Study on spatio-temporal evolution of habitat quality based on land-use change in Chongming Dongtan, China

Sheng Li1 · Bin Dong1 · Xiang Gao1 · Haifeng Xu1 · Chunqiu Ren1 · Yaru Liu1 · Liang Peng1

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Abstract
Chongming Dongtan is an important habitat for international migratory birds. It is of great significance to study its land use and habitat quality change for rare waterfowl protection and ecological environment restoration. Based on the land use data in 2002, 2008, 2012, 2016 and 2020, this paper analyzes the relationship between land-use change and habitat quality evolution in Chongming Dongtan in recent 18 years using InVEST model, land use dynamic degree and land use degree index. The results show that the main types of land use in the study area are water area and cultivated land, followed by woodland, reed beach, grass beach, bare beach and construction land. Among them, bare beach and construction land have changed dramatically, the former continuing to decrease while the latter continuing to increase. Moreover, the increasing speed began to slow down after 2012, and the increasing part was mainly from the surrounding cultivated land. Second, in terms of time change, the degradation of habitat quality in Chongming Dongtan has been gradually improved from aggravating trend in the past 18 years. In terms of spatial distribution, the habitat degradation degree of Chongming Dongtan is higher in the east and lower in the west, spreading from the center to the surrounding. Based on this, the change of land use and the interference of human activities are the important reasons for the change of ecological environment quality.

Keywords Land-use change · InVEST model · Habitat quality · Chongming Dongtan

Introduction
Habitat quality refers to the ability of the ecosystem to provide suitable individuals and populations with sustainable survival and reproduction within a certain space and time range, and is an important ecosystem service. Stable habitat quality is an important basis for maintaining biodiversity of the ecosystem, which reflects regional biodiversity to a certain extent (Li et al. 2020, 2015). Studies have shown that land-use change is the main driving force of habitat quality change. By changing the ecosystem structure and function, land-use change causes the fragmentation and loss of species and effective habitats of the ecosystem, and then leads to habitat degradation (Yubin et al. 2015). Therefore, the evaluation of habitat quality based on land-use change can not only clarify whether the land use pattern and intensity within the study area are reasonable, but also help to reveal the change law and driving mechanism of habitat quality in the study area, which has important scientific significance for promoting regional ecological protection and sustainable development (Wu et al. 2020).

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) was jointly organized and developed by Stanford University, The Nature Conservancy and Century Nature Foundation. Habitat Quality module in the model has been widely used by scholars at home and abroad to evaluate Habitat Quality. For example, foreign scholars used InVEST model to evaluate the temporal and spatial variation of habitat quality in the Nile Basin of the Ethiopian Plateau and its relationship with landscape characteristics (Yohannes et al. 2020), the change of habitat quality in Jeju Island (Lee and Jeon 2020), and the habitat environment of amphibians in the North American prairie (Mushet et al. 2014). In addition, Akbari et al. (2021) used the InVEST Habitat Quality (HQ) module and a novel approach to parameterize the relative sensitivity scores in this framework and quantified, mapped, and evaluated the relative HQ values for Burrowing Owls in...
the prairies. A model built in the InVEST tool, is utilized to analyze the effect of land cover changes and increase in P. juliflora on habitat quality for bird species in the park (Choudhary et al. 2021). At present, habitat quality assessment based on land-use change and revealing the impact of land-use change on habitat quality have become one of the research hotspots (Yanyan et al. 2020). Liu et al. (2020) used InVEST model combined with Markov model to quantitatively evaluate the habitat quality of Xinjiang Corps and non-Corps and the evolution of habitat quality caused by land-use change. Wang et al. (2021) used GIS technology and InVEST model to conduct quantitative assessment of habitat quality in coastal areas of Dandong, and analyzed the impact of land-use change on habitat quality in combination with the law of land-use change. Huang et al. (2020) analyzed the spatial and temporal evolution of habitat quality and the interaction and gradient effect of landscape pattern based on InVEST model and topographic position method in the Dabie Mountain in western Anhui Province. Han et al. (2019) used InVEST model and “3S” technology to quantitatively estimate the habitat quality in the Qinghai Lake Basin, analyzed the temporal and spatial distribution characteristics of habitat quality in the Qinghai Lake Basin, and revealed the impact of land-use change on habitat quality in the basin. Moreover, there are many studies using INVEST model to study the spatio-temporal changes of migratory bird habitat quality, revealing the impact of land-use change on migratory bird habitat (Zhang et al. 2019; Yu et al. 2020; Li et al. 2021; Sun et al. 2015).

