Study on wetland landscape pattern evolution in the Dongping Lake

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Abstract
Wetland structure evolution is a basis of healthy ecosystem and one of the important indicators for restoration and protection of wetlands. In this paper, based on the Landsat remote sensing images from 1980 to 2020, the wetland structure was extracted by using the supervised classification method in the Dongping Lake. A CA–Markov Model was put forward to set up wetland transfer matrix and to improve the space and quantity of simulation results. The temporal-spatial evolution of the wetland and landscape indicators were studied, and the evolution trend as well as driving forces were analyzed. The studied results show that, in recent years, the wetland landscape pattern transfer were occurred continuously, in which the area of bare land significantly decreased, the infrastructure land use significantly increased, the natural water surface increased gradually. The studied landscape pattern indices show that the wetland landscape evenness index increased, the landscape diversity index tends to be decreased, the degree of wetland landscape fragmentation is basically balanced, but the overall trend is increasing, and the landscape diversity tends to be simple. At present, the area of wild reeds takes the dominant trend in the main wetland area, which accounts for 55% of the total wetland area. The proportion of forest and grass land area accounts for 9%.

Keywords Wetland evolution · Landscape pattern and variation · Index evaluation · The Dongping Lake

Introduction
Global climate change and the disturbance of human activities result in wetland ecological environment deteriorated (Gill et al. 2018). Wetland restoration and protection are facing a great challenge. The study of wetland structure evolution plays an important role in protecting the rational structure and diversity of wetland and promoting the sustainable wetland ecosystem development (Davidson 2014; Xu et al. 2019).

In recent years, a lot of researchers have studied the wetland landscape patterns (Chang et al. 2014). In 2017, Jiang et al. conducted a study on marsh wetland degradation risk assessment and change analysis. They selected a case study in the Zoige Plateau of China and achieved important results (Jiang et al. 2017). In 2015, Dronova carried out a study on object-based image analysis in wetland research (Dronova 2015). In 2016, Liu et al. used the TM image data (1989–2014) to classify and calculate the wetland index by using artificial visual identification, which reflects the intensity of human activities. The impact of human activities on the Yellow River delta was analyzed from a quantitative point (Liu et al. 2016).

From the viewpoint of data, with the rapid development of remote sensing technology, in recent years, high resolution series and aerial photography data have become the mainstream of wetland dynamic monitoring (Fu et al. 2013; Mui et al. 2015). In 2013, Klemas studied the high resolution images, low-medium resolution images and aerial photograph data to find that the long-term and short-term changing trend of wetland vegetation and hydrology can be effectively determined by conjunctive use of satellite images, aerial images and ground observation survey data (Klemas 2013). Data conjunctive use has become the mainstream trend of wetland information collection in recent years (Dong et al. 2016).

From the perspective of classification method, the traditional classification method is based on supervised and unsupervised classification, which only takes into account the spectral information of images (Escorihuel et al. 2016). In 2017, Li et al. put forward an early warning method on ecological risk and its application to improve landscape ecological security pattern regulation, which combines regional
and stratification information to improve the accuracy of traditional classification method, the precision was increased from 85.8 to 91.97%, which greatly improves the accuracy of wetland classification (Li et al. 2017). In 2018, by using the Landsat satellite images and taking the wetland in the south bank of Hangzhou Bay as the study area, Mao et al. used the objective-oriented method to classify the wetland landscape (Mao et al. 2018). The studied results were compared with the corresponding classification results obtained by using the maximum likelihood method, artificial neural network and support-vector machine method to prove that the objective-oriented method has higher classification accuracy. In 2013, Liu et al. used regional classification method to identify wetland landscape in eastern coastal China (Liu et al. 2013). In 2017, Mu et al. used the remote sensing data of the Yellow River Delta from the six phases of Landsat series to extract the information of human activities. Based on the objective-oriented decision tree algorithm, the landscape patterns were classified and the changing rate, transfer types and other characteristics were analyzed (Mu et al. 2000). In 2020, Li et al. made an ecological risk assessment of the wetlands in Beijing-Tianjin-Hebei urban agglomeration and obtained risk situation for the coming years (Li et al. 2020).

