

# Analyzing coastal wetland change in the Yancheng National Nature Reserve, China

Chang-Qing Ke · Dong Zhang · Fu-Qiang Wang ·  
Shu-Xing Chen · Christance Schmallius ·  
Wolfgang-Martin Boerner · Hui Wang

Received: 1 January 2010 / Accepted: 21 May 2010 / Published online: 5 June 2010  
© Springer-Verlag 2010

**Abstract** Coastal zones provide habitat cores and corridors that maintain the diversity of entire landscapes, and they can form the cornerstone elements of regional conservation strategies. Natural environmental driving factors and excessive anthropogenic activities play important roles in coastal wetland change. Many studies have used remote sensing images to map and assess coastal wetland change on local or regional scales. This paper aims to provide insight into coastal wetland change in the Yancheng National Nature Reserve (YNNR) using remote sensing technology and landscape metrics analysis. The results

reveal that grass flat and reed areas have significantly decreased, whereas agriculture fields, aquaculture ponds and built-up areas have continuously increased from 1988 to 2006. The spatial pattern of the coastal landscape has become fragmented and heterogeneous under great pressure from rapid economic development and population growth. The wetland changes have important impacts on natural habitat of the red-crowned cranes. The results of this study provide basic information that is required for developing measures toward a sustainable management and conservation of the YNNR.

---

C.-Q. Ke (✉) · D. Zhang · F.-Q. Wang · S.-X. Chen  
Department of Geographic Information Science,  
Nanjing University, No.22 Hankou Road, 210093 Nanjing,  
People's Republic of China  
e-mail: kecq@nju.edu.cn

D. Zhang  
e-mail: zhangdonggazx@163.com

F.-Q. Wang  
e-mail: fuqwsun@126.com

S.-X. Chen  
e-mail: webgis2006@163.com

C. Schmallius  
Institute of Geography, Jena University, Grietgasse 6,  
07743 Jena, Germany  
e-mail: c.schmallius@uni-jena.de

W.-M. Boerner  
Communications, Sensing & Navigation Laboratory,  
Illinois University at Chicago, Chicago, IL 60607-7018, USA  
e-mail: wmb1uic@yahoo.com

H. Wang  
Administration of Yancheng National Natural Reserve,  
224002 Yanhceng, People's Republic of China  
e-mail: ycwangh@yahoo.com.cn

**Keywords** Coastal wetland · Land use change ·  
Remote sensing · Landscape metrics · Driving forces ·  
The Yancheng National Nature Reserve (YNNR)

## Abbreviations

YNNR The Yancheng National Nature Reserve  
NBSC National Bureau of Statistics of China

## Introduction

Coastal zones are important boundaries, forming transition areas between terrestrial and marine environments. With approximately 41% of the world's human population living within 100 km of the coast (Martinez et al. 2007), the coastal zones and issues of sustainability are paramount. Coastal zones play an important role in land-based socio-economic development such as agriculture, industry and tourism (Ramachandran et al. 2005). Coastal zones are environments with high risk of hydrogeological hazards and are seriously affected by coastal erosion, saltwater

encroachment in the phreatic aquifer and sea-level rise (Cai et al. 2009; Ryu et al. 2008; Zhang et al. 2002). Thus, coastal environments are currently affected by natural environmental changes, anthropogenic activities and synergistic combinations of the two (Burak et al. 2004; Fan et al. 2006; Long and Skewes 1996; Ramessur 2002). The expected accelerated rise in global mean sea levels during the 21st century may endanger coastal human populations and infrastructure and threaten many coastal ecosystems (Lewsey et al. 2004; Thanh et al. 2004). Natural habitats have been lost due to the reclamation of land for urban and industrial development, agriculture, aquaculture and mariculture (LeDee et al. 2008; Walker et al. 2008). The large and growing extent of human activity in coastal zones has caused or enhanced a variety of environmental problems (Alonso-Perez et al. 2003; Chen et al. 2006; Zhang 2002).

Coastal wetlands have wet, spongy soils and are located in the transition zone between terrestrial land and ocean, and they include freshwater, saltwater and mixed areas. Due to these characteristics, wetlands contain a diverse variety of wildlife and plants (Gibbes et al. 2009). Coastal wetlands are a vital element of coastal zones and are valued for a wide range of ecological, economic and cultural reasons (Mackay et al. 2009). Coastal wetlands are remarkable and crucial ecosystems in terms of environmental health, distinctive geomorphologic features, typical vegetation and faunal associations, and the human activities related to their singular environment (Jones et al. 2009; Turner et al. 2004). Wetlands play a key role in supporting the diversity and abundance of plants and animals of entire landscape, and they provide habitats and refuges for many migratory, rare or threatened species (Gan et al. 2009). Some wetlands provide coastal protection against destructive natural events such as cyclones and storm tide inundations (Rebello et al. 2009). Moreover, coastal wetlands can form the cornerstone elements of regional conservation strategies (Weber 2004).

Land use maps are regarded to be fundamental for the purpose of assessment and management planning of coastal environments (Baban 1997; Chen et al. 2005; Sarma et al. 2008). Accurate coastal land use maps are essential for monitoring changes over time, for assessing habitat condition and for investigating their links with other ecological system components that rely directly or indirectly on them (Carreno et al. 2008). Remote sensing could play an important and effective role in the coastal land use mapping and environmental monitoring (Mas 2004; White and Asmar 1999) and can provide data in support of decision making for the management of coastal resource and environment, including in the context of international protocols (Seto and Fragkias 2007). Kumar et al. (2007) studied land use changes on Sagar Island, India, using Indian Remote Sensing Satellite 1C (IRS IC) data from 1998 and 1999.

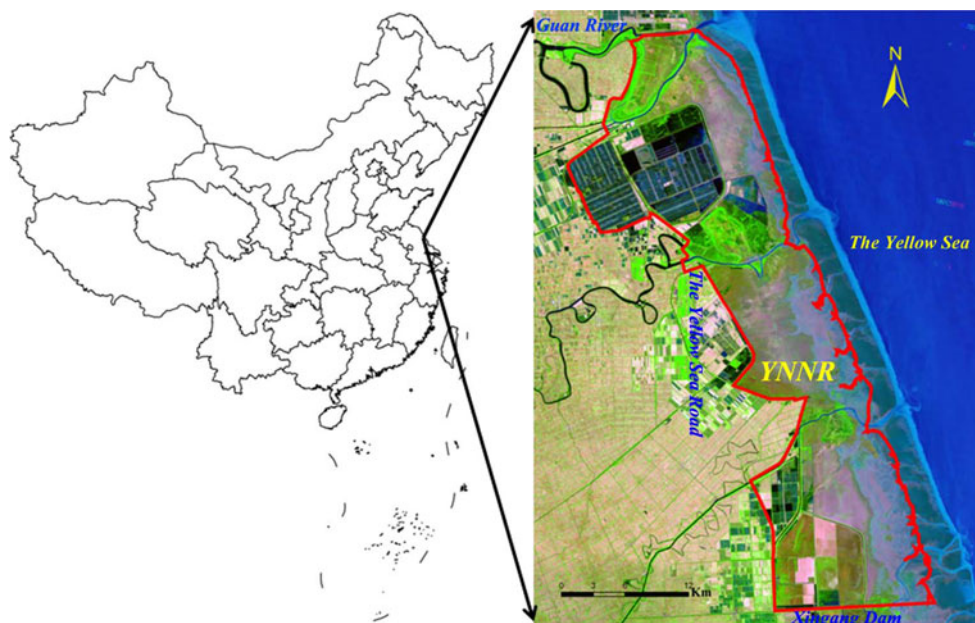
Barducci et al. (2009) studied coastal wetland change in the San Rossore Natural Park with hyperspectral imaging sensors. These coastal land use studies have helped assess and monitor the status of wetland resources by detecting changes on spatial and temporal scales, as well as predicting potential future trends.