Chongming Dongtan, located at the estuary of the Yangtze River, is an internationally important estuarine tidal flat wetland, as well as an important post station and wintering habitat on the migration route of global migratory birds “East Asia—Australia”, among which Chongming Dongtan Bird National Nature Reserve is located (Tian et al. 2008). As one of the most important ecologically sensitive regions in the world, Chongming Dongtan is rich in natural resources and has an extremely important ecological location. Therefore, it is of great significance to evaluate the habitat quality based on land-use change and reveal the impact of land-use change on the habitat quality of Chongming Dongtan. However, with the increasing impact of a series of factors such as reduced water and sediment in the upper reaches of the Yangtze River, reclamation utilization of tidal flats, invasion of alien plant species and disturbance of human production and construction activities (Kuang et al. 2009), the land use types in the east beach of Chongming have changed dramatically, which has threatened the habitat of migratory birds. Based on this, this paper takes Chongming Dongtan as the research area, based on the analysis of land-use change in the Chongming Dongtan during 2002–2020, this paper evaluated the habitat quality spatio-temporal by InVEST model, and discussed the impact of land-use change on habitat quality, aiming to restore the low-value area of habitat quality and coordinate the relationship between economic development and ecological environment protection. It is expected to provide some theoretical support for land management and ecological construction of Chongming Dongtan in the future.

Data and methods

General situations of research area

Chongming Dongtan (121° 43′–122° 05′E, 31° 24′–31° 39′ N), located in the north of Shanghai and the easternmost part of Chongming Island, was deposited by a huge amount of sediment transported by the runoff of the Yangtze River under the interaction of the river and sea. Based on Chongming Dongtan Wetland Reserve and adjacent agricultural reclamation areas, the study area is buffered 5 kms to the west (Fig. 1), with a total area of 552.17 square kilometers.

Chongming Dongtan belongs to the subtropical monsoon climate, humid climate, four distinct seasons. The annual average temperature is 15–16 °C, the extremely high temperature is 37.3 °C, the extremely low temperature is −10.5 °C, the annual average frost-free period is about 320 days, the annual average rainfall is 900–1050 mm, mainly from April to September, and the relative humidity of the air is 82%.

Chongming Dongtan is formed by sediment accumulation. The terrain is flat and the elevation is between 3.2 and 4.4 m. Generally, it is higher in the west and lower in the east, with little difference in elevation. From west to East, it can be divided into high tide beach, middle tide beach and low tide beach. In 1992, Chongming Dongtan Wetland was listed in

![Fig. 1 Location map of Chongming Dongtan](image-url)
China Protected Wetlands List. In 1998, Chongming Dongtan Wetland Reserve was established. In 2002, Chongming Dongtan Wetland Reserve and its surrounding constructed wetlands were listed as internationally important wetlands, and in 2005, it was upgraded to the national nature reserve.

**Data source and processing**

The land use data in this paper (2002, 2008, 2012, 2016, 2020) were obtained mainly through interpretation of remote sensing images, all from geospatial Data Cloud Platform of Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn). This study covers a long period from 2002 to 2020, and the study area is the wintering habitat of migratory birds. To ensure the operability and comparability of data results, remote sensing images with cloud coverage less than 5% in winter are selected to interpret and classify. Among them, 2002 and 2008 are Landsat-5 satellite data, 2012 is Landsat-7 satellite data, 2016 and 2020 are Landsat-8 satellite data. The spatial resolution of the data is 30 m. According to the actual situation of the study area and the ground features reflected by each band, band 4, 3 and 2 were selected for combination of Landsat-5 and Landsat-7 series, while band 5, 4 and 3 were selected for combination of Landsat-8 series.

Due to this article mainly studies the Chongming Dongtan wetland of land-use change, and also serves the research on the habitat characteristics of wintering migratory birds. Referring to the relevant research of domestic and foreign scholars and classification standards such as “Classification of Land Use Status” (GB/T21010-2017) and “Technical Regulation of National Wetland Resources Investigation (Trial)”, combined with the actual characteristics of Chongming Dongtan wetland, the bird habitat is divided into reed beach, grass beach and bare beach (Yang et al. 2021; Cao et al. 2018; Lixin et al. 2021), and the cultivated land is divided into paddy field and dry land, which are divided into 8 categories in total. They are: reed beach, grass beach, bare beach, water area, dry land, paddy field, woodland and construction land. The standard image was generated by the steps of band combination, radiation correction, image fusion and image cropping with ENVI5.2 software, and the land use status map of the three phases was obtained by human–computer interactive interpretation method (Fig. 2).

