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Review of Rapid Transformation of Floodplain Wetlands in Northeast China: Roles of Human Development and Global Environmental Change

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Abstract: Northeast China is the region with the largest area of wetlands in China. The Sanjiang Plain and the Songnen Plain are large freshwater marsh distribution regions that are affected by climate warming and by the increasing frequency and density of extreme weather and are the regions most subject to disturbances by human activities in Northeast China. The wetlands of the Sanjiang Plain and the Songnen Plain have shrunk severely in the past 60 years, and wetland functions have been reduced substantially because of climate change, unreasonable land use, fire episodes, engineering and construction works and urbanization. Large-scale agricultural development started in the 1950s has been the most important driving factor for wetland loss and degradation in the Sanjiang Plain. Water shortage has been the most important factor for degradation and fragmentation of wetlands in the Songnen Plain. To mitigate wetland degradation and better protect wetlands, special regulations, long-term mechanisms and technical support of wetland protection should be established. A wetland compensation program should be implemented, and technologies for increasing the adaptive capacity of wetlands should be developed. Moreover, it is most important to find the balanced threshold between agricultural development and wetland protection.

Keywords: wetland; climate change; human activities; wetland recovery; Sanjiang Plain; Songnen Plain

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1 Introduction

China holds some of the world's largest river systems (e.g., the Yangtze (Changjing) River) and vast numbers of associated floodplain wetlands. The total wetland area of China is 3.85×10^7 km^2, which ranks first in Asia and fourth in the world. Natural wetlands occupy 94.06% of the total wetland area, with an area of 3.62×10^7 km^2 (Lu, 2008). The livelihood of more than 300 million people depends on China's natural wetlands, and the annual ecosystem service value of these wetlands accounts for 54.9% of China's total (Wang and Wu, 2012).

Northeast China is the region with the largest area of wetland distribution and the most types of wetlands in China. The total area of wetlands in Northeast China is 1.06×10^7 km^2. Natural wetlands occupy 67.83% of this area, with an area of 7.19×10^6 km^2 (Zhang and Liu,

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2006). Northeast China's wetlands provide a significant amount of ecosystem services, including freshwater supply, flood control, water purification, wildlife habitat, aquatic life preserves and barriers for sandification. Wetlands in Northeast China can be divided into the Sanjiang Plain wetlands, the Songnen Plain wetlands, the Liaohe River wetlands, the Da Hinggan Mountains wetlands, the Xiao Hinggan Mountains wetlands, and the Changbai Mountains wetlands. Among these wetlands, the Sanjiang Plain wetlands and the Songnen Plain wetlands are most seriously disturbed by human activities.

Northeast China is located at high latitude in eastern Eurasia, which is one of the places on the earth that is most vulnerable to the effects of global warming. In the past 100 years, the air temperature of Northeast China has increased 2℃ (Lu, 2008). In the past 60 years, the air temperature has increased 0.36℃ every 10 years (Dong and Wu, 2008), significantly higher than the national average increase level of 0.22℃ every 10 years (Ren et al., 2005). Northeast China has become the fastest warming area in China. Recently, extreme weather events have occurred frequently in Northeast China. In June to mid-August 1998, heavy rainfall in the Nenjiang River caused a flood in the Songhua River mainstream, which was the largest flood in China in the 20th century. From February to June 2004, a once-in-a-century drought in spring and summer occurred in the west of Northeast China and the east of Inner Mongolia. In late June 2010, high temperature reaching an extreme event standard occurred over a large range of Northeast China and the northeast of Inner Mongolia. In mid-November 2012, the largest snowfall since 1951 occurred in three provinces of Northeast China and the eastern part of Inner Mongolia, with average snowfall 3 times greater than the average snowfall of the same period in other years.

At the beginning of the new Chinese regime, influenced by an emphasis on production and agricultural policy, an extensive reclamation program was undertaken. In the 1960s, due to natural disasters and human factors, large areas of wetlands were reclaimed in order to revive the economy and improve the standard of living. In the early 1990s, livestock product prices declined, while food prices were protected by the state. As a result, a new period of reclamation occurred. Thus, because of the large-scale development, there was a rapid expansion of cultivated land area in Northeast China (Liu, 2006). The areal statistics of important wetlands in Northeast China at different times are shown in Table 1.

