Analysis of wetland change in the Songhua River Basin from 1995 to 2008

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Abstract. Wetlands in the Songhua River Basin in both 1995 and 2008 were mapped from land use/land cover maps generated from Landsat Thematic Mapper imagery. These maps were then divided into two categories, i.e. artificial wetland and natural wetland. From 1995 to 2008, the total area of wetland in the Songhua River Basin increased from 93 072.3 km^2 to 99 179.6 km^2, a net increase of 6107.3 km^2. The area of natural wetland decreased by 4043.7 km^2, while the area of artificial wetland increased by 10 166.2 km^2. Swamp wetland and paddy field wetland became the dominant wetlands and the swamp wetland in the east of the Heilong River system and the north of the Wusuli River system disappeared, being transformed into paddy field wetland. The diversity of wetland landscape is worsening and the distribution of wetland landscape is becoming more unbalanced; the fragmentation of natural wetland has intensified whereas the patch connectivity of artificial wetland has increased. Changes in natural wetlands were primarily caused by climate and socio-economic changes, while changes in artificial wetland were mainly caused by the growth of population and gross domestic product.

1. Introduction

Wetland refers to areas covered by natural or artificial, permanent or temporary still water or running water, freshwater, saltwater marshlands, peat lands, or water bodies including seawater less than 6 m in depth at low tides [1]. Wetland is an important natural resource and ecosystem, playing an important role in regulating climate, conserving water, dispersing floods, protecting biological diversity, and many others, and is known as the "kidney of the earth" [2]. Areas of wetlands are distributed in the Songhua River Basin, including seven key national wetland reserves.

In recent years, scholars have carried out various types of research into the changing wetlands in the Songhua River Basin, and their studies have mainly focused on wetlands in the Sanjiang Plain [3–5], wetland national reserves [6,7], and three provinces in northeast China [8,9]. In the work reported in this paper, wetlands in the Songhua River Basin as a whole were selected to carry out our research.

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2. Data and methods

2.1. Study area

As shown in Figure 1, the Songhua River Basin is located in northeast China, across the Inner Mongolia Autonomous Region, Heilongjiang province, and Jilin province, and has a total area of 93.56×10^4 km^2. It includes six river systems and its main wetland categories are river wetland, lake wetland, swamp wetland, and paddy field wetland.

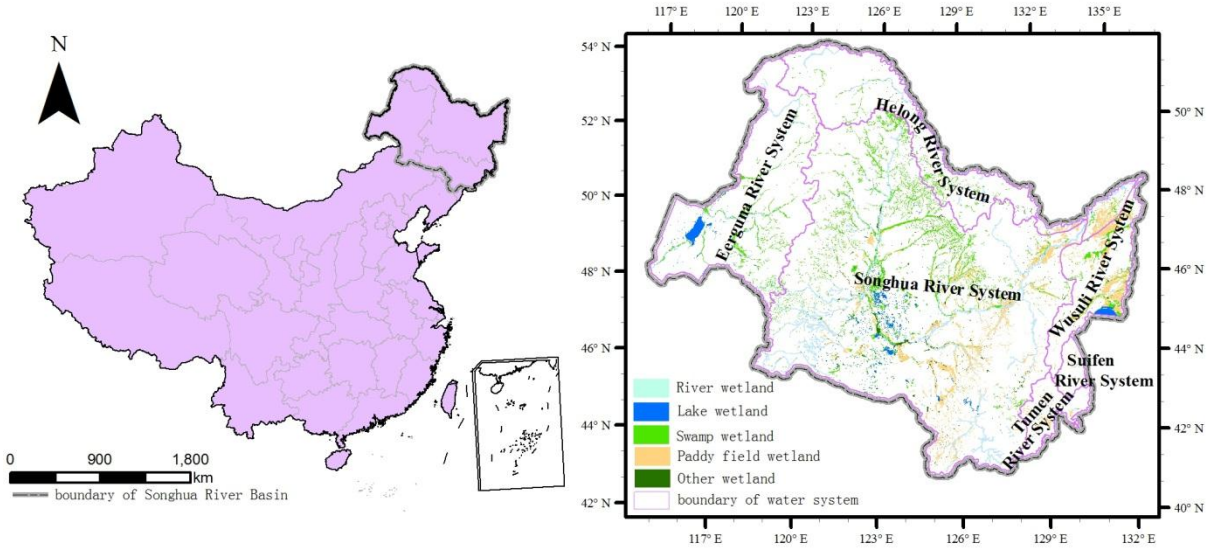

Figure 1. The location of the Songhua River Basin.

