RESEARCH ARTICLE

Main Features and Problems of Modern Evolution Process of Coastal Wetlands in North Jiangsu, China

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Abstract

Based on field monitoring and remote sensing extraction, this paper analyzed the landscape evolution, reclamation process and transformation characteristics in north Jiangsu coastal region since 1980 through landscape transfer analysis, landscape spatial conversion model, and landscape dynamicity model. Results indicated that natural wetland decreased while in contrast the artificial wetland increased. Natural wetland was mostly converted into mudflats, and large proportion of mudflats were subsequently exploited into aquaculture waters, and other man-made construction projects. Significant transformation ranking ahead were mudflat to aquaculture waters, *Suaeda glauca* to dry land, *Suaeda glauca* to aquaculture waters, *Couch grass* to aquaculture waters, respectively. The proportion of transformation caused by anthropogenic activities was up to 82%, much higher than natural succession. Coastal ecological systems were severely disturbed and destroyed largely due to wetland reclamation and resources exploitation. The results suggest that the impact of human activity on wetland ecology needs more attention.

Keywords Coastal wetlands · Jiangsu · Remote sensing · Evolution · Reclamation

Introduction

Coastal wetland is one of the most productive coastal systems (Fickas et al. 2015; Cui et al. 2016; Liao et al. 2014a), providing essential ecosystem services, such as, shoreline stabilization, hurricane protection, erosion control, wildlife habitat maintenance, biochemical transformation and biological diversity sustaining (Behera et al. 2012; Ma et al. 2015; Liu and Mou 2014; Liao et al. 2014a). Though the coastal zone accounts for merely 5% of the land mass in the world, it affords a mismatching amount of ecosystem services that support almost 40% of the global population. Meanwhile, nearly 66% of the coastal zone ecosystem services are threatened by climate change and human activities for millennia (Allison and Bassett 2015), and the coastal wetland has shrunk by 70–80% over the past five decades at the global scale (Fickas et al. 2015). Coastal regions in China are considered to be the most densely populated areas for they support over 42% of the nation's population and provide over 60% of the GDP with only 13% of the overall territory (Yao 2013). Thus, reclamation for obtaining lands have become the most effective strategy of solving the problem of shortage of land (Zhang et al. 2016).

Substantial evidence indicates that human activities can affect the land cover patterns and processes significantly, it has been a booming realm of study to monitor the temporal and spatial dynamic change of the coastal wetland (Peng et al. 2014), reveal the evolution mechanism, and lastly forecast the future evolution ultimately (Webb et al. 2013). However, most related research is either a macro analysis at a globe scale (Spencer et al. 2016; Webb et al. 2013), or merely focus on reserves (Xu et al. 2016). In addition, scholars with different academic background always select

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various methods to describe evolution characteristics. Most landscape ecologists choose the Landscape Pattern Index (LPI) as a basic way to analysis the evolution at the landscape scale. Though LPI can simply and intuitively reflect the characteristics of the landscape structure, morphology, and spatial configuration (Sun 2010), this mainstream method is featured with ecological significance statistically (Kong et al. 2013). Moreover, the standard of the index is numerous and varied, and the mutual independence between them is still not clear, and result's accuracy is not sufficiently high (Wu 2000). Thus, it's necessary to analyze the main temporal and spatial trend in evolution features on wetland system along the coastal line comprehensively, and grasp dynamic changes of the wetland landscape characteristics and trajectory direction.

Jiangsu is one of the provinces with the smallest per capita land area in China. It convers an area of only about 1.07% of the country, but supporting 5.7% of its population. The tidal flat along the coastline in Jiangsu is unique in the world. Besides, Jiangsu is one of the most highly developed and urbanized provinces, therefore the contradiction between human and land is becoming increasingly prominent with the increased land demand of urbanization and industrial construction. The area of the coastal tidal flats in Jiangsu accounts for about 1/4 of the total area of the coastal tidal flats in China. Since the 1950s, reclamation and infrastructure construction in tidal flats have been playing an important role in relieving the tense situation between population and land, and ensuring the rapid economy development. This region covers north Yangtze River delta, and is located in the junction of south Bahia bay and the northeast Asian countries, thus has a robust location advantage for economic development. Apart from the particularity of its geographical environment and, geological structure, its both social and economic development are remarkable since the reform and opening. In sum, Jiangsu coastal wetland area is the most representative region for the research of mechanism and evolution between human activities and wetland ecological evolution. The research results will provide decision support to wetland conservation management and sustainable regional development. More precisely, this paper intended to reveal: ① The change patterns and dynamic conversions of the land use in the coastal zone of Jiangsu province over the past several decades; ② The factors and their corresponding contribution to the changes.

Materials and Methods

Study Area

The Jiangsu coast, with a length of 954 km, is located in the middle west of the Yellow Sea between the Shandong Peninsula and Yangtze River mouth. The coastline between the Ruzikou River mouth, south of Lianyungang and Qidongzui, is occupied by tidal flat sediment, which is the longest continuous stretch of tidal flat coastline in China (Liu et al. 2013; Wang et al. 2016). The study area, located between 31°40′–34°32′N and 119°28′–121°58′E (Fig. 1), has a subtropical monsoon climate, and an average air temperature ranging from − 1.5 to 27.5 °C, and an average annual precipitation ranging from 850 to 1000 mm (Cui et al. 2014).

Geographically, the study area is located in the west margin of the Pacific Ocean where the long, gentle slope of coastal plains extends offshore toward the Yellow Sea. The sediments here are related closely to the Yangtze River and the Yellow River in the region. Landscape from the land to the coast is coastal plain, intertidal zone and offshore bottom plain, respectively. And topography of the coastal plain from north to south are Haizhou Bay sea plain, the abandoned Yellow River Estuary, Yangtze River Delta, respectively.

