# STUDY ON THE LANDSCAPE HABITAT STABILITY FROM THE PERSPECTIVE OF NICHE THEORY IN THE YANCHENG COASTAL WETLANDS OF CHINA

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(Received 17th Nov 2022; accepted 27th Feb 2023)

**Abstract.** Taking the core zone of Yancheng National Nature Reserve (YNNR) as an example, the landscape habitat stability was analyzed by Ecological Niche models from 1983 to 2021. The evaluation index system of landscape habitat stability was constructed from the 'State' and 'Trend' dimensions by using the 'State-Pressure-Response' model. The landscape structure changed significantly, showing a trend of continuous expansion of *Phragmites australis* (*P. australis*) marsh and *Spartina alterniflora* (*S. alterniflora*) marsh, and first increase and then decrease of *Suaeda salsa* (*S. salsa*) marsh. The niche breadth ranged from 2.4297 to 2.6187, the highest value appeared in 1992 and the lowest value was found in 2017. The niche overlap was high in different years, and there was still more than 50% overlap in the nearly 40 years span. The niche value was the highest in 1992 and the lowest in 2017, showing the trend of rising first, then falling, and then rising. The annual gradient of the ecological niche was 0.0002 in 1983-1992, −0.0058 in 1992-2017, and 0.0025 in 2017-2021. The niche expansion value showed a slow upward trend, indicating a good development trend of landscape habitat. The results can provide reference for the sustainable construction of Yancheng coastal wetlands.
**Keywords:** *niche theory, landscape pattern, habitat quality, ecological stability, Yancheng National Nature Reserve*

## Introduction

Habitat quality, as an essential indicator to measure the level of biodiversity, refers to the ability of the environment to provide suitable habitats for the survival and development of individuals or populations (Peng et al., 2019; Johnson et al., 2007; Zhang et al., 2021). Studying the landscape habitat stability is of great significance for maintaining regional ecological balance and carrying out directional restoration of habitat. Generally, a landscape habitat is said to be stable if the long-term changes in its parameters show a horizontal state or the amplitude and period of swinging along the horizontal line are statistically significant (Zhao et al., 2020; Hu et al., 2016; Duan et al., 2018). From the perspective of landscape ecology, landscape habitat stability is the continuity of landscape pattern characteristics, ecological processes, and ecological functions (Hu et al., 2016; Duan et al., 2018), which mainly includes the two abilities of maintaining the status quo and recovering after being disturbed (Liu et al., 2017; Cabral et


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

al., 2009; Liu et al., 2012). The evaluation of landscape habitat stability, whose core is to analyze the relationship between pattern, process, function, and stability, can provide a measure basis for regional habitat risk analysis as one of the critical research contents of landscape ecology (Liu et al., 2016, 2018a; Wen et al., 2018). At present, there have been lots of studies on landscape stability using landscape pattern indexes primarily, some of which applied multiple indexes to describe it respectively (Xie et al., 2005; Chang et al., 2020) or integrated a new index based on a series of landscape pattern indexes (Liu et al., 2012, 2016, 2018a; Wang et al., 2020; Gong et al., 2014). Meanwhile, some other scholars utilized series indexes to calculate the comprehensive value to characterize the regional landscape stability and its changing characteristics (Zhao et al., 2020; Hu et al., 2016; Wen et al., 2018; Zhang et al., 2018; Xiao et al., 2007; Lv et al., 2015; Li et al., 2017; Liu et al., 2018b; Wang et al., 2018). In addition, the regional landscape habitat quality is also measured by landscape elasticity, resilience, and the structural equation model (Zhao et al., 2019; Zhang et al., 2019; Cui et al., 2019). A series of research results also provide methodological guidance for this study.

Coastal wetland, a transitional zone between land and sea, is a typically fragile edge zone and an ecologically sensitive area. The landscape of coastal wetlands changes significantly under the constant dual effects of humans and nature, resulting in variation in its environmental processes and functions, thus affecting the quality of habitats. It is necessary and urgent to conduct in-depth research on habitats of coastal wetlands from long time series and large regional scale. Relevant predictions and studies have proved that about 20%-90% of the world's coastal wetlands will disappear in the 21st century due to sea level rise and human activities (Blankespoor et al., 2014; Schuerch et al., 2018), which will be a devastating blow to global migratory waterbirds, especially to the ecologically sensitive and rare endangered species (Wang et al., 2022b).

The Yancheng coastal wetlands is located in the middle of the Jiangsu coast, bordering the Yellow Sea in the east, with a coastline of 582 km. It is the largest muddy coastal wetlands in Asia and one of the most typical muddy coastal wetlands distribution areas in China and in the world. It is also the first Coastal Wetlands Natural Heritage in China and an irreplaceable natural habitat for protecting the rare and endangered migratory birds. The habitat quality of the Yancheng coastal wetlands has been the focus of management sectors and scholars for a long time, the evaluation of habitat quality on a landscape scale is the basis of coastal wetland landscape analysis and restoration. Some studies have been carried out to analyze the temporal-spatial variation characteristics of habitat quality in the Yancheng coastal wetlands by using InVEST model, and compared the impacts of human activities and Spartina alterniflora (*S. alterniflora)* marshes expansion on habitat quality (Zhang et al., 2021, 2020). And some other studies focused on evaluating the habitat in the Yancheng coastal wetlands with MaxENT and BRT models by constructing the evaluation index system of red-crowned cranes (*Grus japonensis*) overwintering habitat from different scales (Wang, 2020, 2021; Cao et al., 2016). Landscape structure connectivity and functional connectivity were also adopted to study the degradation characteristics of suitable habitats for red-crowned cranes in the Yancheng coastal wetlands (Li et al., 2021). However, due to the complexity of landscape structure, diversity of function, and temporal-spatial variability of coastal wetlands, coupled with the lack of expression model of landscape habitat stability, studies on landscape habitat stability of Yancheng coastal wetlands are rare. Based on the analysis above, using seven remote sensing images from 1983 to 2021 as data sources, this paper intends to reveal the


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

characteristics of landscape habitat stability in the core zone of Yancheng National Nature Reserve (YNNR) from the perspective of the niche theory. The niche evaluation index system is constructed using the ‘pressure-state-response’ model to integrate the landscape pattern index and the number of wintering populations of red-crowned cranes on the two scales of type and landscape. The conclusion can provide a reference for the scientific management of coastal wetlands and sustainable development of the coastal zone in Yancheng.

