Natural Wetland Evolution in China: A Review

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Abstract

Wetlands are vulnerable and sensitive to climate change and human activities. Based on literature research, this paper analyzes the characteristics of wetland evolution in China. The results show that the current researches mainly focus on the wetlands of East China and North China, especially key river valleys and protected areas have attracted extensive attention. The main research methods include remote sensing, GIS, landscape index and mathematical model etc., which are still relatively simple. The area of China's natural wetland reduced by a mean of 0.19–1.67% per year, and some wetlands reach 5.56%. The constructed wetland area increased by a mean of 1.80–5.95% per year, with the increase of paddy field area. Meanwhile, the degree of fragmentation of natural wetlands in China increased by human factors. This paper analyzes China's natural wetlands generally show a trend of obvious degradation, and the relevant research results provide an important basis for wetland protection, and at the same time to provide reference for relevant policy making.

Keywords

Wetland • Evolution • GIS • Model

1 Introduction

The types of climates in China are complex and diverse, which across the plateau climate zones, cold temperate, temperate, subtropical and tropical. The annual precipitation decreased gradually from the southeast coast to the Northwest inland, wetland has obvious regional characteristics. According to the Ramsar Convention on Wetlands, wetlands in China could be divided into five types, including constructed wetlands (CWs), marsh wetlands, offshore and coastal wetlands, lake wetlands and river wetlands.

The total area of wetland in China is 5360.26 $\times$ 10^2 km^2, and the wetland rate is about 5.58%. The natural wetland area is 4667.47 $\times$ 10^2 km^2 which accounts for 87.37% of the global wetland area. Marsh wetlands and CW were 2173.29 $\times$ 10^2 km^2 and 674.59 $\times$ 10^2 km^2 which respectively accounts for 40.68% and 12.63% of the global wetland area, and the proportion of marsh wetland area was the largest (The state forestry administration of the People's Republic of China 2015). The wetland plant resources are abundant in China with rich plant species and complex elements of flora. The angiosperm is the main part of the wetland plant, accounting for about 92% of the total number of wetland plants.

Wetlands are one of the most biodiverse ecological landscapes, and wetland ecosystem is also one of the most threatened ecosystems (Gao et al., 2010; Lemly et al., 2000). Due to the large scale of wetlands in space, the study of wetland is carried out by remote sensing and meteorological data, at the same time to carry out field investigation, isotope measurement, analysis of wetland area, ecological factors, and function change etc. (Barbieri et al., 2013; Goldhaber et al., 2011; Li et al., 2016). The evolution of wetlands is

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affected by the external factors (natural and social factors) in addition to its internal factors, especially human factors (Medjani et al., 2015; Puy et al., 2014; Zhang et al., 2015a). At present, the study of wetland in developed countries focuses on the change of biology and sediment, especially changes in wetland species and changes in biodiversity (Caraballo et al., 2012; Jasper et al., 2010; Kearsey et al., 2016; Reuter et al., 2010; Sullivan et al., 2016). Wetland hydrological change is the main factor causing wetland change, it is necessary to study the change of groundwater level and the relationship between groundwater and surface water for better protection of wetlands (Liu et al., 2012; Twilley et al., 2016; You et al., 2015). Affected by social factors, wetland research shows that the natural wetland area is decreasing, while the area of CW is increasing (Liao et al., 2014a). The change of wetland policy has experienced 3 stages: wetland development, policy transformation and wetland protection in developed countries, and gradually reduced the rate of wetland degradation (Kim, 2010).

The wetland has important carbon fixation and carbon storage function, which has important impacts on global climate change. The global climate change has changed the function of natural wetland, and affected the evolution of wetlands, therefore, studying wetland evolution is of great significance for addressing global climate change (Bernal et al., 2016; Garris et al., 2015; Helbig et al., 2017; Lewis & Feit, 2015; Osland et al., 2016). This paper analyzes the northeast (Including Liaoning, Jilin and Heilongjiang), North China (Including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, and Hebei), East China branch (Including Shandong, Jiangsu, Anhui, Zhejiang, Fujian, Jiangxi, Hubei, Hunan, and Shanghai), Southern China (Including Guangdong, Guangxi and Hainan), northwest (Including Ningxia, Xinjiang, Qinghai, Shaanxi, and Gansu) and southwest (Including Sichuan, Yunnan, Guizhou, Tibet and Chongqing) of the 6 regions for the study of China wetland evolution, the relevant research results provide an important basis for wetland protection, and at the same time to provide reference for relevant policy making.