Data Sources and Data Pre-process

A combination of remote sensing and GIS-based approach has significant ecologic and economic benefits by gaining
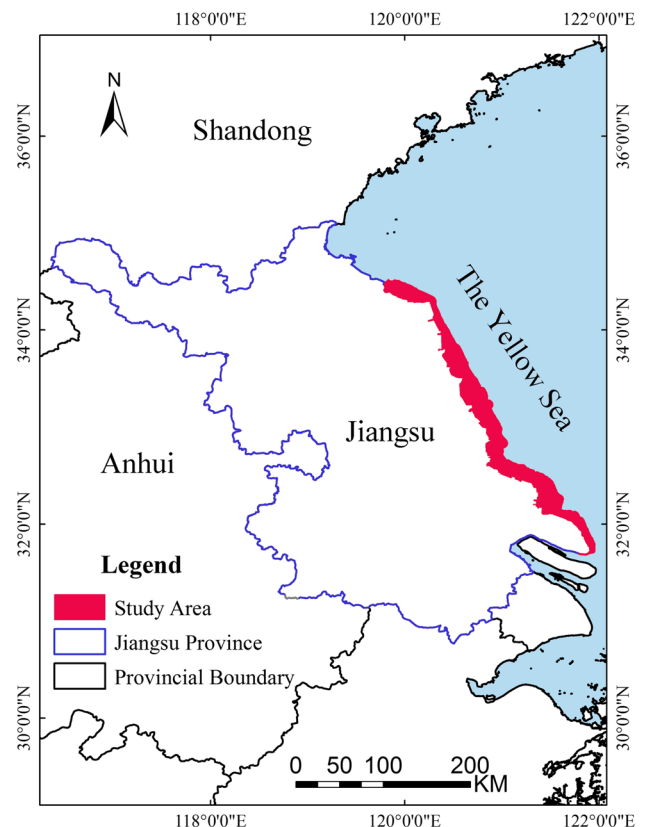

Fig. 1 The location of the study coastal wetland in north of Jiangsu, China

real-time data from inaccessible areas, and will provide new approaches of identifying, measuring, monitoring, and managing the change (Li et al. 2010; Lu et al. 2013). This paper selected the TM, MSS, ETM + data as data sources, which are one of the most commonly used, publicly available data sets on ecological landscape process analysis (Tian et al. 2015; Han et al. 2015). All the images are downloaded from https://earthexplorer.usgs.gov/.

The influence of sea-land moisture transport on coastal zone is very obvious (Guo-Sheng and Wang 2012), and satellite images obtained are often covered by clouds, thus the time period of the images chosen in this paper is not completely consistent to make sure the all earth objects could be read. Finally, imagery series data from 1980 to 2014 in about 6 or 8 year time interval were used to quantify the spatial–temporal changes in coastal ecosystems. Even though, in some years, there are still some areas where there is no fully applicable image, so some images of adjacent years are used to supplement or replace data. All the images used in this paper were listed as shown in Table 1.

Each image was corrected and geo-referenced to the WGS 84 datum and UTM Zone 51 North coordinate system based on 1:50,000 topographic maps. Each remote sensing image was precisely geometrically corrected, and all the geometric correction with the nearest neighbor resembling resulted in the root mean square error (RMSE) of less than 0.5 pixels. Atmospheric correction is an essential process in quantitative remote sensing studies, and this paper used DOS (Dark object subtraction)-Iterationv method to complete this procedure, as this method can achieve better results and can thus be a more reasonable correction model than the other methods (L. Cui et al. 2014).

Other data that were gathered and processed: Jiangsu coastal 1:200 000 vegetation survey map (1980), Jiangsu 1: 200 000 land use survey map (1980), Jiangsu 1: 200 000 topographic survey map (1980) (Data from http://www.geodata.cn). All the survey maps were scanned, registered, and traced into vectors with reference to 1: 250 000 basic maps by ArcGis10.0. The transition matrices were then computed and analyzed by using Excel and SPSS statistics software (Liao et al. 2014a).

Coastal Wetlands Landscape Classification

A classification system of wetland landscapes was constructed based on field investigations, historical data, and the object recognition capacity of the remote sensing data utilized in this study (Cui et al. 2015; Liao et al. 2014a). A total of 18 classes were clustered into two main categories: natural and artificial landscapes. The natural landscape contains mudflat (MF), river, *Suaeda glauca* (*SG*), *Phragmites australis* (*PA*), *Couch grass* (*CG*), *Spartina alterniflora* (*SA*), shallow sea water (SW). The artificial landscape refers to constructed wetlands and non-wetlands. "Constructed wetlands" include paddy fields (PF), salt pans (SP), aquaculture waters (AW), and reservoirs. Dry land (DL), urban land (UL), rural residential land (RS), construction land, woodland (CL), and bare field (BF) are classed as "non-wetlands"(Liao et al. 2014b).

Remote sensing data and the atlas of the "National Multipurpose Investigation of the Coastal Zone" and "Tidal Wetland Resources (1980s)" were used to monitor landscape changes after the re-processing. The hybrid classification technique, which includes the iterative self-organizing data analysis technique, supports vector machine classifier and visual interpretation, was applied to extract different wetland clusters (Cui et al. 2015). Finally, the Kappa coefficient was calculated to determine the process accuracy, and the obtained coefficient was higher than 0.7.

Analytical Methods

Dynamic change analysis should gain understanding about the complexity of landscape change, and the process, extent and trend of the change (X. Zhang et al. 2010). For a thorough observation of the dynamic change process of different landscape classes, we have managed a quantitative and positioning spatial information analysis of each kind of landscape change from a perspective. To explain the detail steps in the study, this paper presents a clear flow diagram as shown in Fig. 2.