In 2018, Wu et al. made an assessment of ecological vulnerability in the Yellow River Delta using the fuzzy analytic hierarchy process (Wu et al. 2018). In 2019, Fernandez et al. studied landscape indicators and ecological condition for mapped wetlands in Pennsylvania, USA, (Fernandez et al. 2019) and made a detail analysis on ecological indicators in the studied region.

In the studies mentioned above, manual vector and image-based classification methods are mostly applied. Unfortunately, the manual vector classification method has the disadvantages of complex artificial interference factors, high cost and heavy workload. The traditional image-based classification methods result in large degree of fragmentation. The minimum unit of object-oriented image analysis is a single object rather than an entire image.

Considering the Dongping Lake landscape construction and development situation and the disadvantages of manual vector methods and traditional image-based classification methods, and based on combination of Landsat remote sensing images from 1980 to 2020 and the results of field investigation, this paper constructed transfer matrix of wetland landscape structure pattern in different time periods. In accordance with the national planning of South-to-North Water Transfer and high quality development of the Dongping Lake (Hu et al. 2016), the future evolution of the Dongping Lake wetland is predicted. Landscape diversity index, ecology dominant degree index, evenness degree index and landscape fragmentation degree index were used to analyze the landscape pattern evolution. The spatial distribution pattern of wetland landscape in the Dongping Lake was studied, mechanism of wetland landscape evolution was revealed. The development trend of the Dongping Lake wetland landscape pattern was predicted. The studied results could provide important support for high quality development of wetland landscape pattern, the virtuous circle of wetland landscape ecosystem and wetland landscape ecosystem protection and restoration.

### Materials and methods

#### Data sources and processing

The remote sensing data used in this paper are images in 1980, 1990, 2000, 2005, 2010, 2015 and 2020, respectively (Table 1). According to the classification principles proposed by the technical regulation of national wetland resources survey and monitoring, and considering the actual situation of the Dongping Lake wetland (Chen 2019), the plants in the Dongping Lake wetland could be classified into eight categories: i.e., natural water surface, emerged plants, floating plants, submerged plants, grass beach, wasteland, cultivated land and construction land. Based on color, shape and texture of remote sensing images and its relationship with the surrounding environment, the remote sensing interpretation marks of the Dongping Lake wetland were established (Ozesmi and Bauer 2002). According to the interpretation marks, ENVI software and maximum likelihood method were used to identify and classify remote sensing images (Mishra et al. 2014).

#### Accuracy verification

The visual interpretation results from high resolution images were used as the verification data to verify the accuracy of the extracted results (Tian et al. 2017; Fernandez et al. 2019). Due to large area of the Dongping Lake, visual interpretation method was used to classify wetland structures. Compared with the field investigation, the interpretation results are put onto the Google map to compare and verify the accuracy of the interpretation results.

| Time       | Sensor | Water level/m | Wetland extraction methods     |
|------------|--------|---------------|--------------------------------|
| 1980-8-22  | MSS    | 5.76          | Supervised classification      |
| 1990-9-18  | TM     | 7.50          | Supervised classification      |
| 2000-10-15 | TM     | 5.25          | Supervised classification      |
| 2005-6-2   | TM     | 5.42          | Supervised classification      |
| 2010-5-15  | ETM+   | 5.86          | Supervised classification      |
| 2015-9-1   | OLI    | 7.28          | Supervised classification      |
| 2020-7-10  | OLI    | 6.73          | Supervised classification      |
A Kappa coefficient method was adopted in this paper (Ray and Ramachandra 2017), i.e.

\[ K = \frac{p_0 - p_e}{1 - p_e} \]  

(1)

where \( p_0 \) is the sum of all correctly classified samples divided by the number of samples. Suppose, for each class, the correct sample number is \( a_1, a_2, a_3, a_4, a_5 \), the extracted sample number is \( b_1, b_2, b_3, b_4, b_5 \), then,

\[ P_e = \frac{(a_1b_1 + a_2b_2 + a_3b_3 + a_4b_4 + a_5b_5)}{n^2} \]  

(2)

Kappa coefficients can be classified into five levels, i.e., extreme low consistency (0–0.2), low consistency (0.21–0.40), middle consistency (0.41–0.60), high consistency (0.61–0.80) and full consistency (0.81–1.00).