![Fig. 2 The distribution of land use of Chongming Dongtan](image-url)
Radiometric correction can eliminate or correct image distortion caused by various uncertain factors and ensure the authenticity and operability of remote sensing image data. Secondly, image fusion is to improve the classification accuracy, image fusion of different sensors, so as to obtain image information with high resolution and multi-spectral characteristics. Human–computer interaction remote sensing interpretation is a remote sensing image manual interpretation method based on remote sensing and geographic information system under the guidance of personal and expert experience, that is, artificial visual interpretation combined with computer algorithm judgment remote sensing image interpretation, which has the characteristics of visual analysis, convenient and quick, wysiwyg and so on.

After classification was completed, the error matrix was established with ENVI software and the Kappa coefficient was calculated. The results of Kappa coefficient in 2002, 2008, 2012, 2016 and 2020 are 0.8828, 0.8805, 0.8733, 0.8915 and 0.8939, respectively, which indicates that the classification results are authentic and reliable. According to the accuracy evaluation of 85 GPS verification points collected from the field, the average overall accuracy of land cover types can reach 91.25%, and the classification accuracy is high, which provides a guarantee for the follow-up research.

Research methods

Single land use dynamic degree

The single land use dynamic degree represents the quantitative change rate of a certain land use type in a certain period of time in a region (Li et al. 2014), and its calculation formula is as follows:

\[ K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \] (1)

In the formula, \( K \) represents the single land use dynamic degree of a certain land type; \( U_a \) and \( U_b \) represent the area of a certain land use type in the early and late stages; \( T \) is the length of a given period of time; \( K \) value reflects the change rate of a specific land use type in a given period of time.

Land-use transfer matrix

The land use transfer matrix can reflect the land use type structure and internal transformation in the study area and quantitatively reflect the regional spatial evolution (Zhao and Fan 2020; Duan et al. 2020). The expression formula is:

\[
S_{ij} = \begin{bmatrix}
S_{11} & S_{12} & \cdots & S_{1n} \\
S_{21} & S_{22} & \cdots & S_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
S_{n1} & S_{n2} & \cdots & S_{nn}
\end{bmatrix}
\] (2)

where, \( S_{ij} \) represents the transfer area of different land use types, \( n \) represents the number of land use classifications, and \( ij \) represents the land types at the beginning and end of the research stage.

Land-use degree

The degree of land use can not only reflect the law of land-use change, but also reflect the influence of human activities and natural environment on land use (Zhu et al. 2003). According to the land use grading index method and land use degree model proposed by Liu Jiyuan et al. land use is divided into four grades (Zhuang et al. 1997), as shown in Table 1.

| Grade | Description |
|-------|-------------|
| 1     | Unused land class |
| 2     | Forests, grasses and water class |
| 3     | Land grade in agriculture |
| 4     | Urban settlements class |

The model of land use degree is as follows:

\[ L_a = 100 \times \sum_{i=1}^{n} A_i \times C_i, \quad L_a \in (100, 400) \] (3)

\( L_a \) is the comprehensive index of land use degree in the study area; \( A_i \) is the grade \( i \) index of land use degree in the study area; \( C_i \) is the area percentage of grade \( i \) land use type in the study area.

InVEST habitat quality model

InVEST habitat quality assessment model is based on land use type data to evaluate habitat quality. In this study, this module was used to evaluate the spatial and temporal evolution of habitat quality in Chongming Dongtan in 2002, 2012 and 2020.

