SPATIAL CONFLICT MEASUREMENT BASED ON LANDSCAPE PATTERNS IN THE YANCHENG COASTAL WETLAND OF CHINA

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Abstract. The spatiotemporal changes of spatial conflict not only reflect changes in the structure of regional ecosystems, but also have an impact on regional ecological security. Taking the Yancheng Coastal Wetland as a case and using remote sensing images in 1997, 2007, and 2017 as data sources, a spatial conflict model was selected from three dimensions of external pressure, landscape vulnerability and landscape stability. The spatiotemporal changes of spatial conflict were analyzed based on landscape patterns. From 1997 to 2017, influenced by human activities, the landscape structure and pattern underwent significant changes in the Yancheng coastal wetlands, with a significant reduction in natural wetlands. The external pressure showed a characteristic of first decreasing and then increasing, with a low level of spatial differentiation. The landscape vulnerability first decreased and then increased, with significant spatial differentiation in the sea-land direction. The landscape stability also first decreased and then increased, with a low level of spatial differentiation. The spatial conflict first increased and then decreased, the mean values were 0.356, 0.406, 0.380 in 1997, 2007 and 2017 respectively, at the levels of stable and controllable and basically controllable level, with significant spatial differentiation in the sea-land direction. There were significant differences in the level of spatial conflict among different landscape types, with natural wetlands facing the largest spatial conflict and human production and living land having smaller spatial conflicts. This research can provide theoretical reference for creating a model of harmonious development between humans and nature in Yancheng.
Keywords: *landscape pattern, external pressure, landscape vulnerability, landscape stability, Yancheng coastal wetland*

Introduction

Spatial conflicts are opposing phenomena that arise from the competition among spatial resource occupants due to human-land relationships during the process of spatial resource allocation, resulting in increasingly scarce spatial resources and the continuous expansion of spatial functions as objective geographic phenomena (He et al., 2014). With the continuous development of socio-economics, the unreasonable use of spatial resources and the unfairness of spatial resource competition have led to an increasingly prominent spatial conflict between ecological conservation and socio-economic development. Once the conflict reached the threshold of spatial resource balance, various negative effects would become apparent. Therefore, scientifically identifying and assessing spatial conflicts are important foundations and prerequisites for achieving optimized allocation of spatial resources and coordinating socio-economic development with ecological environmental protection.

Currently, there is no unified definition for the concept of spatial conflict. The existing explanations mainly focused on the perspective of land use, emphasizing the spatial competition and conflicts of interests between humans and land resulting from

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land usage (Luo et al., 2022). Foreign scholars have proposed that spatial conflicts are the contradictions and disharmonies that arise from the divergent demands of two or more social groups on land management rights, land using rights, revenue rights of land, and other land rights (Rusu, 2012). In the same region or on the same resource, two or more interdependent individuals or groups have incompatible interest demands and development goals (Madulu,2003). Domestic scholars believe that spatial conflicts are caused by the synergistic effects of spatial resources and their spatial functions, the core of which lies in the scarcity of resources and the spillover of functions, also it is considered a geographical phenomenon generated in the process of the human-land interaction, emphasizing the conflicting and opposing status between the various stakeholders in the process of land using and the environmental aspect (Zhou et al., 2015). In terms of spatial manifestation, it mainly includes imbalance in the ratio of ecological land space and construction land space, the fragmentation and complexity of land landscape and other problems (Gao, 2019).

Currently, both domestic and foreign academic research studies on spatial conflicts mainly focus on two dimensions: theoretical research and empirical research. Theoretical research constructs conceptual models (De, 2006) and spatial models (Iojă et al., 2014) of spatial conflicts, and various qualitative and quantitative methods are used to measure spatial conflicts. Foreign related research is relatively early, and a series of studies have been carried out from the aspects of spatial conflict identification, causes, intensity, and countermeasures. For example, the sustainable livelihood framework is used to analyze changes in household livelihood strategies through 50 cases in Blantyre County Highlands in southern Malawi from 1990 to 2000 (Orr and Mwale, 2001). Based on the relationship between animal husbandry, agricultural cultivation, and wildlife protection, the research pointed out that land use conflicts are caused by competition and contradictions caused by different land development and utilization methods due to the scarcity of land (Campbell et al., 2000). Carr and Zwick (2005) believed that conflicts could be characterized as the suitability between different uses of land parcels, and established a bridge between conflicts and land parcel space through the LUGIS model. Henderson (2005) combined field investigation with interview methods to explore the conflicts between urban construction land and agricultural land in the process of urban development in Australia. Mbonile (2005) used a questionnaire survey method to analyze the issue of water and soil use conflicts in its research area. Khatiwada (2014) used the Moran’s I index to detect spatial correlation in conflict areas in Nepal, and showed that there were many socio-economic issues in high conflict areas. Pacheco and Fernandes (2016) used the least squares regression model combined with GIS to analyze environmental conflicts in land use in Portugal. Deininger and Castagnini (2006) used the least squares method to study the relationship between land output and land use conflicts in Uganda. Using the pressure, state, and corresponding indicators to analyze the causal relationship between land ownership, land use, land degradation, and land use conflicts (Duraiappah et al., 2000). There were also studies pointing out the role of institutions in managing land use conflicts and proposing policy measures to alleviate land use conflicts (Goodale and Sky, 2001). In China, with the gradual emergence of land use issues, the identification and governance of spatial conflicts had gradually become a hot research topic. The actor-network method is used to study the land use conflicts and governance mechanisms in the Guolin Protection Zone of Zhuhai District, Guangzhou City (Wang et al., 2010). The land competitiveness measurement index of “Three Lives” spatial is used to identify land use conflicts in typical regions of Southeast Hills (Luo et al., 2022). The

