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Analyses on Temporal and Spatial Variation Characteristics of Erosion and Deposition in the Front Edge of Salt Marsh Wetland

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Abstract: Taking Yancheng Nature Reserve Salt Marsh as the research object, the remote sensing images from 2005 to 2020 were interpreted by using remote sensing and geographic information system technology. In this paper, the temporal and spatial variation characteristics of erosion and deposition in the front edge of salt marsh wetland were analyzed. The influence of sea level rise on the annual change of salt marsh area was analyzed. The characteristics of flow and sediment movement in salt marsh and the causes of erosion and deposition in front of salt marsh were analyzed. The results showed that: (1) During 2005-2007, the sea level was relatively low, and *Spartina alterniflora* in salt marsh expanded to the sea. Since 2007, the front edge of salt marsh wetland has coexisted with erosion and deposition. From 2008 to 2010, the front edge of salt marsh wetland once again showed a trend of comprehensive deposition to the sea side. From 2010 to 2012, the erosion of salt marsh wetland was serious. From 2012 to 2020, the front edge of salt marsh wetland in the range of 9 km south of Xinyang estuary was eroded. (2) The correlation analysis was carried out between the area of salt marsh wetland and sea level rise. *Spartina alterniflora* is easily affected by sea level change, owing to it having a low ecological niche. With the rise of sea level, the area of salt marsh has been decreasing since 2013. (3) In the front sea area of salt marsh wetland, the maximum velocity of the ebb and flood can reach the threshold velocity during the spring tide. The sediment starts to move at water depth of 10 m under wave actions. Owing to wave stirs up sediment and current transports the sediment, resuspended sediment causes the erosion of marsh-edge scarps.

Key words: Salt marsh wetland, remote sensing, deposition erosion, sea level rise, wave-current action.

1. Introduction

As an important ecological type of coastal wetland, salt marsh is usually located at the middle and upper part of intertidal zone. As a buffer zone for sea-land interaction, its niche is usually above the mean tide level. Salt marsh plays a key role in coastal wetland ecosystem diversity. A large number of existing studies show that salt marsh development is controlled by extreme events such as relative sea level change, land subsidence, nearshore hydrodynamic conditions and sediment transport, etc. [1-3].

Salt marsh along the eastern coast of China has experienced rapid expansion since the introduction of *Spartina alterniflora* (1960s). Many studies in recent years show that since *Spartina alterniflora* was introduced into the inter tidal zone of Jiangsu, it has promoted coastal siltation and changed the intertidal geomorphology [10-12].

Remote sensing and geographic information technology has been widely used in monitoring the dynamic changes of Yancheng coastal wetlands and achieved a series of results. Using remote sensing and geographic information technology to interpret remote sensing images of coastal wetlands can better understand the present situation of coastal wetlands. The remote sensing images of Landsat series of land resources satellite of NASA (National Aeronautics and Space Administration) are selected for the study [9].

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2. Study Area

The study area is located in Yancheng Nature Reserve Salt Marsh, which is between Xinyang Port and Doulong Port. The wetland area is 225.96 km^2. The study area is less disturbed by human activities, and the growth of salt marsh vegetation still shows obvious zoning. From land to sea, there are grass beach (mainly *Phragmites australis*), *Suaeda salsa*, *Spartina alterniflora* beach and naked beach [4, 5]. The location and terrain profile of the study area can be seen from Figs. 1 to 3.

Fig. 1 Location of study area.

Fig. 2 Erosion status in northern part of core area of Yancheng national rare bird nature reserve (2019).