(1) The calculation formula of habitat degradation degree \( (D_{ij}) \) (Han 2018) is as follows:

\[ D_{ij} = \frac{S_{ij} - S_{ij0}}{S_{ij0}} \times 100\% \] (4)
\[ D_{ij} = \sum_{r=1}^{R} \sum_{y=1}^{Y} \left( \frac{a_r}{\sum_{r=1}^{R} a_r} \right) r_y i_{xy} \beta x_{yr} \]  

(4)

\[ i_{xy} = 1 - \left( \frac{d_{xy}}{d_{r_{max}}} \right) \text{if linear} \]  

(5)

\[ i_{xy} = \exp \left( - \left( \frac{2.99}{d_{r_{max}}} \right) d_{xy} \right) \text{if exponential} \]  

(6)

In formula (3) to (5), \( D_{ij} \) represents the degradation degree of the total threat level of grid unit \( x \) in land use type \( j \); \( r \) is the threat factor; \( Y_r \) represents the total number of all grid units of threat factor \( r \) in the current land use/cover type map; \( \omega_r \) is the weight coefficient of the threat factor, and its value is \([0,1]\). \( r_y \) represents the number of threat factors in all grid units of threat factors in the current land use/cover type map; \( B \) is the level at which law/institution/society/nature protects each unit from interference, with a value of \([0,1]\) (this factor is not taken into account in this paper, so the model will automatically assign this value as 1 at run time). \( S_{yr} \) represents the sensitivity of each land use type to different threat factors. \( i_{xy} \) represents the influence of threat factors on the whole space, \( d_{xy} \) represents the linear distance between grid units \( x \) and \( y \), and \( d_{r_{max}} \) represents the maximum image distance that each threat factor can reach in the space.

(2) The calculation formula of habitat quality (Han 2018) is as follows:

\[ Q_{sj} = H_j \left( 1 - \left( \frac{D_{sj}^{\beta}}{D_{sj}^{\beta} + k^z} \right) \right) \]  

(7)

In Eq. (6), \( Q_{sj} \) represents the habitat quality of grid unit \( x \) in land use type \( j \); \( H_j \) represents Habitat (suitability) values of different land use types \( j \); \( D_{sj} \) represents the degradation degree of the total threat level of raster unit \( x \) in land use type \( j \); \( z \) is a fixed value provided by the system, with a value of 2.5; \( k \) is the half-saturation constant.

The operation of this module needs to obtain four kinds of necessary data, which are the current land use/cover map, threat data, sensitivity of land cover type to each threat factor, half-saturation constant. On the basis of invest model manual and related research (Tallis et al. 2016; Peng et al. 2019; Chen et al. 2020; Qingyan et al. 2021; Zhang et al. 2019), reed beach, dry land, paddy field and construction land were selected as threat factors in this study. According to the actual situation of the study area and experts’ suggestions, threat factors and sensitivity of threat factors were assigned (Tables 2 and 3).

### Table 2: Ecological threat factor attribute table

| Threat factor | Maximum distance of stress (km) | Weight | Spatial decay function |
|---------------|---------------------------------|--------|-----------------------|
| Reed beach    | 0.5                             | 0.2    | exponential           |
| Dry land      | 2                               | 0.4    | exponential           |
| Paddy field   | 2                               | 0.4    | exponential           |
| Construction land | 1                        | 0.8    | exponential           |

### Table 3: Sensitivity of various land use types to ecological threats

| Land-use type | Habitat suitability | reed beach | dry land | construction land | paddy field |
|---------------|---------------------|------------|----------|-------------------|-------------|
| Reed beach    | 1                   | 0          | 0.2      | 0                 | 0.2         |
| Grass beach   | 1                   | 0.2        | 0        | 0                 | 0           |
| Bare beach    | 0.8                 | 0.5        | 0        | 0                 | 0           |
| Water area    | 0.8                 | 0          | 0        | 0.5               | 0           |
| Dry land      | 0                   | 0.2        | 0        | 0.5               | 0.6         |
| Paddy field   | 0                   | 0.2        | 0.6      | 0                 | 0.2         |
| Construction land | 0             | 0          | 0.2      | 0                 | 0           |

Habitat suitability is assigned according to the contribution of each habitat type to the maintenance of main animal and plant resources in the study area.

### Results and analysis

#### Analysis of land-use change

In the past 18 years, the changes in land use in Chongming east beach are different (Table 4; Fig. 3). Water area is the main land use type in the study area, accounting for more than 37% in the five periods. The area of bare beach decreased significantly and the change range was the largest, with a total decrease of 5310.31 ha, which reached 9.62%. The area of bare beach and water area fluctuates. Research can find that there is a trade-off between the two changes, which is mainly because the bare beach, as a kind of mud flat existing on the shore and submerged or partially submerged in water, is greatly affected by the ebb and flow of sea water. Under the action of tide, the rising tide of sea water reduces the area of bare beach, on the contrary, the area of bare beach increases when the sea water ebbs. By stacking the water area and bare beach, it is found that the total area of the two shows a downward trend, and the rate of decline has slowed down in recent ten years. This is mainly due to many factors, such as the establishment of reclamation dike in recent
years, the enhancement of sea erosion and the rise of sea level, which make the growth speed of Dongtan begin to slow down.

