Evolution of wetland landscape disturbance in Jiaozhou Gulf between 1973 and 2018 based on remote sensing

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ABSTRACT

Wetlands are important ecosystems but face a grim future due to the impacts of human activities, such as lost area and function. Their landscape patterns and the environment quickly respond to external disturbance. This paper selected Jiaozhou Bay as the study area and used man-machine interactive remote sensing to extract information from wetlands. Human disturbance indices and landscape transition methods were used to conduct a scenario analysis of the evolution of landscape disturbance in Jiaozhou Bay wetlands from 1973 ~ 2018. The quantitative and spatial changes in landscape disturbance types on the wetlands were also analyzed. The changes were clustered and merged, and the dynamic change types of disturbance in the study area were summarized. Among landscape disturbance types, anthropogenic renewable and non-renewable landscapes increased continuously: in particular, the anthropogenic non-renewable type had the largest area increase, a testament to continued human disturbance.

Introduction

As important natural habitats, wetlands are widely distributed throughout the world (He et al., 2014) and feature-rich biodiversity (Balla, 1994). They ensure global ecological security and play a vital role in urban ecological security patterns (Wu et al., 2018), they are highly sensitive to disturbance from human activities, and their landscape patterns and environment can quickly respond to external disturbance (Cui et al., 2004; V. J. Chapman, 1977). In recent years, with the continuous increase in the intensity and scope of human disturbance in an ever-intensifying manner (Bell, 1999; Bostrom et al., 2006; Paine & Levin, 1981; Robbins & Bell, 1994; Sousa, 1984). Currently, basic heterogeneity, natural disturbance, and human disturbance are three mechanisms that contribute to the formation of existing spatio-temporal patterns in wetland landscapes (Forman, 1995). Of these, human disturbance is constantly expanding its influence on pattern formation. In this context, landscape use types can be described for illustration and landscape use status can be adopted to indicate the applicability of studies on human disturbance in certain areas. For instance, Jon Pasher et al. introduced the disturbance footprint to measure human disturbance in Canada and found that the main forms of human disturbance included

KEYWORDS

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This article has been retracted. Please see Retraction (http://dx.doi.org/10.1080/22797254.2020.1758963) for illustration and landscape use status can be adopted to indicate the applicability of studies on human disturbance in certain areas. For instance, Jon Pasher et al. introduced the disturbance footprint to measure human disturbance in Canada and found that the main forms of human disturbance included
The human disturbance mechanism is complex and difficult to characterize, so certain challenges must be overcome first to quantitatively describe its influence on the spatio-temporal evolution of wetland landscapes. Some scholars have used regional wetland landscape indices to analyze the mechanisms of human disturbance (Liu et al., 2016); however, they rarely explore the spatio-temporal differentiation of wetlands in coastal areas. It is of particular urgency that the changing characteristics of human disturbance be identified and analyzed on a regional scale.

Since China’s reform and opening-up, population growth has been converging in coastal areas and land use patterns have undergone profound changes. Human exploration is significantly changing coastal landscape and seriously damaging wetland ecosystems. The coastal areas of Jiaozhou Bay are ecologically fragile and have little capacity for self-purification. Wetland landscape patterns in the region have clearly become fragmented (State Council, 2018), which has been accompanied by increasingly severe degradation. This paper used a series of Landsat image data as its primary data source and constructed comprehensive human disturbance indices for the ecosystem, analyzed landscape transition magnitudes for wetlands in different phases to explore the changing human disturbance, and summarized the characteristics and types of wetland evolution. The results can effectively guide the reconstruction and restoration of wetland landscape patterns and have positive implications for reducing threats to biodiversity and promoting a harmonious man–land relationship. They can also provide valuable scientific information for environmental protection, restoration, and sustainable use of the coastal wetlands of Jiaozhou Bay.

Materials and methodology

Overview of the study area

In China, the coastline is defined as the land-sea location of multi-year mean high water spring tides (Yang et al., 2015). This paper used man-machine interactive remote sensing interpretation to extract the coastline. The multi-year mean high water spring tides for Jiaozhou Bay were traced from imagery while referring to secondary data sources. The Jiaozhou Bay coastline in 1973 was selected as the baseline and all wetland types within 30 km inland and all neritic regions within 0.5 km of the sea were selected as the study area (Suo et al., 2016). This area contains over 70% of the population of Qingdao (Pang et al., 2017) and is facing significant urbanization, the greatest disturbance to wetlands, and the most prominent man–land contradiction.

