000, the smallest patch of land use selected was not less than 25 pixels (2.25 ha), and the shortest edge was longer than 3 pixels (90 m) (Wang et al. 2012). The eliminate function of the ArcGIS software was used to control the sizes and lengths of final polygons for land use development types. A second round of field surveys was conducted on September 2015 to verify the interpreted land use types of 2014 combined with the land use maps from local land agencies and high-resolution Landsat images. The overall accuracy of the land development type classification was 94.1% (Table 2).

To obtain land use maps for 1995 and 2006, the interpreters drew the land use patches based on remote sensing images for these 2 years. The land use maps in 2014 were used as supporting information to identify the types of land use for each patch. As the patch number and areas in 1995 and 2006 were smaller than those in 2014, less number of sample patches were obtained from field investigation, aerial photos and historical land use maps in the process of accuracy evaluation. Finally, we chose 68 and 110 sample patches to evaluate map accuracy in 1995 and 2006, respectively, by interviewing administration staff and longtime residents in the YRDNR. The results showed that the overall identification accuracies were 95.7% in 1995 and 95.0% in 2006 (Table 2).

Establishment of spatial stress assessment model

This research assumes that the pressures on nature reserve are determined by two factors: disturbance due to land development activities (D) and accessibility of disturbance (A). To simplify the calculation in a GIS software, the spatial stress $S(x, y)$ on a given nature reserve cell (x, y) due to land development activities (R) is calculated as:

$$S_{(x,y)} = \sum_{r=1}^{R} D_r \times A \qquad (1)$$

Distance is considered as one of the determining factors for the disturbance of human activities on nature reserves (Ode and Fry 2006). Although human activities in tens to hundreds of kilometers away sometimes can impact ecological function and biodiversity within the protected areas, many studies suppose that the fringe of a nature reserve will suffer greater disturbance and outside impacts are always happening within a certain distance (Bao et al. 2015). For example, Beth and Catherine (2008) concluded that the range of impact distances for roads and settlements to the number bird populations was 1.63~19.01 km. Foreman's study (2003) in west of Canada showed that the forest coverage increased while economic factors decreased with the distance away from the road, and the balance distance range was 8.18~12.77 km. Thus, the disturbance (D_r) due to land development activities (r) is determined by the max influence distance of land development $(d_{r\max})$, the impact index/weight (W_r) and the distance $(d(r, x, y))$ between nature reserve cell and land development type cell. The disturbance of land development type cell can be calculated using Eq. (2) and the distances are obtained using the buffer function of the ArcGIS software:

$$D_r = W_r \times \left(1 - \frac{d(r, x, y)}{d_{r\max}} \right) \qquad (2)$$

where, $d(r, x, y)$ is the pixel distances between nature reserve cell and land development type cell; $d_{r\max}$ is the max influence distance of land development activity (r). The $d_{r\max}$ is threat and its changes with distance, which can be found in Table 3.

Accessibility of disturbance is determined based on the slope at a fringe cell by using Eq. (3). The assumption is that a low slope (<5°) implies a relatively very easy access to the cell while a steep slope (>15°) means the access to it is extremely difficult. The accessibility to

Table 2 Accuracy assessment of the land development types for 1995, 2006, and 2014

Types	1995			2006			2014		
	SPN	CPN	ACC	SPN	CPN	ACC	SPN	CPN	ACC
Aquafarm	12	11	91.7	29	27	93.1	42	38	90.5
Salt pan	8	8	100.0	10	10	100.0	18	18	100.0
Cultivated land	29	28	96.6	34	32	94.1	60	58	96.7
Construction and	19	18	94.7	37	35	94.6	44	41	93.2
Oil pumps	25	24	96.0	30	29	96.7	40	37	92.5
Total	93	89	95.7	140	133	95.0	204	192	94.1

SPN sampling patch number, *CPN* correct patch number, *ACC* accuracy (%)

any slopes in between 5° and 15° is inversely related to their steepness (He et al. 2011).

