J. Geogr. Sci. 2018, 28(8): 1127-1151
DOI: 10.1007/s11442-018-1546-1

Coastline and landscape changes in bay areas caused by human activities:

A comparative analysis of Xiangshan Bay, China and Tampa Bay, USA

LI Jialin[1,2], LIU Yongchao[1,3,4], PU Ruiliang[5], YUAN Qixiang[6], SHI Xiaoli[7], GUO Qiandong[5], SONG Xiayun[8]

1. Department of Geography & Spatial Information Techniques, Ningbo University, Ningbo 315211, Zhejiang, China;
2. East China Sea Institute of Ningbo University, Ningbo 315211, Zhejiang, China;
3. Department of Geographic Information Science, Nanjing University, Nanjing 210023, China;
4. Collaborative Innovation Center of South China Sea Studies, Nanjing University, Nanjing 210023, China;
5. School of Geosciences, University of South Florida, Tampa, FL 33620, USA;
6. Center for Marine Resource Management, Ocean and Fishery Bureau of Xiangshan, Xiangshan 315700, Zhejiang, China;
7. Editorial Department of Journal of Ningbo University, Ningbo 315211, Zhejiang, China;
8. School of Accountancy, Zhejiang University of Finance and Economics, Hangzhou 310018, China

Abstract: Using multitemporal Landsat TM/OLI images at a 10-year interval, in this study, we (1) extracted information of spatial location, length, and sinuosity of coastline and landscape configuration, diversity and fragmentation in the bay areas of Xiangshan Bay (XB), China and Tampa Bay (TB), USA from 1985 to 2015; (2) constructed indices of artificial coastlines and human disturbance on bay area landscapes; and (3) explored and discussed the impacts of human activities on changes of coastlines and landscape types in the two bay areas. Our analysis results demonstrate the following five points. (1) During the past 30 years, the lengths of natural coastline in XB and TB shrank, while the lengths of their artificial coastline increased first and then maintained stable. Since there were different influences of human activities on coastlines and landscape types between the two bay areas, XB experienced dramatic changes in parts of coastline geomorphologies and continuous decrease of coastline sinuosity, while, in TB, there was a little change in coastline geomorphologies and its coastline sinuosity was almost unchanged. (2) The intensity of human activities in XB was continuously enhanced from 1985 to 1995, and then the degree of enhancement had slowed down after 1995. However, in the time period, the impacted extent of human activities gradually increased and finally covered almost entire coastlines in XB. In TB area, although the intensity of human activities was enhanced, the degree of enhancement slowed down from 1985 to 2015 and the impacted areas of human activates were concentrated in several

Received: 2017-06-17 **Accepted:** 2017-08-10
Foundation: NSFC-Zhejiang Joint Fund for the Integration of Industrialization and Informatization, No.U1609203; Natural Science Foundation of Zhejiang Province, No.LY16G030014; The K. C. Wong Magna Fund of Ningbo University and Natural Science Foundation of Ningbo City, No.2017A610300
Author: Li Jialin (1973–), PhD and Professor, specialized in physical geography and coastal geomorphology.
E-mail: nbnj2001@163.com

coastal city areas. (3) The average area of landscape patches strongly disturbed by human activities in both XB and TB generally showed a trend of decreasing from 1985 to 2005. However, during the period of 2005 to 2015, the average patch area of landscapes disturbed by different degrees of human activities in XB changed differently, while in TB it almost did not change. (4) From 1985 to 2005, the indices of landscape diversity in various areas of human disturbance in XB gradually increased, while in TB, changes in indices of the landscape diversity varied. From 2005 to 2015, the changes in the intensity of human disturbance in both bay areas were from weak to strong, whereas the indices of landscape diversity in XB and TB increased first and then decreased. (5) The landscape fragmentation index in different human disturbance areas in both XB and TB gradually increased from 1985 to 2005, while from 2005 to 2015, in both bay areas, the landscape fragmentation index presented a decreasing trend.

Keywords: bay coastline; bay landscape; coastline and landscape change; human activities; Xiangshan Bay; Tampa Bay

1 Introduction

With socio-economic development and depletion of land resources, exploitation of coastal and marine resources has become a strategic choice of coastal states and regions (Xu *et al.*, 2015b). Bay area becomes a frontier and a hotspot of coastal zone exploitation. Surface processes and eco-environmental evolution in the bay area have been severely challenged by human activities. Relying on increasing accessibility of research data supported by 3S technologies, shortage of resources and other environmental issues caused by human activities in coastal zones have gradually become a major concern of scholars and government administrators in the world (Wu *et al.*, 2012).

Factors influencing these changes include types of shorelines (e.g., rocky, sandy), wave activity, tidal variations, storms and human impacts (Kannan *et al.*, 2016). Human's utilization of the coastlines with different intensity levels will directly impact the evolution of coastline (Tirkey *et al.*, 2005; Paterson *et al.*, 2014). The evolution process of a resource-environment system of coastline can be revealed through coastline change analysis (Xu *et al.*, 2013; Li *et al.*, 2014; Ghosh *et al.*, 2015). Information on dynamic changes of coastline is usually obtained by using spectral analysis of remote sensing imagery (Chu *et al.*, 2013; Sun *et al.*, 2011; Lantuit *et al.*, 2008), human-computer interactive interpretation (Yao *et al.*, 2013; Xu *et al.*, 2017), multispectral classification (Blodget *et al.*, 1991), threshold value segmentation (Zhu *et al.*, 2013), cluster-based segmentation (Burningham and French, 2017) and wavelet transform (Fan *et al.*, 2002), etc. The research areas mainly involve mud coast (Ryu *et al.*, 2014), island coast (Ghosh *et al.*, 2015), estuarine coast (White *et al.*, 1999) and coastal administrative elements (Xu *et al.*, 2015a). Spatial statistical analysis (Guo *et al.*, 2009), landscape pattern index analysis (Verbutg *et al.*, 2002) and landscape simulation based on cellular automata (Qin *et al.*, 2007), etc. were generally used to explore the evolution of resource-environment system of coastal landscapes. Research based on a large-scale temporal/spatial analysis is popular abroad (e.g., Solon *et al.*, 2009; Olsen *et al.*, 2007; Tzanopoulos *et al.*, 2011; Tian *et al.*, 2002), whereas a medium- and a small-scale analysis is a major direction in China (e.g., Parcerisas *et al.*, 2012). Currently, studies on bay areas focus on the impacts of human activity on sedimentary dynamics of tidal inlets (Zhang *et al.*, 1995), tidal current in a bay mouth (Wan *et al.*, 2014), coastal landform (Li, 1986), area of tidal prism (Ma *et al.*, 2014), and eco-environmental effects (Wang *et al.*, 2007; Lin and Zuo, 2006).

In coastal zones, man-made coastal landforms replace the natural ones, which changes the process and law of evolution of landforms, resulting in changes of material structure and geomorphic characteristics (Li *et al*., 2017). As an important geomorphic element in a coastal zone, the bay area has its increasingly salient meaning as a state-level strategic vital area, a key area for coastline exploration, and a site for leisure and tourism (Chen *et al*., 2007). However, only fewer studies on systematic quantitative evaluation of impacts of human activities on changes of coastlines and landscapes of bay areas were found (Wang *et al*., 2014; Yuan *et al*., 2015). In particular, comparative research on different regions and states was rarely seen.

China and USA share the same features of rich harbor resources and intensified exploring activities, both with significant anthropogenic impacts on resource-environment systems of bay areas. However, due to different exploration phases residing in and protective measures adopted, there are huge differences between the two countries with respect to the effects of human activities on succession of resource-environment system of bays. Xiangshan Bay, Zhejiang, China and Tampa Bay, Florida, USA share the same climatic feature as transitional zones of tropical and subtropical climate, similar natural conditions for production and life, both with long exploitation history. However, the two regions have distinct features in population scale, socio-economic development level, management mechanism of recreation and leisure industry, and land utilization and exploitation, etc. Hence, in this study, we propose to carry out a comparative analysis on the impacts of contemporary human activities on the Earth surface on the evolution of coastline and landscape resources between the two bay areas, under different strategies of exploitation and utilization, and different protective measures adopted for the two regions. The major purpose is to understand in-depth the process of coastal artificialization and the response to coastline and landscape changes in order to provide a scientific reference for exploiting and utilizing, as well as protecting and planning bay areas in China.

2 Overview of the study areas

Xiangshan Bay (XB) is located in the coastal area in the eastern Zhejiang Province, China, adjacent to Hangzhou Bay in the north and to Sanmen Bay in the south. It neighbors the Zhoushan sea area through the Fudu Channel and the Shuangyumen Channel in the northeast, and connects the Damu Sea by Niubishan Channel in the southeast (Figure 1). Within XB, there are 65 islands and three secondary bays including the Xihu Bay, the Tie Bay and the Huangdun Bay, across Xiangshan, Ninghai, Fenghua, Yinzhou and Beilun counties/districts. XB covers a basin area of 1455 km^2, with 392 km coastlines, in which 260 km belong to mainland coastline. The bay belongs to subtropical monsoon region, dominated by low mountainous-hilly terrains, with natural alluvial coast, erosion coast and artificial coast, respectively. It has extensive tidal flats and wetlands, as well as developed aquaculture production and mariculture industry. Since the Qingli period (1041) of the Song Dynasty, a series of engineering projects of seawalls had been constructed, including Dasong seawall in the eighth year of Yongzheng’s reign (1730), Yongcheng seawall in the eighth year of Xianfeng’s reign (1858), and Xianning seawall in the 31st year of Guangxu’s reign (1905) of the Qing Dynasty. Since 1950, seawall constructions of Xize, Tuanjie, Feiyue and Liansheng, etc. have been carried out. By 2015, a total reclaimed area of XB has surpassed 170 km^2, which seriously disturbed natural ecological processes of the bay area.

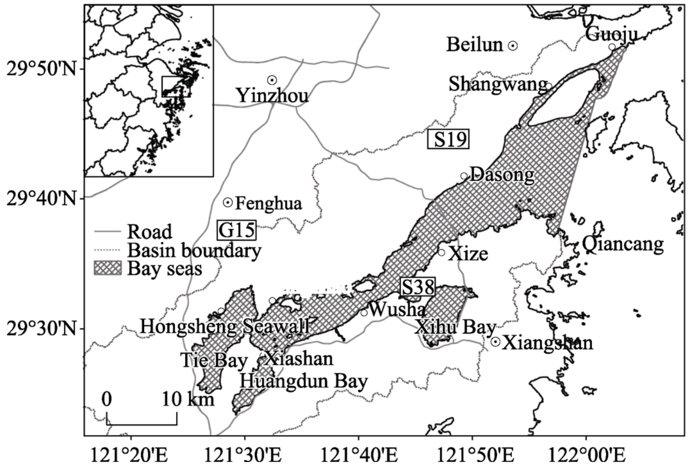

Figure 1 Location of Xiangshan Bay (XB), Zhejiang Province, China

Tampa Bay (TB) is located in the western coast of the middle section of Florida, USA. It neighbors the Gulf of Mexico on the west, with mainland on all other directions. Within the bay, there are two artificial islands, together with four secondary bays, i.e., Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay (Figure 2), covering major areas of Hillsborough, Manatee and Pinellas counties, as well as a small portion of Pasco and Sarasota counties, surrounded by the cities of Tampa, St. Petersburg, and Clearwater. TB watershed covers an area of 5700 km^2 and has a long zigzag coastline of 1040 km. Since as early as 5000 to 6000 years ago, indigenous people on the Weedon Island has settled down on the coast of TB. In the late 1800s, TB developed very fast, and as a result, a "Clearwater–St.Petersburg–Tampa" metropolitan region was gradually formed on the Pinellas Peninsula and coastal Hillsborough. Tourism industry highly developed in the bay area. Meanwhile, human activities also posed great impacts and interferences on resource and environment in the TB.