## Materials and methods

### *Study area*

The YNNR ranges from 32°20’N to 34°37’N and 119°29’E to 121°16’E, with an area of $2.47 \times 10^5$ $hm^2$. The reserve is divided into three parts of the core area, the buffer area, and the experimental area. The core area is one of the vital ecological nodes of the Yancheng coastal wetlands. Therefore, the core zone of YNNR was selected as the case area in the present study, the location of which is shown in *Figure 1*. As a typical silting tidal flat wetland, the core zone of YNNR is about $1.92 \times 10^4$ $hm^2$, and its main protected objects are rare species such as red-crowned cranes and their habitats. According to the ecosystem characteristics of the study area and the definition of wetland in the ‘*Wetland Convention*’, the landscape types are divided into the natural wetland, the constructed wetland, and the non-wetland. Natural wetlands include *Phragmites australis* (*P. australis*) marsh, *Spartina alterniflora* (*S. alterniflora*) marsh, *Suaeda salsa (S. salsa)* marsh, mudflats, and rivers, while constructed wetlands and non-wetlands refer to aquaculture ponds and roads (embankments), respectively.

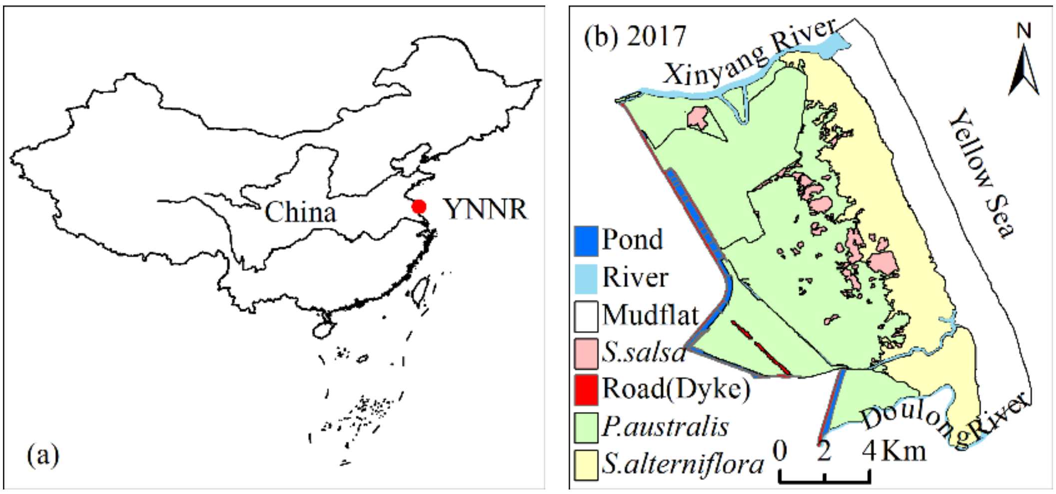


***Figure 1.*** *(a) The Yancheng National Nature Reserve (YNNR) is located in the central east coast of China; (b) The scope of the core zone of the YNNR and Landscape classification in 2017*

### *Data source*

According to the principle of combining important event nodes with processes, seven remote sensing images were selected as the landscape data sources. The sensing images include: the MSS images of 1983 when the study area became a provincial nature


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reserve, the TM image of 1992 when the Yancheng coastal wetlands was promoted to a National Nature Reserve, the TM image of 1987, the TM images of the second year after the implementation of the ‘*Marine Sudong’* strategy and becoming a member of the ‘*Northeast Asia Crane Protection Network’* and the year when Spartina alterniflora expanded into larger patches (1997), the ETM+ image of 2007 when the reserve was renamed as ‘Jiangsu Yancheng Wetlands Rare Birds National Nature Reserve’, the ETM+ image of 2017 when Jiangsu Province launched the construction of the Special Ecological Zone and the Yancheng coastal wetlands was listed in the preliminary list of World Natural Heritage Sites as well as the GF-1 image of 2021 when the Yancheng coastal wetlands had successfully applied for World Heritage. The specific information of the remote sensing images are shown in *Table 1*. Due to the failure of the Landsat-7 ETM+ airborne scanner after 2003, it is necessary to perform seven-stage strip removal processing in ENVI 5.0, and then perform atmospheric correction and geometric correction on the images. The remote sensing images were interpreted by Unsupervised Classification and Decision Tree Classification Method combined with field verification in ENVI 5.0. And a series of landscape-type maps were drawn in Arcgis10.0.

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

| Time | Sensor | Strip No. | Row No. | Cloud cover |
|---|---|---|---|---|
| 1983.04.04 | Land4-MSS | 119 | 37 | 20% |
| 1987.06.10 | Land5-TM | 119 | 37 | 1.18% |
| 1992.04.20 | Land5-TM | 119 | 37 | 0 |
| 1997.05.20 | Land5-TM | 119 | 37 | 0 |
| 2007.05.08 | Land7-ETM | 119 | 37 | 0.05% |
| 2017.04.01 | Land7-ETM | 119 | 37 | 0.13% |
| 2021.09.22 | GF1-PMS2 | 596 | 99 | 0 |

### *Construction of evaluation index system*

Based on landscape structure, pattern characteristics, and the requirements of habitat function in the Yancheng coastal wetlands, fourteen indicators were selected from the perspective of ‘state-pressure-response’ to build an index system for evaluating the landscape habitat stability. The specific index system is shown in *Table 2*.

