Original Articles

Assessing and predicting changes in ecosystem service values based on land use/cover change in the Bohai Rim coastal zone

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ARTICLE INFO

Keywords:

Bohai Rim coastal zone
Land use/cover change
Scenario simulation
Ecosystem service

ABSTRACT

Land use/cover change (LUCC) in the Bohai Rim coastal zone has accelerated as a result of rampant economic development, which has directly caused many negative effects on ecosystem functions and services. Based on multi-temporal land use data (2000, 2005, 2010 and 2015), the benefit transfer method was used to assess the ecosystem service value (ESV) of the Bohai Rim coastal zone, and the impact of LUCC on ecosystem services was studied. Multi-scenario simulations for 2025 were conducted using the future land use simulation model. The result of the analysis showed that during the period from 2000 to 2015, the total ESV lost was 22.09 billion yuan, representing a decrease of 3.80%. The spatial distribution of the ESV showed a certain regularity, with obvious characteristics of a land-sea gradient change. As the distance from the coastline increased, the ESV per unit area gradually declined. Compared with those in 2015, the total ESVs of the socio-economic development scenario and the business-as-usual scenario in 2025 showed a declining trend, while they increased under the ecological protection priority scenario. Under the ecological protection priority scenario, regulating services and support services increased significantly, but those declined dramatically under the socio-economic development scenario. The patterns of LUCC are the main reasons for the decrease in ESV. This research provides a theoretical basis and support for the development and utilization of coastal space and the improvement of “ecological-economic-social” benefits; additionally, the results provide support for scientific decision-making services for the sustainable use of resources in the coastal zone and for the sustainable management of ecosystems.

1. Introduction

Ecosystem services refer to the natural environmental conditions and functions formed and maintained by the ecosystem and processes for human survival, including provisioning services (e.g., food, fresh water and fuel), regulating services (e.g., climate regulation, water purification and pollination), cultural services (e.g., recreation cultural heritage and inspirational value), and supporting services (e.g., soil formation and provision of habitat) (Millennium Ecosystem Assessment, 2005; Xie et al., 2015). The sustainable development of the social economy depends on the sustainable supply of ecosystem services (Yan et al., 2017). However, over the past 100 years, global climate change (Boone et al., 2018), environmental pollution (Escobedo et al., 2011), ecological destruction (Bussmann, 1996), resource depletion (de Araujo Barbosa et al., 2016), and land use/cover change (LUCC) (Dadashpoor et al., 2019) have had a tremendous impact on ecosystem

functions and consequently have led to changes in ecosystem services. The Millennium Ecosystem Assessment (MA) report showed that more than 60% of the global ecosystems are or have been degraded, and one of the main causes for this degradation is disruptions by human activities (Millennium Ecosystem Assessment, 2005). Furthermore, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment report showed that three-quarters of the land-based environment and approximately 66% of the marine environment have been significantly altered by human actions. Some serious damage to the environment by human beings has reached or even exceeded the ecosystem carrying capacity, and some ecosystems have reached an irreversible amount of damage. In recent decades, research on ecosystem service functions has received more attention than ever before. Costanza et al. proposed the classification of ecosystem service values (ESVs) and the method of economic value evaluation, which provided new ideas and methods for the study of ESVs

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<https://doi.org/10.1016/j.ecolind.2019.106004>

Received 26 August 2019; Received in revised form 5 December 2019; Accepted 8 December 2019

Available online 17 December 2019

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(Costanza et al., 1997). Since then, ESVs have been extensively studied globally and have become a popular and cutting-edge issue for global or regional organizations and their scientific communities (Li et al., 2017; Odgaard et al., 2017; Song, 2018).

LUCC is a crucial way in which human activities affect ecosystems, and LUCC changes the supply of ecosystem products and services by influencing ecosystem patterns and processes (Li et al., 2018). The MA report noted that LUCC has been the most important driving force of the change in terrestrial ESV since the 1950s (Millennium Ecosystem Assessment, 2005). The integration of LUCC and ecosystem services research has been greatly facilitated by the implementation of a range of international projects, such as the Global Land Project (GLP), The Economics of Ecosystems and Biodiversity (TEEB), and the IPBES. Global scholars have focused increasing attention on the impact of LUCC on ecosystem services and have conducted extensive research on the global scale, national scale, regional scale and watershed scale, achieving remarkable results (de Groot et al., 2012; Song and Deng, 2017). However, most research has focused on terrestrial ecosystem services, and there has been less research on coastal and offshore marine ecosystem services (Suo et al., 2011; Li et al., 2016).

Coastal ecosystems (including terrestrial coastal wetlands and shallow waters) play an irreplaceable role in material production, climate regulation, water conservation, pollutant removal, biodiversity maintenance and other factors, and are some of the most valuable natural ecosystems on Earth. However, more than half of the world's population, production and consumption activities are concentrated in coastal zones that account for less than 10% of the global area (Cohen, 2006). This has led to a series of ecological and environmental problems, especially the destruction of the components and structures of the natural ecosystem, and the weakening or the partial or total loss of ecosystem services (Dittman et al., 2015).

Over recent decades, China's coastal zone, with sustained and rapid population growth, has experienced unprecedented intensive development (e.g., rapid urbanization, over reclamation, and construction of manufacturing facilities and mines), leading to the prominence of problems with the ecological environment; these problems have seriously threatened the sustainable economic and social development of the region (Wang et al., 2015). Under intensive development activities, the LUCC has been among the most important perceptible change occurring on the Earth's surface (Roy et al., 2010). The transformation of land use types has direct economic benefits for human beings, and at the same time, it greatly changes or even causes imbalances in ecosystem services. These changes or imbalances are embodied in water resources, air quality, disaster prevention, biodiversity and other aspects, and they affect human well-being. The Bohai Rim coastal zone was selected as the study area because it is a typical area for the high-intensity development of human activities in the coastal zone of China. The main objectives of this study are to assess the ESV of the Bohai Rim coastal zone, predict the future distribution of LUCC by multi-scenario simulation analysis, and estimate variations in ESV resulting from the impacts of LUCC on the Bohai Rim coastal zone.