2.2. Data sources and processing

Wetland areas in the Songhua River Basin in both 1995 and 2008 were obtained from land use/land cover maps generated from Landsat Thematic Mapper images. Wetlands were divided into two categories, i.e. artificial wetland and natural wetland. Artificial wetland includes paddy field wetland, ponds, and reservoirs; natural wetland includes swamp wetland, river wetland, lake wetland, and beach wetland.

Annual mean temperature and annual calculated precipitation data from 73 stations in the Songhua River Basin from 1995 to 2008 were collected from the national meteorological information centre of the meteorological administration in China, and were further interpolated by the inverse distance weighting method.

Socio-economic data were obtained from the Statistical Yearbook database in China from 1995 to 2008, including population and gross domestic product (GDP) data in Heilongjiang and Jilin provinces, and Hulunbeier city and Xing-anmeng of the Inner Mongolia Autonomous Region.

2.3. Wetland change analysis

2.3.1. Change of wetland area and rate of change. Change in area is calculated as follows:

$$\Delta S = S_b - S_a, \tag{1}$$

where S_a is the area of the former period and S_b is the area of the latter period.

Dynamic degree, which can highlight the temporal change of wetland areas, is used to reflect the rate of change:

$$K = \frac{S_b - S_a}{S_a \cdot T} \times 100\%, \tag{2}$$

where T is the study period and K refers to the dynamic degree of wetland in T years.

2.3.2. Change in the distribution. In this paper, the three words "increase", "stable", and "decrease" are used to describe the distribution change of dominant wetlands.

2.3.3. Change of landscape indices. Diversity index, evenness index, and dominance index were applied to analyse the overall wetland change; patch number and patch density were used to analyse the changes of both natural and artificial wetlands in terms of the level of patch.

Diversity index can reflect the changes in the proportion of landscape types. It is calculated by the equation proposed by Shannon and Weaver:

$$H = -\sum_{i=1}^{m} P_k \ln(P_k), \tag{3}$$

where P_k is the percentage of the total area of landscape of type *k* and *m* is the number of landscape types.

Evenness index indicates the degree of uniformity for landscape patch type in the distribution:

$$E = H / H_{\max} = -\sum_{i=1}^{m} P_k \ln(P_k) / H_{\max}, \tag{4}$$

where $H_{\max} = \ln(m)$, which is the maximum diversity of the landscape.

The dominance index shows the degree to which certain landscape types dominate the landscape:

$$D = H_{\max} - H = H_{\max} + \sum_{i=1}^{m} P_k \ln(P_k). \tag{5}$$

Patch number and patch density are used to represent the fragmentation of landscape.

3. Results

3.1. Wetland distribution, wetland area change and rate of change of area

3.1.1. Current wetland distribution. The wetland map for the Songhua River Basin in 2008 can approximately reflect the current wetland distribution, as shown in Figure 2. The river wetland includes Heilong River, Wusuli River, Eerguna River, Nen River, Songhua River main stream, and the second Songhua River. Lake wetland is mainly located at the Xingkai Lake, Hulun Lake, and the central part of the Songhua River system. Swamp wetland is mostly situated in the Eerguna River system, Wusuli River system, and the north and west of the Songhua River system. Paddy field wetland is principally distributed in the Songhua River system, the north and south of the Wusuli River system, and the east of the Heilong River system.