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transference matrix and the comprehensive index model of spatial conflict are used to analyze the evolutionary characteristics of “Three Lives” spatial conflicts in Hubei Province (Pan et al., 2023). Many studies had constructed the spatial conflict measurement model of ecological risk from the perspective of landscape pattern, measured the level of land using spatial conflict in different urban, and used models such as CLUE-S and PLUS to simulate and predict spatial conflicts (Chen et al., 2021; Luo et al., 2021; Dong, 2022; Qiu et al., 2022; Chen and Chen, 2023; Chen et al., 2023a). The minimum cumulative resistance model was used to identify and optimize spatial conflicts in some regions (Yang et al., 2019; Li, 2022; Lv et al., 2022; Wang and Wu, 2022; Luan and Guo, 2023). From the perspective of spatial pressure indicators, spatial exposure indicators, and ecological pattern structure response, 9 factors are selected to construct an evaluation index system of spatial conflicts in Nanchang City (Chen et al., 2023b). From the perspective of ecosystem services, considering the scarcity of spatial resources as carriers of ecosystem services, the multi-suitability of spatial ecological functions, and the competitiveness of spatial resource utilization, the formation mechanism of spatial conflicts is analyzed, and a spatial conflict measurement index is constructed to study the spatiotemporal evolution of spatial conflicts in the Jiangsu-Zhejiang-Shanghai region (Wu et al., 2021). An analysis of spatial conflicts in Xintai City of Shandong Province is conducted using a spatial conflict measurement index model based on ecosystem service value coefficients (Zheng et al., 2023). From the perspectives of the importance of ecological conservation and urban land expansion, a conflict index is constructed to analyze the spatial conflicts between urban construction land and the importance of ecological environment protection in Jiangsu Province from 2000 to 2020 (Liu et al., 2023). Some scholars had used methods such as Analytic Hierarchy Process (AHP) and Entropy Weight Method, Pressure-State-Response Model, Multi Factor Superimposition, Multi Objective Programming, and Type-Pattern-Process to construct the spatial conflict measurement index to identify regional spatial conflicts and propose corresponding governance suggestions. (Chen et al., 2023; Dai et al., 2019; Li et al., 2022; Min et al., 2018; Tian et al., 2023). The above series of research results have certain theoretical and practical significance for optimizing regional ecological security patterns and managing spatial conflicts.

Spatial conflicts in nature reserves are based on land use of specific resource types, and the imbalance in the aggregation and distribution of various factors can lead to spatial conflicts, emphasizing the guidance of land use functional conflicts (Li et al., 2022). The Yancheng Coastal Wetland, located in the central coastal area of Jiangsu Province, is one of the most typical and representative distribution areas of silty coastal wetlands in China and even in the world, integrating intertidal flats, tides, rivers, salt marshes, *Phragmites australis* marshes and *Spartina alterniflora* marshes. It is a rare primitive coastal wetland in China and even the world. It is a member of the Man and Biosphere Reserve Network and an important member of the East Asia-Australasia Flyway Network. It is an internationally important wetland. Conducting quantitative research on its spatial conflicts is of great significance for appropriate human development and utilization of spatial resources, reducing regional ecological risks, and optimizing regional ecological structure. However, there are few studies reported on this aspect. Therefore, focusing on the Yancheng Coastal Wetland, this study combines the model of spatial conflicts intensity with GIS to analyze the spatiotemporal characteristics of spatial conflicts from 1997 to 2017, which can provide references for the protection and sustainable development of the World Natural Heritage site in Yancheng Coastal Wetland.

Materials and methods

Study area

The Yancheng Coastal Wetland is located in the central coastal area of Jiangsu Province, China. It is situated between 32°20’N to 34°37’N and 119°29’E to 121°16’E. Facing the Yellow Sea to the east, with a total length of the mainland coastline reaching 582 km, it covers an approximate area of 45.33 × 10^4 hm^2, accounting for 61% of the total coastline length of Jiangsu province. The coastal wetland area covers around 70% of the total land area of Jiangsu Province and is the largest silt-based coastal wetland in China (*Fig. 1*). The Yancheng Coastal Wetland is located in the transitional zone between subtropical zone and warm temperate zone. It experiences a distinct monsoon climate with distinct seasons. The annual average temperature is between 13.7℃ and 14.8℃, and the annual precipitation is about 1000 mm (Zhang, 2019).

Yancheng Coastal Wetland has multiple rivers flowing into the sea, along with abundant flora and fauna resources and diverse coastal wetland ecosystem. There are China’s first coastal wetland type world natural heritage site (Yellow Sea and Bohai Sea migratory bird habitat) and two national level nature reserves (Yancheng National Rare Bird Nature Reserve and Dafeng Elk Nature Reserve), with unique ecological status. 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. The main landscape types include rivers, forests, salt fields, natural wetlands, cultivated land, aquaculture pond, and construction land.

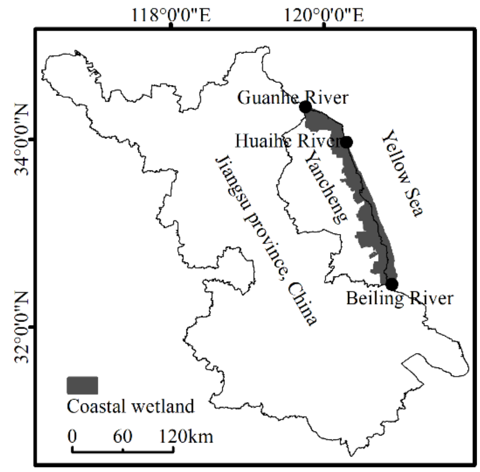

Figure 1. *The location and scope of the study area*

Data sources and processing

The data sources included TM images of 1997, ETM + images of 2007 and 2017. Annual images include 2 scenes, their row and column numbers are (119, 37) and (120, 36) respectively (*Table 1*). Due to the malfunction in the Scan Line Corrector (SLC) of the landsat-7 ETM + sensor, the image data strips after May 21, 2003 were lost, which affected the quality of the images. Therefore, it was necessary to perform destriping on the images of 2007 and 2017. After that, in order to obtain more accurate multi-spectral information of the land features, an atmospheric correction module was used to eliminate the impact of meteorological factors on the reflection of land objects. Further,

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through GPS positioning monitoring of field characteristic points, the images were geometrically corrected by using the method of secondary polynomial and nearest neighbor pixel resampling, ensuring that the RMS accuracy of geometric correction was less than 0.5 pixels. In ENVI 5.0, the two corresponding images were stitched together, and regions of interest (ROI) were created based on the research area for image cropping. The RGB_{432} was applied in ENVI 5.0 to synthesize the multi-spectral information, enhancing the contrast of ground features. Based on this, the unsupervised classification method was adopted for computer interpretation of the remote sensing images. The interpretation results were then validated using field survey samples and land use/land cover data from the Chinese Academy of Sciences' Resource and Environmental Science Data Center for corresponding years, achieving an overall interpretation accuracy of over 85%. Finally, landscape type maps of the study area in 1997, 2007, and 2017 were created by using ArcGIS 10.0.