Relying on leading technologies and economic advantages in USA, exploitation in TB in the late 1800s was carried out in a broader range than that of XB in China, so did the reliance of national economy and population on the bay areas. Correspondingly, severe adverse effects were brought in TB. Hence, management activities for bays and estuaries have been implemented in USA since the 1990s. A comprehensive management scheme was also adopted, involving a legal system for exploitation and management of bay areas, a prewarning mechanism to monitor the exploitation intensity, and a management information platform. To do so, sustainable exploitation and maintenance of bay areas have risen to national strategy, and environmental awareness of the general public has been promoted, leading to positive results. In contrast, the exploitation and utilization, as well as protective measures in XB lagged behind compared with those in TB. For example, there is a lack of laws and regulations on exploitation and management of bay areas, an incomplete protection mechanisms, and inadequate theoretical

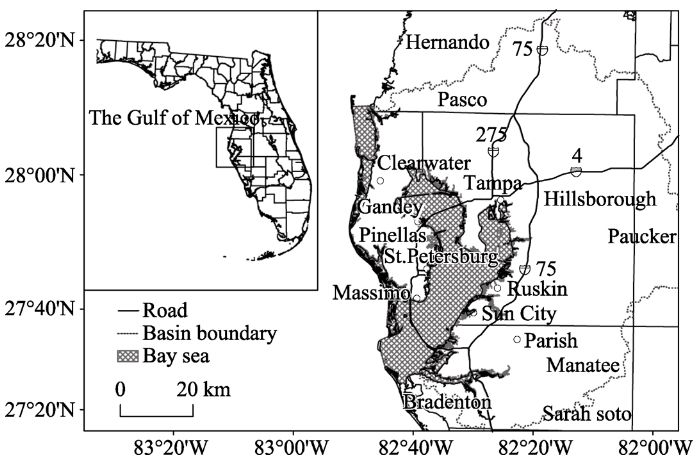

Figure 2 Location of Tampa Bay (TB), Florida, USA

research on coastal and landscape resources, etc., which leads to considerable adverse impact and damage on marine water quality, ecology of intertidal zone, coastline and watershed landscape in XB. Therefore, in order to promote sustainable, coordinated development of ecology, economy and environment in bay areas in China, it is crucially significant to refer to the management experiences of bay areas from USA, and enhance issuance of policies and construction of legal systems concerning sustainable management of bay areas in China.

3 Data and methodology

3.1 Data sources and image pre-processing

Landsat TM/OLI images of watersheds in XB and TB in 1985, 1995, 2005 and 2015 were provided by the United States Geological Survey (USGS) and Geospatial Data Cloud, as the data sources of this research[1,2]. Image pre-processing including waveband combination, geometric correction and alignment, and false color composition was carried out before implementing image mosaicking based on geographic coordinate using Mosaic tools in the Map module of software ENVI4.8. On such a basis, the extent of the study areas was demarcated using a continuous "Watershed–Coast–Ocean" system (Wang *et al*., 2011). Specifically, Archydro tool embedded in ArcGIS10.2 was used to obtain the boundaries of watersheds in XB and TB, according to D8 algorithm and using ASRTER GDEM V2 digital elevation model with a 30 m horizontal accuracy (Yuan *et al*., 2014). Finally, with the vector data of watershed and the ocean as a mask, the extractor in the spatial analysis module of ArcGIS10.2 was used to extract raster graphs of remote-sensing images of the four years mentioned above, which led to the images covering the both study areas. In this study, data sources also include a 1:50,000 digital elevation model of XB, vector data of boundary of watershed of TB, 1:50,000 topographic map of XB, 1:50,000 topographic map of TB provided by The University of Texas, USA, Bays in China (The fifth part), as well as historical data of tide at different observation stations and historical monitoring data of marine environment[3] for TB.

3.2 Research methodology

3.2.1 Classification and extraction of coastlines

According to unique features of coastlines of XB and TB and referring to the planning of basic functions of coastlines in China, the coastlines in the study areas were classified into two types: natural coastline and artificial coastline (Table 1). Boundaries between waters and lands were extracted effectively based on remote-sensing interpretation standards for coastlines of each type (Sun *et al*., 2011) and using a threshold approach combined with NDVI index (Li *et al*., 2009). Local corrections of coastlines were done based on interpretation keys of coastlines, associated with tones, textures, spatial patterns and distributions, and the standard false color composite images for coastlines for each type. Finally, spatial location, length and sinuosity of coastlines of each time period were extracted.

[1] Official website of United States Geological Survey. Image data can be downloaded at [EB/OL]. http://glovis.usgs.gov/
[2] Official website of Geospatial Data Cloud. Image data can be downloaded at [EB/OL]. http://datamirror.csdb.cn/
[3] Official website of Tampa Bay. Water Atlas of Tampa Bay [EB/OL]. http://www.tampabay.wateratlas.usf.edu/digitallibrary/

ArcGIS10.2 was used to randomly select pixels on coastlines from the four years' images. Points extracted automatically were located on corresponding coastlines. The extraction accuracy could be determined according to the number of points with displacement (Li *et al*., 2009). Eighty pixels of coastlines were selected from the four years' images, respectively. Our results show that the extraction accuracy of bedrock coastline, gravel coastline and mud coastline was above 95%; that of aquaculture, construction, recreation and leisure, protection, and wharf was above 90%; and that of mud coastline and estuary coastline was above 80%. Therefore, for this case, our results were fairly reliable.

Table 1 A summary of coastline classification system in this study

Primary type	Secondary type	Note
Natural coastline	Bedrock coastline	Land-sea boundary at bedrock coast
	Estuary coastline	Boundary between estuaries and the sea
	Biological coastline	Boundary between mangroves and tidal flats/wetlands
	Gravel coastline	Coastline of sand and gravel beach
	Mud coastline	Coastline of mud or salty mudflat
Artificial coastline	Coastline formed by aquaculture	Seaside coastline formed by aquaculture establishments on tidal flats and wetlands
	Coastline formed by construction	Seaside coastline formed by land for urban construction
	Coastline formed by protection	Coastline formed by wave protection and damp-proof purposes
	Coastline formed by recreation and leisure	Coastline used for recreation and leisure
	Coastline formed by ports and wharfs	Coastline formed by construction of ports and wharfs

3.2.2 Indices for coastline changes and intensity levels of coastal artificialization

Spatial analysis to coastlines was carried out to interpret the data of coastlines in bays in the four periods of time. Thus, spatiotemporal changes of coastlines in XB and TB can be monitored. In order to investigate temporal features, spatial patterns and their evolutions of coastline changes in the two bays, length of coastline, sinuosity of coastline, and intensity levels of coastal artificialization were introduced as the evaluation indices (Yuan *et al*., 2015; Zhao, 2013).

(1) Length of coastline

To reveal the spatiotemporal changes of coastlines in XB and TB, a change rate of length of coastline was used in this study:

$$V = (L_{i+1} - L_i) / \Delta t \tag{1}$$

where L_{i+1} and L_i are the lengths of coastlines of two periods (km), and Δt is the change time of coastline of adjacent times (year).

(2) Sinuosity of coastline

Curvature reflects the degree of unevenness of a geometric body. The greater the curvature, the greater the degree of deflection of a curve. Hence, a curvature can be used to reflect the sinuosity of coastlines in XB and TB.

Discrete points with an interval of 200 m were chosen along coastlines of Guoju–Qiancang section in XB and Massimo–Bradenton section in TB. Since distribution of the discrete points was centralized in some sections, statistical errors would be brought in, which requires screening of the discrete points obtained. A threshold e is selected, assuming $A(i)$ and $A(i+1)$ are the adjacent discrete points, where an initial value of d is defined as a straight line distance between $A(i)$ and $A(i+1)$, and s as a corresponding curve distance of the two points. When $s/d>e$, the curvature is calculated; when $s/d\leqslant e$, the next adjacent point is connected to generate a new discrete point series iteratively as above. In the new series, each of the two adjacent points is connected to their midpoint to form a triangle. Then the radius r of the circumscribed triangle can be calculated using the formula for solving circumference of a triangle and Heron's formula:

$$r=\frac{l_a\cdot l_b\cdot l_c}{\sqrt{\left(l_a^2\cdot l_b^2\cdot l_c^2\right)^2-2\left(l_a^4\cdot l_b^4\cdot l_c^4\right)}} \tag{2}$$

where l_a, l_b and l_c are the three side lengths of the circumscribed triangle; curvature radius r is approximated to the radius of a curve; and curvature $c = 1/r$.

(3) Intensity levels of coastal artificialization

The pressure caused human activity on coast of bays can be expressed by the intensity of coastal artificialization. In this study, the model of pressure intensity in physics was used to represent the intensity of coastal artificialization in XB and TB.

$$A=\frac{\sum_{i=1}^{n} l_i\cdot p_i}{L} \tag{3}$$

where A represents the intensity of coastal artificialization; L represents the total length of coastline in the study area (km); l_i indicates the length of coastline of the i-th type(km); n indicates the number of types of coastlines; p_i indicates the factor of impact on resource-environment of the i-th coastline type ($0\leqslant p_i<1$). p represents the degree of impact of different coast types on the resource and environment. For instance, the p value for natural coast is 0. The greater p is, the more significant adverse impact is posed. Per a reference of monitoring data of stations along the sampling coastlines for resource and water quality survey of the two bays, several sections of artificial coastlines of various types were selected as samples to monitor coastlines. Concrete weight of index layer w_{ij}, proposed by Yuan *et al*. (2015), and results after data range standardization were used to carry out product summation to obtain the impact factor P of human activity on resource and environment of bays. The impact factors calculated consist of p_1 (coastline formed by construction), p_2 (coastline formed by protection), p_3 (coastline formed by aquaculture), p_4 (coastline formed by ports and wharfs), and p_5 (coastline formed by recreation and leisure) with their corresponding values of 0.84, 0.33, 0.68, 0.48, and 0.46, respectively.