2 Materials and Methods

2.1 Literature Retrieval and Analysis

The authors searched respectively journal article, dissertations and conference papers by "wetland" and"evolution" as the key words on CNKI. 1764 articles were retrieved, there are 531 articles from 2000 to 2020, and accounting for about 90.69% of the total number of articles, the mean annual published articles are stable at about 88 during the last 20 years (Fig. 1), the annual publication of the articles are below 10 before 2002. The related dissertations retrieved are 921, and there were about 858 dissertations in the last 20 years, accounting for about 93.16% of the total number of dissertations, the number of dissertations retrieved every year is about 40 in the past 20 years. The research articles including Northeast China, North China, East China, Central China, Southern China, Northwest, and Southwest regions within the past 5 years. The basins focused on the Yangtze River, the Yellow River and Songhua River. The proportion of the articles in East China accounted for more than 50% among them, which is the hot spot in the past 6 years (Fig. 2).

Searched on the web of science website with "wetland" and "navigation" as keywords, and retrieved 233 SCI (E) papers from 2000 to 2020. There are more than 10

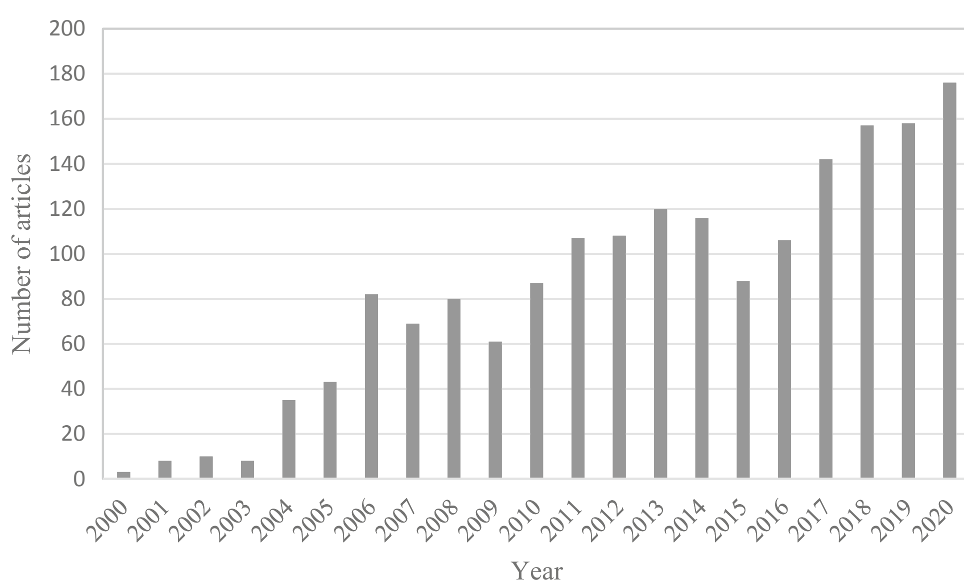

Fig. 1 The number of articles published from 2000 to 2020

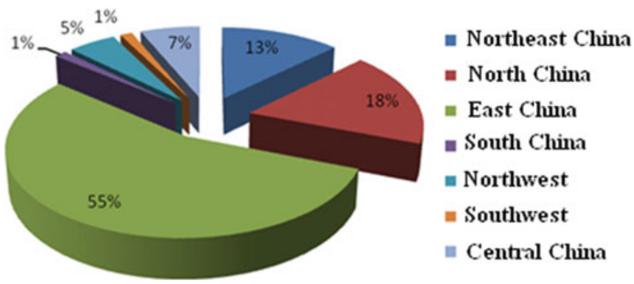

Fig. 2 Regional distribution of articles published from 2000 to 2020

papers at 2005, 2010, 2016, 2017, 2018, 2019, and 2020, and the number of papers showed an increasing trend in the past 5 years (Fig. 3).

The largest number of papers published in the United States on wetland research retrieved by SCI in the past 6 years, mainland China is in second, which shows that mainland China has carried out more wetland research in the world (Table 1).

2.2 Literature Content Analysis

The problems and shortcomings can find out in the research process by analyzing the searching literatures of data, the research methods, the analysis process, and the main research results etc. The authors carried out in-depth research on the problems of single research method, too concentrated research field, insufficient analysis depth, etc. The research results will point out the direction for the evolution of wetlands in China.