Data source

This paper downloaded a series of Landsat level-1 standard image data for 6 days (i.e., 5 December 1973; 2 October 1980; 15 October 1990; 16 September 2000; 6 October 2010; and 28 October 2018) from the United States Geological Survey (USGS) (http://glovis.usgs.gov), which met interpretation requirements. To ensure seasonal consistency, the data acquisition times were uniformly distributed during the period from September to December.

Division of land types

In line with the national standards Current land use classification (GB/ T 21010-2017) and Wetland classification (GB/T 24708-2009) and referring to visual interpretation (Mei et al., 2001), manual visual interpretation was performed for the remote sensing image from 1973, all wetland regions were extracted, and the remote sensing images of the remaining five dates were interpreted. Random precision evaluation points were created and the confusion matrix was calculated to test the classification results. An overall precision greater than 90% was obtained, which met the precision requirement of this study. Based on this, the land use/cover types within the study area were divided into 13 secondary types: permanent shallow marine water, coastal mudflat, permanent estuarine water, riverine wetland, inland tidal flat, reservoirs, culture pond, salt fields, arable land, woodland, bare land, grassland and construction land (Zhao et al., 2014).

Disturbance transition magnitude

Spatial overlay and a transfer matrix were used to extract land use/cover change characteristics for the study area across time and space. Based on these results, categories for comprehensive human disturbance indices were adopted (Table 1) along with disturbance transition coefficients (Table 2) to define disturbance transition magnitude. The equation is as follows:

$$ DM = \sum \{(i-j) \times a_{ij}\} $$

where $DM$ represents the disturbance transition magnitude; $a_{ij}$ represents the transition area in the disturbance change transfer matrix for different years; $i$ and $j$ represent the $i^{th}$ disturbance type and the $j^{th}$ disturbance type, respectively; $(i-j)$ represents the transition...
coefficient. In this study, disturbance transition magnitude > 0 indicates weakening disturbance and disturbance transition magnitude < 0 indicates enhancing disturbance. Table 2 provides the transition coefficient (i→j) values corresponding to different disturbance types during transition.

Results

Change in primary types

As can be seen in Table 3, natural wetlands tended to reduce over time but the degree of reduction gradually declined. The most significant average annual reduction occurred from 1980 ~ 1990, i.e., −1.54%. Constructed wetlands continued to grow until 2000, but the magnitude of growth declined and after 1990, they began to be reduced. The other land use types they experienced reductions in area from 1973 ~ 1990 followed by continuous growth after that. From 2000 ~ 2010, they had an average annual growth rate of 9.92%.

From 1973 to 1980, most transitions occurred in constructed wetlands but other land and natural wetland types also clearly increased. Natural wetlands transitioned into both constructed wetlands and other land cover types at rates of 3.62 km²/a and 2.84 km²/a, respectively. From 1980 ~ 1990, most transitions occurred in constructed wetlands. In fact, the largest source areas for constructed wetlands were natural wetlands (with an average annual transition rate of 5.40 km²/a, Table 4), followed by other land cover types (2.65 km²/a). Natural wetlands also transitioned into other land cover types at a rate of 1.22 km²/a. Clearly, the primary transition source was natural wetlands. From 1990 to 2000, most transitions still occurred in constructed wetlands but other land types also clearly increased. Both natural and constructed wetlands transitioned into other land cover types at rates of 2.32 km²/a and 2.15 km²/a, respectively. From 2000 ~ 2010 and 2010 ~ 2018, the transitions characteristics were similar with each other. According to area, the most transitions occurred in constructed wetlands→other land types and natural wetlands→other land types. The total area of transition from 2010 to 2018 was significantly less than from 2000 to 2010, but the area transitioning from other land types into constructed wetlands increased slightly. Overall, in the latter two phases, the primary target of transition was other land types.