3.2.3 Index of intensity of artificial interference

The change of bay landscapes is affected by a set of natural and artificial factors. However, at a short time scale, human activities interfere and dominate the formation of landscape patterns and processes of the two bays. Hence, an index of intensity of human interference with a landscape (LHAI, Landscape human active interference index) was adopted based on the landscape type and change characteristics. Its calculation formula is as follows:

$$LHAI=\frac{\sum_{i=1}^{N} A_iP_i}{TA} \tag{4}$$

where *LHAI* represents the index of intensity of human interference; N represents the number of landscape types, which is 9 in this study; A_i represents the area of the i-th landscape type (km^2); p_i represents the factor of impact on resource and environment of the i-th landscape type; TA indicates the total area of landscapes (km^2). Per referring to advices from experts in the fields of geoscience, ecology, oceanography, and environmental sciences, as well as existing research results on change of landscape resource (Zhou *et al*., 2011; Lin *et al*., 2007), the factors of impact on resource and environment of landscapes in XB and TB were determined (Table 2).

Table 2 Impact factors of landscape resources and environments in XB and TB areas

Landscape type	Conditions of impact on resource and environment of the landscape	Impact factor
Land for construction	There are significant impacts on landscape resources and eco-environment of bays, some of which are irreversible	0.85
Land for aquaculture and salt field	There are considerable impacts on landscape resources and eco-environment of bays, most of which are irreversible	0.65
Land for recreation	There are slight impacts on landscape resources and eco-environment of bays, most of which are irreversible	0.55
Unutilized land	There are slight impacts on landscape resources and eco-environment of bays, most of which are irreversible	0.48
Cultivated land	There are small impacts on landscape resources and eco-environment of bays, some of which are reversible	0.25
Lakes and rivers	There are minor impacts on landscape resources and eco-environment of bays, some of which are capable of ecological conservation and regulation	0.10
Forest land	There are minor impacts on landscape resources and eco-environment of bays, some of which are capable of ecological conservation and regulation	0.10
Sea area	There are minor impacts on landscape resources and eco-environment of bays, some of which are capable of ecological conservation and regulation	0.10
Tidal flats and wetlands	There are minor impacts on landscape resources and eco-environment of bays, some of which are capable of ecological conservation and regulation	0.10

For this case, the Create Fishnet Toolset in the data management module of ArcGIS10.2 was used to create a 600 m × 600 m grid as the template for the two study areas. Intensity of artificial interference within each grid in the two study areas was calculated and was used as a value of the centroid of each grid. Based on the trend analysis and normality test, the spatiotemporal distributions of intensity of artificial interference with landscapes in the two bays were obtained using Kriging interpolation with a 3D submodule in ArcGIS 10.2.

4 Result and analysis

4.1 Change of length of coastline

As presented in Table 3, with intensified coast exploitation, the proportion of artificial coastlines has been increasing during the past 30 years in both bays. However, since there exist distinct features of land use and harbor management, historical changes of length of coastlines in the two bay areas differed from each other. The length of artificial coastlines in XB grew from 80.24 km in 1985 to 133.07 km in 2015, showing a 52.83 km growth in the 30 years, accounting for yearly rising proportions of the total length of coastlines, from 28.27% in 1985 to 49.08%, 51.08%, and 51.49%, in 1995, 2005, and 2015, respectively. The average rate of length reduction for natural coastlines in XB within the 30 years was 2.61 km·yr^{-1}. In the meantime, the length of artificial coastlines in TB grew from 492.17 km in 1985 to 528.54 km in 2015, showing an increase by only 36.37 km within the 30 years, accounting for yearly slowly rising proportions of the total length of coastlines, from 46.94% in 1985 to 48.19%, 50.37%, and 50.58%, in 1995, 2005, and 2015, respectively. The average rate of length reduction for natural coastlines in TB within the 30 years was only 50.96% of that in XB. It could be seen that the proportions of artificial coastlines exhibited a continuous growth in both bays; but the increasing magnitude of proportion of artificial coastlines in XB was far larger than that in TB. It would be constructive to refer to protection strategies in TB for the exploitation in XB in the aspects of scientific conservation of natural coastlines and control of increase rate of artificial coastlines.

Table 3 Changes in length of various coastline types during different periods in XB and TB from 1985 to 2015 (km)

	XB, China				TB, USA			
	Type	1985–1995	1995–2005	2005–2015	Type	1985–1995	1995–2005	2005–2015
Natural coastline	Bedrock coastline	–46.21	–10.71	–3.83	Bedrock coastline	–0.22	0.01	–0.04
	Estuary coastline	–2.74	1.71	–1.17	Biological coastline	–14.97	–20.13	–2.54
	Gravel coastline	0.14	0.05	0.41	Gravel coastline	0.27	–1.38	0.1
	Mud coastline	–15.56	–0.4	0.12	Mud coastline	0.68	–1.72	0
	Subtotal	–64.37	–9.34	–4.48	Subtotal	–14.26	–23.21	–2.49
Artificial coastline	Coastline formed by aquaculture	35.6	6.8	–5.11	Coastline formed by protection	–3.27	–0.85	0.4
	Coastline formed by construction	0.09	–0.25	4.24	Coastline formed by construction	7.01	0.92	1.62
	Coastline formed by protection	12.13	–6.5	–0.96	Coastline formed by recreation and leisure	2.53	5.54	–0.22
	Coastline formed by ports and wharfs	6.08	1.41	–0.69	Coastline formed by ports and wharfs	5.64	16.97	0.08
	Subtotal	53.91	1.45	–2.53	Subtotal	11.91	22.58	1.88
	Total	–10.46	–7.89	–7.02	Total	–2.34	–0.64	–0.61

Note: "+" means the growth; "–" means the decrease.

Significant transformation of some local sections of coastlines is a direct quantitative indicator to reflect the actual exploitation process and intensity of key sections of bays. The sections in the two bays with significant transformation during the recent 30 years include Guoju-Dasong, Dasong-Tongzhao, Tongzhao-Wusha, and Wusha-Qiancang sections in XB, and Massimo-Gandy, Gandy-Tampa, Tampa-Citrus, and Citrus-Bradenton sections in TB (Figures 3 and 4). With respect to the change of lengths of natural coastlines in XB, a gradual decreasing trend for the four sections from 1985 to 1995 could be seen. Among the four sections, Tongzhao-Wusha section had the largest decreasing magnitude. Slight difference could be observed for the change of coastline sections from 1995 to 2015. In this period, Guoju-Dasong section exhibited a slow decrease, while Dasong-Tongzhao section showed a gradual increase. Tongzhao-Wusha section exhibited an increase of tidal flats and wetlands due to suspension of construction of Hongsheng seawall in the period, so that the shrinkage rate of coastline of the section slowed down as influenced by the growth of the mud coastline, with a change rate of –0.86 km·yr^{-1} in coastline length in recent decades. Wusha-Qiancang section exhibited a stable decrease in the length of coastlines. However, a consistent

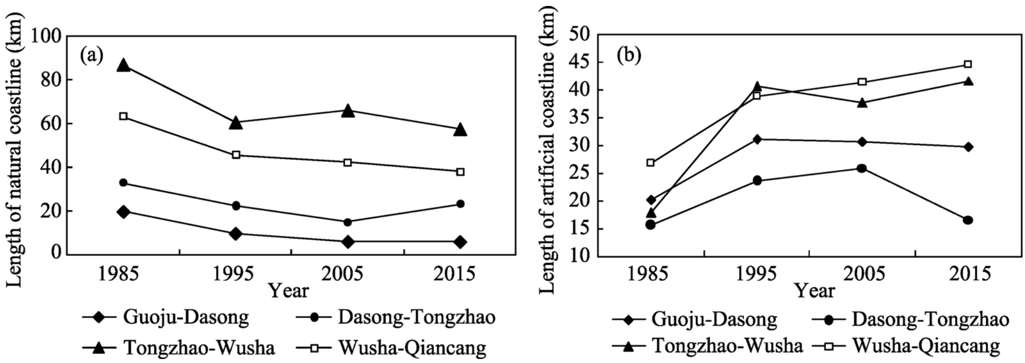

Figure 3 Changes in length of different natural (a) and artificial (b) coastline types in XB from 1985 to 2015

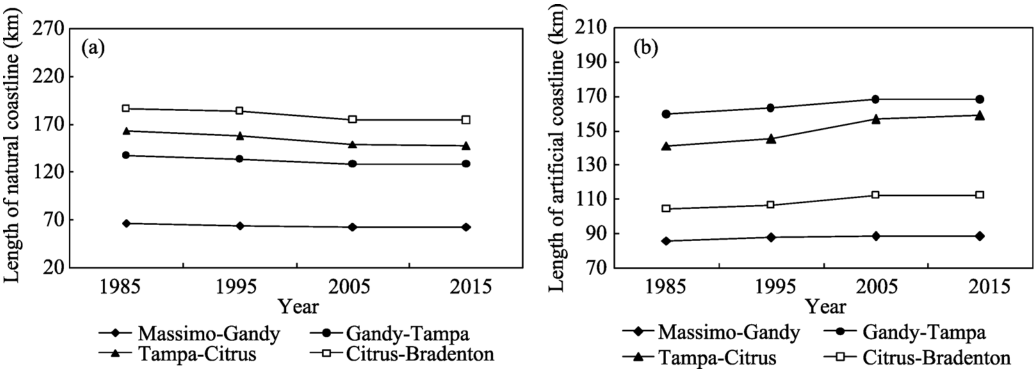

Figure 4 Changes in length of different natural (a) and artificial (b) coastline types in TB from 1985 to 2015

decreasing trend of length of natural coastlines for all sections was observed in TB during the 30 years; among all sections, Massimo-Gandy section presented the lowest decrease magnitude. Gandy-Tampa section showed a decrease of coastline length from 1985 to 2005 due to the construction of reclamation engineering of David peninsula, which tended to be stable at the end of the project. The change of Tampa-Citrus section was flat. Citrus-Bradenton section had a fast transformation from natural coastline to artificial coastline due to the development of Manatee watershed from 1995 to 2005, showing a significant decrease of coastline length in that time period.

With respect to the change of lengths of artificial coastlines, the four sections of artificial coastlines in XB exhibited a gradual increasing trend from 1985 to 1995; among the four sections, Tongzhao-Wusha section had the highest increase rate. Coastlines of some portions in Guoju-Dasong and Tongzhao-Wusha sections were connected during the period from 1995 to 2005, leading to the shrinkage of length of total coastline, and thus the shrinkage of artificial coastlines. Dasong-Tongzhao section showed a decreasing trend in recent decades, while Guoju-Dasong section remained basically unchangeable. The reason is that while coastlines for aquaculture in Dasong-Tongzhao section decreased, reclamation in Dasong-Yangshashan section was carried out, which increased the proportion of artificial coastlines. With respect to the change of lengths of artificial coastlines in TB, the four sections all exhibited a gradual increase in the recent 30 years; among all sections, Massimo-Gandy section showed a relatively smaller increase rate of 0.24 km·yr^{-1}. Gandy-Tampa section presented an increase before stabilization; Tampa-Citrus section had the highest change rate compared with the other three sections, especially from 1995 to 2005, reaching 1.18 km·yr^{-1}. Citrus-Bradenton section had a significant change from natural coastline to artificial coastline due to the establishment of recreation and leisure sites along the Manatee River from 1995 to 2005.

