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An approach of habitat degradation assessment for characterization on coastal habitat conservation tendency

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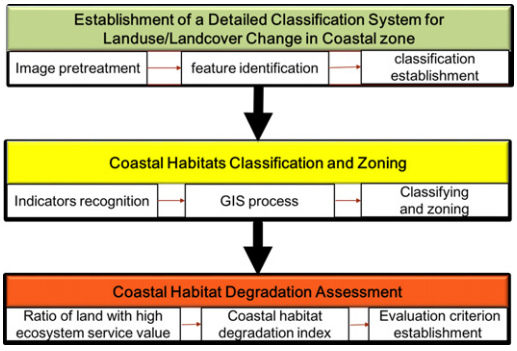
HIGHLIGHTS

- An integrated framework of coastal habitat degradation assessment was established.
- Coastal habitat classifying and zoning was achieved according to geographic characteristic.
- The evaluation criterion of habitat degradation through internal comparison was established.
- Coastal habitat degradation index could distinguish the human disturbances intensity.

GRAPHICAL ABSTRACT



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ABSTRACT

Coastal zones are population and economy highly intensity regions all over the world, and coastal habitat supports the sustainable development of human society. The accurate assessment of coastal habitat degradation is the essential prerequisite for coastal zone protection. In this study, an integrated framework of coastal habitat degradation assessment including landuse classification, habitat classifying and zoning, evaluation criterion of coastal habitat degradation and coastal habitat degradation index has been established for better regional coastal habitat assessment. Through establishment of detailed three-class landuse classification, the fine landscape change is revealed, the evaluation criterion of coastal habitat degradation through internal comparison based on the results of habitat classifying and zoning could indicate the levels of habitat degradation and distinguish the intensity of human disturbances in different habitat subareas under the same habitat classification. Finally, the results of coastal habitat degradation assessment could be achieved through coastal habitat degradation index (CHI). A case study of the framework is carried out in the Circum-Bohai-Sea-Coast, China, and the main results show the following: (1) The accuracy of all land use classes are above 90%, which indicates a satisfactory accuracy for the classification map. (2) The Circum-Bohai-Sea-Coast is divided into 3 kinds of habitats and 5 subareas. (3) In the five subareas of the Circum-Bohai-Sea-Coast, the levels of coastal habitat degradation own significant difference. The whole Circum-Bohai-Sea-Coast generally is in a worse state according to area weighting of each habitat subarea. This assessment framework of coastal habitat degradation would characterize the landuse change trend, realize better coastal habitat degradation assessment, reveal the habitat conservation tendency and distinguish intensity of human disturbances. Furthermore, it would support for accurate coastal zone protection measures for the specific coastal area.

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1. Introduction

The world's 2/3 major cities and 60% population are located in coastal areas, and a portion of economic activities are concentrated in these cities, and it induces great pressure on the coastal environment (Lotze et al., 2006; Jackson et al., 2001). Coastal habitat supports the sustainable development of human society (Hopkins et al., 2012; Rönnbäck et al., 2002; Fujita et al., 2013; Visbeck et al., 2014). The coastal zone, especially the land with high ecosystems service, such as wetland land, not only provides the ecosystem goods, but also provide a range of ecosystem functions (Liquete et al., 2013a; Liquete et al., 2013b; Luisetti et al., 2014; Guerry et al., 2012). The excessive human activities, such as sea reclamation, aquaculture, and industrial pollution discharge into the sea have obviously reduced natural areas and threaten remaining habitat by causing increased runoff of sediment, nutrient and chemical pollutants to these areas (King, 2013; Xue et al., 2004). Habitat Destruction directly induces the loss of ecosystems service value (Coverdale et al., 2013). Diminished and degraded habitats are less available to support healthy populations of wildlife and marine organisms. Additionally, they are less able to perform the economic, environmental and aesthetic functions that coastal populations depend on for their livelihoods and protection (Wolanski, 2006).