2. Materials and methods

2.1. Study area

The Bohai Rim region is a “C”-shaped region composed of the Liaodong Peninsula, the Shandong Peninsula and the North China Plain. The Bohai Sea is a semi-enclosed inland sea in China, that is divided into five parts: Liaodong Bay, Bohai Bay, Laizhou Bay, the Central Bohai Sea and the Bohai Strait (Zhang et al., 2002). The ecosystems around the Bohai Sea are an important part of the overall ecosystem of northern China. The main types of ecosystem in this area include estuarine delta wetland, farmland, aquaculture pond, salt pan, coastal mountain forest, coastal beaches and towns, which provide

many ecosystem products and services (Suo et al., 2011).

The Bohai Rim region is an important industrial and agricultural base in China that has rich marine biological resources, mineral resources, oil-gas resources, coal resources and tourism resources. With Beijing and Tianjin at the centre, this region is an important economic zone, with a relatively concentrated population and increasingly concentrated industries, in eastern China. The Bohai Economic Rim or the Bohai Bay Economic Rim is rapidly emerging and is becoming the third largest metropolitan economic zone in China, following the “Yangtze River Delta” and “Pearl River Delta” urban economic zones (Guo et al., 2009).

With the rapid development of urbanization and industrialization around the Bohai Rim region, coastal development activities have become more and more frequent, land use has changed significantly, and the ecological environment is facing unprecedented pressure. A large number of land-based pollutants are being discharged, resulting in water pollution in coastal waters, declining fishery resources, and a sharp decline in biodiversity. Frequent marine disasters (such as red tides, oil spills, etc.) have put great pressure on the offshore ecological environment (Mei and Yin, 2009; Zhang and Zhang, 2014). Unreasonable marine development and utilization activities, such as large-scale cofferdams and damming, have resulted in a large loss of coastal wetlands. These factors have led to continuous declines in the ecosystem service functions and the sustainable uses of the Bohai Sea and threaten the economic and social development of the region around the Bohai Sea (Gai et al., 2018).

The Bohai Rim coastal zone was selected as the study area, and the boundary of the zone was defined considering both the research needs and the actual situation of the research area. The land area is bordered by district and county administrative divisions, and the sea area boundary is underwater at the 10 m isobath. The study area includes 110 counties and districts in three provinces and one city (i.e., Liaoning, Hebei, Shandong and Tianjin, respectively) (Fig. 1).

2.2. Data collection

The LUCC data are used for LUCC multi-scenario simulation analysis and ESV assessment. The LUCC data source is the China Coastal Land Use Data Set, which has established data products for 2000, 2005, 2010 and 2015, and has divided the LUCC of the coastal zone of China into 8 first-level types and 24 s-level types (Di et al., 2014; Di et al., 2015; Hou et al., 2018). In this paper, shallow sea water was listed separately so that the types of LUCC were reclassified into 9 categories: farmland, forest land, grassland, inland freshwater, saltwater wetland, shallow water, human-made wetland, built-up land and unused land. The driving force factor data set for LUCC multi-scenario simulations were selected according to the actual situation of existing research and research areas and considering the availability of data (Su et al., 2016). A total of 8 driving factors were selected, including the digital elevation model (DEM) (<http://www.gscloud.cn/>), slope (generated by the DEM), population density (<http://www.resdc.cn/>), temperature and precipitation (<http://www.resdc.cn/>), distance to town, distance to traffic, and distance to a water system (extracted from land use data, obtained by Euclidean Distance Analysis).

2.3. Ecosystem service valuation

There are three main methods used to evaluate the ESVs: energy value analysis method, physical assessment method and value assessment method (Cui, 2005). The value assessment method includes the functional price method and the equivalent coefficients table method (Xie et al., 2017). The functional price method has more input parameters and a complicated calculation process. In contrast, the equivalent coefficients table method is more intuitive and easier to use, as it has fewer data requirements and is particularly suitable for the

Fig. 1. Location of the Bohai Rim coastal zone.

assessment of ESVs at the regional and global scales. The equivalent coefficients table method is more directly and easily understood and accepted by the public. Therefore, this paper adopted the equivalent coefficients table method to estimate the ESVs.

Costanza et al. estimated the ESVs on a global scale. To reduce the errors caused by applying this method to China, Xie et al. (2015) revised it by using a questionnaire survey of domestic ecological scholars to obtain the equivalent coefficients table of the ecosystem services that are applicable to China, and this information has been widely used in China. Therefore, the values per unit area of ecosystem services that were used in this study refer to this previous research. Then, the standard equivalent factor was determined, mainly using the average net profit per unit area (2015 price level) of the three major foods (rice, wheat and corn) from 2000 to 2015, with a value of 2181.78 yuan/hm² (Xie et al., 2017). The unit area values of land use/cover types not covered by this equivalent coefficients table were directly obtained by BTM, including those for shallow waters (Zhang et al., 2015a,b) and human-made wetland (including saltern/salt pan and aquaculture ponds) (Li, 2011), in which the service value coefficient of built-up land was 0. Finally, the value tables of the ecosystem services per unit area of different land use types were obtained (Table 1). The ESV was

calculated using the following equations:

$$ESV_k = \sum_f A_k \times VC_{kf}$$

$$ESV_f = \sum_k A_k \times VC_{kf}$$

$$ESV = \sum_k \sum_f A_k \times VC_{kf}$$

where ESV_k , ESV_f and ESV refer to the ESV of the type k ecosystems, the ability category of ESV_f , and the total ESV , respectively. A_k is the area (in ha) of the type k ecosystem, and VC_{kf} (Chinese yuan/hm²) denotes the value coefficient for land use type k and ecosystem service function type f .

