Dynamic evolution assessing of Dongsha shoal of the Radial Sand Ridges in South Yellow Sea, based on the smallest enclosing rectangle centroids method

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Abstract. The smallest enclosing rectangle is an important parameter in the target features of geographic elements. Its centroid can indicate the general movement trend of geographic elements. Taking Dongsha in the radiant sandbar area off Jiangsu as an example, the shape was derived from long-period remote sensing images from 1973 to 2016, learning the concepts of the smallest enclosing rectangle and centroid, extract the Dongsha Shoal of each phase by ArcGIS. The smallest enclosing rectangle centroids compare the centroids of different periods to determine the overall movement trend of Dongsha Shoal in different periods. The study found that during the 43-year period, the overall movement direction of Dongsha shoal was north-north-east, specifically divided into five stages, each of which has a different direction and speed of movement. The smallest enclosing rectangle can be used as an useful method to study the dynamic change trend of marine sandbar.

1. Introduction

The coastal areas of the South Yellow Sea from the abandon Waste Yellow River estuary to the modern Yangtze River estuary have developed the world's unique and typical radial sand ridge group [1], which is an important area to study the interaction of global environmental changes between land and sea [2]. Therefore, this area has always been a hotspot of academic attention and research. Foreign scholars have studied the type of sand ridges on the continental shelf [3], formation mechanism [4], sand ridge evolution process [5, 6], comparative analysis of measured data and models [7, 8] and sand ridge geomorphic dynamics. A lot of empirical research has been carried out in the process [9], and great progress has been made. Since the comprehensive survey, related thematic research and engineering projects of Jiangsu coastal zone from the 1980s, domestic scholars have made many classic research results in the field of radiation sand ridge group deposition and landform dynamics research [10, 11, 12, 13].

With the development of remote sensing technology, domestic scholars have carried out a large number of studies on the dynamic evolution, evolution mechanism and sediment moving trend of typical sandbars, tidal trench landforms of radiant sand ridge groups [14, 15]. However, when researchers using remote sensing technology to study the dynamic trend of radiant sandbars, they often...
compared the change of sandbar contours to determine the change trend. They only extracted the water line and tide level correction, but the time scale of the study was too short, and there was no long-term continuous observation, the research was limited.

Based on the existing research, this study takes Dongsha Shoal as the research area, using remote sensing method to extract the smallest enclosing rectangle centroids to quantitatively infer the evolution trend of Dongsha Shoal. The erosion and siltation situation and stability of each part of Shoal helps to understand the overall movement speed of Dongsha Shoal, the expansion trend and the stability of each part. Then we can speculate the erosion and siltation of each part of Dongsha Shoal, and also provides a new method for monitoring the change of sandbank at sea.

2. Study area

2.1. Study areas

Figure 1 shows the Dongsha Shoal located off the coast of Jiangsu Province, which is the largest and highest of all the radial sand ridges. The Dongsha Shoal is surrounded by a series of sand ridges and deep trenches. The total area of the shoal above sea level is about 69,400 hectares, and the area above the mid-section of the tidal flats is about 19,300 hectares. The maximum elevation of the shoal is about 5.8 m. At this elevation the top of the shoal is not submerged by the normal tidal flow.

![Figure 1. Study area and the image of Dongsha Shoal in the low tide condition.](image)

3. Data and methods

3.1. Remote sensing image processing

Using the United States Geological Survey's Global Visualization Viewer (http://glovis.usgs.gov/) to obtain NASA's Landsat MSS / TM / ETM / OLI data from 1973 to 2016[16], It can be seen from Table 1 that the quality of each time-phase satellite image is good, with the imaging time interval is relatively uniform, and the cloud cover is Less than 5%, and the outline of the sandbar is clearly visible. The time resolution of MSS data products is 18d, and the spatial resolution is 78m × 78m. The time resolution of TM / ETM / OLI data products is 16d, and the spatial resolution is 30m × 30m. The specific parameters are shown in Table 1. ENVI 5.0 software is used to preprocess the images,
including projection transformation and geometric precision correction. All images are projected to UTM 51N and WGS84 datum. Selecting MSS7, MSS6 and MSS5 for RGB false color synthesis, TM / ETM 7, TM / ETM 4 and TM / ETM 3 for simulated true color synthesis, and OLI5, OLI4 and OLI3 for standard false color synthesis.