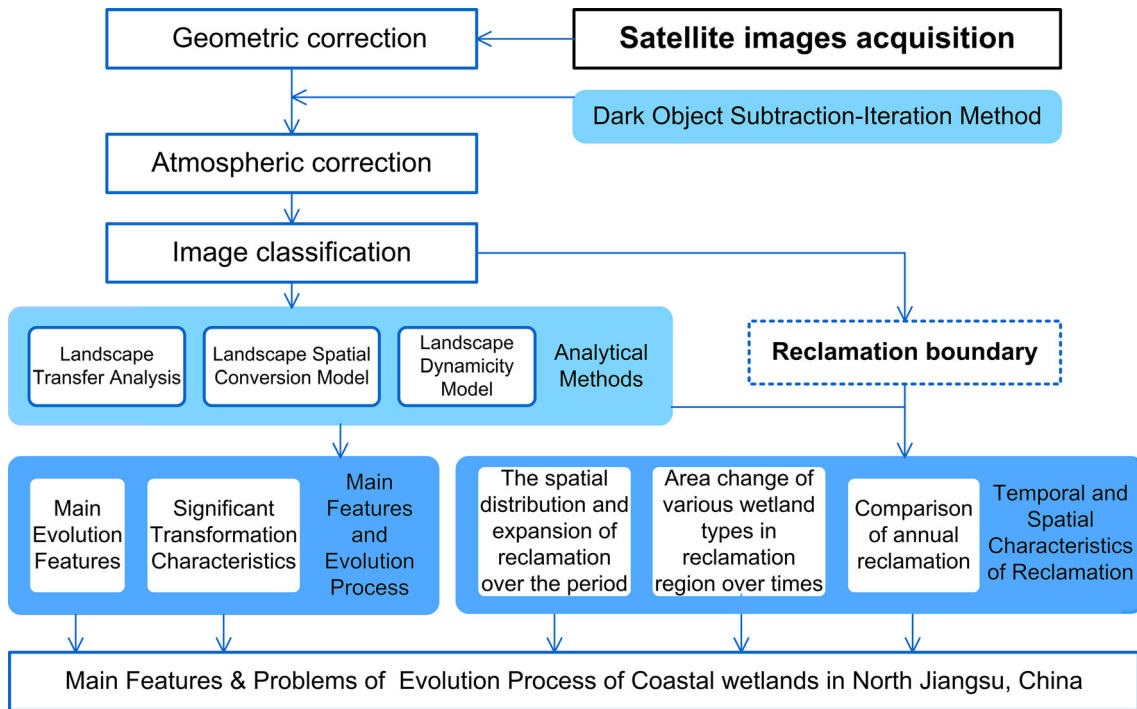1. Landscape Transfer Analysis (LTA)

Table 1 List of the collected remote sensing images

Date acquired images	Sensor	Spatial resolution	Path	Row
1981.09.08	MSS	80 m	129[a]	36
1985.09.24	TM	30 m	120	36
2002.05.26	ETM+	30 m	120	36
2013.10.23	OLI	30 m	120	36
1986/1992/2000/2008/2014	TM	30 m	118/119/120	36/37/38

[a]Path 129(in 1981) corresponds to the present path of 120

Fig. 2 Analytical flow diagram in methodology of this study

LTA has been regarded as an effective approach to obtain the transition among different landscape, considering more detailed landscape information, and basic geographical data. The traditional statistical data can only express the type of landscape and its area, thus it cannot imply the mechanism of landscape change. The transfer matrix of land use from system analysis on the quantitative description of the state and state transfer system, through the initial state of the region in a certain period and termination of state land use transformation relationship between the types (Yu 2016). It matrix reflects the dynamic process of mutual information conversion of a region before and after a certain period. It contains static information of areas of all types of landuse within an certatin region at some time, and dynamic information of roll-in and roll-out of area data at the beginning and end of the statistical time intervals, respectively (Qiao et al. 2013). And it can well reflect the balance of payments among the landscape change, and reflect the mechanism of landscape change (Liao et al. 2014a). Furthermore, It can comprehensively and concretely study and analyze the structural characteristics of land use in quantity distribution and the direction of mutual transformation between different types of land use, so it can be widely used in the study of land use dynamic change (Zhang et al. 2010). The common land use transfer matrix is shown in Table 2.

In Table 2, A_i indiates land use type i, and S represents area. The sum of the row elements of the matrix represents

Table 2 Land use transition matrix

	A_1	A_2	…	A_i
A_1	S_{11}	S_{12}	…	S_{1n}
A_2	S_{21}	S_{22}	…	S_{2n}
…	…	…	…	…
A_i	S_{n1}	S_{n2}	…	S_{nn}

the area of the land before the transfer, and the sum of the elements of a column indicates the area of the land after the transfer. The element S_{ij} (i = j) on the diagonal of the matrix represents the unchanged area of class i in the study period (Xu et al. 2017). And the mathematical formula of transfer matrix is as shown in Eq. 1.

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{vmatrix} \qquad (1)$$

where S represents the area of one certain type as in Table 2; n refers to the wetland landscape type number; i and j are wetland landscape type in different periods, respectively (Wang and Liu 2014; Xu et al. 2017). According to the analysis of the transfer matrix, those results can be clearly calculated: (1) the area change of one certain type of land use under the starting and ending states; (2) transfer ratio of land use types from initial state to ending state (Yu 2016).

2. Landscape Spatial Position and Quantity Conversion Model

Due to the interaction of various interference factors, the stability of some individual landscape elements, as well as the landscape spatial structure, will change gradually and result in landscape pattern change (Ou et al. 2006). For further analysis of structure characteristics and wetland evolution direction, it's an effective way to reveal the regional ecological condition and spatial variation characteristics, by using the transfer matrix to calculate the retention rate of landscape components and the contribution rate of specific transfer process in different periods.

