

Analysis of the spatiotemporal correlation between vegetation pattern and human activity intensity in Yancheng coastal wetland, China¹

Zheng Zang, Xinqing Zou, Qiaochu Song, and Yulong Yao

Abstract: Remote sensing images were used to reproduce the changes in wetland vegetation since 1987, and the potential impact of policy changes and human activities on vegetation restoration and biodiversity conservation in coastal wetlands was explored based on the landscape pattern index and the human disturbance index (HDI). The results showed that the vegetation displayed a zonal distribution pattern in which, perpendicular to the coastline early in the study period, the vegetation type changed from coastal wetland to bare mud flat with *Spartina alterniflora*, *Suaeda glauca*, and *Phragmites australis* as well as to constructed wetlands dominated by rice. Under the influence of human activities, the number of patches (NP) and mean nearest-neighbor distance (MNN) between patches gradually increased during the study period, while the mean patch size gradually decreased. The patch density increased from 179 (1987) to 296 patches per ha (2013). Additionally, human activity in the study area intensified. The HDI increased from 0.353 (1987) to 0.471 (1987) and showed positive correlations ($R^2 > 80\%$, $p < 0.01$) with NP and MNN. Human activity, such as changes in land use, resulted in more fragmented vegetation patterns, and the nonzonal (intrazonal) distribution of the vegetation became more obvious in coastal wetlands.

Key words: coastal wetland, vegetation restoration, remote sensing interpretation, human activity intensity, land use and cover change.

Introduction

In the coastal zone, vegetation is one element in the landscape pattern of coastal wetlands, and it plays an important role in the global carbon cycle and in biodiversity conservation (Romigh et al. 2006; Mendoza-González et al. 2016). Wetlands may be sensitive to human activity; therefore, exploring strategies for coastal wetland protection has become a globally important issue (Sudhakar Reddy et al. 2016; Salgado and Luisa Martinez 2017). The coastal zone is an important area that connects the sea and the land, and it is also a typical ecologically fragile zone. The rational protection and use of coastal wetland vegetation and the designing of diverse constructed wetlands can help relieve the conflicts between community interests and natural protective goals. Generally, constructing a strict coastal

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Z. Zang. School of Urban and Environmental Sciences, Huaiyin Normal University, Huai'an 223300, China.

X. Zou. School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China; Collaborative Innovation Center of South China Sea Studies, Nanjing 210093, China; Key Laboratory of Coast and Island Development (Nanjing University), Ministry of Education, Nanjing 210093, China.

Q. Song and Y. Yao. School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China.

Corresponding author: Xinqing Zou (e-mail: zouxq@nju.edu.cn).

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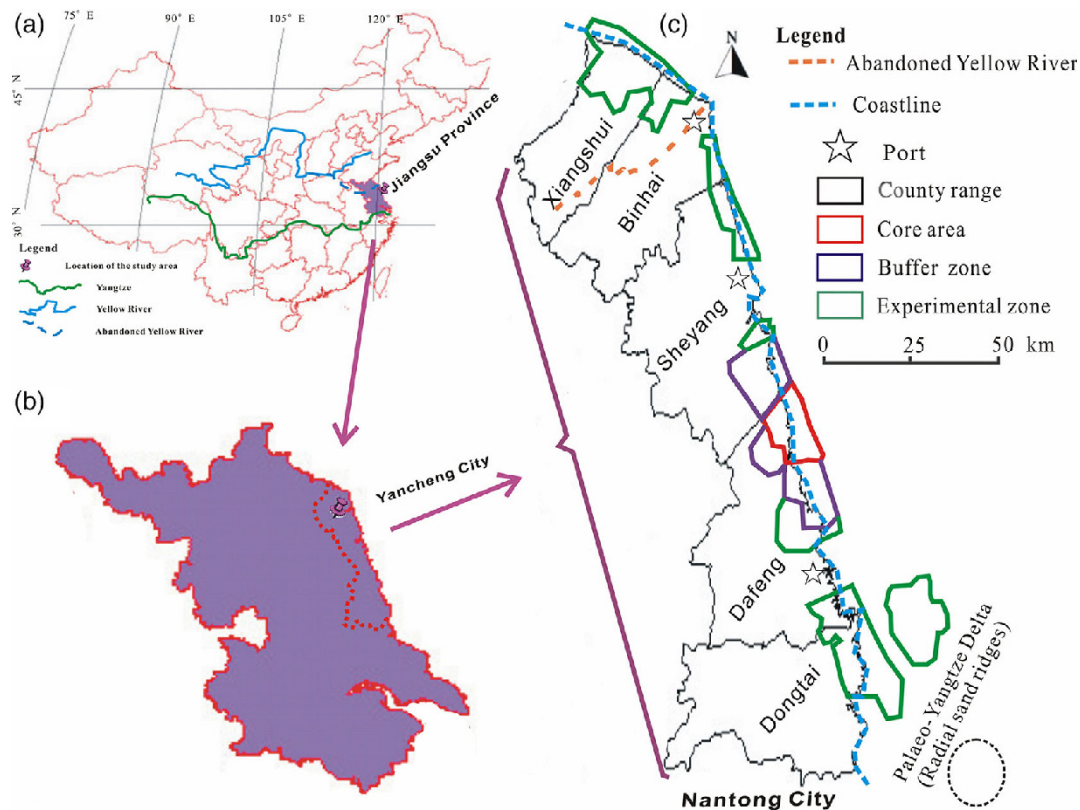
nature reserve and setting up a buffer in the coastal zone are the primary approaches to protecting coastal wetlands (Bockstael et al. 2016; Jusys 2016; Medina et al. 2016). As the intensity and breadth of human activity progressively increase, compared with these passive protective measures, the concept of Integrated Coastal Zone Management (ICZM) based on the theory of adaptability has received growing attention (Lei et al. 2015; Kuhfuss et al. 2016; Runhaar et al. 2016), leading to new ideas for coastal wetland protection work.