### *Standardization of data*

The original data were different in dimension and size. To eliminate their influence on the calculation results, the data were first standardized. In this paper, the normalization method was adopted to standardize the original data (0-1), which is expressed as follows:

$$\text{Positive indexes: } X_i' = \frac{X_i}{MaxX_i} \quad \text{(Eq.1)}$$

$$\text{Negative indexes: } X_i' = 1 - 0.9 \times \frac{X_i}{MaxX_i} \quad \text{(Eq.2)}$$

$X'_i$ in the formula is the standardized value of the indexes, $X_i$ is the original value, $MaxX_i$ represents the maximum value.


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When calculating the total development score of each system, it is necessary to assign weight to each index in the system. Weighting methods are divided into subjective and objective methods. In this paper, the entropy method in the objective weighting method was adopted to determine the weight of each index in the system, which can avoid the defects of the subjective valuation method to a certain extent.

***Table 2.*** *Evaluation index system of landscape habitat stability in Yancheng coastal wetlands*

| First-grade indexes | Second-grade indexes | Third-grade indexes | Fourth-grade indexes | Index feature |
|---|---|---|---|---|
| Landscape habitat stability | Niche 'State' | State | Largest Patch Index (LPI) | + |
| | | | The proportion of *Suaeda salsa* marsh area | + |
| | | | The proportion of natural wetland area | + |
| | | Pressure | The proportion of *Spartina alterniflora* marsh area | - |
| | | | The proportion of non-wetland area | - |
| | Niche 'Potential' | Response | Landscape Shape Index (LSI) | + |
| | | | Shannon´s Evenness Index (SHEI) | + |
| | | | Total Edge (TE) | - |
| | | | Core Area_Mean (CORE_MN) | + |
| | | | Aggregation Index (AI) | + |
| | | | Interspersion Juxtaposition Index (IJI) | + |
| | | | Fractal Dimension Index_Mean (FRAC_MN) | + |
| | | | Number of Red-crowned cranes Population | + |
| | | | Shannon´s Diversity Index (SHDI) | + |

### *Niche breadth and overlap*

Niche breadth is used in biology to characterize the degree of occupation or utilization of resources by species, the greater of which, the more resources occupied or utilized by species. We set the niche breadth to measure the response degree of Yancheng coastal wetlands landscape habitat stability to each index, or the niche breadth reflects the development degree of each index to measure the coastal wetland landscape habitat stability. The wider the niche breadth in a specific year, the more stable the landscape habitat is. In this paper, the Shannon-Wiener index was selected to measure niche breadth, which is shown as follows (Wang et al., 2022d; Shi et al., 2020):

$$B_i = -\sum_{j=1}^{n} (M_{ij} \ln M_{ij}) \quad \text{(Eq.3)}$$

In the formula, $B_i$ refers to the niche breadth of landscape habitat stability in the *i* year, $M_{ij}$ represents the proportion of the *j* index of landscape habitat stability in the *i* year in all measured years.

Niche overlap is used to evaluate the stability of landscape habitat over time. The higher the niche overlap, the minor change of landscape habitat, indicating a good state


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of landscape habitat stability. In this paper, the Schoener Overlap Index was used to calculate the niche overlap between different years, which is expressed as follows:

$$Q_{ik} = 1 - \frac{1}{2}\sum_{j=1}^{n}|M_{ij} - M_{kj}| \qquad \text{(Eq.4)}$$

In the formula, $Q_{ik}$ is the niche overlap value of landscape habitat stability in the year *i* and the year *k*, which is in the range of [0,1].

### *Analysis of niche 'state-potential'*

The landscape stability of the Yancheng coastal wetlands was evaluated from static and dynamic aspects using the niche 'state-potential' theory (see *Table 1*). Niche 'State' is the structural state of the coastal wetlands at patch and type scale. In contrast, niche 'potential' refers to the response of the coastal wetlands to the accumulation of structural condition in function. The calculating formulas are as follows:

$$N_i = \frac{S_i + A_i P_i}{\sum_{i=1}^{n} S_i + A_i P_i} \qquad \text{(Eq.5)}$$

$$S_i = \sum_{j=1}^{5} X'_{ij}\omega_j \qquad \text{(Eq.6)}$$

$$P_i = \sum_{j=6}^{14} X'_{ij}\omega_j \qquad \text{(Eq.7)}$$

In the formulas, $N_i$ is the niche value of landscape habitat stability in the *i* year, the higher of which, the more significant the landscape habitat stability in the corresponding year; $S_i$ represents the niche 'state' value of landscape habitat stability in the *i* year, $\omega_j$ is the weight of each index, $P_i$ represents the niche 'potential' value of landscape habitat stability in the *i* year, $A_i$ is the dimensional conversion coefficient, which value was set as one (Shi et al., 2020).

$$\rho = \frac{\Delta N}{\Delta T} \qquad \text{(Eq.8)}$$

In *Equation 8*, $\rho$ is the annual gradient of niche of landscape habitat stability, $\Delta N$ is the change value of niche of landscape habitat stability in a specific period and $\Delta T$ represents the corresponding time interval.

### *Analysis of niche expansion*

The degree of niche expansion was chosen to evaluate the sustainable development trend of landscape habitat stability in the Yancheng coastal wetlands. And the formula is as follows (Shi et al., 2020):

$$T_i = \frac{P_i}{S_i} \qquad \text{(Eq.9)}$$


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## Results

### *Landscape structure and pattern change*

As shown in *Figure 2*, from 1983 to 2021, the landscape of the core zone of YNNR was composed of *P. australis* marshes, *S. salsa* marshes, *S. alterniflora* marshes, mudflats, aquaculture ponds, construction land, rivers, etc. And the landscape structure changed significantly over time, with the *P. australis* marshes showing a trend of increasing first, then decreasing, and then increasing, while *S. alterniflora* marshes expanded continuously and *S. salsa* marshes increased first and then decreased. Detailed landscape change data are shown in *Table 3*.

