SPATIOTEMPORAL CHANGE OF LANDSCAPE ELASTICITY IN YANCHENG COASTAL WETLAND OF CHINA

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Abstract. Taking Yancheng coastal wetland of China as the case, and using remote sensing images in 1997, 2007 and 2017 as the data sources, the spatial-temporal changes characteristics of landscape elasticity (LE) were analyzed from three dimensions of ecosystem service value (ESV), ecological vulnerability (EV) and human disturbance (H). From 1997 to 2017, Yancheng coastal wetland landscape structure showed a trend of increasing proportion of aquaculture ponds and construction land area, while decreasing proportion of natural wetland area The total ESV decreased first and then increased, the average ESV per unit area in 1997, 2007 and 2017 were 5.23×10^4 USD·hm^{-2}, 4.28×10^4 USD·hm^{-2}, 5.95×10^4 USD·hm^{-2}, respectively. The average EV decreased from 0.182 to 0.170 during 1997 to 2017. The average H increased from 0.175 to 0.198 during 1997 to 2017. In terms of spatial differentiation, the ESV, the EV and the H all showed the characteristics of land-sea differences. The average LE increased from 0.263 in 1997 to 0.914 in 2017, showing a downward trend from land to sea and the southern region was better than the northern region. This study can provide reference for the sustainable construction and management in Yancheng Coastal wetland World Natural Heritage Site.

Keywords: *ecosystem services, ecological vulnerability, landscape elasticity, landscape structure, Yancheng coastal wetland*

Introduction

Elasticity was defined that the ability of the ecosystem to remain unchanged through self-regulation when it is acted on by external forces, which first introduced into the ecosystem by Holling (1973). Elasticity in ecology mainly emphasizes the resistance and adaptability to the outside world (Adger, 2003; Evans, 2011), the ability of ecosystem to recover to ideal state after shock (Derisssen et al., 2011). Ecosystem elasticity, as an ability to maintain its important characteristics such as biological composition, system structure and function, has received extensive attention from researchers and governments (Wang et al., 2004). It is of great reference value to further understand the stability and dynamics of the ecosystem to analyze the elasticity of the ecosystem under the disturbance of human and natural factors.

Ecosystem elasticity is an important index to measure stability and dynamics (Zhao et al., 2019). Through accurate cognition, judgment and improvement, it has become the focus of research in the fields of natural disaster prevention, meteorological change and ecological destruction (Li et al., 2016). And it has quickly become an important measure to understand the effect of human activity on ecological environment system. Using different methods, scholars have conducted extensive research in cities, mining areas, drainage basins and other specific areas, and achieved a series of results (Wang

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and Lu, 2011; Zhao et al., 2015; Yang et al., 2020; Li et al., 2014; Lu et al., 2020; Gotham and Campanella, 2011). However, there are few studies on ecological elasticity from the perspective of landscape pattern.

Coastal wetland is the intersection of marine ecosystem and terrestrial ecosystem, which plays an important role in maintaining regional biodiversity, enhancing social service value and improving economic benefits. However, the coastal wetland is also the region where human activities are most intensive and frequent, the ecosystem elasticity of the coastal wetland is damaged to varying degrees (Guo et al., 2021). Yancheng coastal wetland is the largest muddy coastal wetland along the west Pacific Coast, and is the main part of the World Natural Heritage of *The Yellow sea* and *The Bohai Sea* migratory bird habitat (Phase I). Studying the elasticity of its ecosystem is of great significance for maintaining regional biodiversity. Extensive research has been carried out on specific population dynamics, hydrological connectivity, landscape change, habitat quality and suitability assessment, ecosystem stability, habitat restoration and other relevant studies, laying a foundation for landscape elasticity research (Lei, 2020; Tian, 2020; Li, 2021; Song et al., 2021; Wang et al., 2021, 2022; Xu, 2021; Zhou, 2021;). Therefore, this article takes Yancheng coastal wetland as the research object and establishes the landscape elasticity evaluation model to analyze the temporal and spatial changes of landscape elasticity from the three dimensions of ecosystem service function, ecological vulnerability and the intensity of surface human activities by RS and GIS technology. It is of great importance to promote the coordinated development of the coastal wetland development and protection and to promote the sustainable construction and management of world natural heritage sites.

Material and methods

Study area

Yancheng coastal wetland is located in the central coastal region of Jiangsu province, is between 32°20’~34°37’ N, 119°29’~121°16’ E, with an area of 4.533×10^5 km^2, with a continental coastline of 582 km. It is the largest coastal wetland in China (*Fig. 1*). The region is located in the transition zone between subtropical zone and warm temperate zone. Because it is located in the eastern coastal area of China, the monsoon climate is remarkable. The annual average temperature is between 13.7 °C and 14.8 °C, and the annual precipitation is about 1000 mm. Its moisture and heat are abundant. The study area reaches Guanhe River in the north, Beiling River in the south, old seawall in the west, and the isobath of -3 meters in the east (Zhang et al., 2020a,b).