Through calculation, the coefficient Kappa is 0.83, which means that both the results of remote sensing and visual interpretation are completely consistent, which shows that the extraction methods used in this paper are dependable.

**Methods**

**CA–Markov model**

**CA model** The cellular automation (CA) was proposed by Neumann and Ulan in 1940s (Olmedo et al. 2015). The principle is to predict the state transformation in the next period based on the specific conversion rules starting from the current cell state and the neighborhood state.

CA model is a dynamic model with temporal-spatial computational ability and spatial modeling ability, which is characterized by the discrete time, the space and the state, as shown in Eq. (3).

\[ S_{(t+1)} = f(S_{(t)}, N) \]  

(3)

where \( S \) is a set of finite and discrete states, \( N \) is the neighborhood of the cell, \( f \) is the cell state transformation rule in the local space.

CA model consists of four important parts, i.e., cell (wetland pixel), state (wetland landscape types), neighborhood (a pixel adjacent to several surrounding pixels) and conversion rule (wetland conversion rule to other types of wetland pixels).

**Markov model** A Markov transfer matrix was constructed using the classification results. Model matrix \( P \) can be calculated using Eq. (4).

\[
\begin{pmatrix}
P_{11} & P_{12} & \cdots & P_{1n} \\
P_{21} & P_{22} & \cdots & P_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
P_{n1} & P_{n2} & \cdots & P_{nn}
\end{pmatrix}
\]  

(4)

where the value for diagonal \( P_{11}, P_{22}, \ldots P_{nn} \) represent unchanged transfer elements from \( T_0 \) to \( T_1 \). The value for off-diagonal \( P_{12}, P_{21}, \ldots P_{1n}, P_{n1} \) represent changed transfer elements from \( T_0 \) to \( T_1 \).

CA model has a strong ability to simulate spatial information, but low ability to capture large amount of data. The combination of CA with Markov model can improve the space and quantity for simulation results.

**Wetland landscape evolution index**

**Landscape diversity index (SHDI)** Landscape diversity index reflects the diversity of patch types and is often used to reveal the complexity of landscape structure, the integrity or diversity of patch types. Shannon diversity index (SHDI) is usually used in practice, the calculation formula is as follows,

\[ H = -\sum_{k=1}^{n} P_k \log_2 P_k \]  

(5)

In which \( H \) is landscape diversity index, \( P_k \) is the proportion of the patch \( k \) in landscape, \( n \) is the number of various patches. When there is only one type of patch in the landscape, SHDI = 0, when the patch type increases or the proportion of various patches tends to be similar, the SHDI also increases accordingly.

**Landscape dominant degree index (LDI)** The landscape dominant degree index represents the deviation degree of the landscape diversity from the maximum landscape diversity index, or describes the degree to which the landscape is controlled by a few patch types. It is the difference between the maximum value of the diversity index and the calculated mean value, the formula is as follows,

\[ D_0 = H_{\text{max}} - H = \log_2 n + \sum_{k=1}^{n} P_k \cdot \log_2 P_k \]  

(6)

where \( D_0 \) is dominant degree index, \( H_{\text{max}} \) is the maximum diversity index; \( H \) is the mean value of diversity index; \( P_k \) is ratio of patch \( k \) to the landscape; \( n \) is the number of patch types.

The value of the \( D_0 \) is proportional to the deviation degree, the larger the \( D_0 \), the greater the deviation degree, and when \( D_0 = 0 \), the landscape is completely homogeneous.

**Landscape evenness index (LEI)** A landscape evenness index (LEI) reflects the uniformity of the landscape patch distribution in the entire area, which is usually expressed by the ratio of diversity index to its maximum value, as follows,
where $E$ is landscape evenness index (LEI), $P_k$ is the proportion of the patch $k$ to the landscape, $n$ is the number of patch types.

**Landscape fragmentation index (LFI)** Landscape fragmentation is an important feature of landscape heterogeneity, it reflects the fragmentation degree by landscape segmentation, which not only reflects the complexity of landscape spatial structure, but also reflects the degree of human interference with landscape, the calculation formula is as follows,

$$C_k = \frac{N_k}{A_k}$$

(8)

where $C_k$ is the fragmentation degree of the landscape $k$, $N_k$ is the number of patches in the landscape $k$, $A_k$ is the total area of the landscape $k$.