The paddy field area in the study area fluctuated slightly, with an overall increase of 375.41 hm², accounting for 0.68% of the study area. On the whole, the dry land shows a decreasing trend, and its net decreasing area and proportion are 832.95 hm² and 1.51% respectively. The total area change of the two is very small, mainly because the three large reclamation activities of Chongming Dongtan occurred before 2002. Secondly, Chongming Dongtan Bird Nature Reserve demarcated strict boundary of the protection area, and prohibited all kinds of human production activities, so that the area of paddy field and dry land tended to be stable, and would not continue to expand eastward.

The grassland increased first and then decreased, with an overall increase of 375.41 hm², accounting for 0.68% of the study area. On the whole, the dry land shows a decreasing trend, and its net decreasing area and proportion are 832.95 hm² and 1.51% respectively. The total area change of the two is very small, mainly because the three large reclamation activities of Chongming Dongtan occurred before 2002. Secondly, Chongming Dongtan Bird Nature Reserve demarcated strict boundary of the protection area, and prohibited all kinds of human production activities, so that the area of paddy field and dry land tended to be stable, and would not continue to expand eastward.

The area of woodland and construction land has been continuously increased and expanded. Among them, the net increased area and growth rate of woodland were 1004.47 hm² and 1.82% respectively, and the net increased area and growth rate of construction land were 1598.15 hm² and 2.89% respectively. From the perspective of spatial distribution, the woodland is mainly located on both sides of the roads in Chenjia town and Zhongxing town in the West and between some cultivated land, including economic forest, ecological forest and coastal windbreak forest. The construction land is scattered in linear form

### Table 4 Area and proportion of each land use type in Chongming Dongtan from 2002 to 2020

| Land-use type      | 2002          | Ratio/% | 2008          | Ratio/% | 2012          | Ratio/% | 2016          | Ratio/% | 2020          | Ratio/% |
|-------------------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|---------------|---------|
| Reed beach        | 2033.19       | 3.68    | 1825.83       | 3.31    | 2007.54       | 3.57    | 2847.51       | 5.16    | 3214.89       | 5.82    |
| Grass beach       | 3228.21       | 5.85    | 3696.39       | 6.69    | 3592.44       | 6.39    | 2442.29       | 4.42    | 2438.82       | 4.42    |
| Bare beach        | 7277.13       | 13.18   | 6113.07       | 11.07   | 2205.9        | 3.92    | 4690.85       | 8.50    | 1966.82       | 3.56    |
| Water area        | 21,840.84     | 39.55   | 20,466.54     | 37.07   | 26,172.99     | 46.56   | 22,356.01     | 40.49   | 24,613.4      | 44.58   |
| Dry land          | 5555.52       | 10.06   | 5449.68       | 9.87    | 5702          | 10.14   | 5011.99       | 9.08    | 4722.57       | 8.55    |
| Paddy field       | 10,368.81     | 18.44   | 11,878.20     | 21.51   | 10,084.46     | 17.94   | 10,932.54     | 19.80   | 10,744.22     | 19.46   |
| Woodland          | 2955.78       | 5.35    | 3137.67       | 5.68    | 3357.27       | 5.97    | 3553.83       | 6.44    | 3960.25       | 7.17    |
| Construction land | 1957.95       | 3.55    | 2650.05       | 4.80    | 3094.83       | 5.51    | 3382.07       | 6.13    | 3556.1        | 6.44    |
according to roads, and the concentrated area is mainly the location of township fairs, located in the middle of the research area.