Data sources and processing

The TM remote sensing images in 1997, 2007 and 2017 were used as data sources, details in *Table 1*. Due to the large north-south area of the study area, two images are required to cover the landscape. The row and column numbers of the two images in the same period are respectively (119, 37) and (120, 36). First, images from 2007 and 2017 were stripped (the quality of the images was affected by the loss of ETM+ image data strips after May 21, 2003 due to a failure of the Landsat-7 ETM+ on-board scan’s row rector SLC). Atmospheric correction module was selected for atmospheric correction of 6 images to eliminate the influence of meteorological factors on ground object emissivity and better obtain the real multispectral information of ground object. On this basis, through GPS positioning monitoring of field feature points, the geometric correction of the initial image was carried out by using quadratic polynomial and nearest pixel resampling method, so that the geometric correction accuracy RMS was less than 0.5 pixels. In ENVI5.0, two images of the same period are stitched together. Establishing ROI in ENVI 5.0 and tailoring it according to the study area. In ENVI 5.0, the multispectral information was synthesized and RGB_{432} was used to highlight the contrast of ground objects. Through human-computer interaction, the remote sensing images were interpreted by unsupervised classification method, and the interpretation results were corrected by using field survey samples and land use/land cover data of similar years from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. The overall interpretation accuracy reached more than 85%. ArcGIS 10.0 was used to make landscape type maps of the study area in 1997, 2007 and 2017.

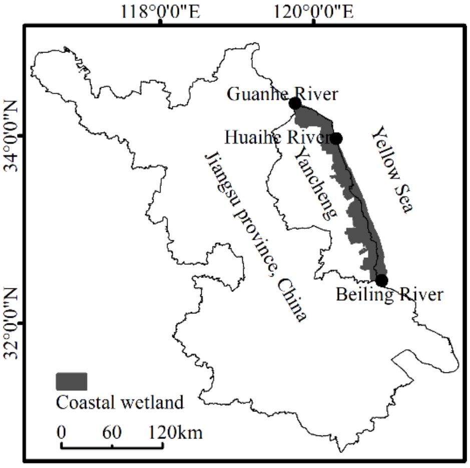

Figure 1. *The location and scope of the study area*

Table 1. *The information of TM remote sensing images*

Time	**Strip No.**	**Row No.**	**Cloud amount**
1997.10.11	119	37	1.54%
1997.10.18	120	36	0.02%
2007.05.08	119	37	0.05%
2007.03.20	120	36	3.17%
2017.04.01	119	37	0.13%
2017.04.24	120	36	3.66%

Ecosystem services value (ESV)

Ecological service value is an important indicator to measure the strength of an ecosystem service function. Therefore, in view of the actual development of Yancheng coastal wetland, we referred to the *Ecosystem Service Function Unit Equivalent Table of China*, the equivalent factor of each landscape type in Yancheng coastal wetland was modified, and the ecosystem service value coefficient per unit area of each landscape type in *Table 2* was finally obtained through calculation (Xie et al., 2015; Xiao et al., 2019). The ecosystem service value was calculated as follows (Zheng et al., 2021):

$$ESV_k = \sum \left(A_{ki} \times VC_{ki} \right) \tag{Eq.1}$$

In this equation, ESV_k is the total value of ecosystem services in the grid, A_{ki} is the area of the ith landscape type in the grid, and VC_{ki} is the unit area value coefficient of ecosystem services in the ith landscape type in the grid.

Table 2. *The ecosystem service value coefficient in Yancheng coastal wetland (USD·hm^{-2}a^{-1})*

Ecosystem service classification		**Land use type**							
		Cultivated land	**Forest**	**Grass**	**Construction land**	**Offshore waters**	**Natural wetland**	**Salt field**	**Aquaculture pond**
Supply service	Food	2543.616	295.632	1305.216		443.52	1042.416		19619.424
	Raw materials	239.76	166.464	59.184		222.336	455.472	325.296	1962
Provisioning services	Water purification	438.048	156.528	65.664			1050.048		
	Genetic resources	1140.912	490.608	1329.264		352.512	266.112		
Regulating services	Gas conditioning	450	778.464	43.776	896.832	82.08	219.024		
	Carbon storage		4.32	9.792					
	Interference to adjust		20.736			167.472	5032.512		
	Waste disposal	434.736	131.328	82.08		1.152	121920.048		
	Water treatment		3.312	3.312	17.568		1968.768		
	Erosion control	117.216	109.44	48.24		5221.872	3840.048		
	Pollination	24.048	9.792	38.304					
	Biological control	36.144	185.04	33.984		50.4	331.776		
Cultural services	Entertainment	89.856	1043.568	28.512	6285.168	988.704			
	Aesthetic value	0	1.152	182.88		221.184	696.384		
Supporting services	Habitat	0	677.808	1329.264		188.352	13634.64		
	Soil formation	582.48	15.264	2.16					
	Nutrient cycling	0	72.288			1853.856	631.872		