It is necessary to strengthen coastal habitat protection for human-natural sustainable development, and achievement of accurate knowledge about the coastal habitat change and assessment of coastal habitat degradation is the essential prerequisite of coastal zone protection. Normally, there are many indicators to evaluate degree of costal habitat degradation (CHD) such as land use/land cover change (LUCC), pollution load towards the sea and biodiversity loss (Meng, 2005). LUCC is the most intuitive index for CHD assessment which directly represents the process of human disturbance and economic activities including urban sprawl, sea reclamation and mariculture, subsequently the following results of human activities such as seawater pollution, loss in ecosystem service function can be revealed through the index of LUCC. Caims et al. classified the degraded ecosystems into two kinds according to the degradation degree: irreversible ecosystem and reversible ecosystems (Cairns et al., 1977). Hobbs et al. put forwards a thresholds theory that it exists four stable states in the ecosystems including undegraded state, partially degraded and highly degraded and thought the accurate assessment of habitat degradation is the precondition of ecosystems restoration (Hobbs and Norton, 1996). John developed an evaluation index system for wetland degradation based on landscape change, named Landscape Development Intensity Index (EPA, 2004).

Obviously, the accurate revelation of LUCC process is the prerequisite for coastal habitat degradation assessment, and the detailed land use classification is the basis for the exact revelation of LUCC process, particularly in the coastal regions, along with the development of economic development and urbanization, the great changes in the spatial pattern of LUCC have taken place, including the construction land reclamation and aquaculture land expansion (Yang et al., 2011; Li and Damen, 2010), these two activities are the main human activities in the coastline, which has produced an enormous economic effect for human, however the rapid modification of the coastal land use pattern also considered to be the most important threats to the sustainability of the coastal ecosystem (Al-Jamali et al., 2011). The classifying and zoning of coastal zone has been attempt in the United States and European (Douvere and Ehler, 2006), nevertheless, the results were mainly provided for coastal management without consideration of the CHD situation in classes and districts. For now, the related research of coastal habitat assessment is still inadequate that the accurate degraded levels of coastal habitat are not clear and the intensity of driving force is lack of quantitative reveal. Due to the lack of detailed land use classification and method of zoning and classification for specific coastal habitat assessment, the specific characteristic of coastal habitat degradation cannot be properly uncovered.

In this study, in order to develop the deficiencies in the research of CHDA (coastal habitat degradation assessment), a comprehensive approach of zoning and habitat degradation assessment is established: (1) a detailed coastal land use classification is constructed in coastal zone which could reveal the special coastal landuse features such as construction land reclamation, aquaculture land expansion and spatial-temporal change of mangrove. (2) an approach of coastal habitats classification and zoning is created which could represent the coastal natural geographical characteristics of each spatial unit, and support for establishing evaluation criterion. (3) The method of CHDA is realized based on the results of the two former approaches, coastal habitat degradation index is set and the evaluation criterion of coastal habitat degradation through internal comparison under the same habitat types is established. Through this integrated approach, habitat degradation assessment could be achieved.

This paper is organized as follows: Section 2 emphasizes the methodology, including landuse classification establishment, coastal habitats classification and zoning approach and coastal habitat degradation index. Section 3 illustrates the study region and data sources. Section 4 offers a discussion of a range of analysis results and applications in the case study. The last section evaluates the value and deficiency of the assessment approach.

2. Methods

2.1. Analytical framework

An analytical framework of coastal habitat degradation assessment is established including three steps: landuse classification, classification and zoning of coastal habitats, coastal habitat degradation assessment (Fig. 1). Achievement of each step includes few processes. The detailed procedure of each step is explained below.

2.2. Landuse classification

2.2.1. Image pretreatment

According to the remote sensing image metadata, through theRPC calibration module based on the Erdas software platform 2013, the GF1, TM and ETM remote sensing images were rough rectified. Then they were RGB false-color composed correspondent in 4, 3, 2 bands. The images were mosaicked together based on the boundary vector of research area. The preprocessing images realized the goal of geometric registration. To strengthen the position accuracy between the three datasets, firstly no less than sixteen pairs of points were adopted as control points, including four verification points that express the effective features on each image and topographic map. Then the topographic map was set as the geo-referenced standard to resample images