Table 1. Categories of comprehensive ecosystem human disturbance indices.

| Ecosystem types         | The natural unutilized | The natural renewable | The anthropogenic renewable | The anthropogenic non-renewable |
|-------------------------|------------------------|-----------------------|----------------------------|--------------------------------|
| Coastal mud flat, Inland tidal flat, bare land | 0                      | 1                     | 2                          | 3                              |
| Woodland, grassland, Permanent shallow marine wetland, Reservoirs, | 0                      | 1                     | 0                          | 0                              |
| Arable land             | 1                      | 0                     | 1                          | 2                              |
| Construction land, culture pond, salt fields, | 2                      | 1                     | 1                          | 1                              |

Table 2. Disturbance transition coefficients.

| Transition (i→j)          | The natural unutilized | The natural renewable | The anthropogenic renewable | The anthropogenic non-renewable |
|---------------------------|------------------------|-----------------------|----------------------------|--------------------------------|
| The natural unutilized    | 0                      | 1                     | 2                          | 3                              |
| The natural renewable     | −1                     | 0                     | 1                          | 2                              |
| The anthropogenic renewable | −2                    | −2                    | 0                          | 1                              |
| The anthropogenic renewable | −3                    | −2                    | −1                         | 0                              |

Table 3. Change in area of primary land use/cover types from 1973 to 2018.

| Types                  | Natural wetland | Constructed wetland | Other land |
|------------------------|-----------------|---------------------|------------|
| Time (Sort Period)     | AAC (km²) (%)   | AAC (km²) (%)       | AAC (km²) (%) |
| 1973/1980              | 408.24          | 90.65               | 91.48      |
| 1980                   | 381.81          | −0.92               | 117.41     |
| 1990                   | 322.95          | −1.54               | 193.25     |
| 2000                   | 280.85          | −1.30               | 209.51     |
| 2010                   | 253.10          | −0.99               | 138.03     |
| 2018                   | 236.43          | −0.82               | 110.71     |

AAC (Average Annual Change) = (area in this phase-area in last phase)/duration (positive value: increase; negative value: decrease).

The phases from 1973 ~ 1980 and 2010 ~ 2018 were different from the earlier phases, encompassing only seven or 8 years instead of 10, so average annual change was used.

Table 4. Main transition types and average annual transition area of wetlands in 1973 ~ 2018 (km²).

| Sort Period | 1     | 2     | 3     |
|-------------|-------|-------|-------|
| 1973–1980   | NW→CW | NW→OL | OL→NW |
| 1980–1990   | NW→CW | OL→CW | NW→OL |
| 1990–2000   | NW→CW | NW→OL | CW→OL |
| 2000–2010   | CW→OL | NW→OL | OL→CW |
| 2010–2018   | CW→OL | NW→OL | NW→CW |

NW nature wetlands, CW constructed wetlands, OL other land. This table only lists the top three transition types in terms of average annual transition area; average annual transition area was obtained from the transfer matrix.
Quantitative change in landscape disturbance types

Over the past 45 years, anthropogenic renewable and non-renewable landscapes were consistently in high proportions and are very active landscape disturbance types. The natural unutilized landscape constituted a minor part of the wetlands in Jiaozhou Bay and accounted for roughly 5.48%–33.14% of the total area (Figure 1). There was a trade-off between natural unutilized landscapes and artificially utilized landscapes.

From 1973 ~ 2018, the area of landscape disturbance types increased continuously and the increased area accounted for about 10% of the total study area. Of these, artificially utilized landscapes made the largest contribution to the increase. The area of natural unutilized landscapes was continuously reduced, from 33.14% in 1973 to 5.48% in 2010 (in 2018, it recovered to 5.78%). The area of natural renewable types remained relatively unchanged and stabilized at about around 50% over the study period. The area of anthropogenic renewable types was similar to that of the natural unutilized type and also declined relatively significantly. The anthropogenic non-renewable type saw the largest increase in area. Based on the annual rates of change for different landscape disturbance types (Figure 2), changes in the natural unutilized type, the natural renewable type, and the anthropogenic renewable type were dominated by negative growth. The natural unutilized type with the lowest degree of disturbance had the largest reduction, while the anthropogenic non-renewable type with the highest degree of disturbance-maintained growth all along (although at a lower rate in the later phase of the study).

Spatial change in landscape disturbance types

The natural unutilized type was mainly distributed near the Wind River estuary and along the nearby coastline, as well as near the Yuejin River estuary and to the northeast of Jiaozhou Bay. This type was reduced significantly, while the other landscape disturbance types were all distributed along the coastline and clearly expanded. On the whole, the natural unutilized type was mainly distributed near estuaries, the natural renewable type was mainly found around neritic wetlands, and the anthropogenic disturbing landscape type was scattered in between. Wetlands to the northwest, northeast, and southwest of Jiaozhou Bay were subjected to the most intense disturbance.

Figure 1. Landscape composition of disturbance types in the Jiaozhou Bay wetlands.