Analyzing the changes in landscape patterns helps identifying some of the most critical implications of complex interactions between natural environmental changes and anthropogenic activities (Forman 1997; Turner et al. 2001; Yue et al. 2003) and, therefore, plays an important role in guiding the planning and management efforts. Landscape metrics can be used to assess the ecological integrity of landscapes or as variables for models that support planning actions (Yang and Liu 1995). Land use transformation stages (Forman 1997) such as fragmentation, shrinkage and attrition (disappearance) can easily be detected by landscape metrics. Landscape metrics can also be used to analyze habitat change (Liu et al. 2003; Fletcher et al. 2009), especially habitat fragmentation (Gibbes et al. 2009).

Habitat fragmentation and natural vegetation loss have been recognized as a major threat to ecosystems (Laurance 1999; Noss 2001). These two processes may have negative effects on biodiversity, by increasing isolation of habitats and putting at risk the viability of resident species populations (Debinski and Holt 2000), endangering species as their habitat disappears (Armenteras et al. 2003) and modifying species population dynamics (Watson et al. 2004). Fragmentation may also have negative effects on species richness by reducing the probability of successful dispersal and establishment (Gigord et al. 1999) as well as by reducing the capacity of a patch of habitat to sustain a resident population (Iida and Nakashizuka 1995). Therefore, an understanding of the relationship between landscape patterns and the ecological processes influencing distribution of species is required by resource managers to provide a basis for making land use decisions (Turner et al. 2001).

The Yancheng National Nature Reserve (YNNR) was established in 1983 with the major aim of protecting an endangered bird species, the red-crowned cranes (*Grus japonensis*), and its habitats. In 1992, the YNNR was approved as an international biosphere reserve under UNESCO's Man and the Biosphere Programme (MAB), and in 2002, it was included in the Ramsar Convention List of Wetlands of International Importance. It is one of the world's major winter habitats for red-crowned cranes. Every November to March, about two-thirds of the world population of red-crowned cranes winter in the reserve. The YNNR is also a stop-over site for over 300 species of migratory birds from Northeast Asia and Australia (Zhu et al. 2004). The YNNR is a critical area for the rescue of

**Fig. 1** Location of study area in China



threatened species including the red-crowned crane, the black-mouthed gull, etc. It is a vital element of China's conservation of both coastal wetland ecosystem and biodiversity.

Due to human population growth and economic development, the YNNR is subjected to a multiple resource use conflict, overexploitation of coastal resources and environmental degradation (Ou et al. 2004). Therefore, a large part of the original coastal wetland has been developed since the late 1980s, and some natural coastal wetlands have been transformed into other land types, such as fish ponds and agricultural fields (Zuo et al. 2004). This has resulted in a change to the coastal landscape and a reduction and fragmentation of the red-crowned crane habitat. In order to better protect coastal wetland ecosystem and biodiversity in the YNNR, periodic mapping of land use and coastal habitats should be performed to observe trends and changes.

However, very few studies have been conducted to identify coastal wetland and habitat change in the YNNR. The present study provides a new dimension to understand this. Through field investigations, the present study, by adopting remote sensing data and landscape metrics analysis, examines coastal wetland change and its impact on the red-crowned cranes habitat during the past few decades and analyzes the underlying causes, which are also the specific purposes of this study.

### Study area

The YNNR is located on the east coast of Jiangsu Province, China, from 32°20'N to 34°37'N and from 119°29'E to

121°16'E (Fig. 1). The YNNR spans the five counties of Yancheng City: Xiangshui County, Binhai County, Sheyang County, Dafeng City and Dongtai County. The northern border of the reserve is the Guan River in Xiangshui County; the southern border is the Xingang dam; the western border is the Yellow Sea Road; and the reserve's eastern border is the Yellow Sea. It includes 582 km of coastline and many sand dunes of the continental shelf (Xu et al. 2005). It is normally divided into three zones: the core zones of 175 km<sup>2</sup> located in Sheyang County, the buffer zone and the experimental zone. Above 0 m bathymetric, the total area is about 57,033 ha. It is an alluvial plain and beach area, and a typical intertidal mudflat coast. There are many small rivers and lakes in the area. Elevation in the YNNR varies between 0 and 4 m, with an average slope of less than 5 degrees. The YNNR lies in the transition belt between the warm temperate and northern subtropical zones. As a result, the reserve's climate is governed by seasonality, with a dry, cold winter and a hot, rainy summer (Ma et al. 1998).

The YNNR is a coastal wetland typical of the Jiangsu coastline. Its original landscape comprises coastal salt marsh, so the variety of vegetation is poor and dominated by salt tolerant plants. The plant community had a typical landward succession sere type (Wan et al. 2001): (1) the pioneer species *Spartina alterniflora* dominates the elevated part of the intertidal zones; (2) a *Suaeda salsa* and *Suaeda glauca* community is dominant in the high tidal zones; and (3) in the supratidal zone, *Aeluropus littoralis*, *Phragmites australis*, *Imperata cylindrical*, *Scripus karuizawensis* and *Zoysiam jacrostachys* are prevalent. The original vegetation of the YNNR was comprised of *Suaeda salsa* (L. Pall.) and common reed (*Phragmites communis*

*Trin*). In 1963 and 1979, *common cordgrass* (*Spartina anglica* C.E. Hubbard) and *smooth cordgrass* (*Spartina alterniflora* Loisel) were introduced from England and the United States, respectively, and after the 1990s, they became the two dominant plants of the intertidal zone in the YNNR (Li et al. 2005). The main land use types in the YNNR are reeds, grass flats, ponds, agriculture fields, rivers, salt fields and developed areas.

## Data and methods

### Data

In this study, three remote sensing images were used to examine coastal wetland change in the YNNR. Landsat images (Table 1) were purchased from China Remote Sensing Satellite Ground Station. Late spring time images were selected because, for this area, main plants flourish and have different height and density in late spring, which reduced the spectral confusion between reeds and grass flats during land use interpretation from the images. The images, which have six bands (except for the thermal band) and 30-m spatial resolution, are predominantly cloud-free. 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 YNNR boundary was delineated using administrative maps. The aerial photos and land use maps were used as a reference for satellite images interpretation and land use mapping.

### Land use mapping

The raw images used for this study were georeferenced based on the digital topographical maps. After georeferencing, the images had a Gaussian–Krueger projection and a Root Mean Squared Error (RMS error) of less than one pixel. The images were cut to include only the study area in order to create a multi-temporal image data set. The empirical method referred to by Hall et al. (1991) as ‘radiometric rectification’ 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. After this processing, image statistics and histograms from the three periods were found to be similar and comparable for the study area.

Classification of land use based on multi-spectral or multi-temporal remote sensing images has been the main approach for detecting wetland change (Franklin et al. 2001). But visual interpretation is also a popular method, and it is particularly suitable for small areas (Liu et al. 2005). Although visual interpretation is a time-consuming and difficult method, it can more accurately provide land use maps compared with automatic classification (Liu et al. 2005). In order to obtain high quality land use change information on the basis of Landsat TM image in 2006, 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 March 2007 covering the entire study area. Therefore, we had a priori knowledge of the study area as a whole, including landform, soil, vegetation, ponds, rivers, salt fields, agriculture fields and built-up areas.