2.4. Land use/cover change multi-scenario simulation

LUC simulation models are effective and reproducible tools for analysing both the causes and the consequences of future landscape dynamics under various scenarios (Liu et al., 2017). In this paper, we used GeoSOS-FLUS software (Liu et al., 2017) to facilitate the LUC

Table 1

Ecosystem service value per unit area for different land use/cover types in the Bohai Rim coastal zone (yuan/hm²) (2015 prices).

Primary classification	Secondary classification	Farmland	Forest	Grassland	Inland freshwater	Saltwater wetland	Shallow water	Human-made wetland	Unused land
Provisioning services	Food supply	2181.78	719.99	938.17	1156.34	785.44	29998.44	37846.40	43.64
	Raw material supply	850.90	6501.71	785.44	763.62	523.63	497.82	0.00	87.27
Regulating services	Air quality regulation	1570.88	9425.30	3272.67	1112.71	5258.10	4111.60	0.00	130.91
	Climate regulation	2116.33	8879.85	3403.58	4494.47	29563.15	5459.23	4505.28	283.63
	Regulation of water flows	1679.97	8923.49	3316.31	40952.05	29323.15	739.02	0.00	152.72
Supporting services	Waste treatment	3032.68	3752.67	2879.95	32399.47	31417.67	0.00	0.00	567.26
	Maintenance of soil	3207.22	8770.76	4887.19	894.53	4341.75	0.00	0.00	370.90
	Fertility habitat services	2225.42	9839.84	4079.93	7483.51	8050.78	1.40	5070.21	872.71
Cultural services	Cultural & amenity services	370.90	4538.11	1898.15	9687.11	10232.56	18652.27	47421.90	523.63

multi-scenario simulation by coupling human and natural effects (available for free download at <http://www.geosimulation.cn/flus.html>). GeoSOS-FLUS is a powerful tool that can be used to make LUCC simulations more convenient and efficient and can be easily used for several purposes (Liang et al., 2018a). According to the current situation and characteristics of land use and social-economic development in the research area, three scenarios, including business-as-usual (BAU), socio-economic development (SED) and ecological protection priority (EPP), were established. Based on the probability matrix of land use transfer from 2005 to 2015, the total land use area of the three scenarios in 2025 was calculated by the Markov mathematical method. Using GeoSOS-FLUS software, the land use adaptability probability was calculated based on the land use data and driving factors of LUCC (e.g., DEM, slope, temperature, precipitation, population density, distance to town, distance to traffic, distance to water system), and the spatial distribution data of LUCC under the BAU, SED and EPP scenarios were obtained by modifying the transfer probability matrix and the class transformation restriction matrix (Liang et al., 2018b).

3. Results

3.1. Land use/cover change during 2000–2015

3.1.1. Temporal analysis of land use/cover change

Based on the proportions of land use/cover types (Table 2), farmland was the predominant land use type in the Bohai Rim coastal zone in 2000, 2005, 2010 and 2015, accounting for 48.92%, 48.68%, 47.38% and 47.36%, respectively, and its proportion has shown a continuous downward trend. Shallow water and forest accounted for a large proportion, but these types also appeared to experience a sustained slow decline. However, the proportion of built-up land showed a trend of continuous increase, from 8.48% in 2000 to 11.44% in 2015. Furthermore, inland freshwater and saltwater wetlands accounted for a small proportion, and both showed a decreasing trend. Moreover, the proportion of grassland initially decreased and then increased, while salt pan and mariculture first increased and then decreased. The proportion of unused land was the smallest, at only approximately 1%.

During 2000–2015, the largest net area change occurred in the built-up land type, resulting in a total increase of 5026.22 km² (Table 2). The net area changes in farmland, shallow water and mariculture were larger, followed by those of saltwater wetlands, grasslands, inland freshwater, salt pan and unused land; finally, the net area change in forestland was the smallest. The change area of the land use/

cover types showed varying characteristics during different phases. In 2000–2015, the areas of grassland, inland freshwater and shallow water decreased significantly, while mariculture and salt pan increased most significantly at this stage. From 2005 to 2010, the area of farmland decreased the most. Similar to farmland, saltwater wetland decreased more during this stage, and built-up land had the highest significant increase. During 2010–2015, the area of shallow water decreased the most, while the area of grassland increased.

The change rates of the land use/cover types showed varying characteristics during different periods (Table 2). During 2000–2015, farmland, shallow water, grassland, inland freshwater and forest all showed stages of slow decline, while saltwater wetland and unused land decreased more rapidly. In 2000–2015, unused land decreased the fastest (−3.08%), while mariculture increased the fastest (6.84%). During 2005–2010, saltwater wetland decreased at the fastest rate (−2.85%), and mariculture grew at the fastest rate (4.51%). From 2010 to 2015, unused land and shallow water decreased rapidly, with values of 1.82% and 0.53%, respectively.

3.1.2. Spatial patterns of land use/cover change

The spatial distribution of land use/cover types in the Bohai Rim coastal zone exhibited an overall pattern of “shallow water → saltwater wetland → human-made wetland → terrestrial multi-type mixed region” from the sea to the land (Fig. 2). Shallow water was mainly distributed in the eastern region. Saltwater wetland, salt pan and mariculture were concentrated in the coastal zone. Grassland was mainly scattered in the Yellow River Delta, the Liao River Delta and the mountainous regions. Forestland was mainly located in the Liaodong Peninsula, Jiaodong Peninsula and the mountainous regions. Unused land was mainly concentrated in the coastal zone. Farmland was widely distributed across the entire region, while built-up land was scattered.

To analyse the spatial distribution characteristics of land use in this area, nine circular buffers were established at 20-km intervals with the coastline as the baseline, and the area of each land use/cover type was calculated (Table A.1). The land use/cover type structure between land and sea has spatial differences based on the distance from the coastline. The areas of saltwater wetland, salt pan, mariculture, inland freshwater and unused land decreased significantly with increasing distance from the coastline, while forestland and grassland decreased slowly. There was no significant change in farmland or built-up land. Saltwater wetland, salt pan and mariculture were mainly concentrated within 20 km of the coastline, both accounting for more than 73%.