### Case study

#### Background

The Dongping Lake wetland is located at the Dongping County, Shandong Province, China, to the east of Beijing-Hangzhou Grand Canal, to the west of the Dawen River, to the north of Liuhe River, to the south of the Yellow River, with the total area of 209 km$^2$, perennial water surface area 124.3 km$^2$, average water depth is 2.5 m, total water storage is 4 billion m$^3$, as shown in Fig. 1. The main water source of the Dongping Lake comes from the Dawen river basin and flows into the Yellow River.

The climate in the Dongping Lake belongs to mainland monsoon, high temperature and rainy in summer, more wind and less rain in winter and spring, annual average temperature is 13.3 °C, annual precipitation is 640.5 mm.

The Dongping Lake wetland is a large wetland in the north of China with abundant animal and plant resources. The water source in the Dongping Lake mainly comes from the Dawen River which has the basin area of 8536 km$^2$. The flow variation in rainy and dry seasons in the Dawen River makes the mixed distribution of cultivated

![Wetland location of the Dongping Lake](image_url)
land and water surface in the lake area. Both fishery and agriculture are co-developed in the area.

The Dongping Lake is an important storage lake in the East Route of South-to-North Water Transfer in China, it is also the second largest freshwater lake in Shandong Province, which enjoys extremely important geographical location and has an important ecological service function. With the rapid development of economy, industrialization and human activities, the pollution in the lake area is increasing, which threatens the sustainable development and utilization of wetland resources. Therefore, in order to maintain biodiversity and wetland ecological balance, to realize sustainable, rational utilization of wetland resources and to fully exploit various wetland functions, it is necessary to carry out study on wetland landscape evolution in the Dongping Lake.

### Wetland landscape index calculation and analysis

#### Wetland landscape index calculation

The calculated results for Dongping Lake wetland landscape indexes from 1980 to 2020 are shown in Table 2. The variation of wetland landscape index is shown in Fig. 2.

#### Analysis on wetland landscape indexes

The wetland landscape diversity index (SHDI) was 1.4759 in 1980, which was decreased to 1.3731 in 1990 and increased to 1.6817 in 2000, which is the highest value in the study period. At the same time, the landscape evenness (LEI) reached the maximum value 0.8087, which shows that the balanced proportion of landscape patches were realized and the landscape diversity is in desirable situation. The landscape diversity index (SHDI) continues to decline from 2000

| Years | Diversity (SHDI) | Evenness (LEI) | The number of patches (NP) | Dominant degree (LDI) |
|-------|------------------|----------------|--------------------------|----------------------|
| 1980  | 1.4759           | 0.7098         | 1231                     | 0.2902               |
| 1990  | 1.3731           | 0.6606         | 919                      | 0.3394               |
| 2000  | 1.6817           | 0.8087         | 1201                     | 0.1913               |
| 2005  | 1.3689           | 0.6583         | 1300                     | 0.3417               |
| 2010  | 1.0956           | 0.5269         | 1113                     | 0.4731               |
| 2015  | 1.0126           | 0.5081         | 681                      | 0.4919               |
| 2020  | 1.3357           | 0.6547         | 1266                     | 0.3453               |

![Fig. 2](image-url)  
Variation of wetland landscape indices from 1980 to 2020
to 2015 (1.0956 in 2000, 1.0126 in 2015). The landscape diversity index begins to rise from 2015 to 2020 (1.3357 in 2020). During 2000 and 2015, declination of landscape diversity index shows that the landscape diversity was reduced. During 2015 and 2020, the rising diversity index indicates that the landscape diversity was increased.

From Table 2 and Fig. 2, we can see that the landscape evenness (LEI) varies with diversity. From 2000 to 2015, the landscape evenness index was decreased continuously from 0.8087 to 0.5081. The area distribution of landscape types becomes gradually uneven. The landscape evenness index in 2020 was 0.6547, which tends to be even compared with the distribution of landscape types (LEI) in 2015 (0.5081 in 2015).

Dominant degree index (LDI) was 0.2902 in 1980. The lowest dominant degree index (LDI = 0.1913) was found in 2000. The dominant degree index was gradually increased from 2000 to 2015. The highest dominant degree index (LDI = 0.4919) was reached in 2015.