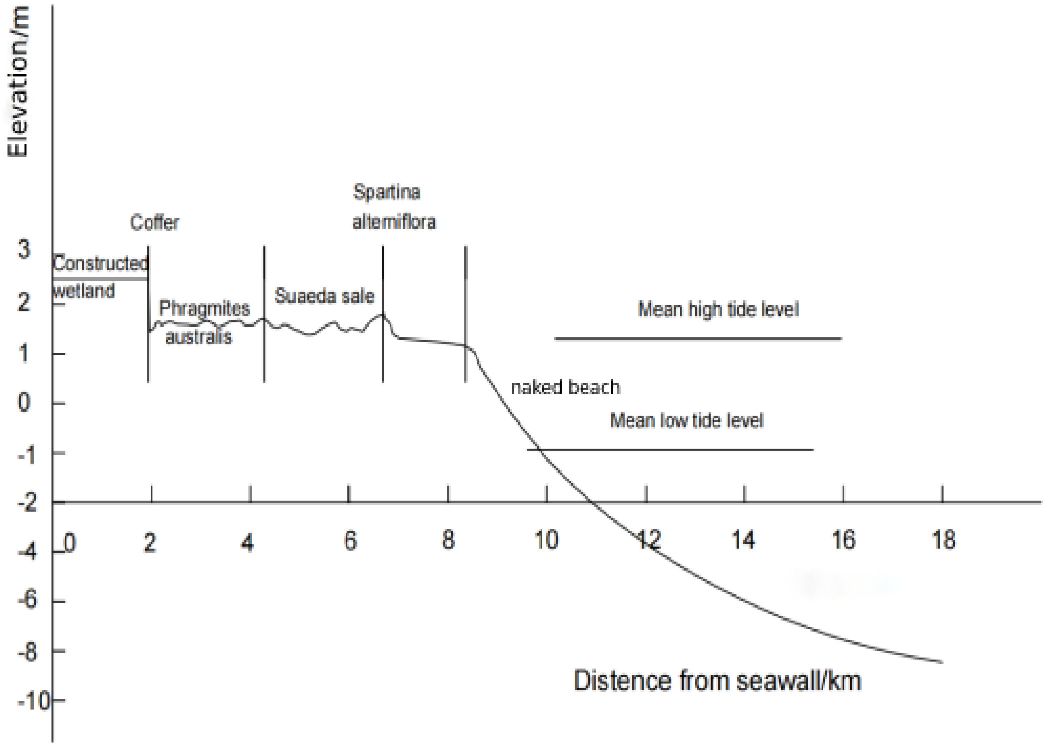

Fig. 3 Schematic diagram of section elevation of study area.

3. Methods

3. 1 Observational Data

A time series of remote sensing images in 2014, 2016, 2018, 2019 and 2020 are selected to calculate the salt marsh erosion rate (Fig. 4). According to the dry wet line, vegetation line, artificial shoreline and other shoreline indicators, the human-computer interactive visual interpretation of the shoreline position is carried out on ArcGIS to generate vector data and obtain the waterline at the imaging time [6-8]. The average spring tide high tide line is calculated by using the tide level data and slope at the imaging time. The coastline in 2014, 2016, 2018, 2019 and 2020 is determined through the combination of remote sensing interpretation and visual interpretation.

Fig. 4 Cross-section distribution map of core area.

3.2 Calculation Method of Retreating Rate

EPR (End Point Rate) can reflect the net change of coastline. The calculation method is relatively simple. A baseline is drawn to parallel the selected coastline. Then a vertical line is drawn every 20 m to divide the baseline. The specific calculation method is as follows:

$$EPR = \frac{d_2 - d_1}{t_2 - t_1} \tag{1}$$

where d_1 is the distance (m) from the intersection of the vertical line and the first shoreline to the baseline. d_2 is the distance (m) from the intersection of the vertical line and the latest shoreline to the baseline. t_1 is the shoreline earlier time (year). t_2 is the shoreline later period (year).

3.3 Threshold of Sediment

Zhang's [14] expression of threshold velocity of sediment the current flow is as follows:

$$V_c = 1.34(\mathrm{h/D})^{0.14}\sqrt{(\gamma_s - \gamma)\mathrm{g}\mathrm{D}/\gamma} \tag{2}$$

where, h is the water depth, D is sediment diameter, γ_s is the bulk density, g is 9.8 m/s^2.