Table 1. Study area image collections and the marine environmental parameters.

| No. | Satellite | Sensor | Acquisition Time | Water level (cm) | No. | Satellite | Sensor | Acquisition Time | Water level (cm) |
|-----|-----------|--------|-----------------|------------------|-----|-----------|--------|-----------------|------------------|
| 1   | Landsat 1 | MSS    | 1973-11-16, 02:01 | -154             | 18  | Landsat 5 | TM     | 1999-02-19, 02:10 | 21               |
| 2   | Landsat 2 | MSS    | 1976-03-20, 01:48 | -230             | 19  | Landsat 5 | TM     | 2000-04-10, 02:05 | -215             |
| 3   | Landsat 2 | MSS    | 1977-10-17, 01:24 | -189             | 20  | Landsat 5 | TM     | 2001-03-12, 02:10 | -12              |
| 4   | Landsat 3 | MSS    | 1979-09-10, 01:51 | -226             | 21  | Landsat 5 | TM     | 2002-03-31, 02:08 | 107              |
| 5   | Landsat 4 | MSS    | 1983-04-04, 02:00 | -129             | 22  | Landsat 7 | ETM+  | 2003-01-21, 02:19 | 132              |
| 6   | Landsat 4 | MSS    | 1984-03-21, 01:58 | -74              | 23  | Landsat 5 | TM     | 2004-05-23, 02:11 | 143              |
| 7   | Landsat 5 | TM     | 1985-01-11, 02:01 | -173             | 24  | Landsat 7 | ETM+  | 2005-03-31, 02:20 | -34              |
| 8   | Landsat 5 | TM     | 1986-03-03, 01:57 | -155             | 25  | Landsat 7 | ETM+  | 2006-04-03, 02:20 | -15              |
| 9   | Landsat 5 | TM     | 1988-03-08, 02:00 | -181             | 26  | Landsat 5 | TM     | 2007-01-24, 02:25 | -6               |
| 10  | Landsat 5 | TM     | 1989-10-21, 01:55 | -44              | 27  | Landsat 5 | TM     | 2008-02-28, 02:21 | 17               |
| 11  | Landsat 5 | MSS    | 1991-04-02, 01:52 | -128.5           | 28  | Landsat 7 | ETM+  | 2009-06-14, 02:21 | 96               |
| 12  | Landsat 5 | TM     | 1992-06-07, 01:54 | -136             | 29  | Landsat 5 | TM     | 2011-04-25, 02:20 | 124              |
| 13  | Landsat 5 | TM     | 1994-12-06, 01:44 | -192             | 30  | Landsat 7 | ETM+  | 2013-08-12, 02:26 | -21              |
| 14  | Landsat 5 | TM     | 1995-01-07, 01:43 | -131             | 31  | Landsat 7 | ETM+  | 2014-02-20, 02:27 | 78               |
| 15  | Landsat 5 | TM     | 1996-01-10, 01:33 | -140             | 32  | Landsat 8 | OLI    | 2015-12-16, 02:30 | 115              |
| 16  | Landsat 5 | TM     | 1997-02-13, 01:55 | -128             | 33  | Landsat 8 | OLI    | 2016-01-01, 02:30 | -32              |
| 17  | Landsat 5 | MSS    | 1998-01-31, 02:06 | -54              |     |           |        |                 |                  |

aData Sources: USGS Global Visualization Viewer (http://glovis.usgs.gov/).