Figure 2. Rates of change of landscape disturbance types in different phases.
Spatio-temporal analysis of disturbance transition magnitude

The main difference in wetland landscape disturbance transitions was the change in disturbance grade. When this was greater than 0, it meant that more patches changed into landscape types with a stronger human disturbance. When it was less than 0, it meant that more patches changed into landscape types with a weaker human disturbance. This was based on the change in disturbance grade that was used to calculate the change in landscape transition magnitude and the dynamic change characteristics of landscape disturbance types were analyzed from 1973 ~ 2018.

From a temporal standpoint, the landscape transition magnitudes of wetlands in Jiaozhou Bay were all greater than 0, which was evidence of the continuance disturbance throughout the study period. From 1973 ~ 1980, the disturbance transition magnitude reached its peak. As indicated by a spatial comparison which the disturbance changed among five phases (Figure 3), there were more disturbance-free types in the early phase. Many tidal flats were distributed around estuaries and there were relatively broad tidal flat feature zones along the coastline, implying that the wetlands were connected. Over time and impacted by continuous human disturbance, the Jiaozhou Bay wetlands became clearly fragmented, accompanied by a large increase of anthropogenic non-renewable landscapes. In particular, the disturbance was most obviously enhanced from 1973 to 1980 and was mainly distributed in the city’s national hi-tech industrial development zone, Jihongtan reservoir and the Dagu river estuary. From 2000 to 2010, the increased disturbance was mainly observed at the South Xin’an and Licun River estuaries. From 2000 to 2018, disturbance declined rapidly in spatial area and to some extent in intensity, but the trend persisted.

Analysis of the dynamic disturbance change types

Different land types were affected by human disturbance to varying degrees and the disturbance transition magnitude and change trend were fragmented. To evaluate the change in disturbance transition magnitude, a K-Means clustering algorithm was used to analyze the dynamic characteristics of the transition (Zhang et al., 2017). Nine types were identified (Figure 4): Improved type, invert U type, N type, M type, U type, invert N type, W type, weaken type and stable type.

Improved type (Figures 4(a) and 5). This type indicates improved trend during the whole period. The disturbance was enhanced from 1973 to 1980 and the increasing state spread to the two following phases of 1980 ~ 1990 and 1990 ~ 2000 with a low

![Figure 3. Spatial distribution of disturbance transition coefficients in different phases.](image-url)
extent. There is no change from 2000 to 2010. The disturbance was weakened during the stage of 2010 ~ 2018. The landscape disturbance transition coefficients in these regions ranged from −1.31 to 0.69 with a relatively high magnitude. The figure shows that this type was mainly distributed around estuaries near the Dagu, Xiangmao, and Moshui Rivers.

Invert U type (Figures 4(b) and 5). This type of movement trend looks like a mountain. But the peak is not so obvious. The figure indicates that the interference was enhanced at the beginning and end of the entire period. This type is mainly distributed in the reservoirs and in northeast and northwest of the Jiaozhou Gulf.

N type (Figures 4(c) and 5). This type indicates the characteristic of fluctuations. The disturbance shows stronger weakening trend from 1980 to 1990 than that from 2010 to 2018. In contrast, there are enhanced disturbance in the other stages with a strongest interference from 2000 to 2010. The distribution of this type is similar to that of the U type.

M type (Figures 4(d) and 5). This type is the opposite of the W type. Three peaks and two valleys are replaced with two peaks and three valleys. The appearance of peaks and valleys is absolutely contrast to that of W type. The area of this type is less than that of W type, which is mainly distributed in and around rivers and reservoirs.
U type (Figures 4(e) and 5). It is a trend with the characteristic like a valley. The shape of wave curve like a “U”. The degree of weaken disturbance during 2010 ~ 2018 is stronger than that during 1973 ~ 1980. The disturbance was enhanced in the other stages with a lower extent. The landscape disturbance transition coefficients in these regions ranged from -0.83 to 0.45 with a low magnitude. This type is mainly distributed in the reclamations and lower reaches of Dagu river.

Invert N type (Figures 4(f) and 5). The status of disturbance is contrary to the N type except for 1990 ~ 2000. The difference is that weakening disturbance appears at the stages of 1973 ~ 1980 and 2000 ~ 2010, but it is stronger weaken in the latter. The increased disturbance occurs during the other stages which includes the most increase from 1980 to 1990. This type is fragmental in the region. Relatively, it is centralized in north of Jiaozhou Gulf.