Liu's [15] expression of threshold depth of sediment the wave motion is as follows:

$$\mathrm{d}_* = \frac{\mathrm{L}}{4\pi}\mathrm{arcsh}\left[\frac{\pi \mathrm{g} \mathrm{H}^2}{\mathrm{M}^2\mathrm{L}\left(\frac{\rho_s - \rho}{\rho}\mathrm{g}\mathrm{D} + \beta\frac{\varepsilon_k}{\mathrm{D}}\right)}\right] \tag{3}$$

where, L represent wavelength, H is recommended as $H_{1/10}$, $\varepsilon_k = 2.56\ \mathrm{cm}^3/\mathrm{s}^2$, β is 0.039, and $M = 0.12\left(\frac{\mathrm{L}}{\mathrm{D}}\right)^{1/3}$.

Schwinmmer (2001) [16] found that rates of erosion are correlated with wave power in Rehoboth Bay. As wave power increases, the rate of erosion increases.

$$R = 0.35P^{1.1} \tag{4}$$

where R is erosion rate (m/yr) and P is wave power (kW/m).

4. Result

According to the process of remote sensing image interpretation in the study area from 2005 to 2020, from 2005 to 2007, the sea level was relatively low, and it was at the stage of *Spartina alterniflora* expanding to the sea side. At this stage, the area of salt marsh is expanding continuously, and the front edge of salt marsh is fully silted to the seaward side. With the rise of sea level, erosion and siltation have coexisted in the front edge of salt marsh since 2007. During the three months from the end of 2007 to the beginning of 2008, the core area basically showed a changing trend of "silting in the north and eroding in the south". The maximum advancing distance in the north can reach 86 m, while the maximum retreating distance in the south is 72 m. From 2008 to 2010, the front edge of the salt marsh wetland once again showed a trend of comprehensive siltation towards the sea side. From the beginning of 2008 to September, 2010, the edge of *Spartina alterniflora* salt marsh pushed forward to the sea in an all-round way. The average advancing distance is 192 m, the maximum advancing distance is 556 m, the average advancing speed is 72 m/yr, and the maximum advancing speed is 208 m/yr. From 2010 to 2012, the erosion of salt marsh was serious (overall erosion), which was closely related to the change of sea level during the period. It may also be related to Typhoon Davi, which landed in Jiangsu in 2012. As the landing of "Davi" coincides with the astronomical tide of the 15th lunar calendar, it will have a disastrous impact of the three encounters of wind and rain. At the same time, the intensity of the typhoon will keep the typhoon intensity when landing, and it is also the strongest typhoon landing north of the Yangtze River since 1949. However, from October 2010 to the end of 2012, the edge of *Spartina alterniflora* salt marsh was completely eroded and retreated. Average retreat distance is 111 m, maximum retreat distance is 349 m, average retreat rate is 48 m/yr, and maximum retreat distance is 151 m/yr. From the end of 2012 to the end of 2014, the edge of *Spartina alterniflora* salt marsh showed a change pattern of "middle migration and erosion at both ends". The average advancing distance