In the past 60 years, the wetlands in Northeast China have been affected both by natural changes and human activities. The wetland area is decreasing, and the main ecological function has declined. According to the survey results of the Chinese Academy of Engineering, the marsh area of Northeast China has declined by 42.4% from the 1950s to the 2000s. The wetlands of the lower reaches of the Nenjiang River, including the Zhalong, Xianghai and Momoge Wetland National Nature Reserves, are facing shrinkage and eutrophication. The wetland area of the Sanjiang Plain has decreased significantly. The Liaohe River wetlands have also experienced severe degradation.

According to the sixth national population census (2010), the total population of Northeast China is about 109 million people, accounting for approximately 7.99% of the population of China. Northeast China is an old industrial base, a commodity grain production base and a forestry and animal husbandry base. In 2012, Northeast China contributed approximately 9.72% of the gross domestic product of China. At present, the Northeast agricultural production is developing towards commercialization, specialization, regionalization and

Table 1 Areal statistics of important wetlands in Northeast China at different times (Mao et al., 2016) (km^2)

Wetland region	Natural wetland			Constructed wetland		
	1990	2000	2013	1990	2000	2013
Da Hinggan Mountains	50904.5	49932.3	49925.9	213.3	168.4	288.3
Xiao Hinggan Mountains	9575.6	9013.8	9520.5	96.4	121.2	172.8
Changbai Mountains	2975.2	2923.8	2788.0	994.9	1090.9	1147.8
Sanjiang Plain	19894.1	12273.9	9958.9	505.5	625.2	731.3
Songnen Plain	24465.5	21855.9	20413.5	1595.6	1462.6	2737.5
Liaohe River	4712.1	4036.1	3269.3	2044.8	2188.1	2384.7

industrialization. An industrial belt of advantageous agricultural products with different characteristics has been formed. Meanwhile, developing agriculture and increasing population made severely impacts on the environment of wetlands including degradation and loss of marshes and the pollution stemming from excessive use of agricultural fertilizers and pesticides (Zhou and Liu, 2005; Cui et al., 2014).

The northeast region is an important industrial base in China. There has been large-scale exploitation of coal, iron, nonferrous metals and non-metallic minerals for 100 years, and the large-scale exploitation of oil and natural gas has occurred for 40 years. The mining industry has made enormous contributions to the national economy but at the same time has created a number of serious environmental pollution problems (Liu, 2006).

From a management perspective, the state has not issued special regulations about wetland protection. Long-term mechanisms have not been established, and the technical support for wetland protection is also weak. The whole social awareness of wetland protection needs improvement.

The purpose of this study is to review the important natural and human factors affecting wetland ecosystems in Northeast China and to provide theoretical support and management strategies for the protection of wetland ecological systems under the influence of climate change and human disturbance.

2 Wetland Changes

2.1 Wetland Changes in the Sanjiang Plain

The Sanjiang Plain, an alluvial plain of the Songhua River, Heilong River and Wusuli River in Heilongjiang Province of China, is considered as the typical representative of wetlands in the northeastern China. The total area of the Sanjiang Plain is about 108 829 km^2. The climate is temperate humid or sub-humid continental monsoon climate, with a mean annual temperature of 1.4–4.3℃, frost-free days of 130–145, and a mean annual precipitation of 450–700 mm (Zhou and Liu, 2005; Wang et al., 2006). There are three major topographic areas: 1) low mountains, 2) slopes, low hills and terraces, 3) alluvial plains (floodplains). The mainly types of soil are meadow soil, lessive, swamp soil and black soil (Wang et al., 2006)

Eight wetland nature reserves have been established in the Sanjiang Plain (Wang et al., 2006; Zhang et al., 2011). Three of these reserves are of international importance and have Ramsar site numbers: 1) Sanjiang National Nature Reserve (Ramsar site No. 1152) covers approximately 1644 km^2; 2) Honghe National Nature Reserve (Ramsar site No. 1149) covers approximately 218 km^2; and 3) Xingkai Lake National Nature Reserve (Ramsar site No. 1155) covers approximately 2225 km^2 (The Ramsar Convention on Wetlands 2002).