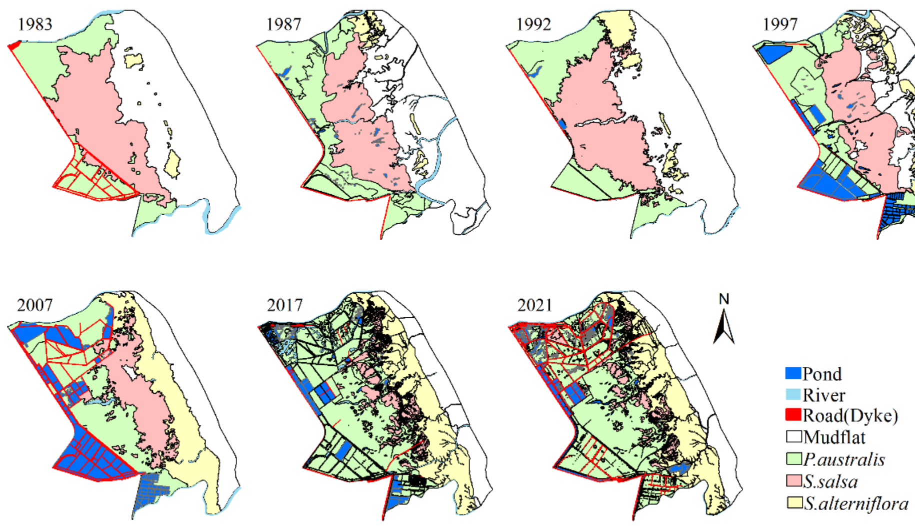


***Figure 2.*** *Landscape changes in the study area*

***Table 3.*** *Landscape change in the study area from 1983 to 2021*

| Year | | 1983 | 1987 | 1992 | 1997 | 2007 | 2017 | 2021 |
|---|---|---|---|---|---|---|---|---|
| Dyke | Area ($hm^2$) | 0 | 194.492 | 107.205 | 88.779 | 505.535 | 200.650 | 197.058 |
| | Percentage (%) | 0 | 1.090 | 0.604 | 0.498 | 2.849 | 1.125 | 1.105 |
| Aquaculture pond | Area ($hm^2$) | 200.389 | 48.751 | 54.094 | 1682.690 | 2853.716 | 847.760 | 1462.539 |
| | Percentage (%) | 1.125 | 0.273 | 0.305 | 9.431 | 16.083 | 4.752 | 8.197 |
| River | Area ($hm^2$) | 399.733 | 580.397 | 186.379 | 612.214 | 254.735 | 787.205 | 280.192 |
| | Percentage (%) | 2.244 | 3.253 | 1.050 | 3.431 | 1.436 | 4.412 | 1.571 |
| *Phragmites australis* | Area ($hm^2$) | 3696.393 | 4772.496 | 3940.026 | 3762.061 | 4821.762 | 7874.106 | 7890.527 |
| | Percentage (%) | 20.749 | 26.750 | 22.205 | 21.086 | 27.174 | 44.134 | 44.226 |
| *Suaeda salsa* | Area ($hm^2$) | 5175.955 | 4114.097 | 5099.117 | 3841.603 | 2970.264 | 1684.229 | 1421.486 |
| | Percentage (%) | 29.055 | 23.059 | 28.737 | 21.532 | 16.740 | 9.440 | 7.967 |
| *Spartina alterniflora* | Area ($hm^2$) | 329.461 | 542.422 | 1009.103 | 1934.657 | 3613.002 | 4100.242 | 4124.361 |
| | Percentage (%) | 1.849 | 3.040 | 5.687 | 10.844 | 20.362 | 22.982 | 23.117 |
| Mudflat | Area ($hm^2$) | 8012.535 | 7588.782 | 7347.961 | 5919.435 | 2724.873 | 2347.247 | 2465.277 |
| | Percentage (%) | 44.978 | 42.535 | 41.411 | 33.178 | 15.357 | 13.156 | 13.818 |

The *P. australis* marshes gradually expanded eastward from the west of the study area, and the area ratio increased from 20.7493% in 1983 to 44.2258% in 2021. Being


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

converted into aquaculture ponds was the main reason for the decrease of *P. australis* marshes from 1987 to 1997. It also induced the area of aquaculture ponds to experience a process of expansion, reduction, and restoration into the marsh. In 2021, the percentage of *S. alterniflora* marshes area increased from 1.8494% to 23.1167%. The rate of *S. salsa* marshes area increased to 28.7373% in 1992, but decreased to 7.9673% in 2021, which was due to the bidirectional compression of the *P. australis* marshes and *S. alterniflora* marshes. The proportion of non-wetland areas has been maintained at a low level. Shallow, loose *P. australis* marshes, and *S. salsa* marshes are the wintering habitats that red-crowned cranes often choose. The continuous decrease of the *S. salsa* marshes seriously affected the habitat quality and the stability of landscape habitats in the study area.

To further clarify the landscape pattern characteristics of the study area, the indexes of Largest Patch Index (LPI), Total Edge (TE), Fractal Dimension Index_Mean (FRAC_MN), Core Area_Mean (CORE_MN), Landscape Shape Index (LSI), Aggregation Index (AI), Interspersion Juxtaposition Index (IJI), Shannon's Diversity Index (SHDI) and Shannon's Evenness Index (SHEI) were selected to characterize the landscape pattern changes in the study area from 1983 to 2021 (see *Table 4*).

The results showed that, the value of LPI ranged from 20 to 45, presenting an evident characteristic of decreasing first and then increasing. TE rose from 199,280 in 1983 to 704,754 in 2021 with a fluctuating upward trend, reflecting the direction of landscape fragmentation in the study area. FRAC_MN increased from 1.1177 in 1983 to 1.2244 in 2021, showing that the study area was less and less disturbed by humans. CORE_MN decreased from 148.454 in 1983 to 19.4351 in 2021, the apparent downward trend of which also reflected the characteristics of landscape fragmentation. LSI increased from 5.3263 in 1983 to 14.7963 in 2021, indicating that the landscape shape was becoming more and more complex. The AI value decreased from 96.1946 to 85.9806, showing the characteristics of fluctuating decrease. IJI increased from 66.2619 in 1983 to 75.2608 in 1997, then reduced to 66.1825 in 2017, exhibiting a trend of rising first and then falling. Both SHDI and SHEI showed the characteristics of rising first and then falling.