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. The smallest patch of land use we selected was not less than 25 pixels (2.25 ha), and the shortest edge was longer than 3 pixels (90 m). After the preliminary interpretation, an inventory was conducted of the areas, which had not been definitely delineated or identified. A second round of field surveys, conducted on April–May 2007, had two targets: areas where ground surveys were the only solution and areas where it sufficed to study aerial photographs. The field data were statistically analyzed. The checked cases were reviewed based on the field verification and the photographs; if the results of the verifications were unsatisfactory, some or all of the interpretation process was repeated. The final vector land use maps, which form the core of the spatial database, were edited and compiled by comparing the results of visual interpretation and fieldwork with the help of land use maps from local land agencies.

A system of land use classification was established in which land use was grouped into 7 categories: river, reed, grass flat, agriculture field, built-up area, salt field and pond. Reed areas were defined as areas covered with reed beds (*Phragmites communis Trin*). Grass flat areas included areas covered with *Spartina alterniflora*, *Suaeda salsa*, etc. Agriculture field areas included paddy and dry farming land. Built-up areas included urban areas, rural settlements and others areas such as roads. Areas used for salt

**Table 1** List of satellite images used in this study

Platform	Sensor	Path/row	Resolution (m)	Acquisition date
Landsat 5	Thematic Mapper	119-37	30	April 9, 1988
Landsat 5	Thematic Mapper	119-37	30	May 20, 1997
Landsat 5	Thematic Mapper	119-37	30	May 29, 2006

production was classified as salt field areas. Pond areas included lakes and artificial aquaculture areas.

In order to evaluate the accuracy of the land use maps derived from remote sensing images covering the YNNR, we conducted a third round of field surveys in June 2007, covering a total survey length of 61 km across the study area, 123 patches and more than 80 photos located with GPS facilities. The overall accuracy of the land cover classification was found to be 93.4% (Table 2). For the reed and grass flat areas, the accuracy was 95.5 and 90.0% respectively, based on the evaluation of 22 and 10 patches, respectively. For pond areas, the accuracy was 94.7% based on an evaluation of 19 patches. For agriculture land areas, the accuracy was 93.5% based on an evaluation of 31 patches. The identification of built-up areas was 92.8% accurate based on 14 patches. We collected 47 slices to evaluate the accuracy of location during mapping process. The results indicated that 96.7% of the polygon boundaries show less than one pixel (30 m) shift from the real boundary.

To obtain land use maps for 1988 and 1997, the interpreters drew the land use patches based on remote sensing images from those years. The land use maps for 2006 were used as supporting information to identify the types of land use for each patch. We chose 54 and 110 land use patches in 1988 and 1997, respectively, to make an accuracy evaluation by interviewing YNNR administration staff and longtime residents in the YNNR. We also referred to aerial photos and historical land use maps obtained from the local authorities. The results showed that the overall identification accuracies were 96.2% in 1988 and 95.6% in 1997 (Table 2).

### Quantifying landscape metrics

Time series landscape metrics can be used to quantify coastal wetland structure and spatial configuration (Seto and Fragkias 2005). Moreover, they can be used as

indicators of habitat quality and other environmental concerns (Hansen et al. 2001; Hargis et al. 1999; Revenga 2005). Of interest to us is the coastal wetland change of the YNNR as a whole; we analyze the coastal wetland change and habitat fragmentation by examining the changing landscape metrics in the last few decades.

Numerous landscape metrics have been proposed (Forman and Godron 1986). Choices for appropriate landscape metrics are dependent upon the scale of analysis and objectives of the study (Turner and Gardner 1991; Forman 1995; Turner et al. 2001). For example, if landscape fragmentation is to be examined, one will choose indicators that relate to patch number, mean patch size, patch density, etc. In the YNNR study area, we sought to identify those indicators that best reflect the landscape's temporal change and habitat fragmentation. Five landscape metrics at the class level were selected: NP, PD, MPS, SHAPE-AM and IJI (Table 3). Another 5 landscape metrics at the landscape level were chosen: NP, MPS, LPI, SHAPE-AM and IJI (Table 3). Metrics computed at the class level are helpful for the understanding of landscape development. Indicators computed at the landscape level yield relatively general information averaged over the entire landscape (unit) under investigation.

The definition and description of these landscape metrics (Table 3) in FRAGSTATS are given in the FRAGSTATS user's guide (McGarigal and Marks 1995). FRAGSTATS, developed by the Forest Science Department, Oregon State University, USA, is a program for quantifying landscape structure (McGarigal and Marks 1995), and the vector version of this program was used to calculate landscape metrics for each land use map in the YNNR. The choice of these metrics seems appropriate, because the utilized metrics either individually or in conjunction reveal a distinct but complementary aspect of complex processes such as fragmentation in a particular land use class. Moreover, these metrics are in the core set of landscape metrics indicated by Leitao and Ahern (2002).

**Table 2** Accuracy assessment for the land use maps for 1988, 1997 and 2006

Year		AF	Pond	BA	SF	GF	Reed	River	Total
1988	SPN	6	8	5	2	6	15	12	54
	CPN	6	8	5	2	6	14	11	52
	ACC	100%	100%	100%	100%	100%	93.3%	91.7%	96.2%
1997	SPN	32	20	21	2	5	19	11	110
	CPN	31	19	20	2	5	18	10	105
	ACC	96.9%	95%	95.2%	100%	100%	94.7%	90.9%	95.8%
2006	SPN	31	19	14	1	10	22	26	123
	CPN	29	18	13	1	9	21	24	115
	ACC	93.5%	94.7%	92.8%	100%	90%	95.5%	92.3%	93.4%

AF agriculture land, BA built-up area, SF salt flat, GF grass flat, SPN sampling patch number, CPN correct patch number, ACC accuracy

**Table 3** Landscape pattern metrics description

Index (unit)	Level	Description
NP	Class	Number of patches
PD	Class	Patch density
MPS (ha)	Class	Mean patch size
AWMSI	Class	Area-weighted mean shape index
IJI	Class	Interspersion and juxtaposition index
NP	Landscape	Number of patches
MPS (ha)	Landscape	Mean patch size
LPI	Landscape	Largest patch index
AWMSI	Landscape	Area-weighted mean shape index
ENN_MN (m)	Landscape	Mean Euclidean nearest neighbor distance

Metrics calculated using Fragstats. Index and description definition adapted from McGarigal and Marks (1995)

## Results

### Land use change

Land use changes are presented in Figs. 2 and Fig. 3, Tables 4, 5 and 6. The grass flat dominated the YNNR in 1988 and 1997, accounting for 44.04 and 36.55% of the total area, respectively. It continuously decreased from 1988 to 2006, and 66.91% (16,843.50 ha) of the 1988 area was lost by 2006. Moreover, as of 2006, only the central region of the YNNR still remained as grass flat habitat, with most of the decrease recorded in the north and south regions. The grass flat area decreased most quickly between 1997 and 2006. Reed area was the second largest land use type in 1988, and it experienced the same change trend as the grass flat, decreasing from 33.68% in 1988 to 14.15% in 2006. In terms of spatial distribution, the reed area is adjacent to the grass flat area. The grass flat and reed areas were the main vegetation cover type in the YNNR, and they also constitute the habitat of the red-crowned cranes. Salt flat, concentrated in the north part of the study area, increased from 1988 to 1997 but significantly decreased from 1997 to 2006.