As miniature versions of the Sanjiang Plain wetlands, the Sanjiang National Nature Reserve, the Honghe National Nature Reserve and the Xingkai Lake National Nature Reserve maintain almost the whole plant biodiversity of this area, and all basic types of plants can be observed in the three reserves.

Between 1835 and 1942, *Carex lasiocarpa* and *Drepanocladus aduncus* were the dominant species in the Honghe wetland, accompanied by *Equisetum fluviatile* and *Menyanthes trifoliate*. Some *Carex pseudocuraica* appeared in the wetland. From 1942 to 1990, larger amounts of *D. aduncus* dominated the wetland and reached a maximum at 1963, along with a decrease of *C. lasiocarpa*. *Carex* sp. was also dominant during this interval. *C. pseudocuraica* was present from 1942 to 1953. *E. fluviatile* and *Menyanthestri foliate* both decreased during this period. From 1990 to 2009, the dominant species were *C. lasiocarpa* and *Carex* sp. *Menyanthestri foliata* disappeared while *D. aduncus* drastically decreased from 1990. *E. fluviatile* became extinct. *C. pseudocuraica* began to grow in 1990 and reached a maximum in 2009, but it was not the dominant species.

C. lasiocarpa marsh is the representative type of wetlands with a wide distribution area in the Sanjiang Plain, and the change of this species is a significant representative of the situation in the Sanjiang Plain. In the 1970s, *C. lasiocarpa* marshes were widely distributed in the lower river floodplains and riparian areas. Due to the perennial flooding with water depths of 60–70 cm, the root layer was well developed, floating like a drifting raft. The stems were tall and stout, with an average height of 73 cm. The distribution area has been reduced by more than 4/5 at present, and the surface water has been greatly reduced or even dried out in the drought years. Now, the stems are low and small. According to survey data from 2003 to 2004, the mean height was 40.5 cm and the biomass was 403 g/m^2, reductions of 33.2 cm and nearly 30%, respectively, compared with 50 years ago (Lu, 2009). The species richness is 6.7/m^2 at present, a reduction of nearly 1/m^2 (Ji et al., 2004).

There were once thousands of *Cygnus cygnus*, hundreds of *Grus japonensis* and nearly one thousand *Ciconia boyciana* in the Sanjiang Plain. Due to over-exploitation of wetlands and extensive human activity, the number of waterfowl sharply declined. Compared with the records of the 1960s, more than 90% of waterfowl have now disappeared. For example, the number of birds in the Honghe National Nature Reserve reduced by 1646 from the years 1995 to 2004, and the population density decreased by 0.6777 ha. The changes of numbers of *C. boyciana* are shown in Table 2. The biodiversity index decreased from 3.9464 in 1995 to 3.5724 in 2004 (Lu et al., 2009).

Before the 1950s, the original state of the Sanjiang Plain was lush plants and abundant marshes. The locals living along the rivers fished for a living, and only a few people engaged in extensive farming activities in the mountains and island-shaped highlands. After the 1950s, large-scale wetland reclamation occurred in the Sanjiang Plain (Zhang et al., 2001a). From the late 1950s to the early 1990s, the wetlands in the Sanjiang Plain were severely reclaimed to farmlands, resulting in an 80% loss of wetlands (Liu and Ma, 2002). The wetland area was 48 984 km^2 in 1949 and 23 932 km^2 in 1975. The area of wetlands decreased by 38% from 1976 to 1986, by 16% from 1986 to 1995, and by 31% from 1995 to 2005 (Song et al., 2014). The wetland distribution in the Sanjiang Plain in the 1950 and 2012 are shown in Fig. 1.

In addition, agricultural development has led to the former contiguous wetlands becoming isolated and fragmented. Construction of drains and roads caused a lowering of wetland water levels and the drying up of rivers, which affected the water supply of wetlands and resulted in serious degradation. Consequently, species have lost resource distribution areas and habitats.

Gao et al. (2014) studied the 150-year historical changes in concentrations of pollution elements (Pb, Cu and Zn) in sediment profiles from four wetlands in the Sanjiang Plain and found that human activities, especially the rapid development of cities, have caused a gradual increase in the concentrations of heavy metals since the 1960s and a dramatically increasing trend in the most recent years.