***Table 4.*** *Landscape pattern changes in the study area*

| Index category | Pattern indexes | 1983 | 1987 | 1992 | 1997 | 2007 | 2017 | 2021 |
|---|---|---|---|---|---|---|---|---|
| Area-Edge | LPI | 44.9776 | 41.8356 | 41.2727 | 31.8923 | 20.6723 | 43.9727 | 43.9037 |
| | TE | 199280 | 351517 | 266408 | 488056 | 496982 | 703537 | 704754 |
| Shape | FRAC_MN | 1.1177 | 1.1782 | 1.1515 | 1.1816 | 1.1828 | 1.2200 | 1.2244 |
| Core area | CORE_MN | 148.4542 | 44.8277 | 133.4127 | 35.8262 | 47.8272 | 18.5077 | 19.4351 |
| Aggregation | LSI | 5.3263 | 8.1863 | 6.5961 | 10.7413 | 10.9224 | 14.7735 | 14.7963 |
| | AI | 96.1946 | 93.0843 | 94.9079 | 90.4452 | 90.4668 | 86.025 | 85.9806 |
| | IJI | 66.2619 | 71.4231 | 67.3804 | 75.2608 | 71.159 | 70.2958 | 66.1825 |
| Diversity | SHDI | 1.2543 | 1.3377 | 1.317 | 1.6306 | 1.7212 | 1.5215 | 1.4945 |
| | SHEI | 0.7000 | 0.6874 | 0.6768 | 0.8380 | 0.8845 | 0.7819 | 0.7680 |

### *Analysis of niche breadth*

The niche breadth of landscape habitat stability in the study area from 1983 to 2021 was obtained by standardizing the data of evaluation indexes in *Table 2* and


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

calculating by *Equation 3*. From 1983 to 2021, the niche breadth of landscape habitat stability ranged from 2.4297 to 2.6187, representing an overall trend of rising first, then falling, and then rising over time. The highest value of niche breadth appeared in 1992 when the study area had just been upgraded to a National Nature Reserve. The lowest value appeared in 2017 when the importance of ecological protection began to be emphasized because of the study area becoming a Unique Environmental Zone of Jiangsu Province. And the niche breadth rebounded by 2021. In general, the niche breadth of landscape habitat stability in the Yancheng coastal wetlands fluctuated little between years with a coefficient of variation of 2.904%, which fluctuated around the value of 2.5.

In addition, it was found that the Niche Breadth (B) showed opposite trends with the SHDI, although both are based on the Shannon-Wiener diversity index method, as shown in *Figure 3*. This is mainly because the SHDI is obtained based on landscape type and quantity, while the Niche Breadth method pays more attention to landscape pattern and function. The peak of SHDI appeared in 2007-2017. The peak of niche breadth appeared in 1992, mainly related to the evaluation indexes and their weight of landscape habitat stability. For example, in the evaluation index system, the importance of the functional status of the red-crowned cranes overwintering habitat was emphasized, whose weight was set as 0.139. However, SHDI was only used as an index in the evaluation system, and its weight was only 0.004.

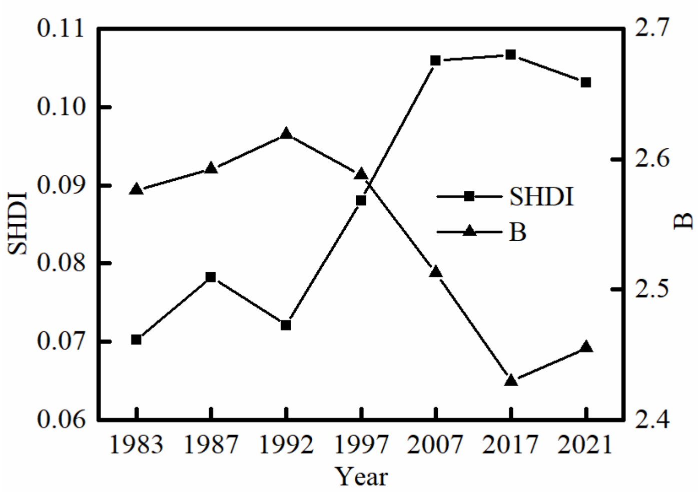


***Figure 3.*** *Comparison of SHDI and Niche Breadth*

### *Analysis of niche overlap*

According to *Equation 4*, the niche overlap of the Yancheng coastal wetlands landscape habitat over time was calculated to display the development of landscape habitat stability, as shown in *Table 5*.

It was found from *Table 5* that the niche overlap of landscape habitat stability in the Yancheng coastal wetlands presented the characteristics of 'the higher the ecological overlap, the stronger the landscape habitat stability' and 'the longer the time interval, the lower the niche overlap'. And this was a response to the dual effects of nature and human beings. In general, the niche overlap of Yancheng coastal wetlands landscape habitat stability was high in different years, and there was still


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

more than 50% overlap in the time variation of nearly 40 years, indicating that the landscape habitat was relatively stable. Furthermore, the niche change rate was calculated based on the niche overlap degree. The niche change rate of landscape habitat stability in the Yancheng coastal wetlands generally showed a fluctuating downward trend. The annual gradient of the niche reached the highest of 0.0473 between 1992 and 1997. Meanwhile, the lowest annual gradient of the niche was 0.0154, occurring between 2017 and 2021.