W type (Figures 4(g) and 5). This type has three peaks with weaken interference and two valleys with enhanced interference. Three peaks appear at the stages of 1973 ~ 1980, 1990 ~ 2000 and 2010 ~ 2018. The disturbance weakened most obviously from 1990 to 2000. Two valleys appear at phases of 1980 ~ 1990 and 2000 ~ 2010 with increased interference at similar extent. The area of this type is small with a disjoined distribution. It is often seen beside the reservoirs.

Weakened type (Figures 4(h) and 5). There is a weakened trend in this type during the whole period. The disturbance shows a diminishing state from 1973 to 1980. After that, the disturbance has been increasing which reached the bottom at the stage of 2010 ~ 2018.

Stable type (Figure 5). There has no change in the disturbance. This type with the largest area mainly distributed alongside the coastline. This type also appears in north of Jiaozhou Gulf where culture ponds are.

In terms of area distribution, there were clear differences between the nine dynamic change types of disturbance. The M type had the smallest area and the stable type had the largest. After 2010, these four types, including Invert U type, Invert N type, weakened type and M type, experienced increased disturbance and jointly accounted for 18.47% of the total area (Table 5), suggesting that the wetlands were still under great pressure from human disturbance.

| Dynamic change types of disturbance | Area (km²) | Ratio (%) |
|-----------------------------------|------------|-----------|
| Stable type                        | 250.68     | 42.46%    |
| U type                             | 111.64     | 18.91%    |
| N type                             | 56.44      | 9.56%     |
| Invert U type                      | 55.87      | 9.46%     |
| Improved type                      | 48.85      | 8.27%     |
| Invert N type                      | 31.07      | 5.26%     |
| W type                             | 13.73      | 2.33%     |
| Weakened type                      | 12.9       | 2.19%     |
| M type                             | 9.2        | 1.56%     |
| Total                              | 590.38     | 100.0%    |

**Table 5. Statistics for dynamic change types of landscape disturbance.**

Jiaozhou Bay is a semi-enclosed bay with excellent natural conditions (such as climate and terrain) and rich fishery resources, providing an ideal living environment. However, the wetlands of this area are vulnerable to disturbance by human activities. The estuaries of many rivers, such as the Dagu and Yang Rivers, are located northwest of Jiaozhou Bay. This area is characterized by flat terrain, wide beaches (miles in width), and fertile soil on the muddy tidal flats; as a typical embayed coast, it produces Hongdao clams (a well-known local shellfish) and many other shellfish varieties, and provides an ideal place for mudflat aquaculture. Due to these conditions, culture ponds are very frequent and study results showed a continuous increase in the area of culture ponds. The estuaries of the Moshui River, the Baisha River, and other rivers are located northeast of Jiaozhou Bay and the environment is similar to that of the Dagu River estuary. There are large areas of lowland mudflats, which are frequently flooded by seawater. Because they make brine infiltration difficult, they provide very favorable conditions for developing salt fields. In the early phase of the study, this region had many salt fields, while in the middle phase economic interests caused a rapid increase in the number of culture ponds, and in the late phase, this area was largely reclaimed by construction land.

After being listed as one of the first set of 14 open coastal cities in 1984, Qingdao experienced rapid development: its population increased from 5.74 million in 1975 to 9.39 in 2018, the GDP increased from 2.91 billion RMB to 1200.15 billion RMB, and other socio-economic indices also improved. In particular, while the implementation of national industrial policies made a substantial contribution to economic development, it also intensified human disturbance. The Qingdao Economic & Technological Development Area is situated on the west bank of Jiaozhou Bay. From 1973 ~ 1980, Qingdao was approved as a city fully open to the outside world, Huangdao Oil Port Projection was started. Some main projects of Qingdao Port had been completed in this stage. From 1980 ~ 1990, the construction of Qianwan Port resulted in a substantial increase of coastal reclamation area. From 1990 ~ 2000, landscape change was dominated by the transition from coastal tidal flats to culture ponds, and from 2000 ~ 2010, with the continuous construction of the Qingdao National High-tech Industrial Development Zone north of Jiaozhou Bay, reclaimed tidal flats.
increased rapidly accompanied by an increase in construction land. From 2010 ~ 2018, the filling of reclaimed culture ponds for construction land were a typical characteristic of this phase. With greater ecological and environmental awareness and the implementation of “culture ponds for sea” and other policies in Qingdao, the increase in construction land slowed down after 2010. Thanks to the establishment of Jiaozhou Bay National Ocean Park, Shaohai National Wetland Park, Qingdao Yangmaogou Flower Sea Wetland Park, and Riverside Park, the other land types in this area are being converted into constructed wetlands at an increasingly faster pace, and the effects of wetland restoration are now visible.