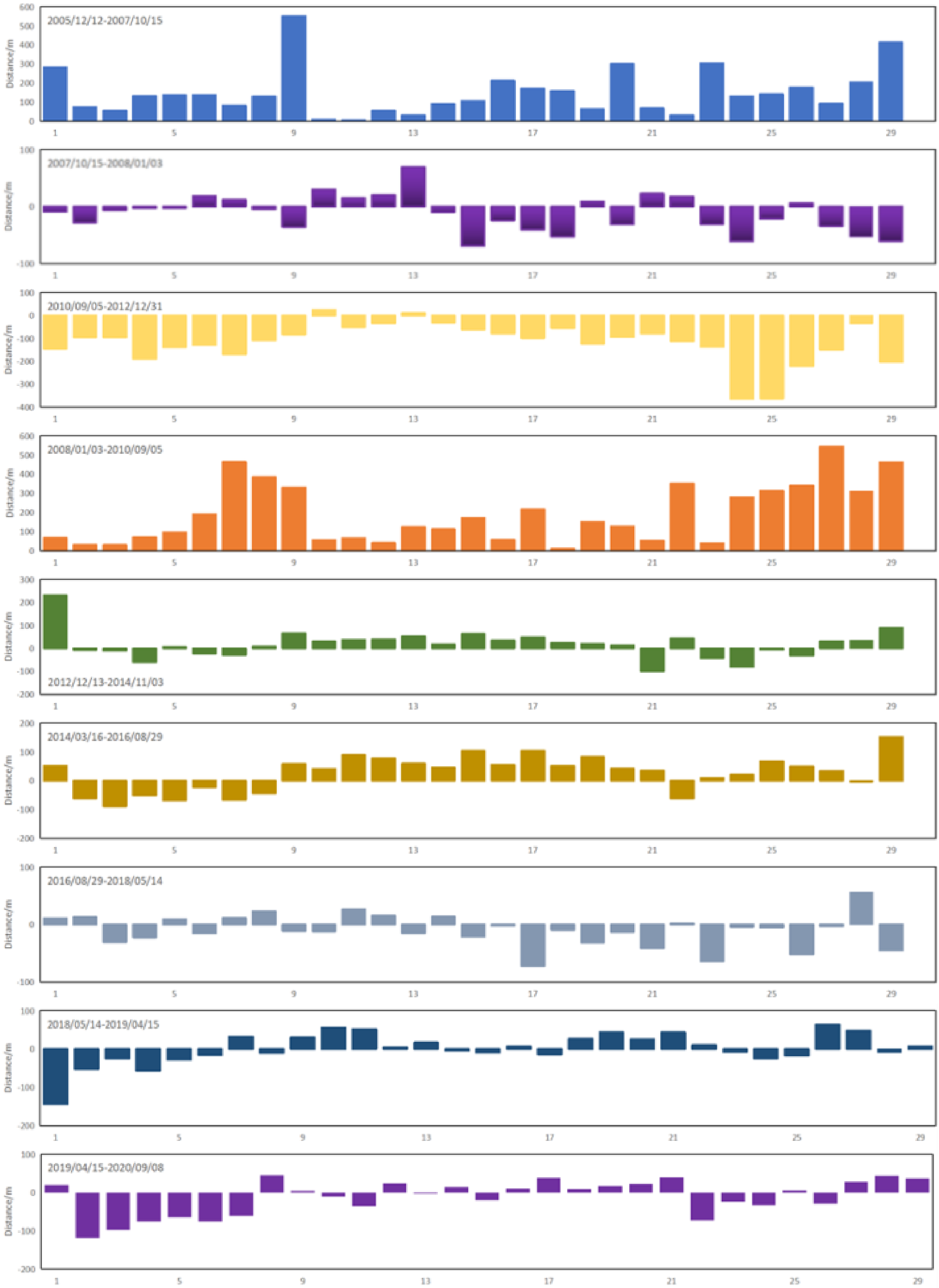

Fig. 5 **Change map of core area.**

of the middle bank is 29 m and the average advancing speed is 16 m/yr, while the average retreating distance of both ends is 40 m and the average retreating speed is 22 m/yr. From March, 2014 to August, 2016, the average advancing distance of the central bank was 25.4 m. The average advancing speed is 10.5 m/yr, while the average retreating distance between the two ends is 2.6 m and the average retreating speed is 1.1 m/yr. From August, 2016 to May, 2018, the average advancing distance of the central bank was 9.5 m. The average advancing speed is 5.4m/yr, while the average retreating distance at both ends is 9.5 m and the average retreating speed is 5.4 m/yr. From May 2018 to April 2019, the average advancing distance of the central bank section was 1.6 m. The average advancing speed is 1.7 m/yr, while the average retreating distance between both ends is 3.7 m and the average retreating speed is 4 m/yr. From April, 2019 to September, 2020, the average advancing distance of the central bank is 12.3 m. The average advancing speed is 8.7 m/yr, while the average retreating distance between both ends is 21.3 m and the average retreating speed is 15 m/yr, the results can be seen in Fig. 5.

5. Discussion

5.1 Erosion Rate and Sea Level Rise

According to *China Sea Level Bulletin 2020* [16], the rising rate of China's coastal sea level is 3.4 mm/year. It is expected that China's coastal sea level will rise 55~170 mm in the next 30 years [13].