***Table 5.*** *Niche overlap of landscape habitat stability in the Yancheng coastal wetlands*

| Time | 1983 | 1987 | 1992 | 1997 | 2007 | 2017 | 2021 |
|---|---|---|---|---|---|---|---|
| 1983 | 1.0000 | | | | | | |
| 1987 | 0.8182 | 1.0000 | | | | | |
| 1992 | 0.8878 | 0.8501 | 1.0000 | | | | |
| 1997 | 0.6590 | 0.8226 | 0.7635 | 1.0000 | | | |
| 2007 | 0.5294 | 0.6468 | 0.6052 | 0.7727 | 1.0000 | | |
| 2017 | 0.5363 | 0.6433 | 0.5337 | 0.6655 | 0.6546 | 1.0000 | |
| 2021 | 0.5071 | 0.6648 | 0.5723 | 0.7019 | 0.6746 | 0.9384 | 1.0000 |

### *Niche analysis of landscape habitat stability*

As mentioned above, the niche ‘state’ mainly focuses on the number and type of patches in the coastal wetlands landscape. In this paper, we considered the niche ‘state’ as the accumulation of the landscape evolution in the study area over time. In the index system, the niche ‘state’ was represented from two dimensions of ‘state’ and ‘pressure’. Meanwhile, the niche ‘potential’ was considered as the result of landscape structure evolution, which was reflected by landscape pattern and habitat function. The indexes were selected from the dimension of ‘response’ to evaluate the niche ‘potential’. The entropy weight method was conducted to assess the landscape habitat stability and its subsystems, and finally realize it through SPSS16 software, as shown in *Table 6*. The results showed that the weights of several factors which have greatly influence on the landscape habitat of the Yancheng coastal wetlands were significant, which confirmed the rationality of the index system. As the index reflects the invasion of alien species, the weight of ‘The proportion of Spartina alterniflora marsh area’ index was 0.2151. In the ‘potential’ index system, the importance of the TE index and the CORE_MN index, representing the landscape fragmentation and integrity, were 0.1543 and 0.2345, respectively. And the index weight of the ‘Number of Red-crowned cranes Population’, which was used to exhibit the habitat quality, was 0.1557.

Analyzing the result from the perspective of ‘P-S-R’, as shown in *Table 7*, the ‘state’ index of landscape habitat stability in the study area was the highest in 1983 and 1992, and showed a significant downward trend after 1992, while the ‘state’ value was only 0.0439 in 2021. From 1983 to 2021, the ‘pressure’ value of landscape habitat stability showed a significant downward trend. Since the negative attribute of the ‘pressure’ index, after standardization, the smaller the ‘pressure’ value, the greater the pressure on landscape habitat stability. From 1983 to 2021, the ‘response’ value of habitat stability of coastal wetland landscape exhibited the characteristic of rising first, then falling, and then rising over time. The highest value was 0.2516 in 1992, then decreased to the lowest in 2017, and increased again in 2021.


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

***Table 6.** Index weight of landscape habitat stability of Yancheng coastal wetlands*

| Second-grade indexes | | Third-grade indexes | | Fourth-grade indexes | |
|---|---|---|---|---|---|
| **Code** | **Weight** | **Code** | **Weight** | **Code** | **Weight** |
| NS | 0.3956 | S | 0.0987 | X1 | 0.0221 |
| | | | | X2 | 0.0745 |
| | | | | X3 | 0.0021 |
| | | P | 0.2969 | X4 | 0.2150 |
| | | | | X5 | 0.0819 |
| NP | 0.6044 | S | 0.6044 | X6 | 0.0492 |
| | | | | X7 | 0.0038 |
| | | | | X8 | 0.1543 |
| | | | | X9 | 0.2345 |
| | | | | X10 | 0.0007 |
| | | | | X11 | 0.0008 |
| | | | | X12 | 0.0004 |
| | | | | X13 | 0.1557 |
| | | | | X14 | 0.0050 |

***Table 7.** Landscape habitat stability analysis in the core zone of Yancheng coastal wetlands*

| Time | ‘State’ | | ‘Potential’ | | Niche | | State | Pressure | Response |
|---|---|---|---|---|---|---|---|---|---|
| | **Value** | **Ranking** | **Value** | **Ranking** | **Value** | **Ranking** | | | |
| 1983 | 0.2143 | 3 | 0.2415 | 2 | 0.2084 | 2 | 0.0987 | 0.2021 | 0.3999 |
| 1987 | 0.2184 | 2 | 0.1520 | 5 | 0.1693 | 3 | 0.0818 | 0.1921 | 0.2516 |
| 1992 | 0.1990 | 1 | 0.2621 | 1 | 0.2108 | 1 | 0.0958 | 0.1695 | 0.4340 |
| 1997 | 0.1631 | 4 | 0.1911 | 3 | 0.1619 | 4 | 0.0726 | 0.1265 | 0.3163 |
| 2007 | 0.0529 | 7 | 0.1826 | 4 | 0.1077 | 5 | 0.0546 | 0.0459 | 0.3023 |
| 2017 | 0.0683 | 5 | 0.0760 | 7 | 0.0660 | 7 | 0.0474 | 0.0242 | 0.1258 |
| 2021 | 0.0668 | 6 | 0.0994 | 6 | 0.0760 | 6 | 0.0439 | 0.0235 | 0.1646 |

As shown in *Figure 4*, the ‘state’ value, the ‘potential’ value, and the niche of landscape habitat stability in the study area changed significantly from 1983 to 2021. Niche ‘state’ overall showed a downward trend, and rose slightly in the later period. The ‘state’ value was the highest in 1992, when the proportion of natural wetland and *S. salsa* marshes peaked, the ratio of *S. alterniflora* marshes and non-wetland was only 5.6870% and 0.6042%, respectively. The ‘state’ value was the lowest in 2007, when the proportion of natural wetlands decreased to 81.0681% and the ratio of non-wetland increased to 2.8491%. These indicated the evolution trend of landscape structure in the study area that the area of local vegetation of *S. salsa* marshes decreased continuously while the exotic species of *S. alterniflora* marshes had been expanding. The increase of *S. salsa* marshes after 2017 was mainly due to the restoration project of *S. salsa* marshes in the northern part of the study area and the implementation of the ‘return of fishing to marsh’ project in the southwestern part.