Ecological vulnerability (EV)

Ecological vulnerability refers to the sensitive response and resilience of an ecosystem to external disturbance under specific circumstances. It is the performance of the inherent attributes of an ecosystem under external disturbance and the result of the joint action of natural attributes and human activities. The more vulnerable an ecosystem is to external disturbance, the higher its vulnerability. Through consulting experts, the vulnerability of various landscape types was assigned and normalized, and the vulnerability of seven landscape types was obtained as follows: 0.037 for construction land, 0.074 for salt field, 0.222 for natural wetland, 0.111 for forest, 0.148 for cultivated land, 0.185 for aquaculture pond and 0.222 for river. The calculation formula of ecological vulnerability index was as follows (Meng et al., 2020):

$$E_k = \sum \frac{F_i \times a_i}{S_k} \tag{Eq.2}$$

In this equation, E_k is the ecological vulnerability of the grid, F_i is the vulnerability of the ith landscape type in the grid, a_i is the area of the ith landscape type in the grid, and S_k is the total area of the grid.

Intensity of human activity on the surface (H)

The intensity of human activities refers to the degree of exploitation, utilization and transformation of an ecosystem by human beings. The intensity of human activities on the surface only represents a part of human activities to the nature, and does not represent the full extent of human exploitation to the nature. According to *Table of Equivalent Conversion Coefficients of Construction Land of Land Use/Cover Type*, the equivalent conversion coefficients of construction land suitable for each landscape type in the study area were constructed in *Table 3* (Xu et al., 2015). The calculation formula of human activity intensity was as follows:

$$H = \frac{S_{kC}}{S_k} \times 100\% \qquad \text{(Eq.3)}$$

$$S_{kC} = \sum_{i=1}^{n} \left(SL_i \times CI_i \right) \qquad \text{(Eq.4)}$$

In these equations, H is the intensity of surface human activities, S_{kC} is the equivalent area of landscape land of the grid, S_k is the total area of the grid, SL_i is the area of the ith landscape type, CI_i is the equivalent conversion coefficient of construction land of the ith landscape type, and n is 7.

Table 3. *Equivalent conversion coefficients of construction land in Yancheng coastal wetland*

Landscape types	Descriptions	CI
Construction land	The natural surface cover changes, and the exchange of air, water, heat and nutrients is impeded	1
Salt field	The natural surface cover changes, altering the air and water heat exchange	0.6
Natural wetlands	The natural land cover has not changed and has not been exploited	0
Forest	The natural land cover has not changed and has not been exploited	0
Cultivated land	The natural cover of the land is changed and the crops are planted for 1 year	0.2
Aquaculture pond	The natural surface cover changes, altering the air and water heat exchange	0.067
River	The natural land cover has not changed and has not been exploited	0

Landscape elasticity (LE)

Landscape elasticity is an important index to measure the stability and vulnerability of ecosystem. The landscape elasticity evaluation model of Yancheng coastal wetland was constructed from three factors including ecosystem service function, ecological vulnerability and surface human activity intensity. Landscape elasticity is directly proportional to the function of ecosystem service, and inversely proportional to the intensity of ecological vulnerability and human disturbance on the surface. According to the actual situation, landscape elastic adjustment coefficient and disturbance coefficient were set up to establish evaluation model of landscape elasticity (Zhao et al., 2019), the formula was as follows:

$$L = \frac{ESV}{(1 + \mu H)E} \beta \qquad \text{(Eq.5)}$$

In this equation, L is the landscape elasticity, ESV is the ecological service function. E is the ecological vulnerability. H is the intensity of surface human activity. μ is the human disturbance coefficient, which set as 0.05. β is the landscape elastic adjustment coefficient, which set as 1.

For spatial analysis and calculation, a grid of 3 km × 3 km was used to resample the covered research area. After calculating the corresponding values of different grids, the center points of corresponding grids were assigned. Then, the spatial differentiation map of relevant elements could be obtained through spatial interpolation using inverse distance weighting method in ArcGis 10.0. All the values were divided into 5 levels by geometric intervals, and the spatio-temporal comparison was conducted.

Results

Changes in landscape pattern

From 1997 to 2017, the landscape pattern in Yancheng coastal wetland changed obviously. According to the landscape type maps of 1997, 2007 and 2017 (*Fig. 2; Table 4*), comparing the landscape structure changes in the study area, it was concluded that: the landscape structure of Yancheng coastal wetland was based on cultivated land, natural wetland and aquaculture pond, and the sum of the area of the three accounted for more than 85% of the area of Yancheng coastal wetland. But the proportion of the three changes was also obvious at different times. The proportion of cultivated land, natural wetland and aquaculture pond was 45.97%, 28.46% and 11.03% in 1997, respectively; in 2007, it was 47.13%, 22.31% and 16.05%; in 2017, it was 42.05%, 16.97% and 26.35%, respectively, and the proportion of aquaculture pond exceeded the proportion of natural wetlands. From 1997 to 2017, the landscape changes in Yancheng coastal wetland showed that aquaculture pond and construction land continued to increase, the area of natural wetlands continued to decrease, and the cultivated land area was basically stable.

