



# Loss and Fragmentation of Marshes in the Sanjiang Plain, Northeast China, 1954–2005

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**Abstract** Marshes in the Sanjiang Plain of Northeast China have undergone dramatic loss and fragmentation over the past decades. This paper analyzed the loss and fragmentation of these marshes for the period 1954–2005 using historical land-cover information and remote sensing data. In 1954, marshes covered one-third of the total land area but have decreased by 77% over the 50 year period. Results showed two distinct periods of impact: 1954–1986 and 1987–2005. In the earlier period, the number of marsh patches fell from 4,799 to 1,476 (–69.2%), and total marsh area decreased from 35,270 km<sup>2</sup> to 13,893 km<sup>2</sup> (–60.6%). In the latter period, the number of marshes declined from 1,476 to 1,037 (–29.7%), and the total area decreased from 13,893 km<sup>2</sup> to 8,100 km<sup>2</sup> (–41.7%). The rapid decrease in the number and area of marshes during 1954–1986 was largely attributed to extensive agricultural reclamation under the “Food First” agricultural policy. This resulted in many negative ecological consequences. In contrast, the slower reduction of marsh areas during 1987–2005 was due

to the implementation of governmental policies for protecting and restoring marshes. Increasing air temperature would otherwise have enhanced crop yields and stimulated the conversion of marsh into crops.

**Keywords** Agriculture · Climatic changes · Marsh loss · Policy · Remote sensing

## Introduction

Wetlands provide many important services to human society, but are at the same time ecologically sensitive (Turner et al. 2000). Over the past century, wetlands all over the world have experienced intensive destruction from anthropogenic impacts (Balmford et al. 2002). Loss or degradation of wetland habitat can result in loss of plant and animal diversity (Cushman 2005), reduction in water supplies and water storage (Finlayson and Rea 1999; Kingsford 2000), increased sedimentation that negatively impacts natural filtration (Coveney et al. 2002; Ying and Wang 2010), loss of floodplain land and protection (Nicholls 2004; Erwin 2009), reduction in groundwater recharge (Maltby 1991; Acharya 2000), and increased soil erosion (Nyman et al. 1994; Lee et al. 2006).

Marshes are seasonally or continually inundated wetlands, characterized by emergent non-woody vegetation adapted for saturated soil conditions. Marshes typically receive most of their water from surface water, although some are fed by ground water (United States Environmental Protection Agency 2009). Freshwater marshes play important roles in flood protection, water quality improvement, climate change mitigation, and provide habitat for wildlife (Mitsch and Gosselink 2007). Despite their value, freshwater marshes have been greatly altered and degraded by

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human activities (Brinson and Malvárez 2002). Freshwater marshes in China have been rapidly shrinking due to population pressures and past misguided policies. A previous study suggests that China lost 23.0% of its freshwater marshes over the past five decades (An et al. 2007). How freshwater marshes change as a result of human activities and the ecological consequences of these changes have received much attention (Holland et al. 1995; Liu et al. 2005a), but there have been few studies conducted at decadal time scales in major agricultural regions.

The Sanjiang Plain, Northeast China, is the largest area of freshwater marsh in the country. The Sanjiang Plain is a conducive place to study human-induced loss and fragmentation of freshwater marshes and the resulting ecological consequences. When the “Food First” agricultural policy was instituted in 1957 to deal with increasing population pressure, the conversion of marshes to croplands became a major activity in the Sanjiang Plain. Land reclamation practices accelerated from the late 1950s to the mid-1980s (Wang et al. 2006; Song et al. 2008), resulting in many negative consequences (Liu and Ma 2002). Other studies have investigated marsh loss and landscape changes in some portions of the Sanjiang Plain (e.g., Liu et al. 2004; Hou et al. 2004; Zheng et al. 2008; Zhang et al. 2009) or over the whole region for the last 20 or 30 years (Li et al. 2002; Wang et al. 2006; Song et al. 2008). However, earlier periods in the 1950–1970s, a key time for marsh loss and cropland expansion in the Sanjiang Plain, has not been fully considered. Thus, to develop a complete picture, it would be very useful to acquire and analyze available data over the whole Sanjiang Plain at decadal scales for the 50 year period. The objectives of this study were: (1) to analyze the spatial and temporal characteristics of marshes in the Sanjiang Plain from 1954 to 2005, using historical land-cover information and remote sensing data; (2) to investigate possible causes for marsh loss and fragmentation such as climatic change, agricultural development, and governmental policies; and (3) to explore the ecological consequences of large scale loss and fragmentation of marshes.