Retention rate of landscape components refers to a percentage of area of landscape components has not been shifted since the initial year. This rate is used for a comparative analysis of the stability of the main landscape components in different periods of a region. The rate can be calculated as:

$$BR_j = BA_j/TA_j \tag{2}$$

where BR_j represents the retention rate of category j, TA_j stands for the area of category j, BA_j stands for the area of category j with no change. Contribution rate of specific transfer process refers to a percentage of area of landscape components has been shifted in proportion to the total transfer area since the beginning. The rate is used for comparing the degree in the importance of specific landscape transfer process during the dynamic change happened over the years, calculated as:

$$T_{pi} = A_{ij}/A_t \tag{3}$$

where T_{pi} represents the contribution rate of specific transfer process, A_{ij} stands for the transfer area from category i to j, A_t stands for the whole area of landscape transfer.

3. Landscape Dynamicity Model

Wetland landscape dynamicity was chosen in this paper to represent the quantitative change of the wetland, including single landscape dynamicity and comprehensive landscape dynamicity.

The two landscape dynamicity represent the quantitative change of one single landscape class, and quantitative change of several landscape classes in a particular region at a certain period of time, respectively. It can be calculated as (Zhang et al. 2010; Hao et al. 2012; Dan et al. 2015):

$$K = \frac{(U_a - U_b)}{U_a} \times \frac{1}{T} \times 100\% \tag{4}$$

where K refers to the dynamicity of one landscape type over the research period, U_a and U_b stand for the areas of one landscape class at the beginning (moment a) and at the end (moment b) of the research period respectively. T refers to the time span from moment a to moment b. When T is set to be multiple years, K will be the annual changing rate of the landscape class during the period.

Results and Discussion

Main Evolution Features

Six phase maps of the wetland landscape in North of Jiangsu's coastal zone. Figure 3 indicates the landscape patterns of 1980, 1986, 1992, 2000, 2008, 2014 in the region respectively.
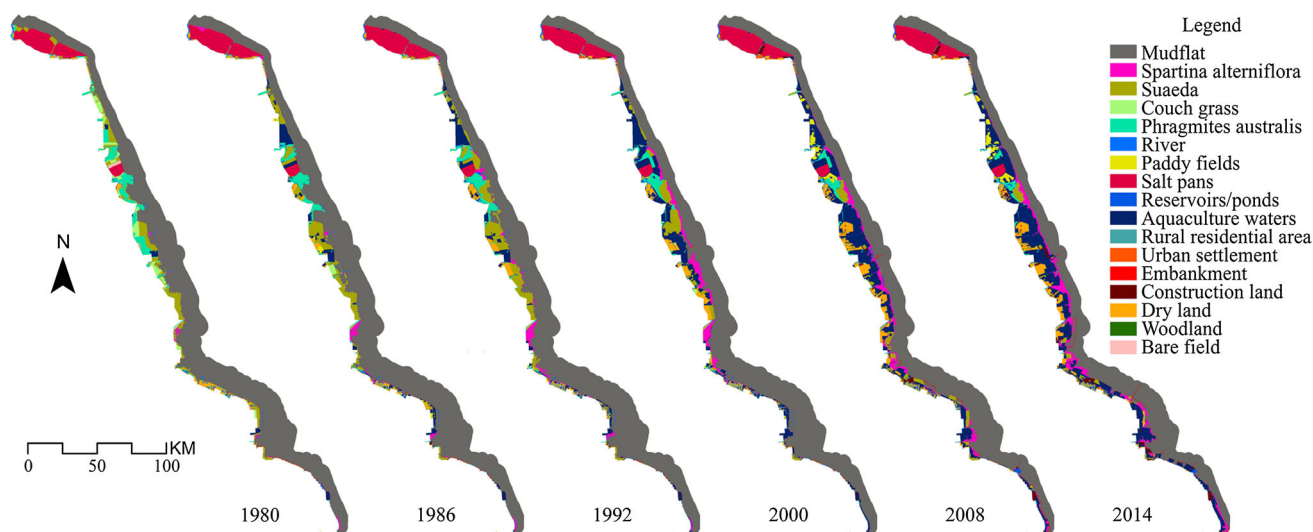

Fig. 3 The Landscape mappings in North of Jiangsu's coastal zone in the six phases

Based on the classification of wetland landscape, wetland spatial attribute data of different period was extracted using the spatial analysis function of ArcGIS. The landscape pattern change of the whole region are mainly embodied in the class composition and spatial pattern.

Based on the TM images, over the past decades, there has been significant disturbance and loss of natural wetlands in the coastal region. As the proportion change of different wetland landscape over the last three decades shown in Fig. 4, and the changes in different wetland types extent over this period shown in Fig. 5, the following results are obtained.

Coastal wetlands reduced by 910.6 km^2 and has been decreasing tendency frequently with a yearly descending rate of 26.8 km^2/a. The natural wetlands declined by 2310.6 km^2 between 1980 and 2014 at 68 km^2/a annual rate of loss, and the mudflat area decreased most. By contrast, natural wetlands are diminishing in size and their vegetation is degrading, constructed wetlands are

extending over 1400 km^2 during this period, accounting for 4.6% of the entire coastal countries, and the average annual growth rate is up to 60.6 km^2/a. The loss of natural wetlands area is greater than the artificial wetlands growth over this period. The increase of the artificial wetland in this region mainly expressed increase of aquaculture ponds, paddy fields, and reservoir, and the increase of the aquaculture ponds is dominated one, with an expanded area rises dramatically to 1566.6 km^2.