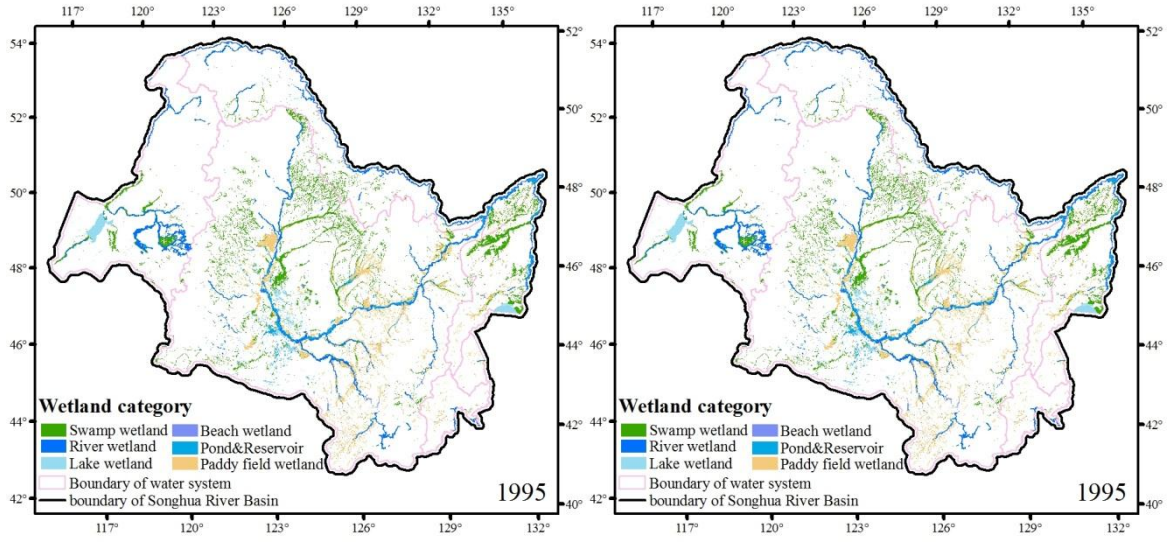

Figure 2. Spatial distribution of the wetlands in the Songhua River Basin.

As shown in Table 1, swamp wetland and paddy field wetland account for 44.14% and 38.03% of the total wetland area, respectively, indicating that they have become the dominant wetlands in the basin.

3.1.2. Wetland area change and rate of change. In 1995, the total area of wetland in the Songhua River Basin was 93 072.3 km^2, whereas in 2008 the area increased to 99 179.6 km^2, an increase of 6107.3 km^2. Its dynamic degree is 0.47%.

From 1995 to 2008, the area of natural wetland decreased from 6.35×10^4 km^2 to 5.94×10^4 km^2, a net loss of 4043.7 km^2, among which beach wetland area decreased enormously with a loss of 5855 km^2; its dynamic degree is 4.88%. The area of river wetland decreased by 785.4 km^2; however, such an obvious decrease in the area is not observed for the lake wetland. Swamp wetland area increased by 2983.5 km^2 and its dynamic degree is 0.52%.

From 1995 to 2008, the area of artificial wetland increased from 2.96×10^4 km^2 to 3.77×10^4 km^2, a very large increase of 10 166.2 km^2, among which the area of paddy field wetland increased by 10 176.2 km^2 with a dynamic degree of 2.46%. The area of pond and reservoir wetland decreased by a small amount.

Table 1. Statistics of wetland data for the Songhua River Basin

Wetland category	Sub-category	1995		2008		1995–2008	
		Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Change (km^2)	Dynamic degree (%)
Natural wetland	River wetland	5462.0	5.87	4676.6	4.72	−785.4	−1.03
	Lake wetland	8640.9	9.28	8254.1	8.32	−386.8	−0.32
	Beach wetland	8576.1	9.21	2721.1	2.74	−5855	−4.88
	Swamp wetland	40798.1	43.83	43781.6	44.14	2983.5	0.52
	Total	63477.1	68.20	59433.4	59.93	−4043.7	−0.46
Artificial wetland	Paddy field	27542.9	29.59	37719.1	38.03	10176.2	2.64
	Pond and reservoir	2052.3	2.21	2027.1	2.04	−25.2	−0.09
	Total	29595.2	31.80	39746.2	40.07	10151	2.45
Total		93072.3		99179.6		6107.3	0.47

3.2. Distribution change of dominant types of wetlands

The increased areas of swamp wetland are located in the Wusuli River system, Eerguna River system, both sides of the Nen River, and the north side of the Songhua River main stream. The reduced areas are mainly located in the Eerguna River system, east of the Heilong River system, north of the Wusuli River system, and both sides of Nen River. Swamp wetland in the southeast of the Eerguna River system, and north and centre of the Songhua River and Wusuli river systems is stable, as shown in Figure 3.