Environmental and geo-spatial factors have long been considered as crucial determinants of species composition and distribution (Tian et al. 2018). On large scales (e.g., global scales), vegetation distribution is primarily influenced by solar radiation and rainfall, the sea-land direction, and altitude, among various natural factors. The vegetation distribution shows latitudinal zonal characteristics in the south–north direction (Liu and Huang 1982; Ma et al. 2013; Gao et al. 2014), longitudinal zonal characteristics in the sea–land direction (Mu et al. 2013), and vertical zonal characteristics in alpine regions (Fang et al. 2015). At the medium scale, the environmental dynamics of the eastern coastal wetlands of China exhibit latitudinal zonality, which has led to the geographical difference in the distribution of *Spartina alterniflora* Loisel (*S. alterniflora*) and its ecological effects (Gao et al. 2014). Previous studies showed that there was no longitudinal zonality of the vegetation distribution in Jiangsu Province (Liu and Huang 1982).

Coastal wetland ecosystems follow distinct distributions corresponding to environmental gradients (Bantilan-Smith et al. 2009; Chin et al. 2015). It is critical to establish stable vegetation patterns to lessen the negative impacts of human and natural factors on biodiversity conservation in coastal wetlands. Nevertheless, because wetlands are influenced by many ecological factors (Steven and Toner 2004), especially in coastal areas where urbanization is rapid and natural hazards are frequent, it is difficult to quantitatively identify the corresponding contribution of each factor. At small scales (e.g., regional scales), the distribution and landscape patterns of coastal wetland vegetation are not only subjected to natural factors, such as tidal fluctuations, but are also strongly influenced by human activities, such as agriculture, aquaculture, and tourism. Therefore, analyzing the spatiotemporal changes in the distribution of coastal wetland vegetation and their influencing factors (especially human interference) at small scales provides the basis for setting up buffers for natural reserve, which is of great importance for the effective conservation of global biodiversity and for implementing ICZM. However, the zonal distribution pattern of vegetation is often ignored in coastal wetlands, leading to limited guidance for performing landscape planning and ecological restoration work. Therefore, in the present study, the coastal wetlands of Yancheng were selected as an example to analyze the spatial distribution characteristics of vegetation and their variation patterns. The analysis was combined with remote sensing data from different stages, which were based on multiple years of field investigations and relevant study results. On this basis, we expect to identify the changes caused by policy adjustments of land use on coastal wetland vegetation cover, and we explore ecological restoration strategies to provide a reference for performing biodiversity conservation and ICZM work in similar regions.

Study area and study object

The coastal wetlands of Yancheng (Fig. 1c) are located on the east coast of Jiangsu Province (Fig. 1b), China (Fig. 1a), and the entire range of this coastal area lies between the abandoned Yellow River Estuary and the Palaeo-Yangtze River Delta (northern of modern Yangtze River Estuary). These wetlands include the *Grus japonensis* Müller (*G. japonensis*) national nature reserve in Sheyang, the *Elaphurus davidianus* David (*E. davidianus*) national nature reserve in Dafeng (both are included in the List of Ramsar Wetlands of International Importance), and the *Acipenser sinensis* Gray (*A. sinensis*) national nature reserve

Fig. 1. Location (a, b) and functional zones (c) of the study area.

in Dongtai, which play an important role in global biodiversity conservation work; research on regional goals contributes globally. Owing to the high population density and relatively developed economy in this region (Song et al. 2016; Sun et al. 2016), the continuing demand for economic development has necessitated ongoing adjustments of land use policies in recent years. Thus, the nature reserve has been subject to disturbance from industry (Wang et al. 2010), agriculture (Li et al. 2014), and aquaculture (Zuo et al. 2004), both locally and in adjacent areas, and native wetland vegetation is being extensively converted for urbanization, farming, or aquaculture (Shi et al. 2017). Conflicts between ecological protection and economic development have thus become increasingly prominent (Lu et al. 2007; Xu et al. 2016a, 2016b).