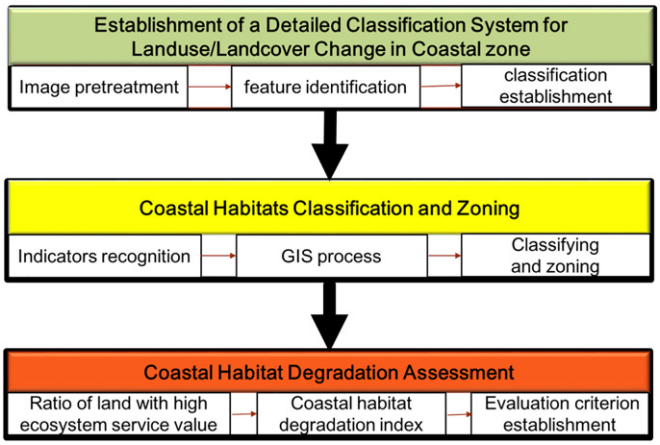

Fig. 1. Analytical framework of coastal habitat degradation assessment.

datasets of GF1, TM and ETM into a Universal Transverse Mercator coordinate system. The specification for image to image registration is 0.5 pixels in both directions and the pixel size was kept as 30*30 m. During the interpretation process of land use vector datasets, the topography, geomorphology, traffic and climate data were adopted for ancillary interpretation. Finally, the land use vector datasets were corrected onto the uniform coordination system based on the Transverse_Mercator projection. The central longitude is 111°E.

2.2.2. Establishment of a detailed landuse classification

Based on the features of existing land cover and land use classification and the images data in the coastal zone, a more detailed land use classification in coastal zone according to the local real situation is established to analyze the regional land use difference. This classification system is designed as a three-stage classification system including 2 broad categories, 8 categories and 26 subcategories. The first level classification including two kinds of land: the land with high ecosystem service value (LHESV) and the land with low ecosystem service value (LLESV). The second level classification divided the land of first level classification into 5 kinds and 3 kinds separately. Finally, the three level classification further divided the land use type specifically and contributed to the impact of human influence on the intertidal wetland during the land-ocean interaction. The detailed classes are shown in Table 1. The seven generic land categories which were identified include: construction land, intertidal flats, aquaculture land, farmland, forestry land, sea land, natural water bodies, grassland and un-used land. The category of construction land consists of eight subcategories such as urban land, rural residential land, port land and traffic land. The category of aquaculture land contains six subcategories such as aquaculture pond, cage culture and enclosure culture. The category of intertidal land includes ten subcategories, the mangrove swamp is one of the intertidal land. The relative detailed land use classification has a better revelation of the spatial pattern relative to construction land reclamation, aquaculture land expansion, change of mangrove.

The land use interpretation index of the corresponding land use types was established (Table 1). Afterwards the technology of artificial visual interpretation was adopted to extract land use information from remote sensing. Finally, the land use database of the Guangxi Coastal Zone is established by pre-treating GFQ/ETM/TM images, setting up interpretation indexes and classifying land use.

2.3. Habitat classification and zoning

Coastal habitat has high diversity, it is heavily influenced by Geological background, landscape types, regional climate, watershed hydrological characteristics. Habitat classification would provide convenience for unified coastal management. The Circum-Bohai-Sea-Coast is divided into 3 habitat categories including sandy coast habitat, bedrock coast habitat and muddy coastal habitat according to geographical difference, especially the factor of sediment grain size.

Based on the results of habitat classification, each spatial unit of study region is merged or separated according to the similarities and differences of landscape ecological characteristics, thus to form an independent habitat system of each subarea. The results of habitat zoning are achieved through overlay analysis of spatial location, topography, geomorphic character, hydrological character in ArcGIS software. The Circum-Bohai-Sea-Coast contains 5 kinds habitat subareas including (Fig. 2): (1) muddy coastal habitat area of Liaodong Bay north shore, (2) Sandy coast habitat area of Jidong western Liaoning, (3) bedrock coast habitat area of Shandong peninsula north shore, (4) muddy coastal habitat area of Bohai Bay and Laizhou Bay, (5) Bedrock coast habitat area of Liaodong peninsula west bank (Fig. 2).