During 2000–2015, the land use/cover structure changed

Table 2
Land use/cover patterns in the Bohai Rim coastal zone.

LUCC	Area/km ²		Proportion/%		Area change/km ²		Dynamic rate of change/%	
	2000	2005	2010	2015	2000–2005	2005–2010	2010–2015	2000–2015
Farmland	82974.99	82566.82	80374.27	80323.32	−408.17	−2192.55	−50.95	−2651.67
	48.92	48.68	47.39	47.36	−0.10	−0.53	−0.01	−0.64
Forestland	19629.01	19570.88	19532.07	19497.4	−58.13	−38.81	−34.67	−131.61
	11.57	11.54	11.52	11.50	−0.06	−0.04	−0.04	−0.13
Grassland	8552.52	7984.44	7704.77	8045.75	−568.08	−279.67	340.98	−506.77
	5.04	4.71	4.54	4.74	−1.33	−0.70	0.89	−1.19
Built-up land	14380.02	15804.75	18652.1	19406.24	1424.73	2847.35	754.14	5026.22
	8.48	9.32	10.99	11.44	1.98	3.60	0.81	6.99
Inland freshwater	5580.19	5208.05	5173.4	5109.84	−372.14	−34.65	−63.56	−470.35
	3.29	3.07	3.05	3.01	−1.33	−0.13	−0.25	−1.69
Saltwater wetland	3716.87	3419.73	2931.81	2939.91	−297.14	−487.92	8.10	−776.96
	2.19	2.01	1.73	1.73	−1.60	−2.85	0.06	−4.18
Shallow water	28820.65	28495.86	27912.78	27173.79	−324.79	−583.08	−738.99	−1646.86
	16.99	16.80	16.46	16.02	−0.23	−0.41	−0.53	−1.14
Human-made wetland	4238.57	5106.89	5771.96	5698.66	868.32	665.07	−73.30	1460.09
	2.50	3.01	3.40	3.36	4.10	2.60	−0.25	6.89
Unused land	1720.86	1456.26	1560.52	1418.77	−264.60	104.26	−141.75	−302.09
	1.02	0.86	0.92	0.84	−3.08	1.43	−1.82	−3.51

Fig. 2. Spatial distribution of land use/cover types in the Bohai Rim coastal zone.

significantly within 20 km of the coastline. Within the range of 0–20 km from the coastline, the areas of built-up land and mariculture increased significantly, increasing by 1473.95 km² and 719.55 km², respectively. However, the area of saltwater wetland decreased the most, reaching 1092.78 km², and farmland and grassland decreased significantly, with reductions of 628.79 km² and 373.07 km², respectively. Within the range of –20–0 km from the coastline, the area of shallow water decreased the most, reaching 1546.73 km². However, the areas of built-up land, saltwater wetland, mariculture, grassland and inland freshwater all showed trends of substantial increases. These changes were mainly caused by the high-intensity development activities of humans as well as the estuary delta land-building activities.

3.1.3. Transformation patterns of land use/cover types

The total conversion area of land use/cover types in the Bohai Rim coastal zone reached 12330.13 km² during of 2000–2015 (Fig. 3, Table A.2). The transformed land use types were mainly farmland, shallow water, inland freshwater, saltwater wetland and grassland, which accounted for 33.83%, 13.45%, 11.63%, 10.73% and 10.28% of the total transformed area, respectively; these land use types were mainly converted into built-up land, salt pan and mariculture.

Built-up land increased rapidly by 34.95%, mainly occupying farmland (3188.39 km²) and shallow water (701.21 km²), which were converted into city, rural settlement and isolated industrial mining. Saltwater wetland was reclaimed within a large area but declined by 1322.96 km², and this area mainly converted into mariculture, salt pan and built-up land. The newly formed area of saltwater wetland was 546 km², and this change was mainly caused by land formation in the estuary delta. As a result of port construction and large-scale reclamation, the shallow water was transformed into built-up land (701.21 km²) and mariculture (240.77 km²), and the shallow water was transformed into saltwater wetland (335.85 km²) as a result of estuary land formation. The transformation of unused land mainly entailed conversions into farmland, built-up land, mariculture and salt pan. Grassland was typically converted into farmland, built-up land, mariculture and salt pan, while the transformation of forestland was the lowest. Thus, it can be seen that human activities represented the most important driving factors for the transformations of land use/cover types in the Bohai Rim coastal zone.

Fig. 3. Transformation distribution of land use/cover types in the Bohai Rim coastal zone.

3.2. Changes in ecosystem service values during 2000–2015

3.2.1. Temporal patterns of ecosystem service values

With the high-speed development of industrialization and urbanization in the Bohai Rim coastal zone, the expansion of urban and rural construction land; the construction related to industry, mining and transportation; and the expansion of salt pan and aquaculture areas resulted in the occupation of tidal flats, estuary delta wetlands, cultivated land, forestland and grassland, representing the primary drivers of the reductions in ESVs. The ESVs for each land use category and the total value for each study year are shown in Table 3. During 2000–2015, the total ESVs showed a trend of continuous decline, and the losses in the ESVs of shallow water and saltwater wetlands were significant. From 2000 to 2015, the total ESVs decreased by 3.80%, from 581.06 billion yuan to 558.97 billion yuan. The value of ecosystem services provided by different land types was different. Shallow water contributed most, at more than 28% of the total ESV, followed by the contributions of farmland and forestland, which accounted for more than 24% and 20%, respectively. In contrast to the ESVs of salt pan and mariculture, those of all other land use/cover types decreased. The ESVs of shallow water and saltwater wetlands decreased significantly by 9.79 billion yuan and 9.28 billion yuan, respectively, followed by those of inland freshwater and farmland, which decreased by 4.65 billion yuan and 4.57 billion yuan, respectively. The ESVs of grassland and forestland decreased slightly, by 1.29 billion yuan and 807 million yuan, respectively, while that of unused land was the lowest, reaching

93 million yuan. In contrast, the ESV of mariculture and salt pan increased by 6.88 billion yuan and 1.52 billion yuan, respectively. The rate of decrease was greatest for saltwater wetlands (20.90%), followed by that of unused land (17.78%), while the rate of increase was largest for mariculture (60.00%).