4.2 Variation of sinuosity of coastline

Curvature measures a degree of unevenness of a geometric body. The larger the curvature, the larger the degree of deflection of a curve. Curvature of discrete points selected from the coastlines was used to analyze the sinuosity of coastlines. The change of curvature reflects the degree of exploitation and utilization of coastlines by human beings. In order to reflect the distribution of curvature of coastlines with more accuracy in the two bays, 10 test thresholds were selected in this study, based on the calculation formula for sinuosity mentioned previously, previous experience and comparative experiments. The threshold values (e) were an arithmetic progression starting from 1.005 to 1.050, with a common difference of 0.005. Our experiments showed that, when e approached 1.020 or 1.040, the median value of curvatures of all distributed discrete points could well reflect the change of sinuosity of coastlines in XB and TB in the four periods (Table 4).

Table 4 Changes in sinuosity of different coastline types in different years in XB and TB (10^{-3}·m^{-1})

Time	1985		1995		2005		2015	
Bay	XB	TB	XB	TB	XB	TB	XB	TB
Natural coastline	4.25	7.98	4.18	8.22	4.35	8.18	4.42	8.13
Artificial coastline	3.28	4.32	3.01	4.18	2.86	4.15	2.81	4.03
Entire coastline	3.71	5.23	3.42	5.15	3.25	5.09	3.17	5.07

Figures 5a and 5b provide the changing trends of natural coastlines, artificial coastlines and entire coastlines in XB and TB from 1985 to 2015. It is noticeable that from Figure 5a, sinuosity of coastlines in XB decreased gradually within the last 30 years; the change magnitude of sinuosity of natural coastlines was less than that of artificial coastlines, but the value of sinuosity of the former was still higher than the latter. As seen from the overall trend, the magnitude of change of sinuosity decreased yearly; the change rate of sinuosity of the first decade was 0.78%, higher than 0.50% from 1995 to 2005 and 0.25% from 2005 to 2015. Similar to XB, TB showed a decreasing trend of sinuosity of coastlines within the recent 30 years, too, but with a smaller magnitude; the sinuosity of natural coastlines main

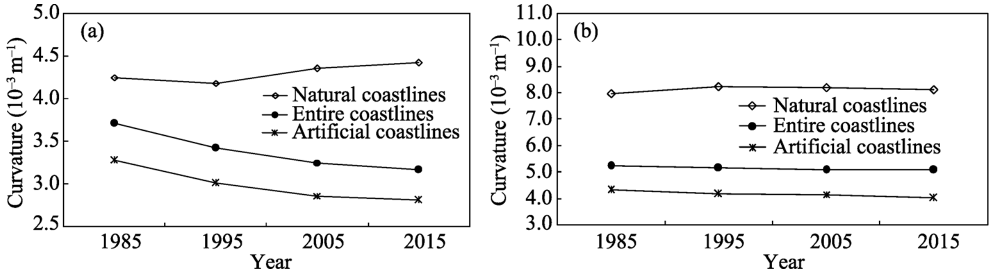

Figure 5 Changes in sinuosity of natural, artificial and entire coastlines in different years in XB (a) and TB (b) from 1985 to 2015

tained basically unchanged, while that of artificial coastlines slightly decreased. On the whole, the magnitude of change of curvature was small, being 0.15%, 0.12%, and 0.04% for the three periods, respectively. It can be seen that reclamation engineering and marine aquaculture activities in some sections in XB resulted in a flat morphology in a short time period, leading to obviously less sinuosity of coastlines compared with TB. This situation would pose a severe damage on the ecological function of bays and resources along the coastlines. Hence, the curved structural patterns of architectures in TB can be borrowed in the development in XB, to maintain the conservation rate of resource and the sinuosity of coastlines.

Spatially, the change of sinuosity of coastlines is mainly reflected in the curve/flat morphology of coastlines. As seen from Figure 5, the change of sinuosity of natural coastlines in XB and TB was small during the recent 30 years. The change trends of artificial coastlines and entire coastlines were similar to that of natural coastlines. Therefore, it is necessary to further analyze sinuosity features of coastlines with significant changes so that the reasons underlying the change of sinuosity of coastlines in each period could be clarified. To do so, remote-sensing images of two adjacent periods were used to create standard false color composite images by using three TM image bands 4, 3, and 2 or three OLI image bands 5, 4, and 3 with corresponding R, G, and B color guns, respectively. Segments with significant changes of coastlines were extracted from the composite images and presented in Figures 6 and 7.

Coastline segments with significant changes between two adjacent periods were caused by either substituting straightened artificial coastlines for natural coastlines between headlands or extruding coastlines from land to sea after reclaiming tidal flats or wetlands (Figures 6 and 7). Clearly, the evolution of artificial coastlines profoundly affected the overall changes of sinuosity of all coastlines. TB had a small scale of reclamation and thus owned a high sinuosity of coastlines, which is different from the case in XB. The overall sinuosity of coastlines in both bays showed a decreasing trend from 1985 to 1995. The changes of sinuosity in Tongzhao-Wusha and Wusha-Qiancang sections in XB were more significant than the other sections due to the fast growth of land for construction and aquaculture on the east side of Huangdun Bay, which resulted in the substitution of meandering natural coastlines by artificial coastlines extruded to the sea. Gandy-Tampa section in TB also exhibited an obvious change due to a massive increase of land for construction on the east side of David peninsula. Compared with those in 1995, the sinuosities of coastlines in both bays were higher in 2005, which was a result of reclamation in Qiangjiao and aquaculture in Xiahuan Beach in XB, and a result of reclamation engineering on the east side of David peninsula in TB. Compared with that in 2005, the sinuosity of coastlines in XB decreased slightly in 2015, which was a result of disappearance of natural coastlines along the Chun Lake and an increase of artificial coastlines on the north bank of Qiancang due to reclamation in the Hongsheng seawall project. However, the sinuosity of coastlines in TB was only affected by the constructions of ports and wharfs in the southeastern city of Tampa, showing a negligible change. Because of different socio-economic development phases in China and USA, it is worth noting that different development and utilization approaches in the two bays resulted in different features in the utilization and succession speed of coastlines.

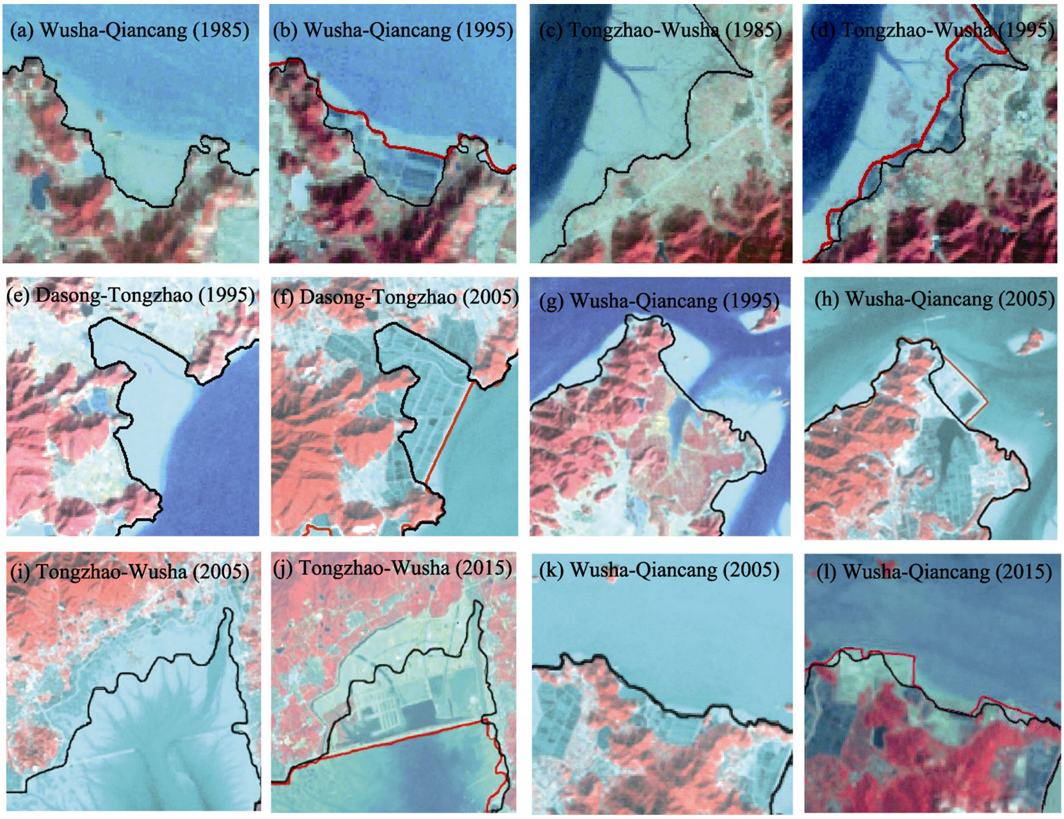

Figure 6 The coastline segments with significant changes in sinuosity between two adjacent periods in XB from 1985 to 2015

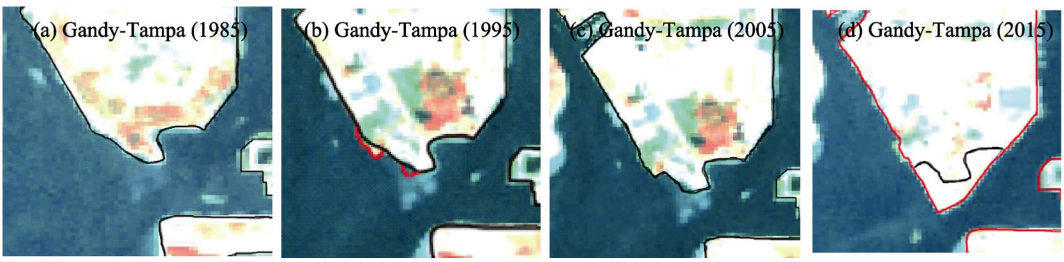

Figure 7 The coastline segments with significant changes in sinuosity between two adjacent periods in TB from 1985 to 2015

4.3 Change of intensity levels of coastal artificialization in bays

4.3.1 Spatiotemporal change analysis of coastal artificialization intensity in bays

To further reveal spatiotemporal change features of coastal artificialization intensity in XB and TB during the last 30 years, the image segmentation tool of ArcGIS10.2 was used to obtain coastlines with an increment of 2 km from Guoju-Qiancang section in XB and Massimo-Bradenton section in TB in 1985, 1995, 2005, and 2015, respectively. Based on the length of a coastline type and the calculated results of factor of impact on resource and environment by human activities, the intensity of coastal artificialization of each section was obtained using the field calculation function of ArcGIS10.2. Furthermore, the intensities of coastal artificialization were classified into four levels: low intensity (level I<0.21), medium intensity (0.21≤level II<0.45), medium high intensity (0.45≤level III <0.69), and high intensity (level IV≥0.69) (Figures 8 and 9). Following the categories, the intensity levels of coastal artificialization of the two bays were compared and analyzed (Figures 8 and 9).