## Methods

### Description of the Study Area

The Sanjiang Plain is located in the northeastern part of Heilongjiang Province, China, and ranges from 43°49'55" to 48°27'40" in latitude and from 129°11'20" to 135°05'26" in longitude, with an altitude of <200 m in most parts (Fig. 1). It is the low alluvial plain of the Heilongjiang, Songhua, and Wusuli Rivers, encompassing a total area of 108,829 km<sup>2</sup> and 23 counties. The climate is temperate humid and sub-humid continental monsoon, with a mean

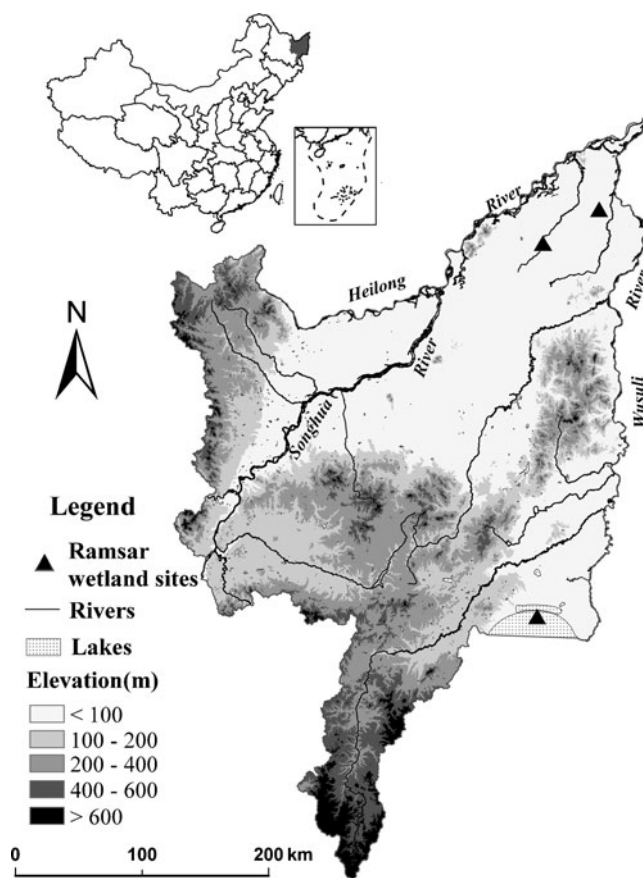


Fig. 1 Location of the Sanjiang Plain of Northeast China

annual precipitation of 500–650 mm and a mean annual temperature of 1.4–4.3°C. The zonal soil types include Luvisols, Phaeozems, Cambisols, and Histosols, which occupy more than 90% of the region. The natural vegetation in the surrounding uplands consists of coniferous forest, deciduous broadleaf forest, and coniferous and broadleaf mixed forest. The natural vegetation in the plain itself is wet meadow and marsh communities. Dominant wetland plants include *Phragmites communis*, *Carex lasiocarpa*, *Carex pseudocuraica*, *Carex meyeriana*, *Alnus sibirica*, *Betula fruticosa*, *Salix brachypoda*, *Lythrum salicaria*, *Calamagrostis angustifolia*, and *Pedicularis grandiflora*.

Three sites in the Sanjiang Plain have been designated as wetlands of international importance (see Fig. 1). Honghe National Nature Reserve (Ramsar site No. 1149) covers 21,836 ha (47°49'N 133°40'E). This near-natural marsh ecosystem has a large variety of wetland types, providing habitat for six endangered and rare species of plants and three species of birds. The second site is San Jiang National Nature Reserve (Ramsar site No. 1152), which covers 164,400 ha (47°56'N 134°20'E). It is an alluvial floodplain consisting of a mixture of rivers, open bogs, seasonally flooded meadows, and sedge marshes. The site is internationally important for waterfowl, particularly ducks, sup-

ports extensive fishery resources, and serves as a natural reservoir that provides vital flood control. The third site is Xingkai Lake National Nature Reserve (Ramsar site No. 1155), covering 222,488 ha (45°17'N 132°32'E). This complex wetland system includes grasslands, marshes, lakes, and forests. The site provides important habitats for a number of protected bird species, about 65 fish species, and more than 460 higher plant species (The Ramsar Convention on Wetlands 2009).