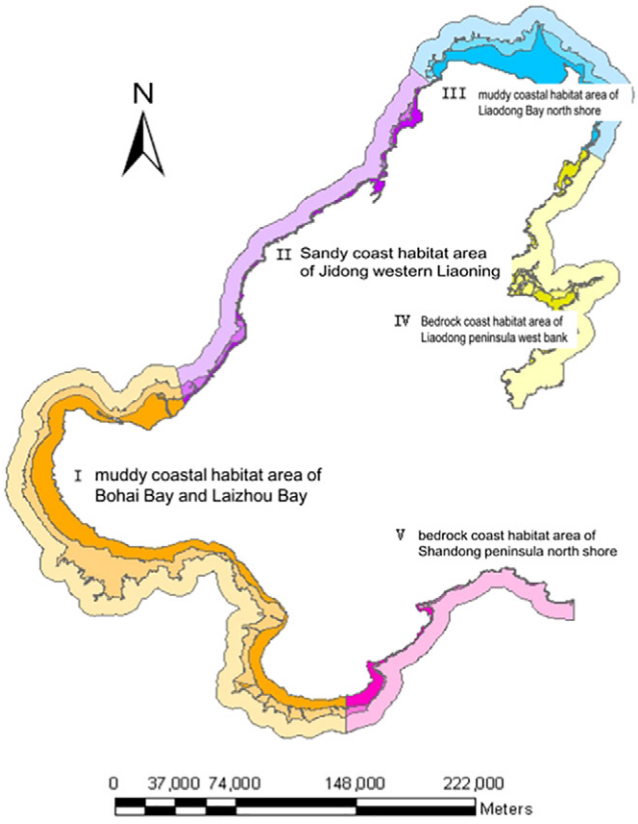

Fig. 2. Coastal habitat classification and zoning in the Circum-Bohai-Sea-Coast.

2.4. Coastal habitat degradation assessment

2.4.1. Coastal habitat degradation index

To reveal the coastal habitat degradation situation among the year of 1950, 2000 and 2008, the index of ratio of LHESV area (RLA) is introduced. It is the result of the ratio of land area with high ecosystems service value and the area of the whole coastal zone, it represents the habitat status in a certain year. The formula is below:

$$RLA = \text{LHESV area}/\text{Total area}(\%) \quad (1)$$

Table 1
The detailed land use classification.

Categories		Subcategories
Land with high ecosystems service value(LHESV)	Sea Area	Sea area, estuarine waters
	Intertidal Zone	Gravel Beaches, sandbank, mudflat, rock foreshore, sand and mud forest, mangrove flat, clump of grassland, reed pond, coastal lagoons, coral reef
	Natural waters	Lakes, canals, bottomland
	Grassland	Wetland, high coverage grasslands, moderate coverage grassland, low coverage grassland
	Forestry land	Woodland, shrubbery, open forest, other forest
Land with low ecosystems service value(LLESV)	Aquaculture land	Aquaculture Pond, pit-pond, cage Culture, enclosure culture, salt pan, reservoir
	Farmland	paddy field, dry land, garden plot
	Construction land	Urban land, rural residential area, parkland, industrial land, mining land, road, airport, port

To assess the coastal habitat degraded tendency in the Circum-Bohai-Sea-Coast, the coastal habitat degradation index of ten years(CHI) is employed to represent the situation of coastal habitat degradation in a certain period time. The formula is below:

$$\mathrm{CHI}\ (10\mathrm{y}) = \mathrm{RLAt2} - \mathrm{RLAt1}, \quad t2 - t1 = 10 \tag{2}$$

$$\mathrm{CHI}\ (10\mathrm{y}) = (\mathrm{RLAt2} - \mathrm{RLAt1})/2, \quad t2 - t1 = 20 \tag{3}$$

$$\mathrm{CHI}\ (10\mathrm{y}) = (\mathrm{RLAt2} - \mathrm{RLAt1})/3, \quad t2 - t1 = 30 \tag{4}$$

Based on the value and change scope of RLA, the CHI value of area weighting can be achieved. The coastal habitat degradation situation is divided into five levels through the CHI value according to the principle of proportion including best, better, normal, worse and worst. The grade table of coastal habitat degradation is shown in Table 2.

2.4.2. CHDA evaluation criterion establishment

The evaluation criterion of each habitat classification is different because of their special geography, geomorphology, hydrology and other natural features. The single coastal habitat degradation assessment for the whole Circum-Bohai-Sea-Coast is meaningless. Therefore, it is necessary to establish proper evaluation criterion to reflect the coastal degradation levels according to their geographical characteristic. In this study, the CHDA evaluation criterion is developed according to the previous results of habitat classification and zoning, the detailed process is below:

(1) The Circum-Bohai-Sea-Coast is divided into 24 transect belts further based on the previous 3 habitat types. In which, 5 transect belts belong to sandy coast habitat, 11 transect belts belong to muddy coastal habitat and 8 transect belts belong to bedrock coast habitat.
(2) The CHI value of the 24 transect belts is calculated.
(3) The CHI value of the 24 transect bests is classified into the 3 habitat types separately.
(4) Thus, the maximum CHI value, the minimum CHI value and the scope of each habitat types would be achieved.
(5) The CHI evaluation criterion of the 3 habitat types would be established based on the CHI threshold value and the scope.

