A Study on the Wetland Dynamic and Its Relation with Cropland Reclamation in Sanjiang Plain, China

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EXTENDED ABSTRACT

Sanjiang Plain, located in the northeast of Heilongjiang province, is the largest concentrated area of the freshwater wetlands in China (Figure.1). It was mainly primeval landscape before the 1950s. From the late 1950s to the early 1990s, a number of large farms were built concomitant with the loss of wetlands. Now, it is one of the main food and agricultural bases of the nation. Due to large-scale agricultural development, nearly 80% of the freshwater wetlands have been reclaimed during the past decades.

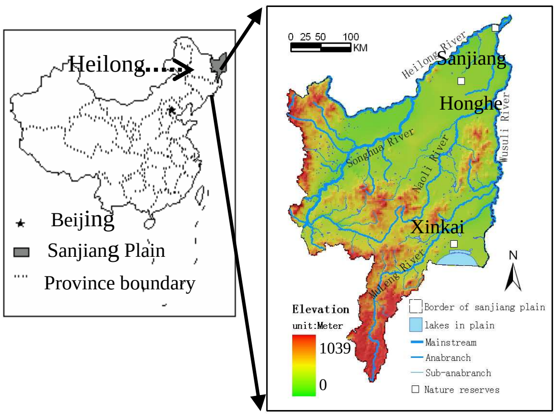

Figure.1 Location of the Sanjiang Plain in China, DEM, main rivers and lakes in Sanjiang Plain

This study analysed the dynamics of the wetland and its conversion to other land uses in Sanjiang Plain from 1976 to 2005 with remote sensing imagery data and GIS spatial analysis (figure.2). It shows that the wetland in Sanjiang Plain has been severely damaged. The wetland area decreased by 37.72% from 1976 to 1986, by 15.54% from 1986 to 1995, and by 30.97% from 1995 to 2005, which shows that the situation of wetland loss had much slowed down in 1986 to 1995, but in recent years, especially after rural Fee-Tax-Free policies adopted, which again speed up the reclamation rate of wetland. The result indicated that most wetland losing was due to reclamation, and only small part of lost wetland was converted into grassland and forest. Land use conversion is a complex process; there also some other types of land use converted to wetland during this study period, our study research showed that cropland contributed the main part for the increase in wetland area where aimless reclaimed cropland was converted into wetland during flood inundation. Both demographic and resource management policies reason were analysed for the wetland reduction. The result showed that population increasing was the main reason for wetland reduction in the past decades since 1950s, the lost wetland was mainly converted to dry farming land and paddy field, and the trend of wetland conversion to paddy field increased for the sake of its high agricultural output. Though the reclamation speed of wetland decreased during the later periods, wetland reclamation still happened, so strict and practicable protection measurement of the wetland in Sanjiang Plain should be reinforced further.

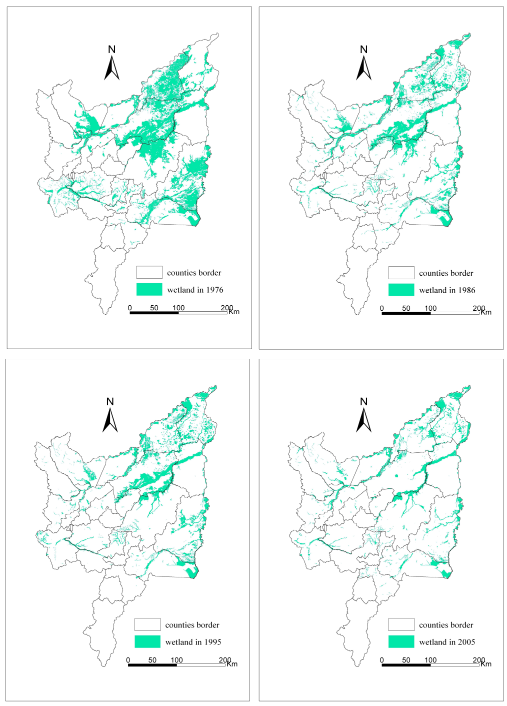

Figure.2 Wetland distribution changing trend in Sanjiang Plain in four different stages