The Sanjiang Plain also contains a historically famous marsh, Bei Da Huang (Huang et al. 2009). In the 1940s, more than 50,000 km<sup>2</sup> of marshes and wet meadows existed (Liu and Ma 2002). Land use practices significantly changed the original land-cover, and the area experienced extensive reclamation prior to the mid-1980s that resulted in rapid loss of marsh area. Prior to 1954, the cropland area was only 780 km<sup>2</sup> (<1% of the total land area), but by the 1990s occupied about 45,000 km<sup>2</sup> (>40% of the total land area) (He 2000). As a result, the Sanjiang Plain is one of the most productive agricultural regions in China. However, only a few large patches of marsh exist outside the wetland nature reserves (Wang et al. 2009a).

#### Data Sources and Processing

ERDAS 8.5 image processing software and ArcGIS 9.2 software were used for data processing. Albers Equal Area Conic Projection System and Beijing 1954 Coordinate System integrated different spatial data. Data on loss and fragmentation of marshes during 1954–2005 were acquired from historical land-cover information and remote sensing data. Data used in this study spanned approximately 50 years and were divided into five periods: 1954–1976, 1977–1986, 1987–1995, 1996–2000, and 2001–2005. The land-cover data for 1954 were obtained from topographic maps (scanned and indexed color maps including land cover types with clear boundaries, with a scale of 1:100,000) with quality sufficient for the study's purpose (Li et al. 2007; Wang et al. 2009b). These maps spanning 1953–1956, with a mean year of 1954, were surveyed during the plant growing season by the China Army General Consultation. Land-cover information from the 1970s to 2000 was acquired from cloud-free Landsat remote-sensing images: 12 scenes of Landsat Multispectral Scanner (MSS) data with a resolution of 80 m in 1976 and 12 scenes of Landsat Thematic Mapper (TM) data with a resolution of 30 m in 1986, 1995, and 2000. Land-cover information in 2005 was acquired from 26 cloud-free scenes of China-Brazil Earth Resources Satellite (CBERS-1) data with a resolution of 23 m. Landsat and CBERS-1 data were obtained from China's Satellite Ground Station and the website of CBERS ([www.cbears.inpe.br/en/programas/cbers1-2\\_cameras.htm](http://www.cbears.inpe.br/en/programas/cbers1-2_cameras.htm)). Remote sensing images recorded

from June to October were selected because land use types are easy to identify during this period when plants grow actively in Northeast China. In this study, several spatial data sources with different resolutions were used, with Landsat MSS having the coarsest spatial resolution of 80×80 m. So, we used 80×80 m as the resolution for data processing for all land cover data in all periods, which means the minimum size of polygons was 6400 m<sup>2</sup>.

First, a fishnet was generated that rectified all historical maps. To obtain land-cover information in 1954, visual map interpretations were made using on-screen digitizing by directly drawing polygons along the boundaries of land-cover types using a mouse, saving them to different polygons, and then adding attributes (labels) of the polygons to produce digital maps. Finally, the vector digital maps were edited and compiled. Focusing on the changes of marsh area, the final classification was comprised of only two categories: marsh and non-marsh.

Before interpretation, remote sensing images were geo-rectified to 1:100,000 topographic maps using ground control points (GCPs) collected by global positioning system (GPS). Each image scene had at least 20 evenly distributed sites that served as GCPs. Remote sensing imageries were masked using the region boundary. In this study, unsupervised classification was carried out using the interactive self-organizing data analysis (ISODATA) algorithm to identify spectral clusters in the images. Based on results of the unsupervised classifications, training sites were chosen from the images. Spectral signatures for the training sites were carefully chosen and examined for each image. The widely used supervised classification method, maximum likelihood, was used to classify the remote sensing images. The training data for the classification of the classes were selected by combining visual identification and site visits. The preliminary classification indicated that misclassification errors included both boundary and spectral confusion. As demonstrated in previous studies (Herold et al. 2003), visual interpretation of remote sensing imagery can be useful in land cover mapping. In this study, the preliminary classification results were therefore revised according to visual interpretation and ground survey, to reduce any noise caused by mixed scattered point features. Finally, land-cover maps extracted from remote sensing images showed seven land-cover types: (1) cropland, (2) woodland, (3) grassland, (4) water body, (5) built-up land, (6) marsh, and (7) barren land. Finally, these land-cover types were reclassified into marsh and non-marsh types. For details on the data processing, see Wang et al. (2006, 2009a).