3 Results and Discussion

3.1 Wetlands of Northeast

3.1.1 Results

At present, the area of wetlands in Northeast China is 753.57×10^2 km^2, of which the proportion of CW is about 8.51%. The study found that the total area of wetlands is decreasing year by year, and most of the disappeared wetlands converted to cultivated land. The natural wetlands in the Sanjiang Plain, the CWs in the Songnen Plain and the marsh areas in the northeast all change over time (Table 2) (Mao et al., 2016). The change of landscape pattern is characterized by landscape pattern index. The coastal wetland in Zhuanghe City is rapidly deteriorating and experiencing landscape fragmentation (Li et al., 2013a, 2013b). By analyzing the changes of the main landscape elements and landscape structure of Zhalong Wetland, it was found that the swamp landscape, water area landscape, cropland landscape and grassland landscape had higher protection rates, and the transition and swamp between grassland is the main process of landscape type transfer (Gong et al., 2010).

Analysis of the temporal and spatial changes of marsh wetlands and their driving forces from 1975 to 2007. The center of Raoyang River wetland moved, and the temporal and spatial changes of paddy fields were the direct driving force. The area of marshes and wetlands was positively correlated with the river area (Sun et al., 2010). Analyzing the landscape changes of the Liaohe Estuary wetland in the past 30 years, the landscape types not changed, but the landscape pattern changed (Huang & He, 2011). Analyzing the characteristics of the water environment evolution of the

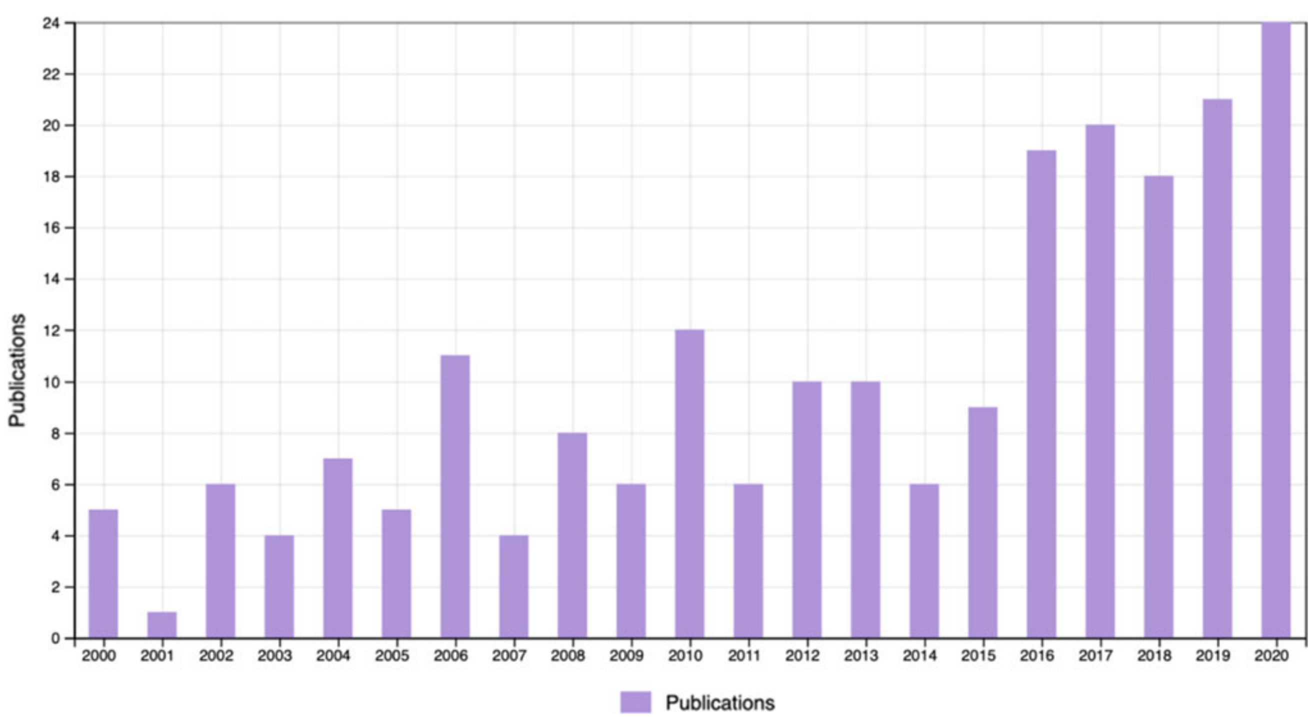

Fig. 3 The number of articles retrieved by SCI (E) from 2000 to 2020

Table 1 List of published papers on wetland research in major countries by SCI (E) in the past 6 years