$$A(r,x,y) = \begin{cases} 1 & slope \leq 5 \\ -0.1 \times slope + 1.5 & 5 < slope \leq 15 \\ 0 & slope > 15 \end{cases}$$

$$(3)$$

The impacts of different land development type could be mutual accumulation, and impacted area by land development (IALD) was defined as the cell with the spatial stress value $S(x, y)$ larger than that of a single land development type (W_r). IALD was selected using Eq. (4):

$$IALD = \begin{cases} 0 & S_{(x,y)} < \min(Wr) \\ 1 & S_{(x,y)} \geq \min(Wr) \end{cases}$$

$$(4)$$

Where, IALD is defined as the pixel with the spatial stress value $(S_{(x, y)})$ bigger than the minimum impact index of a single land development type (W_r). In this research, the aquafarm had minimum impact index of 0.6.

Table 3 Threats and their changes along with distance

Threat factor	Maximum stress distance(km)	Decreasing rate	Weight
Cultivated land	3	0.33	0.7
Construction land	5	0.2	1
Aquafarm	3	0.33	0.6
Salt pan	4	0.25	0.7
Oil pump	1	1	1

Results

Land development in YRDNR

The land development areas for cultivated land, aquafarm, salt pan, and construction land within the YRDNR in different function zones of 1995, 2006, and 2014 were given in Table 4. In 2014, the total area the four land use types in the YRDNR was 345.8 km² accounting for 22.6% of the YRDNR, and the area in experiment zone was 339.5 km² accounting for 41.2% of the experiment zone. The total area of four land development types increased from 292.3 km² in 1995 to 334.0 km² in 2006, and then increased by 11.8 km² from 2006 to 2014. During 1995~2014, almost all increased areas of the four land development types were in the experiment zone expect small area of salt pan increased in the buffer zone of the ER (Fig. 2). According to the regulations of the People's Republic of China on Nature Reserves, the construction of production facilities within the core zone and buffer zone of the nature reserve and the original production facilities built before the establishment of nature reserve should be moved out gradually. Therefore, agricultural land in the core zone (2.6 km²) and buffer zone (1.5 km²) of the NR was returned to wetland in the period from 2006 to 2014. In the experimental zones for both parts, the areas of construction land and salt pan kept increasing from 1995 to 2014, while the areas of cultivated land and aquafarm varied from year to year.
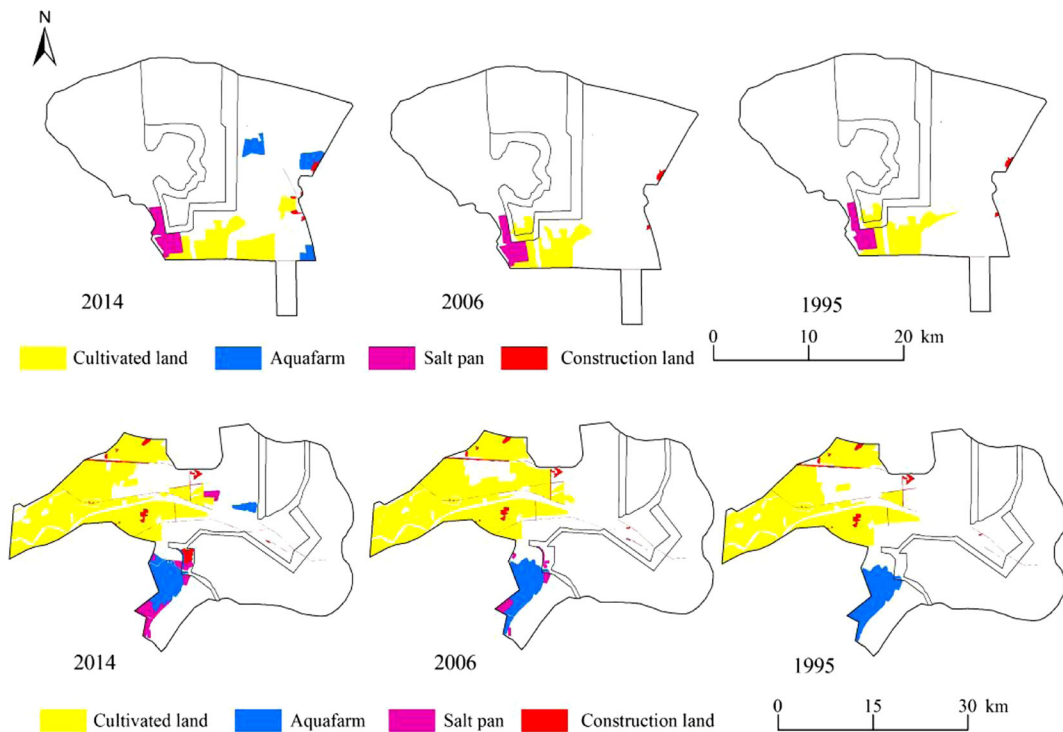
The spread of oil pumps between 1995 and 2014 and overall pump number changes in the YRDNR were shown in Figs. 3 and 4. In 2014, the number of oil pumps in the YRDNR was 1198, in which 1129 (accounting for 94.2%) were located in experimental zone,