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%

Landscape pattern index

The landscape pattern index is a highly concentrated form of landscape pattern information that reflects a simple quantitative analysis of certain aspects of its structural composition and spatial configuration. Patch density (PD), Total edge length (TE), Landscape shape index (LSI), Area-weighted shape index (SHAPE_AM), Aggregation index (AI), Largest patch index (LPI) and Average core patch area (CORE_MN), Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI) were selected in this paper. The calculation formula and ecological significance of landscape pattern index were shown in *Table 2.*

The external pressure factor of spatial conflict (the external pressure, P)

External pressure factors influence the harmonious development of space and exist potential risks to resource exploitation. The degree of interaction and interference between spatial units and their surrounding units are the main factors affecting external pressure factors. To measure the value of external pressure by considering spatial units comprehensively, this study adopted the Area-Weighted Mean Patch Fractal Dimension (AWMPFD) as a measure of spatial patch interference (Chen et al., 2020). AWMPFD is an index that reflects the overall spatial characteristics of landscape patterns, and the impact of human activities on landscape patterns can also be expressed through the AWMPFD. Generally, the greater the interference of human activities on landscape patterns, the smaller the value of AWMPFD, while areas with less interference have larger AWMPFD values. To ensure the consistency of subsequent data calculations, the results of AWMPFD are standardized using the

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range standardization method, resulting in a data value within the range of 0-1. Subtracting the AWMPFD standardized value from 1 to obtain the external pressure value (P) of the spatial unit, indicates the degree of interference in the landscape spatial unit. The result is positively correlated with the degree of interference. The calculation formula of AWMPFD and P are as follows:

$$P = 1 - AWMPFD \tag{Eq.1}$$

$$\text{AWMPFD} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\frac{2\ln(0.25P_{ij})}{\ln(a_{ij})} \left(\frac{a_{ij}}{A} \right) \right] \tag{Eq.2}$$

In *Equations 1* and *2*, a_{ij} represents the patch area in square kilometers (km²), P_{ij} represents the patch perimeter in kilometers (km), A represents the total study area in km², i represents the patch type, and j represents the number of patches.

Table 2. *The calculation formula and ecological significance of landscape pattern index*

Name	Formula	Ecological significance
PD	$PD = \frac{n}{A}$ n represents the patch quantity, A represents the region area	It can reflect the degree of fragmentation of the landscape being segmented
TE	$TE = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}$ i represents the landscape type, j represents Number of patches for a landscape type. C_{ij} represents the circumference of a patch	It can reflect the degree of fragmentation of the landscape and the degree of interference from human activities
LSI	$LSI = \frac{0.25E}{\sqrt{A}}$ E represents the total length of all patch boundaries in the landscape, A represents the region area	The regularity of the shape can reflect the degree to which the landscape is influenced by humans
SHAPE_AM	$\text{SHAPE\_AM} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[\frac{2\ln(0.25C_{ij})}{\ln(a_{ij})} \left(\frac{a_{ij}}{A} \right) \right]$ a_{ij} represents the patch area, C_{ij} represents the patch perimeter, A represents the total study area, i represents the patch type, and j represents the number of patches	It can reflect to some extent the impact of human activities on the landscape pattern
AI	$\text{AI} = \left[1 + \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{P_{ij} ln(Q_{ij})}{2\ln(m)} \right] \times 100$ Q_{ij} represents the probability that two adjacent grids belong to type i and type j	It can reflect the adjacent relationship between landscape patch types and the spatial configuration characteristics of landscape composition
LPI	$\text{LPI} = \frac{A_{max}}{A} \times 100$ A_{max} represents the largest patch area	It helps to determine the dominant type of landscape y, and its value changes can reflect the direction and strength of human activities
CORE_MN	$CORE\_MN = \frac{A_{Co}}{TN}$ A_{Co} represents the core patch area, TN represents the number of patches	It can reflect the composition characteristics of the landscape, and can reflect the stability and anti-interference degree of the landscape
SHDI	$\text{SHDI} = -\sum_{i=1}^{m} [P_i \ln(P_i)]$ P_i represents the percentage of area for different landscape types	It can reflect the richness and complexity of landscape composition
SHEI	$SHEI = \frac{SHDI}{\ln(m)}$	It can describe the degree of control of a few major landscape types in a landscape

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The vulnerability value spatial conflict (the vulnerability value, E)

Landscape vulnerability is one of the important aspects to characterize spatial conflict. The spatial vulnerability index is used to describe the difficulty of destroying spatial units under external disturbances. The ability of spatial units to resist disturbances varies due to the differences of landscape types and spatial patterns. The landscape vulnerability index (F_i) represents the ability of different landscape types to resist disturbances. A higher value of F_i indicates a weaker resistance and greater ecological vulnerability of that landscape type, while a lower F_i value indicates a more stable landscape. Based on the actual research conditions, F_i values are mainly obtained through consultation with experts and empirical data. In this study, the values for different landscape types were assigned as follows: 1 for construction land, 2 for salt fields, 3 for forests, 4 for cultivated land, 5 for aquaculture ponds, 6 for rivers and natural wetlands. Further normalized processing was conducted to obtain the F_i values for different landscape types. The calculation formula for the vulnerability index (*E*) of spatial units is shown in equation (3). Then, the values of each spatial unit will be standardized using the range standardization method, ensuring that they fall within the range of [0,1].

$$E = \sum_{i=1}^{n} F_i \times \frac{a_i}{S} \quad \text{(Eq.3)}$$

In *Equation 3,* F_i represents the vulnerability index for each landscape type, a_i represents the area of each landscape type within the unit, S represents the total area of the spatial unit, and n represents the number of patches within each spatial unit.

The stability value of spatial conflicts (the stability value, S)

The spatial unit stability index represents the ability of spatial units to recover after being damaged. The intensification of spatial conflicts can lead to the overall degradation of landscapes and increased fragmentation. In landscape ecology, the degree of fragmentation is commonly used to measure landscape stability. The more homogeneous, fragmented, and incomplete a landscape type is, the lower the stability of spatial units, and the greater the intensity of spatial conflicts. This study adopted a landscape fragmentation index to characterize the stability of spatial units, with the calculation formula as follows:

$$\mathrm{S} = 1 - \frac{PD - PD_{min}}{PD_{max} - PD_{min}} \quad \text{(Eq.4)}$$

$$PD = \frac{n_i}{A} \quad \text{(Eq.5)}$$

In *Equations 4* and *5,* i represents the spatial unit index; n_i represents the number of patches within each landscape spatial unit; A representing the area of spatial landscape units in square kilometers (km^2); PD represents the patch density index within a specific landscape unit; PD_{max} represents the maximum patch density index among all landscape spatial units in the region; PD_{min} represents the minimum patch density index among all landscape spatial units in the region; S represents the spatial stability index.