From the definition of the dominant degree index, the higher the dominant degree index, the greater the difference of the proportion of landscape types, which means that the landscape in an area is controlled by a few landscape types. Dominant degree index in 2020 was 0.3453, which was lower than that in 2015, which indicates that the proportion difference of landscape type was decreased. This is mainly due to the impact of human activities. Wetland landscape types vary with the wetland development planning. In general, wetland landscape type in the Dongping Lake is evenly distributed. During recent years, some dominant landscape types have appeared, the overall landscape diversity shows a downward trend.

Landscape fragmentation in the Dongping Lake Wetland is mainly manifested by the patch number rising, the irregular patch shape, and short of connection among different patches.

The total patch number of wetland landscape in Dongping Lake is 1231 in 1980, 919 in 1990. From 1990 to 2005, the number of patches was increased from 919 to 1300, which indicates that the fragmentation degree of wetland landscape in the Dongping Lake was increased continuously, and the overall wetland landscape was relatively fragmented. However, the number of landscape patches was decreased and the fragmentation degree was also decreased from 2005 to 2015, which was due to the lake water level rising from South-to-North water transfer. The South-to-North water transfer passes through the Dongping Lake, which increases the natural water surface area in the wetland and results in the patch number decreasing. From 2015 to 2020, the patch number was increased from 681 to 1266, the patch number was increasing, and the trend of landscape fragmentation is developing.

### Wetland structure evolution matrix construction

According to the development plan of the South-to-North Water Transfer and the Dongping Lake high quality improvement, the period 1980–2020 can be divided into three periods, i.e., 1980–2000, 2000–2015 and 2015–2020. According to the variation of wetland structure types during the corresponding time periods in the lake area and using Eqs. (3) and (4), the transfer matrix of wetland structure was constructed as shown in Tables 3, 4 and 5.

### Prediction on the Dongping Lake wetland evolution

According to the lake storage planning in the East Route of South-to-North Water Transfer and high quality development plan both in the Dongping Lake and in the Yellow River Basin, the wetland structure variation is mainly the mutual transformation among the natural wetland structure types. The comprehensive development direction of the wetland structure is to integrate ecological values based on the foundation of 2015. Considering this development direction and based on the matrix above, the future wetland structure transformation in the Dongping Lake is shown in Table 6.

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**Table 3** Transfer matrix of wetland structure in the Dongping Lake from 1980 to 2000 (km²)

| Types  | ①  | ②  | ③  | ④  | ⑤  | ⑥  | ⑦  | ⑧  |
|--------|----|----|----|----|----|----|----|----|
| ①     | 0.20| 0.00| 0.07| 0.12| 0.11| 0.13| 0.35| 0.20|
| ②     | 0.17| 6.22| 0.29| 0.06| 2.69| 0.21| 0.25| 0.28|
| ③     | 0.00| 0.00| 0.87| 0.01| 0.01| 0.06| 0.10| 0.12|
| ④     | 3.61| 0.02| 0.12| 9.75| 1.17| 3.17| 3.15| 3.20|
| ⑤     | 0.45| 5.67| 0.56| 0.11| 21.54| 2.85| 2.90| 2.95|
| ⑥     | 0.70| 1.14| 0.24| 0.82| 8.86| 9.25| 8.15| 6.50|
| ⑦     | 0.39| 0.04| 0.05| 0.99| 0.08| 0.17| 0.16| 0.15|
| ⑧     | 0.19| 6.83| 0.60| 0.01| 1.67| 0.13| 0.15| 0.20|
The proportion of increased forest and grassland area accounts to about 9%.

**Discussions**

**Dynamic variation of wetland landscape pattern**

Through analyzing landscape transfer between various landscape types, we can reach a general trend of wetland variation and the wetland structure evolution, as shown in Table 7.

It can be seen from Table 7 that the area of Dongping Lake wetland landscape changed greatly from 1980 to 2020, in which the area of wasteland decreased from 15.01 km$^2$ in 1980 to 2.10 km$^2$ in 2020.

The area of construction land was increasing from 1980 to 2020, which increased from 3.07 km$^2$ in 1980 to 6.74 km$^2$ in 2020.