Table 4 Areas of land development type within the YRDNR from 1995 to 2014

Reserve part	Function zone	Cultivated land			Aquafarm			Salt pan			Construction land		
		1995	2006	2014	1995	2006	2014	1995	2006	2014	1995	2006	2014
NR	Core	2.6	2.6										
	Buffer	1.5	1.5										
	Experimental	18.8	17.8	28.8		0.0	9.6	6.9	7.8	9.0	1.2	1.2	1.7
	Total	22.9	21.9	28.8		0.0	9.6	6.9	7.8	9.0	1.2	1.2	1.7
ER	Core											0.1	0.1
	Buffer				0.6	0.5	1.3		1.5	1.6	0.1	0.1	3.3
	Experimental	213.2	251.4	230.0	37.8	32.9	33.7	0.1	6.2	16.4	9.6	10.4	10.4
	Total	213.2	251.4	230.0	38.4	33.4	35.0	0.1	7.8	18.0	9.7	10.5	13.8
YRDNR	Core	2.6	2.6									0.1	0.1
	Buffer	1.5	1.5		0.6	0.5	1.3		1.5	1.6	0.1	0.1	3.3
	Experimental	232.0	269.2	258.8	37.8	32.9	43.3	7.0	14.0	25.4	10.8	11.6	12.1
	Total	236.1	273.3	258.8	38.4	33.4	44.6	7.0	15.5	27.0	10.8	11.8	15.5

48 in the buffer zone, and 21 in the core zone. From 1995 to 2014, pumps increased in number by 856, which was 2.5 time that of 1995. About 93.7% of the 856 are located in the experimental zone, 38 in the buffer zone, and 16 in the core zone. The common characteristic for two parts of the YRDNR was that the increased pumps were almost all in the experimental zone, and the percent of increased pumps for the NR and the ER are 94.8 and 93.8%, respectively. The difference between the two parts was that a large uncontrolled spread of pumps occurred irrespective of