Most other land use types increased during the study period. Agriculture fields significantly increased from 1.46% in 1988 to 18.57% in 2006 and the annual mean increase rate was 599.84 ha. The increase in agriculture fields occurred on the north bank of Xinyanggang River, i.e. the north and south part of the study area, replacing both grass flat and reed cover. Pond area, another fast increasing land use type, was distributed mainly in the north and south parts and increased by 25,241.84 ha over 18 years. Its area in 2006 was 7 times greater than in 1988, and its annual mean increase rate was 1,402.38 ha—the highest rate of increase for any land type. Pond area

increased most quickly from 1997 to 2006, when its annual mean increase rate reached 2,062.76 ha. The areas in which pond increased were also the areas where grass flat and reed cover decreased. Built-up areas increased fivefold from 77.76 ha in 1988 to 468 ha in 2006 but still accounted for only a small proportion of the total area. River area (mainly canals, channels and ditches) showed a little increase from 1988 to 2006.

### Landscape change

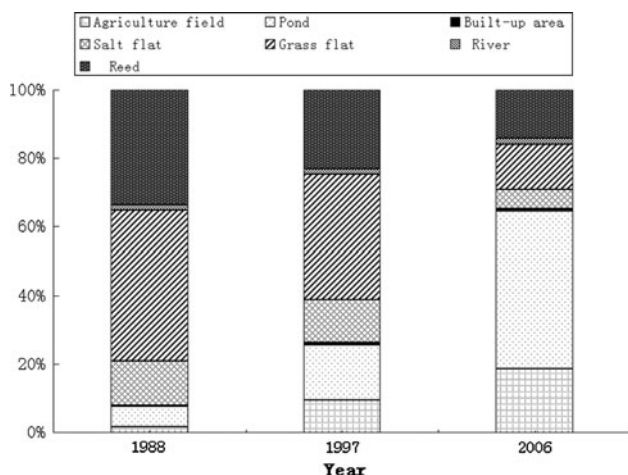
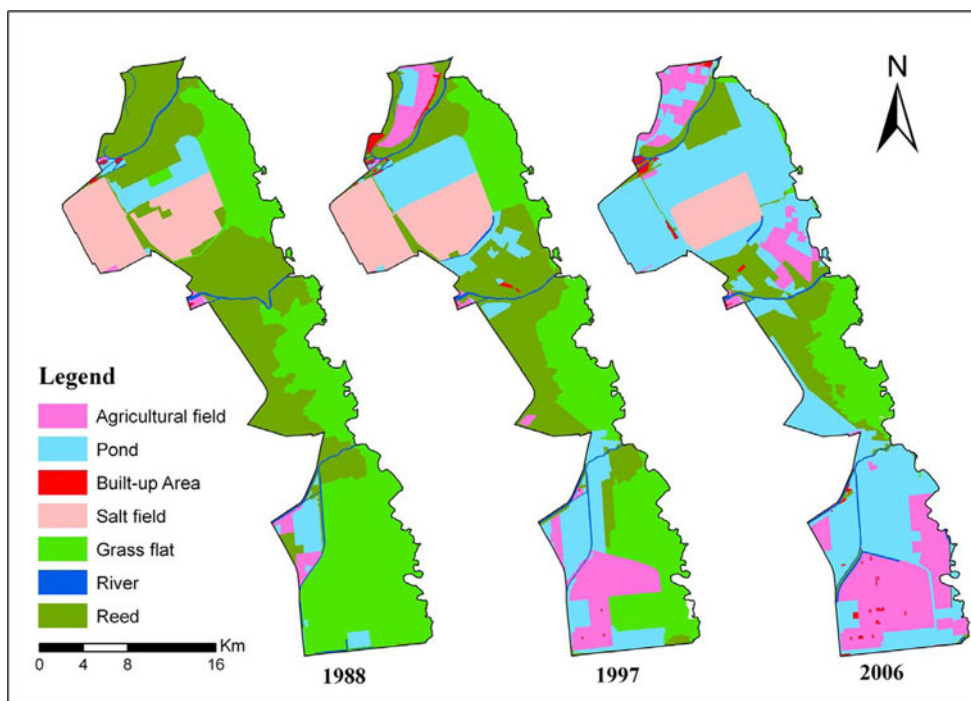
The quantification of landscape pattern through landscape metrics is a key element for studying landscape function and change (Forman and Godron 1986; Turner et al. 2001). Figure 4 and Table 7 compared changes in landscape metrics at the class level. Grass flat areas were the fastest decreasing landscape patch type: the NP of grass flat decreased from 7 in 1988 to 5 in 1997 but then increased to 12 by 2006, and the MPS increased in the first 9 years but quickly decreased in the second 9 years. PD and AWMSI decreased in the first period and increased in the second period. Reed areas also showed rapid loss over the 18-year period. The NP and PD for reed areas continuously increased during the study period but the MPS decreased. The landscape metrics changes in grass flat and reed areas reflect coastal wetland and vegetation ecosystem change, and natural vegetation is disturbed and reduced.

Agriculture field area was the highest variable landscape patch type: the NP dramatically increased at first before decreasing slightly in the second period (Fig. 4; Table 7). Pond area was the fastest increasing landscape patch type: its NP increased in the first study period and then increased by another patch from 1997 to 2006. In particular, MPS increased very quickly from 1997 to 2006. Such growth changes in agriculture fields and ponds resulted from the high economic benefits of transforming grass flat, reed and salt flat areas into agriculture fields and aquaculture ponds from 1988 to 2006. Built-up area was another highly variable patch type. NP continuously increased from 6 in 1988 to 21 in 1997 and to 33 in 2006. The expansion of built-up area further shows the effects of human activities on the red-crowned cranes habitat.

The above results reveal that spatial patterns in the YNNR have become more heterogeneous and fragmented: grass flat and reed areas consistently shrank, while agriculture field and pond area significantly grew, but the NP for all these land use types increased from 1988 to 2006. Changes in other landscape metrics also support this inference. Overall, the change direction of the coastal landscape has been toward increased heterogeneity and fragmentation.

Comparison of the change of landscape metrics at the landscape level is shown in Table 8. The NP continuously

**Fig. 2** Land use maps of the YNNR in 1988, 1997 and 2006



**Fig. 3** Land use of the YNNR in 1988, 1997 and 2006 as a percent of the total area

increased from 69 in 1988 to 147 in 1997 and then 195 in 2006. Correspondingly, MPS steadily decreased from 828.40 to 426.62 ha and then 321.17 ha, showing that some original patches were divided and that landscape heterogeneity and fragmentation was rising. The spatial context of the landscape patches also changed significantly. For instance, the ENN-MN steadily shortened from 1,354 m in 1988 to 539 m in 1997 and then 509 m in 2006. This illustrates that the spatial distribution of various patches in the YNNR became fragmented. Landscape metrics helped in quantification of coastal landscape structures in the YNNR and conveys the extent of changes and their effects.

## Discussions

### Driving force analysis

The wetland changes revealed for the YNNR have occurred as a result of interactions of a number of socioeconomic forces. Many studies indicate that population growth is an important driving force of wetland change and also one of the main factors in landscape change. The human population of the coastal region in Yancheng city significantly increased from 750 million in 1988 to 805 million in 2006 (Editing committee of “50 Years in Jiangsu” 1999; City Social-Economic Investigation Department of NBSC 2008). Population growth has resulted in the expansion of built-up areas and also contributed to the reclamation of natural grass flat and reed areas for agricultural purposes. Some canals, channels and ditches were dug to meet growing demands for irrigation. Increased agricultural land area facilitates the increased grain production necessary to feed a growing population. Clearly, human activities have disturbed the natural coastal wetland ecosystem and the red-crowned cranes habitat.