3.2. The smallest enclosing rectangle centroid extraction

The smallest enclosing rectangle of the image is an important parameter in the target features of the image and the basis for further analysis and recognition of the image. There is an infinite number of circumscribed rectangles of a geometric figure, but the smallest enclosing rectangle is unique. It
describes some geometric features of the figure, namely the length and width to a certain extent, which can be used to describe the characteristics of the image outline. Extracting the smallest enclosing rectangle of each Dongsha Shoal’s satellite image by ArcGIS 10.2 software and using MATLAB to extract the centroid (geometric center) of each rectangle at the same time. Taking Dongsha Shoal as a point, and the comprehensive change trend of each edge of Dongsha Shoal is reflected in this point. By comparing the centroids of different periods, we can analyze the overall movement trend of Dongsha Shoal in different periods.

4. Results and discussion

4.1. Dynamic evolution trend of Dongsha shoal from 1973 to 2016

Through the superimposed analysis of the smallest enclosing rectangle centroids of the extracted Dongsha Shoal remote sensing imagery of each year, the general movement trajectory of Dongsha Shoal the smallest enclosing rectangle centroids from 1973 to 2016 was obtained. Figure 2 shows that the smallest enclosing rectangle centroids of Dongsha Shoal moved from 33° 4'50"N, 121° 9'23"E in 1973 to 33° 6'30"N, 121° 9'45.72"E in 2016, the overall direction of movement during 43a was north-northeast, and Dongsha Shoal moved 3.1713km in the direction of Taipingsha Sandbank, and the speed was 0.0991km/a.

![Image](image_url)

**Figure 2.** The smallest external tangent centroid movement trajectory of Dongsha Shoal.

Summarizing the movement speed of the smallest enclosing rectangle centroids every year and drawing a trend line, Results in Figure 3 imply that on the whole, Dongsha Shoal's movement speed has a trend of gradually accelerating.
Figure 3. The smallest external tangent centroid movement trajectory of Dongsha Shoal.

As shown in Table 2, Dongsha Shoal movement can be roughly divided into 5 stages: The first stage is from 1973 to 1979. Dongsha Shoal is relatively gentle in the direction of Liangyuesha sandbank Movement, the moving distance is 0.8494km, and the speed is 0.2831 km/a, which reflects the tendency of the siltation and expansion of the north edge of the main beach of Dongsha Shoal during this period, so that the main beach of Dongsha Shoal slowly expanded northward; The second stage is from 1983 to 1989. Dongsha Shoal made a relatively high-speed movement in the direction of Liangyuesha sandbank, with a moving distance of 2.9630km and a speed of 0.5926 km/a. It can be seen that the silting and swelling speed of Dongsha Shoal main beach on this side was slower during this period. The increase in the amount of sediment carried by the South Yellow Sea tidal wave caused the siltation of the north side of the main beach and the Niluohang sandbank to rise faster, which caused Dongsha Shoal to expand northward at this stage. The third stage was from 1991 to 1999. Shoal moved towards the direction of Macaihang sandbank in the northeast and east, with a travel distance of 1.5088km and a speed of 0.2156 km/a, reflecting the Dongsha Shoal of this period. The siltation of the Niluohang sandbank in Hoal increased rapidly, causing Dongsha Shoal to expand east-northeast; the fourth stage was from 2000 to 2009, Dongsha Shoal moved slowly towards the Gaoni sandbank in the south, with a moving distance of 1.4402km and a speed of 0.1600 km/a. It shows that at this stage, the siltation rate of Dongsha Shoal main beach is slowed down in the north, and the siltation rate in the south is accelerated, which makes Dongsha Shoal expand southward in the south; the fifth stage is from 2011 to 2016, Dongsha Shoal moves towards the Zhugensha sandbank in the southeast and southeast. Relatively high-speed movement, the moving distance is 1.6718km and the speed is 0.4180 km / a, which reflects that the siltation of Dongsha Shoal main beach and the southeast is faster than other directions at this stage, which makes Dongsha Shoal south expand toward Zhugensha sandbank. The west side of Dongsha adjoins the flared Xiyang tidal channel, which is wide in the north and narrow in the south. The tidal wave of the South Yellow Sea passes through the Xiyang tidal channel from north to south. Due to the flared shape of the Xiyang tidal channel, the tidal current causes the high tide to flow from north to south. The area of the water cross-section decreases and the flow velocity increases, and the ebb tide current velocity of the western ocean is much smaller than the upwelling velocity. Under such hydrodynamic conditions, the west side of the Dongsha Shoal profile, especially the southwest edge, has been obviously eroded. Therefore, the smallest enclosing rectangle centroids did not appear to move westward.
Table 2. The trend of the smallest enclosing rectangle centroids movement in Dongsha Shoal.