As a response to the niche ‘state’, the niche ‘potential’ showed a trend of rising first, then falling, and then rising as a whole. The highest value of the niche ‘potential’ was


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

0.2621 in 1992, then decreased to the lowest in 2017. The evolutionary trend of the niche ‘potential’ also indicated to some extent that the response of the niche ‘potential’ to the niche ‘state’ had a lag effect. The evolution trend of niche ‘potential’ could be further reflected by the variation of some specific indicators. In 1992, the TE of the study area was 266,408.6740 m, only higher than that in 1983. The CORE_MN was the highest in 1992, which was 133.4127 $hm^2$, while the overwintering population of red-crowned cranes was 319, which was only less than the quantities of 1997 and 2007. In 2017, the TE of the core zone of YNNR reached the highest, while the CORE_MN value and the ‘Number of Red-crowned cranes Population’ value were the lowest.

The niche value was the highest in 1992 and the lowest in 2017, consistent with the trend of the niche ‘potential’, showing a trend of rising first, then falling, and then rising as a whole. The annual growth rate of the niche was 0.0002 in the first period from 1983 to 1992, while the niche value declined with an annual change rate of -0.0058 from 1992 to 2017. From 2017 to 2021, the niche value experienced an upturn with a yearly rate of 0.0025. It can be seen from the evolution characteristics of the niche value that the improvement of the niche was relatively arduous and slow, while the decline of it was relatively fast. Therefore, scientific protection strategies should be strengthened in the core zone of YNNR to reduce human disturbance. In short, the niche is the result of the combined effect of ‘state’ and ‘potential’, and the changing trend of the niche is closely related to regional development and protection policies and natural evolution characteristics.

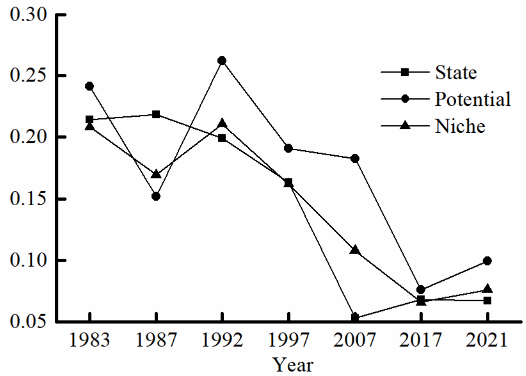


***Figure 4.*** *Niche changes*

## *Analysis of niche expansion*

According to *Equation 9*, the niche expansion of landscape habitat stability in the core zone of YNNR was obtained through the further calculation of niche ‘state’ and ‘potential’, as shown in *Figure 5*. The results showed that, the niche expansion values in different years of the study period were greater than one except for 1987, with the highest value of 3.4519 in 2007 and the lowest value of 0.6960 in 1987. In 1987, the niche ‘state’ value reached a relatively high level, which resulted in the limitation of the ‘state’ value to rise. Meanwhile, the niche ‘potential’ value was relatively low. Therefore, the niche expansion in 1987 was the weakest because of the affection of the ‘state’ value on the ‘potential’ value. When the niche ‘state’ of the landscape was already in a relatively suitable situation, the space for the ‘state’ to be promoted was limited, directly affecting the increasing room for the niche ‘potential’. In contrast to


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DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

1987, the niche ‘state’ value was at the lowest level in 2007, while the niche ‘potential’ value was relatively high. Therefore, the niche expansion value was the highest in 2007. The low level of niche ‘state’ reserved more space for subsequent improvement. The niche ‘state’ was able to be continuously optimized through ecological engineering, thereby further increasing the niche ‘potential’ value.

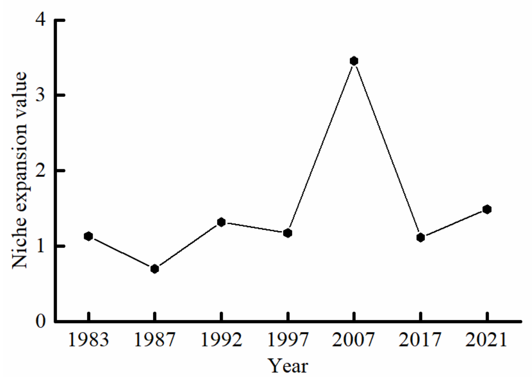


***Figure 5.*** *Niche expansion changes*

The upward trend of the niche expansion indicated that the ecological landscape of the core zone of YNNR had been getting better and better, especially after the study area became the ecological protection zone of Jiangsu Province in 2017. With the successful application and approval of Yancheng coastal wetlands as a World Natural Heritage Site in 2019, the intensity of ecological protection and scientific management has been further strengthened. The quality of landscape habitat will undoubtedly improve with the further enhanced trend of niche expansion.

## Conclusions and discussion

### *Conclusions*

Based on the seven remote sensing images from1983 to 2021, empirical research was conducted on the landscape habitat stability of the core zone of YNNR, and the following conclusions were drawn:

1. From 1983 to 2021, the landscape pattern of the core zone of YNNR changed significantly. Overall, the *P. australis* marshes and *S. alterniflora* marshes expanded significantly, while the area of the *S. salsa* marshes decreased continuously under the compression of the two. The nine landscape pattern indexes exhibited three different evolutionary trends, with the indexes of LPI, IJI, SHDI, and SHEI decreasing first and then increasing, the TE, FRAC_MN, and LSI showing a fluctuating upward trend, while CORE_MN and AI representing a fluctuating downward trend.

2. The niche breadth value of landscape habitat stability in the study area ranged from 2.4297 to 2.6187 with a low degree of variation, showing a trend of rising first, then falling, and then rising. The niche overlap of landscape habitat stability in the core zone of YNNR exhibited a high level in different years, with more than 50% overlap in the past 40 years. The evolution characteristics of the niche breadth and the niche overlap both indicated that the landscape habitat stability in the study area was in favorable condition.