For the natural wetland part of the entire beach area, the proportion of tidal flats showed a trend of obvious reduction (linear trend rate s = 3.95) for years, the impacts of the human activities of exploiting and utilizing on the tidal flat has been increasing year by year. The proportion of *Suaeda glauca* have fallen sharply, from 8.2% in 1980 to 2.7% in 2014 (s = 1.22), and the same downwards trend is evident in *Phragmites australis* and Couch grass too. Compared to 1980, the area of the couch grass was decreased by 94% till 2014, the ratio of its percentage to

Fig. 4 The proportion change of different wetland landscape over the last three decades
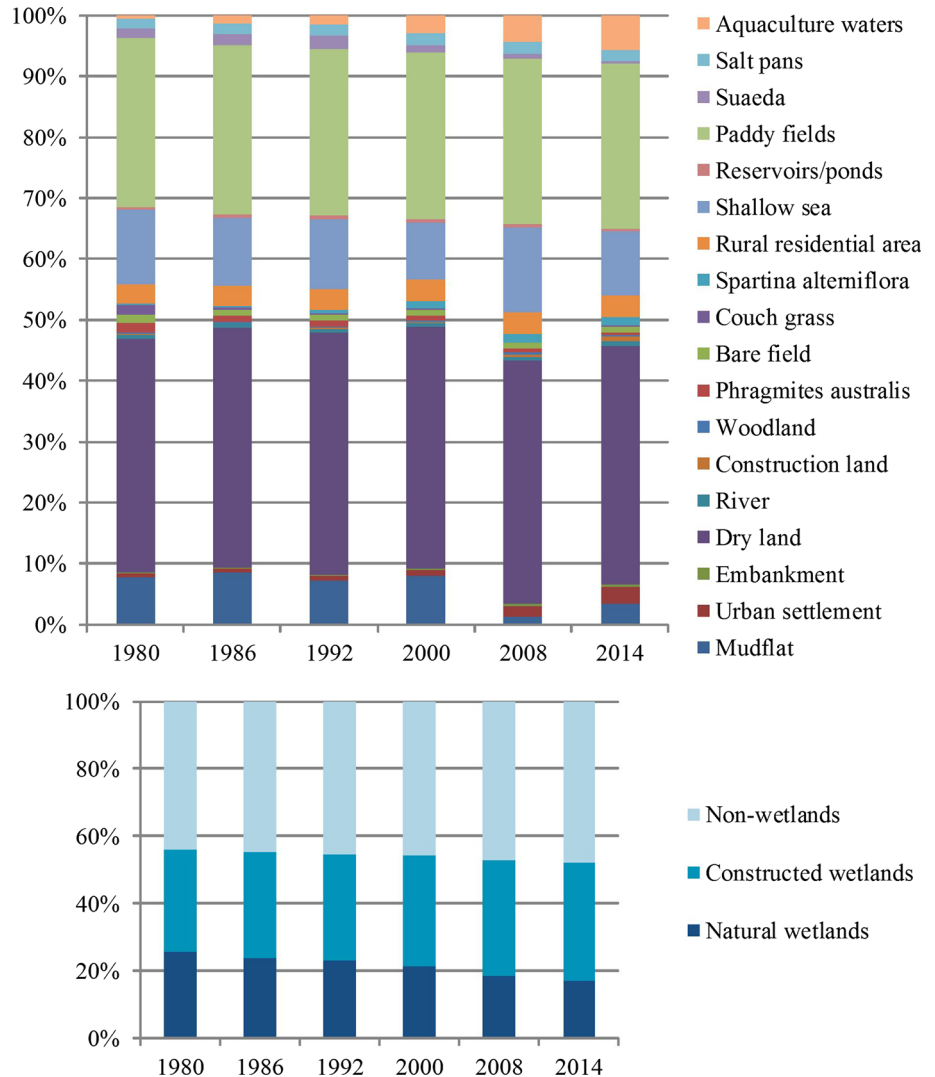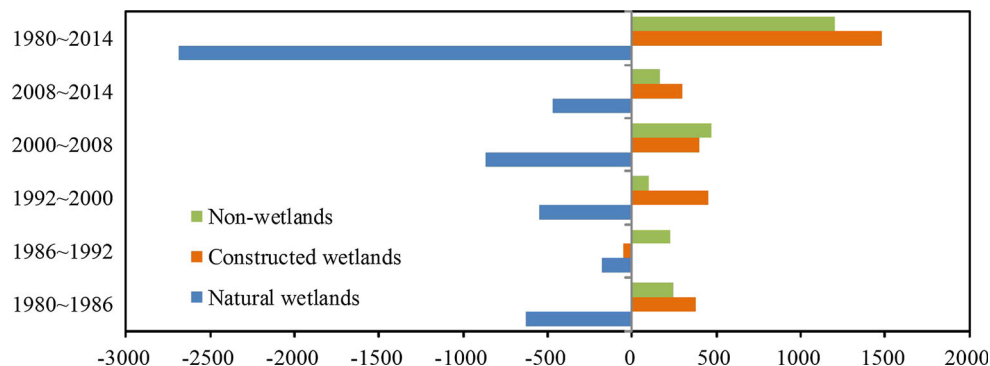
Fig. 5 Changes in different wetland types extent over the last three decades (km²)

total coastal region dropped from 3.7% at the beginning to 0.2%. In all natural wetlands, only the proportion of *Spartina alterniflora* increased slightly (s = 0.97), the percentage rose by over 4% in the past few decades. On the contrary, variation trend of the artificial wetlands is markedly different from the natural kind. One of the representative types goes to aquaculture waters, which has ballooned from less than 1% of the whole coastal zone in 1980 to almost 20% in 2014, and the growth rate is up to 3.9. Additionally, due to the ongoing urbanization, and the increase of construction land and tideland reclamation, Non-wetlands present a small growth. Natural wetland area is decreasing year by year, the proportion is also continues to decline, down from 87.3% in the early 1980s to 62.6% in 2014. The area of artificial wetland is increasing year by year, accounting for the proportion of whole coastal shoal area also showed a trend of increase, from the very beginning of a proportion less than 10%, then gradually developed up to more than a quarter (27.5%) of the whole tidal flats area.