2.2 Wetland changes in the Songnen Plain

The Songnen Plain, a fragile ecozone of semi-humid to semi-arid climate between the Songhua River and the Nenjiang River, is located in the northeastern China. The total area of Songnen Plain is 1.87 × 10^5 km^2, including 32.31 million people (Zhang et al., 2012). The average annual temperature of this area is 3.4–6.4℃, and the average annual precipitation is 400–450 mm. In addition, the soil of the Songnen Plain can be divided into seven forms, including black soil, chernozem, meadow soil, swamp soil, halic soil, sandy soil, and paddy soil (Wang et al., 2004). Because of special natural environmental characteristics such as clay alluvial parent materials, a low basin and many rivers, many alluvial plain marsh wetlands were formed there (Fig. 1) (Bai et al., 2008). Famous wetlands, including the Zhalong wetland, the Xianghai wetland, the Momoge wetland, the Horqin Wetland, and the Chagan Lake wetland, are distributed in the Songnen Plain. Moreover, the Xianghai wetland and the Zhalong wetland have been listed as 'international important wetlands'. *Phragmite saustralis*, *Carex* sp. and *Typha orientalis* are the dominant wetland plants in the Songnen Plain. Rare and endangered waterfowl are found in the Songnen Plain, and the marsh wetlands provide habitats for them. These

Table 2 Numbers of *Ciconia boyciana* in Sanjiang Plain (Lu, 2008)

Year	Honghe National Nature Reserve	Sanjiang National Nature Reserve	Changlin Island National Nature Reserve	Xingkai Lake National Nature Reserve	Other sites	Total in Sanjiang Plain	Total in Heilongjiang Province
Pre-1990	200–400	100–150	200–300	20–50	30–50	550–950	730–1220
1970–1980	100–200	30–50	–	10–20	30–50	170–320	280–470
1981–1985	30–40	30–40	–	6–10	8–10	74–100	120–170
1986–1990	6–10	4–6	–	4–8	8–10	22–34	50–60
1990–1995	10–20	4–6	–	8–10	8–10	30–46	50–70
1996–1999	20–30	6–10	–	6–8	8–10	40–58	80–100