Changes in ecosystem service value (ESV)

From the perspective of total ecosystem service value, Yancheng coastal wetland decreased firstly and then increased from 1997 to 2017. The value of ecosystem services in 1997 was 1.551×10^{11} Yuan, the average ecosystem service value coefficient was 3.63×10^5 Yuan/hm^2. The value of ecosystem services in 2007 was 1.317×10^{11} Yuan, the average ecosystem service value coefficient was 2.97×10^5 Yuan/hm^2. Ecosystem services value in 2017 was 1.871×10^{11} Yuan, the average ecosystem service value coefficient was 4.13×10^5 Yuan/hm^2.

Table 4. *Changes of landscape pattern in Yancheng coastal wetland from 1997 to 2017*

Landscape type	1997		2007		2017	
	Area (hm^2)	**Percentage (%)**	**Area/hm^2**	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**
Aquaculture pond	47078.56	11.03	71153.61	16.05	119354.76	26.35
Cultivated land	196167.22	45.97	208900	47.13	190487.13	42.05
Construction land	15396.86	3.61	32725.89	7.38	44285.45	9.78
Natural wetlands	121458.66	28.46	98890.66	22.31	76859.51	16.97
Salt field	33298.75	7.80	19240.83	4.34	5060.55	1.11
River	12466.73	2.92	11797.88	2.66	10047.94	2.22
Forest	840.72	0.20	528.51	0.12	6884.61	1.52

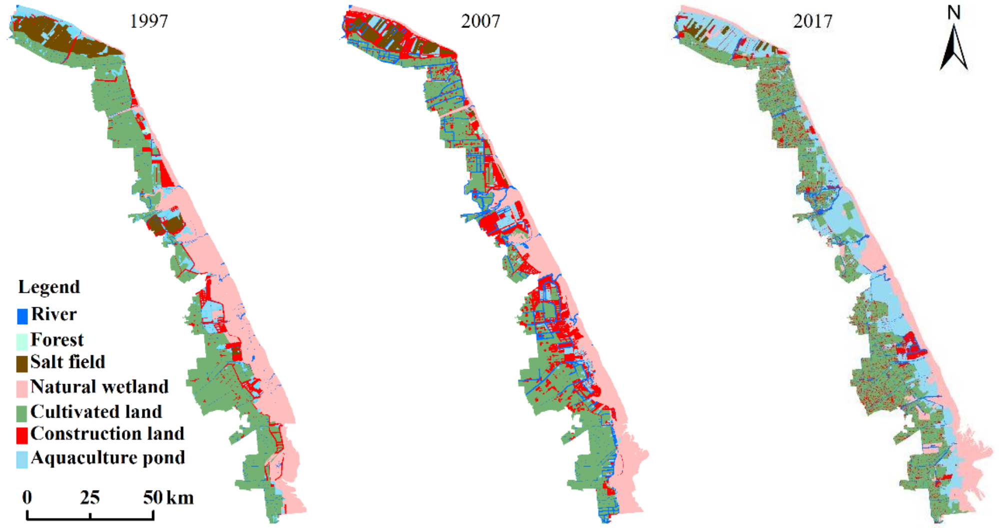

Figure 2. *Landscape types in Yancheng coastal wetland from 1997 to 2017*

Through the calculation of ecosystem service value of each grid, the temporal and spatial changes of ecosystem service value were significant in Yancheng coastal wetland. In 1997, among 608 grids, the maximum value of ecosystem service value coefficient was 1.58×10^7 yuan/hm^2, and the minimum value was 2.37×10^3 yuan/hm^2. The spatial variation coefficient reached 227.97%, indicating strong variation and significant spatial difference. In 2007, the maximum value of ecosystem service value coefficient was 7.91×10^7 yuan/hm^2, and the minimum value was 2.26×10^3 yuan/hm^2. The spatial variation coefficient was up to 696.98%, which was a strong variation, and the spatial difference was more significant. In 2017, the maximum value of ecosystem service value coefficient was 2.44×10^6 yuan/hm^2, and the minimum value was 2.66×10^4 yuan/hm^2 in 648 grids. The spatial variation coefficient was 130.78%, which was strong and the spatial difference slowed down. On the whole, from the grid scale, the distribution of ecosystem service value in Yancheng coastal wetland was significantly different, and the intensity of spatial difference showed a trend of increasing first and then decreasing from 1997 to 2017.