Government policy plays an important role in the coastal wetland change in the YNNR. The government strategy to develop the marine zone in eastern Jiangsu, referred to in the Province as “constructing marine eastern Jiangsu”, has been promoted since the early 1990s, and the coastal development of Jiangsu has gradually entered a new era. Preferential policies for coastal development in Jiangsu were implemented in order to promote aquaculture development and

**Table 4** Percentage and rate of land use changes for 1988, 1997 and 2006

Land use types	AF	Pond	BA	SF	GF	River	Reed
1988–1997							
CP (%)	599.71	187.08	390.39	6.43	−8.96	19.65	−25.08
AMCR (ha/a)	556.77	742.00	33.73	52.73	−250.49	18.80	−536.53
1997–2006							
CP (%)	98.97	181.16	22.73	−56.60	−63.66	7.64	−38.56
AMCR (ha/a)	642.91	2062.76	9.63	−494.35	−1621.01	8.74	−618.08
1988–2006							
CP (%)	1292.20	707.15	501.85	−53.81	−66.91	28.79	−53.96
AMCR (ha/a)	599.84	1402.38	21.68	−220.81	−935.75	13.77	−577.31

CP change percentage, AMCR annual mean change rate

**Table 5** Change matrix for 1988 and 1997 (area in ha)

	AF	Pond	BA	SF	GF	River	Reed	1988 Total
AF	186.96	8.28	10.44	0.00	0.00	0.03	59.37	265.08
Pond	32.69	2932.54	10.75	224.73	0.00	0.32	54.75	3255.78
BA	41.15	55.41	53.09	0.00	0.00	0.00	29.07	178.72
SF	0.00	0.00	0.00	7341.96	0.00	0.00	42.53	7384.49
GF	4325.46	3952.34	12.93	218.81	22580.30	3.88	510.58	31604.30
River	1.33	73.06	0.00	0.00	0.14	930.01	62.86	1067.40
Reed	825.11	2757.16	703.84	523.52	2112.24	18.08	6338.20	13278.15
1997 Total	5412.70	9778.79	791.05	8309.02	24692.68	952.32	7097.36	57033.92

AF agriculture land, BA built-up area, SF salt flat, GF grass flat

**Table 6** Change matrix for 1997 and 2006 (area in ha)

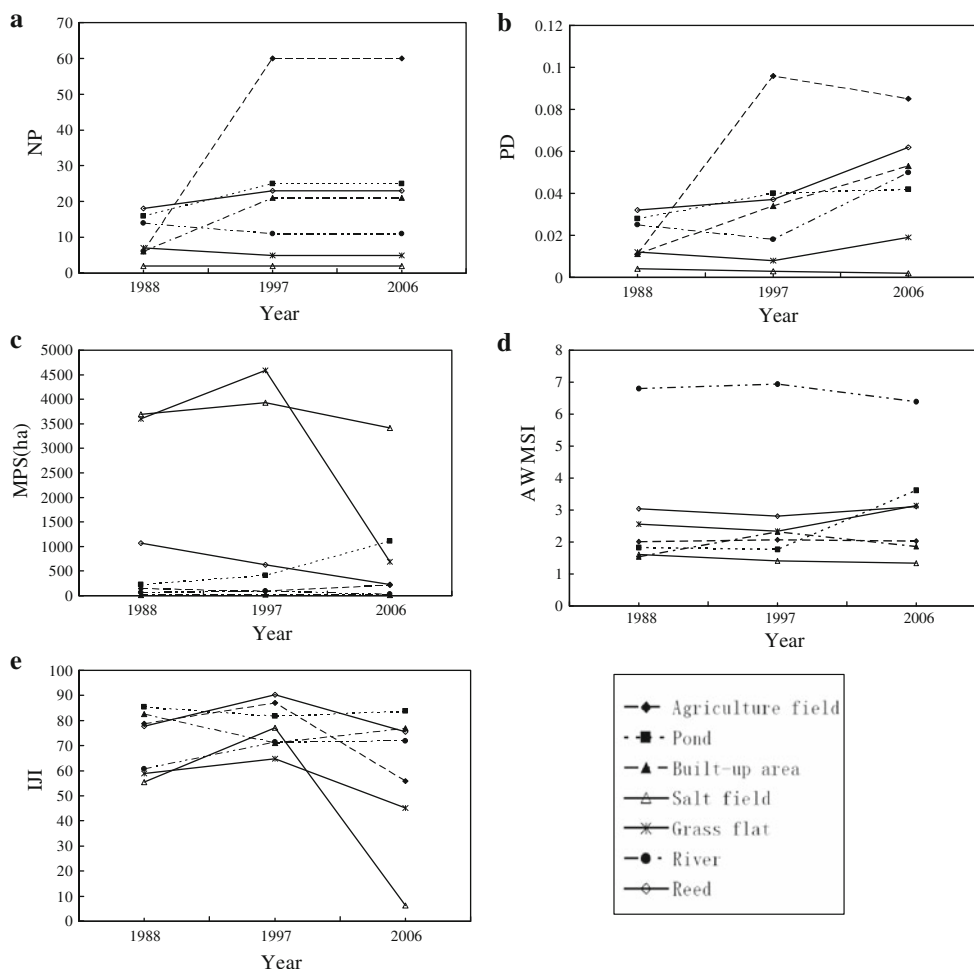
	AF	Pond	BA	SF	GF	River	Reed	1997 Total
AF	4330.13	761.06	101.23	0.00	0.00	121.60	98.69	5412.71
Pond	732.23	8468.18	79.03	1.43	9.69	52.67	435.56	9778.79
BA	66.87	398.68	106.08	0.00	0.00	12.55	206.98	791.16
SF	0.00	4894.02	0.02	3409.03	0.00	5.94	0.00	8309.01
GF	4699.34	10089.28	28.80	0.00	8462.19	63.35	1349.58	24692.54
River	42.87	93.12	7.83	0.60	5.18	671.52	131.21	952.33
Reed	1331.10	1809.50	146.22	0.00	194.99	67.55	3548.02	7097.38
2006 Total	11202.54	26513.84	469.21	3411.06	8672.05	995.18	5770.04	57033.92

AF agriculture land, BA built-up area, SF salt flat, GF grass flat

resulted in quick economic growth. Gross domestic product (GDP) of Yancheng city was about 1.2 billion \$ in 1988 and 167.8 billion \$ in 2006, respectively (Editing committee of “50 Years in Jiangsu” 1999; City Social-Economic Investigation Department of NBSC 2008). In order to implement government policy of economic growth, many grass flat and reed areas were reclaimed and transformed into aquaculture ponds to obtain greater economic benefits compared with the modest economic benefits of agriculture. At the same time,

the salt industry, with low economic benefit, was replaced by more profitable aquaculture. Artificial channels area increase also showed the development of aquaculture. The aquaculture output significantly increased from 132 thousand ton in 1988 to 852 thousand ton in 2006 (Editing committee of “50 Years in Jiangsu” 1999; City Social-Economic Investigation Department of NBSC 2008). The fast development of aquaculture led to significant increase of ponds area and area reduction of reed, grass flat and salt flat.