3.2.2. Spatial change in ecosystem service value

The spatial distribution of the ESV in the Bohai Rim coastal zone showed some regularity from 2000 to 2015 (Fig. 4); specifically, there were obvious characteristics of a land and sea gradient change, and the value of ecological service per unit area decreased gradually with the distance from the coastline (Fig. 5). The high-value areas of ecosystem services were distributed in patches or islands, mainly in the coastal wetlands of the Liaohe River Delta, Yellow River Delta and Laizhou Bay, which were less disturbed by human activities, while the low-value areas were mainly concentrated in high-intensity development zones, such as those of urban construction, industrial and mining transportation, aquaculture and reclamation.

From 2000 to 2015, the hotspots of ESV increasing and decreasing both could be found in the Bohai Rim coastal zone. Overall, the areas with declines were more widely distributed, while the areas with increases were small and scattered (Fig. 6). The ESV in the coastal zone changed more than that in the inland area. Within the range of 0–20 km from the coastline, the decline in the ESV per unit area was most significant. This area is mainly the concentrated area of saltwater wetlands, which are caused by large-scale reclamation activities and lead to

Table 3
Ecosystem service values of different land use/cover types (10⁸ yuan).

LUCC	Farmland	Forestland	Grassland	Inland freshwater	Saltwater wetland	Shallow water	Human-made wetland	Unused land	Total
2000	1430.16	1204.27	217.76	552.13	444.15	1713.67	402.00	5.22	5969.36
2005	1423.13	1200.71	203.29	515.30	408.64	1694.36	484.36	4.42	5934.21
2010	1385.34	1198.33	196.17	511.88	350.34	1659.69	547.43	4.73	5853.91
2015	1384.46	1196.20	204.86	505.59	351.31	1615.75	540.48	4.30	5802.94

Fig. 4. Variation in sea-land gradient of ESV per unit area in the Bohai Rim coastal zone.

Fig. 5. Spatial distribution of ESV in the Bohai Rim coastal zone.

Fig. 6. Spatial change in the distribution of ESV in the Bohai Rim coastal zone from 2000 to 2015.

the loss of saltwater wetlands. The areas with the large increases in the ESVs are mainly concentrated in areas with improved ecological environments and newly developed wetland areas, especially in the newly developed Yellow River Delta.

3.2.3. Changes in different ecosystem service values

The value of regulating services accounted for the highest proportion, with more than 42% in all periods, followed by the value of provisioning services and supporting services, which accounted for more than 25% and 17%, respectively, while cultural services contributed the least to the total ESV (Table 4). During all periods, regulating services and cultural services generally showed a decreasing trend, while provisioning services showed an initial increasing trend followed by a decreasing trend. However, supporting services initially

decreased and then increased slightly. From 2000 to 2015, the regulating services, cultural services and supporting services decreased by 15.20 billion yuan, 3.85 billion yuan and 2.51 billion yuan, respectively, while the provisioning services declined slightly by 526 million yuan.

In terms of the ecosystem service sub-types, the food supply contributed most to the total ESV, followed by the cultural and amenity services, regulation of water flows, climate regulation, waste treatment, fertility habitat services, maintenance of soil and air quality regulation; in contrast, the raw material supply contributed the least. The value of food supply and raw material supply first increased and then decreased. In contrast to the ESVs of food supply and raw material supply, those of all other ecosystem service sub-types decreased during all periods.

Table 4
Values of different ecosystem services in the Bohai Rim coastal zone (10^8 yuan).

Primary classification	Secondary classification	2000	2005	2010	2015
Provisioning services	Food supply	1237.63	1258.6	1260.79	1235.96
	Raw material supply	225.65	223.85	220.95	220.53
	Toal	1463.28	1482.45	1481.74	1456.49
Regulating services	Air quality regulation	487.82	481.42	471.71	469.34
	Climate regulation	690.90	679.19	658.52	654.81
	Regulation of water flows	701.99	674.67	653.57	651.37
	Waste treatment	648.48	623.84	599.85	598.66
	Toal	2529.19	2459.12	2383.65	2374.18
Supporting services	Maintenance of soil	501.85	495.53	484.68	485.80
	Fertility habitat services	507.41	502.61	495.48	495.51
	Toal	1009.26	998.14	980.16	981.31
Cultural services	Cultural & amenity services	967.65	994.49	1008.36	990.96
	Toal	967.65	994.49	1008.36	990.96

Table 5Transfer matrix of ecosystem service value changes caused by land use conversion in the Bohai Rim coastal zone (10⁶ yuan).

LUC	Farmland	Forestland	Grassland	Built-up land	Inland freshwater	Saltwater wetland	Shallow water	Human-made wetland	Unused
Farmland	0.00	2.38	0.54	−54.96	32.08	0.50	0.00	34.49	−0.30
Forestland	−3.44	0.00	−0.73	−8.61	1.02	0.04	0.00	0.18	−0.09
Grassland	−3.85	2.23	0.00	−6.08	8.70	7.22	0.00	18.83	−0.73
Built-up land	1.15	0.27	0.53	0.00	4.18	0.91	0.02	13.26	0.02
Inland freshwater	−44.69	−0.58	−10.04	−23.30	0.00	1.55	−0.01	−1.63	−2.46
Saltwater wetland	−1.91	−0.10	−10.45	−29.18	−3.00	0.00	−0.62	−15.05	−21.02
Shallow water	−0.08	0.00	−4.81	−41.69	5.27	20.17	0.00	8.56	−5.75
Human-made wetland	−3.86	−0.01	−16.41	−39.40	0.20	0.51	−0.01	0.00	−4.95
Unused land	4.12	0.18	0.65	−0.45	5.38	2.79	0.00	15.88	0.00

3.2.4. Impacts of land use/cover change conversions on ecosystem service value

Over the last several decades, the Bohai Rim coastal area has experienced profound LUCs primarily due to intensive development activities, such as urban sprawl and the construction of manufacturing, mines and ports. These changes have significant impacts on the values of ecosystem services. Our study investigated the changes in ecosystem services in response to LUCs (Table 5).