**Fig. 2** Land development maps in YRDNR for 1995, 2006, and 2014
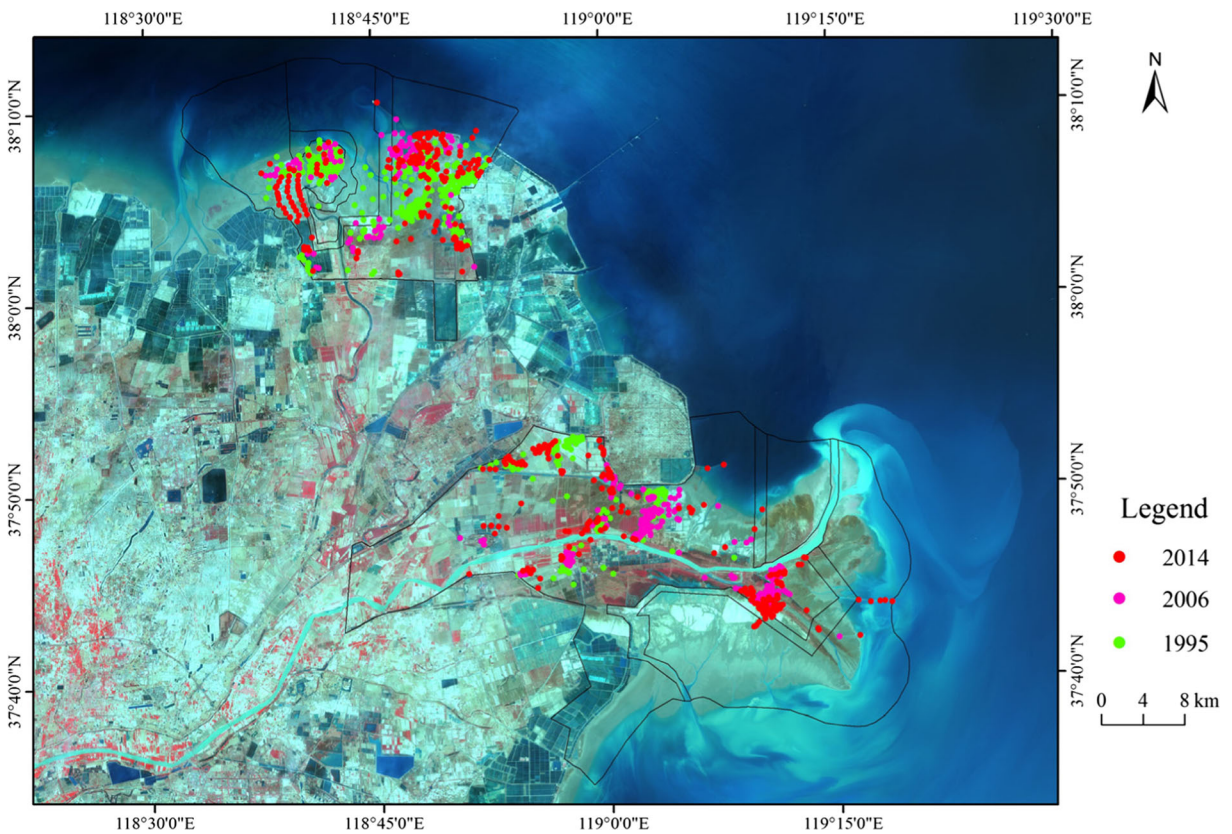
Fig. 3 The spread of oil pumps in the YRDNR between 1995 and 2014

the protection status in the NR, while the spread into the restricted zones was less severe in the ER.