From the perspective of spatial distribution (*Fig. 3; Table 5*), from 1997 to 2017, the spatial differentiation of ecosystem services value in Yancheng coastal wetland showed obvious sea-land differentiation characteristics, and the closer to the coast, the higher the value of ecosystem services. Conversely, the farther away from the coast, the lower the value of ecosystem services. In terms of specific distribution, the highest ecological service value areas were mainly natural wetland and aquaculture pond. The low-value area was mainly construction land. In 1997, the area of relatively high ecosystem service value was the largest, followed by the high value area. The relatively low value area and low value area were mainly distributed in the western edge in Yancheng coastal wetland. To 2007, the area of high ecosystem service value decreased significantly, the relatively high value area and the medium area increased significantly, and the areas of low-value area and relatively low-value area were decreased. By 2017, the high value area increased, mainly concentrated in the seaward edge of the south of Yancheng National Rare Birds Nature Reserve. The area of relatively high value decreased obviously and tended to shrink seaward. In the southwest of the region, the area of relatively low value and low value had increased, and had a trend of seaward expansion.

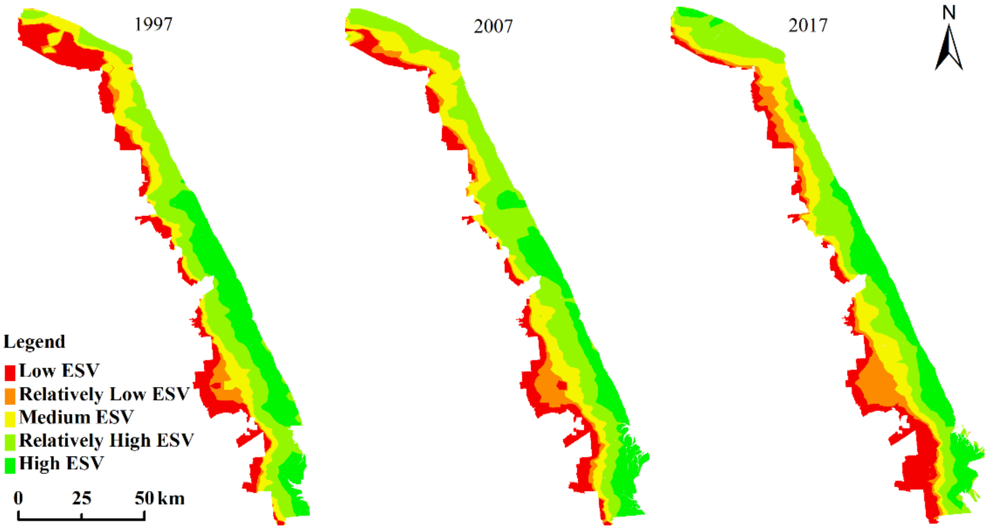

Figure 3. *Spatial distribution of ecosystem service in Yancheng coastal wetland from 1997 to 2017*

Table 5. *The ecosystem service value classification statistics from 1997 to 2017*

Grade	**1997**		**2007**		**2017**	
	Area (hm^2)	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**
Low	88439.00	21.39	69935.92	16.23	77367.04	17.74
Relatively low	26578.95	6.43	34056.97	7.90	56421.21	12.94
Medium	76661.98	18.54	97084.08	22.53	83453.38	19.14
Relatively high	121085.43	29.29	148955.30	34.57	126868.16	29.09
High	100633.64	24.34	80866.48	18.77	91952.61	21.09

Changes in ecological vulnerability (EV)

From 1997 to 2017, ecological vulnerability decreased slightly. Although the spatial difference was strong variation, the spatial difference was gradually becoming smaller. The maximum value, of ecological vulnerability in 1997 was 0.276, the minimum value was 0.050 and the average value was 0.182 respectively. The spatial variation coefficient was 143.48%. The maximum value of ecological vulnerability in 2007 was 0.219, the minimum value was 0.068 and the average value was 0.172 respectively. The spatial variation coefficient was 139.54%. In 2017, the maximum value of ecological vulnerability was 0.247, the minimum value was 0.045, and the average value was 0.170. The spatial variation coefficient was 121.01%. From 1997 to 2017, the decline of ecological vulnerability indicated that the natural landscape of Yancheng coastal wetland was decreasing and human activities were increasing.

From the perspective of spatial distribution (*Fig. 4; Table 6*), the spatial differentiation of coastal ecological vulnerability in Yancheng from 1997 to 2017 also showed obvious sea-land differentiation characteristics. The eastern part of the study area was close to the coast, and the wetland landscape was less affected by human activities, and the vulnerability was higher. In the western part of the study area, the stronger the human activities, the lower the ecological vulnerability. From the perspective of landscape types, the high value and relatively high value areas of ecological vulnerability were mainly natural wetlands, aquaculture ponds and rivers, while the low value areas were mainly construction land and cultivated land. From 1997 to 2017, the sum of the area of the high value and relatively high value decreased significantly. The sum of the area of the low value and relatively low value decreased first and then increased.