The study object is the Yancheng National Nature Reserve, established in 1983. This area generally ranges from 32°48' to 34°29' N and 119°53' to 121°18' E (it is bound by the seawall highway to the west, a 3 m isobath to the east, the Guanhe River to the north, and Dongtai County to the south). The study area is 453.3×10^3 ha and consists of three basic functional zones (Fig. 1c) as follows: the central core zones, whose landscape type was primarily wetland plants, such as *S. alterniflora*, *Suaeda glauca* Bunge (*S. glauca*), and *Phragmites australis* Trin. (*P. australis*); southern buffer zones and northern buffer zones adjacent to each of the southern and northern wings of the core zone, whose landscape type was primarily river and freshwater lake; southern experimental zones and northern experimental zones in each of the southern and northern parts of the buffer zone, whose landscape type was primarily constructed wetland, such as salt pans and rice fields.

Data sources and analysis method

Image interpretation

We downloaded Landsat satellite images (Thematic Mapper, Enhanced Thematic Mapper Plus, and Landsat 8 Operational Land Imager), all with a consistent spatial resolution of 30 m, from the Computer Network Information Center (CNIC; <http://www.gscloud.cn/>) and used them to map the extent of wetlands in 1987, 1992, 1997, 2002, 2007, and 2013. These images are the best data of the Landsat images available for our study area, as determined from a search of the Landsat archives. The dates of the satellite images are also very important to distinguish different types of vegetation because the color of vegetation changes by season. Therefore, the imaging dates of satellite images are all August in this study used. Visual inspection and correction based on DEM and high-resolution Google Earth images were necessary, to avoid the misclassification of wetlands as a result of topographic shadows or cloud cover. Before interpretation, remote sensing images were geo-rectified to 1:100 000 topographic maps using ground control points (GCPs) collected by global positioning system. Each image scene had at least 20 evenly distributed sites that served as GCPs. Remote sensing imagery was masked using the region boundary. ENVI V4.3 and ArcGIS V10.0 were used to conduct a series of preprocessing procedures, including geometric correction (Map Registration), band synthesis (Layer Stacking), and interpretation (Zuo et al. 2004; Zang et al. 2017).

First, a fishnet was generated that rectified all historical maps. To obtain land-cover information in relevant year, visual map interpretations were made using on-screen digitizing by directly drawing polygons along the boundaries of land cover types using a mouse, saving them to different polygons, and then adding attributes (labels) of the polygons to produce digital maps. Finally, land-cover maps extracted from remote sensing images showed eight land-cover types. For different types of vegetation, the criteria for visual interpretation were as follows: the bare mud flat was nearly white and the adjacent waters were deep blue; farmland on the land side took the form of regularly shaped red patches; the salt pan and aquaculture water were light blue, while the salt pans showed bright patches and were concentrated in the northern part of the study area. *P. australis* was reddish brown with variegated patches, *S. glauca* was dark brown, and *P. australis* was pink. The project group conducted field investigations in the study area in August 2007, May 2008, July 2013, December 2015, August 2016, and June 2017. Combined with historical data analysis, this group believed that the interpretation accuracy could meet the requirements of subsequent analytical work.

Landscape pattern indices

Landscape pattern indices can reflect the spatial structure of landscape elements. These indices are a collection of indicators in landscape ecology that can be computed with the aid of geographic information systems and patch statistics software (McGarigal et al. 2012; Plexida et al. 2014). Landscape fragmentation is the process of gradual landscape evolution from a single, homogeneous, continuous whole landscape to complex, heterogeneous, discontinuous patch mosaics due to the combined effects of human and natural factors (Zang et al. 2017).

We obtained 30 m × 30 m raster data by interpreting remote sensing images in the study area for the relevant period. FRAGSTATS V4.2 software was used to statistically analyze the number of patches (NP), mean patch size (MPS), mean nearest-neighbor distance (MNN), and patch density in the study area. Here, we selected four landscape pattern indices with typical ecological significance to characterize the degree of vegetation belt fragmentation (Hu and Dong 2013; Xu et al. 2013). The physical meanings and ecological connotations of these indices are summarized in Table 1.

Table 1. Physical meanings and ecological connotations of landscape pattern indices.

Index	Computational methods and ecological connotations
Number of patches (NP)	The total number of different types of patches in the entire landscape. NP reflects the spatial pattern and heterogeneity of the landscape and is positively correlated with the degree of landscape fragmentation.
Mean nearest-neighbor distance (MNN)	The sum of nearest-neighbor distances from one patch to other patches divided by the total NP with this nearest-neighbor distance. MNN reflects the connectivity between patches and is positively correlated with the degree of landscape fragmentation.
Mean patch size (MPS)	The total size of patches divided by the NP. Within a fixed study area, a smaller MPS indicates greater landscape discretization.
Patch density (PD)	The NP per unit area. PD reflects the intensity of patches in the entire landscape type and is positively correlated with the trend in landscape fragmentation.

FRAGSTATS V4 is a stand-alone program written in Microsoft Visual C++ for use in the Windows operating environment (McGarigal et al. 2012). It accepts raster images in a variety of formats, including as an ESRI grid. This paper used the patch-based metrics function in FRAGSTATS V4.2 and combined data related to vegetation classification (ESRI grid) during different study periods in the coastal zone to compute the number, size, distance, and density of patches based on the four indices shown in Table 1.