Sequence number	Country	Article number	Proportion (%)	Column shape
1	USA	32	49.23	
2	PRC	13	20.00	
3	Australia	5	7.69	
4	Hong Kong, Macao and Taiwan of China	5	7.69	
5	Canada	3	4.62	
6	France	3	4.62	
7	Brazil	2	3.08	
8	Germany	2	3.08	

Table 2 List of wetland changes in different regions

Distribution area	Wetland type	Loss area (km^2)	Reason
Sanjiang plain	Natural wetland	− 9935.2	Transition to farmland
Songnen plain	CW	+ 1141.9	Opened wasteland
Northeast China	Marsh wetland	− 16,091.4	Climate change and human activity

Note "+" for the increase, "−" for the reduction

Chagan Lake wetland, the trends of alkalization and organic pollution have been serious since 2006, and the water quality has changed from Class III to Class IV. The water quality of Chagan Lake is cross-affected by discharge, endogenous release and hydrological conditions, and show significant phosphorus-restricted mesotrophic (Li et al., 2014). By the dynamic model of land, patch area, patch number and patch density and so on, it is clear in fragmentation of the landscape in the year 1988 and it will be continued in fragmentation (Cheng et al., 2012). In 1983, 1995 and 2007, the study on the changing laws of wetlands in the Yalu-river Estuary found that the reduction of wetland area led to the reduction of wetland biological living space and the corresponding degradation of ecological functions (Table 3) (Zhang et al., 2014).

3.1.2 Discussion

At present, the research data of the wetland in the northeast China are mainly from remote sensing, hydrological data and meteorological data etc., interval of data collection is mostly between 5 and 10 years, the longest up to 13 years., it affects the accuracy of the analysis results on account of the lack of field investigation and experimental data. The main research methods include RS technology, GIS technology, landscape feature index method and comprehensive evaluation method etc. The annual loss rate of wetland in Northeast China was 0.88–1.00%, and the maximum amount of the Yalu-river estuary wetland was 4.86% (Table 4). The main driving factors are human activities for decrease of natural wetland and increase of CW in northeast China, the main types of increase of paddy field area for CW area increased, and farmland reclamation, engineering construction, intensified human activity disturbance is the main reason for the wetland reduction. The change of landscape pattern is influenced by human activities, especially agricultural development, oil field development and urbanization. The reduction of marsh area in natural wetland is not only related to the hydro logical factors caused by climate change, but also closely related to human activities including water conservancy construction and land use.

3.2 Wetlands of North China

3.2.1 Results

The total area of wetland in North China is 744.81×10^2 km^2, the CW area accounted for 6.34%. Beijing, Tianjin, Hebei and Shanxi area of CW accounts for a larger

Table 3 Changes of wetland pattern in the Yalu-river Estuary from 1983 to 2007

Item	Wetland change (km^2/a)	Increase or decrease	Types of changes	Reason
Natural wetland	4.16	Decrease	Beach and reed	Industrial and agricultural production activities
CW	23.43	Increase	Rice fields and farms	

Table 4 Changes of wetland area in Northeast China

Loss area (km^2)	Various cycles (a)	Mean annual loss rate (%)	Geographical location
1.18×10^4	1990 → 2000	1.00	Wetlands of northeast (Mao et al., 2016)
1.34×10^4	2000 → 2013	0.88	
97.64	2000 → 2010	0.74	Zhuanghe coastal wetlands (Li et al., 2013a)
99.10	1975 → 2007	3.01	Raoyanghe marsh wetland (Sun et al., 2010)
90.85	1983 → 1995	4.86	Yalu-river estuary wetland (Zhang et al., 2014)
13.60	1995 → 2007	1.74	

proportion, respectively 49.75%, 48.87%, 26.26%, and 28.78%, the Inner Mongolia area of CW area accounted for a smaller proportion of about 2.19%. Affected by the economy, scholars have carried out a lot of research on North China at present, which has accumulated rich experience in the protection of wetland. Affected by the economy, lots of research were carried out on North China and accumulated rich experience in wetland protection. For example, the area of the Baiyangdian Wetland (Hebei Province) decreased, and its landscape diversity showed a downward trend. The landscape index changed greatly during 1979–1991, and minor changes were observed after 1991 (Bai et al., 2013; Zhang et al., 2016). According to the hydrological data of the Baiyangdian Wetland, during the period 1960–2003, all inflows into the wetland, precipitation in the basin, and potential evapotranspiration all showed a downward trend, and were affected by climate change, artificial water intake, and evaporative seepage processes on the changes in the wetland water intake. It is 25.1%, 57.53% and 17.4%, and the integration of all human activities has an impact on the wetland water intake of 74.9%. In addition, the Baiyangdian Lake Basin has reduced precipitation, increased temperature, reduced water surfaces and depressions, and made the ecosystem more fragile (Fang et al., 2012; Yuan et al., 2014).