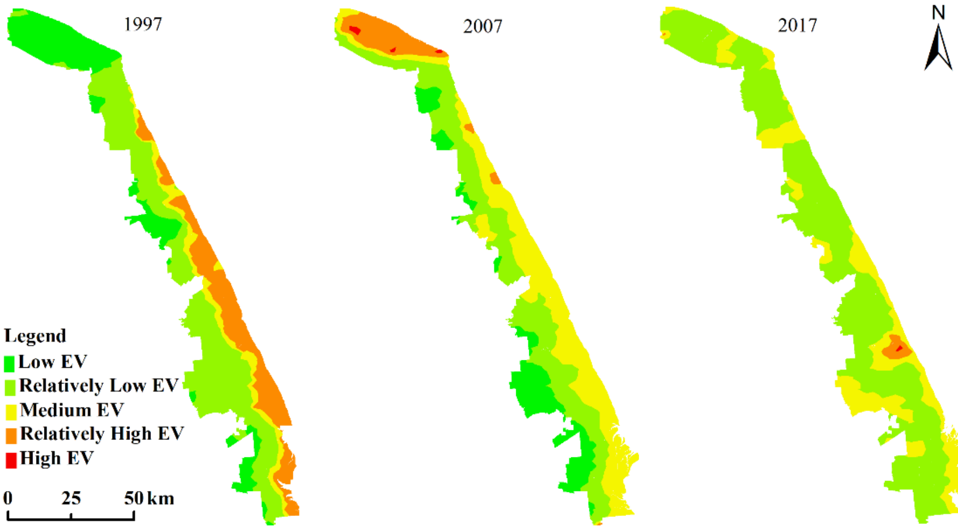

Figure 4. *Spatial distribution of Ecological vulnerability in Yancheng coastal wetlands from 1997 to 2017*

Table 6. *The Ecological vulnerability classification statistics from 1997 to 2017*

Grade	**1997**		**2007**		**2017**	
	Area (hm^2)	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**
Low	100303.54	24.26	79851.93	18.53	3629.29	0.83
Relatively low	185835.06	44.95	161098.35	37.39	295259.20	67.71
Medium	37979.66	9.19	152996.85	35.51	129585.32	29.72
Relatively high	88567.73	21.42	31694.33	7.36	6488.38	1.49
High	713.02	0.17	5257.29	1.22	1100.20	0.25

Changes in surface human disturbance intensity (H)

From 1997 to 2017, human disturbance intensity showed a trend of continuous increase. In 1997, the maximum value of human disturbance intensity was 0.923, the lowest value was 0, the average value was 0.175, and the spatial variation coefficient was 81.21%. In 2007, the maximum value of human disturbance intensity was 0.827, the lowest value was 0, the average value was 0.189, and the spatial variation coefficient was 68.05%. In 2017, the maximum value of surface human disturbance intensity was 0.965, the lowest value was 0, the average value was 0.198, and the spatial variation coefficient was 76.63%. The degree of spatial variation in the three years was moderate, and the spatial difference decreased first and then increased.

From the perspective of spatial distribution (*Fig. 5; Table 7*), the spatial differentiation of surface human disturbance intensity in Yancheng coastal wetland was both sea-land and north-south direction. In general, the intensity of human activity in the western part of the study area was greater than that in the eastern part, and that in the northern part was greater than that in the southern part. From 1997 to 2017, the high value area of human activity intensity decreased first and then increased, while the relatively high value area decreased first and then increased. The sum of the area of the low value and relatively low value increased first and then decreased. From the direction of north-south, it can be seen that Binhai and Xiangshui counties in the north of Yancheng had the highest exploitation and utilization of coastal wetlands in 1997. In 2017, the intensity of development and utilization of coastal wetlands in Dafeng, south of Yancheng, was significantly improved.

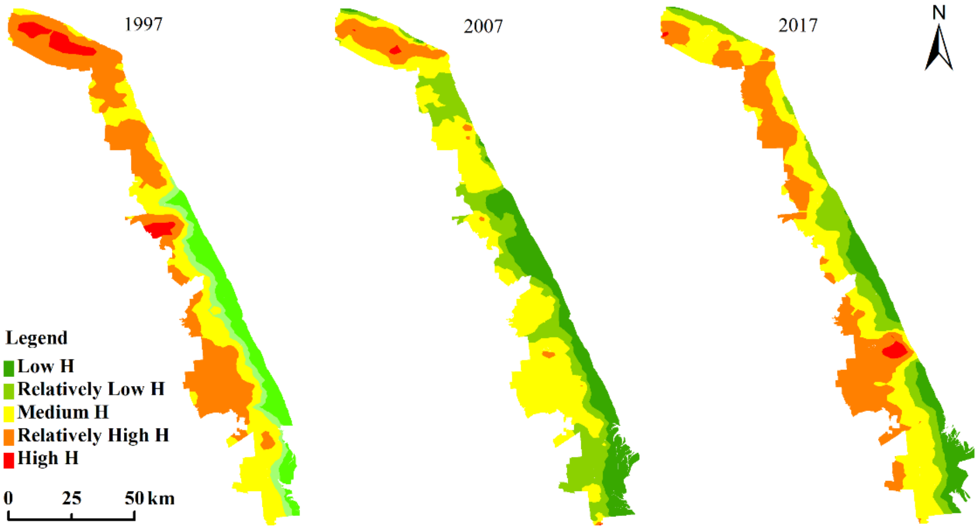

Figure 5. *Spatial distribution of human disturbance intensity in Yancheng coastal wetland from 1997 to 2017*