The single dynamic degree of land use type indicates the speed of land-use change. The change of single land use dynamic degree in Chongming Dongtan from 2002 to 2020 is shown in the figure (Fig. 4). The change rates of reed beach and grassland showed an opposite trend, and the change rates were high from 2012 to 2016, reaching 10.46% and -8% respectively, which was mainly caused by the governance of Spartina alterniflora and the mutual transfer of reed beach and grassland after 2013. Due to the influence of tidal action, the dynamic rate of the bare beach varies greatly in each stage. Due to the large area base of the water area, the variation of dynamic degree of water area is relatively stable, and the maximum difference of stages is 10.62%. The dynamic degree of dry land and paddy field in the whole stage is only -0.83% and 0.2%, and the change is relatively stable. This is mainly due to the lack of large-scale reclamation activities and the establishment of national nature reserve in Chongming Dongtan after 2002. The land use dynamic degree of woodland and construction land in four stages is positive, and the annual change rate is increasing. However, the change rate of woodland is gradually accelerating, while the change rate of construction land is gradually slowing down, which is closely related to the policies made by the state to protect the biodiversity of Chongming Dongtan wetland since the new century. On the whole, reed beach, water area, paddy field, woodland and construction land showed an increasing trend, and the dynamic degrees were 3.23%, 0.71%, 0.20%, 1.89% and 4.53% respectively. On the other hand, grass beach, bare beach and dry land showed a decreasing trend, and the dynamic degree was -1.36%, -4.05% and -0.83%, respectively.

To fully understand the structural characteristics of land-use change in Chongming Dongtan during this period, the land use transfer matrix (Table 5) was constructed. From 2002 to 2012, reed beach and grass beach were transformed into each other in this stage, and the area of reed beach land converted to grass beach land (844.84 hm²) was larger than that of grass beach land converted to reed beach land (696.51 hm²). This was mainly due to Spartina alterniflora began to invade the living range of reed and Scirpus mariqueter since it was introduced in the late 1990s. After the introduction of Spartina alterniflora, the invasion threat began to appear gradually. The bare beach is mainly transferred to grass beach and reed beach, and it is still the reserve living space of beach vegetation. The area transferred from water area to paddy field reached 754.42 hm², accounting for 41.00% of the amount transferred from water area, mainly from the previously reclaimed and uncultivated areas. The area of cultivated land transferred to water area was 1319.59 hm², which is mainly the result of developing aquaculture and aquatic crops in Dongtan. The conversion area of woodland is small, the retention rate is high, and the main types of conversion are construction land, dry land and paddy field. The construction land increased rapidly at this stage, and the transferred increased area was 1720.92 hm², in which the proportion of dry land and paddy field was up to 36.15% and 42.11%, respectively.

Compared with the previous stage, from 2012 to 2020, the area of reed beach to grass beach (273.39 hm²) is much smaller than that of grass beach to reed beach (1240.92 hm²), which is mainly due to the large-scale management of...
Spartina alterniflora in Dongtan area, which makes the reed beach gradually recover. The transfer area of bare beach to reed beach and grass beach was 895.31 hm², which was 934.72 hm² less than that of the previous stage. The water area transferred into reed beach and grass beach increased by 1201.49 hm² compared with the previous stage. Dry land and paddy field still maintained a relatively high unchanged area, accounting for 68.94% and 81.46% of the total area, respectively. Water area accounted for a relatively large proportion of the converted area of paddy field, mainly because that part of the cultivation ponds were converted into cultivated land after reclamation. Forestland was mainly transferred to dry land and paddy field, accounting for 36.02% and 37.69%, respectively. The transfer out area of construction land is small, and the main types of transfer out are cultivated land and woodland, which is mainly due to the land reclamation caused by the withdrawal of homestead. In the transfer type of construction land, cultivated land and forest land are still the main sources.

### Impact of land-use change on habitat

Table 5 Land-use transfer matrix in Chongming Dongtan hm²

| Land-use type | 2002 | 2012 | 2020 |
|---------------|------|------|------|
| Reed beach    | 476.96 | 844.84 | 108.51 |
| Grass beach   | 696.51 | 1354.10 | 380.28 |
| Bare beach    | 584.59 | 1245.44 | 808.24 |
| Water area    | 224.02 | 108.00 | 643.19 |
| Dry land      | 3.24 | 4.13 | 7.80 |
| Paddy field   | 10.66 | 16.97 | 8.71 |
| Woodland      | 8.01 | 6.83 | 7.38 |
| Construction land | 3.55 | 12.13 | 2.13 |

Impact of land-use change on habitat

Based on the land use data of three periods, the average habitat quality index and habitat degradation degree were calculated based on formula (4)–(7), and the habitat degradation degree was divided into five grades: basically unchanged, weak degradation, moderate degradation, high degradation and strong degradation; ArcGIS software was used to make statistics on the above calculation results, and combined with the land use degree index in Fig. 4, the response of habitat change to land-use change in Chongming Dongtan was analyzed.