| ID | Times       | Moving distance/km | Rate/km·a⁻¹ | Direction |
|----|-------------|--------------------|-------------|-----------|
| 1  | 1973-1979   | 0.8494             | 0.2831      | N         |
| 2  | 1983-1989   | 2.9630             | 0.5926      | N         |
| 3  | 1991-1999   | 1.5088             | 0.2156      | ENE       |
| 4  | 2000-2009   | 1.4402             | 0.1600      | S         |
| 5  | 2011-2016   | 1.6718             | 0.4180      | SSE       |
| Total | 1973-2016 | 3.1713             | 0.0991      | NNE       |

4.2. Why Dongsha Shoal changes like this

The overall movement speed of Dongsha Shoal, and the expansion trend of each part and the changes of erosion and deposition are closely related to the surrounding ocean and topographic environment. The sediments of the Radial Sand Ridges mainly originate from the subaqueous delta of the abandoned Yellow River and from discharges of the Huai River and Yangtze River[17]. Sediment delivery by the Huai River and the Yangtze River has decreased over the past several decades [18]. For example, the sediment discharge of the Huai River in 2015 was 6.32 Mt, no more than 60% of the average sediment delivered for the previous years. The sediment discharge of the Yangtze River in 2015 was 116 Mt, no more than 30% of the sediment delivered in the 1970s [19].

In addition, in the past few decades, large-scale tidal flat reclamation has been carried out along the coast of Jiangsu. For example, from 1974 to 2012, the tidal flat area along the tidal flat in Jiangsu exceeded 1986 km², accounted for approximately 1.9% of the province's area[20]. The construction of the seawall greatly reduces the buffering capacity of the coastal beaches, which greatly enhances the hydrodynamic force of the Xiyang tidal Channel. This process led to the Xiyang tidal channel becoming the most severely eroded area on the central coast of Jiangsu[21]. The low-lying areas along the beach and the west coast of Dongsha suffered severe erosion. The sediments in Xiyang were carried and deposited further offshore.

Due to the decreasing sediment flux entering the Jiangsu coastal area and increasing mean sea level and ground subsidence, the west coast of Dongsha will likely undergo further serious erosion in the near future.

5. Conclusion

The smallest enclosing rectangle centroids is a method for extracting the location of geographic elements. In this paper, by studying the changing trend of Dongsha Shoal, the smallest enclosing rectangle centroids, we can find out the dynamic changes of Dongsha Shoal landforms, not only does it provide important scientific basic data for the marine resource protection and shipping in the surrounding sea area of Dongsha Shoal, but it also proves that the smallest enclosing rectangle centroids is a simple and effective method that can be used to monitor the evolution trend of offshore sandbanks. By studying the overall movement trend of Dongsha Shoal, it was found that the general movement direction of Dongsha Shoal during 43a was northeast and northeast, Dongsha Shoal moved 3.1713 km in the direction of Taipingsha, the speed was 0.0991 km/a, and Dongsha Shoal movement was roughly divided into 5 stages. The impact of storm surges, reclamation and seaweed cultivation on the sedimentary environment of Dongsha Shoal needs further study.

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