Note: '–'means no data

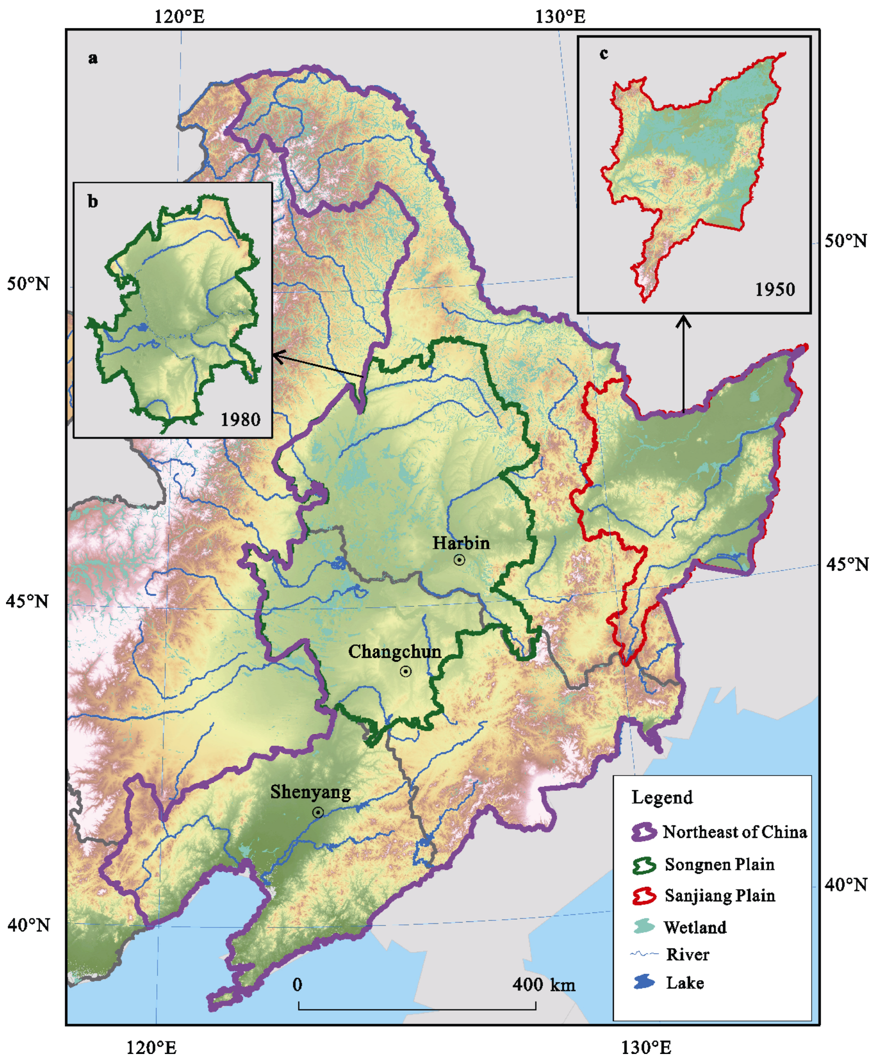

Fig. 1 Wetland distribution in Northeast China in 2012 (a), Songnen Plain in 1980 (b), and Sanjiang Plain in 1950 (c)

wetlands also control floods, purify pollutants and aid regional ecological safety. However, in the past several decades, many of the wetlands in the Songnen Plain have been greatly degraded and fragmented, and climate change, intensive human activities and water shortages are the most direct and important causes. The marsh area decreased from 5604 km^2 to 3204 km^2 from 1954 to 2000. The annual loss rate of marsh area was 1.48% from 1954 to 1976 and 0.76% from 1976 to 2000 (Huang et al., 2007b). This has led to reduction or loss of ecological service functions, and most birds or fishes have disappeared due to habitat loss (Bai et al., 2008). The distribution of wetlands in the Songnen Plain in the 1980 and in 2012 are shown in Fig. 1. Salinity and alkalinity of wetlands and water pollution of wetlands are also serious problems in the Songnen Plain.

3 Driving Forces

3.1 Climate

The study of Piao et al. (2010) showed that the overall mean temperature of China has significantly increased in past 50 years. Northeast China is the largest warming place, with decreasing precipitation trends. Further, according to predictions, continuous warming will occur in Northeast China well into the 21st century. Given larger increases in temperature and small increases or even slight decreases of precipitation, evaporation is bound to increase. Human water requirements will increase because of climate warming, which will further reduce the supply of water and draw down the water area or surface water levels of wetlands. The wetlands in Northeast China are mainly supplied by precipitation. For example, the shrinkage of the Da'an wetlands in the West Songnen Plain is driven by climate warming and drying (Li et al., 2009).

Zhang et al. (2001a) found that the wetland area change in the Sanjiang Plain is highly correlated with climate warming and drying trends, with a positive correlation with temperature and negative correlations with humidity and precipitation. The spatial distribution of wetlands in Heilongjiang Province is correlated with latitude (temperature) and longitude (humidity), and accumulated temperatures above 10℃ inhibit the formation and development of wetlands (Liu et al., 2005). Therefore, the projected climate warming would decrease the wetland area due to increased evaporation and water supply shortages (Gui et al., 2010).

In addition to climate warming, extreme droughts with greater frequency and intensity will further reduce the water supply and the area of wetlands. A 3-year continuous drought (1999–2001), coupled with increased human consumption of water, resulted in the complete drying up of many wetlands in the Sanjiang Plain, with groundwater levels dropping from 3–5 m to approximately 1–2 m and large areas of reed and sedge wetland being degraded (Pan et al., 2003).

Wetland water quality is affected by climate change. There are certain relationships between the concentrations of F^-, Na^+, HCO_3^- and pH and temperature and precipitation (Chen et al., 1999; Wang and Zhang, 1999; Zhang et al., 2001b).

Biodiversity is affected by climate change as well. Under the influence of climate warming and drying, shrinking wetland areas result in the reduction of habitats and biodiversity. Extreme weather events affect biodiversity through habitat destruction (Gui et al, 2010). Lu et al. (2000) found that precipitation change has significantly affected vegetation succession in the Momoge wetland of the Songnen Plain in recent years. The variety and amounts of wetland birds have decreased due to the impact of climate warming and drying. For example, the number of bird species in the Zhalong wetland was reduced from 61 in 1984 to 42 in 1999, and the number of birds decreased from 13 620 to 4555. The number of wetland bird nests in the Momoge wetland was reduced from more than 50 during 1999–2001 to 3–4 at present. The number of swans also tended to decrease (Tong and Lu, 2007).