Human disturbance index (HDI)

The Anthropocene has been proposed as a new geo-stratigraphic epoch in which humans have become a global factor affecting ecosystems (Biermann et al. 2016). To further separate the respective contributions of human activity and natural factors to changes in landscape patterns based on previous studies (Walz and Stein 2014; Xu et al. 2016a, 2016b), we constructed a qualitatively and quantitatively integrated HDI model:

$$(1) \quad HDI = \sum_{i=1}^n A_{it} \times S_i \times S_{cle}$$

where HDI is a nondimensional index; A_{it} is the area of landscape type i as a percentage of the total area of n landscape types in the study area at time t ; S_i is the intensity of interference from human activity on landscape type i ; and S_{cle} is the construction land equivalent, used to compare effects on coastal wetlands by different human activities, and is reflected by the land use or cover types. Scores were assigned by experts according to the Delphi method (Walz and Stein 2014; Xu et al. 2016a, 2016b; Chuai et al. 2018), as shown in Table 2.

Finally, based on the simple regression analysis module available in IBM SPSS 20.0, this study analyzed the trend of human disturbance indices and landscape patterns during the study period in the coastal zone, thus demonstrating the correlation and significance of both trends.

Results

Spatiotemporal distribution of the vegetation belt

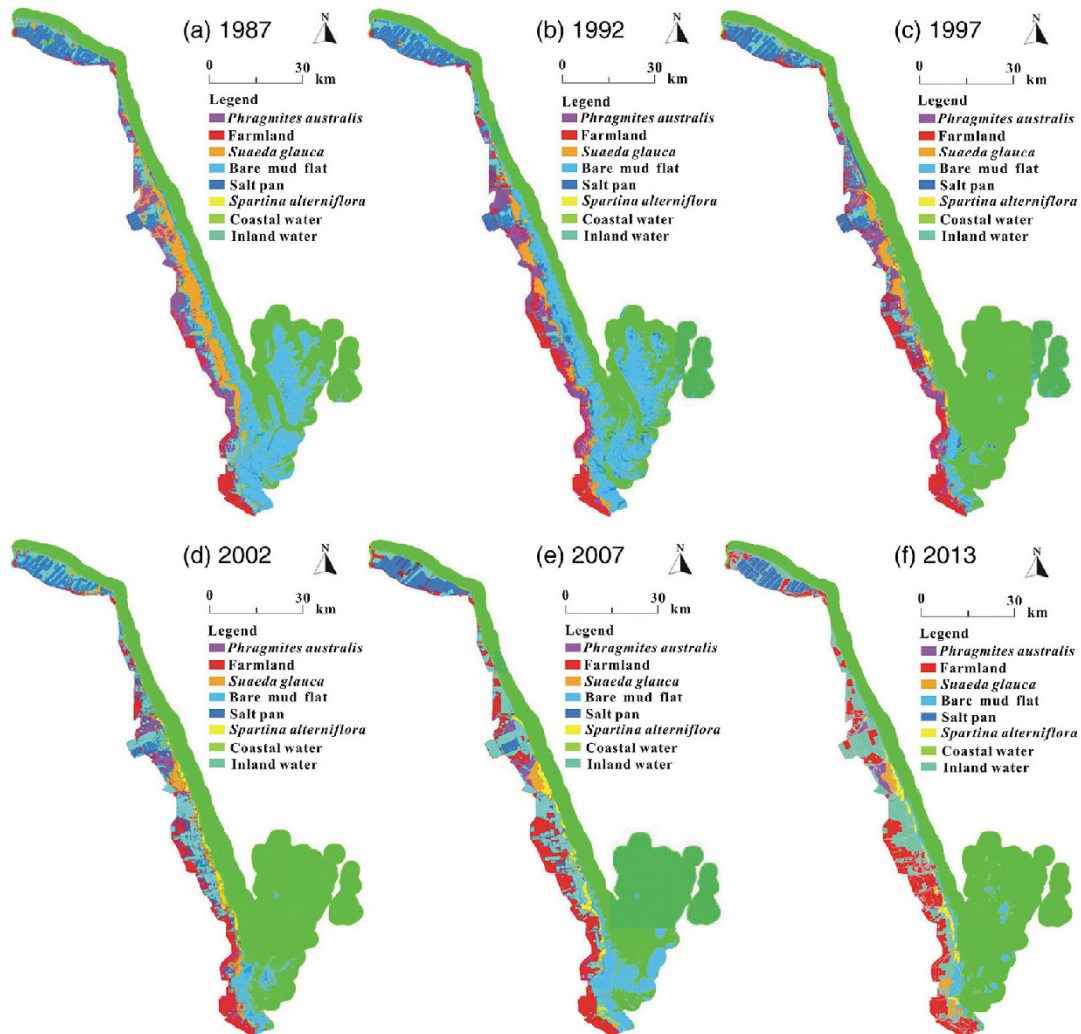
Six stages in the vegetation type distribution were obtained for the years 1987–2013 by unsupervised classification and visual interpretation, based on the remote sensing images of the study area during the relevant years (Fig. 2).