Significant Transformation Characteristics

Landscape change is one major driver behind the loss of coastal wetland ecosystem services, and landscape change analysis was assessed by comparing the areas occupied by each landscape in each period through transfer matrix. For each study period, the total area lost or gained by each landscape type and the landscape dynamic index was calculated.

For more in-depth analysis of specific transfer type, transfer area, and transfer contribution rate of different period of time, further operations of the transfer matrix was done. And the contribution of specific transfer process of the landscape was also calculated. In order to omit unnecessary analysis, the results only display the main dominant transfer process. This whole part of work is done based on Table 2 and Eq. (1), and the related research results is as shown in Tables 3 and 4.

Despite the ecologic, social and economic functions, the coastal wetland is continuously under threat due to anthropogenic activity and climatic vulnerability. And the wetland landscape evolution is a process mainly deriving from both the rapid expansion of anthropogenic activities and natural processes that have occurred in the last decades. Tables 3 and 4 basically reflect the main dynamic changes of the landscape in research area under driving factors. Mudflat occupied the most swap change (− 1356.6 km², 16.3%), gaining about 638 km² from the shallow sea, while losing about 883.2 km² to aquaculture waters (26.6%) and 380.3 km² to *Spartina alterniflora* (12.7%), and 174.2 km² to non-wetlands (2%). Statistics indicated that, during this period of increased pressures from human activities, most mudflat were exploited into aquaculture waters, and other man-made construction projects resulted from the expanding of industrial zone and development of the large-scale feeding, and this trend has been gathering steam for decades. Besides aquaculture waters, *Spartina alterniflora* occupied mudflat with a less but growing Influence, and the expansion of the *Spartina alterniflora* suppressed the natural succession between *Suaeda glauca*, *Phragmites australis*, and Couch grass in the meanwhile. In addition, land reclamation has been a major human activity along coastal zones worldwide, especially among coastal provinces. Mudflats and other natural wetlands are usually replaced by artificial landscape during the period of reclamation in coastal areas, such as aquaculture waters and dry land mostly. From 1980 to 2014, significant transformation occurred in this research region ranking ahead are mudflat to aquaculture waters, *Suaeda glauca* to dry land, *Suaeda glauca* to aquaculture waters, Couch grass to aquaculture waters, Couch grass to dry land, *Phragmites australis* to dry land, respectively. And the cumulative contribution rate is over 55%. Furthermore, the contribution of landscape transfer caused by human activities has increased obviously since 1986. Before 1992, human activities lead to the type of transfer is slightly less than the natural factors, but since then, its scale is much larger than the natural factors. To the whole study area over this period, transfer caused by human activity accounted for a proportion as high as 75%, more than three times of the natural succession. Comparative

Table 3 The dominant transfer process and the corresponding contribution rate of the study area in different periods (unit: %)

Transfer	Contribution	Transfer	Contribution	Transfer	Contribution
1980–1986		*1986–1992*		*1992–2000*	
CG → SG	10.3	MF → SG	30.4	SG → AW	21.6
SG → AW	7.2	MF → SA	7.7	MF → SA	16
PA → SG	5.4	SA → MF	5	MF → SG	9.4
PA → AW	5.1	SG → AW	5	SG → DL	7
SA → MF	4.1	SG → DL	4.4	MF → AW	4.7
SG → SA	3.8	MF → PA	4.3	PA → AW	4.5
PA → DL	3.4	CG → DL	3.4	SA → MF	2.2
MF → SA	3.3	PF → AW	2.5	SA → AW	2.2
SG → SP	2.6	PF → DL	2.3	SG → SA	1.9
2000–2008		*2008–2014*		*1980–2014*	
MF → SA	22.5	MF → AW	16.2	MF → AW	26.6
MF → AW	15	MF → SA	13	MF → SA	12.7
SA → AW	10.2	SA → AW	11.1	SG → AW	9.7
SG → AW	9.6	SA → MF	7.6	SG → DL	4.79
SG → DL	4.4	SG → SA	5.3	PA → AW	4.6
AW → DL	2.6	PA → SG	5.2	CG → AW	4.3
SA → SG	2.5	AW → DL	4.47	CG → DL	3.1
DL → AW	2.4	AW → SG	3.4	MF → SG	2.7
AW → PF	1.9	PA → AW	3.1	PA → DL	2.5

Table 4 Landscape transfer contribution (%) of human and natural activities in different period and the corresponding transfer area (km²)

Source	1980–1986	1986–1992	1992–2000	2000–2008	2008–2014	1980–2014
Human	54.7%	53%	63.4%	69.5%	65.1%	82%
Natural	45.3%	47%	36.6%	30.5%	34.9%	18%
All	1435.68 km²	814.3 km²	1208.3 km²	1676.8 km²	1147 km²	3152.4 km²

figures proved that human activity is the leading factor that brought the main features and problems of modern evolution on coastal wetland in North Jiangsu, and mainly embodied in the natural wetland reclamation.

Reclamation and Wetland Evolution

Since 1950s, the development and utilization along coast have entered a peak period worldwide, Among them, reclamation is the main occupation. Although reclamation can create land for agriculture, industry, even urban, and has brought economic benefits (Jiang et al. 2015), it products impacted environment and ecology on negative aspect (Wang et al. 2014b), and causes a repid loss to coastal wetlands (Blankespoor et al. 2014; Cui et al. 2016). So far, the harmful effects of reclamation and infrastructure activities in coastal areas still persist (Jiang et al. 2015).

