# Spatial and temporal change of wetlands in Bohai rim during 2000—2008: An analysis based on satellite images

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**Abstract:** The coastal wetlands along the Bohai rim are undergoing rapid change. It is significant for regional planning to aware of these spatial and temporal changes. Multi-years of Landsat TM data and some other remote sensing data are used to conduct Human-Computer interaction visual interpretation of wetlands. Assisted by the collection of field samples, the distribution and classification of wetlands along the Bohai Sea in 2000, 2005 and 2008 are extracted. The change rate model of single type and the regional dynamic degree model are constructed under GIS to reconstruct spatial and temporal pattern and dynamic pattern of the wetlands. The dynamic transfer matrix is constructed to reflect the dynamics reasons. The results show that: the brine pan and reservoirs/aquiculture, which are all manmade wetlands, have the biggest area amount and the biggest growth rate, with annual growth 205.52 $km^2$ and 146.10 $km^2$, respectively. The reduction of bottomland and tideland are more obvious than the other types. The Yellow River basin has the most significant wetland change, which is twice bigger than that of Liao River basin and Hai River basin, and still growing larger. The dynamic degree of the Hai River basin has shown the reducing trends. The wetland change driven by human activities is more obvious than the natural drive. The main wetland types transfering are caused by human activities such as the reclamation, tideland or bottomland for aquiculture, constructed land or brine pan.

**Key words:** Bohai Rim, change of wetlands, monitor by remote sensing, spatiotemporal analysis

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## 1 INTRODUCTION

Wetlands encompass many different habitats and perform a wide range of stabilizing functions, so wetlands are called earth renal (Niu *et al.*, 2009). Bohai rim is a gold coast in North China, where coastal wetlands concentrated in this region (Liu *et al.*, 2001). Coastal wetlands grow on the region where land and ocean meet and land ocean interaction is intensive. Costal wetlands perform significant functions in preventing of wind, minimization of flooding and erosion, maintenance of water quality protection through particulate and nutrient retention, climate regulation (Wetland in China, 2010). However, the voice of construction of Bohai economic rim is booming in recent years, its position in national coastal open up strategy becomes more and more important. The conflict between protection and exploitation of coastal wetlands is getting more and more irreconcilable (Xie, *et al.*, 2009). The study of spatial and temporal changes of wetland classes is significant for planning a reasonable protection of wetlands, ensuring the regional economic development, evaluating carrying capacity of Bohai coast and keeping regional sustainable development.

Traditional wetland inventory needs a plenty of time, manpower and material resources as well as the natural conditions in some wetland regions make it difficult to conduct extensive field measurements. What's more, the past wetland condition is hard to retrieve. Numerous studies have focused on the wetland monitor using remote sensing images in the Bohai rim. Liu, *et al.* (1999, 2000), Liu and Buheaosier (2000) discussed the similarities and differences of wetlands in Huanghe and Liaohe deltas by means of remote sensing, geographical information system and global position system. Based on the classification system of wetlands, the present situation and distribution characteristics in the Liaohe and Huanghe Deltas were studied through RS and GIS techniques by Liu, *et al.* (2001). Some strategies concerning protection of ecological function of wetlands and solution to the problems of the sustainable development between resources exploitation and wetland protection were put forward. Jiang, *et al.* (2005) analyzed the changes and driving forces of wetland resources

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using RS and GIS in Liaohe river delta. Zhao *et al.* (2007) investigated the wetland from Bohai Gulf to Laizhou Bay by GIS and Landsat. Most of them have, however, analyzed wetlands in each river delta in 2007 or before. As a result, little is known about wetlands in the whole Bohai rim in the latest years.

Two time periods before and after the government launched Eleventh Five-Year Plan for National Economic and Social Development are selected as monitoring period (2000—2005 and 2005–2008). The monitor region is the whole Bohai rim. Our work are to: (1) reconstruct spatial and temporal pattern and dynamic pattern of the wetlands in the Bohai rim; (2) compare the wetland dynamic pattern among three river basin; (3) construct the dynamic transfer matrix to reflect the dynamics reasons; and (4) offer long time series of remote sensing dynamic monitoring data and evidences for the protection of coastal wetlands and holistically coordinating plans for the Bohai rim developing.

## 2 STUDY AREA AND MATERIALS

### 2.1 Study area

Bohai Sea is a "C"-shaped nearly enclosed sea. The Bohai Rim is the geographical scope around the Bohai Sea involving several administrative areas. The study area is selected according to the administrative boundaries, involving 13 coastal Prefectural-Level cities in three provinces and one city as Liaoning Province, Hebei Province, Shandong Province and Tianjin city, all of which are Dalian, Yingkou, Panjin, Jinzhou and Huludao in Liaoning Province, Tangshan, Qinhuangdao, Cangzhou in Hebei Province, Binzhou, Dongying, Weifang, Yantai in Shandong Province and Tianjin, with a combined area of $1.35 \times 10^7 hm^2$ (Liu, *et al.*, 2006). The study area is located in the north temperate zone, rich in wetland resources, including the Yellow River, Liaohe River, Luan River, Haihe River, Duliujian River, Ji canal, Daling River, Bohai sea, beaches, estuaries, swamps, lakes, reservoirs, brine pan, paddy field and other types of wetland. It is considered as one of the most concentrated geographical area where China's coastal wetlands and tidal distribute.

### 2.2 Data sources

The information of wetland is extracted from the remote sensing images in three years: 2000, 2005 and 2008. The main data sources are Landsat Thematic Mapper (TM) images with 30 m spatial resolution during June to September. The areas lacking of data or low quality TM images are replaced by China-Brazil Earth Resources Satellite Charge Coupled Device (CCD) data and Environment Satellite 1 images. Data of land transfer between wetland and other land are sourced from the assistant data. The main assistant data are national land use databases at a spatial scale of 1∶100,000 in 2000, 2005 and 2008 (Liu, *et al.*, 2002). Land use classes of this database include arable land, woodland, grassland, water, constructed land, unused land and sea.

## 3 METHODS

### 3.1 Classification system

Wetlands classification system in Bohai rim(Table 1) is confirmed on the basis of two existing classification system, International Wetlands Classification passed by Convention on Wetlands(*Convention of Wetlands* compliance office of the National Forestry Bureau, 2001) and coastal wetlands classification system in 908 project order of the State Bureau of Oceanic Administration (908 project office in the State Bureau of Oceanic Administration, 2005). Besides, the classification system is confirmed on principle of benefiting remote sensing monitor and environment evaluation.

**Table 1 Wetlands classification system of the Bohai rim**

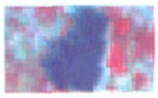
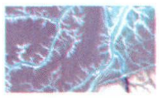
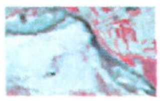
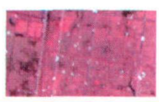
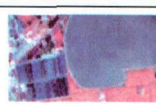
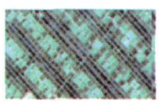
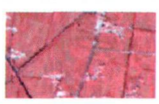
| code | types | Secondary code | Secondary types |
|---|---|---|---|
| 1 | Natural Wetland | 11 | River |
| | | 12 | Lake |
| | | 13 | Tideland |
| | | 14 | Bottomland |
| | | 15 | Suaeda salsa land |
| | | 16 | Reed land |
| 2 | Constructed Wetland | 21 | Reservoirs/aquiculture |
| | | 22 | Brine pan |
| | | 23 | Paddy field[a)] |

a) Paddy field (23) is usually considered as farmland, it doesn't considered as the study object in this study

### 3.2 Wetland extraction

Wetland landscape diversity in Bohai rim is obvious, which make automated classification accuracy not satisfactory (Niu, 2009). Wetland classification in this study is conducted by Human-Computer interaction visual interpretation, including six technical processes: (1) Preprocessing of remote sensing data, including NIR / R / G-band composition, geo-reference and image mosaic. The Root Mean Squared Error (RMS error) of geometric rectification is less than 2 pixels. (2)Base map of wetland types in 2008 is produced basing on Human-Computer interaction visual interpretation, assistant by the related information of the land use vector data. Uncertainty patches are signed for further corrections. (3) Field survey is conducted, including a total of 128 patches, to evaluate the interpretation accuracy and correct the uncertainty interpretation patches. (4) Base map of wetland types in 2008 is revised according to 18 field survey patches aimed at these uncertainty interpretation patches, and then map of wetland types in 2008 is finished. Meanwhile wetland interpretation signs by remote sensing data are established (Table 2). (5) Accuracy validation is conducted

**Table 2 Interpretation symbol of the wetlands in the Bohai rim (standard false color composite)**

| | | NIR / R / G-band composition | shape | color | texture | distribution |
|---|---|---|---|---|---|---|
| Natural Wetland | River |  | Naturally curved band | Dark blue or sky blue | Fine, uniform | Vertical distributed in inland and coastal areas |
| | Lake |  | Natural boundary area | Dark blue or sky blue | Delicate, uniform | Inland |
| | Tideland |  | Band or area | Gray or white | Relatively uniform | Distributed along the coast |
| | Bottomland |  | Naturally curved band | White or light gray | Relatively uniform | By the edge of rivers, lakes, reservoiror ponds |
| | Suaeda glauca Bge land |  | Irregular shape | Brown red | Relatively Rough | Intertidal area |
| | Reed land |  | Irregular shape | Pink | Uniform, with signs of irregular water | By the edge of eservoirs and other places where water conditions are good |
| Constructed Wetland | Reservoirs/aquiculture |  | With artificial traces; aquiculture takes regular grid shape | Dark blue or sky blue | Delicate, uniform | Distributed in inland and coast |
| | Brine pan |  | Small regular box-like | Blue and white | Clear, box-shaped blue and white or triangular-shaped blue and white | Mainly located in the coast, a small amount distributed in inland |
| | Paddy field |  | Regular shaped, with ridges and ditches | Scarlet | Homogeneous | Inland with good water conditions |

for map of wetland types in 2008 on the basis of 110 field survey patches. The validation processes indicated an overall attribute accuracy of 95%. (6) Wetland types in 2000 and 2005 are interpreted on the basis of the interpretation signs and interpreter's knowledge.

### 3.3 Spatial and temporal analysis models

Change rate of each wetland type, regional dynamic degree, and dynamic transfer matrix are calculated in order to analysis the spatial and temporal dynamic pattern of the wetlands in Bohai rim.

(1) Change rate of each wetland type

Change rate of each wetland type $C$ is calculated to compare the dynamic differences among each types of wetland (Wang & Bao, 1999; Liu & Buheaosier, 2000).

$$C_i = \frac{W_{bi} - W_{ai}}{W_{ai}} \times \frac{1}{t} \times 100\% \quad (1)$$

where $C_i$ is the change rate of a certain wetland type during the study period, $W_{ai}$ and $W_{bi}$ are wetland area at the beginning and the end of the study period, $t$ is the study period, when measured by yea, the calculation results indicate annual change rate of the wetland.