Figure 2 illustrates that in the study area, the landscape pattern showed zonal distribution characteristics in the east–west distribution during the investigation period (especially in the early portion of the study period). Overall, three gradients were divided from sea to land as follows: first, coastal water and bare mud flats without vegetative growth

Table 2. Criteria for evaluating the interference intensity of human activities in different landscapes.

HDI		Score by expert		
Value	Level	Scoring criteria	Typical landscape type	Assignment
≥ 0.8	Very high	Frequent human activity throughout the year (constructed wetland)	Aquaculture ponds, salt pans, and rice fields	5
≥ 0.6	High	Frequent human activity during some seasons (semi-constructed wetland)	Rivers, and <i>P. australis</i> marshes	4
≥ 0.4	Medium	Vegetation cover type dominated by annual herbaceous plants	<i>S. glauca</i> marshes, <i>A. littoralis</i> marshes etc.	3
≥ 0.2	Low	Vegetation cover type dominated by perennial herbaceous plants	<i>S. alterniflora</i> marshes	2
< 0.2	Very low	Lacking vegetation cover and not fully utilized	Bare mud flats and coastal waters	1

Notes: In this study, construction land is regarded as a land cover type with the strongest effects of human activities (assignment > 5, value = 1). Therefore, the construction land equivalent is designated as the basic unit to unify the measure of the effects on the land surface.

Fig. 2. Spatial distribution of vegetation types in the study area during different stages.

constituted a high proportion of the area (note that the acquisition times of the remote sensing images were not identical, so the area ratio of coastal water and bare mud flats may be influenced by tidal fluctuations). Next, the adjacent landscape type was wetland with natural vegetation, including *S. alterniflora*, *S. glauca*, and *P. australis*. Finally, the native wetland was adjacent to constructed wetland, including inland water (aquaculture ponds), farmland (paddy field), and salt pans, which constituted a relatively high proportion on the land side. In particular, farmland rapidly expanded.

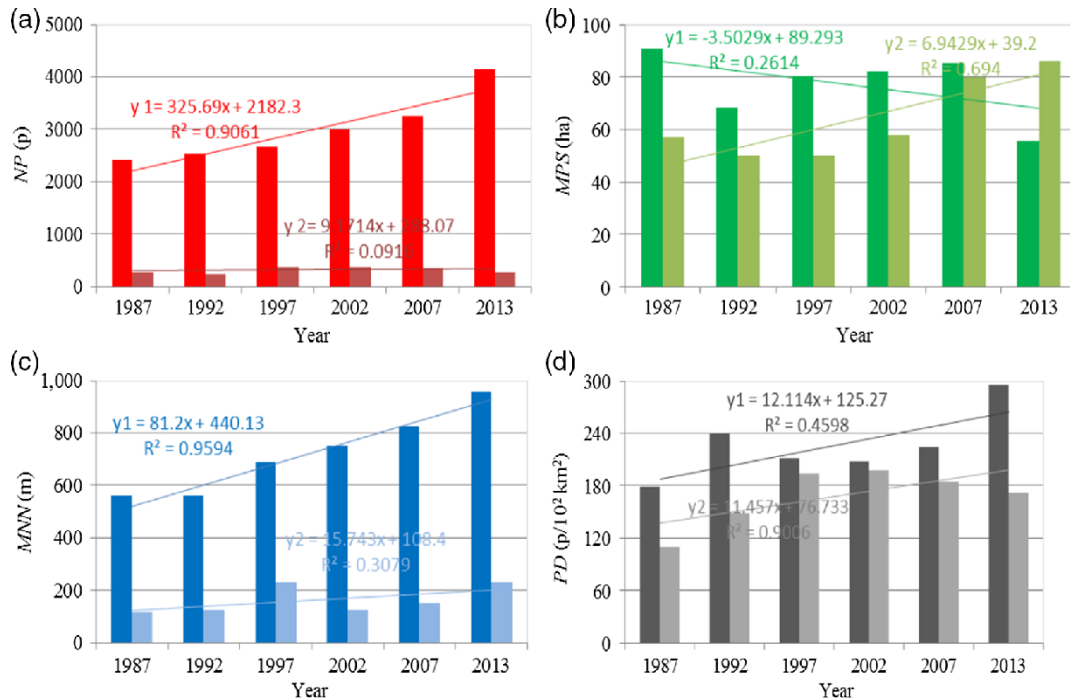
We observed the six stages of landscape patterns in the study area as presented in Figs. 2a–2f in combination with Fig. 1c. In the east–west direction, the spatial distribution of different landscape types showed a gradient feature early in the study period; that is, zonal characteristics were present, especially at the initial stage (Fig. 2a). In contrast, over time in the east–west direction and the south–north direction, the spatial distribution of different landscape types showed nonzonality, which is especially notable in the north–south direction. In a direction parallel to the coastline, the zonal distribution pattern was not notable; that is, intrazonal characteristics were present. First, the northern experimental zone can be further divided into two types, with the old Yellow River estuary as the boundary; the northern end was primarily salt pans, and the southern end primarily consisted of inland aquaculture water and farmland. Second, the landscape type primarily included *S. alterniflora*, *S. glauca*, *P. australis*, and inland water in the central area, primarily the core and buffer zones, which were under a strict protective status; and a small amount of farmland and salt pan was distributed only in the adjacent southern buffer zone, northern buffer zone, southern experimental zone, and northern experimental zone (a small area in each zone). Finally, the majority of the southern experimental zone was composed of farmland and inland water. Owing to the protective effect of a radial sand-bank formed by the siltation of a large amount of sediment, the artificially cultivated *S. alterniflora* in the core area gradually expanded toward the bare mud flat of this area during a later stage.