The activities of building up oil pumps in the core and buffer zones of nature reserves are not allowed. However, numerous pumps were set up in the core zone of the nature reserves even after the reserve was upgraded to the national reserve. The reason is that oil industry is pillar industry of Dongying city and the economic relevance oil companies are extremely influential because the income of many families is somehow associated with this industry. Dongying city is famous for its oil industries, and the oil fields were built far before the establishment of Dongying city and the YRDNR. Shengli oil field company got the exploration rights of oil and gas in Shandong province in 1964, and then obtained the exploration and development permits of Bohai area and its coastal zone. The YRDNR was established in December 1990 and was upgraded to nature reserve in October, 1992. The newly established YRDNR overlapped with Shengli oilfield development
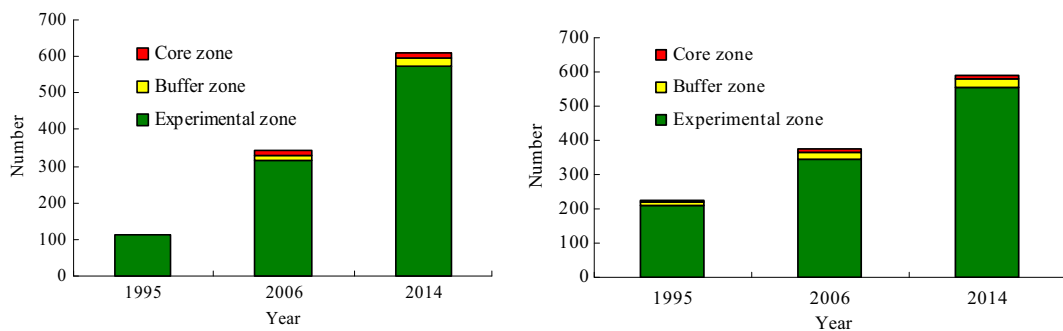
**Fig. 4** Total number of pumps and development in the NR (*left*) and the ER (*right*)
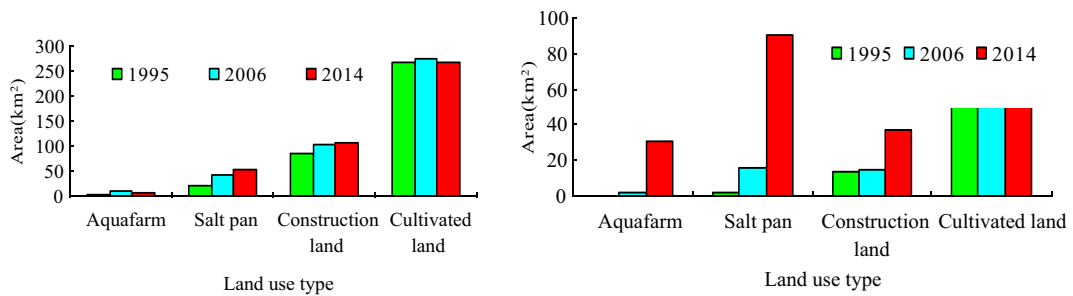
Fig. 5 Area changes of each land development types around the NR (*left*) and the ER (*right*)

zone greatly. For example, the Feiyanta oil field, Xintan oil field were both in the core area of the YRDNR, and Hongliu oil field was in the buffer zone. The competition of oil field development and environment protection lasted for a long time, and the government adjusted the YRDNR's function zone in 2001 trying to alleviate the contradiction. However, it was difficult to stop and move all the oil pumps away from the YRDNR in a short time period. The administration of the nature reserves was, furthermore, controlled by the government of the Dongying city.