Discussion

This paper used comprehensive human disturbance indices for an ecosystem to analyze wetland response to human disturbance in the coastal areas of Jiaozhou Bay from 1973 ~ 2018. The main conclusions are as follows:

Wetland disturbance types differed across the different phases: In the initial two stages of 1973 ~ 1980 and 1980 ~ 1990, the most typical change was the transition into constructed wetlands and other land types. From 1990 ~ 2000, culture ponds, construction land, and bare land increased dramatically in the study area. From 2000 ~ 2010, the most typical change was the substantial growth of construction land. From 2010 ~ 2018, the magnitude of construction land growth declined, constructed wetlands increased slightly, and the effects of wetland restoration became apparent. Seen from the change in spatial distribution, natural wetland landscapes transitioned more readily into constructed wetlands and other land types and the wetland landscape pattern became increasingly fragmented.

Wetlands were intensely affected by human disturbance: Anthropogenic renewable and non-renewable landscapes increased continuously, the latter of which had the largest increase in area. Landscape disturbance types had a non-uniform spatial distribution and were mostly observed in the concentrated estuarine regions in the northeast, northwest, and west of Jiaozhou Bay, where human disturbance was the highest.

Disturbance transition magnitude changed clearly with time: Over the study period, disturbance continuously increased: in particular, from 1973 ~ 1980 the magnitude of the transition peaked at 26.73 km²/a. The dynamic characteristics of disturbance transition were classified into nine types. After 2010, these four types, including Invert U type, Invert N type, weakened type and M type, experienced increased disturbance and jointly accounted for 18.47% of the total area, suggesting that the Jiaozhou Bay wetlands were still under great pressure from the increased human disturbance.

Because of the superior natural resources in Jiaozhou Bay, the wetlands of this area inevitably experienced frequent human exploration and disturbance. National industrial policies, socio-economic development, and other factors also contributed to the intensification of human disturbance.

Human disturbance indices are used to evaluate levels of disturbance caused by human activities (Zhao et al., 2014); however, the mechanisms of land use change are complicated, and it is difficult to fully depict trends on a regional scale. In this case, disturbance transition coefficients can perform clustering and merging on sequential changes according to statistical methods (Zhang, Su, et al., 2015). This helps to identify the anti-disturbance capacity of a wetland landscape, identify differences in the spatial pattern of human disturbance and its dynamic change types, and clarify the mechanisms of disturbance. It can also guide the adoption of protective measures for wetlands.

Overall, the wetlands of Jiaozhou Bay have changed alongside local socio-economic development: In the initial phase of reform and opening-up, economic development was beginning and the reclamation of natural wetlands and the construction of culture ponds, salt fields, and other projects of higher economic value began. After entering the 1990s and driven by the pursuit of economic values, natural wetlands continued to transition into culture ponds, construction land, and other types of higher economic value. After 2000, significant intensification of urbanization resulted in the increased occupation of wetlands by construction land. After 2010, with the enhancement of wetland protection awareness and the decline of urbanization, wetland losses slowed and the area of constructed wetlands increased. As can be seen from the dynamic change types of landscape disturbance, most areas are now still affected by increased disturbance and wetlands are still under great pressure from human disturbance. In general, in the past 45 years, the Jiaozhou Bay wetlands have evolved from natural wetlands → culture ponds and salt fields → bare land and grassland → construction land.

Conclusions

This paper mainly analyzed the quantitative and spatial changes of wetland landscape ecosystem types due to land use/cover transitions. Depending on the type of change, the study area was classified into nine types with the purposes of exploring changes in disturbance, clarifying the response of coastal wetlands in Jiaozhou Bay to human disturbance, and offering guidance for wetland restoration and the evaluation
of disturbance. This study only considered the differences in degree of disturbance and did not take into account the different disturbances among subtypes or within the same wetland ecosystem (or the ecosystems in adjacent areas), so comprehensive follow-up studies are needed. Meanwhile, as important ecosystems between land and sea, wetlands are highly sensitive to human disturbance and it is important to explore their response to human disturbance at different scales in the future.

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