Through the analysis of changes of urban Reservoir Wetland in Beijing, the driving factors in different periods are different in the past 30 years. The fractal dimension of total patch area, average patch area and landscape pattern index is selected to analyze the evolution characteristics of Beijing wetland landscape pattern. The total area of wetlands increases first, then decreases sharply, and then slightly increases. The offset of the wetland space centroid is constructed as the main form of wetlands in Beijing, and the total area of wetlands leads the trend change (Table 5) (Gong et al., 2012, 2013; Li et al., 2012). By analyzing the dynamic evolution of Beijing wetlands, it is found that the wetland patches are irregular and the degree of fragmentation is increasing. The transition probability matrix of the two main states is established (Gu et al., 2010). Six driving factors, annual rainfall, evaporation, inflow, available groundwater, urbanization rate and average daily sewage discharge, are the main factors affecting the change of wetland area in Beijing. Rainfall and evaporation affect changes in wetland area, with a contribution rate of 36.54%, and urbanization rate and average daily sewage volume affect 19.52% (Jiang et al., 2012).

Analyzed the landscape changes of TBNA wetlands in 1984–2008, the area of wetland was continuously declining during 2004 to 2008, about 13.4% of TBNA total land area was transferred from wetland into construction land, which was the main component of land use change.

By analyzing the changes of wetland landscape in TBNA from 1984 to 2008, it is found that the wetland area continued to decrease from 2004 to 2008, and about 13.4% of the total land area of TBNA was converted from wetland to construction land, which is the main component of land use change (Li et al., 2011). Since 1960s, the total quantity of water resource and water entry decreased in Tianjin City, low-lying pond and marsh wetland area were reduced (Qin, 2012). Remote sensing data from Tangshan City show that the dynamic changes and landscape pattern evolution from 2000 to 2010 show that the total area of wetlands has decreased, and the wetland morphology has become complex and fragmented (Hu & Ye, 2014).

3.2.2 Discussion

At present, the main data for wetland research in North China mainly comes from remote sensing images, hydrological data and aerial photos, mainly through GIS, RS and mathematical model analysis. Some researchers collected longer data, the longest being 13 years. In addition, site surveys and field sampling experiments have less data, which brings difficulties to quantitative analysis and makes the research results deviate from the actual situation. The focus of current wetland research in North China is mainly in the Beijing-Tianjin-Hebei region. The types are mainly natural wetlands such as river wetlands, coastal wetlands, lake wetlands, swamp wetlands and some CWs. The annual loss rate of wetland in North China is 0.19–5.56%, mainly due to the natural wetland area reduction. The area of CWs has generally increased, and the mean annual increase of wetlands in Beijing reservoirs is about 4.8% (Table 6). Compared with other regions, there are more researches on

Table 5 The centroid deviation of wetland in Beijing

Date	Wetland type	Offset	Reason
1984–1998	River Wetland	Northeast offset 10.43 km	Adequate precipitation
1999–2006	River Wetland	Southwest offset 10.75 km	Continuous drought and many unreasonable exploitations
After 2006	Pond paddy wetland	Shifts southerly	Effect of “converting paddy drought” policy
2008	Park Wetland	To the north of Haidian District offset	The construction of the Olympic Forest Park

Table 6 The change of wetland area in North China

Loss area (km^2)	Various cycles (a)	Mean annual loss rate (%)	Geographical location
66.10	1979–2006	0.61	Baiyangdian wetland (Bai et al., 2013; Zhang et al., 2016)
34.35	1984–2013	0.47	
− 4.8	1984–2010	− 0.18	Beijing Reservoir Wetland (Li et al., 2012)
314.54	1996–2005	5.56	Beijing Wetland (Gu et al., 2010)
370.02	1984–2008	1.41	Tianjin Coastal New Area Wetland (Li, 2011)
24.11	2000–2010	0.19	Tangshan City wetland (Hu & Ye, 2014)

Note “−” for wetland area increase

CWs. From the research results, the level of socio-economic development, total population, agricultural development, and the change of climatic conditions are the main driving forces for the changes in the wetland landscape pattern in North China.