1. INTRODUCTION

Wetlands are important natural habitats, which must be conserved (Williams, 1990). They improve water quality, provide flood control, mitigate climate change, and assist groundwater recharge (Koeln, 1992; Munyati, 2000). Wetland ecosystems are associated with a diverse and complex array of direct and indirect uses. Human activities in the wetlands themselves may be fairly related to alternations of wetlands. However, alternations may also be caused by activities in the wetland watersheds and predominantly by agricultural ones, i.e., crop and livestock production (Zalidis *et al.*, 1997). Changes in wetland areas may significantly affect the ecosystem processes. Concern about changes in the size and quality of many of the world's wetland systems has been growing as more and more wetlands are being converted to agricultural or urban uses and by natural factors like drought (Jensen *et al.*, 1995). It is widely known that land use and land cover changes play a pivotal role in environmental and ecological changes and furthermore contribute to global change (Lambin *et al.*, 2001). These changes directly impact the biotic diversity world widely (Sala *et al.*, 2000); contribute to local and regional climate change (Chase *et al.*, 1999).

Because the basic information on wetland resource status and trends is critical for evaluating the effectiveness of wetland management activities (Megan *et al.*, 2001), government and wetland experts have been paying more and more attention to the loss and gain of the Sanjiang Plain wetland. Liu and Ma (2002) argued that the conservation of wetland landscape structure was very important for the protection of wetland. But because of a lack of the necessary temporal and spatial dynamic data of the whole area, there are few quantitative research reports about wetland landscape structure and its dynamic change. The objectives of this paper are: (1) to study the temporal and spatial dynamic characteristics of the wetland in Sanjiang Plain from 1976 to 2005; (2) to analyze the land use change of the whole area and the transfer of land use from wetland to others in Sanjiang Plain and its driving forces; and (3) to explore the impacts of such changes at regional scale.

2. MATERIALS AND METHODS

2.1. Study Area Description

The latitude and longitude of Sanjiang Plain are 43°49′55″~48°27′40″N, 129°11′20″~135°05′26″E, respectively, with a total area of 108,900 km^2. The population is 8.71 million in 2005, among which 53.2% are directly or indirectly engaged in farming (HPSB, 2005). The plain occurs on a low alluvial plain of three rivers: Heilong River, Songhua River, and Wusuli River. The climate in this area belongs to the temperate humid and sub-humid continental monsoon climate. The annual average temperature is 1.5℃. Annual precipitation is 500-650 mm, mainly concentrating from May to September, which is up to 80% of the whole year's precipitation. Most of the rivers in the area have the characteristics of the alluvial plain: the slight gradient and large channel curve coefficient. Wetland mainly distributed along rivers in the study area. *Carex* marsh is the main wetland type distributed widely in Sanjiang Plain, *Phragmites* marsh scattered in some places (Chen, 1997). So far, Sanjiang Plain has been one of the important commodity grain bases in China, and the total yield of grain and bean was about 704.25 million tons per year (Chen, 1997).

2.2. Spatial Database Development

To understand how land use/land cover change affects and interacts with global earth systems, information is needed on what changes occur, where and when the occurrence taking place, the rates at which they occur, and the social and physical forces that drive those changes (Lambin *et al.*, 2001). Despite ongoing research efforts on land cover/land use patterns, there remains a need for development of basic land-cover datasets providing quantitative and spatial land-cover information, especially at regional scale (Xavier and Szejwah, 1998).

2.2.1 Imagery Data Set

The spatial database consisted of land cover maps derived from remote sensing (RS) data (Landsat MSS images data during 1975-1977; Landsat TM data during 1984-1986, 1994-1995 and 2004-2005) and extensive ground truth survey. TM data acquired during 1994-1995 was registered to topographic maps by collecting ground control points (the average ground control points are about 25~35), and remotely sensed data acquired in 1975-1977, 1985-1987 and 2004-2005 were co-registered to the master image of 1995's (MSS data re-sampled to 30 × 30 m with linear re-sampling method) in ERDAS Imagine 8.5. The Root Mean Squared Error (RMSE) of geometric rectification was less than 1.1 pixels (or 33 m).