Temporally, the impact of land-use change on habitat

From the perspective of time change (Table 6), from 2002 to 2020, the area of the basically unchanged level of habitat quality degradation continued to decline, with a decline rate of 4.6%. However, the area of weak degradation level of habitat quality increased continuously, and the increasing area and proportion were 4072.5 hm² and 7.37%, respectively. This is mainly due to the area of the basically unchanged level of habitat quality degradation was transferring to the weak degradation level, It leads to the continuous increase of its area. The basically unchanged level of habitat quality degradation and the weak degradation level of habitat quality belong to the low-value area of habitat quality degradation, which can be classified as one kind of research. From 2002 to 2020, the sum of the two areas accounted for more than 70% of the total area, which indicated that the overall habitat quality of Chongming Dongtan is good, and the degradation degree of habitat quality is low. This is closely related to the small proportion of construction land area (all less than 7%) and the weak disturbance of human activities in Chongming Dongtan. The area proportion of moderate degradation and high degradation habitats showed the same trend of increasing at first and then decreasing. The increase of habitat degradation area in the former stage was mainly related to the increase of the inflow area of construction land and the increase of dry land and paddy fields as threat factors.
in the study area. The reduction of habitat degradation area in the latter stage was mainly related to the implementation of the ecological control of Spartina alterniflora and bird habitat optimization project in Chongming Dongtan since 2013, which artificially improved the habitat quality of bird habitat in the reserve. The area of strong degradation habitats has been increasing year by year, directly related to the increase of a series of human disturbance factors such as the increase of population and human production and construction activities in Chongming Dongtan. However, the proportion of strong degradation habitats is lower than 10%, which indicates that the protection of the habitat in Chongming Dongtan is relatively good and the degradation of habitat quality is under control.

Secondly, combining with the land use degree index (Fig. 5), it was found that the land use degree index increased continuously from 222.75 to 235.8 during 2002–2012, while the average habitat quality index decreased from 0.5171 in 2002 to 0.4874 in 2020, and the proportion of strong degradation level area of habitat quality also increased from 5.19% to 8.07%. The main reason is that with the increase of human construction activities in this stage, the intensity of land use increased, resulting in the deterioration of the habitat quality of Chongming Dongtan. However, as the land use index declined after 2012, the area proportion of moderate degradation and high degradation habitat quality decreased, while the area proportion of basically unchanged and weak degradation habitat quality increased, which fully indicated that there was the correlation between land use degree and habitat quality change. In a sense, it is revealed that land-use change has a direct impact on the evolution of habitat quality.

**Spatially, the impact of land-use change on habitat**

From the perspective of spatial pattern change (Fig. 6), the habitat degradation degree of Chongming Dongtan from 2002 to 2020 has a trend of high in the East and low in the west, spreading from the center to the surrounding, and the spatial performance is the expansion of degraded areas. The area of basically unchanged and weak degradation habitats is mainly located in the peripheral waters of Chongming Dongtan and the eastern protection area. These areas are mainly reed beach, grass beach and bare beach, which are close to the ocean and are rich in biodiversity. The moderate degradation level of habitat quality was mainly distributed in

### Table 6 Degraded area, proportion and average value of habitat quality of different grades in Chongming Dongtan

| Degradation grade of habitat quality | 2002 Area/hm² | 2002 Ratio/% | 2012 Area/hm² | 2012 Ratio/% | 2020 Area/hm² | 2020 Ratio/% |
|-------------------------------------|---------------|--------------|---------------|--------------|---------------|--------------|
| Basically unchanged                 | 33,681.06     | 61.00        | 30,822.66     | 55.82        | 30,589.85     | 55.40        |
| Weak degradation                    | 8149.77       | 14.76        | 8274.96       | 14.99        | 12,222.27     | 22.13        |
| Moderate degradation                | 5261.85       | 9.53         | 6797.79       | 12.31        | 4105.67       | 7.44         |
| High degradation                    | 5256.9        | 9.52         | 6292.8        | 11.40        | 3841.22       | 6.96         |
| Strong degradation                  | 2867.76       | 5.19         | 3029.22       | 5.49         | 4458.04       | 8.07         |
| Average habitat quality index       | 0.5171        |              | 0.5125        |              | 0.4874        |              |

The average habitat quality index is a continuous variable ranging from 0 to 1. The closer it is to 1, the better the habitat quality will be.