3. Data sources and study area

The study area is the Circum-Bohai-Sea-Coast of China, stretching 10 km from coastline to inland, extending to the −5 m depth contour in the sea, which is an industrial concentration district, the ecological environment habitat is in a poor state (Fig. 3). The data used to reveal the land use spatial pattern is extracted from cloud-free LANDSAT Thematic Mapper (TM) images, LANDSAT Enhanced Thematic Mapper (ETM) image in the year of 1954, 2000 and 2008.

Table 2
Grading levels of coastal habitat degradation.

Grading	Status
Best	RLA value shows a tendency of increasing, stabilization, or a slight decreasing, (CHI value of area weighting < 20%)
Better	RLA value shows a decreasing trend (CHI value of area weighting: 20–40%)
Normal	RLA value shows a normal decreasing trend (CHI value of area weighting: 40–60%)
Worse	RLA value shows an obvious decreasing trend (CHI value of area weighting: 60–80%)
Worst	RLA value shows a dramatic decreasing trend (CHI value of area weighting: CHI > 80%)

4. Results

4.1. Accuracy assessment of landuse classification

The accuracy of the land use map was assessed by a set of random selected 800 points for each of the classes of the established land use classification in year of 2000 and 2008. These validation points were projected on to the up-to-date GF1/ETM/TM images, visually verified by auxiliary data, such as google image data, the land use data provided by local government and field survey data. It is shown that all accuracy values of all the classes in Table 3 are above 90%, which indicates a satisfactory accuracy for the classification map.

4.2. Evaluation criterion of coastal habitat degradation

According to the grading levels of coastal habitat degradation, the specific evaluation criterion of 3 habitat results is obtained (Table 4). There is significant difference among the three habitat classification, Bedrock coast habitat has the lowest value of evaluation criterion, following by sandy coast habitat, then is muddy coast habitat. It is mainly due to the strong stability of bedrock coast habitat, and muddy coast habitat is the easiest habitat to be degraded. Thus, the grading level is relative strict for bedrock coast habitat. The results also indicate the necessity to carry on coastal habitat degradation assessment in classes and districts. The CHI value is quite different due to the habitat types.

4.3. Coastal habitat degradation assessment

4.3.1. Coastal habitat conservation status

Through comparison of the habitat conservation status amount the 3 types of coast habitats in the Circum-Bohai-Sea-Coast (Fig. 4), it can be found that: (1) The muddy coast habitat owns the largest ratio of LHSEV, accounted for >50% in each year of 1954, 2000 and 2008. The ratio of LHSEV of sandy coast habitat and bedrock coast habitat is between 30% and 50% from 1954 to 2008. (2) The RLA value of all the 3 types of coast habitat has reduced in different degree, the RLA value of muddy coast habitat and sandy coast habitat represents a significant reduction trend during the 54 years, in which the RLA value of sandy coast habitat decreased from 53% to 31%, and muddy coast habitat decreased from 78% to 52%. The bedrock habitat remains a relative stable status, and the RLA value of bedrock coast habitat decreased from 50% to 37%,

4.3.2. Coastal habitat degradation tendency

The Circum-Bohai-Sea-Coast is divided into 3 kinds of habitats and 5 subareas, among them, the levels of coastal habitat degradation own significant difference, in which the CHDA status in the most of subareas is in worse level or even worst level, except for MLBNS which is in a better level. There is a remarkable fact that although SJWL and BLPWB belong to the same habitat classification, their CHI value is different, one is in worse level and the other is in worst, so as MLBNS and MBBLB. Ideally, the CHI should be nearly the same value under the same habitat classification if only natural factors took effects, in contrast, the function of human disturbance can be distinguished in different habitat subareas under the same habitat classification to some degree. MBBLB may be affected by human activities more serious than in MLBNS, and induced the more severe habitat degradation situation, so as BSPNS and BLPWB. The habitat of the whole Circum-Bohai-Sea-Coast generally is in a worse state according to area weighting of each habitat subarea (Table 5).