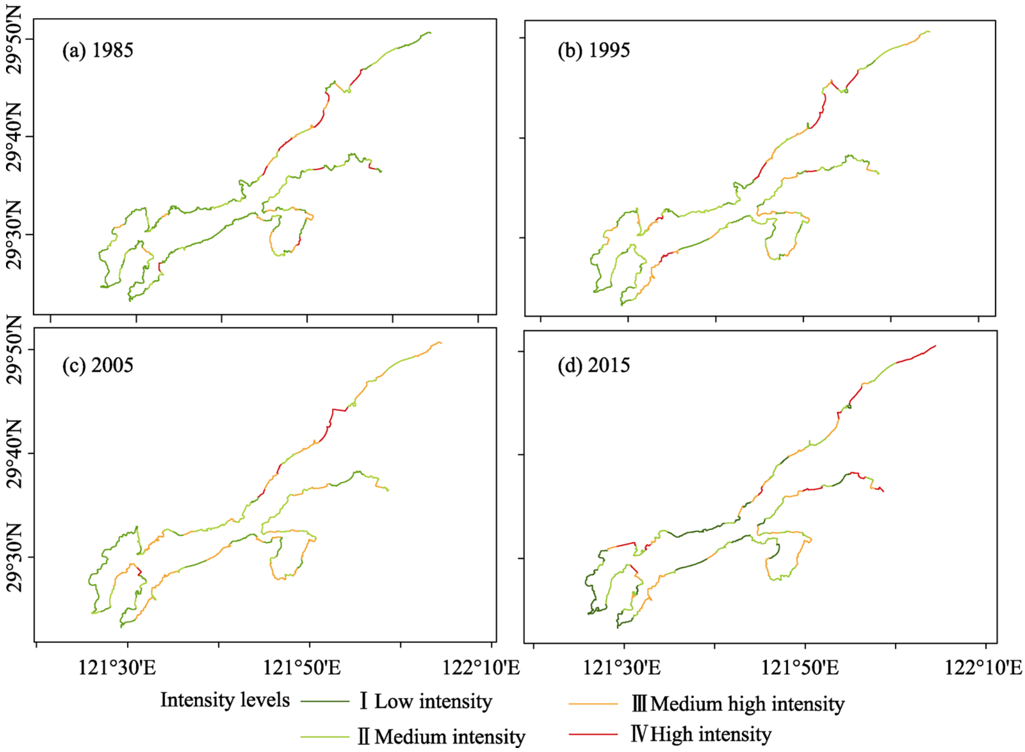

Figure 8 Distribution of artificial coastline intensity levels in XB from 1985 to 2015

Overall, the intensity of coastal artificialization in XB increased obviously during the study period; the change rate of coastal artificialization intensity for the recent 30 years was 1.59%. The change rate of intensity of coastal artificialization from 1985 to 1995 was the highest among the last 30 years, reaching 3.83%; after 1995 it slowed down, but the absolute value of intensity increased continuously. In contrast, the change rate of intensity of coastal artificialization in TB for the recent 30 years was only 0.14%; it was only 0.03% in the last 10 years. Human activities in coastlines in TB were concentrated in the western part of St. Petersburg and middle-lower reaches of the Manatee River on the south, as well as some parts of the City of Tampa in the northeast.

Locally, with the progression of coastline development, the concentration of human activities along the coastlines in XB was spread spatially. In the first decade, coastlines with intensity of coastal artificialization higher than level III were concentrated in Guoju-Dasong section, mainly due to a result of engineering construction of reclamation projects in the zone of Yangshashan and Xizhou and the Hongsheng seawall projects at the early stage. In the last decade, coastlines with intensity of coastal artificialization higher than level III increased, typically in the northern and southern coast of the bay. However, with the impact of human activity weakening along the coastlines, the development potential of natural coastlines decreased, so did the rate of coastal artificialization. Coastlines with intensity levels III

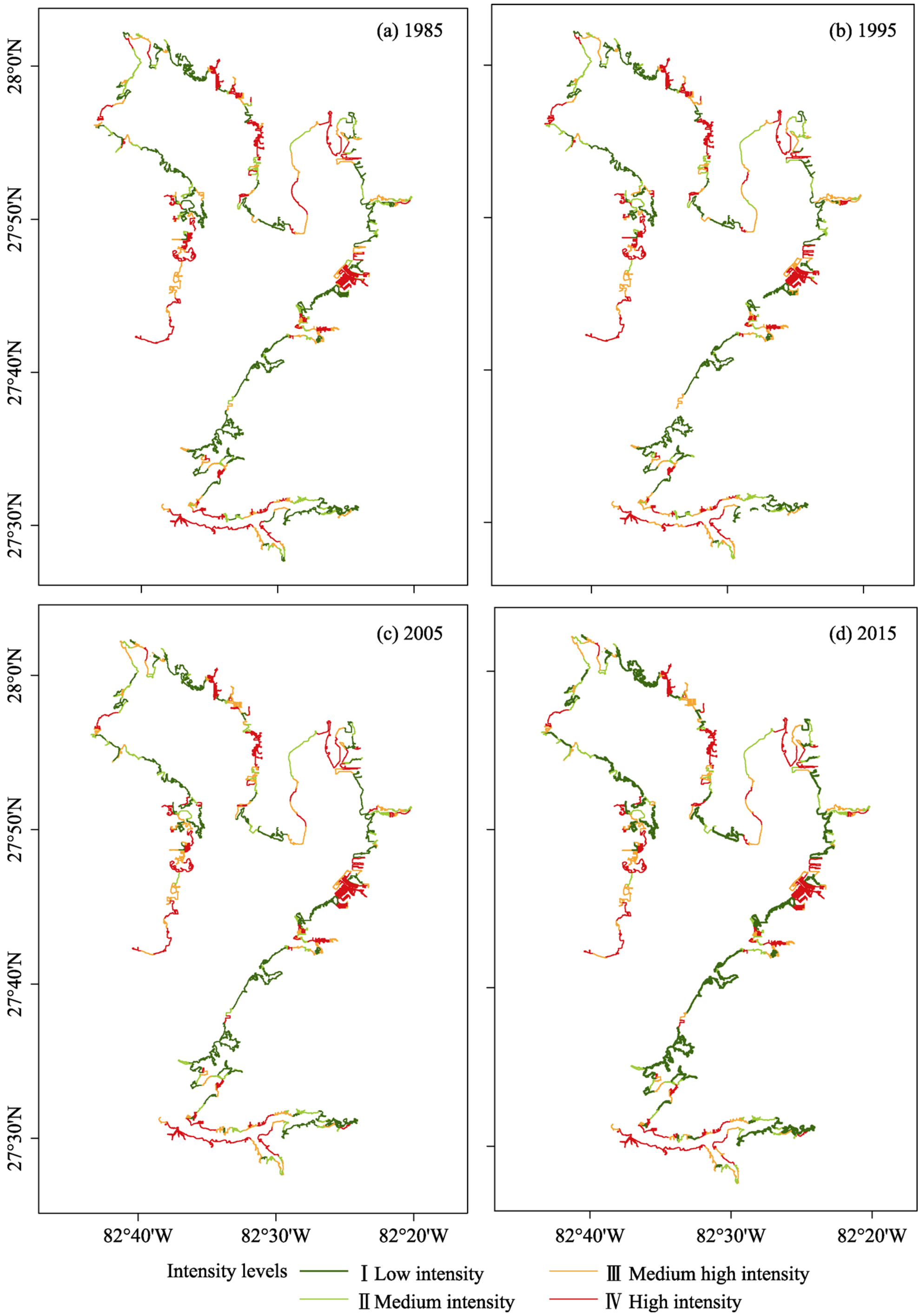

Figure 9 Distribution of artificial coastline intensity levels in TB from 1985 to 2015

and IV of artificialization were mostly factories and aquaculture ponds which have made a significant impact on the resource-environment system of coast, which exhibited a growing trend. In contrast, the changes of coastal artificialization intensity of some sections in TB were small, occurring only on the eastern side of David peninsula; zones with coastlines with intensity of levels I–IV had a steady variation, which was closely related to a perfect prewarning system for evaluating development intensity in TB. Based on the TB experience, in XB, a series of actions can be carried out to control the coastal artificialization intensity in coastlines with levels III and IV. The management activities include an evaluation on sensitivity on resource and environment of coastlines, a follow-up survey of water quality index of seawater, and an analysis of potential of coastal land use in the bay. Meanwhile, the sinuosity of artificial coastlines should be increased when conducting a construction of artificial landscapes, and a real-time monitoring of intensity of coastal artificialization and a comprehensive evaluation of utilization potential in corresponding zones should also be carried out.

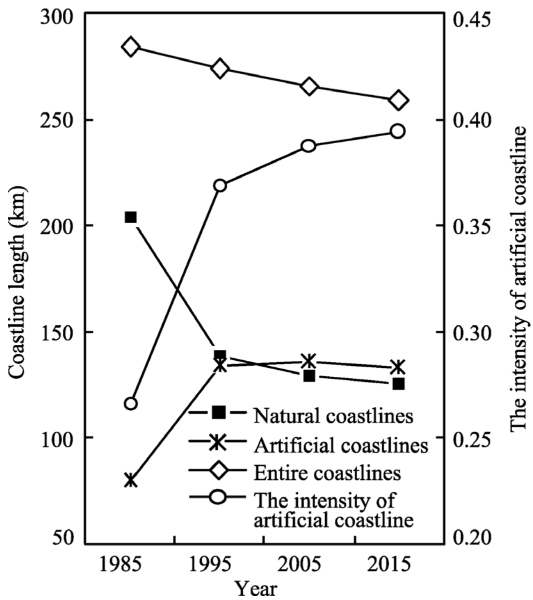

Figure 10 The relationship between the intensity of artificial coastline and coastline length in XB from 1985 to 2015

4.3.2 The relationship between intensity of coastal artificialization and length of coastline

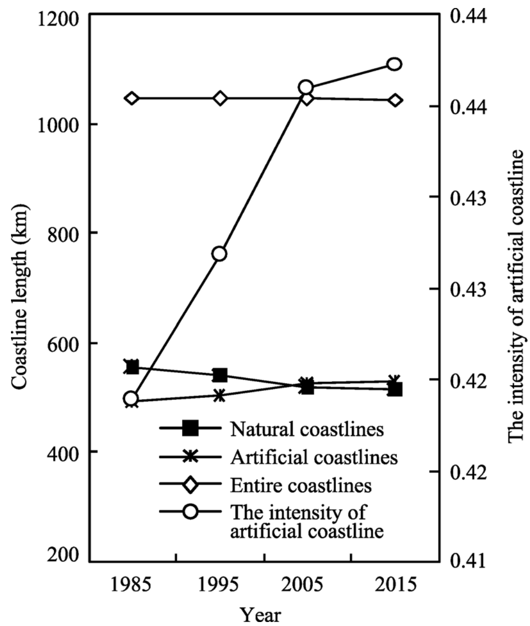

Figure 11 The relationship between the intensity of artificial coastline and coastline length in TB from 1985 to 2015

The total lengths of coastlines in both XB and TB shrank consistently, while those of natural coastlines and artificial coastlines traded off with each other. As presented in Figure 10, the intensity of coastal artificialization in XB was negatively correlated with lengths of both entire coastlines and natural coastlines, indicating a gradual decrease of natural and entire coastlines with increasing intensity of human activities. In addition, the intensity of coastal artificialization was positively correlated to the length of artificial coastlines, indicating an increase of length of artificial coastlines with a high intensity of coastal artificialization. As shown in Figure 11, the intensity of coastal artificialization in TB was negatively correlated to lengths of both entire coastlines and natural coastlines, also indicating a decrease of natural and entire coastlines with increased intensity of human activities. In addition, the intensity of coastal artificialization was also positively correlated to the length of artificial coastlines, indicating an increase of length of artificial coastlines with the intensity of coastal artificialization, similar to the case in XB.