Trend of sequential variation in landscape patterns

The NP indirectly indicates the spatial heterogeneity of the structure of the landscape, and the NP level is positively correlated with the degree of landscape fragmentation. Figure 3a shows that the NP in the core zone was reduced from 286 to 279, and it gradually increased in the buffer and experimental zones during the investigation period, from 2418 in 1987 to 4142 in 2013. MPS indirectly reflects the trend in landscape discretization, but its meaning is the opposite of that of NP; Fig. 3b shows that although the MPS increased in the core zone since 1992, overall, it showed fluctuating changes in the buffer and experimental zone. Therefore, MPS is irrelevant because landscape fragmentation has not been discovered in the study area.

In Fig. 3c, the MNNs of the buffer and experimental zones were higher than that of the core zone, further reflecting the degree of discretization between all the patches on a landscape scale, which is also positively correlated with the degree of landscape fragmentation. An increase in MNN indicated that vegetation belt fragmentation gradually increased. The patch density can reflect the degree of agglomeration for the spatial structure of the landscape, and this index can more accurately reflect the trend in landscape fragmentation (these two factors are also positively correlated). Figure 3d shows that the patch density in the buffer–experimentation zone gradually increased from 179 patches/ha in 1987 to 296 patches/ha in 2013. This upward trend was similar to the upward trends of NP and MNN, further demonstrating the fragmentation of the vegetation pattern in the study area during different stages.

Fig. 3. Landscape pattern indices in the buffer and experimental zone (left-hand side, y1) and core zone (right-hand side, y2) during different stages (NP, number of patches; MPS, mean patch size; MNN, mean nearest-neighbor distance; PD, patch density).



Relationship between vegetation distribution and human disturbance

Figure 4a shows that the farmland percent cover increased linearly during different stages of the investigation period within the buffer and experimentation zones. Compared with this area in 1987, the farmland increased by 47 270 ha (+214.4%) over 26 years, gradually becoming the largest vegetation type outside the core zone. Simultaneously, the areas of *S. glauca* and *P. australis* decreased linearly. Specifically, the *S. glauca* area gradually decreased from 33 962 ha in 1987 (the largest in the native wetlands) to 10 360 ha (−69.5%) in 2013 and the *P. australis* area decreased from 11 610 ha to 5396 ha (−53.5%). Compared with the above two plants, the *S. alterniflora* area changed in a slightly different direction (i.e., it first increased and then decreased). Since its successful introduction in the 1980s, the *S. alterniflora* area continued to expand; it increased from 169 ha in 1987 to 12 544 ha and reached a peak, followed by gradual decreases after 2002.

Figure 4b shows that the *P. australis* area in the core zone, which first decreased and then increased, followed the opposite trend of the inland water area, such as aquaculture ponds, which first increased and then decreased during the study period. Meanwhile, the *S. glauca* area, which continuously decreased, also followed a trend opposite to that of the *S. alterniflora* area, which continuously increased. Comparatively, the difference between the buffer and experimentation zones and the core zone is as follows: in the buffer–experimentation zone, the total native wetland area showed the opposite trend to that of constructed wetlands. During the early stage, the native wetland area was dominant; however, with the continued expansion of farmland, the native wetland vegetation area was sharply reduced. In contrast, during the late stage, the constructed wetland area became dominant. In the core zone, the area of constructed wetland (inland water, such

Fig. 4. Changes in the vegetation area percent in the buffer and experimentation zones (a) and core zone (b) during different stages.