2.2.2 Imagery Data Interpretation

Interpreters used ArcView GIS 3.3 software to identify the land use types on the computer screen, based on his/her understanding on the object's spectral reflectance, structure and other information (Liu, *et al.,* 2005). Then they drew the boundaries of the objects and added the attributes (labels) of the polygons to produce the digital spatial database. Finally, we edited and compiled the vector database. Landsat TM images in 1995 (1:100,000 scale) were firstly interpreted. The classified types in each image were grouped into seven land cover categories: woodland, grassland, farmland, water body, wetland, residential land and barren land, referenced by Chinese National Technical Standard for Land-Use Survey according to the classification standard of remote sensing interpretation of land resource investigation of China (Liu *et al.,* 2002). Land use/cover data in 1976, 1985 and 2005 was interpreted in the same way with data interpreted in 1995 as the reference data.

2.2.2 Spatial Data Accuracy Assessment

Assessment of classification accuracy was made with the methods proposed by Liu *et al.,* (2002; 2005). Five random routes in Sanjiang Plain, 522 site-evaluation points were done with the global positioning system (GPS) along these routes in total. The longitude and latitude of the cross of each land use/cover type boundary with the routes were measured. The errors and the routes were registered to the spatial data in 1995 (230 samples) and 2005 (292 samples), and then transferred to grids with equal size of TM image pixel. By comparing the pixels of the errors with those of the routes, the errors of the classification of the remote sensing images in 1995 and 2005 were calculated. Because the remote sensing images in 1976, 1986 were strictly registered with those in 1995, the errors of classification of the year 1995 could represent for those year as well. Still some auxiliary data and land use maps of concurrent with images in 1976, 1986, 1995 and 2005 were collected for testimony of corresponding to land use interpreting data. Overall, per-pixel classification accuracy of the three periods for the spatial data was 93.2%.

2.3. Spatial Data Analysis Methods

Overlays were made between land use spatial data, and land use change information was acquired by a cross-tabulation detection method with ArcGIS 8.5. Then quantitative data of the overall land use changes, gains and losses in each category can be compiled. The change rate was calculated by formula (Wang *et al*., 2002):

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

Where U_b was area of a specific land use at the end of study period, and U_a was that at the beginning of the study period, T was the interval length.

To determine socio-economic factors and develop interventions influencing land use changes, a series of participatory workshops and interviews were conducted with the local population. Furthermore, historical information about natural resource and agricultural policies of the region for the past 30 years was obtained for the analysis of their impacts on land uses. The soil nutrient dynamic information of meadow soil after development for different years, and oriental white stork changing trend in three natural reserves at different reclamation period in Sanjiang Plain were also collected.

3. RESULTS AND DISCUSSIONS

3.1. Changes in Land Use

Natural resource management is a complex undertaking, which is influenced by environmental, economic, social and political factors (Rao and Rekha, 2001). Traditional field survey methods and satellite survey techniques use quite different criteria for classifying wetland dominated areas. Although difficult to maintain a consistent performance between two field surveys, there are even greatly difficulties in trying to obtain comparable classifications using two quite different methodologies. However, when broad classes of features are used between 1976 and 2005, the wetland area of Sanjiang Plain has undergone drastic modifications, which can be easily seen on Figure.2.

3.1.1 Land Use Changing Characteristics

Wetland and cropland changing characteristics were listed in Table 1, and it can be found that the wetland cover of Sanjiang Plain was about 20.45% in 1976, and these areas were under a stratified intensity of anthropogenic pressure. The main agricultural activity was a basic grain production for both local resident consumption and commercial purpose. During the next 10 years until 1986, major reclamation events took place causing a 37.72% reduction in the total wetland area with a reduction rate of 3.77% per year, largely due to an increase in agricultural and livestock production activities. Between 1986 and 1995 the annual reclamation rates in Sanjiang Plain decreased significantly, but sill caused the wetland area losing with a rate of 1.73% per year, which nearly equals to the rate of that in the previous 10 years (Table 2). While, between 1995 and 2005, the losing speed of the wetland area had slightly accelerated with a rate of 2.21%. From Table 2, it can be deduced that the wetland losing area nearly equals to cropland increasing area during 1976 and 1986, and that is nearly half of the cropland increasing area during 1986 and 1995, while the losing wetland area in only a little bit more 1/3 of cropland area increasing during 1995 to 2005, so there must be more other land use area converted into cropland in the last study stage.