4.3.3 The relationship between intensity of coastal artificialization and sinuosity of coastlines

The overall sinuosity of coastlines in both XB and TB decreased gradually; the sinuosity of natural coastlines remained basically stable, whereas that of artificial coastlines decreased gradually. To analyze the relationship between sinuosity of coastlines and intensity of coastal artificialization, Figures 12 and 13 show the relationships between change of intensity of coastal artificialization and sinuosity of coastlines in the four periods in both XB and TB. It is noticable that intensities of coastal artificialization in XB and TB had a significantly negative correlation with sinuosity of entire coastlines and artificial coastlines. With the increase of the intensity of human activities, the sinuosity of entire coastlines and artificial coastlines decreased gradually. But the intensity of coastal artificialization had a significantly positive correlation with the sinuosity of natural coastlines. As can be seen, the intensity of coastal artificialization had a close connection to the sinuosity of coastlines in a certain period; when the intensity of coastal artificialization increased with time, the sinuosity of coastlines decreased correspondingly. Therefore, the principle of reasonable and appropriate coastal artificialization should be complied. Theoretical research on the relationship between sinuosity and intensity of coastal artificialization should be strengthened, and its result should be applied to the utilization and protection of resource of coastlines.

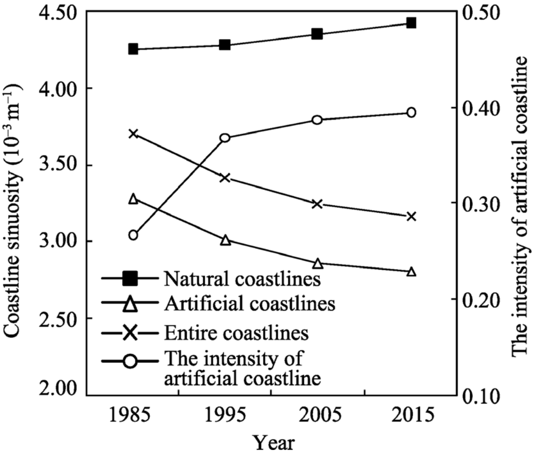

Figure 12 The relationship between the intensity of artificial coastline and coastline sinuosity in XB from 1985 to 2015

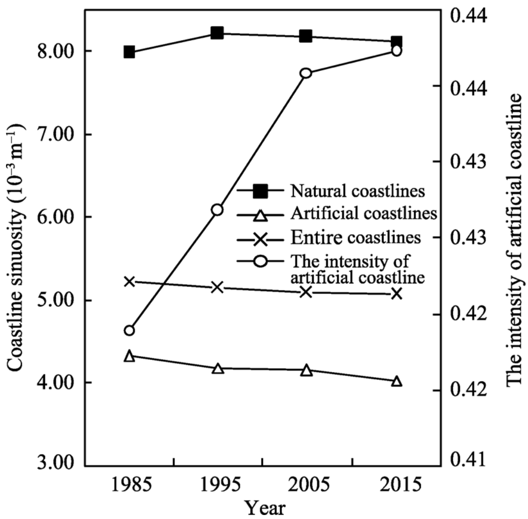

Figure 13 The relationship between the intensity of artificial coastline and coastline sinuosity in TB from 1985 to 2015

4.4 Analysis of change of intensity of artificial interference with different landscapes

According to Equation (4), we conducted an index calculation and spatiotemporal simulation of intensity of artificial interference with different landscapes in the two bays. In order to compare intensities of artificial interference with landscapes between XB and TB in different periods, the whole range of intensity was normalized and divided into five grades: low intensity ($LHAI$<0.21), medium low intensity (0.21≤$LHAI$<0.37), medium intensity (0.37≤$LHAI$<0.53), medium high intensity (0.53≤$LHAI$<0.69), and high intensity ($LHAI$≥0.69), with an interval of 0.16. In such a way, the spatial distributions of intensity of human activity in the two bays were obtained (Figures 14 and 15). It is easy to see that the spatial distributions of landscapes with low and medium low intensity of artificial interference in both XB and TB were consistent, both in natural landscapes of forest lands, sea areas, lakes and rivers, tidal flats and wetlands, etc. Areas with medium, medium high, and high intensity of artificial interference were distributed in plains, covering landscapes of lands mainly for construction, aquaculture ponds, salt fields and cultivated lands in XB, and those of lands for construction and for recreation in TB.

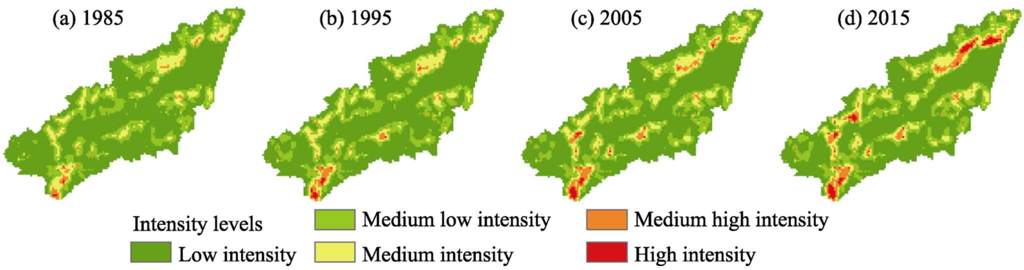

Figure 14 The intensity of landscape disturbed by human in XB from 1985 to 2015

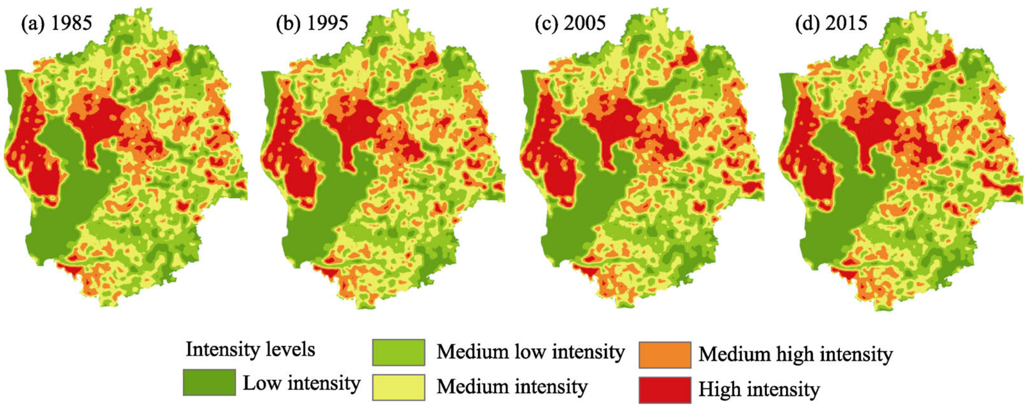

Figure 15 The intensity of landscape disturbed by human in TB from 1985 to 2015

Spatially, low and medium low intensity of artificial interference dominated in XB; areas with medium and medium high intensity of artificial interference spread gradually outward, while those with high intensity were distributed dispersedly, but with a trend of merging into a continuous zone. However, in TB, human activities with low and medium low intensity were sparsely distributed; areas with medium intensity of artificial interference were distributed in the north of the bay and the southeast of Hillsborough county, with primarily cultivated lands in the suburbs and lands for construction; and areas with medium high and high intensity of artificial interference were concentrated in the "Clearwater–St. Petersburg–Tampa" metropolitan region, the connected region of Brandon and Plant city (to the east of Hillsborough county), as well as the downstream of the Manatee river. Per the overall change pattern of intensity of artificial interference with landscapes, areas with the low and medium low intensity in XB were relatively stable in the size on the land side, but shrank on the sea side; areas with medium, medium high, and high intensity were distributed in coastal regions, with a trend of expansion. However, the variation of artificial interference with low and medium low intensity in TB was small, especially for that on the sea side. Areas with medium, medium high, and high intensity showed an expansion in the southeastern Pasco county, the southern Hillsborough county, and the northern Sarasota county. As can be seen, the landscape patterns and intensity of artificial interference with landscapes obviously changed under the impact of human activities in both XB and TB during the last 30 years.

In addition, areas with medium high and high intensity of artificial interference with landscapes in both XB and TB were mainly distributed in plains located near national and provincial/state freeways, or in the hinterland of counties (towns), such as Ninghai county and the "Clearwater–St. Petersburg–Tampa" metropolitan region. Industries with priority, such as vessel construction, reclamation engineering, real estate development, also resulted in significant changes in intensity of artificial interference with landscapes. For example, the accelerated investment, development and construction of real estate projects in TB in the 1990s resulted in significant changes in the intensity of artificial interference with landscapes in the northern, eastern and southern TB. In the early 21st century, power plant construction in Wushashan, Datang, continued construction of Haitang seawall, and reclamation engineering in Dasong–Yangshashan section made possible great changes in the intensity of artificial interference with landscapes in the northeastern, southeastern and western XB.

4.5 Response of bay landscapes to intensity of artificial interference

Coastal development caused acceleration of artificialization rate of landscapes in bay areas, resulting in responses of spatial patterns, diversity and fragmentation of the landscapes to human activities to different extents. According to the division standard for intensity grade of artificial interference with landscapes in the two bays in 2015, the study areas of the two bays were respectively divided into five zones with different intensity grades of artificial interference. The grid reclassification tool in the module of spatial analysis of ArcGIS10.2 was used to normalize the grades of intensity, with an increment of 0.14. The five zones consist of low intensity of interference (<0.33, grade 1), medium low intensity of interference ($\geqslant 0.33$ and <0.47, grade 2), medium intensity of interference ($\geqslant 0.47$ and <0.61, grade 3), medium high intensity of interference ($\geqslant 0.61$ and <0.75, grade 4), and high intensity of interference ($\geqslant 0.75$, grade 5). The five zones with intensity grades from 1 to 5 were obtained after coding (Table 5). Then the average area of patch and proportion of area of landscapes of each zone in the four periods were created based on calculated number of patches and area of landscapes. Changes of landscapes in XB and TB under the impact of artificial interference of different intensities from 1985 to 2015 were compared (Figures 16 and 17).