3.2 Fire episodes

Fire episodes are common in wetlands. It is considered as an important part of wetland ecosystem, with a broad impact on the structure and function of wetland ecosystems. For instance, fire episode will affect the plant community (structure, biomass, function, *etc*.), the physical, chemical and biological characters of soil and water, the nutrient cycling of wetland ecosystem, and the habitat for wildlife (Zhao et al., 2010). A study classified fire severity as three levels (low severity, medium severity and high severity) according by remnant vegetation cover of approximately 75%, 25% and 5%. According to whether prescribed or not, fires of wetlands also can be classified as peat burns, root burns, and cover burns. Different frequency, intensity and fire extent will have different impacts on wetlands. The conditions of wetlands (e.g., water and soil conditions, water levels) will also affect the response to fire episodes (Nyman and Chabreck, 1995; Salvia et al., 2012).

Several fires of varying degrees occur every spring in the Zhalong wetland. Three fires occurred in 2001 and burned approximately 200 km^2 of reed. A severe fire occurred in March 2005, and another fire with less burning area occurred again when reeds began to germinate in May of the same year. Studies showed that the biomass of the forest marsh increased from 466 g/m^2 to 611–1 315 g/m^2 after the fire in the Da Hingan Mountains, with an average increase of 296 g/m^2 (Yang et al., 1995). For the Zhalong wetland, the impact of the fire on non-flooding and seasonal flooding habitats was significant and caused serious degradation of reed vegetation, while the short-term impact on the perennial flooding habitat with water depths over 30 cm was insignificant. Fire leads to a progression from reed marsh to reed meadow and even to meadow steppe (Shao et al., 2012). Fire can also kill wild animals and destroy wildlife habitats. For example, a fire that occurred in 2001 not only destroyed a large area of wetland vegetation but also destroyed the habitats of red-crowned cranes and other waterfowl in the Zhalong wetland. In addition, burning fires have a significant impact on soil properties and greenhouse gas emissions in marsh wetlands (Zhao et al., 2010).

3.3 Land use

With the rapidly development of human activities, some wetlands in Northeast China has significantly changed. For instance, the paddy field and artificial wetland in Huolinhe catchment has gradually shrunk recently years. On the contrary, the area of natural wetland appeared a contrary situation (Bai et al., 2004). According the study of Wo and Sun (2010), during 1995–2004, the grassland, farmland, reed swamp, residential area and alkaline land present increasing trend which confirm that the impact of agricultural and livestock on wetland become severe.

So, we simply summarize the forms of land use of wetlands in Northeast China: reclamation, over-drainage and grazing. These will be illustrated as follows:

Historically, because of the underestimation of wetland functions and values, large areas of wetlands have been converted to farmlands, resulting in the serious loss of wetlands in Northeast China. Reclamation of natural wetlands has been an important cause of wetland loss and degradation in the Sanjiang Plain during the past 60 years. A large growth of regional population is the most direct and the most important driving factor for natural wetland reclamation. Large-scale agricultural development lasting for 60 years has caused the loss of a large area of natural wetlands and triggered a series of regional environmental problems (Liu and Ma, 2002).

The over-drainage of marshes and enclosed lakes for reclamation in the Songnen Plain directly resulted in the conversion from natural wetlands to paddy fields and dry lands. Irrigated rice planting in saline areas caused drawdown of the surface water levels and groundwater tables in wetlands by unreasonable extraction of groundwater, which resulted in the loss or degradation of wetlands, with large areas of reeds (*Phragmites communis*) and sedge (*Carex* spp.) converted to common seepweed (*Suaeda glauca*) and even to salinized bare land (Wan et al., 2003).

Grazing may cause wetland degradation by use of food and water in wetlands. The urine and feces left by livestock in the wetlands can cause high loads of urea and other nutrients, leading to eutrophication of wetland water bodies. Trampling by livestock can also cause the fringes and tunnels of wetlands to collapse. Overgrazing on the riversides can reduce the riverine vegetation, which affects the filtration efficiency, increases water temperature, and decreases the food supply and habitats for some wetland wildlife. Due to the reduction of vegetation, erosion in riverbanks and downstream sedimentation increases while the capacity of the rivers and lakes decreases, causing the reduction of water supply, irrigation, flood control, hydroelectric power and water quality. The aquatic organisms and wetland habitats would be damaged as well (Lu et al., 2008).