5. Discussion

An integrated analytical framework is established for coastal habitat degradation assessment. This study provides the detailed land use classification realized the specific subdivision of all the construction land, aquaculture land and intertidal land, and provide direct and precise expression of spatial-temporal change for the concrete sources and

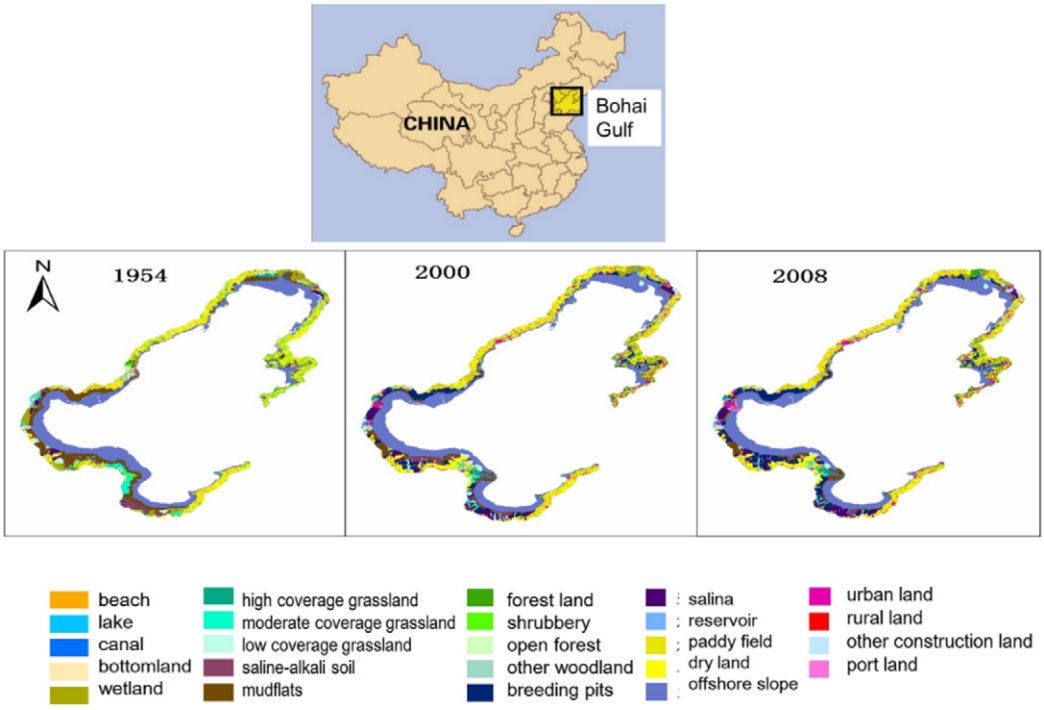

Fig. 3. Location of the study area.

direction of landuse change, it can ensure the accuracy of landscape data to some degree. Afterwards, the approach of habitat classification and zoning supports the following CHDA with consideration geographical features, furthermore, the approach can be used for distinguish the human factors under the same geographical types and realize the intensity of human disturbances. Then the CHDA evaluation criterion is developed by dividing the study region into 24 transect belts based on the results of habitat classification and zoning. It establishes the relative reasonable standard to evaluate the situation of coastal habitat degradation through internal comparison under the same habitat types. The criterion is more able to reveal the local natural and human condition, and represent the concreate level of coastal habitat degradation. In addition, there is no need to explore the international agreed criteria which is a normal way. This evaluation criterion of CHDA would provide quantitative information for future costal environment management and protection.

The integrated approach could characterize the landuse status and landuse change trend specifically such as construction land reclamation, aquaculture land expansion, change of mangrove. Accordingly, the habitat degradation or conservation tendency would be revealed according to CHI and CHDA evaluation criterion. The results of CHDA in the 5 habitat subareas show that the habitat of the whole Circum-Bohai-Sea-Coast generally is in a worse state, and the habitat of the most area is in a degraded tendency. The detailed coastal zone protection measures should be put forward, especially the serious degraded habitat, such as BLPWB. MBBLB and BLPWB should moderately reduce human activities, or taken more protection measures compared with MLBNS and BSPNS.

Table 3
The accuracy of the land use classification.