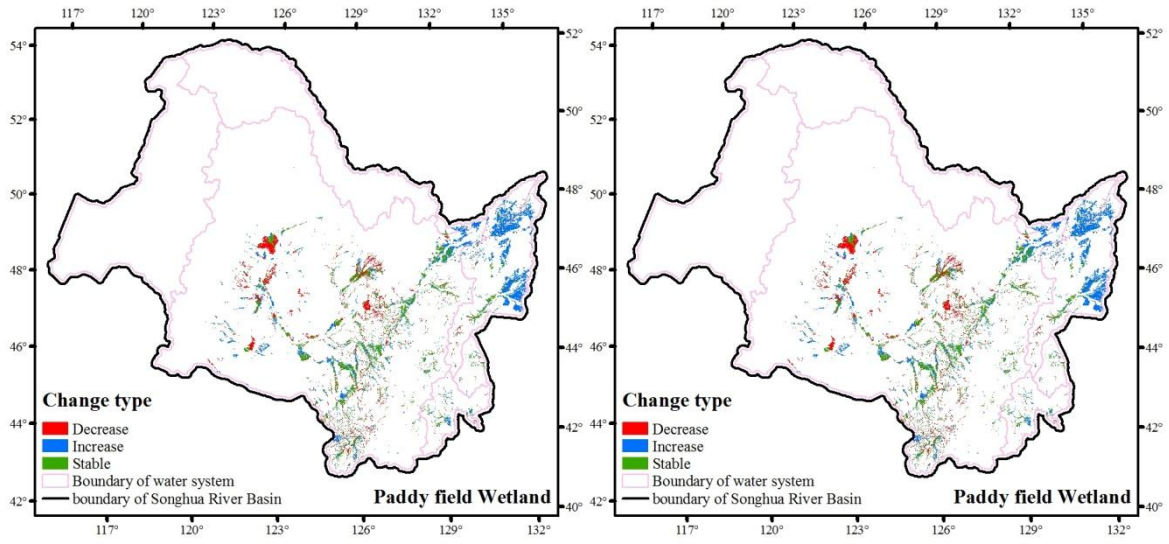

Figure 3. Distribution change of dominant wetlands.

The increased areas of paddy field wetland are in the east of the Heilong River system and the north and east of the Wusuli River system. The reduced areas are mainly located in Nen River and the north sides of the Songhua River main stream. The stable areas are mainly along both sides of the Songhua River main stream, as shown in Figure 3.

It can be seen that the swamp wetland in the east of the Heilong River system and the north of the Wusuli River system has disappeared, being transformed into paddy field wetland. This change may be caused by the growth of population and agricultural activity [9].

3.3. Change of landscape indices

Firstly, the change of the overall wetland was studied. The diversity index decreased from 1.413 to 1.258 and the evenness index dropped from 0.547 to 0.481, while the dominance index increased from 0.379 to 0.534, indicating that (1) the diversity of the wetland landscape has worsened; (2) the distribution of the wetland landscape has become increasingly unbalanced; and (3) certain wetland categories have come to dominate the landscape in the basin.

Table 2. Statistics of wetland patch number and patch density in the Songhua River Basin

Wetland category	Sub-category	Patch number		Patch density	
		1995	2008	1995	2008
Natural wetland	River wetland	378	1364	0.069	0.292
	Lake wetland	5839	4932	0.676	0.597
	Beach wetland	2420	3890	0.282	1.430
	Swamp wetland	5003	7666	0.123	0.175
	Total	13640	17852	0.215	0.300
Artificial wetland	Paddy field	6623	4956	0.240	0.131
	Reservoir	1939	2226	0.944	1.098
	Total	8562	7182	0.289	0.180

Secondly, the changes of both natural wetland and artificial wetland were analysed. Patch number of natural wetland increased from 13 640 to 17 852 and patch density increased from 0.215 to 0.300, as shown in Table 2, indicating that the fragmentation of natural wetland has intensified. Patch number and patch density of river wetland, beach wetland, and swamp wetland increased, indicating that the fragmentation of these wetlands has also intensified; but patch number and patch density of lake wetland decreased, indicating its fragmentation has decreased. Patch number of artificial wetland

decreased from 8562 to 7182 and patch density dropped from 0.289 to 0.180, as shown in Table 2, meaning that connectivity of patches is enhanced.

3.4. Wetland driving factors

Driving factors are generally divided into two categories, i.e. climatic and socio-economic driving factors. Climatic driving factors include temperature and precipitation; socio-economic driving factors include population and GDP.

3.4.1. Climatic driving factors. As shown in Figure 4, annual mean temperature shows an increasing trend and annual calculated precipitation shows a downward trend from 1995 to 2008 in the Songhua River Basin. The increase in temperature and the decrease in precipitation can affect the hydrology of wetlands [10], resulting in two problems: (1) the atrophying of the areas of river wetland, lake wetland, and beach wetland; and (2) intensification of the fragmentation of natural wetland.