Table 5 Intensity divisions of human-disturbed landscapes and their internal main composition

Name	Grade	Composition of landscape
Zone with low intensity of artificial interference	1	Composed mainly of seas, forest lands, with low impermeability, including tidal flats, wetlands and mangrove forests, etc.
Zone with medium low intensity of artificial interference	2	Composed mainly of natural landscapes, i.e., forest lands and lakes, as well as some farm lands and dispersed residences
Zone with medium intensity of artificial interference	3	Composed mainly of architectures and vegetation mixed, as well as dispersed residences and farm lands
Zone with medium high intensity of artificial interference	4	Composed mainly of dispersed residences and open spaces ready to be developed
Zone with high intensity of artificial interference	5	Composed mainly of large-size structures, with high impermeability, including factories, highly dense residences, and airports

In terms of the overall trend, the average area of patches in XB decreased gradually because of the increase of intensity of artificial interference. From zones 1 to 3, natural landscapes occupied relatively large proportion, but were fragmented and separated by dispersed artificial interferences; patches with small area gradually increased, resulting in the shrinkage of overall average area of patches. Proportion of natural landscapes of zone 4 was low, but artificial landscapes scattered, leading to an increase of number of patches and a decrease of average area of patches. Proportion of natural landscapes in zone 5 was low; connected artificial landscapes under concentrated artificial interferences dominated in this zone, resulting in an increase of patched area of landscapes. The changing trend of average area of patches in TB was basically consistent with that in XB, namely, with the increase of intensity of artificial interference for the zones, the average area of patches decreased. The average area of patches of landscapes from zones 1 to 4 was small, but for zone 5, artificial landscapes dominated because of concentrated human activities, resulting in an increase of average area of patches. Therefore, it is important to protect natural landscapes in the development in XB, enhance theoretical research on layout of bay landscapes and construction of information platforms, ensure a reasonable distribution of lands for recreation and leisure, factories and enterprises, and industries and mining, and encourage environmental awareness of the public, as well as increase promptness of ecological restoration of landscapes. It is also necessary to prevent damage on ecological systems and implement protective measures under laws and regulations so as to reduce the degree of artificial interference with natural landscapes during the development process in bays.

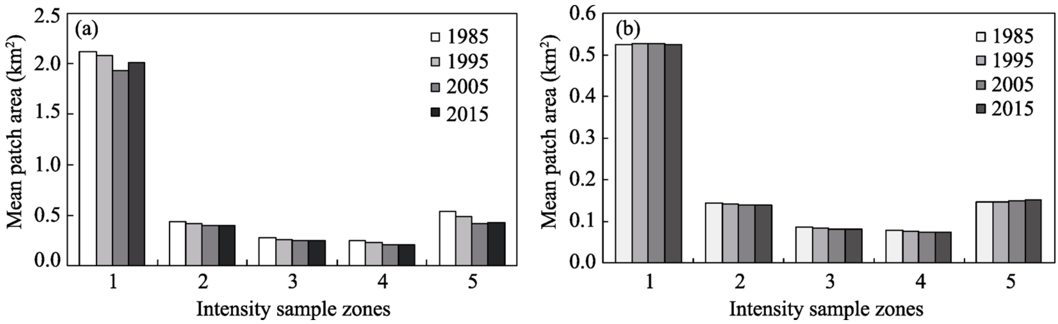

Figure 16 Responses of landscape mean patch area to intensities of different human disturbance in XB (a) and TB (b) from 1985 to 2015

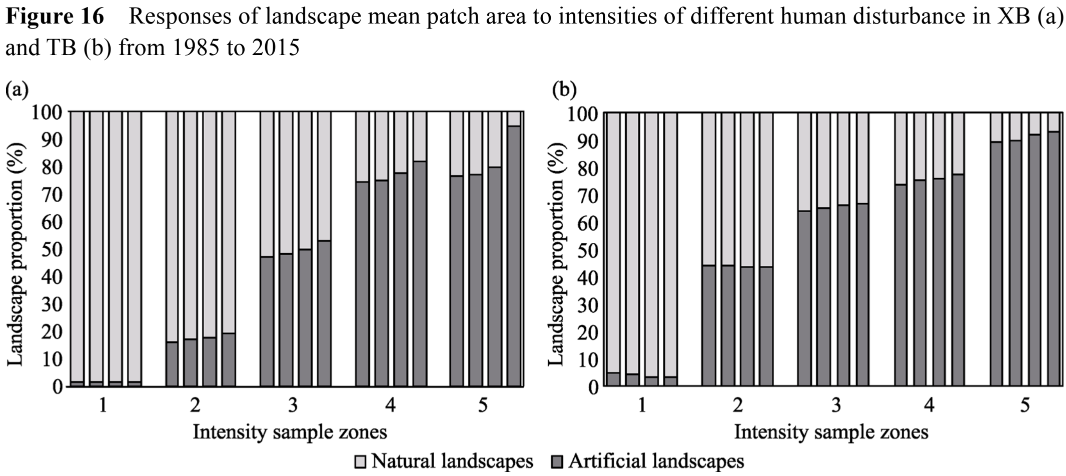

Figure 17 Responses of proportion of natural and artificial landscapes to intensities of different human disturbance in XB (a) and TB (b) from 1985 to 2015

The landscape diversity in XB and TB was characterized using Shannon diversity index. An overall trend of increasing and then becoming stable of landscape diversity was found for zones 1 to 5 in XB (Figure 18a). For zones 1 to 3, the landscape diversity index increased gradually; since human activities were dispersed, only natural landscapes on the fringe were interfered, while artificial landscapes still took a small proportion. From zones 3 to 5, a stable trend was observed. An overall trend of gradual increase of landscape diversity was shown from zones 1 to 3 in TB, but landscape diversity from zones 4 to 5 decreased apparently (Figure 18b). The reasons could be as follows: from zones 1 to 3, diversified natural landscapes existed, which was further enhanced by the introduction of artificial landscapes; From zones 4 to 5, monotonous landscape types existed, and lands for construction dominated, resulting in a small landscape diversity index. Therefore, it is important to avoid monotonous landscapes during the development and utilization process in XB. It is also important to ensure a virtuous development of landscape patterns on the basis of comparative study of changes of diversity and heterogeneity of coastline sections of different landscapes or a landscape in different time periods, as well as analysis on sensitivity of landscapes during development and utilization of lands in the bays.

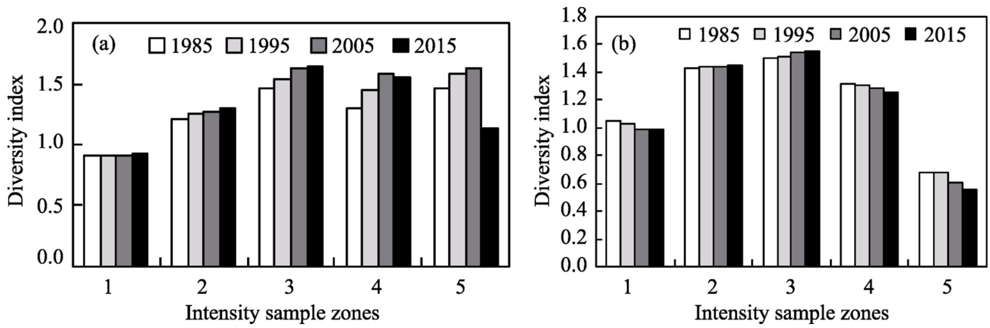

Figure 18 Responses of landscape diversity to intensities of different human disturbance in XB (a) and TB (b) from 1985 to 2015

A landscape fragmentation index reflects the degree of fragmentation of a landscape resulted from natural partition and artificial segmentation, namely, a measurement indicating the change of ecological pattern of landscape from continuous structures into patches and blocks. It can reflect the complexity of spatial pattern of landscapes and the degree of interference with landscapes by human activities. As seen from Figure 19, with the intensity of artificial interference with landscapes in XB, the continuously distributed natural landscapes in zones 1 to 4 were gradually fragmented under artificial interference, with separated patches and dispersed blocks as well as an increased degree of fragmentation. In zone 5, artificial landscapes were highly densely distributed with a relatively large average area of patches, which decreased the degree of fragmentation of landscapes from zones 4 to 5. Viewed from different time periods, the degree of landscape fragmentation in XB under different intensities of artificialization increased gradually from 1985 to 2005; in zones 3 and 5 from 2005 to 2015, the degree of landscape fragmentation decreased, mainly due to increased connection of artificial landscapes including cultivated lands and highly dense lands for construction, etc. Likewise, the trend of landscape fragmentation in TB was consistent with that in XB, i.e., an increase of landscape fragmentation from zones 1 to 4 and decrease of landscape fragmentation from zones 4 to 5. However, the change magnitude in TB was small and tended to keep stable, indicating small artificial interference in TB because of reasonable management activities. Hence, it is important to conserve some natural landscapes during the development and utilization in XB. Particularly, when the intensity of development reaches a certain degree, aggregated landscape types and their spatial spreads should be monitored in a wide range, so as to avoid separation of landscapes at a large scale under extraordinary interference by human activities.

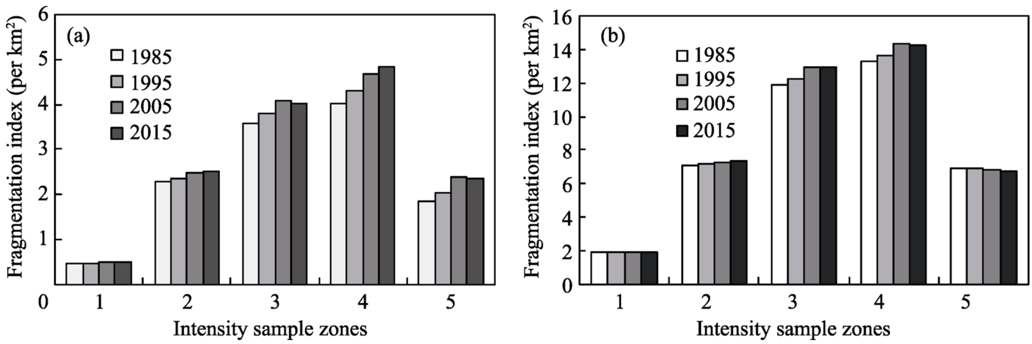

Figure 19 Responses of landscape fragmentation to intensities of different human disturbance in XB (a) and TB (b) from 1985 to 2015

5 Conclusions

In this study, the impacts of human activities on the evolution of coastlines and landscapes in bay areas were explored in terms of quantitative comparison on the transformation of coastlines and landscapes in the two bay areas in China and USA. The conclusions derived from this study are summarized as follows:

(1) With the intensity of coastal development, the proportions of artificial coastlines in the two bays exhibited continuous growth during the last 30 years, while the length of natural coastlines decreased gradually. The increasing magnitude of proportion of length of artificial coastlines to the total length in Xiangshan Bay (XB) was far greater than that in Tampa Bay (TB). Resources of coastlines were irreversible and vulnerable to the destruction. Hence, protective measures adopted in TB should be referred to the development in XB, so as to scientifically conserve resources of natural coastlines and control the increasing rate of artificialization of coastlines.

(2) Sinuosity of coastlines in XB decreased continuously within the last 30 years. Change of sinuosity of natural coastlines was smaller than that of artificial coastlines, while the absolute value of sinuosity of the former was still higher than that of the latter. Likewise, the sinuosity of coastlines in TB exhibited a decreasing trend within the recent 30 years, but with a small change magnitude. Such a difference in the two bays was caused by different strategies of land utilization and socioeconomic development in the two countries. In addition, the evolution trend of artificial coastlines in XB and TB under the interference of human activities also profoundly affected the change process of sinuosity of all coastlines. Therefore, it is important in the development of XB to construct meandering coastlines to ensure the rate of conserved resources of coastlines in the bay area, based on the experience of TB in utilization of coastlines.