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Finally, the range standardization method was used to standardize the stability values of all units in the region, ensuring that they fall within the range of 0 to 1.

Spatial conflict intensity (spatial conflict, SC)

The intensity of spatial conflicts can be intuitively represented by the magnitude of regional ecological risks. The lower the value, the smaller the ecological risk in the study area. Conversely, regional ecological risk is positively correlated with the level of spatial conflict. Drawing on traditional risk assessment models and the research of relevant scholars, the spatial conflict intensity model is typically constructed using spatial external pressure, spatial vulnerability, and spatial stability index to represent risk sources, risk receptors, and risk effects (Chen et al., 2020; Meng et al., 2020). The greater the external pressure on the region, the higher the landscape risk, the worse the landscape stability, and the higher the intensity of regional spatial conflicts. Therefore, the measurement of spatial conflict level can be summarized as follows:

$$SC = P + E - S \quad \text{(Eq.6)}$$

In *Equation 6*, SC represents the value of spatial conflict intensity. P represents the external pressure factor. E represents the spatial vulnerability index. S represents the stability index of each unit.

Based on the above method, for better calculation and quantitative assessment of spatial conflict levels, this study selects a 3 km × 3 km grid as the spatial unit for spatial conflict evaluation. The spatial interpolation is performed using the inverse distance weighting method in ArcGIS software, and spatial differentiation maps for each evaluation attribute are generated.

Results

Landscape pattern changes

It can be observed from *Figures 2* and *3* that the landscape pattern in Yancheng Coastal Wetland changed obviously in the twenty years. The changes in landscape structure were mainly manifested as: Yancheng Coastal Wetland Landscape was mainly composed of aquaculture ponds, cultivated land, construction land, natural wetlands, salt fields, rivers, and forests, with aquaculture ponds, cultivated land, construction land, and natural wetlands being the main components. From 1997 to 2017, the landscape changes in Yancheng Coastal Wetland showed that the area of natural wetlands continued to decrease, the area of aquaculture pond and construction land continued to increase, and the cultivated land area was basically stable. From 1997 to 2017, the area of natural wetlands decreased from 121,458.66 hm^2 to 76,859.51 hm^2, with the percentage decreasing from 28.46% to 16.97%; the area of aquaculture ponds increased from 47,078.56 ha to 119,354.76 hm^2, with the percentage increasing from 11.03% to 26.35%; the area of construction land increased from 15,396.86 hm^2 to 44,285.45 hm^2, with the percentage increasing from 3.61% to 9.78%.

It can be observed from *Tables 3* and *4* that the area of natural wetlands transferred to aquaculture ponds, cultivated land, and construction land ranked in the top three from

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1997 to 2017. The transfer of aquaculture ponds to cultivated land, construction land, and natural wetlands occupied the top three positions in sequence. The transfer of cultivated land to construction land was the largest.

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

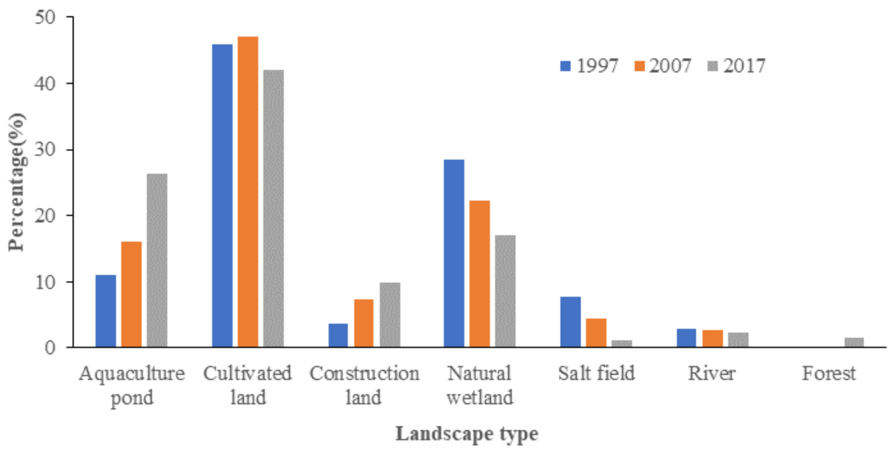

Figure 3. *The changes of Landscape structure in Yancheng coastal wetland*

Table 3. *The landscape transfer matrix from 1997 to 2007/hm^2*

1997 \ 2007	Aquaculture pond	Cultivated land	Natural wetland	River	Salt field	Forest	Construction land
Aquaculture pond	21044.305	8944.956	4844.246	743.535	1081.506	0.000	6060.940
Cultivated land	3740.208	165830.925	1013.912	3807.802	45.063	0.000	7773.325
Natural wetland	23162.254	11468.470	68225.006	2343.263	968.849	0.000	5948.283
River	1644.790	3424.769	2478.451	2050.355	67.594	22.531	1351.883
Salt field	11806.441	112.657	0.000	495.690	15388.930	0.000	3064.267
Forest	157.720	112.657	22.531	0.000	22.531	450.628	45.063
Construction land	4889.309	3492.363	766.067	608.347	247.845	0.000	4461.212

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It can be observed from *Table 5* that the landscape pattern of the Yancheng Coastal Wetland showed significant changes. Patch density (PD), Total edge length (TE), Landscape shape index (LSI), Area-weighted shape index (SHAPE_AM), and Aggregation index (AI) showed a continuous increase. While Largest patch index (LPI) and Average core patch area (CORE_MN) showed a continuous decrease. This indicates that the study area has been continuously impacted by human activities. Shannon's diversity index (SHDI) showed a trend of initially increasing and then decreasing, while Shannon's evenness index (SHEI) showed a trend of initially decreasing and then increasing.