In order to analyze the impact of sea level change on the salt marsh wet land, Landsat series satellite data from 2013 to 2020 were used. The correlation between the annual changes of core area and sea level is analyzed. As shown in Fig. 6, the salt marsh wetland is a *Spartina alterniflora* wetland near the seaside. Because of the low niche of *Spartina alterniflora* in salt marsh, the plant grows near the mean sea level and is easily affected by sea level changes. It can be seen from Fig. 6 that since 2013, the area of salt marsh in the core area has decreased with the the previous year . While the sea level change decreased compared with the previous year, the core area increased. Whether there is a linear relationship between erosion rate and rise of sea level, it is still necessary to pay close attention year by year. It is can be seen in Figs. 7 and 8.

5.2 Erosion Impact by Hydrodynamic

Some hydrodynamic field data were collect measured from 10: 00 on September 8th to 00: 00 on October 10th, 2013 (Fig. 9). The tide near the coastal is reciprocating flow at observed station 1# and 2#. The flood tide direction is south, and the ebb tide is north. The maximum flood tide current can reach 2.2 m/s, and the maximum flow velocity at ebb tide is about 1.8 m/s. The median diameter sizes are 0.088 mm and 0.084 mm respectively (Table 1).

According to Zhang's Eq. (2) [14], sediment starts to move when current velocity reach 0.5-0.65 m/s. According to the field data at station 1# and 2#, the maximum velocity of tidal current is much larger than the threshold velocity of sediment. The sediment concentration near the salt marsh coastal line is between 2 and 3 kg/m^3 during the ebb and flood tide period. The sediment concentration changed slightly in tide period. The variation range is less than 0.8 kg/m^3 (Fig. 10).

According to Liu's Eq. (3) [15], under the action of the wave, the sediment threshold depth of study area is about 4 m. That is to say, the sediment transports frequently by wave action in the nearshore part with shallow water depth. When the 50-year wave attacked the salt marsh wet land, the threshold depth of sediment can reach about 10 m.

To sum up, the mechanism of salt marsh wetland coastal sediment transport is: wave and current stirs up sediment, current transports the sediment. The resuspension of beach sediment under the combined action of wave and current causes the erosion of beach surface and the erosion of steep slope in front of salt marsh wetland.

Fig. 6 Schematic diagram of core area change from 2013 to 2020.

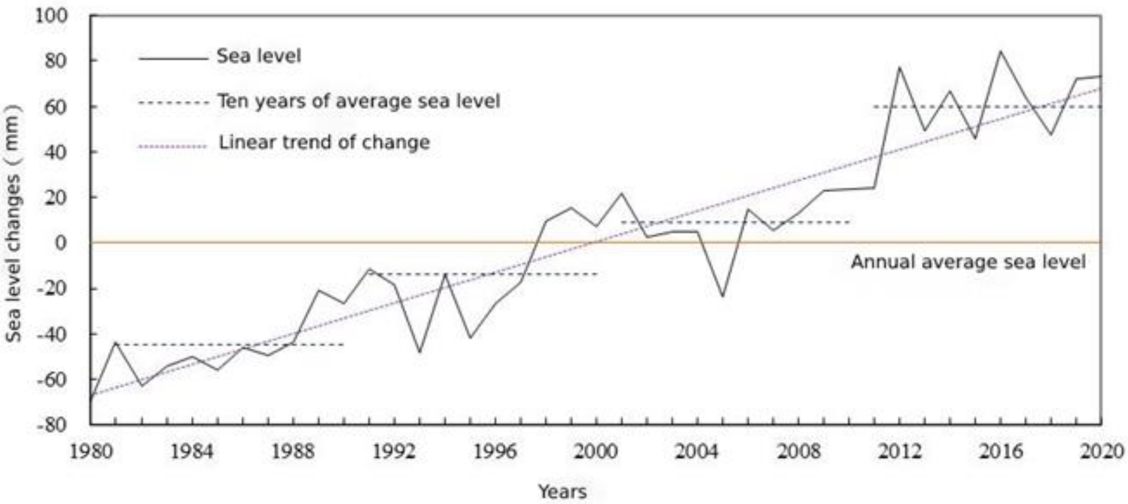

Fig. 7 Sea level changes in China's coastal areas from 1980 to 2020.
Data from *China Sea Level Bulletin 2020*.