During 2000–2015, the main reason for the decrease in the value of ecosystem services was that saltwater wetland and inland freshwater were encroached, resulting in losses of 10.42 billion yuan and 9.60 billion yuan, respectively. The conversions from saltwater wetland to built-up land and unused land have resulted in an ESV loss of 2.92 billion yuan and 2.10 billion yuan, respectively. The ESV losses that resulted from conversions from inland freshwater to farmland and built-up land were considerable, with values of 4.47 billion yuan and 2.33 billion yuan, respectively. Additionally, the conversion of salt pan and mariculture to built-up land led to an ESV loss of 2.38 billion yuan. As a result of social and economic factors, the expansion of built-up land (such as urban expansion, industry and mining traffic construction) and farmland reclamation have caused large losses in ESVs, with values of 18.81 billion yuan and 5.07 billion yuan, respectively. Human development activities (built-up land) in shallow water have caused a total ESV loss of 4.17 billion yuan, while the land-building activities (saltwater wetland) in the Yellow River estuary and Liaohe River estuary increased the ESV by 2.02 billion yuan. The changes in the ESVs in the Bohai Rim coastal zone are mainly due to a decrease in saltwater wetland area and a sharp increase in built-up land area.

3.3. Future changes in land use/cover and ecosystem service value under multi-scenario simulation

3.3.1. Land use/cover change in 2025

Under the different scenarios (BAU, SED and EPP), the spatial patterns of land use/cover in Bohai Rim coastal zone were basically consistent, but there were differences in local areas (Fig. 7). Compared with 2015, the area of each land use type was considerably different in 2025, and the degree of overall land use fragmentation was more significant (Table 6).

Under the BAU scenario, the areas of built-up land and mariculture increased by 1790.76 km² and 398.09 km², respectively. However, the areas of farmland, saltwater wetland and forestland decreased by 2148.84 km², 134.74 km² and 72.49 km², respectively. It can be seen that the increase in the area of built-up land mostly came from the occupation of farmland, while the other land use types changed only slightly. Under the SED scenario, to continuously meet the demands of rapid economic and social growth on land resources, cities and towns continued to expand, and built-up land increased by 5783.59 km². Urban growth showed an extensional feature, that is, most of the increase was located in the periphery of the original cities and towns. Mariculture increased significantly, with a value of 1470.09 km², while farmland declined sharply, with a total reduction of 5632.12 km². In

addition, the areas of shallow water, grassland, saltwater wetland, unused land and inland freshwater decreased more, while the areas of forestland changed only slightly. The development and utilization of land made the characteristics of artificialization and fragmentation of land use in coastal areas extremely significant. Under the EPP scenario, the area of built-up land increased the least among all scenarios, with an increase of only 1183.96 km². The areas of saltwater wetland, forestland, inland freshwater, and grassland increased significantly, with a total increase of 1661.86 km². The largest reduction was in the area of unused land, which declined by 860.74 km². Additionally, shallow water and farmland declined by 875.24 km² and 643.71 km², respectively. Under the BAU and SED scenarios, the increase in construction land was highly coincident with the spatial position of the reduction in cultivated, which was typically located around the original towns, indicating that the urbanization process will seriously encroach on farmland.

3.3.2. Changes in ecosystem service values in 2025

The changes in ESVs in the Bohai Rim coastal zone under different scenarios in 2025 are shown in Table 7. The ESVs of the SED scenario and BAU scenario showed a downward trend, while they increased under the EPP scenario. Under the EPP scenario, regulating services and support services increased significantly, while they declined dramatically under the SED scenario.

According to the type of ecosystem service, compared with 2015, the values of the regulating services under the SED and BAU scenarios decreased significantly, with decreases of 10.71 billion yuan and 2.07 billion yuan, respectively. In contrast, the value of regulating services increased significantly in the EPP scenario, with an increase of 7.70 billion yuan. The value of provisioning services declined the most in the EPP scenario, reaching 4.09 billion yuan, while the value of provisioning services in the SED scenario increased significantly by 3.93 billion yuan. The value of cultural services decreased under the SED and EPP scenarios, while it increased slightly under the BAU scenario. In addition, the value of supporting services declined under both the SED and the BAU scenarios, with decreases of 2.97 billion yuan and 0.98 billion yuan, respectively.

The ESVs under different scenarios changed differently because of different purposes. Under the SED scenario, for the purpose of pursuing economic benefits, construction land, salt pan and mariculture increased rapidly, while ecological land was lost in large quantities, which eventually led to the loss of ESV in the region. Under the ecological protection mode, the purpose of protecting the ecological environment was to replace the one-sided pursuit of economic development and to some extent limit development activities and appropriately restore the damaged habitat, causing the ESV to increase significantly in the region.

Fig. 7. Spatial distribution of land use/cover types in the Bohai Rim coastal zone under different scenarios

Table 6

Land use/cover change in the Bohai Rim coastal zone under different scenarios.