**Fig. 4** Change of landscape metrics at class level for 1988, 1997 and 2006 (a NP, b PD, c MPS, d AWMSI, e IJI)

**Impacts on habitat**

The changes in land use and landscape metrics discussed in Sect. 4 provide verification for the habitat change of red-crowned cranes. Correspondingly, the natural coastal wetland consistently decreased from 1988 to 2006 and became fragmented and heterogeneous, with significant decrease in grass flat and reed areas, and thus, the habitat gradually diminished, and even the core area of the YNNR was threatened. At the same time, this variation trends also indicated that the natural coastal landscape and wetland ecosystem in the YNNR deteriorated during the entire study period.

Birds are an indicator species for wetland environment (Foster et al. 2009; Robledano et al. 2010), and the red-crowned cranes can be a symbol of wetland ecosystem (Ma et al. 1999), and bird number and species can reflect the health status of wetland ecosystem. The changing trend of the red-crowned cranes number from 1988 to 2010 also showed the deteriorated habitat and wetland ecosystem of the YNNR (Fig. 5). If conservation measures are not

adopted, the critical habitat will cease to exist and red-crowned cranes may disappear from the YNNR. This species is already considered globally threatened and losing its habitat, especially such an important wintering area will likely put it at the brink of extinction or drive it to extinction altogether. Habitat loss of the YNNR would mean a great loss of a unique ecosystem and of the diversity of species, which will be unrecoverable. Certainly, the habitat changes have negative impacts on the global ecosystem and biodiversity because the YNNR is important to the red-crowned cranes population and other migratory birds.

The study suggested that protecting the natural coastal wetland habitats and reducing human interventions are urgent and crucial problems for the YNNR. Local activity related to land use change should be carefully managed and designed to develop a more suitable environment for the bird species. The essential wintering habitat should be identified and protected from future development, and other key areas should also be restored.

**Table 7** Metrics comparison at class level for 1988, 1997 and 2006

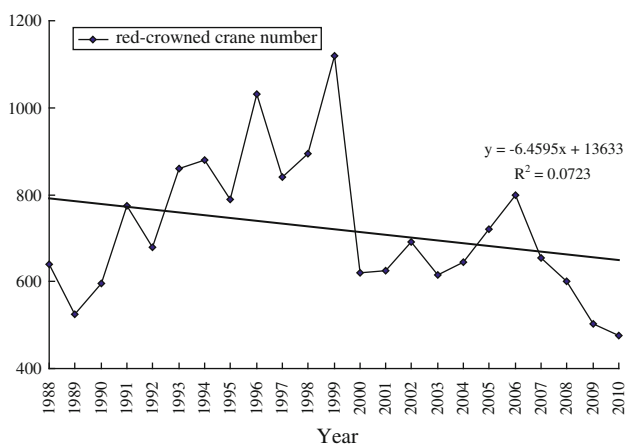
Land use types	AF	Pond	BA	SF	GF	River	Reed
1988							
NP	6	16	6	2	7	14	18
PD	0.011	0.028	0.011	0.004	0.012	0.025	0.032
MPS (ha)	139.26	223.10	12.96	3693.00	3596.20	61.50	1069.80
AWMSI	2.01	1.83	1.54	1.61	2.56	6.80	3.04
IJI	78.82	85.35	82.69	55.54	58.99	60.75	77.74
1997							
NP	60	25	21	2	5	11	23
PD	0.096	0.040	0.034	0.003	0.008	0.018	0.037
MPS (ha)	97.44	409.91	18.16	3930.26	4583.79	93.65	627.29
AWMSI	2.07	1.77	2.32	1.41	2.34	6.94	2.81
IJI	86.98	81.87	71.09	77.11	64.87	71.44	90.23
2006							
NP	53	26	33	1	12	31	39
PD	0.085	0.042	0.053	0.002	0.019	0.050	0.062
MPS (ha)	219.48	1108.17	14.18	3411.36	694.16	35.77	227.31
AWMSI	2.03	3.62	1.86	1.34	3.14	6.39	3.11
IJI	55.87	83.80	76.92	6.27	45.06	71.91	75.54

AF agriculture land, BA built-up area, SF salt flat, GF grass flat, NP number of patches, PD patch density, MPS mean patch size, AWMSI area-weighted mean shape index, IJI interspersed and juxtaposition index

**Table 8** Metrics comparison at landscape level in the YNNR for 1988, 1997 and 2006

Year	NP	MPS (ha)	LPI	AWMSI	ENN_MN (m)
1988	69	828.40	24.49	2.61	1354.80
1997	147	426.62	14.05	2.28	539.26
2006	195	321.17	22.67	3.10	509.44

NP number of patches, MPS mean patch size, LPI largest patch index, AWMSI area-weighted mean shape index, ENN\_MN mean Euclidean nearest neighbor distance

**Fig. 5** Red-crowned cranes number from 1988 to 2010

National nature reserve planning and management are presently insufficient for the preservation of the red-crowned cranes habitat. As a functional unit, a national nature reserve is only one of many interrelated ecological chains crossing a range of scales. Comprehensive conservation strategies should also consider the interrelationships among the complicated ecological and social processes at various scales.

## Conclusions

We applied remote sensing technology and landscape pattern metrics to examine the coastal wetland change in the YNNR. The results revealed that grass flat and reed areas have significantly decreased, whereas agriculture fields, aquaculture ponds and built-up areas have continuously increased from 1988 to 2006, and thus, the red-crowned cranes habitat gradually diminished, and even the core area of the YNNR is threatened. The overall patch number increased, resulting in a reduced mean patch size. The spatial pattern of wetland landscape had become fragmented and heterogeneous. The changes in both landscape metrics and the red-crowned cranes number showed that the natural coastal landscape and wetland ecosystem deteriorated during the entire study period. Anthropogenic driving forces influencing wetland change include population growth and

coastal development policies of aquaculture promotion. It is expected that the trend toward fragmentation and heterogeneity will continue if driving forces are not altered. To protect the red-crowned cranes habitat, conservation measures must be strengthened. From this study, we can see that coastal zone development is leading to the natural wetland decrease and may threaten the survival of the red-crowned cranes and other migratory birds in the YNNR. In any policy development, we should give special consideration to the protection of the coastal wetland ecosystem to seek both economic and environmental benefits.

**Acknowledgments** Thanks are extended to the anonymous reviewers and to the subject editor Prof. Ruth DeFries and editor-in-chief Prof. Wolfgang Cramer for their excellent reviews and constructive comments. This research is financially supported by the National Natural Science Foundation of China (NSFC Grant No. 40730635 and 40971044), Hydrologic public benefit project of Water Resource Ministry of China (Grant No. 200701024), Program for New Century Excellent Talents in University (NCET-08-0276) and Deutscher Akademischer Austauschdienst (DAAD) scholarship.