![Fig. 5](image-url) Land-use degree index change of Chongming Dongtan from 2002 to 2020
the coastal area, and the main land use types were cultivated land and woodland. The high and strong degradation level of habitat quality mainly distributed in the center of Chongming Dongtan, where there is a large population density, intensive construction land for urban residents, strong land use and development intensity, and more disturbance from human activities. From 2002 to 2012, it can be found that the area of high and strong degradation of habitat quality increased significantly, combined with the above land use transfer matrix, the area of construction land increased at this stage, secondly as threat factors of upland and paddy field area is also increasing, indicates that with the change of land use, habitat quality appear the corresponding degradation; Compared with 2002 and 2012, it can be found that the area of strong degradation level of habitat quality in 2020 is still expanding, but the area of moderate and high degradation of habitat quality is significantly reduced, and the reduced area is mainly in the nature reserve, which indicates that the moderate and high degradation of habitat quality in the nature reserve is transferred to the weak degradation of habitat quality. The habitat quality of the nature reserve has been effectively improved, which is mainly due to the implementation of Spartina alterniflora ecological control and bird habitat optimization project in Chongming Dongtan. The improvement of bird habitat quality is promoted through artificially changing land use, which also reveals that land use is the main driving factor of habitat quality change.

**Response of rare cranes to changes in habitat quality**

Chongming Dongtan is not only a distribution center for migratory birds during their migration, but also a wintering place for some rare migratory birds. Based on literature review, monitoring reports and consultation with the management personnel of the reserve, this paper obtained the changes in the numbers of three rare migratory birds (Grus monacha, Grus grus and Ciconia boyciana) from 2000 to 2020 (Fig. 7). The Grus grus and Ciconia boyciana data adopted sub coordinates. The data showed that since 2000, except that the number of Ciconia boyciana has remained at a low level, the number of Grus monacha and Grus grus has changed qualitatively from 2011 to 2013. The number of Grus grus has increased by leaps and bounds in this years, and has remained stable since then. The number of Grus monacha has changed from a decreasing trend to an increasing trend in recent years. Combined with the spatio-temporal changes of the habitat quality of Chongming Dongtan above, the deterioration of the habitat quality of Chongming Dongtan from 2012 to 2020 gradually tended to improve. Although the land use index continued to rise and the area of strong degradation habitats continued to increase, with the decrease of the proportion of the area with moderate and high degradation level of habitat quality, the area with basically unchanged and weak degradation level of habitat quality increased, and the management of Spartina alterniflora and the optimization of bird habitat during the period, the grass beach with low habitat suitability changed to reed beach with high habitat suitability, which promoted the improvement of habitat quality in Chongming Dongtan and the number of migratory birds taking it as habitat also tends to increase.

**Conclusions**

1. The main land use types in the study area are water area and cultivated land, followed by woodland, reed beach, grass beach, bare beach and construction land. Among them, the change of bare beach and construction land was more intense, and the bare beach continued to decrease, with a reduction ratio of up to 9.62%. The area of construction land is increasing continuously, and its increasing speed begins to slow down after 2012. The
increase is mainly from the conversion of surrounding arable land.

2. In terms of time change, the degradation of habitat quality in Chongming Dongtan has been gradually improved from the worsening trend in the past 18 years. From 2002 to 2012, the degradation of habitat quality was relatively obvious. After 2012, although the area of strong degradation habitats continued to increase, with the decrease of the proportion of the area with moderate and high degradation level of habitat quality, the area with basically unchanged and weak degradation level of habitat quality increased. As well as the decrease of dynamic degree of construction land, Spartina alterniflora management and bird habitat optimization, the grassland with low habitat suitability changed to reedland with high habitat suitability, which promoted the improvement of habitat quality in Chongming Dongtan. It can be seen that the change of habitat quality is closely related to the inter-conversion of land use.

3. In terms of spatial distribution, the habitat degradation degree of Chongming Dongtan has a trend of high in the East and low in the west, spreading from the center to the surrounding. The main reasons for the high degradation of habitat quality in the east are the high population density, the intensive construction land for urban residents and the high intensity of land use and development in this region. However, the low degradation degree of habitat quality is due to the fact that it is located in the nature reserve with less interference from human activities.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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