(2) Regional dynamic degree

Bohai rim belongs to Liao river basin, Hai river basin and Huang river basin in Chinese firstly drainage basin zoning (National Geometrics Center of China, 2005). Regional dynamic degree $S$ (Wang & Bao, 1999; Zhu & Li, 2003) is calculated to indicate the characteristics and differences of the wetland dynamic degree in each river basin. Dynamic of wetland on spatial can be fractionized to three parts, stable patches, transfer patches and new addition patches (Liu & He, 2002). Wetland dynamic amount or change rate of each wetland type can only reflect the net value of the changes, and concealed a certain amount of the wetlands which had transfer in and out in the same study period.

Regional dynamic degree $S$ reflects the spatial dynamic well, which indicates the absolute value of wetland changes.

$$S = \sum_{i=1}^{n}\left(\Delta S_{i-j;o-i}\right) \Big/ \sum_{i=1}^{n}\left(S_i\right) \times 100\% \quad (2)$$

where $S$ is the regional dynamic degree during the study period, $S_i$ is the wetland area of the type $i$ at the beginning of the study period, $\Delta S_{i\text{-}j;\ o\text{-}i}$ is the transfering out area of type $i$ wetland and transfer in area of type $i$ wetland from non wetland. $\Delta S_{i\text{-}j;\ o\text{-}i}$ is calculated separately in two conditions in order to avoid the repeated statistic of the wetland transfer among different types and meanwhile involve the land transfer between wetland and non wetland.

The border of Liao river basin, Hai river basin and Huang river basin is close to the provincial-level administrative boundaries. Thus, regional dynamic degree is calculated according to administrative boundaries of five cities in Liaoning province, four cities in Shandong province, three cities in Hebei province and Tianjin city, to indicate the characteristics and differences of the wetland dynamic degree in each river basin.

(3) Dynamic transfer matrix

The dynamic transfer matrix of wetlands reflects the transfer types of the wetland clearly. Thus it is of significant reference value for driving mechanism of wetland changes. Wetland vector data of three periods and land use vector data are overlapped spatially to educe the wetland dynamic transfer matrix during the two monitor periods, 2000—2005 and 2005—2008.

$$\begin{vmatrix} P_{11} & P_{21} & \cdots & P_{i1} \\ P_{12} & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ P_{1j} & \cdots & \cdots & P_{ij} \end{vmatrix}$$

where $i$ and $j$ is the type serial number, $P_{ij}$ is the transfer percentage from type $i$ to type $j$ of total dynamics. When $i=j$, $p_{ij}=0$.The sum of all ranks is 100%. $\sum_{j=1}^{n} p_{ij}$ is the transfer percentage from $i$ to all other land of total dynamics. $\sum_{i=1}^{n} p_{ij}$ is the transfer percentage from $j$ to all other land of total dynamics(Guo *et al*., 2009).

# 4 RESULTS AND ANALYSIS

## 4.1 Spatial pattern and area statistics of wetland

Wetland monitoring results in Bohai rim by remote sensing images in 2000, 2005 and 2008 is shown by Fig. 1. The amount and distribution of each types of wetland take on different characteristics. The area of each types of wetland is shown in Table 3.

Wetland in 2008 is taken as a model to analyze the wetland types and distribution characteristics. In 2008, in the Bohai rim conducted monitoring, the total area of wetlands was 15,113.72 km$^2$. As an artificial wetland, brine pan is the largest secondary

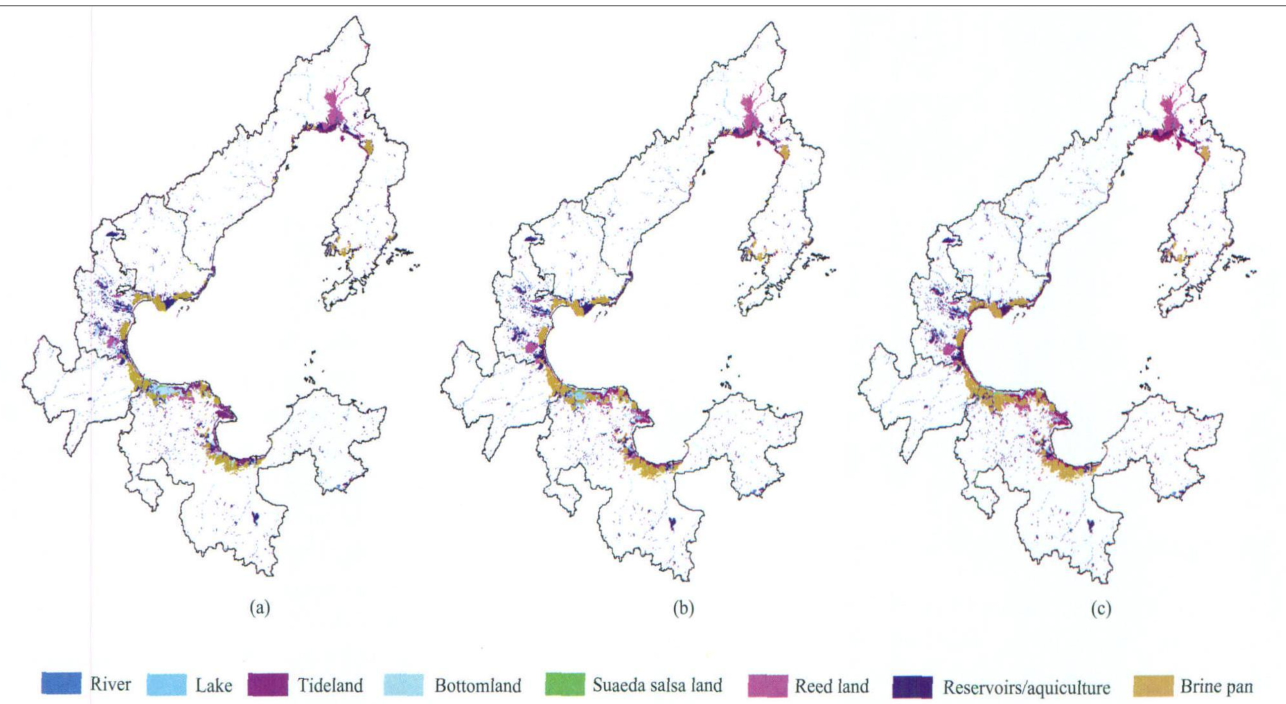



Fig. 1 Map of wetlands of the Bohai rim in 2000, 2005 and 2008

(a) In 2000; (b) In 2005; (c) In 2008

**Table 3 The wetland area and proportion in the Bohai Rim in 2000, 2005 and 2008**

| types(code) | 2000 | | 2005 | | 2008 | |
|---|---|---|---|---|---|---|
| | area/km$^2$ | percentage/(%) | area/km$^2$ | percentage/(%) | area/km$^2$ | percentage/(%) |
| River (11) | 1156.75 | 8.62 | 1585.04 | 10.93 | 1585.81 | 10.49 |
| Lake (12) | 506.43 | 3.77 | 18.67 | 0.13 | 17.91 | 0.12 |
| Tideland (13) | 2262.53 | 16.86 | 1469.08 | 10.13 | 2041.39 | 13.51 |
| Bottomland (14) | 1687.79 | 12.57 | 1196.84 | 8.25 | 819.33 | 5.42 |
| Suaeda glauca Bge land (15) | 168.44 | 1.25 | 72.53 | 0.50 | 73.97 | 0.49 |
| Reed land (16) | 1888.68 | 14.07 | 2025.23 | 13.97 | 2009.18 | 13.29 |
| Reservoirs/aquiculture (21) | 2834.48 | 21.12 | 3966.48 | 27.35 | 4003.3 | 26.49 |
| Brine pan (22) | 2918.64 | 21.74 | 4166.78 | 28.74 | 4562.83 | 30.19 |
| sum | 13423.74 | 100 | 14500.65 | 100 | 15113.72 | 100 |

types of wetland, accounting for 30.19% of the total wetlands area. Brine pan is found mainly along Laizhou Bay and Bohai Bay. The second largest wetland types in Bohai rim is reservoirs/aquiculture, which also belonges to artificial wetland and accounts for 26.49% of the total wetlands area. It is widespread in the Bohai rim. Tideland, reed land and river are the three types that have similar area, and account for 13.51%, 13.29% and 10.49% respectively, of the total wetland area. Tideland is mainly present along Liaodong Bay, Bohai Bay and Laizhou Bay. Reed land is concentrated in three regions that are Liaohe River Delta, Yellow River Delta and South/North Dagang reservoir. Bottomland, Suaeda glauca Bge land and lake are the three types that had the smallest area, and accounted for 5.42%, 0.49% and 0.12%, respectively, of the total wetland area. Bottomland is sparsely distributed over the Bohai rim. Suaeda glauca Bge land is mainly present in the intertidal zone of the Yellow River estuary and Liaohe River estuary.

## 4.2 Dynamic amount and change rate

Under the driving of natural factors and human activities, a certain amount of wetlands transferred into agricultural land or urban land, while various transfer between each types of wetlands also existed, which made the wetland quality and quantity changing.

The total area of wetlands in the Bohai rim is increasing gradually from 2000 to 2008. The main source of increase is new brine pan and new reservoirs/aquiculture, which are all artificial wetland. From 2000 to 2005, wetland in Bohai rim increases 1076.91 km$^2$, with an average annual increase of 215.38 km$^2$. From 2005 to 2008, wetland in Bohai rim increases 613.07 km$^2$, with an average annual increase of 204.36 km$^2$. The area and the dynamic trends of the wetlands in the Bohai rim during the 8 years conducting monitor, which is divided into two study period, is shown in Fig.2.

The areas of four types of wetlands increase, which are brine pan, reservoirs/aquiculture, river and reed land. The other four types of wetland area decrease, which are bottomland, lake, tideland and Suaeda glauca Bge land. Among the four types of wetlands whose area increase, brine pan increases most dramatically, which increase 1644.19 km$^2$ within 8 years, with an average annual increasing of 205.52 km$^2$. The area of the reservoirs/aquiculture increase 1168.82 km$^2$, with an average annual increasing of 146.10 km$^2$. The areas of the river and reed land increasing, respectively, by 429.06 km$^2$ and 120.5 km$^2$, with the average annual increasing of 53.63 km$^2$ and 15.06 km$^2$.