China has become a country reclaiming the largest lands from the sea, with an average reclamation rate of 300 km²/y (Gao and Zhao 2006). Data reports indicate that, till 2005 since 1949, the accumulative loss of the coastal wetland area is up to 22,000 km², taking up about 51.2% of the entire area of coastal wetlands in China (Wang et al. 2014a). To ensure a sustainable use in the newly done or ongoing reclaimed areas, it is of great significance to study the ecological effects of landscape on reclaimed zones (Li et al. 2014). Furthermore, the future research should focus on achieving a balance between ecological losses and economic benefits as a result of reclamation.

Reclamation is defined as human activity use of natural tidal flats, and the boundary is man-made dam or road, thus the shore protection embankment or road nearest to the coast can be seen as the boundary of the reclamation (Li et al. 2015). The boundary confirming method consists of detecting the ever-shifting border between the tidal flats and the adjacent water parts, and reclamation outer boundary, as shown in Fig. 6 (Li et al. 2015).

To understand how the reclamation process affect the wetland landscape, an analysis of temporal and spatial relationship was carried on by qualifying changes in different periods past. And figure out the ecological and environmental influence and challenges associated with large-scale and high-intensity coastal reclamation in North of Jiangsu coast wetlands.
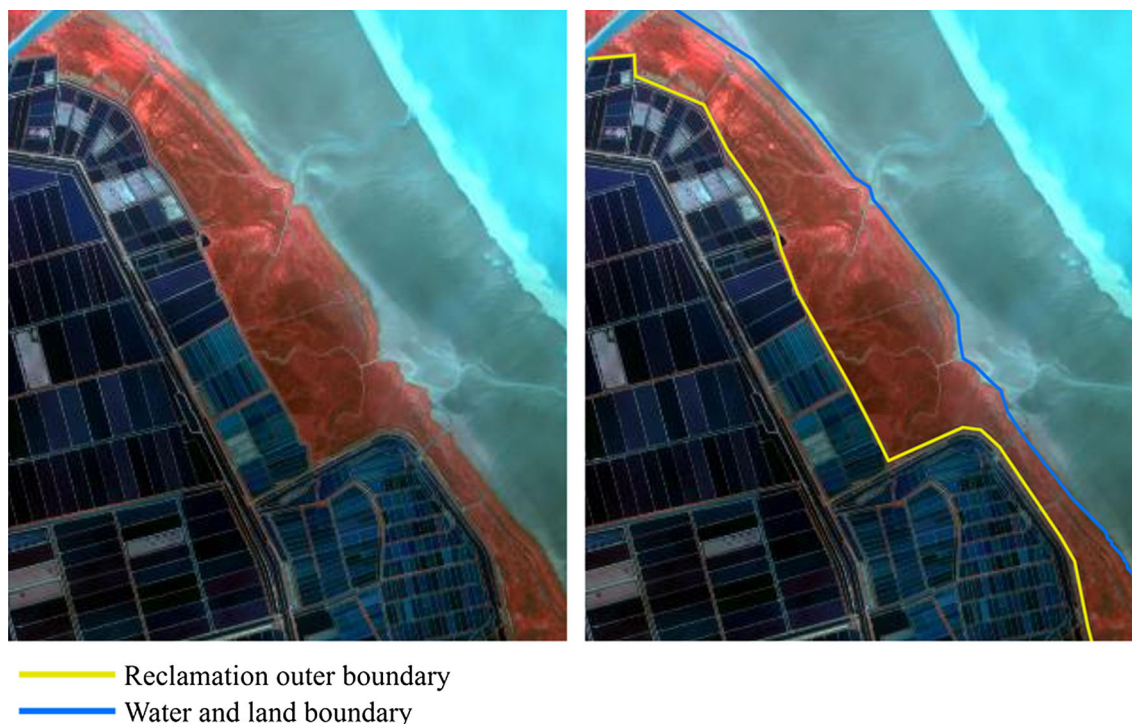
Reclamation outer boundary
Water and land boundary

Fig. 6 Remote sensing images schematic of the boundary of reclamation, water and land

The reclamation area was extracted by remote sensing images selected in the paper (Table 1 and Fig. 7), and the spatial distribution and expansion of reclamation over the period is shown as in Fig. 7a. Over the last several decades, reclamation has accelerated in response to rapid economic development and improved reclamation technology, and has a ranging from a rate of 23 km^2/a (1980–1986) to over 107 km^2/a (2000–2008). In total, from 1980 to 2014, an entire of 2119.4 km^2 of coastal wetlands were reclaimed across all countries along the coastline in Jiangsu Province, and a consistently increasing trend at an annual rate of almost 100% was observed. The reclamation between 2000 and 2008 sharply increased and accounted for over 40.5% of Jiangsu's total reclamation during the 35-year period since 1980. Aquaculture is the anthropogenic activity occupying the largest area and percentage in relation to total reclamation.

Reclamation zones are often managed as aquaculture waters for fishing industries or arable lands by human activity, while without cultivation, these previous tidal flats would mostly transfer into *Phragmites australis*, *Suaeda glauca*, or *Spartina alterniflora*, as shown in Fig. 7b. From the spatial distribution in Fig. 7a, the results show that, artificial reclamation has a southward trend, which is coincident with the previous studies in the field (Li et al. 2015). Approximately 25.8% of the reclamation occurred in Dafeng, where the reclaimed area between 1992 and 2008 was 1.8 times higher than the average level over the

period (Fig. 7c). The other most widely reclamation regions are located in Sheyang, Dongtai, Rudong Country. The growth of reclamation land tended to increase in areas with higher levels of human activity.