Table 4. *The landscape transfer matrix from 2007 to 2017/hm^2*

2007 \ 2017	Aquaculture pond	Cultivated land	Natural wetland	River	Salt field	Forest	Construction land
Aquaculture pond	53793.858	8539.473	1302.632	940.789	554.825	72.368	5982.456
Cultivated land	8901.316	162925.434	289.474	3787.281	0.000	6392.544	24557.017
Natural wetland	26076.754	5668.859	58184.209	1929.825	48.246	168.860	4245.614
River	2677.631	3956.140	1109.649	1592.105	96.491	241.228	1182.018
Salt field	12688.596	144.737	651.316	120.614	4052.631	0.000	1423.246
Forest	0.000	24.123	0.000	0.000	0.000	0.000	482.456
Construction land	13557.017	7960.526	530.702	1109.649	241.228	144.737	7309.210

Table 5. *The landscape pattern index in Yancheng Coastal Wetland from 1997 to 2017*

Year	Rising index					Declining index		Volatility index	
	PD	TE	LSI	SHAPE_AM	AI	LPI	CORE_MN	SHDI	SHEI
1997	0.194	2731737.360	13.875	5.168	83.536	27.756	515.068	1.409	0.678
2007	0.241	3683133.850	17.502	5.551	77.967	25.683	415.862	1.469	0.639
2017	0.243	4225657.2088	19.255	6.799	76.583	22.642	412.367	1.441	0.741

External pressure changes of spatial conflict

From the evaluation of external pressure in spatial conflict, the Yancheng Coastal Wetland showed a characteristic of initially decreasing and then increasing from 1997 to 2017. However, it remained at a relatively low level of human disturbance generally. The mean values in 1997, 2007, and 2017 were 0.353, 0.122, and 0.239, respectively. The coefficient of variation over time was 48.531%, indicating a moderate level of variation.

It can be observed from *Figure 4* that there were small spatial differentiations in external pressures of spatial conflict in the Yancheng Coastal Wetland from 1997 to 2017. The coefficients of spatial variation were 1.856%, 1.815%, and 1.673% respectively, indicating a stable low-level spatial variation with a gradual decrease in spatial differentiation. From the spatial distribution map, there were certain north-south differences in the external pressure values of spatial conflicts. The northern region had a longer history of development and thus experienced higher levels of human impacts compared to the southern region. On the other hand, with the progression of time, human activities gradually moved southward, leading to an increase in the intensity of human impacts in the southern region. It can be observed from the figure that in 1997, the external pressure values in the southern region, such as Dafeng District and Dongtai

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City, were generally at a low level. By 2017, the entire study area was mainly at a low level, but moderate and relatively high levels appeared in Dafeng District and Dongtai City. It can be observed from *Table 6* that the levels of external pressure values, over 98% of the study area was at a low or relatively low level. The area at a low level gradually decreased from 54.480% in 1997 to 28.376% in 2017, while the areas at a relatively low, moderate, and relatively high levels increased significantly from 45.472%, 0.030%, and 0.010% in 1997 to 69.936%, 0.932%, and 0.463% in 2017, respectively. The area of the high level was the lowest in 2007 and the largest in 2017.

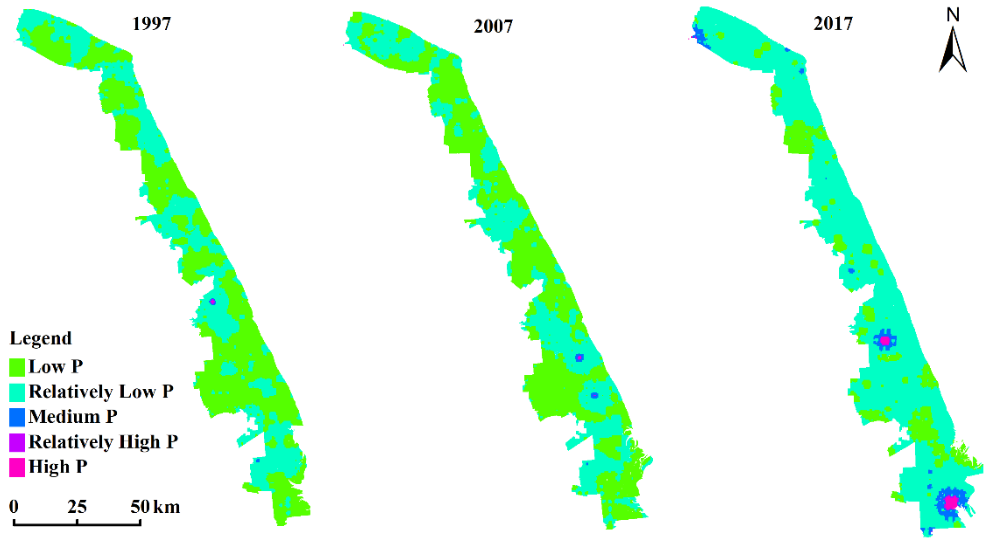

Figure 4. *Spatial distribution of external pressure in Yancheng coastal wetland from 1997 to 2017*

Table 6. *The external pressure classification statistics from 1997 to 2017*

Grade	1997		2007		2017	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Low	232452.276	54.480	237852.135	53.666	128539.532	28.376
Relatively low	194018.128	45.472	204916.499	46.235	316803.741	69.936
Medium	128.075	0.030	361.560	0.082	4221.389	0.932
Relatively high	42.692	0.010	54.654	0.012	2097.392	0.463
High	34.930	0.008	21.021	0.005	1325.836	0.293

The vulnerability changes of spatial conflict

Yancheng Coastal Wetland is a typical ecologically vulnerable area. From 1997 to 2017, the vulnerability index of spatial conflict showed a pattern of initial decrease followed by an increase. The mean values in 1997, 2007, and 2017 were 0.671, 0.643, and 0.657, respectively. The coefficient of variation over time was 2.131%, indicating a low level of variation.

It can be observed from *Figure 5* that there were obvious spatial differentiations in the vulnerability index in the Yancheng Coastal Wetland from 1997 to 2017. The coefficients of spatial variation were 25.800%, 27.326%, and 28.301% respectively, indicating a relatively stable moderate level of spatial variation with an increasing

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spatial differentiation trend. According to the spatial distribution map, the spatial differentiation of the vulnerability of spatial conflict in Yancheng from 1997 to 2017 showed obvious sea-land differentiation characteristics. The eastern part of the study area is mainly composed of natural wetlands, which are highly vulnerable to rapid ecosystem changes under the combined influence of human activities and natural factors. The western part of the study area, with stronger human activities, mainly consists of artificial landscapes such as cultivated land, aquaculture ponds, and construction land. The ecological systems in this area are relatively stable with low ecological vulnerability. It can be observed from *Table 7* that the ecological vulnerability levels, over 98% of the study area was at a relatively low, moderate, relatively high, or high level. The area at a relatively low level showed a pattern of initially decreasing and then increasing, reaching its highest value of 48.794% in 1997. The areas at a moderate, relatively high, and high level showed a pattern of initially increasing and then decreasing, reaching their peaks in 2007 at 30.871%, 33.589%, and 33.052%, respectively.