Table 7. *The human disturbance intensity classification statistics from 1997 to 2017*

Grade	1997		2007		2017	
	Area (hm²)	**Percentage (%)**	**Area (hm²)**	**Percentage (%)**	**Area (hm²)**	**Percentage (%)**
Low	68728.48	16.63	94342.54	21.89	59232.61	13.58
Relatively low	32586.56	7.88	113942.58	26.44	70560.47	16.18
Medium	116476.06	28.18	185009.18	42.94	152580.70	34.99
Relatively high	173783.79	42.04	35279.05	8.19	147687.56	33.87
High	21824.11	5.28	2325.41	0.54	6001.06	1.38

Change of landscape elasticity (LE)

From 1997 to 2017, the landscape elasticity in Yancheng coastal wetland continued to increase, and the maximum value and minimum value of landscape elasticity were the same, which were 6.494 and 0 respectively. The mean value of landscape elasticity in 1997 was 0.263, and the spatial variation coefficient was 168.83%. In 2007, the mean value was 0.312, and the spatial variation coefficient was 163.25%. In 2017, it was

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0.914, with a spatial variation coefficient of 144.25%. From 1997 to 2017, the spatial variation of landscape elasticity in Yancheng coastal wetland was strong, but from 1997 to 2017, the intensity of spatial variation gradually weakened, and the space tended to be more balanced.

From the perspective of spatial distribution (*Fig. 6; Table 8*), the landscape elasticity in Yancheng coastal wetland showed obvious difference between land and sea. In general, human activities in the western part of the study area is relatively strong, landscape reconstruction intensity is high, and landscape elasticity is low. In the eastern part of the study area, the intensity of human activities was relatively weak, and the native natural landscape was dominant, with high landscape elasticity. From 1997 to 2017, the high value area and low value area decreased, while the relatively low value area increased significantly. The medium value area decreased first and then increased, the relatively high value area increased first and then decreased. As a result, the landscape elasticity of the study area showed an upward trend from 1997 to 2017.

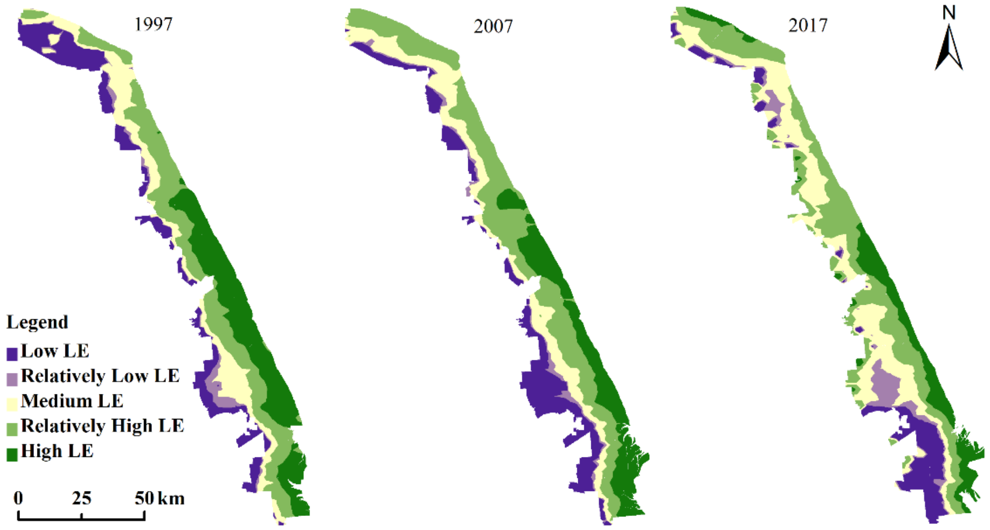

***Figure 6.** Spatial distribution of landscape elasticity in Yancheng coastal wetland from 1997 to 2017*

***Table 8.** The landscape elasticity classification statistics from 1997 to 2017*

Grade	**1997**		**2007**		**2017**	
	Area (hm^2)	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**	**Area (hm^2)**	**Percentage (%)**
Low	82647.38	19.99	85122.44	19.75	61357.43	14.07
Relatively low	17766.74	4.30	20548.13	4.77	38376.34	8.80
Medium	83946.25	20.31	83971.28	19.49	132422.16	30.37
Relatively high	120867.17	29.24	154899.63	35.95	139511.28	31.99
High	108171.44	26.17	86356.83	20.04	64395.19	14.77