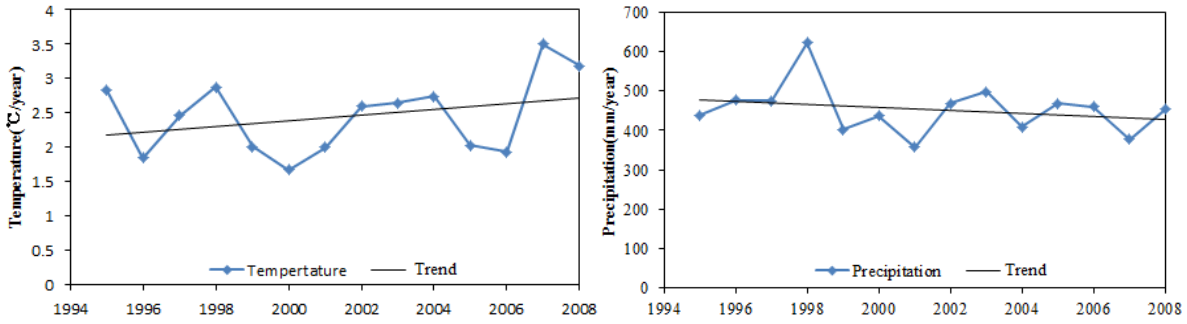

Figure 4. Variation trends of annual mean temperature and calculated precipitation.

3.4.2. Socio-economic driving factors. From 1995 to 2008, the population in the basin showed a rising trend, as illustrated in Figure 5. To ease the contradiction between the growing population and limited land resource inevitably results in land reclamation from natural wetland to yield agricultural land. Thus, natural wetland area has decreased and the area of paddy field wetland has greatly increased. From 1995 to 2008, the basin's GDP showed a growing trend. GDP growth is bound to speed up the process of urbanization, and thus the area of construction land has increased from 16 521.58 km^2 to 19 779.91 km^2. Therefore, land disturbance as a result of human activity has led to (1) a decrease in the natural wetland area and the intensification of fragmentation; and (2) an increase in the artificial wetland and the enhancement of patch connectivity.

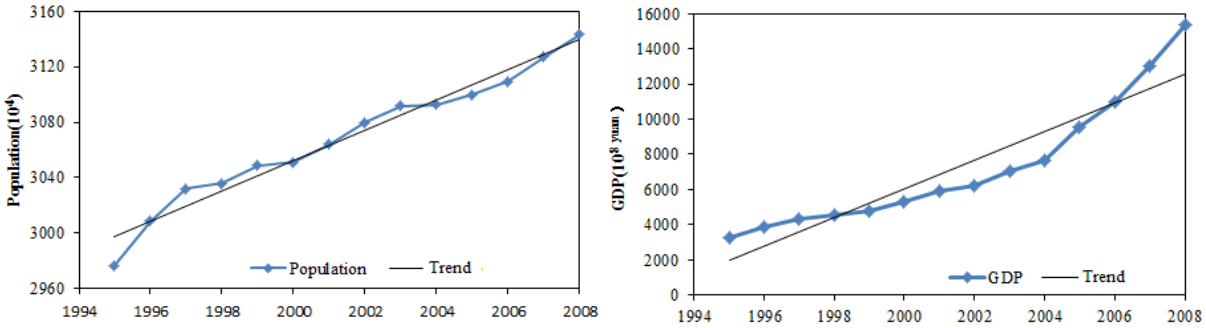

Figure 5. Variation trends of annual population and GDP.

4. Conclusions

From 1995 to 2008, the total area of wetland in the Songhua River Basin increased from 93 072.3 km^2 to 99 179.6 km^2, a net increase of 6107.3 km^2. Natural wetland area decreased by 4043.7 km^2, while artificial wetland area greatly increased by 10 166.2 km^2.

The swamp wetland east of the Heilong River system and north of the Wusuli River system disappeared, being transformed into paddy field wetland. This change may be caused by population growth and agricultural activity.

The diversity of the wetland landscape is worsening and the distribution of the wetland landscape is becoming increasingly unbalanced in the Songhua River Basin. The fragmentation of natural wetland has intensified, whereas the patch connectivity of artificial wetland has increased.

The change in natural wetland is primarily caused by climate change and socio-economic change, while the change in artificial wetland is mainly attributed to the growth of population and GDP.

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