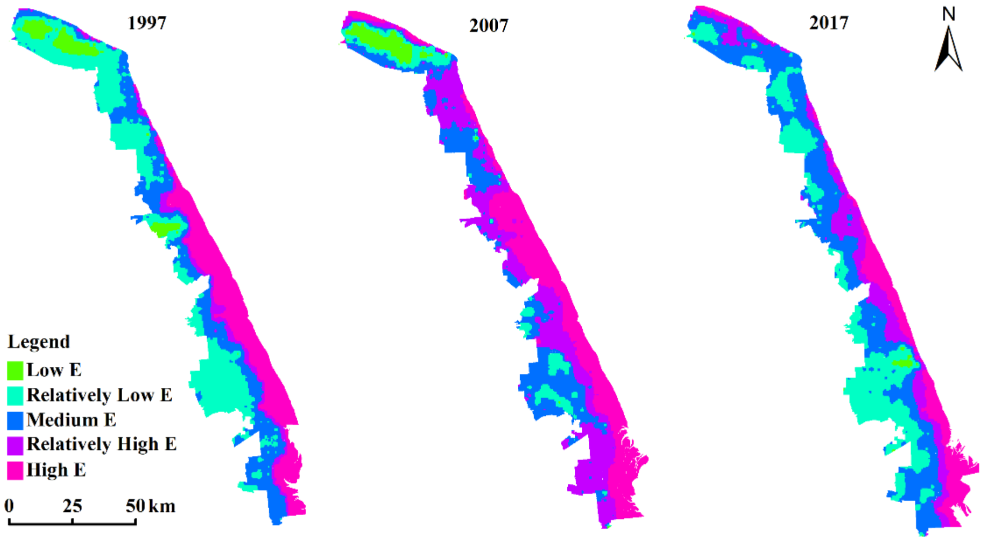

Figure 5. *Spatial distribution of landscape vulnerability in Yancheng coastal wetlands from 1997 to 2017*

Table 7. *The landscape vulnerability classification statistics from 1997 to 2017*

Grade	1997		2007		2017	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Low	4583.533	1.074	3304.495	0.746	563.148	0.124
Relatively low	208191.763	48.794	7727.304	1.744	177697.433	39.228
Medium	88398.930	20.718	136821.209	30.871	114762.371	25.335
Relatively high	33648.800	7.886	148866.218	33.589	68335.957	15.086
High	91853.074	21.528	146486.645	33.052	91628.980	20.228

The stability changes of spatial conflict

From the evaluation results of the stability of spatial conflict, from 1997 to 2017, the stability of spatial conflicts in the Yancheng coastal wetland showed a pattern of initially

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decreasing and then increasing, but overall, it remained at a relatively high level. The mean values in 1997, 2007, and 2017 were 0.895, 0.863, and 0.883, respectively. The coefficient of variation over time is 1.837%, indicating a low degree of variation.

It can be observed from *Figure 6* that the spatial differentiation of spatial conflict stability values in Yancheng Coastal Wetland is relatively low from 1997 to 2017, with spatial variation coefficients of 7.366%, 9.885%, and 6.878%, which still belongs to a low level of spatial variation. Spatial differentiation shows some fluctuations over time. From the spatial distribution map, the spatial differentiation pattern of spatial conflict stability is not obvious. In 1997, the low stability values were mainly concentrated in the northern part of the study area. By 2007, the low stability values gradually shifted southwards, and by 2017, the low stability values significantly decreased, with the disappearance of the north-south difference. From the statistics of spatial conflict stability levels in *Table 8*, the majority of the study area falls into the moderate to high levels, accounting for over 97% of the total. The dominant levels are the higher level and high level, accounting for over 76% of the total. From 1997 to 2017, the area with moderate-level stability showed a characteristic of initially increasing and then decreasing. The largest area was in 2007, accounting for 20.921% of the total area. The area with higher-level stability showed a characteristic of initially decreasing and then increasing, with the largest area in 2017, accounting for 48.281% of the total area. The area with high-level stability showed a continuous decrease, from 51.082% in 1997 to 40.621% in 2017.

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

Table 8. *The stability classification statistics from 1997 to 2017*

Grade	1997		2007		2017	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Low	1249.702	0.293	2636.028	0.595	505.503	0.112
Relatively low	1738.715	0.408	9619.190	2.170	3157.174	0.697
Medium	28758.663	6.740	92723.444	20.921	46612.652	10.290
Relatively high	176976.388	41.478	132141.944	29.815	218705.216	48.281
High	217952.632	51.082	206085.264	46.499	184007.346	40.621

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Changes in spatial conflict intensity

From the evaluation results of the spatial conflict, the spatial conflict in Yancheng coastal wetland was classified into five levels: natural stability (0-0.2), stable controllable (0.2-0.4), basically controllable (0.4-0.6), basically uncontrollable (0.6-0.8), and seriously uncontrollable (0.8-1.0). From 1997 to 2017, the spatial conflict intensity in Yancheng Coastal Wetland showed a characteristic of initially increasing and then decreasing. The mean values in 1997, 2007, and 2017 were 0.356, 0.406, and 0.380, respectively, generally at the levels of stable controllable and basically controllable. The coefficient of variation of spatial conflict intensity over time was 6.570%, indicating a low degree of variation.

It can be observed from *Figure 7* that the spatial differentiation of spatial conflict intensity in the Yancheng Coastal Wetland was significant from 1997 to 2017, with spatial variation coefficients of 26.700%, 28.637%, and 23.078%, which still belonged to a moderate level of spatial variation. Spatial differentiation showed some fluctuations over time. From the spatial distribution map, spatial conflict exhibited significant differences in the land-sea direction, which were related to the advancement of human activities from land to sea. The eastern part of the study area was far from the human activity area, and the wetland landscape was less affected by human activities, and resulting in lower spatial conflict values. In the western part of the study area, the stronger the human activities, spatial conflict became more apparent with stronger human activities. From the statistics of spatial conflict levels in *Table* 9, the spatial conflict levels in the entire study area were mainly stable controllable and basically controllable, accounting for over 96% of the total, with stable controllable being the dominant level, accounting for over 53% of the total. From 1997 to 2017, the area with stable controllable characteristics showed a characteristic of initially decreasing and then increasing, with the largest area in 1997, accounting for 66.804% of the total. The area with basically controllable characteristics showed a characteristic of initially increasing and then decreasing, with the largest area in 2007, accounting for 42.906% of the total. The area with basically uncontrollable characteristics reached its highest point in 2007, accounting for 3.164% of the total. The area of natural stability continuously decreased.