LUCC	Area/km ²			
	BAU	EPP	SED	2015
Farmland	78179.56	79798.52	74737.00	80323.32
Forestland	19424.88	19995.47	19438.78	19497.40
Grassland	8141.24	8253.20	7825.82	8045.75
Built-up land	21981.19	20973.64	24899.98	19406.24
Inland freshwater	5122.08	5329.92	5080.79	5109.84
Saltwater wetland	2591.31	3157.15	2562.71	2939.91
Shallow water	26679.43	26476.81	26760.69	27173.79
Human-made wetland	6122.15	5066.50	7088.67	5698.66
Unused land	1371.84	562.47	1219.24	1418.77

Table 7

Ecosystem service values of the Bohai Rim coastal zone in 2025 under multiple scenarios (10⁸ yuan).

Primary classification	Secondary classification	BAU	SED	EPP
Provisioning services	Food supply	1232.25	1263.40	1190.92
	Raw material supply	217.88	214.78	223.34
	Total	1450.13	1478.18	1414.26
Regulating services	Air quality regulation	461.74	455.55	472.29
	Climate regulation	638.90	634.39	659.35
	Regulation of water flows	637.35	628.15	670.36
	Waste treatment	581.58	567.96	613.00
	Total	2319.57	2286.05	2415.00
Supporting services	Maintenance of soil	477.24	464.56	490.33
	Fertility habitat services	489.80	485.22	499.53
	Total	967.04	949.78	989.86
Cultural services	Cultural & amenity services	997.41	1042.18	954.35
	Total	997.41	1042.18	954.35
Total		5734.16	5756.18	5773.48

4. Discussion and conclusions

4.1. Discussion

The impact of LUCCs on ecosystem services is very complex. LUCC leads to changes in ecosystem structure and function and will lead to changes in the ESV per unit area (Simmons et al., 2008; Wang et al., 2015). This paper ignores the influence of changes in ecosystem structure and function on the value of ecosystem services and does not consider correlations and heterogeneity among ecosystem service types, which would also have an impact on the results. The main limitation of this study is associated with the accuracy and confidence level of the

analysed results, including the land-cover data accuracy and the ESV valuation method.

The LUCC data were obtained from the interpretation of 30-m resolution remote sensing images by Di Xianghong and Hou Xiyong (Di et al., 2015). The quality of ESVs partly depends on the accuracy of the LUCC classification. The higher resolution land use data provide more accurate results (Wang et al., 2018). There is a high total accuracy (both pros and pres) in the land use mapping in China's coastal zone. However, the classification accuracy of built-up land, freshwater wetlands and human-made saltwater wetlands is relatively low, while the accuracy of unused land represents the most serious type of misclassification; finally, the accuracies of farmland, built-up land, forestland, grassland and saltwater wetlands are also easily misclassified. These issues should be given more attention during the continuous updating of land use maps in the future (Hou et al., 2018). In addition, the LUCC datasets do not have a detailed classification. For example, there is no distinction between grassland, forestland and other land types in built-up land because of the limitation of remote sensing image resolution. Thus, to overcome these limitations, a more detailed land use/land cover classification and the generation of land use/cover datasets with high resolution are needed (Konarska et al., 2002; Arowolo et al., 2018).

The BTM (including basic value transfer, expert modified value transfer, and statistical value transfer) for ecosystem services plays a vital role (Costanza et al., 2014; Song and Deng, 2017). It is widely criticized because of its reliability, validity, and uncertainties. We still adopted this approach in our assessment of ecosystem services because of its quick assessment and the low cost associated with collecting the primary data needed to achieve our objectives (Troy and Wilson, 2006).

Several scholars have evaluated the ESV of the Bohai Rim coastal zone and the impacts of LUCC on the ESV (Suo et al., 2011; Miao and Liu, 2014; Zhang et al., 2015a,b). They pointed out that the decline of ESVs in the region was mainly due to the loss of coastal wetlands. In this study, when evaluating the value of ecological services, the BTM was used to supplement the ESV of shallow waters, making the analysis more complete. In addition, we predicted future spatiotemporal changes in LUCC and ESV through a multi-scenario simulation. We also examined spatiotemporal changes in LUCC and ESV along a land-sea gradient. This study will help decision makers better understand trade-offs between ecosystem services caused by LUCC and provide a relevant scientific reference and support for ecosystem protection and integrated management in the Bohai Rim coastal zone.

4.2. Conclusions

This paper focuses on the impacts of LUCCs on ecosystem services in

Table A.1

Area and proportion of land use/cover types in different buffer zones from 2000 to 2015.