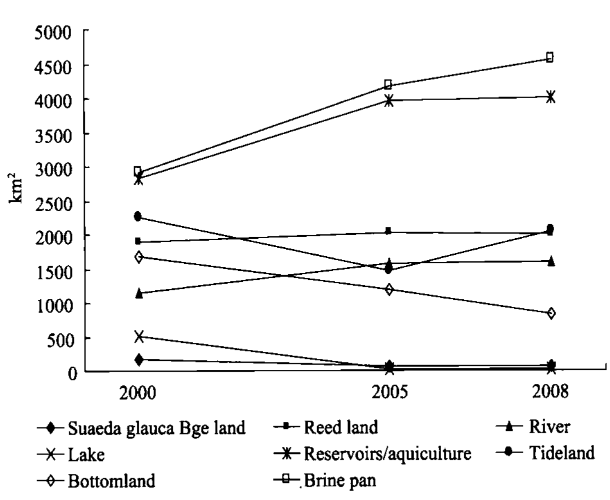



Fig. 2 The area of the wetlands in the Bohai rim during 2000—2008

Among the four types of wetlands whose area decrease, bottomland and tideland are the two types whose areas decrease most obviously. Tideland had reduced 793.45 km$^2$ from 2000 to 2005, and increase 572.31 km$^2$ from 2005 to 2008. Net area decreasing within 8 years is 221.14 km$^2$. Bottomland had decreased 868.46 km$^2$ within 8 years long from 2000 to 2008, with an average annual decrease of 108.56 km$^2$. Lake and Suaeda glauca Bge land had decreased 488.52 km$^2$ and 94.47 km$^2$ respectively, with the average annual decreasing of 61.07 km$^2$ and 11.81 km$^2$.

Annual change rate of wetlands during the period from 2000 to 2008 is shown in Fig.3. Annual change percentage of lake and Suaeda glauca Bge land is very large, although their dynamics are very little. Annual decreasing percentage of lake and Suaeda glauca Bge land achieve at 12% and 7% respectively, which are all higher than the brine pan or the other types of wetland whose dynamic amount is huge. These types of wetland in little distribution amount and under huge dynamic rate should be paid more attention to protect diversity of Bohai rim wetlands.

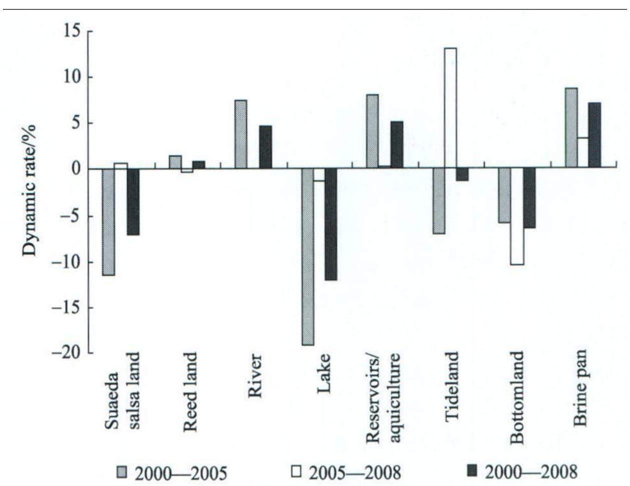



Fig. 3 Annual change rate of wetlands during 2000—2008 in the Bohai rim

## 4.3 Spatial pattern of dynamic and regional differences

The study indicates that: During the period from 2000 to 2008, 89 percent of the wetlands in the Bohai rim kept steady, the other 11 percent had changed, some of which transfer to another types of land and some transfer to another types of wetland.

(1) Spatial pattern of dynamic: Spatial pattern of dynamics of four wetlands are analyzed, whose amount changeings are relatively obvious, and they are brine pan, reservoirs/ aquiculture, bottomland and tideland (Fig.4).

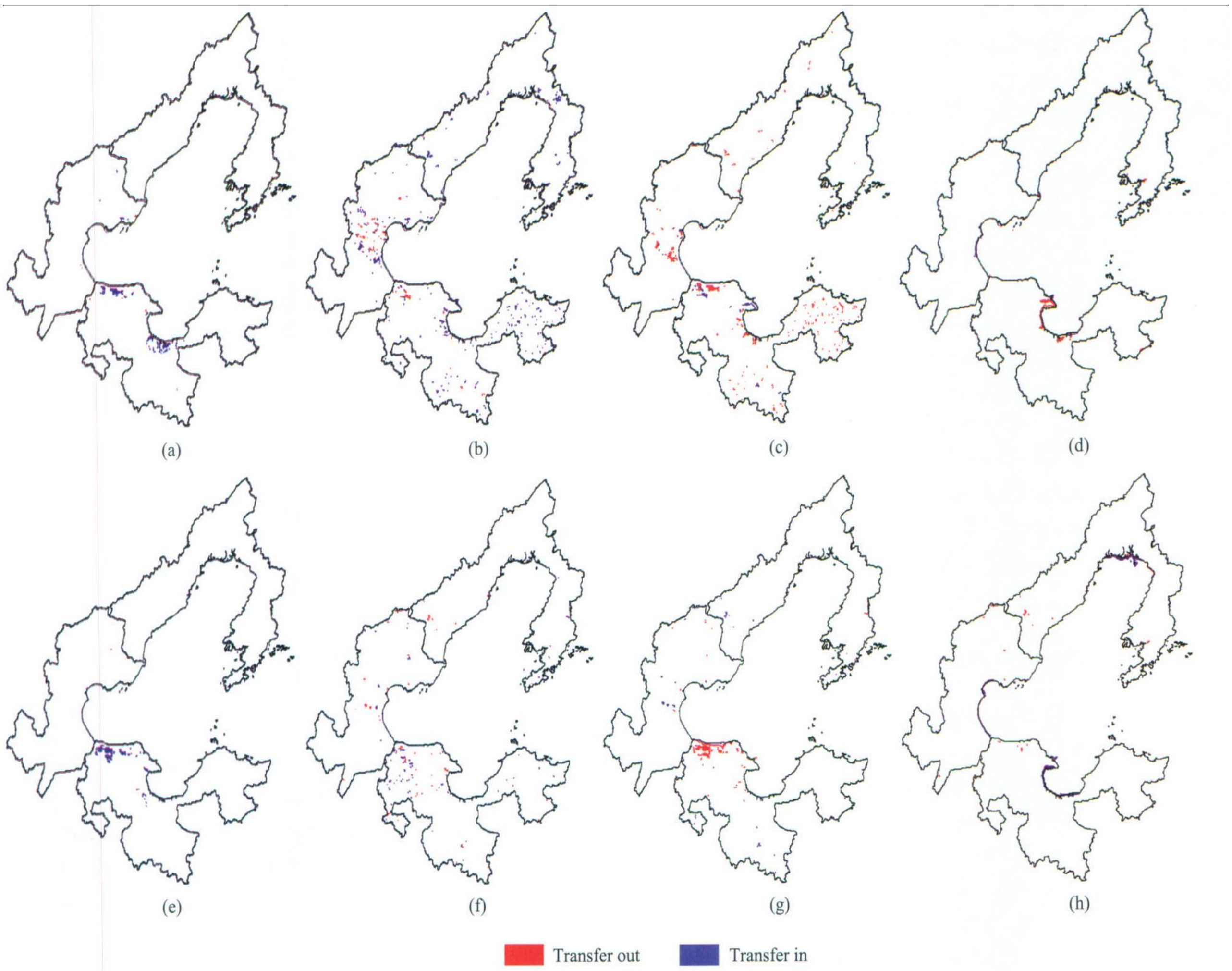



Fig. 4 Spatial and temporal dynamic patterns of the major types of wetlands in the Bohai rim

(a) 2000—2005 Brine pan; (b) 2000—2005 Reservoirs/aquiculture; (c) 2000—2005 Bottomland; (d) 2000—2005 Tideland; (e) 2005—2008 Brine pan; (f) 2005—2008 Reservoirs/aquiculture; (g) 2005—2008 Bottomland; (h) 2005—2008 Tideland

The dynamic of brine pan is mainly present in the Yellow river basin, which is on the rise. During the period from 2000 to 2005, new added brine pan is found mainly along the seashore in Weifang and Binzhou city. During the period from 2005 to 2008, new added brine pan decreased, and distributed mainly along the seashore in Binzhou city.

The dynamic of reservoirs/aquiculture is widespread in the Bohai rim. During the period from 2000 to 2005, new added reservoirs and aquiculture in three river basins are all in large amount, meanwhile reservoirs/aquiculture in the Haihe river basin decreased in a certain amount. During the period from 2005 to 2008, new added reservoirs/ aquiculture is found mainly in the Yellow River Delta areas, only a few new added reservoirs/aquiculture is found in the Haihe river basin, Shandong Peninsula and Liaodong Peninsula.

The dynamic of bottomland is present mainly in the Yellow River and Haihe River Basin, taking decreasing trends, and dynamic characteristics in two study period is different. During the period from 2000 to 2005, the bottomland on both sides of the Yongding River, the Zhangweixin River, in estuary of the Zhangweixin River, and around the Shandong Peninsula decreased more obvious. During the period from 2005 to 2008, the bottomland is found decreasing centralized in the Taoer river estuary in the Yellow River Basin. In the other regions, there is no obvious bottomland decrease.

The dynamic of tideland is present mainly in the three Gulf of Bohai rim, that are Bohai Bay, Laizhou Bay and Liaodong Bay.

(2) Regional change percentages of wetlands indicate that (Table 4):

**Table 4 Regional change percentages of wetlands for Bohai Rim during 2000—2008/%**

<table>
<tr><th>Regional change percentages</th><th>Liaohe Rive Basin (Liaoning)</th><th colspan="2">Haihe River Basin (Heibei and Tianjin)</th><th>Yellow River Basin (Shandong)</th></tr>
<tr><td rowspan="2">2000—2005</td><td rowspan="2">5.99</td><td colspan="2">10.79</td><td rowspan="2">14.84</td></tr>
<tr><td>5.62</td><td>14.52</td></tr>
<tr><td rowspan="2">2005—2008</td><td rowspan="2">8.77</td><td colspan="2">6.26</td><td rowspan="2">16.93</td></tr>
<tr><td>5.01</td><td>7.63</td></tr>
</table>

Wetland dynamic intensity and dynamic trend existed obvious differences among the three river basins in Bohai rim. Regional change percentage in the Yellow River Basin is bigger than that in the other two river basins. Wetland dynamic trend in the Yellow River and Liaohe River is on the rise. Regional change percentage during the period from 2005 to 2008 is 2% bigger than that during the period from 2000 to 2005. On the contrary, the dynamics intensity of wetlands in the Haihe River Basin had been shown decreasing trend. Regional change percentage in the Haihe River Basin during the period from 2005 to 2008 is 4.5% smaller than that during the period from 2000 to 2005, especially in Tianjin, the regional dynamics is reduced by nearly 7%.

## 4.4 Dynamic driving forces-dynamic transfer matrix

The dynamic transfer matrixes of wetlands in the three major river basins during two study periods are calculated to indicate what types of land that the wetlands transferred to, shown in Table 5.