3.3 Wetlands of East China

3.3.1 Results

The total area of the wetland in East China is 804.78×10^2 km^2, which accounts for about 15% of the wetland area in China, and CW accounts for more than 31.29% of the wetland area, which is higher than that in other regions. The analysis of wetlands in Anhui section of the Yangtze River shows that after 2000, the area of floodplain wetlands and artificial aquaculture increased, the area of lakes, permanent rivers and herbaceous swamps decreased (Yang et al., 2011). It is predicted wetland area to biome area ratio was different in Chongming east beach, Nanhui side beach and Jiuduansha under three different scenarios (ecological protection, current situation trend and enhanced reclamation) in 2020 (Table 7) (Li et al., 2015a).

The changes of the mangrove wetland landscape pattern in Luoyang Estuary of Fujian Province were analyzed. It was found that the landscape indicators such as the number of patches, spacing, area-weighted average shape index, and fractal dimension of perimeter area first increased and then decreased; the average patch area showed an opposite trend (Cui et al., 2010). The change of landscape pattern of wulongjiang River Wetland in the last century are quantitatively studied. The total area is in a slight decline state, the degree of landscape heterogeneity reduced, and various changes can be observed (Li and Fan 2012).

The change and forecast trend of wetland in Pudong New Area are analyzed. It was found that the wetland area in Pudong New Area is decreasing. Through the analysis of wetland thematic information, the evolution of coastal wetlands in the southeast of Laizhou Bay in the past 30 years is characterized by the first increase and then the decrease of natural wetlands. Through the analysis of the geomorphic evolution of Chongming Dongtan wetland in the past 60 years, the wetland area increases year by year with human reclamation, but the intertidal structure of the wetland deviates from the natural state, and the proportion of high tide beach decreases (Sun et al., 2011; Zheng et al., 2013; Zhu et al., 2015).

The spatiotemporal characteristics and driving forces of wetlands in the eastern part of Pinghu from 1987 to 2009 are studied. The results showed that the natural wetlands are shrinking and the CWs are growing (Wang et al., 2014). The Nansi Lake wetland dynamic characteristics were analyzed, indicating a decreasing area of the natural wetland and a increasing area of CW from 1982 to 2012 (Fan et al., 2014). Wetland distribution changes were analyzed using landscape gradient and grid models. From 1987 to 2014, the Nansi wetland area gradually increased. The lake area decreased first and then increased, the coastal pond area gradually increased, and the marsh area continued to decrease during this period. From 1987 to 2014, the total area of Nansi wetland gradually

Table 7 Prediction of tidal flat wetland evolution in Changjiang Estuary

Estuarine wetland's location	Characteristic	Total area change (km^2)	Community area ratio
Chongming Dongtan, Nanhui Biantan and Jiuduansha	Ecological protection	+ 56	46:34:20
	Current trends	+ 44	38:38:24
	Intensified inning	− 7	38:37:25

Note "+" for the increase, "−" for the reduction

increased. The lake area first decreased and then increased, and the pond area along the riparian zone gradually increased, while the area of swamp continuously decreased during this period. From 1980 to 2012, the Nansi Lake wetland land use change was slow, but the ecosystem service value decreased. The increase of construction land area is mainly due to the urbanization effect and the decrease of tidal swamp and water area, which leads to the decline of ecological value in this area (Chen et al., 2016; Yang et al., 2014).

Wetlands decreased by 23.15%, and the land system faced the risks of low proportion of wetlands, scarce unused land and broken landscape. The regional sustainability has decreased to a poor level since 2010. In order to analyze wetland landscape changes in the middle reaches of the Huaihe River Basin, a great number of wetlands are transformed into paddy fields and non-wetlands, and some natural wetlands are transformed into CWs. The quantitative structure and spatial variation of Poyang Lake wetland area were analyzed. The results indicated that the fractal degree and dominance index of Poyang Lake wetland landscape pattern decreased, and the diversity index and fragmentation degree increased. This paper analyzes the evolution status of Poyang Lake Wetland affected by comprehensive physical and human factors, land desertification, intensified water pollution, sharp reduction of biological resources and serious degradation (Hu, 2011; Wu et al., 2013; Xiao et al., 2010; Yang et al., 2015).

By analyzing the evolution trend of the two coastal areas in Jiangsu Province, it has mainly changed from natural wetland to CW and non-wetland in the past 30 years (Hao et al., 2010). Through the change analysis of Yancheng Coastal Wetland National Nature Reserve and core area of Spartina alterniflora swamp, the area of Spartina alterniflora swamp increased from 2000 to 2011, and the mean size and aggregation index showed a downward trend (Table 8). Soil analysis results showed that the evolution of coastal wetland in Yancheng Nature Reserve is driven by the interaction of pattern and process, the expansion of reed swamp and rice grass swamp and the shrinkage of sedge swamp. Soil water content and salinity analysis of coastal wetlands showed a decreasing trend from straw marsh to salsa and reed (Zhang et al., 2011, 2012a, 2012b, 2013a, 2013b, 2013c).