## References

- Alonso-Perez F, Ruiz-Luna A, Turner J, Berlanga-Robles CA, Mitchelson-Jacob G (2003) Land cover changes and impact of shrimp aquaculture on the landscape in the Ceuta coastal lagoon system, Sinaloa, Mexico. *Ocean Coast Manag* 46:583–600. doi: [10.1016/S0964-5691\(03\)00036-X](https://doi.org/10.1016/S0964-5691(03)00036-X)
- Armenteras D, Gast F, Villareal H (2003) Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia. *Biol Conserv* 113:245–256
- Baban SMJ (1997) Environmental monitoring of estuaries; estimating and mapping various environmental indicators in Breydon water estuary, UK, using Landsat TM imagery. *Estuar Coast Shelf Sci* 44:589–598
- Bajjouk T, Populus J, Guillaumont B (1998) Quantification of subpixel cover fractions using principal component analysis and a linear programming method: application to the coastal zone of Roscoff (France). *Remote Sens Environ* 64(2):153–165
- Barducci A, Guzzi D, Marcoionni P, Pippi I (2009) Aerospace wetland monitoring by hyperspectral imaging sensors: a case study in the coastal zone of San Rossore Natural Park. *J Environ Manag* 90:2278–2286. doi: [10.1016/j.jenvman.2007.06.033](https://doi.org/10.1016/j.jenvman.2007.06.033)
- Burak S, Dogana E, Gazioglu C (2004) Impact of urbanization and tourism on coastal environment. *Ocean Coast Manag* 47:515–527. doi: [10.1016/j.ocecoaman.2004.07.007](https://doi.org/10.1016/j.ocecoaman.2004.07.007)
- Cai F, Su X, Liu J, Li B, Lei G (2009) Coastal erosion in China under the condition of global climate change and measures for its prevention. *Prog Nat Sci* 19:415–426. doi: [10.1016/j.pnsc.2008.05.034](https://doi.org/10.1016/j.pnsc.2008.05.034)
- Carreno MF, Esteve MA, Martinez J, Palazon JA, Pardo MT (2008) Habitat changes in coastal wetlands associated to hydrological changes in the watershed. *Estuar Coast Shelf Sci* 77:475–483. doi: [10.1016/j.ecss.2007.10.026](https://doi.org/10.1016/j.ecss.2007.10.026)
- Chen SS, Chen LF, Liu QH, Li X, Tan QY (2005) Remote sensing and GIS-based integrated analysis of coastal changes and their environmental impacts in Lingding Bay, Pearl River Estuary, South China. *Ocean Coast Manag* 48:65–83. doi: [10.1016/j.ocecoaman.2004.11.004](https://doi.org/10.1016/j.ocecoaman.2004.11.004)
- Chen Z, Jin J, Chen Y (2006) The status and significance of seashore wetland protection in China. *Environ Pollut Prevent* 28(12):930–933 (in Chinese)
- City Social-Economic Investigation Department of National Bureau of Statistics of China (2008) *Statistics Yearbook of Chinese Cities in 2007*. Chinese Statistics Publishing House, Beijing
- Debinski D, Holt R (2000) A survey and overview of habitat fragmentation experiments. *Conserv Biol* 14:342–355
- Editing committee of <50 Years in Jiangsu> (1999) *50 Years in Jiangsu*. Chinese Statistics Publishing House, Beijing
- ESRI (1999) *ArcGIS Desktop Help*. ESRI, USA. (<http://www.esri.com>)
- Fan H, Huang H, Zeng T (2006) Impacts of anthropogenic activity on the recent evolution of the Huanghe (Yellow) River Delta. *J Coast Res* 22(4):919–929. doi: [10.2112/04-0150](https://doi.org/10.2112/04-0150)
- Fletcher RS, Pulich WJ, Hardegree B (2009) A semiautomated approach for monitoring landscape changes in Texas seagrass beds from aerial photography. *J Coast Res* 25(2):500–506. doi: [10.2112/07-0882](https://doi.org/10.2112/07-0882)
- Forman RTT (1995) Some general principles of landscape and regional ecology. *Landscape Ecol* 10:133–142
- Forman RTT (1997) *Land mosaics*. Cambridge University Press, Cambridge
- Forman RTT, Godron M (1986) *Landscape ecology*. Wiley, New York
- Foster CR, Amos AF, Fuiman LA (2009) Trends in abundance of coastal birds and human activity on a Texas Barrier Island over three decades. *Estuar Coast* 32:1079–1089. doi: [10.1007/s12237-009-9224-2](https://doi.org/10.1007/s12237-009-9224-2)
- Franklin SE, Stenhouse GB, Hansen MJ, Popplewell CC, Dechka JA, Peddle DR (2001) An integrated decision tree approach (IDTA) to mapping landcover using satellite remote sensing in support of grizzly bear habitat analysis in the Alberta yellowhead ecosystem. *Can J Remote Sens* 27:579–592
- Gan X, Cai Y, Choi C, Ma Z, Chen J, Li B (2009) Potential impacts of invasive *Spartina alterniflora* on spring bird communities at Chongming Dongtan, a Chinese wetland of international importance. *Estuar Coast Shelf Sci* 83:211–218. doi: [10.1016/j.jecss.2009.03.026](https://doi.org/10.1016/j.jecss.2009.03.026)
- Gibbes C, Southworth J, Keys E (2009) Wetland conservation: change and fragmentation in Trinidad's protected areas. *Geoforum* 40:91–104. doi: [10.1016/j.geoforum.2008.05.005](https://doi.org/10.1016/j.geoforum.2008.05.005)
- Gigord L, Picot F, Shykoff J (1999) Effects of habitat fragmentation on *Dombeya acutangula* (Sterculiaceae), a native tree on La Re'union (Indian Ocean). *Biol Conserv* 88:43–51
- Hall RJ, Dams RV, Lyseng LN (1991) Forest cut-over mapping from SPOT satellite data. *Int J Remote Sens* 12(11):2193–2204
- Hansen MJ, Franklin SE, Woudsma C, Peterson M (2001) Caribou habitat classification and fragmentation analysis of old growth cedar/hemlock forests in British Columbia using Landsat TM and GIS data. *Remote Sens Environ* 77:50–65
- Hargis CD, Bissonette JA, Turner DL (1999) The influence of forest fragmentation and landscape pattern on American martens. *J Appl Ecol* 36:157–172
- Iida S, Nakashizuka T (1995) Forest fragmentation and its effect on species diversity in sub-urban coppice forests in Japan. *Forest Ecol Manag* 73:197–210
- Jones K, Lanthier Y, Voet P, Valkengoed E, Taylor D, Fernandez-Prieto D (2009) Monitoring and assessment of wetlands using Earth Observation: the GlobWetland project. *J Environ Manag* 90:2154–2169. doi: [10.1016/j.jenvman.2007.07.037](https://doi.org/10.1016/j.jenvman.2007.07.037)
- Kumar PKD, Gopinath G, Laluraj CM, Seralathan P, Mitra D (2007) Change detection studies of Sagar Island, India, using Indian remote sensing satellite 1C Linear Imaging Self-Scan Sensor III data. *J Coast Res* 23(6):1498–1502. doi: [10.2112/05-0599](https://doi.org/10.2112/05-0599)