**Table 5 Regional change percentages of wetlands for Bohai Rim during 2000—2008(/%)**

(a) Liao River Basin (2000—2005)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | - | 1 | - | - | - | - | - | - |
| Ri | - | - | - | - | - | - | - | - | - | - | - |
| Ra | - | 7 | - | - | 15 | 3 | 6 | 25 | - | - | 13 |
| T | - | - | - | - | - | - | - | - | - | - | 1 |
| B | - | - | - | - | - | - | - | - | - | - | - |
| Bp | - | - | - | - | 4 | - | - | - | - | - | 1 |
| A | - | - | - | - | - | 4 | - | - | - | - | - |
| G | - | - | - | - | - | 1 | - | - | - | - | - |
| C | - | 1 | - | 4 | 2 | 1 | - | - | - | - | 11 |
| S | - | - | - | - | - | - | - | - | - | - | - |

(b) Haihe River Basin (2000—2005)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | 1 | - | 12 | - | - | - | - | - |
| Ri | - | - | - | - | - | - | - | - | - | - | - |
| Ra | - | 5 | - | - | 3 | 22 | - | 7 | 1 | 1 | 2 |
| T | - | - | - | - | - | - | - | - | - | - | 12 |
| B | - | - | - | 2 | - | - | - | - | - | - | - |
| Bp | - | - | - | - | - | - | - | 2 | - | - | 1 |
| A | - | 2 | - | 5 | - | - | - | - | - | - | - |
| G | - | - | - | - | - | 1 | - | - | - | - | - |
| C | - | - | - | 12 | - | 7 | - | - | - | - | 2 |
| S | - | - | - | - | - | - | - | - | - | - | - |

(c) Yellow River Basin (2000—2005)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | - | 5 | - | - | - | - | - | - |
| Ri | - | - | - | - | - | 1 | - | - | - | - | - |
| Ra | 1 | - | - | - | 3 | - | 1 | 4 | - | - | 2 |
| T | - | - | - | - | - | 13 | - | - | - | - | 5 |
| B | - | - | 1 | 7 | 4 | - | - | 1 | 1 | - | - |
| Bp | - | 1 | - | - | 7 | 28 | - | 4 | - | - | - |
| A | - | - | - | - | - | - | - | - | - | - | - |
| G | - | - | - | - | - | - | - | - | - | - | - |
| C | - | - | - | - | - | - | - | - | - | - | - |
| S | - | - | - | - | 9 | 2 | - | - | - | - | - |

(d) Liao River Basin (2005—2008)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | 1 | - | - | - | - | - | - | - |
| Ri | - | - | - | - | - | - | - | - | - | - | - |
| Ra | - | - | - | - | 7 | 1 | - | - | - | - | 8 |
| T | - | - | - | - | - | - | - | - | - | - | 56 |
| B | - | - | - | - | - | - | - | - | - | - | - |
| Bp | - | - | - | - | - | - | - | - | - | - | 2 |
| A | - | - | - | - | - | - | - | - | - | - | 5 |
| G | - | - | - | - | - | - | - | - | - | - | - |
| C | - | - | - | - | 1 | - | - | - | - | - | - |
| S | - | - | - | - | 19 | - | - | - | - | - | - |

(e) Haihe River Basin (2005—2008)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | 1 | - | - | - | - | - | - | - |
| Ri | - | - | - | - | - | - | - | - | - | - | - |
| Ra | - | 1 | - | - | - | 5 | - | 8 | - | - | - |
| T | - | - | - | - | - | - | - | - | - | - | 49 |
| B | - | - | 1 | 12 | - | - | - | 1 | - | - | - |
| Bp | - | - | - | - | - | - | - | - | - | - | - |
| A | - | - | 5 | - | - | - | - | - | - | - | - |
| G | - | - | - | - | - | 1 | 3 | - | - | - | - |
| C | - | 1 | - | 2 | 6 | 1 | - | - | - | - | 3 |
| S | - | - | - | - | - | - | - | - | - | - | - |

(f) Yellow River Basin(2005—2008)

| | Ss | Re | Ri | Ra | T | B | Bp | A | G | C | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ss | - | - | - | - | - | - | - | - | - | - | - |
| Re | - | - | - | - | - | 2 | - | 2 | - | - | - |
| Ri | - | - | - | - | - | - | - | - | - | - | - |
| Ra | - | 2 | - | - | - | 3 | - | 3 | - | - | - |
| T | - | - | - | - | - | - | - | - | - | - | 33 |
| B | - | - | 2 | - | - | - | - | - | - | - | - |
| Bp | - | 1 | - | 3 | 2 | 27 | - | 4 | - | - | - |
| A | - | 4 | - | 1 | - | - | - | - | - | - | - |
| G | - | - | - | - | - | - | - | - | - | - | - |
| C | - | - | - | - | - | - | - | - | - | - | - |
| S | - | - | - | - | 11 | - | - | - | - | - | - |

where each row header (columns) are the types of land which are Suaeda salsa land (Ss), Reed land (Re), River (Ri), Reservoirs/aquiculture (Ra), Tideland (T), Bottomland (B), Brine pan (Bp), Arable land (A), Grassland (G), Construction land (C) and Sea (S).

The analysis shows that:

(1) In the Liaohe River Basin, reservoirs/aquiculture and construction land increase and tideland decrease are the main wetland dynamic characteristics.

During the period from 2000 to 2005, aquiculture increase accounted for 69% of the total dynamic amount in the Liaohe River Basin. The main land sources are arable land, tideland and sea reclamation land, and account for 25%, 15% and 13%

of the total dynamic amount in this Basin. Construction land increasing account for 19% of the total dynamic amount in the Liaohe River Basin. The main land sources are sea reclamation land, aquiculture and tideland, and account for 11%, 4% and 2% of the total dynamic amount in this Basin.

During the period from 2005 to 2008, aquiculture increase accounted for 16% of the total dynamic amount in the Liaohe River Basin. The main land sources are sea reclamation land and tideland, and account for 8% and 7% of the total dynamic amount in this Basin. The main land sources of construction land increase are sea reclamation land and tideland, and accounted for 5% and 1% of the total dynamic amount in this basin. In this period, the mutual transformation of coastal saline and sea take a large proportion. The dynamic amount of sea transferrs to the tideland account for 56% of the regional dynamic, which mainly include tidal change, and certain artificial tideland which is in the process of sea reclamation.

(2) In the Haihe River Basin, reservoirs/aquiculture and construction land increasing and bottomland decreasing are the main wetland dynamic characteristics.

During the period from 2000 to 2005, aquiculture increasing account for 41% of the total dynamic amount in the Haihe River Basin. The main land sources are bottomland, arable land and reed land, and account for 22%, 7% and 5% of the total dynamic amount in this Basin. Construction land increasing account for 21% of the total dynamic amount in the Haihe River Basin. The main land sources are aquiculture, bottomland and sea reclamation land, and account for 12%, 7% and 2% of the total dynamic amount in this Basin.

During the period from 2005 to 2008, the aquiculture increasing accountes for 14% of the total dynamic amount in the Haihe River Basin. The main land sources are arable land and bottomland, and account for 8% and 5% of the total dynamic amount in this Basin. The main land sources of increasing construction land are tideland and sea reclamation land, and account for 6% and 3% of the total dynamic amount in this basin. The mutual transformation of coastal saline and sea in the Haihe River Basin also takes a large proportion, which was mainly tidal change.

(3) In the Yellow River Basin, brine pan increase and bottomland decrease are the main wetland dynamic characteristics.

During the period from 2000 to 2005, brine pan increase accounted for 40% of the total dynamic amount in the Yellow River Basin. The main land sources are bottomland, tideland and arable land, and account for 28%, 7% and 4% of the total dynamic amount in this Basin.

During the period from 2005 to 2008, brine pan increasing account for 37% of the total dynamic amount in the Yellow River Basin. The main land sources are bottomland, arable land and aquiculture, and account for 27%, 4% and 3% of the total dynamic amount in this Basin.

The dynamic of wetland in Bohai rim, on the whole, are mainly natural wetland transferred to artificial wetland, which indicated that human activities driving forces are bigger than natural forces. Reed land, as the type of wetland having the most effective environmental adjustment ability, had been protected well. Reed land decrease in the Liaohe River Basin and the Haihe River Basin had been slowing down, but it had been speeding up in Yellow River Basin. During the period from 2000 to 2005, the decreasing reed land in the Liaohe River Basin and the Haihe River Basin is mainly reclaimed for arable land or aquiculture. During the following 3 years, however, it is mainly used for industrial land. The one in the Yellow River Basin is mainly reclaimed for arable land or aquiculture. In addition, wetland increasing shows that the arable land transferred to wetland in the Liaohe River Basin and the Haihe River Basin are mainly aquiculture, but in the Yellow River Basin some of it is used for brine pan. In the Liaohe River Basin, the process trend of arable land being occupied by aquiculture or brine pan had been slowing down, but in the Haihe River Basin and Yellow River Basin, arable land are still occupied for the constructions of aquiculture or brine pan.

## 5 CONCLUSIONS AND DISCUSSIONS

The purpose of this paper is to describe wetland dynamics of Bohai rim in recent years basing on remote sensing images within three years, 2000, 2005 and 2008. Conclusions of the research are summarized as follows.

(1) In 2008 in the Bohai rim under monitoring, the total area of wetlands is 15,113.72 $km^2$, which is mainly artificial wetlands. Brine pan and reservoirs/aquiculture are the two types that have the largest area, and account for 30.19% and 26.49%, respectively, of the total wetland area.

(2) During the period from 2000 to 2008, the wetlands in Bohai rim increases, which was driven by human activity more significantly. Brine pan increases most dramatically, with an average annual increase of 205.52 $km^2$. Reservoirs/aquiculture increase with an average annual increasing of 146.10 $km^2$. River and reed land area increase, respectively, with the average annual increasing of 53.63 $km^2$ and 15.06 $km^2$. Bottomland and tideland are the two types that have the largest decreased area.

(3) Lake and Suaeda salsa land are in little distribution amount but under huge dynamic rate, arrive at 12% and 7% respectively, which are all higher than brine pan or other types of wetland whose dynamic amount is huge.

(4) Regional change percentage in the Yellow River Basin is bigger than that in the other two river basins. Wetland dynamic trend in the Yellow River is on the rise. Regional change percentage during the period from 2005 to 2008 is 2% bigger than that during the period from 2000 to 2005. On the contrary, the dynamics intensity of wetlands in the Haihe River Basin shows in decreasing trend. Regional change percentage in the Haihe River Basin during the period from 2005 to 2008 is 4.5% smaller than that during the period from 2000 to 2005. The Yellow River Basin's regional change percentage is not only big but also on the rise, so more attention should be paid on

ecological environmental protection during the future development, in order to maintain the sustainable development of wetland resources.

(5) The dynamic of wetland in Bohai rim are driven mainly by human activities. The major dynamic patterns are that sea, tideland or bottomland are reclaimed to aquiculture, constructed land or brine pan. Reed land, as the type of wetland having the most effective environmental adjustment ability, had been protected well. During the period from 2000 to 2005, the decreased reed land in the Liaohe River Basin and the Haihe River Basin was mainly reclaimed for arable land or aquiculture, but during the period from 2005 to 2008, it is mainly used for industrial land. The decreased reed land in the Yellow River Basin is mainly reclaimed for arable land or aquiculture.