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2103_23232340

3. The niche value of landscape habitat stability in the core zone of YNNR was the highest (0.2084) in 1992 and the lowest (0.0660) in 2017, showing a trend of rising first, then falling, and then rising. The annual gradient of the niche was the highest from 1992 to 2017 and the lowest from 2017 to 2021. The niche expansion values in different years of the study period were greater than one except for 1987, with the highest value of 3.4519 in 2007 and the lowest value of 0.6960 in 1987. The slow upward trend of the niche expansion indicated that the overall development trend of landscape habitat quality of the Yancheng coastal wetlands is good.

## *Discussion*

Based on the above research conclusions, this paper proposed the following discussion:

1. Human activities have two-way effects on the stability of regional landscape habitat. We defined the disturbance that plays a positive role in changing the structure and function of landscape or ecosystem as an ecologically positive disturbance; otherwise, it is an ecologically negative disturbance (Wang et al., 2021; Xie et al., 2022). The ecologically positive disturbance in the core zone of YNNR mainly refers to the environmental restoration based on habitat function maintenance to promote habitat stability and ecologically sustainable development. These ecological restoration measures carried out in the study area mainly include ecological projects such as returning farmland to wet and returning fishing to marshes, as well as measures such as mowing to control *S. alterniflora* marshes, improving the habitat of red-crowned cranes through water system connectivity and *S. salsa* marshes restoration (Li, 2021), and shallow water hidden ecological projects in the wintering habitat of red-crowned cranes in the north part of the study area. Through these environmental restoration projects, the niche breadth value and the niche value increased from 2.430 and 0.066 in 2007 to 2.455 and 0.076 in 2021, respectively. Relevant research showed that, the human activity intensity index in the core zone of YNNR was less than 0.01 during 1983 to 1992 while it increased rapidly to 0.107 during 1992 to 2007. From 2007 to 2014, the human activity intensity index was between 0.08 and 0.09, showing a relatively stable state. Since 2014, the human activity intensity index has shown a significant downward trend, which has decreased by 80% compared with 2007 (Zhang, 2021). This trend not only verified the scientific nature of the change trend of landscape habitat stability, but also further indicated that human activities were the main driving factors for the change of landscape habitat stability in the study area.

Excavation of aquaculture ponds and construction of dams were the dominant negative disturbances in the study area. These human activities have destroyed the landscape structure and function of the Yancheng coastal wetlands, resulting in reduced habitat stability. The expansion of artificial aquaculture ponds and the extension of dams blocked the exchange of materials and energy in ecosystems, and at the same time led to habitat fragmentation (Yan et al., 2022). Landscape connectivity, vegetation cover types, and even natural succession of vegetation in the core zone of YNNR were also affected accordingly. In addition, the east-west roads in the middle of the study area, which artificially divide the YNNR into north and south parts, have exerted a significant barrier effect on the landscape habitat stability. In 2007, the proportion of non-wetland in the core zone of YNNR reached 2.8%, and human disturbance was the largest, resulting in the lowest ‘state’ value and relatively low niche value of the study area in 2007.


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2. The natural evolution of the landscape in the study area is the basis for the change of habitat stability. Because of the strict environmental protection policy implemented in YNNR, the impact of human disturbance is relatively small, while the natural evolution of the landscape plays a crucial role in the change of landscape structure, pattern, and function. The area of shallow *P. australis* marshes and *S. salsa* marshes is the main factors limiting the distribution of red-crowned cranes (Cao et al., 2016). On the one hand, the continuous expansion of tall and dense reeds and *S. alterniflora* marshes resulted in the lack of open natural water surface and suitable reed shelter (Wang et al., 2022a), and this made the habitat not suitable for the inhabitation of red-crowned cranes. On the other hand, under the two-way extrusion of *S. alterniflora* marshes and *P. australis* marshes, the area ratio of *S. salsa* marshes decreased from 21.5% in 1997 to 8% in 2021, resulting in the continuous reduction of the suitable habitat area of wintering habitat for red-crowned cranes. In particular, the invasion of *S. alterniflora* marshes had changed the hydrogeomorphic process and material exchange function of the Yancheng coastal wetlands, along with destroying the original ecological structure (Wang et al., 2021, 2022c), which is the main reason for habitat degradation in the study area. By 2017, the area proportion of the *S. alterniflora* marshes community had expanded to 23%, and the corresponding niche value had dropped to the lowest of 0.0660. Some studies further compared the effect of human activities and *S. alterniflora* marshes expansion on landscape habitat stability in the study area, pointing out that before 1992, the effects of the two were both weak. In 1997 and 2007, the impact of human activities on landscape habitat stability was greater than that of *S. alterniflora* marshes expansion, while it showed the opposite characteristics in 2017 and 2021 (Zhang, 2021).

3. Strengthening the supervision of human activities and ecological restoration is the way to improve landscape habitat stability in the core zone of YNNR. On the one hand, it is necessary to further strengthen the positive role of human activities in the healthy development of the ecosystem according to the requirements of the sustainable construction of YNNR. Moreover, it is of great significance to carry out proper management, scientific research, education, ecological tourism, and other activities to reduce the negative environmental interference of human activities. On the other hand, the systematic monitoring of landscape patterns and ecological processes in the study area should be paid more attention to make a real-time diagnosis of the landscape habitat quality. From the perspective of ‘pattern-process-function’ and ‘substrate-corridor-node’, the ecological restoration of coastal wetlands based on Nature-Based Solutions should be actively carried out to continuously optimize the landscape pattern and improve the quality of landscape habitats.

**Acknowledgements.** This research was supported by National Natural Science Foundation of China (No. 41771199, No. 42106170), Basic Research Projects of North Jiangsu Institute of Agricultural and Rural Modernization (No. 21NYNC005, No. 22NYNC001), Natural Science Research Projects of Jiangsu Province (No. BK20210948)

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