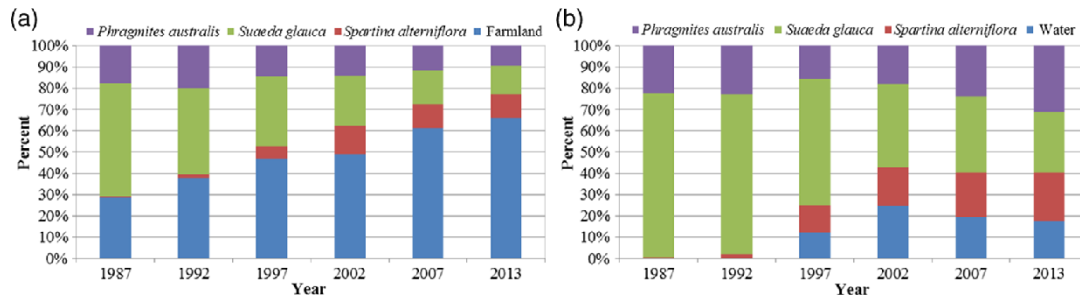
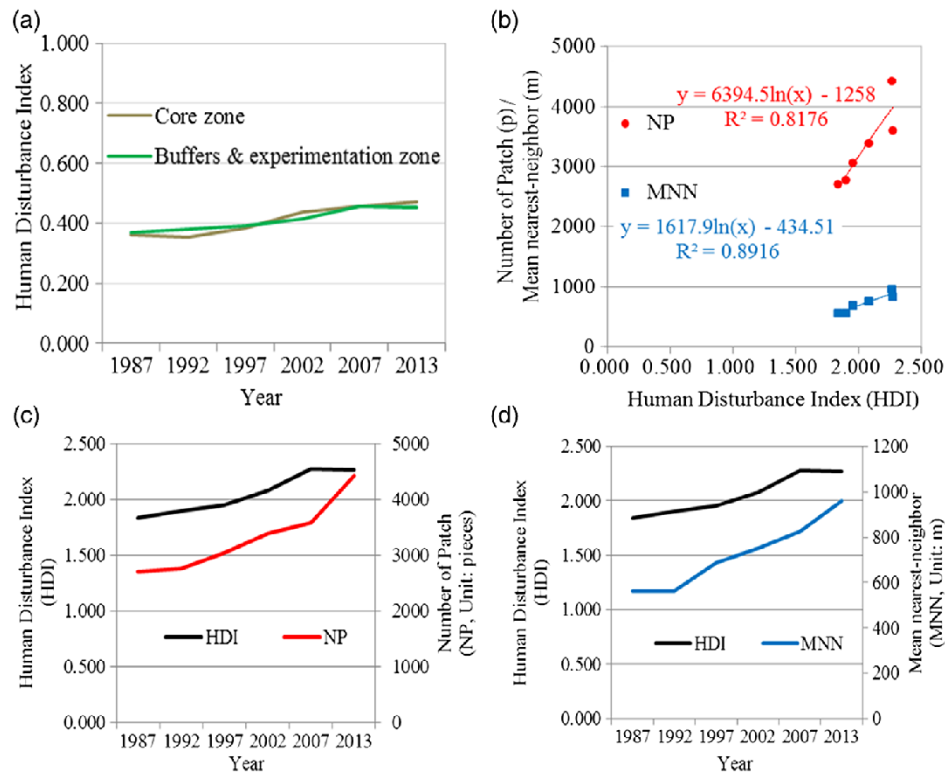


Fig. 5. Comparison of the HDI (a), number of patches (c), mean nearest-neighbor distance (d) and correlation (b) among them in the study area.



as aquaculture ponds) increased by 2725 ha compared to the initial stage, but the native wetland area was always dominant.

Figure 5a presents the trends in the extent of the impacts of human activity on the core zone and the buffer and experimentation zones. Overall, there were no large differences between the two zones during each typical stage. The HDI varied between 0.353 and 0.471, and values lower than 0.400 were observed in 1987, 1992, and 1997, indicating a low intensity of human disturbance. However, the HDI remained higher than 0.400 in 2002, 2007, and 2013, suggesting an increased human disturbance intensity compared with the previous

three stages. The difference observed was in the relative change in the HDI and the human disturbance intensity in the core zone and the buffer and experimentation zones over the two periods: In the earlier three stages, the core zone was subjected to lower human disturbance than the buffer and experimentation zones; In contrast, both the HDI and human disturbance intensity were higher in the core zone than in the buffer and experimentation zones during the later three stages. From Figs. 5b, 5c, and 5d, the landscape fragmentation (NP, MNN) is linearly related to human disturbance: the explanatory ability (R^2) of the HDI for NP is 81.76% ($p < 0.01$); the explanatory ability of the HDI for MNN is 89.16% ($p < 0.01$).

Discussion

Correlation between natural factors and vegetation distribution in coastal wetlands

In the core zone of the Yancheng Nature Reserve, Zhang et al. (2013) revealed spatial variations in soil moisture and salinity and their spatial correlation with vegetation patterns using canonical correspondence analysis (CCA). These researchers found that soil moisture content and salinity show distinct distributions corresponding to the spatial gradient perpendicular to the coastline. The CCA results indicated that the ecological niches of *P. australis*, bare flat, *S. alterniflora*, and *S. glauca* were located in the first, second, third, and fourth quadrants, respectively, in the CCA plot; the anti-clockwise direction of the ecological niches was consistent with the distribution sequence of vegetation in the sea–land direction. This result demonstrates that natural conditions dominate the vegetation patterns in the core zone.

In the 1980s, when Yancheng Natural Reserve was established, the Chinese coastal development policy had just been implemented; therefore, local economic development had a relatively low requirement for land during this period. In addition, because this region was a typical bare mud flat, the local community utilized the mud flat primarily for gathering, indicating a low intensity of human activity. Under this background, soil properties, geographical features, and hydrological conditions played crucial roles in determining the distribution of the vegetation in this area, especially in the strictly conserved core zones. The results of this show that the vegetation displayed a zonal distribution pattern in which, perpendicular to the coastline at the early stage of the study period, the vegetation type changed from coastal wetland to bare mud flat with *S. alterniflora*, *S. glauca*, and *P. australis* as well as to constructed wetlands dominated by rice.