Yancheng coastal wetland landscape changed significantly from 2002 to 2011, in which reed wetland increased by 3 times, Suaeda salsa wetland decreased by 15.29%, and rice grass wetland increased by more than 50% (Hou et al., 2013). Many original natural landscape types were transformed into artificial landscape types in erosion, transition and deposition areas from 1992 to 2010 (Fang et al., 2014). The research on the natural vegetation succession process of Yancheng coastal wetland and the evolution of soil quality after farmland reclamation showed that the physical, chemical and biological properties of wetland soil had been improved, which was reflected in the improvement of soil physical properties and the increase of soil nutrient content, microbial biomass and enzyme activity (Mao et al., 2010). The study of Yancheng coastal wetland shows that in recent 30 years, the wetland area has gradually decreased, and the CW construction land and cultivated land area has gradually increased. Wetland reclamation has become the most powerful reason for the evolution of Yancheng coastal wetland (Yan et al., 2012).

By analyzing the evolution of wetlands in the intertidal zone of northern Jiangsu in the past 30 years, the proportion of wetlands renovated is 38.39%, and the proportion of wetlands that have disappeared is 14.97%. Natural wetlands decreased by 354.1 km^2, while wetlands increased by 1061.45 km^2 (Liao et al., 2014a). In order to study the spatial dynamics of coastal wetlands and reclamation areas in central Jiangsu, the key ecological areas of coastal wetlands in Jiangsu decreased rapidly from 1977 to 2014, and the shrinkage of natural halophytes in southern Sheyang County and Dafeng County (Li et al., 2015b). To quantify the dynamic changes in wetland landscape patterns from 2002 to 2013, the results show that the wetland area in Yangzhou decreases, and the wetland landscape pattern in Yangzhou tends to be fragmented and more complex (Table 9) (Xu & Ye, 2015).

3.3.2 Discussion

Under the influence of regional economy, there are many studies on the distribution of wetlands in eastern China, especially inland wetlands and coastal wetlands such as the Yangtze River, the Yellow River, Shandong and Jiangsu. The main data comes from remote sensing, survey data, satellite data and sampling data. Remote sensing, RS and GIS technology, landscape index and mathematical model methods are mainly used. The time interval of collected data

Table 8 Spatial–temporal evolution characteristics of coastal wetland landscape in Yancheng

Item		Date (a)	Variety (%)
landscape structure	Natural wetland	1987–2007	42.45 → 21.44
	CW	1987–2007	18.19 → 58.88
Wetland transfer	Natural wetland → CW	1987–1997	45.40
	Natural wetland → CW and the non-wetland	1997–2007	37.91
Erosive coastal wetland	Mudflat	1987–2007	76.91 → 60.86
	Salsa wetlands	1987–2007	18.68 → 0
	Reed wetland	1987–2007	4.42 → 15.85

Table 9 Characteristics of wetland change in Yangzhou

Wetland type	Date	Area (km^2)	Rising and falling range (%)	Driving factors
Wetland	2002 → 2007	− 13.69	− 1.1	Economic development, increasing population, changes in the proportion of secondary industry and annual precipitation
	2007 → 2013	− 43.23	− 3.3	
River	2002 → 2013	− 9.64	− 5.6	
Beach	2002 → 2013	39.05	+ 73.2	
Pond	2002 → 2013	40.43	+ 6.2	
Lake	2002 → 2013	− 126.76	− 29.7	

Note "+" for the increase, "−" for the reduction

is long, mostly about 10 years, and the accuracy of analysis results is low. Statistics show that the annual loss of wetlands in eastern China is 0.26–1.67%, and the natural wetlands are gradually decreasing. Affected by economic benefits, the area of CW is increasing, with a mean annual growth rate of 1.8–5.95% (Table 10).

The current research on wetland types is mainly natural wetlands in coastal wetlands, river wetlands and lake wetlands. The results show that the landscape index, patch area, patch shape and land use pattern change dynamically, the wet geological center shifts, and coastal wetland landscape changes greatly. Compared with natural wetlands, there are fewer studies on CWs. According to the research results, the main driving factor for the decline of natural wetlands in eastern China is human activities.

3.4 Other Regions of China

3.4.1 Results

Except for the Northeast, North China and East China, the wetland area in other regions is 3038.90 × 102 km^2, and the CW area accounts for about 10.25% of the total wetland area. The wetland area in this region accounts for more than 50% of the China, and the natural wetland area accounts for 56.05% of the total area of natural wetlands in China.