Land development around YRDNR

The area changes of land development type around nature reserve reflected the level of emphasis on the nature reserve in the layout of land development activities by local governments. In this research, the biggest impact distance of land development activities was 5 km, so 5 km buffer around the YRDNR were created using the spatial analytical module in ArcGIS software. The area of each land development types for the two parts from 1995 to 2014 were plotted (Fig. 5). For both buffer parts of the YRDNR, the areas of cultivated land decreased slightly due to the implementation of returning land from farming to forest policy, but the areas of the other three land development types (aquafarm, salt pan, and construction land) increased greatly. The increased areas in the ER and the NR from 1995 to 2014 were 53.9 and 137.0 km^2, respectively. The similarity between the two parts was that and the increased areas mainly came from salt pan and construction land, and the difference was that the area increasing speeds for salt pan and construction land in the NR were both faster than those in the ER.
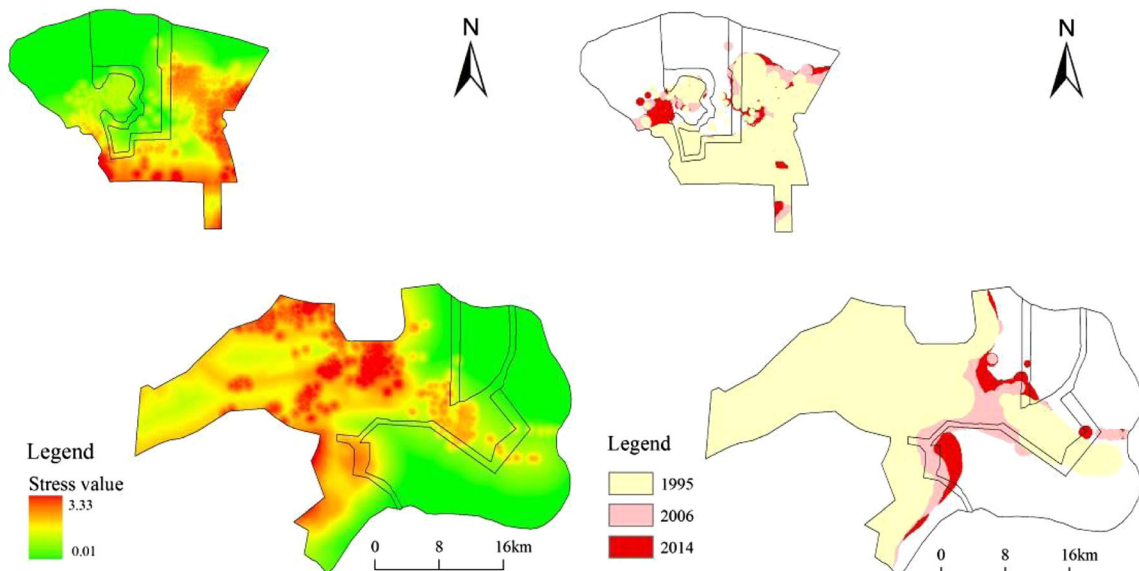
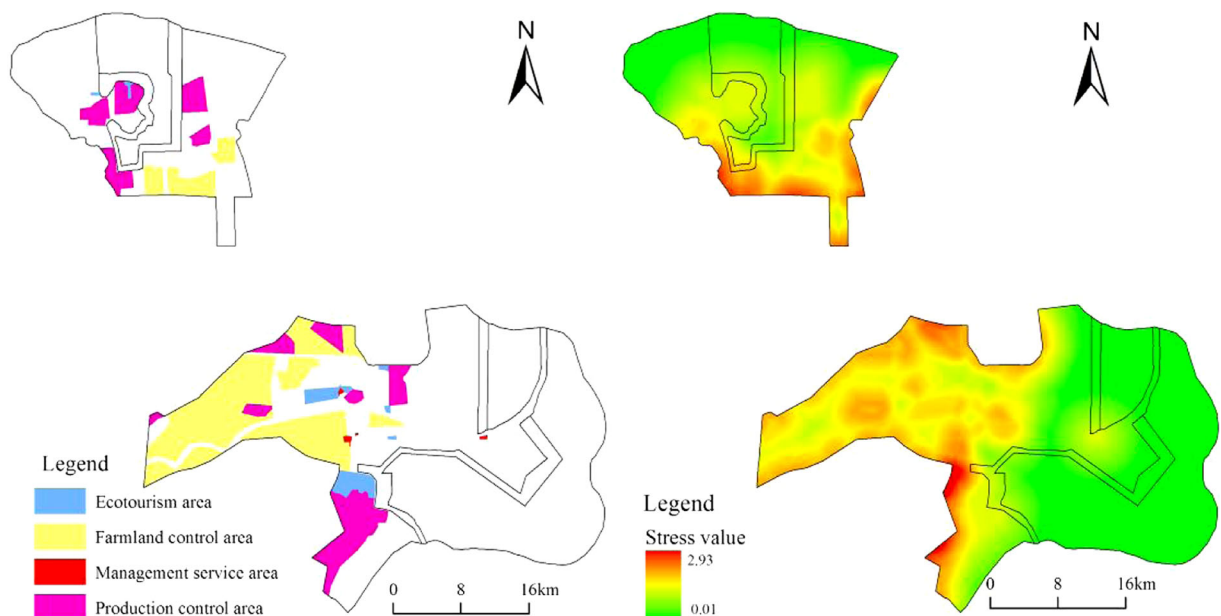Fig. 6 Spatial stress in 2014 (*left*) and IALD change from 1995 to 2014(*right*)