Table 1. Cropland, wetland area and their proportion in four study stages. Units: ha.

Land Use Type	1976		1986	
	Area	%	Area	%
Cropland	3586682	3291	4524880	41.53
Wetland	2230633	20.45	1389296	12.75
Others	5079185	46.67	4831576	45.72
Total	10896500	100	10896500	100
Land Use Type	**1995**		**2005**	
	Area	%	Area	%
Cropland	4940456	45.40	5568849	51.1
Wetland	1173407	10.77	809891	7.43
Others	4782637	43.89	4517760	41.46
Total	10896500	100	10896500	100

Table 2. Change area and rate of cropland and wetland during four study stages. Units: ha

Period	Index	1976-1986	1986-1995	1995-2005
Cropland	Change Area	938198	415575	733191
	K	2.62	1.02	1.38
Wetland	Change Area	-841337	-215889	-363516
	K	-3.77	-1.73	-2.21
Other	Change Area	-96861	-199686	-369175
	K	-0.19	0.41	0.77
Total	Change Area	186396	831150	1465882
	K	1.72	0.76	1.35

3.1.2 The Conversion of Land Use Types

The overall wetland changing characteristics was just discussed above, but how wetland converted to other land use types and what was the proportion converted into cropland is still unclear. GIS spatial overlay analysis was applied to calculate the conversion of wetland to other land use types (John and Jack, 1995). Table 3 shows the ratio that lost wetland was converted to other land use in the Sanjiang Plain. It can be deduced that the lost wetland was mainly converted to cropland, which account for 70.13% wetland losing; 16.16% of wetland turned into grassland; almost the similar amount of wetland turned to forest and water body during 1976 and 1986, but only a very small portion of wetland turned to residential land and barren land in this period. There was 70.14% lost wetland turned to cropland during 1986 to 1995, and it showed a similar trend of the rest part of losing wetland turning into other land use during this period. The amount of losing wetland converted into cropland increased to 85.6% between 1995 and 2005. Overall, more than 75.3% of lost wetland turned into cropland in the whole study period, which account for 1493812 ha (Figure 3). It can be concluded that reclamation is the main reason for wetland losing during the past 30 years from 1976 to 2005 in Sanjiang Plain, and the rest part of wetland mainly turned into forest or grassland.

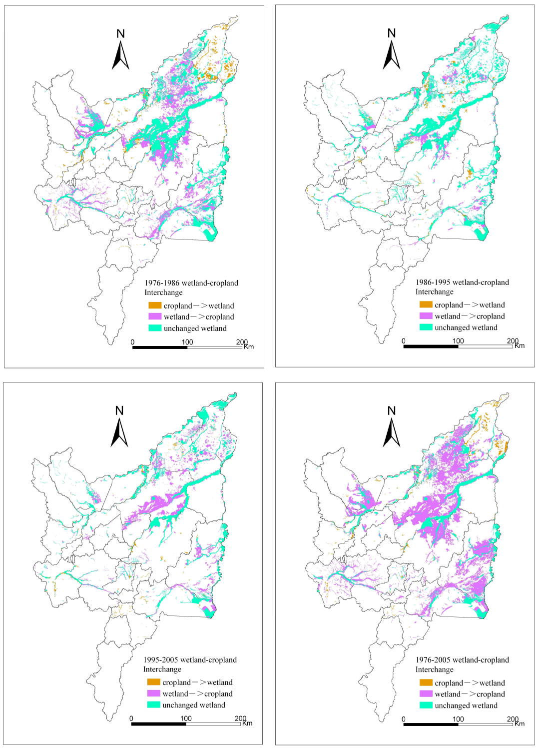

Figure.3 The relation between wetland and cropland during different study period

Table 3. Mutual conversion between cropland and wetland during four study stages. Units: ha

Period	Wetland—>Cropland		Cropland—> Wetland	
	area	%	area	%
1976-1986	852375	70.13	141060	37.73
1986-1995	244756	70.40	75309	57.19
1995-2005	396681	85.6	78664	27.77

Note: other land use conversion information were omitted here for page limitation reason

Meanwhile, only 295033ha of other land use types turned into wetland during 1976 to 2005 (Table 3), cropland contributed more than 40% for the wetland area increasing. Compared to wetland area losing, other land use types area converted to wetland are quite limited. Still, it should be notice that cropland contributed the largest part of wetland area increasing during the study period, which was the result that aimless reclaimed wetland in the low topographic area returned to wetland during the flooding or inundation period.