Although the results show that the wetland in the Bohai rim increased, most of the increasing wetland is artificial wetland. The climate adjust capacity of artificial wetland are significantly weaker than natural wetland, such as reed. What's more, artificial wetland destroyed the natural curvature of the coastline, changed coastal habitats land, which will directly affect biodiversity. These types of wetlands which are in little distribution amount but under huge dynamic rate, such as lake or Suaeda salsa, should be given more attention and reasonable protection.

However, the accuracy of wetland extraction basing on remote sensing images exist uncertainty. Such as tideland extraction, especially, depended on tidal changes seriously. In the further, we will focus on improving the precision of the extraction method of tideland.

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# 环渤海滨海湿地时空格局变化遥感监测与分析

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**摘 要：** 基于多期 Landsat TM 等遥感数据，采用目视解译和实地样点采集相互支撑的方法，完成了环渤海地区 2000 年、2005 年及 2008 年湿地提取和分类；运用单一类型变化率模型、区域动态度模型和动态转移矩阵，揭示了环渤海湿地的时空格局、变化特点和驱动机制。研究显示环渤海地区的 8 类湿地中，属于人工湿地类型的盐场和水库坑塘面积比例大且近 8 年增长速度也最快，年均分别增加 205.52 $km^2$ 和 146.10 $km^2$，滩地和海涂减少最明显；环渤海地区的三大流域中，黄河流域湿地变化最显著，其动态度接近海河流域及辽河流域的 2 倍，且仍在上升，海河流域动态度已经呈现出降低趋势；人类活动驱动下的湿地变化比自然驱动更明显，近海域、海涂及滩地开发，用于建设水库坑塘、建筑用地、盐场等，是环渤海湿地变化的重要形式。

**关键词：** 环渤海，湿地变化,遥感监测，时空分析

**中图分类号：** Q14/TP79 **文献标志码：** A

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## 1 引 言

作为“地球之肾”的湿地生态系统，是目前自然界生物多样性最丰富的生态系统(牛振国等, 2009)。环渤海地区是中国北部沿海的黄金海岸，是中国滨海湿地分布最集中的地理区域(刘红玉, 2001)。滨海湿地发育在陆地与海洋之间，是海洋和大陆相互作用最强烈的地带，生物多样性丰富、生产力高，在全球变化、防风护岸、降解污染、调节气候等诸多方面具有重要价值(湿地中国, 2010)。然而近年来，关于建立环渤海经济圈的呼声日益高涨，环渤海地区进一步成为中国北部沿海重要的黄金海岸，在国家对外开放和沿海发展战略中占有重要地位，国务院于 2009 年 12 月批复了黄河三角洲高效生态经济区发展规划，对土地利用提出了更高的要求，湿地资源正在面临巨大压力(Xie 等, 2009)。掌握环渤海地区湿地时空变化情况，对于保护湿地与保障地区经济发展，评估渤海海岸带开发承载能力，维持环渤海地区可持续发展等具有重要意义。

传统对湿地进行野外调查的方法，需要花费大量的时间、人力和物力，有些湿地区域甚至难以接近进行实地考察，因而难于保证质量和效率，且对于历史湿地状况则更难以恢复。利用遥感技术对大面积湿地资源及其生态环境进行动态监测和分析具有显著的高质量、高时效性，且可以依据积累的历史遥感资料，实现历史湿地状况的恢复。目前，已有不少学者基于遥感技术对环渤海地区的湿地实施监测。如刘振乾等(1999; 2000)、Liu 和 Buheaosier(2000)利用 3S 技术，对黄河三角洲和辽河三角洲湿地资源进行了调查；刘红玉等(2001)利用遥感和地理信息系统技术，对 1998 年以前的黄河三角洲和辽河三角洲湿地类型、资源现状及动态变化进行研究，提出区域资源开发与湿地保护及其可持续发展对策；蒋卫国等(2005)在遥感与 GIS 技术支持下，研究了 1986 年和 2000 年辽河三角洲湿地资源的时空变化特

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征并探讨湿地变化的驱动力；赵玉灵(2007)等应用Landsat遥感数据和GIS技术对环渤海湾–莱州湾地区湿地现状进行了调查。在渤海地区开展的湿地研究为湿地资源管理打下了良好的基础，但还仅限于局部区域，且没有得到及时的更新。

本研究选择"十一五"规划实施前后的两个时间段为监测期(2000年—2005年和2005年—2008年)，将整个渤海湾地区作为完整的区域开展环渤海地区湿地遥感监测，揭示近年来环渤海地区湿地数量、湿地时空变化及湿地流转情况，实现环渤海地区3大流域湿地时空变化的对比，探讨湿地变化的驱动力，为保护滨海湿地和确定海岸带资源所能允许的开发强度提供长时间序列的遥感动态监测数据和决策支持。

# 2 研究区域与数据

## 2.1 研究区域

渤海是一个"C"形的近封闭内海，环渤海地区是指渤海周围的包括多个行政区域的地域范围。以行政界线来划分渤海海岸带陆域，研究范围包括辽宁、河北、山东和天津三省一市辖区内的13个沿海地市,即辽宁省的大连市、营口市、盘锦市、锦州市、葫芦岛市；河北省的唐山市、秦皇岛市、沧州市；山东省的滨州市、东营市、潍坊市、烟台市；天津市，辖区总面积为$1.35\times10^7$ $hm^2$(刘宏娟等, 2006)。从自然地理环境看，研究区地处北温带，湿地资源丰富，包括黄河、辽河、滦河、海河、独流减河、蓟运河、大凌河以及海域、滩涂、河口、沼泽、湖泊、水库、盐田、稻田等湿地类型，是中国滨海湿地和滩涂分布最集中的地理区域。

## 2.2 数据源

主要采用2000年、2005年及2008年3期遥感数据，首先选择6月—9月的30 m空间分辨率的美国陆地卫星(Landsat)TM数据，数据缺失或图像质量较差的地区，选用6月—9月的19.5 m空间分辨率的中巴资源卫星(CBERS2B)CCD数据及30 m空间分辨率的"环境一号"卫星(HJ-1)CCD数据进行补充。主要的辅助数据有2000年、2005年及2008年的1: 1万土地利用矢量数据，来源于中国土地利用数据库(Liu 等, 2002)，用于分析湿地与非湿地类型相互转化过程中，湿地的来源土地类型和湿地的转移去向类型，采用土地利用数据6个一级类型，分别是耕地、林地、草地、水域、城乡工交建设用地、未利用地，还包括土地利用数据库中未作为土地地类的海域类型。

# 3 研究方法

## 3.1 分类系统

结合湿地公约组织通过的国际湿地分类(国家林业局《湿地公约》履约办公室, 2001)和国家海洋局908专项规程(国家海洋局908专项办公室, 2005)的滨海湿地分类，以利于环渤海滨海环境动态监测及评价和实施遥感监测的可行性为原则，应用海岸地貌学、河口生态学的理论与方法，确定了环渤海地区湿地分类系统(表1)。

**表1 环渤海地区湿地分类系统**

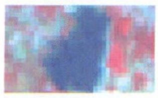
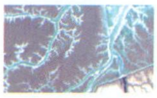
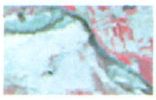
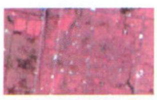
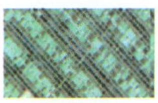
| 编码 | 类型 | 编码 | 亚类 |
|---|---|---|---|
| 1 | 天然湿地 | 11 | 河流水面 |
| | | 12 | 湖泊水面 |
| | | 13 | 海涂 |
| | | 14 | 滩地 |
| | | 15 | 碱蓬地 |
| | | 16 | 芦苇地 |
| 2 | 人工湿地 | 21 | 水库与坑塘 |
| | | 22 | 盐场 |
| | | 23 | 水稻田* |

*人工湿地中的水稻田(23)更多的作为农田资源，在本湿地研究中放弃考虑

## 3.2 湿地信息提取

考虑到环渤海地区湿地景观差异性显著，利用计算机自动分类难以保证分类精度(牛振国等, 2009)，因此本研究以人机交互目视解译方法为主，实现湿地分类。包括6个技术流程：(1)遥感数据预处理，包括NIR/R/G三波段假彩色合成、几何精纠正和数据镶嵌，其中几何精纠正的误差控制在2个像元以内。(2)基于人机交互目视解译方法的2008年湿地类型基础底图制作。参考研究区的土地利用矢量数据中与湿地类型相关的土地利用类型，完成湿地类型室内预判，形成湿地类型基础底图，并对解译存有不确定性的图斑做标记。(3)通过外业考察的方式，检验室内预判湿地类型基础底图的精度。同时，综合所有不确定属性图斑，设计外业验证样点采集路线。实际采集湿地野外验证样点128个。(4)根据面向不确定图斑所采集的外业样点18个，对2008年湿地类型基础底图修正并编辑成图。同时建立环渤海湿地遥感解译标志(表2)。(5)采用110个外业验证样点对2008年湿地类型图进行验证，结果表明，综合精度具有95%以上的定性准确率。(6)根据湿地类型解译标志及专家知识，完成2000年和2005年湿地类型解译并编辑成图。

表 2 环渤海湿地类型解译标志(RGB 标准假彩色合成)

| | | NIR/R/G 波段合成 | 形状 | 色调 | 纹理 | 分布位置 |
|---|---|---|---|---|---|---|
| 天然湿地 | 河流水面 |  | 自然弯曲的条带状 | 深蓝或天蓝 | 细腻、均一 | 内陆、沿海均有交纵分布 |
| | 湖泊水面 |  | 边界自然的面状 | 深蓝或天蓝 | 细腻、均一 | 内陆 |
| | 海涂 |  | 呈条带或片状 | 灰白色或白色 | 较均一 | 沿海分布 |
| | 滩地 |  | 边界自然的条带状 | 白色或淡灰白色 | 较均一 | 河流、湖泊、水库坑塘边的多水地区 |
| | 碱蓬地 |  | 无规则形状 | 褐红色 | 较粗糙 | 海涂上的潮间带 |
| | 芦苇地 |  | 无规则形状 | 粉红色 | 均一, 有不规则水系痕迹 | 水分条件好的河流、水库边缘等地 |
| 人工湿地 | 水库与坑塘 |  | 水库有人工塑造痕迹, 如堤坝; 坑塘为规则方格状 | 深蓝色或天蓝色 | 细腻、均一 | 内陆、沿海均有分布 |
| | 盐场 |  | 规则小方格状 | 蓝色和白色相间 | 清晰, 方格状蓝白相间或三角状蓝白相间 | 多分布于沿海, 内陆有少量分布 |
| | 水稻田 |  | 形状规则, 有田埂、沟渠等农用设施 | 深红色 | 均一 | 水分条件好的内陆地区 |