Table 5 Spatial stress value and percentages of IALD of the YRDNR from 1995 to 2014

Reserve part	Region	Spatial stress value			Percentage of IALD (%)		
		1995	2006	2014	1995	2006	2014
NR	Core	0.21	0.23	0.19	12.65	14.14	11.30
	Buffer	0.50	0.60	0.59	34.57	42.94	41.68
	Experimental	0.64	0.72	1.03	50.26	53.39\	61.46
	NR	0.55	0.62	0.83	41.93	45.30	50.47
ER	Core	0.12	0.18	0.22	5.70	10.05	13.64
	Buffer	0.36	0.62	0.87	25.51	54.26	63.40
	Experimental	1.17	1.36	1.47	78.55	85.40	87.47
	ER	0.76	0.91	1.00	50.17	57.45	60.47
YRDNR	YRDNR	0.69	0.82	0.95	47.59	53.66	57.34

Spatial stresses on YRDNR due to land development

Spatial stress distribution maps of 1995, 2006, and 2014 were shown in Fig. 6. Spatial stress values and percentages of IALD for each function zone of the YRDNR were shown in Table 5. For the whole YRDNR and two separate parts, the impact value of land development and the percentage of human activity areas both kept increasing from 1995 to 2014. The percentages of land development impact area for the NR and the ER both exceeded 50% in 2014, indicating that half of the YRDNR was occupied by land development activities. The stress values and the percentage of IALD for the two parts presented the trend of "experimental zone > buffer zone > core zone", which also reflected the roles of the different function zones. It was worth noting that the stress values and percentages of IALD in buffer and core zone decreased from 2006 to 2014 due to the returning of agricultural land to wetland in these two zones.

Fig. 7 Function programs in 2020 (*left*) and Spatial stress in 2014 (*right*)

Table 6 Spatial stress value and IALD percentage of YRDNR in 2014 and 2020

Reserve part	Function zone	Spatial stress value		Percentage of IALD (%)	
		2014	2020	2014	2020
NR	Core	0.19	0.36	11.30	22.99
	Buffer	0.59	0.74	41.68	72.63
	Experimental	1.03	0.84	61.46	64.26
	NR	0.83	0.74	50.47	57.74
ER	Core	0.22	0.05	13.64	1.33
	Buffer	0.87	0.29	63.40	24.51
	Experimental	1.47	1.07	87.47	78.16
	ER	1.00	0.67	60.47	48.36
YRDNR	YRDNR	0.95	0.70	57.34	51.29

Discussion

Method comparison and application prospect

There have been several approaches to stimulate the impact of human activities on the habits and protected area in the aspects of habit suitability and quality. These approaches include habitat suitability index (HSI) model (Thomasma et al. 1991; Nevo and Garcia 1996), maximum entropy models (MaxEnt) model (Phillips et al. 2004) and InVEST (The Integrate Valuation of Ecosystem Services and Tradeoffs Tool) method (Boumans et al. 2002; Taills et al. 2011; Lin et al. 2016). The commonality with the approach suggested in this paper is that distance is supposed to be the most important factor for the impact of certain human activity. Some kind of distance–decay function is used either based on distance or travel-time (Zohmann et al. 2013; Michael et al. 2015; Phillips and Dudik 2008; Bradley 2013; He et al. 2016). However, those models aim at the evaluation of habit suitability and quality by considering human impact as an important factor, so the impact of human activity is easily underestimated or counteracted by other factors of those models.