- Laurance WF (1999) Reflections on the tropical deforestation crisis. *Biol Conserv* 91:109–117
- LeDee OE, Cuthbert FJ, Bolstad PV (2008) A remote sensing analysis of coastal habitat composition for a threatened shorebird, the Piping Plover (*Charadrius melodus*). *J Coast Res* 24(3):719–726. doi:10.2112/06-0734
- Leitao AB, Ahern J (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape Urban Plan* 59:65–93. doi:10.1016/S0169-2046(02)00005-1
- Lewsey C, Cid G, Kruse E (2004) Assessing climate change impacts on coastal infrastructure in the Eastern Caribbean. *Mar Policy* 28:393–409. doi:10.1016/j.marpol.2003.10.016
- Li YF, Zhu XD, Zou XQ, Gao JH (2005) Study on landscape ecosystem of coastal wetlands in Yancheng, Jiangsu Province. *Mar Sci Bull* 24(4):46–51 (in Chinese)
- Liu YB, Nishiyama S, Kusaka T (2003) Examining landscape dynamics at a watershed scale using Landsat TM imagery for detection of wintering hooded crane decline in Yashiro, Japan. *Environ Manag* 31(3):365–376
- Liu JY, Liu ML, Tian HQ, Zhuang DF, Zhang ZX, Zhang W, Tang XM, Deng XZ (2005) Spatial and temporal patterns of China's cropland during 1990–2000: an analysis based on Landsat TM data. *Remote Sens Environ* 98:442–456. doi:10.1016/j.rse.2005.08.012
- Long BG, Skewes TD (1996) A technique for mapping mangroves with Landsat TM satellite data and geographic information system. *Estuar Coast Shelf Sci* 43:373–381
- Ma ZJ, Li WJ, Wang ZJ, Tang HG (1998) Habitat change and protection of the Red-Crowned Crane (*Grus japonensis*) in Yancheng Biosphere Reserve, China. *Ambio* 27(6):461–464 (in Chinese)
- Ma ZJ, Wang ZJ, Tang HG (1999) Habitat use and selection by Red-Crowned Crane *Grus japonensis* in winter in Yancheng Biosphere Reserve, China. *Ibis* 141:135–139
- MacKay H, Finlayson CM, Fernandez-Prieto D, Davidson N, Pritchard D, Rebelo LM (2009) The role of Earth Observation (EO) technologies in supporting implementation of the Ramsar Convention on Wetlands. *J Environ Manag* 90:2234–2242. doi:10.1016/j.jenvman.2008.01.019
- Martinez ML, Intralawan A, Vázquez G, Pérez-Maqueo O, Sutton P, Landgrave R (2007) The coasts of our world: ecological, economic and social importance. *Ecol Econ* 63: 254–272. doi:10.1016/j.ecolecon.2006.10.022
- Mas JF (2004) Mapping land use/cover in a tropical coastal area using satellite sensor data, GIS and artificial neural networks. *Estuar Coast Shelf Sci* 59:219–230. doi:10.1016/j.ecss.2003.08.011
- McGarigal K, Marks B (1995) FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report PNW-GTR-351. Pacific Northwest Research Station, Portland, OR
- Noss RF (2001) Forest fragmentation in the southern rocky mountains. *Landscape Ecol* 16:371–372
- Ou WX, Yang GS, Li HP, Yu XX (2004) Spatio-temporal variation and driving forces of landscape patterns in the coastal zone of Yancheng, Jiangsu. *Sci Geogr Sin* 24(5):610–615 (in Chinese)
- Ramachandran A, Enserink B, Balchand AN (2005) Coastal regulation zone rules in coastal panchayats (villages) of Kerala, India vis-à-vis socio-economic impacts from the recently introduced peoples' participatory program for local self-governance and sustainable development. *Ocean Coast Manag* 48:632–653. doi:10.1016/j.ocecoaman.2005.03.011
- Ramessur RT (2002) Anthropogenic-driven changes with focus on the coastal zone of Mauritius, south-western Indian Ocean. *Reg Environ Chang* 3:99–106. doi:10.1007/s10113-002-0045-0
- Rebelo LM, Finlayson CM, Nagabhatla N (2009) Remote sensing and GIS for wetland inventory, mapping and change analysis. *J Environ Manag* 90:2144–2153. doi:10.1016/j.jenvman.2007.06.027
- Revena C (2005) Developing indicators of ecosystem condition using geographic information systems and remote sensing. *Reg Environ Chang* 5:205–214. doi:10.1007/s10113-004-0085-8
- Robledano F, Esteve MA, Farinos P, Carreno MF, Martinez-Fernandez J (2010) Terrestrial birds as indicators of agricultural-induced changes and associated loss in conservation value of Mediterranean wetlands. *Ecol Indic* 10:274–286. doi:10.1016/j.ecolind.2009.05.006
- Ryu JH, Kim CH, Lee YK, Won JS, Chun SS, Lee S (2008) Detecting the intertidal morphologic change using satellite data. *Estuar Coast Shelf Sci* 78:623–632. doi:10.1016/j.ecss.2008.01.020
- Sarma PK, Lahkar BP, Ghosh S, Rabha A, Das JP, Nath NK, Dey S, Brahma N (2008) Land use and land cover change and future implication analysis in Manas National Park, India using multitemporal satellite data. *Curr Sci* 95(2):223–227
- Seto KC, Fragkias M (2005) Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics. *Landscape Ecol* 20:871–888
- Seto KC, Fragkias M (2007) Mangrove conversion and aquaculture development in Vietnam: a remote sensing-based approach for evaluating the Ramsar Convention on Wetlands. *Global Environ Chang* 17:486–500. doi:10.1016/j.gloenvcha.2007.03.001
- Thanh TD, Saito Y, Huy DV, Nguyen VL, Ta TKO, Tateishi M (2004) Regimes of human and climate impacts on coastal changes in Vietnam. *Reg Environ Chang* 4:49–62. doi:10.1007/s10113-003-0062-7
- Turner MG, Gardner RH (1991) Quantitative methods in landscape ecology. Springer, New York
- Turner MG, Gardner RH, O'Neill RV (2001) Landscape ecology in theory and practice: pattern and process. Springer, New York
- Turner RK, Bateman IJ, Georgiou S, Jones A, Langford IH, Matias NGN, Subramanian L (2004) An ecologic economics approach to the management of a multi-purpose coastal wetland. *Reg Environ Chang* 4:86–99. doi:10.1007/s10113-004-0075-x
- Walker BK, Riegl B, Dodge RE (2008) Mapping coral reef habitats in southeast Florida using a combined technique approach. *J Coast Res* 24(5):1138–1150. doi:10.2112/06-0809
- Wan SW, Qin P, Li Y (2001) Wetland creation for rare waterfowl conservation: a project designed according to the principles of ecological succession. *Ecol Eng* 18:115–120
- Watson J, Whittaker R, Dawson T (2004) Habitat structure and proximity to forest edge affect the abundance and distribution of forest-dependent birds in tropical coastal forest of southern Madagascar. *Biol Conserv* 120:311–327
- Weber T (2004) Landscape ecological assessment of the Chesapeake Bay watershed. *Environ Monit Assess* 94:39–53
- White K, Asmar HME (1999) Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta. *Geomorphology* 29:93–105
- Xu HG, Zhu GQ, Wang LL, Bao HS (2005) Design of nature reserve system for Red-Crowned Crane in China. *Biodiver Conserv* 14:2275–2289. doi:10.1007/s10531-004-1663-2
- Yang X, Liu Z (1995) Quantifying landscape pattern and its change in an estuarine watershed using satellite images and landscape metrics. *Int J Remote Sens* 16:3585–3594. doi:10.1080/01431169508954647
- Yue TX, Liu JY, Jørgensen SE, Ye QH (2003) Landscape change detection of the newly created wetland in Yellow River Delta. *Ecol Model* 164:21–31. doi:10.1016/S0304-3800(02)00391-5

- Zhang J (2002) Biogeochemistry of Chinese estuarine and coastal waters: nutrients, trace metals and biomarkers. *Reg Environ Chang* 3:65–76. doi:[10.1007/s10113-001-0039-3](https://doi.org/10.1007/s10113-001-0039-3)
- Zhu HG, Qin P, Wang H (2004) Functional group classification and target species selection for Yancheng Nature Reserve, China. *Biodiver Conserv* 13:1335–1353
- Zuo P, Wan SW, Qin P, Du JJ, Wang H (2004) A comparison of the sustainability of original and constructed wetlands in Yancheng Biosphere Reserve, China: implications from emergy evaluation. *Environ Sci Policy* 7:329–343. doi:[10.1016/j.envsci.2004.05.001](https://doi.org/10.1016/j.envsci.2004.05.001)