(3) On the whole, the intensity of coastal artificialization in XB was significantly in-

creased during the 30 years, while that in TB was slowly increased. Locally, with the progression of coastal development, the degree of concentration of human activities along the coastlines in XB distributed spatially, while that in TB in some sections was basically stable. Hence, a series of actions can be carried out to control the intensity of development and exploitation of coastlines with grades III and IV in XB, including evaluation of sensitivity on resource and environment of coastlines, follow-up survey of water quality index of seawater, and analysis of potential of coastal land use in the bay. Meanwhile, the sinuosity of artificial coastlines should be increased during construction of artificial landscapes, while real-time monitoring of intensity of coastal artificialization and a comprehensive evaluation of potentialization utilization value in corresponding zones should be carried out.

(4) The intensity of coastal artificialization has had a close correlation with the sinuosity of coastlines in a certain period, showing a significant negative correlation. When the intensity of coastal artificialization increased with time, the sinuosity of coastlines decreased correspondingly. Therefore, the principle of reasonable and appropriate exploitation of coastal resources should be carried out. Theoretical research on the relationship between sinuosity and intensity of coastal artificialization should be strengthened, and its result should be applied to the utilization and protection of resource of coastlines.

(5) During the last 30 years, human activities have posed profound impacts on the evolution of landscape patterns in XB and TB, mainly reflecting the changes of spatial configuration, diversity and fragmentation of landscapes in coastal areas. The changes of average area of patches and proportion of landscapes in XB and TB were basically consistent: with the intensity of human activities, the average area of patches decreased. A decrease of landscape diversity in XB was significant, while that in TB concentrated in zones with the weakest and strongest human activities, forming a double-peak mode. The degree of landscape fragmentation in the two bays was closely related to the intensity of human activities; specifically, with the intensity of human activities, the degree of landscape fragmentation increased basically, but decreased in the zone with the most concentrated human activities. Hence, it is important to conserve some natural landscapes during the development and utilization in XB. In particular, when the intensity of development reaches a certain degree, aggregated landscape types and their spatial spreads should be monitored in a wide range, so as to avoid fragmentation of landscapes at a large scale under extraordinary interference by human activities.

References

Blodget H W, Taylor P T, Roark J H, 1991. Shoreline changes along the Rosetta-Nile promontory: Monitoring with satellite observations. *Marine Geology*, 99: 67–77.

Burningham H, French J, 2017. Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation. *Geomorphology*, 282: 131–149.

Chen Z S, Wu S Y, Wang W H, 2007. The Gulf of China. Beijing: China Ocean Press. (in Chinese)

Chu Z X, Yang X H, Feng X L *et al*., 2013. Temporal and spatial changes in coastline movement of the Yangtze Delta during 1974–2010. *Journal of Asian Earth Sciences*, 66: 166–174.

Fan D, Guo H D, Yue H Y *et al*., 2002. Detection of lake shoreline in SAR image based on wavelet. *Journal of Remote Sensing*, 6(6): 511–516. (in Chinese)

Ghosh M K, Kumar L, Roy C, 2015. Monitoring the coastline change of Hatiya Island in Bangladesh using remote sensing techniques. *ISPRS Journal of Photogrammetry and Remote Sensing*, 101: 137–144.

Guo L, Du S H, Xue D Y *et al*., 2009. Spatiotemporal variation of landscape patterns during rapid urbanization in Guangzhou City. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 45(1): 129–136. (in Chinese)

Jerzy S, 2009. Spatial context of urbanization: Landscape pattern and changes between 1950 and 1990 in the Warsaw metropolitan area Poland. *Landscape and Urban Planning*, 93(2): 250–261.

Joseph T, Ioannis N, Vogiatzakis, 2011. Processes and patterns of landscape change on a small Aegean island: The case of Sifnos Greece. *Landscape and Urban Planning*, 99(1): 58–64.

Kannan R, Ramanamurthy M V, Kanungo A, 2016. Shoreline change monitoring in Nellore coast at east coast Andhra Pradesh district using remote sensing and GIS. *Journal of Fisheries and Livestock Production*, 4(1): 161. doi: 10.4172/2332-2608.1000161.

Lantuit H, Pollard W H, 2008. Fifty years of coastal erosion and retrogressive thaw slump activity on Herschel Island, southern Beaufort Sea, Yukon Territory, Canada. *Geomorphology*, 95(1/2): 84–102.

Li C C, 1986. Geomorphic characteristics of the harbor coasts in south China. *Acta Geographica Sinica*, 41(4): 311–369. (in Chinese)

Li J L, Yang L, Pu R L *et al*., 2017. A review on anthropogenic geomorphology. *Acta Geographica Sinica*, 27(1): 109–128. (in Chinese)

Li X, Zhang L P, Ji C G *et al*., 2014. Spatiotemporal changes of Jiangsu coastline: A remote sensing and GIS approach. *Geographical Research*, 33(3): 414–426. (in Chinese)

Li Y, Wang Y L, Peng J *et al*., 2009. Research on dynamic changes of coastline in Shenzhen City based on Landsat image. *Resources Science*, 31(5): 875–883. (in Chinese)

Lin G L, Zuo Y H, 2006. Cumulative ecological effects assessment on resource exploitation and utilization in bay. *Journal of Natural Resources*, 21(3): 432–440. (in Chinese)

Lin G L, Zuo Y H, 2007. PRED regulation of Xiamen bay in the process of urbanization. *Acta Geographica Sinica*, 62(2): 137–146. (in Chinese)

Lisa M, Olsen V H, Dale T F, 2007. Landscape patterns as indicators of ecological change at Fort Benning Georgia USA. *Landscape and Urban Planning*, 79(2): 137–149.

Ma L J, Yang X G, Qi Y L *et al*., 2014. Oceanic area change and contributing factor of Jiaozhou bay. *Scientia Geographica Sinica*, 34(3): 365–369. (in Chinese)

Parcerisas L, Marull J, Pino J *et al*., 2012. Land use changes, landscape ecology and their socioeconomic driving forces in the Spanish Mediterranean coast (ElMaresme County, 1850–2005). *Environmental Science and Policy*, 23(11): 120–132.

Paterson K S, David K L, 2014. The human dimension of changing shorelines along the U.S. North Atlantic Coast. *Coastal Management*, 42(1): 17–20.

Qin X D, Min Q W, 2007. Application of cellular automata in landscape pattern optimization. *Resources Science*, 29(4): 85–91. (in Chinese)

Ryu J H, Choi J K, Lee Y K *et al*., 2014. Potential of remote sensing in management of tidal flats: A case study of thematic mapping in the Korean tidal flats. *Ocean and Coastal Management*, 102: 458–470.

Sun W F, Ma Y, Zhang J *et al*., 2011. Study of remote sensing interpretation keys and extraction technique of different types of shoreline. *Bulletin of Surveying and Mapping*, (3): 41–44. (in Chinese)

Tian G J, Zhang Z X, Zhang G P *et al*., 2002. Landscape dynamic change pattern of Haikou City by TM imagery and GIS. *Acta Ecologica Sinica*, 22(7): 1028–1034. (in Chinese)

Tirkey N, Biradar R S, 2005. A study on shoreline changes of Mumbai coast using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing*, 33(1): 85–88.

Verbutg P H, Soepboer W, Veldkamp A *et al*., 2002. Land use change modeling at the regional scale. *The Clues Environmental Management*, 30: 391–405.

Wan K, Bao X W, Yao Z G *et al*., 2014. Tidal and residual current characteristics at mouth of Shangchenggang channel. *Oceanologia et Limnologia Sinica*, 45(4): 669–675. (in Chinese)

Wang M Y, Li J L, Xu L H *et al*., 2014. Beach farmland reclamation from landscape pattern change: Dongtai County, Jiangsu Province as a case study. *Journal of Ningbo University* (*NSEE*), 27(4): 60–65. (in Chinese)

Wang X H, Zhu X D, Li Y F *et al*., 2007. Dynamic assessment of the cumulative ecological effects from Xiamen Bay city development. *Acta Ecologica Sinica*, 27(6): 2375–2381. (in Chinese)

Wang Y, Ji X M, 2011. Environmental characteristics and changes of coastal ocean as land-ocean transitional zone of China. *Scientia Geographica Sinica*, 31(2): 129–135. (in Chinese)

Wu J S, Wang Z, Zhang L Q *et al*., 2012. Research progresses on driving forces of the changes of landscape pattern. *Progress in Geography*, 31(12): 1739–1746. (in Chinese)

Xu J Y, Zhang Z X, Zhao X L *et al*., 2013. Spatial-temporal analysis of coastline changes in northern China from 2000 to 2012. *Acta Geographica Sinica*, 68(5): 651–660. (in Chinese)

Xu L H, Gong H B, Li J L, 2015a. Comprehensive suitability assessment of coastline resources of Zhejiang province, China. *Philippine Agricultural Scientist*, 98(2): 224–236.

Xu L H, Li J L, Yang L *et al*., 2015b. Integrated suitability evaluation on mainland coastline resources in Zhejiang province. *China Land Sciences*, 29(5): 49–56. (in Chinese)

Xu Y, Zhong Y X, Feng X H *et al*., 2017. Response of landuse change to the human activities in Jiangxi province. *Research of Soil and Water Conservation*, 24(1): 181–193. (in Chinese)

Yao X J, Gao Y, Du Y Y *et al*., 2013. Spatial and temporal changes of Hainan coastline in the past 30 years based on RS. *Journal of Natural Resources*, 18(1): 114–125. (in Chinese)

Yuan Q X, Li J L, Xu L H *et al*., 2014. Quantitative analysis of river morphological features in Xiangshangang Bay Basin. *Journal of Marine Sciences*, 32(3): 50–57. (in Chinese)

Yuan Q X, Li J L, Xu L H *et al*., 2015. Temporal and spatial variations of shoreline in tidal inlet system of Xiangshangang Bay and its relation to human activities in the past 40a. *Journal of Applied Oceanography*, 34(2): 279–290. (in Chinese)

Zhang Q M, Zheng D Y, Li S N *et al*., 1995. A study on the sediment dynamics of ebb-tidal delta of Zhanjiang harbor tidal inlet. *Acta Geographica Sinica*, 50(5): 421–429. (in Chinese)

Zhao Z Z, 2013. Mainland Shoreline Change Analysis of Fujian Province of 30 Years on Remote Sensing. Qingdao: Shandong University of Science and Technology. (in Chinese)

Zhou J, Chen B, Yu W W, 2011. Landscape pattern analysis and dynamic change in Quanzhou Bay. *Marine Environmental Science*, 30(3): 370–375. (in Chinese)

Zhu C G, Zhang X, Luo J C *et al*., 2013. Automatic extraction of coastline by remote sensing technology based on SVM and auto-selection of training samples. *Remote Sensing for Land and Resources*, 25(2): 69–74. (in Chinese)