By studying the evolution of coastal wetland landscape pattern in Zhuhai from 1988 to 2008, it is found that the total area of coastal wetland landscape has decreased significantly by 146.89 km^2 in the past 20 years, and the dynamic change of wetland landscape is very significant. Among them, the rice fields and shallow water areas are the most obvious and heterogeneity gradually increases (Liu et al., 2011). Through the dynamic analysis of wetland landscape in Shudu Lake Basin in the past 56 years, it is found that lakeside swamps and swamp meadows have decreased, and landscape diversity and uniformity have decreased (Li et al., 2013b). The total area of urban patch wetlands in Changsha City showed an increasing trend, the area of patch wetlands less than 32 ha increased, and the area of patch wetlands greater than 32 ha showed an opposite trend (Gong et al., 2012). The results indicating the health status of Dongting Lake wetland ecosystem showed a downward trend before 2003, and then gradually recovered (Liao et al., 2014c). The area of Futou Lake Wetland Lake and the area change most obviously, and the dynamic change characteristics of different wetland types are different. The two-way dynamic changes of CW types are more obvious, and they are greatly affected by human activities (Tang et al., 2011). The results show that the natural wetland in Yinchuan Plain shows a radiation attenuation trend from area to the whole, and the CW shows a gradual increase trend (He, 2016; Zhang et al., 2015b).

3.4.2 Discussion

There are few other wetland research fields, except Northeast China, East China and North China. The main data comes from remote sensing images, topographic maps and census data in the research literature, mainly using GIS, land use

Table 10 The change of wetland area in East China

Loss area (km^2)	various cycles (a)	Mean annual loss rate (%)	Geographical location
491.44	1982–2012	1.38	Nansihu Lake Wetland (Fan et al., 2014)
− 50.88	1987–2009	− 1.80	Dongping Lake Wetland (Wang et al., 2014)
120.25	1975–2007	− 0.26	Natural wetland in Anhui section of Yangtze River (Yang et al., 2011)
− 292.02	1975–2007	− 5.95	CW in Anhui section of Yangtze River (Yang et al., 2011)
303.2	1989–2013	0.68	Pudong New Area wetland (Zhu et al., 2015)
713.09	1987–2007	1.67	Jiangsu coastal wetland (Zhang et al., 2012a)
24.6	2000–2011	− 4.7	Yancheng Spartina marsh wetland (Zhang et al., 2013b)
354.1	1980–2008	0.91	Northern jiangsu coastal beach wetland (Liao et al., 2014b)

transfer matrix, landscape pattern index model and grey relational analysis methods. Some research documents are few, and the data collection interval is longer, about 10 years, and the longest can be up to 17 years.

According to the research literature, the wetland types in this area are mainly plateau wetlands, coastal wetlands and lake wetlands. From the research results, in addition to some wetlands that are greatly affected by natural factors, the main factors that cause the wetlands reduction and the CWs increase are the reclamation of lake bottoms, planting crops, and fish pond construction. Research on the evolution of natural wetlands has not been carried out regularly, resulting in a lack of data. In addition, research on wetlands in remote areas such as Xinjiang, Tibet and Qinghai are relatively small and needs to be strengthened.

4 Conclusions

Studies on the development of wetland in China, the main conclusions are as follows:

(1) The number of SCI(E) papers in China ranked second in the world according to the literature, behind the United States.
(2) The study sites are mainly in East China and North China, other regions especially in remote areas of Xinjiang, Tibet and Qinghai of research is less. The river basins focused on the Yangtze River, the Yellow River, Songhua River, and Huaihe River Basin. The national, provincial wetland protection areas and large coastal wetlands are the focus of attention.
(3) The main research methods include remote sensing, GIS, landscape index and mathematical model, etc., the study of some wetlands is based on field investigation, sampling analysis and isotope tracing analysis. In view of the overall situation, the current data collection is limited and the research method is single.
(4) The natural wetland area in China is decreasing in general, the mean annual reduction rate is between 0.19 and 1.67%, the overall natural wetland biodiversity is decreased, the decrease of water level is obvious, and there is a trend of degradation.
(5) The area of CW increased significantly in China, the mean annual increase is between 1.80 and 5.95%, the increase of CW area is mainly paddy field. Few researches on the CW function, which need strengthen.
(6) The total number of natural wetland patches showed an increasing trend because of human disturbance, but the mean patch area decreased significantly, the patch shape tends to be irregular, and the connectivity between plaques tends to be worse. The degree of wetland fragmentation is on an obviously increasing trend.

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