2000 LUCC	Area/km ² Ratio/%								
	– 60 ~ – 40	– 40 ~ – 20	– 20 ~ 0	0 ~ 20	20 ~ 40	40 ~ 60	60 ~ 80	80 ~ 100	> 100
Farmland	4.01	24.04	6.07	13602.96	15167.63	15314.34	15190.76	11642.89	12022.27
	0.00	0.03	0.01	16.39	18.28	18.46	18.31	14.03	14.49
Forest	2.17	39.60	18.40	3844.93	5475.79	4233.79	2579.89	1966.32	1468.13
	0.01	0.20	0.09	19.59	27.90	21.57	13.14	10.02	7.48
Grassland	0.00	11.70	3.10	1724.77	1830.11	1741.39	1222.93	1017.50	1001.03
	0.00	0.14	0.04	20.16	21.40	20.36	14.30	11.90	11.70
Built-up	2.66	10.77	4.13	2927.16	2313.99	2674.51	2556.53	1953.31	1936.96
	0.02	0.07	0.03	20.36	16.09	18.60	17.78	13.58	13.47
Inland freshwaters	0.00	0.11	0.47	1420.39	1420.86	1217.08	669.43	439.47	412.38
	0.00	0.00	0.01	25.45	25.46	21.81	12.00	7.88	7.39
Saltwater wetlands	0.10	8.00	9.92	3258.98	383.56	55.86	0.46	0.00	0.00
	0.00	0.22	0.27	87.68	10.32	1.50	0.01	0.00	0.00
Shallow water	590.86	10745.39	17480.09	4.31	0.00	0.00	0.00	0.00	0.00
	2.05	37.29	60.65	0.01	0.00	0.00	0.00	0.00	0.00
Human made wetland	0.00	0.00	0.00	4030.62	196.63	11.31	0.00	0.00	0.00
	0.00	0.00	0.00	95.09	4.64	0.27	0.00	0.00	0.00
Unused	0.00	0.17	0.19	492.94	456.62	337.71	226.64	123.92	82.67
	0.00	0.01	0.01	28.65	26.53	19.63	13.17	7.20	4.80
2015 LUCC	Area/km ² Ratio/%								
	– 60 ~ – 40	– 40 ~ – 20	– 20 ~ 0	0 ~ 20	20 ~ 40	40 ~ 60	60 ~ 80	80 ~ 100	> 100
Farmland	3.99	22.74	7.37	12974.17	14950.19	14794.42	14611.11	11229.81	11729.53
	0.01	0.03	0.01	16.15	18.61	18.42	18.19	13.98	14.60
Forest	2.16	40.50	19.60	3798.12	5433.64	4208.44	2556.28	1957.13	1481.52
	0.01	0.21	0.10	19.48	27.87	21.58	13.11	10.04	7.60
Grassland	0.00	10.27	143.22	1351.70	1646.02	1697.70	1214.50	1016.24	966.10
	0.00	0.13	1.78	16.80	20.46	21.10	15.09	12.63	12.01
Built-up	2.66	99.34	620.33	4401.11	2985.97	3386.21	3199.39	2407.57	2303.66
	0.01	0.51	3.20	22.68	15.39	17.45	16.49	12.40	11.87
Inland freshwaters	0.00	0.29	133.20	1194.86	1150.46	1128.67	681.62	431.02	389.71
	0.00	0.01	2.61	23.38	22.51	22.09	13.34	8.43	7.63
Saltwater wetlands	0.09	25.85	323.09	2166.19	369.76	54.48	0.45	0.00	0.00
	0.00	0.88	10.99	73.68	12.58	1.85	0.02	0.00	0.00
Shallow water	590.90	10638.00	15933.36	11.53	0.00	0.00	0.00	0.00	0.00
	2.17	39.15	58.64	0.04	0.00	0.00	0.00	0.00	0.00
Human made wetland	0.00	0.00	242.78	4951.44	451.49	33.97	0.00	16.48	2.51
	0.00	0.00	4.26	86.89	7.92	0.60	0.00	0.29	0.04
Unused	0.00	2.78	99.44	457.92	257.66	282.11	183.28	85.17	50.41
	0.00	0.20	7.01	32.28	18.16	19.88	12.92	6.00	3.55

the Bohai Rim coastal zone. The main conclusions are as follows.

Farmland was the predominant land use/cover type in the Bohai Rim coastal zone during the period of 2000–2015, and its proportion showed a decreasing trend. The areas of shallow water and forestland accounted for a large proportion, and both also exhibited sustained small declines. In contrast, the areas of built-up land and mariculture showed a trend of continuous increases. The land use/cover structure changed significantly within 20 km of the coastline because of the high-intensity development activities of humans and the estuary delta land-building activities.

During 2000–2015, the total ESV of the Bohai Rim coastal zone decreased significantly by 22.09 billion yuan, which was a decline of

3.80%. The spatial distribution of ESVs showed some regularity, there were obvious characteristics of a land and sea gradient change, and the ESV per unit area decreased gradually with the distance from the coastline. Within the range of 0–20 km from the coastline, the ESV per unit area showed the most significant declined, and this decline was mainly due to the loss of coastal wetlands caused by large-scale reclamation activities.

Compared with 2015, the total ESVs under the SED scenario and BAU scenario in 2025 showed a declining trend, while they increased under the EPP scenario. Under the EPP scenario, regulating services and support services increased significantly, while they declined dramatically under the SED scenario. LUCC patterns were the main reason for

Table A.2Conversion matrix of land use/cover change (km²) in the Bohai Rim coastal zone from 2000 to 2015.

LUCC	Farmland	Forest	Grassland	Built-up	Inland freshwaters	Saltwater wetlands	Shallow water	Human-made wetland	Unused
Farmland	78804.02	54	65.81	3188.39	392.67	4.90	0.08	444.35	20.77
Forest	78.04	19355.41	20.24	140.37	27.19	0.64	0.07	5.50	1.55
Grassland	467.88	62.21	7284.64	238.64	118.39	76.79	0.07	271.43	32.47
Built-up	66.48	4.39	20.77	14093.07	42.25	7.58	0.26	139.83	5.39
Inland freshwaters	546.9	15.50	136.59	235.53	4146.16	75.43	0.37	398.02	25.69
Saltwater wetlands	18.71	1.77	111.09	244.17	146.00	2393.91	10.40	610.35	180.47
Shallow water	1.78	0.93	141.34	701.21	133.43	335.85	27162.14	242.03	101.94
Human-made wetland	49.69	0.18	236.50	415.38	47.62	20.84	0.34	3414.15	53.87
Unused	289.82	3.01	28.77	149.48	56.13	23.97	0.06	173.00	996.62

the decrease in ESV. For example, urban expansion, the construction of industrial and mining transportation and the development of salt pans and aquaculture ponds have led to the occupation of tidal flats, coastal wetlands, cultivated land, forest and grassland.

CRedit authorship contribution statement

Yubin Liu: Writing - original draft. **Xiyong Hou:** Writing - review & editing. **Xiaowei Li:** Data curation. **Baiyuan Song:** Software. **Chao Wang:** Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences [grant numbers XDA19060205]; the National Natural Science Foundation of China [grant numbers 31461143032]; and Science and Technology Service Network Initiative (STS) Project of the Chinese Academy of Sciences [grant numbers KJF-STZDTP-023]. We are grateful to Dr. Di Xianghong and Wu Li for their contributions during LUCC data downloading and processing. We also thank the anonymous reviewers for their precise and insightful comments.

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