Conclusion and discussion

Based on the three dimensions of ecosystem services, ecological vulnerability and human activities, the landscape elasticity model was constructed, studied the spatial-temporal changes of landscape elasticity in Yancheng coastal wetland from 1997 to 2017 through GIS technology. The conclusions were as follows:

From 1997 to 2017, the landscape pattern in Yancheng coastal wetlands changed significantly, and the proportion of aquaculture pond and construction land increased significantly, while the proportion of natural wetland continued to decrease. The total value of coastal wetland ecosystem service in Yancheng decreased first and then increased. Ecological vulnerability was generally stable and reduced slightly. While the intensity of human activity was relatively stable and rising slightly. Overall, the landscape elasticity showed an upward trend. From 1997 to 2017, the spatial variation intensity of ecosystem services was strong which increased first and then slowed down. Ecological vulnerability also had strong variation, and the variation intensity was decreasing. The grade distribution of habitat quality was closely related to the distribution of land use types, low habitat quality was mainly allowed in the north and west of the research area with high development and utilization intensity (Li et al., 2022). The intensity of human activities showed moderate variation, decreasing first and then increasing. The landscape elasticity was strong variation, showing a gradual weakening trend, and more balanced in space. The spatial variation of ecosystem services, ecological vulnerability, human activities and landscape spatial elasticity in Yancheng coastal wetland showed obvious differences in the direction of sea-land. On the other hand, the ecosystem services, ecological vulnerability, human activities and landscape elasticity showed certain differences from south to north in Yancheng coastal wetland.

The temporal and spatial variation of landscape elasticity in Yancheng coastal wetland was the result of regional nature and human activities. Natural processes included hydrodynamics, geomorphic processes, soil, vegetation evolution and so on. The coastal geomorphological process and the evolution process of vegetation coverage type were the most obvious. The continuous change of ecological process in the direction of sea and land caused the landscape change process to be continuous and stable in Yancheng coastal wetland. The difference of the nature of the bank section had a significant impact on the landscape pattern and landscape elasticity. Due to the influence of geographical conditions and historical industrial structure, the proportion and change of wetland landscape in the north and the south were quite different, the aquaculture and salt industry in the North developed earlier than that in the south (Shen et al., 2022). Therefore, the proportion of natural wetland area was the smallest and the change was small in the north. In the south, the natural wetland evolved to the ocean due to the rapid siltation of the coast to the sea. The large-scale reclamation activities had led to the destruction of the natural evolution of the landscape, the rapid transformation of a large area of natural wetland into aquaculture pond and cultivated land, and the great change in the south.

Human activities, primarily through artificial cultivation, breeding and building the port, the construction of residential area, especially human reclamation activity, through the construction of dam block seawater intrusion, the continuity of coastal wetland hydrological process was damaged, the process changed the landscape and vegetation evolution direction, and the continuity in the evolution of the coastal wetland landscape was destroyed (Zhang et al., 2020). The west area of the study area was mainly due to the fact that almost all of it was natural landscape before development, but after development, cultivated land, aquaculture ponds and construction land increased in a large area, resulting in strong human interference. In space, the center of human interference gradually moved from land to sea (Chen et al., 2014; Xie et al., 2022). The spatial pattern of regional interference is “high in the north, low in the south, high in the West and low in the East” (Wang, 2021). The reclamation area’s ecosystem type gradually evolved to the direction of freshwater wetland. The construction of ports and settlements had the most thorough transformation of the land surface, which made the natural properties of coastal wetland completely changed. Although cultivated land and aquaculture pond do not transform the natural properties of land surface as thoroughly as construction land, compared with natural wetlands, both ecosystem services and ecological vulnerability had undergone significant changes, and human activity attributes were also attached.

On the other hand, the temporal and spatial changes of landscape elasticity in Yancheng coastal wetland were closely related to the policies. In 1996, Jiangsu province started the strategy of *East Jiangsu at sea* marked by *development of one million Mu of tidal flats*. Therefore, from 1997 to 2007, the proportion of aquaculture pond area increased rapidly to 16.05%, and that of construction land increased to 7.38%. In 2009, the Development Plan for Jiangsu Coastal Areas was upgraded to the national strategy, which clearly stated that environmental protection should be adhered to and the scope of ecological protection was further defined in terms of spatial layout. Ecological restoration had been actively carried out, and environmental protection policies and measures had been strictly implemented. Human activities had been strictly controlled. In 2017, Yancheng Coastal wetland became a special ecological zone of Jiangsu Province, further emphasizing ecological protection. In 2019, Yancheng Coastal wetland became the first Coastal wetland type World Natural Heritage site in China (Zhang et al., 2021). Ecological protection and restoration would have been further strengthened, human being and nature would have coexisted more harmoniously, and the landscape elasticity of the study area would have been further improved.

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