3.2. Demographic Development

Both demographic and socio-economic considerations play an important role in the natural resource dynamics (Rao, 2001); this is still true in the natural resource management of Sanjiang Plain. There were 1.39 million people in Sanjiang Plain in 1949, and the average population density was 12.84 person/km^2, while the population increased to 8.71 million in 2005 (HPSB, 1990; 2005) with the average population density increased to 78.52 person/km^2, which was 6 times of population density in 1949. Generally, cropland can be divided into two parts. One is cropland owned by individual farmers, which account to 70% of all the cropland in Sanjiang Plain, while the other part was run by central government ranches. By the above analysis, it was indicated that the main reason for wetland losing was its conversion to cropland. Population and cropland area statistical data both from 23 local counties and government owned ranches were collected in the past decades (HPSB, 1990; 2000; 2005). It indicates from collected data that farmer and cropland from local counties kept increasing in the past decades, while the government owned ranches reach a stable state since 1986.

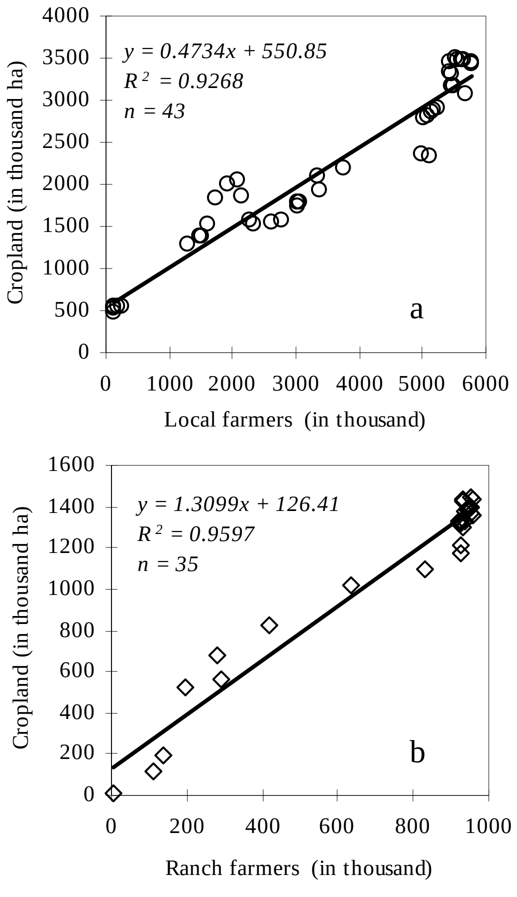

Figure.4 The relationship between farming population and cropland area in Sanjiang Plain, a: farmers owned cropland, and b: government owned cropland and farming population

The relationship between cropland area and farmers were analysed by regression (Figure 4). It can be found that the cropland area and farmers had a significant correlation both from local counties and government owned ranches. The determination coefficients were 0.92 and 0.95, respectively. An interesting feature can be noted in the Figure 4a that cropland increasing speed was not concurrent with farming population increasing. Farming population increased quite limited, while cropland increased with a fast speed in local counties since 1992, and this phenomenon held true in government owned ranches (Figure.4b). The correlation of farming population with cropland is high, but this trend will not possibly hold true in the following years.

3.3. Ecological Impact Analysis

The loss of the wetland area can cause a significant decrease in its ability to perform its essential functions (Klemas, 2001). The change of the Sanjiang Plain wetland both in area loss and in landscape structure has caused serious ecological problems (Liu and Zhang, 2004). A large-scale reclamation has resulted in the damage to the ecological environment such as land degradation, non-point pollution, and decrease in biodiversity.