### 3.3 湿地时空变化分析模型

对环渤海地区湿地变化时空格局的分析, 采用单一类型变化率模型、区域动态度模型和动态转移矩阵, 在 GIS 空间分析技术支持下完成。

(1) 单一湿地类型变化率

利用单一湿地类型变化率 $C$ 定量比较各类型湿地变化的差异(王秀兰和包玉海, 1999; 刘纪远和布和敖斯, 2000)。

$$C_i = \frac{W_{bi} - W_{ai}}{W_{ai}} \times \frac{1}{t} \times 100\% \tag{1}$$

式中, $C_i$ 为研究时段内某一湿地类型的变化率, $W_{ai}$、$W_{bi}$ 分别为研究期初、期末某一湿地类型的面积, $t$ 为研究时段, 当设定为年时, 模型结果表示该区此类湿地类型的年变化率。

(2) 区域湿地动态度

从自然流域角度看, 研究区属于中国一级流域分区(国家基础地理信息中心, 2005)中的 3 大流域, 分属于辽河流域、海河流域和黄河流域。引入区域湿地动态度 $S$(王秀兰和包玉海, 1999; 朱会义和李秀彬, 2003)定量描述 3 大流域湿地动态变化程度的差异。从空间涵义出发, 湿地动态可细分出未变化部分、转移部分和新增部分(刘盛和和何书金, 2002), 湿地动态数量和单一类型变化率分析仅反映湿地变化的数量净值和动态变化的整体趋势, 却弱化了空间转移的细节, 掩盖各类型湿地有转入有转出的动态过程。区域湿地动态度更加具体的揭示湿地的空间数量变化特征。$S$ 中体现了各类型湿地转入和转出的绝对量, 更好地反映出区域动态的强度。

$$S = \sum_{i=1}^{n} \left( \Delta S_{i-j;o-i} \right) \Big/ \sum_{i=1}^{n} (S_i) \times 100\% \tag{2}$$

式中, $S$ 为与研究时段对应的研究区域湿地动态度, $S_i$ 为研究初期第 $i$ 类湿地类型面积; $\Delta S_{i-j;\,o-i}$ 为研究时段内 $i$ 类湿地类型转为非 $i$ 类($j$ 类, $j = 1,2,\cdots,n$)湿地和其他土地利用类型的面积以及其他土地利用类型转为 $i$ 类湿地的面积总和。将 $\Delta S_{i-j;\,o-i}$ 分两段统计, 避免湿地类型间转化的二次统计, 并充分考虑湿地与非湿地类型之间的转换。

辽河流域、海河流域和黄河流域与省级行政界线在空间上非常接近。因此, 分别计算辽宁省沿海 5 市、河北省沿海 3 市、天津市和山东省沿海 4 市的湿地区域动态度, 反映环渤海湿地动态变化在不同流域的过程特点和差异。

(3) 转移矩阵

湿地的动态转移矩阵, 明确反映出湿地的流转去向, 对于湿地变化的驱动机制分析具有重要的参考价值。对 3 期湿地类型矢量数据及相对应时期的土地利用矢量数据, 进行空间叠加分析, 得到 2000 年—2005 年及 2005 年—2008 年两个时间段的湿地类型转移矩阵, 其中包括湿地二级类型的转化和湿地与非湿地的其他土地利用类型的转换。

$$\begin{vmatrix} P_{11} & P_{21} & \cdots & P_{i1} \\ P_{12} & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ P_{1j} & \cdots & \cdots & P_{ij} \end{vmatrix}$$

式中, $i$ 和 $j$ 表示湿地的类型, $p_{ij}$ 为类型 $i$ 转化为类型 $j$ 的面积占发生类型动态转移土地总面积的百分比, 当 $i$=$j$ 时, $p_{ij}$=0。转移矩阵各行列值的总和为 100%。$\sum_{j=1}^{n} p_{ij}$ 为类型 $i$ 转出总量占发生类型动态转移土地总面积的百分比; $\sum_{i=1}^{n} p_{ij}$ 为类型 $j$ 转入总量占发生类型动态转移土地总面积的百分比(Guo 等, 2009)。

# 4 结果和分析

## 4.1 湿地空间格局和面积统计

2000年、2005年和 2008 年环渤海地区湿地遥感监测结果如图 1。受自然及人为因素的综合影响, 各类型湿地面积及分布区域呈现不同的特点。利用地理空间分析软件, 汇总各类型湿地面积(表 3)。

以最新一期(2008 年)监测结果分析环渤海地区湿地的面积比例和分布格局。2008 年, 实施监测的环渤海地区湿地总面积 15113.72 km$^2$, 其中属于人工湿地的盐场所占比例面积最大, 达 30.19%, 盐场主要分布于莱州湾和渤海湾。环渤海地区第二大湿地类型是水库与坑塘类, 仍属人工湿地, 占所有监

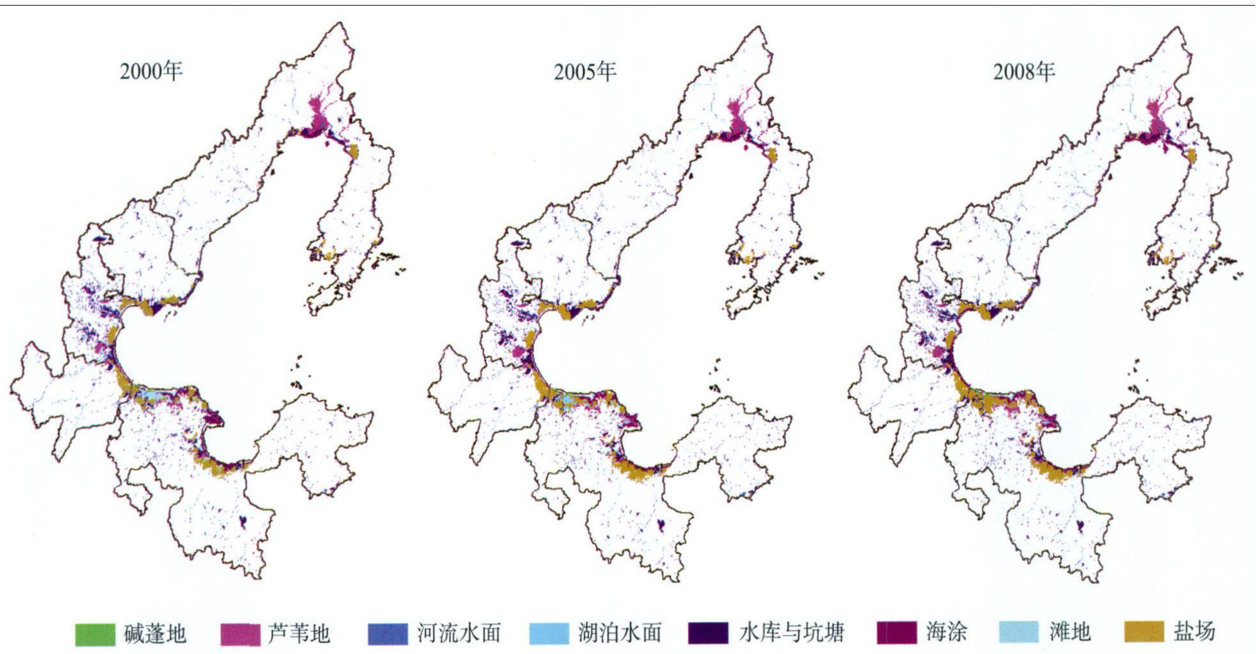



图 1 2000 年、2005 年和 2008 年环渤海地区湿地类型图

**表 3 2000 年、2005 年和 2008 年环渤海地区湿地面积及比例**

| 类型(编码) | 2000 年 | | 2005 年 | | 2008 年 | |
|---|---|---|---|---|---|---|
| | 面积/km$^2$ | 百分比/% | 面积/km$^2$ | 百分比/% | 面积/km$^2$ | 百分比/% |
| 河流水面(11) | 1156.75 | 8.62 | 1585.04 | 10.93 | 1585.81 | 10.49 |
| 湖泊水面(12) | 506.43 | 3.77 | 18.67 | 0.13 | 17.91 | 0.12 |
| 海涂(13) | 2262.53 | 16.86 | 1469.08 | 10.13 | 2041.39 | 13.51 |
| 滩地(14) | 1687.79 | 12.57 | 1196.84 | 8.25 | 819.33 | 5.42 |
| 碱蓬地(15) | 168.44 | 1.25 | 72.53 | 0.50 | 73.97 | 0.49 |
| 芦苇地(16) | 1888.68 | 14.07 | 2025.23 | 13.97 | 2009.18 | 13.29 |
| 水库与坑塘(21) | 2834.48 | 21.12 | 3966.48 | 27.35 | 4003.3 | 26.49 |
| 盐场(22) | 2918.64 | 21.74 | 4166.78 | 28.74 | 4562.83 | 30.19 |
| 湿地合计 | 13423.74 | 100.00 | 14500.65 | 100.00 | 15113.72 | 100.00 |

测类型总面积的 26.49%，水库与坑塘散布于整个环渤海地区。海涂、芦苇地和河流水面的面积接近，三者占所有监测类型总面积的比例分别为 13.51%、13.29%和 10.49%。海涂主要分布在环渤海的 3 个海湾部位-辽东湾、渤海湾和莱州湾。芦苇地分布较为集中，主要有3 大芦苇地块，分别为辽河三角洲、黄河三角洲和南、北大港水库地区。滩地、碱蓬地和湖泊水面是面积非常小的 3 种湿地类型，占所有监测类型总面积的比例分别为 5.42%、0.49%和 0.12%。滩地分散分布于整个环渤海地区。碱蓬地主要分布于黄河入海口和辽河入海口的潮间带。

### 4.2 动态数量和变化率

受自然因素和人为因素的影响，一定量的湿地转化为农业用地和城市用地等其他土地覆被类型，同时各类型湿地之间也存在着类型的转换，使得湿地的质量和数量发生变化。

2000 年—2008 年期间，环渤海湿地总面积逐渐增加，主要的增加来源是填海建盐场及养殖坑塘等人工湿地的增加。2000年—2005 年间湿地增加了 1076.91 $km^2$，平均每年增加 215.38 $km^2$；2005 年—2008年间增加了613.07 $km^2$，平均每年增加204.36 $km^2$。实施监测的 8 年间的 2 个监测时段，各类型湿地面积及变化趋势如图 2。