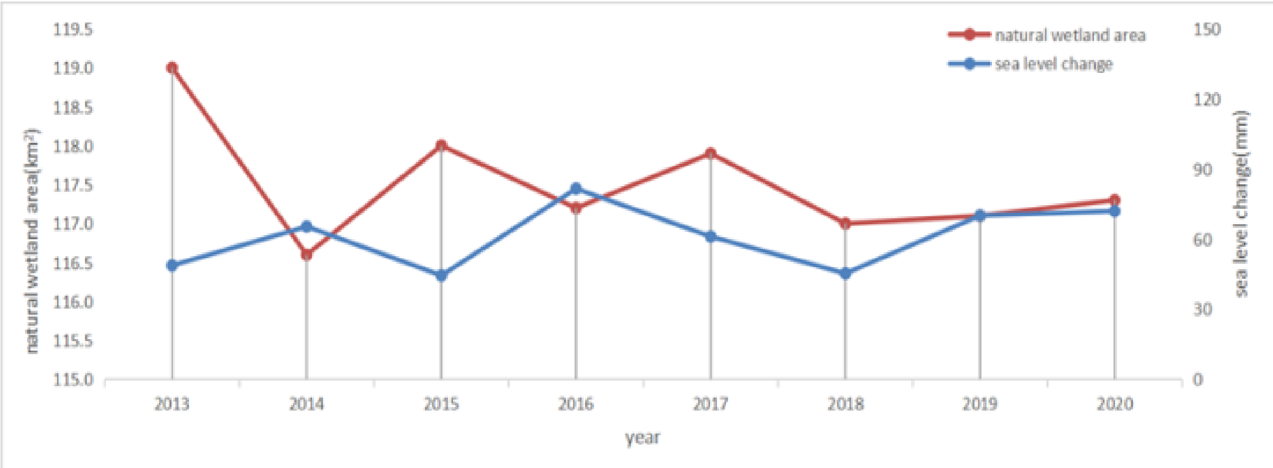

Fig. 8 **Change of core area from 2013 to 2020.**

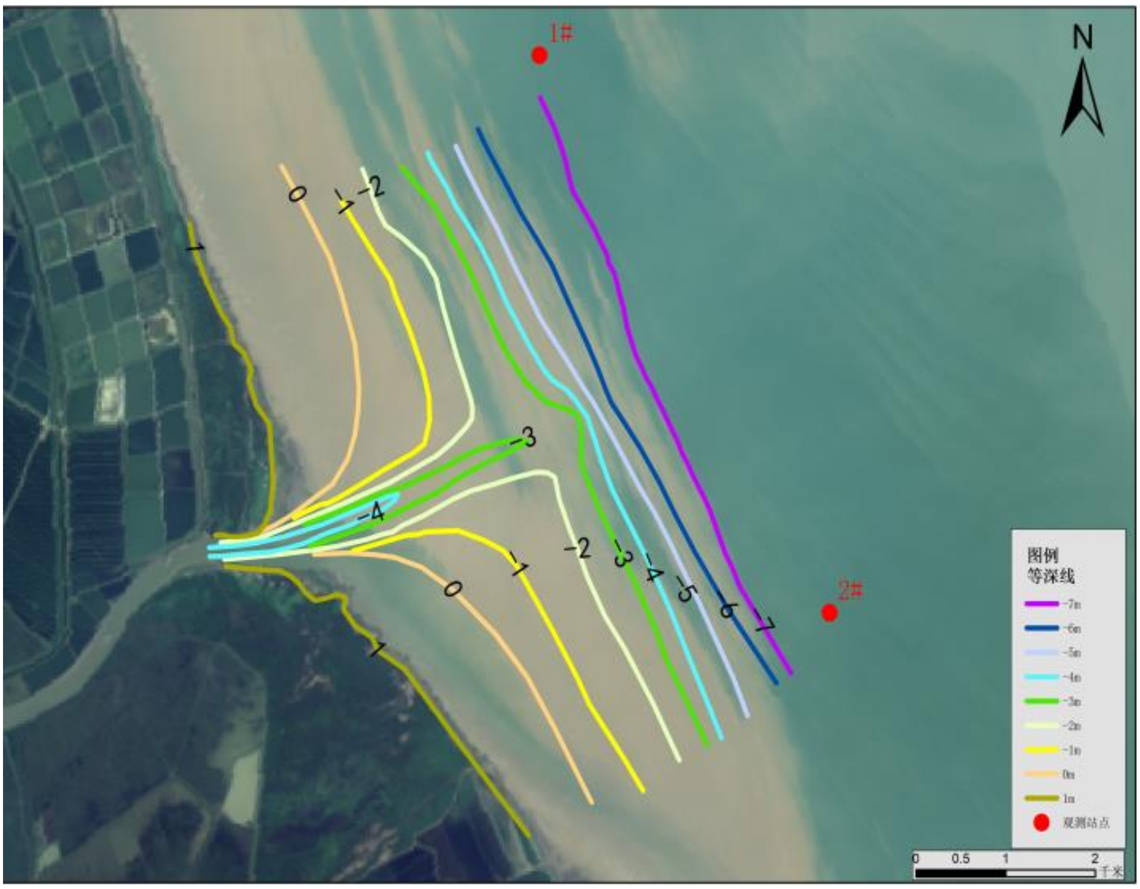

Fig. 9 **Contour distribution of topography at the lower port road and outside the mouth of Xinyanggang Gate.**

Table 1 **Statistics of mean tidal current and mean maximum vertical current (m/s).**