Ode and Fry (2006) presented a GIS-based model to identify visitor pressure by considering distance, accessibility, and quality of woodland as key components affecting visitation rates. He et al.(2011) defined the spatial stress of urban expansion on a regional wetland ecosystem as the probability that the wetland occupied by urban expansion. The similarity between these two methods and the method used in this paper is that they all supposed the disturbance and reaction as the theoretical basis. The differences are the evaluation purposes, the corresponding model forms and key expressing contents. The visitor pressure evaluation paid more attentions to the attraction of woodland, and the wetland potential occupation by urban expansion mainly focused on the future possibility of urban expansion. The aim of the study was to describe the influences of land development on protected areas at a regional scale and provide a tool for identifying protected areas that need special management or strategic measures from decision-makers. This method can evaluate or forecast relative pressure by simply inputting land use map, land use plan map, and even a land plot to be developed. The role of this type of model is not to predict absolute stress values but to delineate the impact scopes of land development by relative spatial pressure values. We believe the approach is robust and could be further improved by (a) better data of different level of development activities such as the grade of roads, the level of urbanization, the form of agriculture and fishery development the, and (b) refining the model based on trials in a wider range of development and social contexts. The general approach could also be developed to describe the pressure of changes of other land use change such as abandoning cropland, afforestation, deforestation, and reclamation, etc.

Spatial stress of the YRDNR in planning scenarios

In June 2015, the local government published detailed planning of the YRDNR (2014–2020), which made detailed arrangement of management, development, and protection in the future. The spatial stresses of the

YRDNR in 2020 were evaluated based on the function programs in detailed planning of YRDNR (2014–2020) and overall land use planning of Dongying City (2006–2020). The development types and their spatial stress were mapped (Fig. 7), and the stress value and percentage of IALD were calculated in Table 6. In 2020, land development activities will be all in the experimental zone and the area of land development types in the YRDNR will be 353.5 km^2 which is bigger than that of 2014 (329.1 km^2). The increased area in the NR and the ER will be 24.0 and 0.4 km^2, respectively. For the ER, the spatial stress value and the percentage of IALD will decrease greatly in 2020, because the increasing area only increases 0.4 km^2 and the distributions of land development activities are more compact and reasonable. For the NR, the area of land development types will be increased by 24.0 km^2 so that the percentage of IALD in each function zone will increase as well. The increased production control area is distributed around the boundary of buffer zone, which will result in increase of stress values in the core zone and buffer zone but decrease in the experimental zone. For the YRDNR, both the stress value and percentage of IALD will decrease greatly. These results suggested that the detailed planning of YRDNR (2014–2020) will decrease the spatial stress of the whole YRDNR and the ER.

Conclusions

This study proposed a GIS-based model that could help assess the spatial stresses on natural reserves due to land development activities. The spatial stresses were simulated by considering disturbance due to land development activities and accessibility of disturbance. The spatial stresses were used to identify the impacted area by land development (IALD). The proposed model is merited for its capability to quantitatively assess not only the present but also future spatial stress, which has a great potential to help understand the influence of land development activities on natural reserves and to support the protection of them.

The model was used in a case study to simulate the spatial stresses faced by the YRDNR due to land development activities for the time period of 1995–2014 and the planning scenarios in 2020. It was found that the spatial stress values and the IALD percentage of each function zone increased greatly from 1995 to 2014 on the condition that more than 93% increased land development area was in the experiment zone. However, the spatial stresses and the IALD percentage for the whole YRDNR decreased in planning scenarios of 2020 on the condition that the area of land development activities increased by 24.4 km^2. This indicated that the compact and reasonable distributed land development may have slight impacts on natural reserves. Therefore, attention should be paid to the disordered land development activities in or around the natural reserves.

The method of this study used to assess the spatial stresses of land development activities on nature reserve that were from the perspective of landscape ecology and spatial analysis. Two key factors were equally considered in modeling the spatial stresses: disturbance due to land development activities and accessibility of disturbance. Since the influence of land development activities on nature reserve can be quite complex, further efforts should be made to improve the model by incorporating more factors and weighing them differently based on the knowledge from analyzing field data.

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