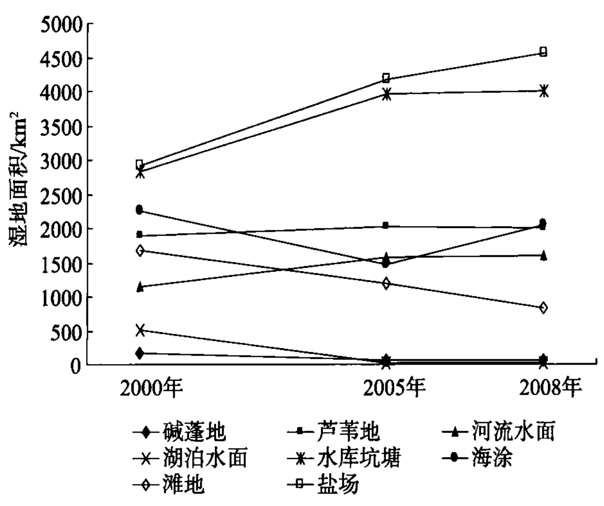



图 2 2000 年—2008 年间环渤海地区湿地面积

面积增加的湿地类型有4个，分别是盐场、水库与坑塘、河流水面和芦苇地。面积减少的湿地类型有 4 个，均为天然湿地，分别为滩地、湖泊水面、海涂和碱蓬地。面积增加最显著的湿地类型是盐场，8 年间增加 1644.19 $km^2$，平均每年增加 205.52 $km^2$；水库坑塘增加 1168.82 $km^2$，平均每年增加 146.10 $km^2$。河流水面和芦苇地面积分别增加 429.06 $km^2$、120.5 $km^2$，平均每年增加量分别为 53.63 $km^2$、15.06 $km^2$。

减少最为明显的湿地类型是滩地和海涂。8年间海涂净减少 221.14 $km^2$，2000 年—2005 年间减少 793.45 $km^2$，2005 年—2008 年增加 572.31 $km^2$。8 年间滩地减少 868.46 $km^2$，平均每年减少 108.56 $km^2$。湖泊水面和碱蓬地分别减少 488.52 $km^2$、94.47 $km^2$，平均每年减少 61.07 $km^2$、11.81 $km^2$。

2000 年—2008 年湿地年均变化率如图 3。变化面积较小的湖泊水面和碱蓬地，年均变化率却非常大。8 年间，湖泊水面以年均 12%的速率减少，碱蓬地以年均 7%的速率减少，均高于变化面积大的水库坑塘和其他类型湿地。从保护湿地类型多样性的角度，这些面积小，变化强度巨大的湿地类型，应得到更多的重视，加以合理保护利用。

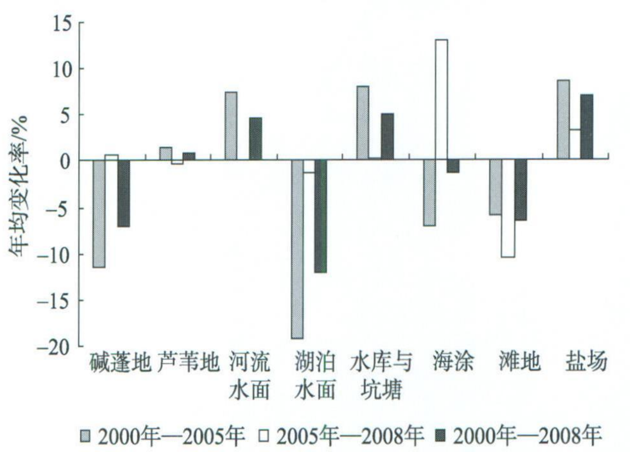



图 3 2000 年—2008 年环渤海地区湿地年均变化率

### 4.3 动态的空间格局和区域差异

研究显示：2000年—2008 年，环渤海约 89%的湿地保持稳定，而其余约11%的湿地发生了变化，包括与非湿地的其他土地利用类型的转变和各湿地类型之间的转换。

(1) 动态的空间格局：针对数量变化明显的4类湿地类型，包括盐场、水库坑塘、滩地和海涂，分析其动态的空间格局(图 4)。盐场的动态变化主要分布于黄河流域，呈现增加的趋势。从时间过程来看，2000 年—2005 年，新增盐场主要分布于潍坊市和滨州市的沿海地区；2005年—2008年，潍坊市新增盐场变少，更主要的增长区集中在滨州市沿海。

水库坑塘的动态变化分布范围最广，遍布于整个环渤海地区。从时间过程看，2000 年—2005 年，3 大流域水库坑塘新增量均较大，同时海河流域水库坑塘也有多处减少；2005 年—2008 年，新增水库坑塘主要集中在黄河三角洲地区；海河流域、山东半岛和辽东半岛的水库坑塘新增量不大。

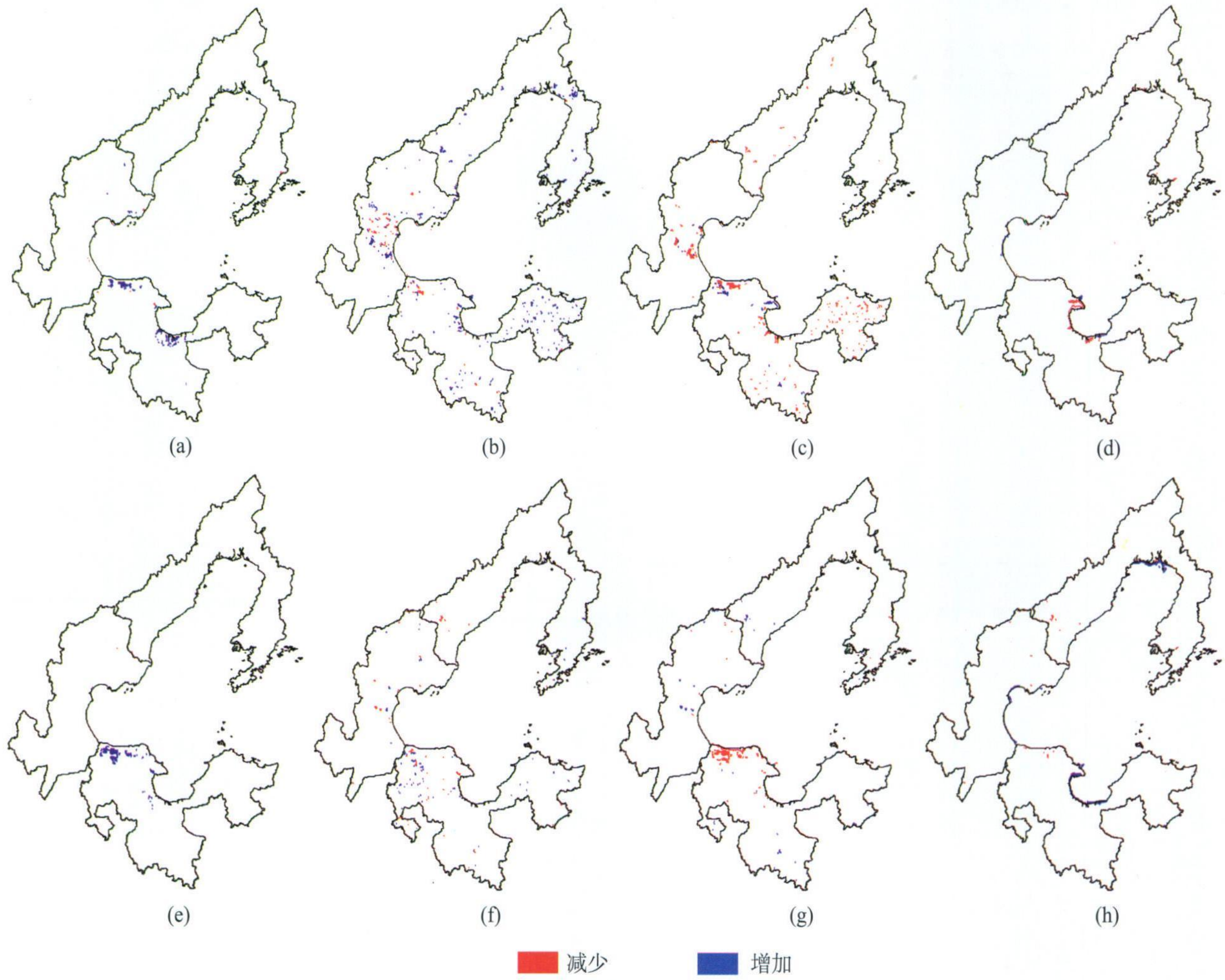



图 4 环渤海主要湿地类型动态变化时空格局

(a) 2000 年—2005 年盐场; (b) 2000 年—2005 年水库坑塘; (c) 2000 年—2005 年滩地; (d) 2005 年—2008 年海涂; (e) 2005 年—2008 年盐场; (f) 2005 年—2008 年水库坑塘; (g) 2000 年—2005 年滩地; (h) 2005 年—2008 年海涂

滩地的动态变化特点是逐渐减少，空间上主要分布于黄河流域和海河流域，且2个监测时期的空间分布格局差异较大。2000 年—2005 年，永定河两侧、漳卫新河两侧及入海口和山东半岛的滩地减少较为明显，在 2005 年—2008 年间，黄河三角洲的套尔河口滩地呈现集中成片的减少状态，其他区域滩地减少不明显。

海涂的动态变化主要集中于环渤海地区的三大海湾—渤海湾、莱州湾和辽东湾。

(2) 区域湿地动态度计算结果显示(表4)：环渤海三大流域之间，湿地的动态变化强度和趋势存在明显区域差异性。黄河流域的湿地动态度大于辽河流域和海河流域，是环渤海地区湿地变化最显著的区域。从变化过程的特点来看，黄河流域和辽河流域的湿地动态变化越发显著，2005 年—2008 年间区域动态度较比 2000 年—2005 年间增加约 2 个百分点。相反，海河流域的湿地动态变化程度已经呈现出降低趋势，2005 年—2008 年间区域动态度较比 2000 年—2005 年间减少约 4.5 个百分点，特别是处于海河流域的天津市，区域动态度降低了近 7 个百分点。

**表 4 2000 年—2008 年环渤海地区湿度动态度/%**

<table>
<tr><th>区域动态度</th><th>辽河流域<br>(辽宁)</th><th colspan="2">海河流域<br>(河北、天津)</th><th>黄河流域<br>(山东)</th></tr>
<tr><td rowspan="2">2000—2005</td><td rowspan="2">5.99</td><td colspan="2">10.79</td><td rowspan="2">14.84</td></tr>
<tr><td>5.62</td><td>14.52</td></tr>
<tr><td rowspan="2">2005—2008</td><td rowspan="2">8.77</td><td colspan="2">6.26</td><td rowspan="2">16.93</td></tr>
<tr><td>5.01</td><td>7.63</td></tr>
</table>

### 4.4 动态的驱动机制 – 转移矩阵

分别计算 3 大流域在两个监测时段的湿地动态转移矩阵，反映湿地的流转去向，如表 5(a)—(f)：其中表头各行(列)所代表的土地类型分别为：碱蓬地、芦苇地、河流水面、水库坑塘、海涂、滩地、盐场、耕地、草地、城乡工交建设用地和海域。