Conclusions

Landscape pattern is the carrier of ecological process,and its change will cause ecological process change correspodingly, thus resulting in changes of the ecological process. To utilize and manage the coastal wetlands reasonably and effectively, it is a paramount precondition to have a deep understanding of the coastal wetlands landscape evolution under integrated interference from human activities and natural environment change.

This paper used remote sensing and GIS to analyze the dynamic landscape evolution and conversion, and evaluated the annual rate of the variation, and conducted a supplementary analysis of the spatial and temporal distributions of coastal reclamation in north of Jiangsu. All the work was calculated and analyzed spatiotemporally across class and landscape level for years 1980–2014.

Results showed that the large-scale reclamation is the most significant influential source to the north Jiangsu coastal area, and it can be seen as the main cause of the severe change that has been happening to this region. The main problem that received top priority in the coastal
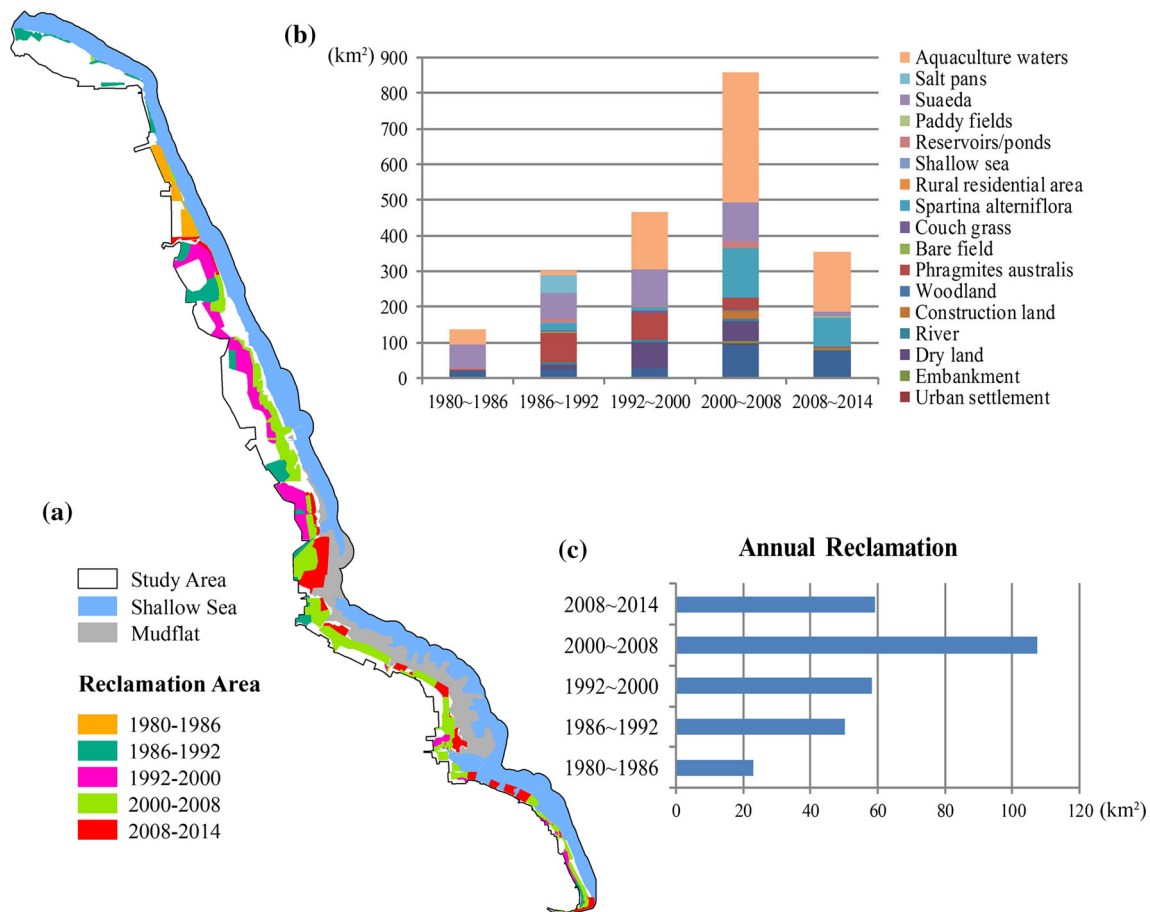
Fig. 7 Temporal and spatial characteristics of reclamation. **a** The spatial distribution and expansion of reclamation over the period. **b** The area change of various wetland types of reclamation region over the period. **c** Comparison of annual reclamation

wetlands distributed in north of Jiangsu province is the drastic natural wetland area reduction. Reclamation of tidal flats on a large scale may not only cause the change of the wetland ecological pattern, but result in qualitative change on the material circulation, energy flow and information transfer. Except the reclamation, *Spartina alterniflora*, as one introduced species for an initial purpose of promoting deposition and protecting beach, has become salt-and flooding-tolerant pioneer communities on mudflats and saltmarshes, and its invasion spread gradually replace the usual plant community in a succession that starts on land periodically inundated by the sea, such as *Suaeda glauca* and *Phragmites australis*. The invasion of *Spartina alterniflora* also leads to the original ecological area shrinking fast, and for some local ecological environment, constitutes an irreversible influence.

Results of this study can provide suggestions and insights to researchers, managers for keeping a sustainable wetland. Further research applying liner indicators of environmental impacts and landscape effects could expand on our research results, and may more deeply clarify the complex nature of the relationship between human activity and landscape-level effects. Furthermore, analyses of water resources, soil condition, and variation in ecosystem conditions could be useful in understanding mechanisms in the relationship between wetland landscape evolutions and external interference factors. Besides, it is necessary to make it clear whether the coastal wetlands landscape condition will remain similar, improve, or deteriorate in the future.

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