Station	Mean velocity of tide	Maximum velocity of tide	Median particle size *D*50 (mm)	Clay content less than 0.05 mm (%)	Particle content greater than 0.075 (%)
1#	0.94	1.85	0.088	9.4	60.9
2#	0.97	2.25	0.084	10	59.5

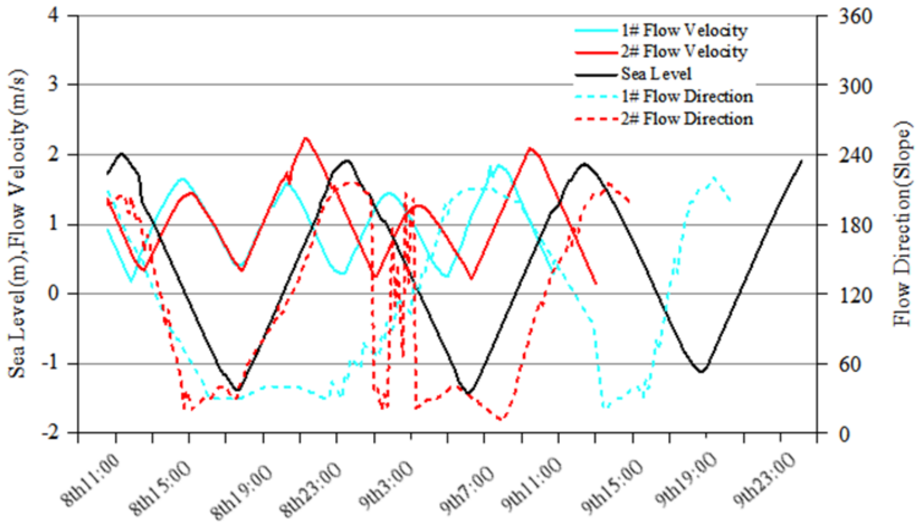

Fig. 10 Measured velocity and direction process.