As for wetland types, natural water surface shows an increasing trend, which was increased from 72.32 km$^2$ in 1980 to 89.59 km$^2$ in 1990 and 115.97 km$^2$ in 2015. This is due to the annual variation of precipitation and the influence of the East Line Project of South-to-North Water transfer. The variation of precipitation and the regulation...
and storage of South-to-North Water transfer Project make the lake water level changed greatly. At the same time, the lake water surface area was also affected by the submerged floras (mainly *Potamogeton crispus*). The rising and falling of floras would affect the exposure of natural water surface. The decrease of natural water surface area in 2000 was mainly due to the lush growth of submerged vegetation and a part of lake natural water surface was covered by floras.

The variation of grass beach area is not obvious. Variation trend of the reeds (dominant floras) is similar to grass beach. The area variation of floating floras (dominated by lotus) and submerged floras (dominated by *Potamogeton crispus* grass) were largely fluctuated. Cultivated land was slightly changed from 1980 to 2005, and greatly decreased from 2005 to 2010. The cultivated land area began to increase gradually from 2015, which reached to 6.33 km² in 2020. In general, the wetland types in the Dongping Lake were changed greatly from 1980 to 2020.

Variation Comparison among different types of wetland Landscape in the Dongping Lake can be seen in Fig. 3.

Table 7 The wetland landscape transfer from 1980 to 2020 (km²)

| Types                  | 1980  | 1990  | 2000  | 2005  | 2010  | 2015  | 2020  |
|------------------------|-------|-------|-------|-------|-------|-------|-------|
| Wasteland              | 15.01 | 13.16 | 12.44 | 8.18  | 3.63  | 2.15  | 2.10  |
| Grass beach            | 5.27  | 5.94  | 9.33  | 7.40  | 8.60  | 5.27  | 7.43  |
| Natural water surface  | 72.32 | 89.59 | 48.81 | 94.49 | 112.53| 115.97| 120.85|
| Emerged plants         | 4.37  | 2.91  | 9.64  | 8.36  | 9.69  | 5.00  | 7.73  |
| Floating plants        | 8.26  | 6.68  | 15.54 | 8.25  | 1.88  | 1.16  | 11.0  |
| Submerged plants       | 45.96 | 31.48 | 53.94 | 25.06 | 14.65 | 18.94 | 14.49 |
| Construction land      | 3.07  | 3.70  | 4.09  | 4.25  | 4.76  | 5.60  | 6.74  |
| Cultivated land        | 4.49  | 5.27  | 4.94  | 4.75  | 2.98  | 4.65  | 6.33  |

The main reasons for the variation of wetland landscape in Fig. 3 is that, in 1980, the area around the north outlet of the Dongping Lake was all wasteland, from 1985 to 2000, it was gradually developed into reed swamp and lake water surface. From 2000 to 2015, it was gradually evolved into reed swamp, grass beach, construction land and lake surface. The area around the inlet of Dawenhe River into the lake was mainly wasteland and cultivated land in 1980, a lot of wasteland were developed into cultivated and construction land from 1985 to 2000. The landscape types were greatly changed from 2000 to 2020. A part of cultivated land gradually converted into construction land. Wasteland was gradually replaced by reed swamp, grass beach and cultivated land. The wasteland on both sides of the river channel was gradually reclaimed into cultivated farmland.

From 1980 to 2020, the water surface of the lake was increasing, the emerged floras (dominated with reeds) are luxuriantly growing on the lake side, and the grass beach was spreading to wasteland continuously.

In general, different types of wetlands structure have been mutually transferred and different evolution trends...
have been appeared. In past 40 years, the landscape types in the Dongping Lake wetland have been changed greatly, but the distribution of each landscape pattern was relatively stable, and the total area of wetland landscape is slightly changed.

**Analysis on the driving force of wetland landscape evolution**

In general, natural and human activity driving forces are the main driving forces in dynamic variation of wetland landscape pattern. Natural driving factors often influence on landscape pattern in a large spatial and temporal scale. Human activity driving factor is a direct driving force to cause landscape pattern variation.