It can be observed that there are significant differences in the intensity of spatial conflicts through the analysis of spatial conflicts among different landscape types in *Table 10*. The landscape types in Yancheng Coastal Wetland have spatial conflicts at the levels of "stable and controllable" and "basically controllable". Among the landscape types, natural wetland has the highest conflict level, which is at the "basically controllable" level. The degree of spatial conflict has decreased from 38.964% in 1997 to 22.794% in 2017, indicating a significant decreasing trend. The spatial conflicts of fishponds were at the "stable and controllable" level in 1997 and 2017, and at the "basically controllable" level in 2007. The degree of spatial conflict has increased from 11.958% in 1997 to 26.009% in 2017, showing a clear upward trend. The spatial conflicts of farmland were at the "stable and controllable" level, and the degree of spatial conflict has remained relatively stable, ranging from 37% to 39%. The spatial conflicts of construction land were at the "stable and controllable" level, and the degree of spatial conflict has increased from 0.715% in 1997 to 7.917% in 2017, indicating a significant increase. Salt fields were in a natural stable state in 1997, and at the "stable and controllable" level in 2007 and 2017. The degree of spatial conflict has decreased from 3.803% in 1997 to 0.952% in 2017. Rivers were also at the "stable and controllable" level, and the degree of spatial conflict has decreased from 3.084% in

1997 to 2.050% in 2017. Forest land was at the "basically controllable" level in 2007, and at the "stable and controllable" level in 1997 and 2017. The degree of spatial conflict showed an increasing and then decreasing trend. Overall, based on the average conditions of the three periods, the order of the intensity of spatial conflicts among landscape types in Yancheng Coastal Wetland is as follows: natural wetland > fishponds > rivers > forest land > farmland > construction land > salt fields. The intensity of spatial conflicts of landscape types is generally positively correlated with the level of landscape ecological services and the vulnerability of the ecosystem.

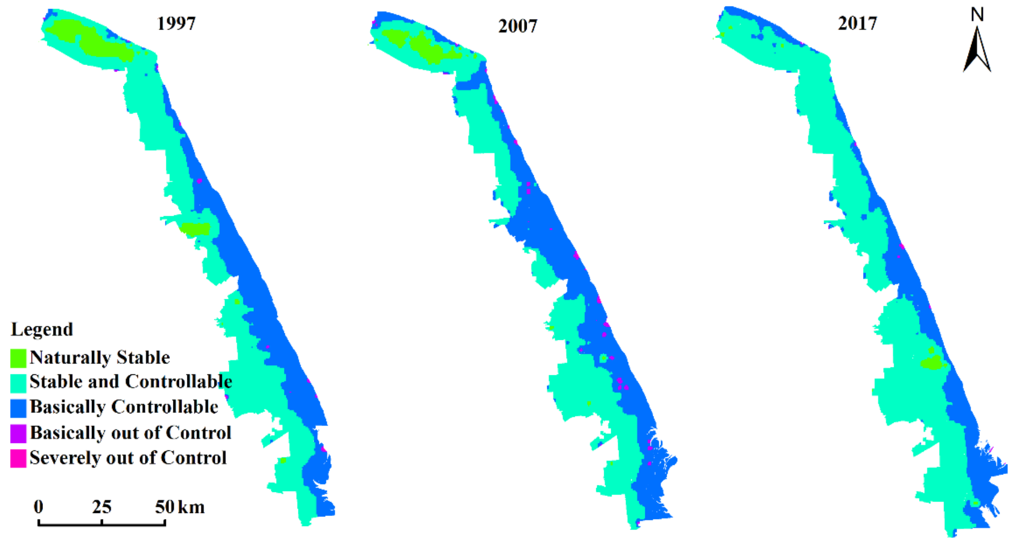

Figure 7. *Spatial distribution of spatial conflict in Yancheng coastal wetland from 1997 to 2017*

Table 9. *The spatial conflict classification statistics from 1997 to 2017*

Grade	1997		2007		2017	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Naturally stable	5868.164	1.375	3165.756	0.714	975.531	0.215
Stable and controllable	285036.774	66.804	235766.856	53.196	265929.792	58.706
Basically controllable	135134.668	31.671	190163.991	42.906	185479.511	40.946
Basically out of control	597.683	0.140	14020.979	3.164	563.148	0.124
Severely out of control	38.811	0.009	88.288	0.020	39.908	0.009

Table 10. *The spatial conflict values of different landscape types*

Landscape type	1997		2007		2017	
	Conflict mean	Contribution rate/%	Conflict mean	Contribution rate/%	Conflict mean	Contribution rate/%
Aquaculture pond	0.369	11.958	0.434	18.012	0.379	26.009
Cultivated land	0.284	38.260	0.318	38.862	0.315	37.077
Construction land	0.305	0.715	0.288	1.532	0.294	7.917
Natural wetland	0.470	38.964	0.533	30.471	0.483	22.794
Salt field	0.167	3.803	0.215	2.441	0.299	0.952
River	0.370	3.084	0.399	2.857	0.339	2.050
Forest	0.370	3.216	0.413	5.826	0.283	3.200

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Conclusion and discussion

Based on the area-weighted average patch fractal index, landscape vulnerability index, and landscape stability index, a model for spatial conflict intensity was constructed. GIS technology was utilized to analyze the spatiotemporal characteristics of spatial conflicts in the Yancheng Coastal Wetland from 1997 to 2017. The following conclusions were drawn:

From 1997 to 2017, significant changes were observed in the landscape structure and pattern of Yancheng Coastal Wetland, with a notable decrease in the area of natural wetlands and a significant increase in the areas of fishponds and construction land. During this period, the external pressure and stability index of spatial conflicts in Yancheng Coastal Wetland showed a decreasing trend followed by an increasing trend, with no significant spatial differentiation. The ecological vulnerability index of spatial conflicts exhibited a pattern of initial decrease followed by an increase, with greater spatial differentiation in the east-west direction compared to the north-south direction. The intensity of spatial conflicts in Yancheng Coastal Wetland showed a pattern of initial increase followed by a decrease, generally maintained at a level of stable and controllable or basically controllable, with significant spatial differentiation in the east-west direction. There were significant differences in the intensity of spatial conflicts among different landscape types, with the order of intensity being as follows: natural wetland > fishponds > rivers > forest land > farmland > construction land > salt fields. These conflicts were generally maintained at levels of stable and controllable or basically controllable.