In the Xianghai wetland, the number of grazing cattle and sheep increased with population growth, which led to the overuse of natural resources and destroyed the ecological environment of wetlands. The most important species in the protected area, the red-crowned crane, was severely affected by overgrazing. A large number of cattle and sheep wandered and trampled in shallow waters, mudflats, reed beds, meadows and other spatial niches of the red-crowned crane and the other waterfowl and seriously interfered with the breeding habitats of the red-crowned cranes and other waterfowl, causing them to migrate to other places (Sheng et al., 2001).

3.4 Engineering and construction works

We concluded three aspects of the influence of engineering and construction works on wetlands: land use, ecological environment and wetland biodiversity.

First, engineering construction has caused the decrease of wetland area by occupying land, including grassland, swamps and lakes. The discarded earth and stone in the construction process also affect wetland areas. Moreover, soil erosion caused by construction will reduce the area of wetland.

Second, engineering construction affects the wetland ecological environment. The living sewage and garbage from the construction personnel stationed in the site cause a certain impact on the surrounding wetland environment. For traffic construction, when the construction is completed, physical pollution (such as noise, light, and micro climate) and chemical pollution (such as thawing salt, petroleum substances, and heavy metal ions) can change the physical and chemical conditions of surrounding wetlands. Artificial reservoirs and embankments, especially those that increase the capacity of reservoirs and the height and length of dikes, reduce or cut off the hydraulic connections downstream and then decrease the upstream water sources of wetlands in the plain. The engineering also cuts off the leakage in the channel flow region, leading to wetland drying and the shrinkage of wetlands (Lu et al., 2000). For example, a reservoir project of Huolinhe downstream in the Xianghai wetland in the Songnen Plain, Northeast China, had great effects on the Xianghai wetland. Branch blockage and water level drops created diversion difficulties. The long-term equilibrium of riverbank collapse and deposition was destroyed. Part of the floodplain no longer experienced flooding (Guo and He, 2005). In the Songnen Plain, there are 67 medium-sized reservoirs and 413 small-sized reservoirs, with a total embankment length of 6338 km. These engineering facilities are far from perfect and are aging and in bad repair. As a result, the wetland cannot be supplied with water adequately and its discharge capacities are reduced (Bai et al., 2008).

Third, engineering construction affects wetland biodiversity. In the process of construction, noise, dust and pollution are generated and the animals with serious habitat requirements or sensitivity to noise are forced to migrate. As a result, the species populations are reduced and face degradation. For example, dam construction cuts off the migratory channel of fish, resulting in a decrease of migratory fish resources and the extinction of some precious migratory spawning fish. The segmentation effect of a dam changes the hydraulic characteristics of the river and hinders aquatic biological habitat and migration. The disappearance of rapids in the reservoir often causes some species of fish (such as the young salmon) to lose their sense of direction downstream during migration and makes them easy prey for other animals. As a result, the migration process of aquatic organisms is hindered or slowed, thereby affecting the food chain function of the river corridor and the spawning field of aquatic organisms. The growth and development of aquatic organisms are disrupted (Wang and Tan, 2004; Lu et al., 2008). It has been reported that the Russia-China oil pipeline project had great effects on the surrounding wetlands in China. Wetland plants were significantly destroyed by the pipeline construction. In the trench area, the shoots and roots of the involved plants were eradicated, and the surrounding plant roots were affected as well. Habitats of fish and birds were also greatly disturbed (Yu et al., 2010).

3.5 Urbanization

With the increasing population and the development of economics, urbanization becomes a major cause of degradation of wetlands. The direct impacts of urbanization on wetlands is habitat destruction and alternation which may causes soil erosion, even change the function of ecosystem. The indirect impacts are the impacts of urbanization on wetland structure and function through altering on the hydrological and sedimentation regimes and the dynamics of nutrients and pollutants (Lee et al., 2006). Some researchers tracked changes in wetlands with urbanization over 16 years indicate that wetlands will rapid changes due to urbanization (Kentula et al., 2014). Therefore, the wetlands in Northeast China are not exception.