分析显示：

(1) 辽河流域湿地的动态变化以坑塘和建设用地增加，海涂减少为主。

**表 5 2000 年—2008 年环渤海地区变化百分比/%**

(a) 辽河流域 2000 年—2005 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | - | 1 | - | - | - | - | - | - |
| 河流 | - | - | - | - | - | - | - | - | - | - | - |
| 坑塘 | - | 7 | - | - | 15 | 3 | 6 | 25 | - | - | 13 |
| 海涂 | - | - | - | - | - | - | - | - | - | - | 1 |
| 滩地 | - | - | - | - | - | - | - | - | - | - | - |
| 盐场 | - | - | - | - | 4 | - | - | - | - | - | 1 |
| 耕地 | - | - | - | - | - | 4 | - | - | - | - | - |
| 草地 | - | - | - | - | - | 1 | - | - | - | - | - |
| 建设 | - | 1 | - | 4 | 2 | 1 | - | - | - | - | 11 |
| 海域 | - | - | - | - | - | - | - | - | - | - | - |

(b) 海河流域 2000 年—2005 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | 1 | - | 12 | - | - | - | - | - |
| 河流 | - | - | - | - | - | - | - | - | - | - | - |
| 坑塘 | - | 5 | - | - | 3 | 22 | - | 7 | 1 | 1 | 2 |
| 海涂 | - | - | - | - | - | - | - | - | - | - | 12 |
| 滩地 | - | - | - | 2 | - | - | - | - | - | - | - |
| 盐场 | - | - | - | - | - | - | - | 2 | - | - | 1 |
| 耕地 | - | 2 | - | 5 | - | - | - | - | - | - | - |
| 草地 | - | - | - | - | - | 1 | - | - | - | - | - |
| 建设 | - | - | - | 12 | - | 7 | - | - | - | - | 2 |
| 海域 | - | - | - | - | - | - | - | - | - | - | - |

(c) 黄河流域 2000 年—2005 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | - | 5 | - | - | - | - | - | - |
| 河流 | - | - | - | - | - | 1 | - | - | - | - | - |
| 坑塘 | 1 | - | - | - | 3 | - | 1 | 4 | - | - | 2 |
| 海涂 | - | - | - | - | - | 13 | - | - | - | - | 5 |
| 滩地 | - | - | 1 | 7 | 4 | - | - | 1 | 1 | - | - |
| 盐场 | - | 1 | - | - | 7 | 28 | - | 4 | - | - | - |
| 耕地 | - | - | - | - | - | - | - | - | - | - | - |
| 草地 | - | - | - | - | - | - | - | - | - | - | - |
| 建设 | - | - | - | - | - | - | - | - | - | - | - |
| 海域 | - | - | - | - | 9 | 2 | - | - | - | - | - |

(d) 辽河流域 2005 年—2008 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | 1 | - | - | - | - | - | - | - |
| 河流 | - | - | - | - | - | - | - | - | - | - | - |
| 坑塘 | - | - | - | - | 7 | 1 | - | - | - | - | 8 |
| 海涂 | - | - | - | - | - | - | - | - | - | - | 56 |
| 滩地 | - | - | - | - | - | - | - | - | - | - | - |
| 盐场 | - | - | - | - | - | - | - | - | - | - | 2 |
| 耕地 | - | - | - | - | - | - | - | - | - | - | 5 |
| 草地 | - | - | - | - | - | - | - | - | - | - | - |
| 建设 | - | - | - | - | 1 | - | - | - | - | - | - |
| 海域 | - | - | - | - | 19 | - | - | - | - | - | - |

(e) 海河流域 2005 年—2008 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | 1 | - | - | - | - | - | - | - |
| 河流 | - | - | - | - | - | - | - | - | - | - | - |
| 坑塘 | - | 1 | - | - | - | 5 | - | 8 | - | - | - |
| 海涂 | - | - | - | - | - | - | - | - | - | - | 49 |
| 滩地 | - | - | 1 | 12 | - | - | - | 1 | - | - | - |
| 盐场 | - | - | - | - | - | - | - | - | - | - | - |
| 耕地 | - | - | 5 | - | - | - | - | - | - | - | - |
| 草地 | - | - | - | - | - | 1 | 3 | - | - | - | - |
| 建设 | - | 1 | - | 2 | 6 | 1 | - | - | - | - | 3 |
| 海域 | - | - | - | - | - | - | - | - | - | - | - |

(f) 黄河流域 2005 年—2008 年

| | 碱蓬 | 芦苇 | 河流 | 坑塘 | 海涂 | 滩地 | 盐场 | 耕地 | 草地 | 建设 | 海域 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 碱蓬 | - | - | - | - | - | - | - | - | - | - | - |
| 芦苇 | - | - | - | - | - | 2 | - | 2 | - | - | - |
| 河流 | - | - | - | - | - | - | - | - | - | - | - |
| 坑塘 | - | 2 | - | - | - | 3 | - | 3 | - | - | - |
| 海涂 | - | - | - | - | - | - | - | - | - | - | 33 |
| 滩地 | - | - | 2 | - | - | - | - | - | - | - | - |
| 盐场 | - | 1 | - | 3 | 2 | 27 | - | 4 | - | - | - |
| 耕地 | - | 4 | - | 1 | - | - | - | - | - | - | - |
| 草地 | - | - | - | - | - | - | - | - | - | - | - |
| 建设 | - | - | - | - | - | - | - | - | - | - | - |
| 海域 | - | - | - | - | 11 | - | - | - | - | - | - |

在2000年—2005年间，坑塘增加占整个区域动态变化量的69%，主要来源是占用耕地、海涂开发以及填海，占区域总动态的比例依次是25%、15%和13%；建设用地增加占区域动态变化量的19%，主要土地来源是填海造地、占用坑塘以及海涂开发，占区域总动态的比例依次是11%、4%和2%。

2005年—2008年间，坑塘增加占整个区域动态变化量的16%，主要来源是海域和海涂的开发，占区域动态变化量的8%和7%；建设用地增加主要是填海造地及海涂开发，分别占区域动态变化量的5%和1%。此监测时段，海涂与海域的相互转化所占

比例较大，海域转变为海涂的比例占区域动态量的56%，这主要包括潮汐变化引起的海涂增减，同时也包括一部分填海造地完成之前的人造海涂。

(2) 海河流域湿地的动态变化以坑塘和建设用地增加，滩地减少为主。

在2000年—2005年间，坑塘增加占整个区域动态变化量的 41%，主要来源是利用滩地、占用耕地和芦苇地，占区域总动态的比例依次是 22%、7%和5%；建设用地增加占区域动态变化量的21%，主要土地来源是占用坑塘、滩地开发以及填海造地，占区域总动态的比例依次是 12%、7%和 2%。

2005 年—2008 年间，坑塘增加占整个区域动态变化量的 14%，主要来源是占用耕地和滩地开发，占区域动态变化量的8%和 5%；建设用地增加主要是海涂开发及填海造地，分别占区域动态变化量的6%和3%。海河流域的海涂与海域的相互转化所占比例也较大，多为潮汐变化引起的海涂增减。

(3) 黄河流域湿地的动态变化以盐场增加和滩地减少为主。

在2000年—2005年间，盐场增加占整个区域动态变化量的40%，主要来源是利用滩地、海涂和占用耕地，占区域总动态的比例依次是 28%、7%和 4%。

2005 年—2008 年间，盐场增加占整个区域动态变化量的37%，主要来源是利用滩地、占用耕地和利用坑塘，占区域动态变化量的 27%、4%和 3%。

综合环渤海地区湿地的动态变化，天然湿地向人工湿地转化占大部分，人类活动驱动下的湿地变化比自然驱动更明显。作为最具环境调节能力的湿地类型，芦苇地得到了较好的保护。辽河流域和海河流域的芦苇地减少速度减慢，但黄河流域的芦苇地减少却加快。2000 年—2005 年间，辽河流域和海河流域减少的芦苇地主要是被开荒种地或用于坑塘养殖，而2005年—2008年间则主要用于工业用地开发。黄河流域芦苇地减少主要是被开荒种地或用于坑塘养殖。另外，从湿地增加情况可以看出，辽河流域和海河流域占用耕地主要用于坑塘养殖，黄河流域则有一部分耕地是用来建盐场；从时间趋势上看，辽河流域占用耕地建养殖场和盐场的趋势已经减弱，而海河流域和黄河流域的仍然占用耕地建养殖场和盐场。

## 5 结论与讨论

基于 2000 年、2005 年和 2008 年 3 个时期的遥感影像，对近年来环渤海地区 13 个地市的湿地实施动态监测和变化分析。研究得出以下主要结论：

(1) 2008年环渤海地区湿地总面积 15113.72 $km^2$，以人工湿地为主，其中盐场和水库坑塘，分别占湿地总面积的 31%和 27%。

(2) 2000年—2008年期间，环渤海各类型湿地面积有增有减，湿地总面积逐渐增加，人类活动影响明显。盐场面积增加最显著，平均每年增加 205.52 $km^2$；水库坑塘增加较快。河流水面和芦苇地分别以年均53.63 $km^2$、15.06 $km^2$ 增加。减少最为明显的湿地类型是滩地和海涂。

(3) 变化面积较小的湖泊水面和碱蓬地，年均变化率却非常大，年均减少速率分别为 12%和 7%，均高于变化面积大的水库坑塘等其他类型湿地。

(4) 黄河流域是环渤海地区湿地变化最显著的区域，其湿地动态度大于辽河流域和海河流域。从时间上来看，黄河流域动态度仍在上升，2005 年—2008 年间区域动态度较比 2000 年—2005 年间增加约 2个百分点。相反，海河流域的湿地动态变化程度已经呈现出降低趋势，2005 年—2008 年间区域动态度较比 2000 年—2005 年间减少约 4.5 个百分点。区域湿地动态度较大且呈上升趋势的黄河流域，在未来发展中需更加注重生态环境保护问题，合理开发利用，以维持黄河流域湿地资源的可持续发展。

(5) 环渤海地区人类活动驱动下的湿地变化比自然驱动更明显。对近海域、海涂及滩地开发，用于建设水库坑塘、建筑用地、盐场等，是环渤海湿地变化的重要形式。作为最具环境调节能力的湿地类型，芦苇地得到了较好保护。2000 年—2005 年间，辽河流域和海河流域减少的芦苇地主要是被开荒种地或用于坑塘养殖，而2005年—2008年间则主要用于工业用地开发。黄河流域芦苇地减少主要是被开荒种地或用于坑塘养殖。

研究结果显示环渤海湿地面积增加，但以人工湿地为主，人工湿地对气候调节能力大大弱于芦苇地等天然湿地，此外，人工湿地破坏了海岸线的自然弯曲度，改变了近海生物栖息地，将直接影响生物多样性。从保护湿地类型多样性的角度，湖泊水面和碱蓬地这些面积小，变化强度巨大的湿地类型，应得到更多的重视，加以合理保护利用。

此外，遥感方法提取湿地信息，特别是海涂类型的信息提取的精度，受潮汐变化的影响较大，在进一步工作中，将重点研究提高海涂类型提取精度的方法。

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