Categories	2000		2008	
	User accuracy	Producer accuracy	User accuracy	Producer accuracy
Sea land	98%	97%	95%	97%
Intertidal land	93%	94%	95%	97%
Natural waters	96%	95%	96%	96%
Grassland	93%	91%	95%	94%
Forestry land	94%	97%	96%	96%
Aquaculture land	97%	96%	96%	97%
Farmland	92%	95%	94%	95%
Construction land	96%	94%	98%	97%
Overall accuracy	94%		96%	
Kappa coefficient	0.84		0.89	

6. Conclusion

The framework of coastal habitat degradation assessment has succeeded in revelation of the coastal habitats degradation situation. Meanwhile, it has some advantages below: (1) the detailed land use change features could be represented accurately, especially the characterized land conversion, such as construction land reclamation, aquaculture land expansion and the intertidal wetland change. (2) The classification and zoning of the coastal habitats is accordance with the natural-social laws, make the following coastal habitat assessment more feasible. (3) Thus, the coastal habitats assessment based on the framework would provide basis for further coastal zone management scientifically.

The coastal habitat has been degraded obviously due to the high-intensity of human disturbance and economic activities. The results of coastal habitats degradation assessment in classes and districts would support for distinguish of human disturbance on the coastal habitat. It would help for provide specific coastal zone management measures according to the detailed coastal habitat and location. Strengthening the coastal habitat protection would provide stable basis for the regional sustainable development.

Table 4
CHI evaluation criterion in 3 habitat classification.

Grading	Sandy coast habitat	Bedrock coast habitat	Muddy coast habitat
Best	CHI < 2.81	CHI < 1.81	CHI < 4.81
Better	CHI 2.81–3.26	CHI 1.81–2.26	CHI 4.81–6.26
Normal	CHI 3.26–3.55	CHI 2.26–3.55	CHI 6.26–7.55
Worse	CHI 3.55–8.68	CHI 3.55–4.68	CHI 7.55–9.68
Worst	CHI > 8.68	CHI > 4.68	CHI > 9.68

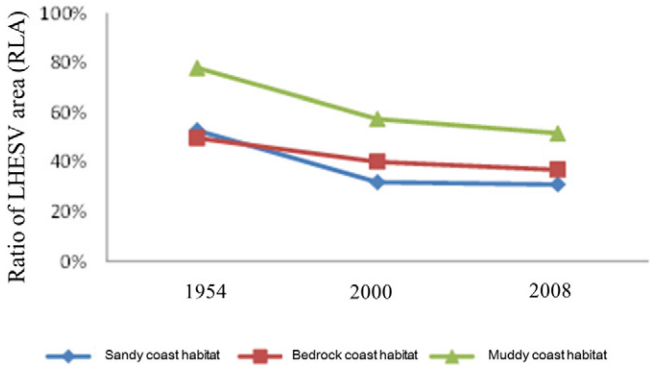

Fig. 4. The habitat conservation status of the 3 types of coast habitat.

Table 5
Levels of coastal habitat degraded levels in the 5 habitat subareas of the Circum-Bohai-Sea-Coast.

Subarea	Coastal habitat index (CHI)	Grading
Muddy coastal habitat area of Liaodong Bay north shore (MLBNS)	4.99	Better
Sandy coast habitat area of Jidong western Liaoning (SJWL)	5.81	Worse
Bedrock coast habitat area of Shandong peninsula north shore (BSPNS)	3.73	Worse
Muddy coastal habitat area of Bohai Bay and Laizhou Bay (MBBLB)	9.54	Worse
Bedrock coast habitat area of Liaodong peninsula west bank (BLPWB)	5.22	Worst

Due to the huge area of study region, the overall habitat degradation assessment was presented in this study with consideration of two major categories between land with high ecosystems service value and land with low ecosystems service value, it characterize the global tendency of habitat conservation tendency. However, the framework is also suitable for the more detailed internal degradation assessment caused by landuse change between subcategories such as transfer between different coverages grassland, it could be used for analysis under a relative small scale of study regions. Therefore, the established approach in this study is feasible for different spatial scale of study region. It could not only analyze the habitat degradation trend with significant landuse change, but also could reveal the more detailed degradation tendency caused by subcategories of landuse change. In order to realize more accurate coastal habitat protection, the driving force of coastal habitat degradation should be analyzed in the following research with combination of social-economic data.

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