The essence of spatial conflict is that the phenomenon of disharmony and imbalance between the structure and quantity of land resources and the requirements of regional economic development and spatial requirements under certain spatiotemporal conditions (Liu and Chen, 2012). It is manifested as the opposition and disharmony between stakeholders in the process of using spatial resources. When the land use contradiction develops to a certain extent and causes significant negative impacts, it may be transformed into spatial conflicts (Jiang and Meng, 2021). The Yancheng Coastal Wetland is particularly unique. Firstly, it is a large muddy coastal wetland along the western Pacific coast, with complete ecological types and unique types. It is an important habitat and holds a unique position in biodiversity maintenance. Therefore, the spatial conflicts should be established from the perspective of habitat protection and biodiversity maintenance. Secondly, from the location of the coastal wetland, it is an ecological transition zone and a concentrated area of human activities, with frequent human activities and rapid economic development. The conflict between socio-economic activities and ecological protection is the main type of spatial conflict. Thirdly, the Yancheng coast has both erosion and siltation characteristics. The stability of the coastline and the role of *Spartina alterniflora* in promoting siltation should be important aspects of the conflict, while also considering the impact of *Spartina alterniflora* on habitat function. Therefore, the spatiotemporal changes of the spatial conflict in the Yancheng Coastal Wetlands are the result of the complex effect of natural and human activities. Ecological processes form the foundation for driving the evolution of regional landscape patterns, and the unique hydrological and geomorphological processes have fostered diverse ecosystems in the Yancheng Coastal Wetland. The continuous change of ecological processes towards the sea and land direction has contributed to the continuous and stable landscape change process in this area (Han et al., 2022). The differences in erosion conditions between different sections

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of the coastline have resulted in significant differences in landscape structure and pattern between eroded and accreted sections. The invasion and widespread spread of *Spartina alterniflora*, through its strong accretion-promoting ability, have reconstructed the hydrological and geomorphological processes. Moreover, its strong interspecific competitive ability severely threatens and damages the local ecosystem, leading the natural ecological system of Yancheng Coastal Wetland to develop from diversification to singularity (Wang et al.,2020). Therefore, the landscape pattern formed by the hydrological and geomorphological processes in the Yancheng Coastal Wetland and the invasion of *Spartina alterniflora* constitutes the basis for regional spatial conflicts.

On the other hand, spatial conflicts are closely related to the intensity of human activities and the difficulty of encroachment. Spatial conflicts are closely related to the ecological characteristics of different landscape types. The coastal wetland ecosystem is nurtured by unique regional ecological processes. Once ecological processes are interrupted by human activities, the development of the ecosystem will be interrupted, or it may transition to another ecological system, fundamentally altering the structure and pattern of the landscape. Typical human activities include reclamation, aquaculture, residential construction, industrial and mining occupation, and the construction of ports, which alter the composition and functional configuration of the coastal wetland landscape and serve as inducing factors for exacerbating spatial conflicts. Furthermore, human activities are often influenced by policy factors. In 1996, Jiangsu initiated the "*Marine Sudong*" strategy, with the "*Million Mu Tidal Flat Developmen*t" as its hallmark. The first step in the development of coastal wetlands was enclosure for aquaculture, resulting in a rapid increase in the area of aquaculture ponds in the study area. In 2009, the "Development Plan for Coastal Areas of Jiangsu Province" was elevated to a national strategy. Although it clearly stated the goal of protecting the environment and ensuring that important ecological functional areas accounted for 15% of the land area, the unstoppable wave of large-scale development led to significant changes in the landscape structure. The areas of aquaculture ponds and construction land rapidly increased, while natural wetlands, salt fields, and farmland dramatically decreased. In 2017, the salt marshes in Yancheng Coastal Wetland area were designated as an ecological special zone by Jiangsu Province, making ecological protection and restoration the main theme. Actions such as returning farmland and fisheries to wetlands were undertaken (Zhang et al., 2020). Due to geographical conditions and the history of development, there are also differences in the north-south landscape structure in the region (Shen et al., 2022).

The prevention and management of spatial conflicts are key areas of future research. The Yancheng Coastal Wetlands, with their unique geographical location and ecological status, demand higher requirements for ecological development. The accelerated development of the coastal areas in Jiangsu Province is also an inevitable historical trend, which requires a higher level of coordination between ecological protection and socio-economic development and the pursuit of a high-quality green development path. The essence of spatial conflicts lies in the land disputes that arise when stakeholders pursue their own interests (Meng et al., 2020). Finding ways to ease conflicts and achieve a win-win situation between socio-economic development and ecological protection is an important scientific proposition (Pan and Li, 2017). The multifunctional use of land is an effective approach to mitigate spatial conflicts in land use (Meyer and Degorski, 2007; De, 2006). To prevent and manage spatial conflicts in Yancheng Coastal Wetland, it is necessary to first conduct rational planning, balance the

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relationship between construction land, farmland, aquaculture ponds, and natural wetlands, strictly adhere to ecological red lines, prioritize ecological protection, and guide the rational development of non-wetland areas. Secondly, in the process of new urbanization and rural revitalization, we need to accelerate industrial restructuring, optimize industrial layout, take the path of green and low-carbon development, achieve intensive and efficient use of land resources, and provide guarantees for mitigating spatial conflicts in land use through development modes.

The spatial conflict intensity model constructed by external pressure factors, spatial vulnerability index, and spatial unit stability index can better depict the spatiotemporal characteristics of spatial conflicts in the study area and provide reference for optimizing the future landscape pattern. However, the selection of model factors, especially the types and quantities of factors, directly affect the research results. On the other hand, the study is limited to the measurement of spatial conflicts using landscape pattern factors, and there is a need to conduct coupled research on pattern-process-function to comprehensively depict spatial conflicts in coastal wetlands. The use of a 3 km × 3 km grid and the division of various evaluation factors and conflict intensities into five levels also have some subjectivity. How to reduce the impact of subjectivity on the research results needs to be strengthened in future studies.

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