Correlation between human activities and landscape pattern of coastal wetlands

From the 1990s, because the local government proposed successive economic development strategies, such as “Marine Jiangsu” and “Marine Yancheng,” in the process of weighing the contradiction of biodiversity conservation and economic development in the study area, this area experienced changes in the name of the nature reserve and the protection goals twice. Subsequently, its land use changed tremendously, with a significant increase in secondary wetland area. Due to increasingly intense human activity in the region, wetland degradation is severe in some localities, and fragmented vegetation patterns are having uncertain effects on biodiversity conservation. Liu et al. (2013) noted that increasingly fragmented vegetation patterns are unfavorable to biodiversity conservation. Because human interference in the core zone is weaker than that in the buffer zones and experimental site (Wang et al. 2011), rare bird species, such as *G. japonensis*, are gradually moving toward the core zone.

The rational protection and use of coastal wetland vegetation and the construction of diverse coastal wetland landscape patterns can help relieve the conflicts between community interests and natural protective objects. The waterfowl ponds were constructed in the nature reserve after 1994 to improve the ecological carrying capacity of the core zone.

Consequently, the area of constructed wetland increased, while native wetland, such as that dominated by *S. glauca*, continuously shrank. To avoid limitations due to the use of a single profile and confined study area, we extended the study area to include the entire Yancheng Nature Reserve, covering the buffer zones and the experimental site. We discovered that vegetation patterns in the region no longer follow distinct distributions corresponding to environmental gradients, and the contribution of human activity cannot be neglected. Although human activity is highly restricted there, we found that the HDI in the core zone was higher than that in non-core zones from 2002 to 2007, which may be inconsistent with the awareness level of the community. Thus, the management recommendations for the restoration or conservation of herb-dominated wetlands should incorporate concepts of temporal stability (Kirkman et al. 1996). In addition to the protection of spatial continuity among partitions with different protection levels being considered, we also recommend that the ICZM be implemented on this basis. Not only can the improvement of the connectivity between the core and the noncore zones provide wildlife with more livable habitats, it also offers safer conditions for their migration.

Natural and human factors jointly affect the vegetation pattern of coastal wetlands

The coastal zone is an important hub connecting the sea and the land, and it is also a typical ecologically fragile zone. Within the study period, the landscape pattern has been increasingly fragmented in the study area; at the same time, the longitudinal zonal distribution pattern of the vegetation has become less significant and gradually has shown nonzonal characteristics. Through the correlation analysis between the intensity of human activities and the fragmentation of the vegetation pattern, we could see the following: the dominant factors of vegetation distribution and landscape pattern change in the study area; the most important reason is that the changes caused by human activities (such as the native wetland to salt field, farmland or water area, with explanatory ability higher than 80%) are more significant than those changes caused by natural factors (for instance, changes of tide effects, with explanatory ability <20%), so the vegetation belt gradually showed intrazonal characteristics.

Furthermore, under conditions of global climate change in which extreme events are becoming more frequent and sea levels are rising, strong sea-land interactions may lead to increasingly complex conflicts between humans and coastal wetlands (Ward et al. 2016). Therefore, it may still be very challenging to accurately identify the dominant factors influencing soil properties and the evolution of vegetation patterns in coastal wetlands in the future. Human disturbance intensity is a very important variable in this work; we realize that there are differences between our results and those from previous studies, in particular those performed under different site conditions. In fact, it is difficult to completely separate natural and human factors. Apart from directly modifying vegetation patterns, human activities, such as urban development (Wei and Chow-Fraser 2005) and introduction of exotic species (Huang et al. 2015), can alter the physical and chemical properties of soil in coastal wetlands, thereby indirectly changing the distribution characteristics of vegetation. On the other hand, changes in natural factors such as soil texture (Steven and Toner 2004) and hydrology (Gathman and Burton 2011) will affect human activity and, consequently, vegetation patterns.

Conclusions

In 2016, the Chinese government proposed a development goal in which the protection rate of coastal wetlands will reach 55% in 2020, and the strength of wetland protection will continue to increase. Therefore, by using the example of Yancheng, China, we explored the spatiotemporal distribution characteristics of coastal wetland vegetation and its

influencing factors through remote sensing data. This study provides a reference for ICZM works in similar regions. The primary conclusions were as follows.

In the context of a gradually growing need for economic development, coastal wetlands have increasingly been threatened by human activities, such as farmland cultivation and aquaculture. Therefore, the landscape pattern of coastal wetlands tended to be fragmented. In the coastal wetland of Yancheng, China, the NP and MNN distance between patches gradually increased during the study period, whereas the MPS gradually decreased during the 26 years between 1987 and 2013.

On middle-small scales, the coastal wetland vegetation exhibited zonal distribution characteristics in the sea–land direction. However, the changes in land use patterns have exacerbated land cover changes, and the intrazonality of coastal wetland vegetation has become increasingly prominent. Because of the strong effects of human factors on the coastal wetland of Yancheng, China, the HDI has gradually increased. Therefore, the landscape pattern of coastal wetlands will tend to become fragmented, whereas the nonzonal distribution will become increasingly prominent.

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