Agricultural activities generate large amounts of chemical fertilizers, pesticides and animal waste, which, when discharged into the wetland runoff, result in eutrophication. Irrigation ditches can intensify pollution in the wetlands receiving irrigation and drainage. Some sewage without purification directly discharged into wetlands can lead to the death of birds, amphibians and fishes. In addition, pesticides and heavy metals entering through wetland runoff and atmospheric deposition can lead to bioaccumulation in fish and other aquatic organisms. With the rapid development of cities, the rapid growth of population and the great development of industry, the resulting industrial waste and domestic wastewater also have serious impacts on wetland ecosystems. The discharge of industrial wastewater leads directly to the enrichment of heavy metals and other harmful substances in aquatic organisms. Domestic sewage discharge leads to eutrophication and even to the explosive growth of some algae, causing the entire habitat to deteriorate. Wetlands in the Songnen Plain face a serious threat of pollution, leading not only to eutrophication but also to damage to wetland biodiversity. The industrial wastewater of Lindian Country and Fuyu Country is discharged directly into the wetlands in nature reserves (Bai et al., 2008). The wetland water in the core area of the Zhalong Nature Reserve has reached V class water quality (Huang et al., 2007a).

4 Recommendations and Conclusions

4.1 Wetland compensation program

The Chinese government has emphasized wetland ecological protection and promised reasonable remunerations for local residents affected by the protection campaigns. However, without a reasonable compensation system, there have been attempts to convert the wetlands to agricultural lands because the farmers' incomes remain low in developing regions such as Northeast China. Therefore, most ongoing wetland compensation cases merely focus on the financial reimbursement and are usually related to local poverty alleviation. It is urgent to find the threshold between wetland protection and reclamation.

There is no doubt that wetlands provide huge ecological services all over the world; however, the valuation of a specific wetland depends greatly on where this wetland is located. Developed countries or districts usually assign wetlands greater value than do developing countries. China used to consider wetland as 'non-arable land' or 'wasteland' in land use statistics. The prerequisite for commissioning compensation of wetland, therefore, is to update the land use property of wetlands legally, and then the valuation methods and financial compensations would be more effective.

Finally, wetland compensation is not wetland consumption. One-time payment to wetland stakeholder(s) by the country, local government or other organization cannot compensate for the total loss of a wetland. Alternatively, more funds and efforts should be expended to restore or create the wetland, followed by continuous monitoring of the consequences. Successful wetland compensation should be assessed by a reliable evaluation of no-loss of the lost wetland's functions and values after a period of restoration or creation.

4.2 Advancement of technology

Currently, most efforts responding to climate change only revolve around how to mitigate the adverse impacts of climate change. In fact, the efficiency of mitigation actions is highly subject to other countries' practices, and unilateral promises cannot resolve the planet's problem.

More and more wetland scientists and managers have noted the publication and release of IPCC AR5 and are inclined to active adaption to climate change. There is no exception in China.

Ongoing wetland protection, restoration, enhancement and /or creation should be incorporated into central and local land use planning and management decisions such as the '13th Five-Year Plan' and National Main Functional Zoning. The existing engineering measures and facilities such as storm water management, floodwater conveyance, and drought alleviation related to wetland ecosystems should be improved according to the climate change scenarios.

4.3 Enhanced adaptive capacity of wetlands

As one of the most complicated ecosystems, wetlands have great self-adaption capacity. The more complicated the structure or trophic levels, the more self-adaptability the wetland contains. Many successful wetland recovery cases suggest that a specific wetland could be recovered naturally without human interference when the basic ecological structure of the wetland is not damaged. Self-adaption of wetlands is recommended in developing regions where huge financial resources for wetland recovery are lacking.

4.4 Conclusions

There is a rapid transformation of floodplain wetlands in Northeast China influenced by climate change and human activities. For example, the wetlands in the Sanjiang Plain and Songnen Plain in Northeast China have shrunk severely in the past 60 years and wetland functions have been reduced substantially. The driving factors are climate change, unreasonable land use, fire episodes, engineering and construction works and urbanization. Wetland management strategies can be carried out in three ways: wetland compensation programs, advancement of technology and enhanced adaptive capacity of wetlands.

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