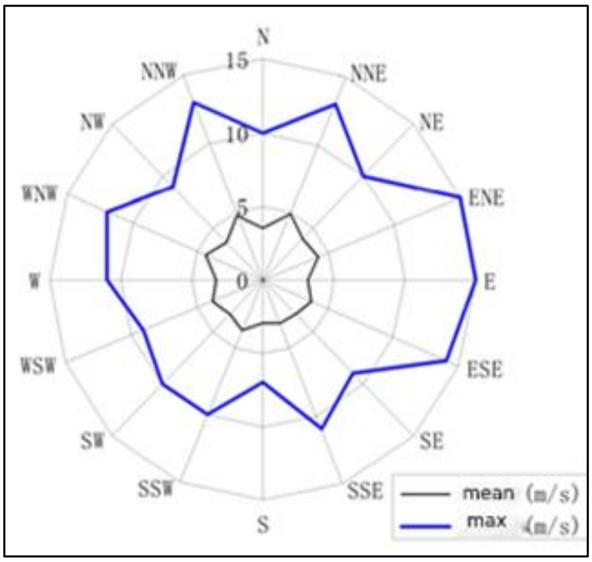

Fig. 11 Rose diagram of the study area wind data illustrating the frequency of winds from sixteen directions. Each wind direction includes data from all recorded wind speeds.

According to Zhao [10] research, in the study area, the significant wave height in marsh shoreline is about 0.54 m in normal day. Wave period is between 0.75 s and 13.0 s. The marsh shoreline erosion rate can be calculated as 0.044 m by using Schwinmmer [16] expression. However, the erosion rate is lower order value compared with value (101-102) calculated by remote sensing technology, which is more like the actual erosion rate.

Schwinmmer [16] expression is got at salt marsh wetland in the Rehoboth Bay. The current velocity and the wave height are relatively small. However, Yancheng Coastal Wetland Core Area is located at opening coastal zone, which has higher velocity and wave height. Turbulence and wave power are much higher intensity. In addition, Yancheng Coastal Wetland Core Area is affected by storms every year. Storms produce a greater frequency of relatively high wave heights and higher erosion rates.

According to the wind rose diagram (Fig. 11), Yancheng Coastal Wetland Core Area is affected by the east wind annual. The wave characteristics can be statistical analysis in Table 2. In order to be consistent

Table 2 Erosion rate calculation.

Case	T (s)	L (m)	σ_w (s^{-1})	K (m^{-1})	$H_{1/10}$ (m)	P_{avg} (kW/m)	R (m)
Once every 50 years	8.19	104.7	0.77	0.060	5.8	44.39	22.7
Once every 25 years	7.97	99.1	0.79	0.063	5.49	37.97	19.1
Once every 5 years	7.32	83.6	0.86	0.075	4.63	23.20	11.1
Once every 2 years	6.75	71.0	0.93	0.088	3.94	14.42	6.6

T is time period, L is wave length, σ_w is wave frequency, K is wave number, $H_{1/10}$ is wave height, P_{avg} is the average wave energy, R is the erosion rate.

with critical water depth threshold of sediment mentioned in Code of Hydrology for Sea Harbour (JTS145-2-2013), it is suggested to use $H_{1/10}$ when calculating wave power (P). The calculation values are the same order as remote sensing results.

6. Conclusions

The main conclusions of this paper are as follows:

(1) During 2005-2007, the sea level was relatively low, and *Spartina alterniflora* in salt marsh expanded to the sea. Since 2007, the front edge of salt marsh wetland has coexisted with erosion and deposition. From 2008 to 2010, the front edge of salt marsh wetland once again showed a trend of comprehensive deposition to the sea side. From 2010 to 2012, the erosion of salt marsh wetland was serious. From 2012 to 2020, the front edge of salt marsh wetland in the range of 9 km south of Xinyang estuary was eroded.

(2) The correlation analysis was carried out between the area of salt marsh wetland and sea level rise. *Spartina alterniflora* is easily affected by sea level change, owing to it having a low ecological niche. With the rise of sea level, the area of salt marsh has been decreasing since 2013.

(3) In the front sea area of salt marsh wetland, the maximum velocity of the ebb and flood can reach the threshold velocity during the spring tide. The sediment starts to move at water depth of 10 m under wave actions. Wave and current stirs up sediment, current transports the sediment. The resuspension of beach sediment under the combined action of wave and current causes the erosion of beach surface and the erosion of steep slope in front of salt marsh wetland.

(4) When the Schwinmmer [16] expression is used for predicting the erosion rate at salt marsh wetland, wave height is recommended to use $H_{1/10}$.

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