Table 4. Change of soil nutrients within different reclamation years in meadow soil. Units: (g kg^{-1})

Years of reclamation	Layers (cm)	Organic Matter	Total N	Total P	Total K
Before Reclamation	0~25	98.97	6.05	12.7	58.6
	Below 25	8.14	0.94	10.5	68.5
5 years after Reclamation	0~26	36.47	3.03	8.76	71.3
	Below 26	3.73	0.88	10.2	71.8
15 years after Reclamation	0~28	34.05	2.82	10.5	80.8
	Below 28	4.72	0.76	5.74	92.4
25 years after Reclamation	0~27cm	21.26	1.44	8.70	68.0
	Below 27	8.44	0.74	8.90	69. 5

Taking meadow soil, one of the important soil types in this region, as an example, the soil has suffered from a substantial degradation after the cultivation (Table.4). All soil nutrient levels declined substantially after the reclamation. There was an obvious phenomenon that all soil nutrient levels decreased most dramatically during the 5-year-after-reclamation period. As for other soil type, this phenomenon is also true, but with different characteristics (Zhang and Song, 2004).

In regard to *Ciconia boyciana* (Oriental White stork), one of the important waterfowls in this region, the population decreased considerably because of the change in living environment and reduction of habitat (Table 5). Numbers of *Ciconia boyciana* in these three Wetland Natural reserves declined quickly before 1990, but began to increase during 1990 to 2005. All these shifts resulted from overuse of the cultivated land converted from wetlands and few nutrient inputs such as manure fertilization, while wetland fragmentation also attributed a lot in this process (Liu and Ma, 2002). Since late 1950s, in order to sustain the rapidly growing human population, the government put forward the 'food first' agricultural policy. As one of the important food bases, Sanjiang Plain needs to supply a large amount of grain to other regions of China. Although this policy played an important role in solving the problem of people's survival, it was against the 'agricultural environmental' law. In recent years, especially since late 1990s, the government has been fully aware of the seriousness of environmental problems resulting from the damage to natural ecosystems and has tried to seek various measures to prevent and cure the severely disturbed environment. With more and more Natural Reserve establishing and protection management enforcing in recent years, people begin to realize the importance of environmental protection. Some of the habitat became more suitable for *Ciconia boyciana* inhabitation, so the numbers began to increase in recent years and this phenomenon was proved by other important waterfowls and animals as well (Cheng, 2004).

Table 5. Number of Oriental White Stork in Sanjiang Plain reserves at different stages.

Periods	Honghe Reserve	Sanjiang Reserve	Xinkai Reserve
Before 1970	200-400	100-150	20-50
1970-1980	100-200	30-50	10-20
1980-1985	30-40	30-40	6-10
1986-1990	6-10	4-6	4-8
1991-1995	10-20	4-6	8-10
1996-2000	20-30	6-10	6-8
2001-2005	26-35	8-10	10-14

4. CONCLUSION

With the help of combining GIS spatial analysis, and the satellite data, it is economically feasible way to get regularly information with high spatial, spectral, and temporal resolution over a large area. Due to the lack of recorded historical land use/land cover information, the limitation of using remotely sensed data to detect land use changes is the difficulty of estimating uncertainty about the land use classification. Even with the uncertainties, simple classification systems, such as those adopted in this study, are reasonable because of the relatively great distinction between gross land cover categories. With an extensive field survey for land use in 1995, 2005 and the interview with local experts, farmers and staffs in wetland nature reserves of nation and Heilongjiang Province for historical land cover data, the use of Landsat images can be an effective means acquiring information on land use changes.

From the analysis on the wetland dynamics of the whole area in Sanjiang Plain and the wetland conversion to other land use types in the whole study area, it is concluded that the wetland in Sanjiang Plain decreased greatly in the past 30 years, the lost wetland was mainly converted into cropland, little converting to forest land, grassland and water area, which shows that human activities are the radical reason of the wetland loss in Sanjiang Plain. Especially, the population pressure was the main factor for wetland losing in the past decades. However, we still insist that, with the importance of wetland environmental and ecological function recognition, the degradation speed of wetland environment in Sanjiang Plain have slowed down in recent years, while some habitats have turned to a better situation. But efforts and policies still need to be taken to protect wetland in Sanjiang Plain.

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