The Dongping Lake region belongs to warm monsoon mainland climate, annual precipitation varies obviously, the lake water surface area increases with the increase of precipitation. During study period, the sediment from the upper reaches of the basin is constantly transported into the Dongping Lake, which causes the lake bottom to rise gradually, aquatic plants (such as reeds) start to appear in the lower water level area. Due to sediment deposition and herbaceous plants growth, the area near the lakeside and riverine were evolved into grass beach. When the lake water level rises, aquatic plants increase and herbaceous plants decrease. Therefore, the variation of the lake water level also leads to the vegetation variation in the wetland, which, in turn, leads to the variation of the integrated wetland types.

Human activities can be basically classified as hydraulic project construction, land development and pollutant discharge. During recent years, with the increase of population and the rapid development of social economy, pollution from industrial and domestic wastewater discharge in the Dongping Lake threatens the wetland ecological environment, which results in simplification of wetland landscape structure. After the Dongping Lake was identified as a natural flood detention area of the Yellow River, a large number of flood control, water storage projects, road facilities and dams were built, which occupied a large part of wetlands, destroyed the integrity of the wetlands and made the wetland landscape trend be fragmented. After the implementation of the East Route Project of the South-to-North Water Transfer, the water level in the Dongping Lake was increased significantly, which cause the lake water level rising and the lake area gradually expanding. From 2015 to 2020, under the influence of water level rising, the natural water surface area was enlarged, the area of floating and emerged plants were reduced, the area of submerged plants was increased, the biodiversity was reduced, and the structure of biological population tends to be simplification.

**Conclusions**

Based on the Landsat remote sensing data, this paper interpreted the wetland landscape structure in the Dongping Lake, analyzed the transformation of wetland landscape structure from 1980 to 2020, and predicted the wetland structure evolution based on the wetland development planning. The dynamic variation characteristics of landscape and different landscape index variation in the Dongping Lake wetland between 1980 and 2020 were studied, and the driving forces of landscape evolution were analyzed.

In the past 40 years, the wetland types in the Dongping Lake have been changed greatly. Some of wasteland has been replaced by cultivated and construction land. The emerged aquatic plants (dominated with reeds) and grass beaches along the lakeside and riverine are spreading into the farmland. The natural water surface area is alternatively increasing, and the Potamogeton grass community is the dominant species in the lake.

According to the East Line development planning of the South-to-North Water Transfer and the Dongping Lake high quality development planning, the period of 1980–2020 was divided into three periods, i.e., 1980–2000, 2000–2015 and 2015–2020. According to the variation of wetland structure in the corresponding time period, the transfer matrix of wetland structure types was set up. Based on the lake water regulation and storage planning in the South-to-North Water Transfer and high quality development planning of the Dongping Lake and the Yellow River basin, the variation of wetland structure is mainly the mutual transformation between different natural wetland structures, which will be developed toward the direction of comprehensive ecological environment on the basis of 2020.

The main wetland landscape types in the lake area are wild reeds, which accounts for about 55% of the lake area, followed by floating plants and open water bodies, with an area of 71.63 km², 41.43 km², respectively. The proportion of increased forest and grass land area accounts for about 9.0% of the total lake area.

From 1980 to 2020, the overall landscape diversity of the Dongping Lake wetland showed a downward trend, the dominant species gradually became obvious, and the landscape fragmentation degree was increased in fluctuation. As for landscape structure development in different time periods, the diversity index of wetland landscape was decreased continuously from 2000 to 2015, the dominant degree index was increased gradually, the number of patches was increased firstly and then decreased, which reduces the diversity of biological species in the Dongping Lake, and results in decrease or disappearance of some
species. From 2015 to 2020, the wetland landscape diversity index showed a recovery trend, the landscape evenness degree index was increased, the dominant degree index for some species was reduced, and the landscape fragmentation degree index was increased.

The evolution of the Dongping Lake wetland is influenced by natural and human driving force factors. In the early stage, the wetland evolution of the Dongping Lake was mainly affected by natural factors such as climate and precipitation, in the later stage, the wetland evolution was mainly affected by human factors such as hydraulic project construction and land development. The regulation and storage of Dongping Lake in the East Line of the South-to-North Water transfer Project is the main factor affecting the increase of the lake natural water surface in the late stage.

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Data availability All the data and materials in the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest There is no conflict of interest in this manuscript.

Consent to participate The author consents to participate in the works under the Ethical Approval and Compliance with Ethical Standards.

Consent to publish All the data in the paper can be published without any competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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