The topographic maps with a 1:100,000 scale were based on air photographs, trigonometric field surveys, and extensive ground truthing (Li et al. 2007). Digital vegetation maps (with scale of 1:500,000) of the study area drawn

in 1958 were also used to revise and validate the digital land-cover map in 1954. Land-cover information for 1954 was obtained directly from the land-cover maps. Our classification was comprised only of marsh and non-marsh categories; thus, the classified products for 1954 were very precise. The classification accuracy for land-cover maps extracted from remote sensing images was assessed in 2002, 2006, and 2007 using reference data of randomly selected patches. Various maps, field data, photos, and interviews with local people were used as reference data. The accuracy assessment was based on an evaluation of 250, 340, 320, 210, and 260 marsh patches for 1976, 1986, 1995, 2000, and 2005, respectively. The accuracy of marsh distribution maps interpreted from remote sensing images all exceeded 84% (84.2% for 1976, 86.7% for 1986, 92.5% for 1995, 89.0% for 2000, and 92.9% for 2005). Results indicated that 94% of the polygon boundaries show less than a 1.5 Landsat TM pixels (45 m) shift from the real boundary.

We collected daily and annual meteorological data during 1951–2005 from 12 meteorological stations evenly distributed throughout the Sanjiang Plain to explore possible impacts of climatic variations on wetland ecosystems. We used socioeconomic data, including cropland area, total population, and agricultural population, to analyze possible factors associated with changes in marsh area. Data were obtained from the statistical yearbooks of Heilongjiang Province, China [National Bureau of Statistics of China (NBSC) 1999; 2001–2006].

## Analyses

The Patch Analyst module, an extension to the ArcView GIS system, was used to conduct the spatial analysis of landscape patches. In this analysis of marsh changes at the class level, six indices were selected: number of patches (NP), patch density (PD), area-weighted mean patch fractal dimension (AWMPFD), largest patch index (LPI), mean patch size (MPS), and patch size coefficient of variance (PSCV). NP is an intuitive and simple measure of the degree of subdivision of a land cover type (McGarigal and Marks 1995). PD is the density of patches for each land-use, representing dissection of patches. AWMPFD reflects the shape complexity weighted by the area of patches. MPS can serve as a landscape fragmentation index. A landscape with a smaller mean patch size for the target patch type than another landscape might be considered more fragmented. PSCV is the variability of patch size relative to the mean patch size, and reflects the patch distribution (McGarigal and Marks 1995). When converting vector files into grid files for analysis of landscape metrics, the cell size was set as 80×80 m, to avoid the effects of differences among data sources.

Potential evapotranspiration (PET) was calculated using the Penman-Monteith (P-M) method proposed by the Food

and Agriculture Organization (FAO) (Allen et al. 1998). The P-M method for calculating daily potential evapotranspiration ( $ET_0$ ) is:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/T + 273)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where  $ET_0$  is the reference evapotranspiration (mm/d);  $R_n$  is the net radiation at the surface ( $\text{MJ}/(\text{m}^2 \text{ d})$ );  $G$  is the soil heat flux ( $\text{MJ}/(\text{m}^2 \text{ d})$ ), which was ignored for daily calculation because the magnitude of the flux in this case was relatively small;  $T$  is the average air temperature at 2 m height ( $^{\circ}\text{C}$ );  $u_2$  is the wind speed at 2 m height (m/s);  $e_s$  is the saturation vapor pressure (kPa);  $e_a$  is the actual vapor pressure (kPa);  $e_s - e_a$  is the saturation vapor pressure deficit (kPa);  $\Delta$  is the slope of the saturated water–vapor pressure curve ( $\text{kPa}/^{\circ}\text{C}$ ); and  $\gamma$  is the psychrometric constant ( $\text{kPa}/^{\circ}\text{C}$ ).

The computation of all data required to calculate  $ET_0$  followed the recommendations of FAO (Allen et al. 1998). In this study, meteorological data with time-steps of 1 day were processed to acquire daily  $ET_0$  with units of mm/d, then daily  $ET_0$  values were multiplied by the number of days for the specific month used to obtain a monthly  $ET_0$  value with units of  $\text{mm month}^{-1}$ . Annual  $ET_0$  was derived by summing up monthly values for a year. For all meteorological data used in this study, regional values were obtained by averaging station values. Furthermore, we analyzed annual variability of the dryness index (DI) (Milly 1994; Wolock and McCabe 1999), to explore the relation between the climatic demand for water ( $PET$ ) and the climatic supply of water ( $PPT$ ), for the study area, over the five decades. The dryness index was calculated as:

$$DI = \frac{PET}{PPT} \quad (2)$$

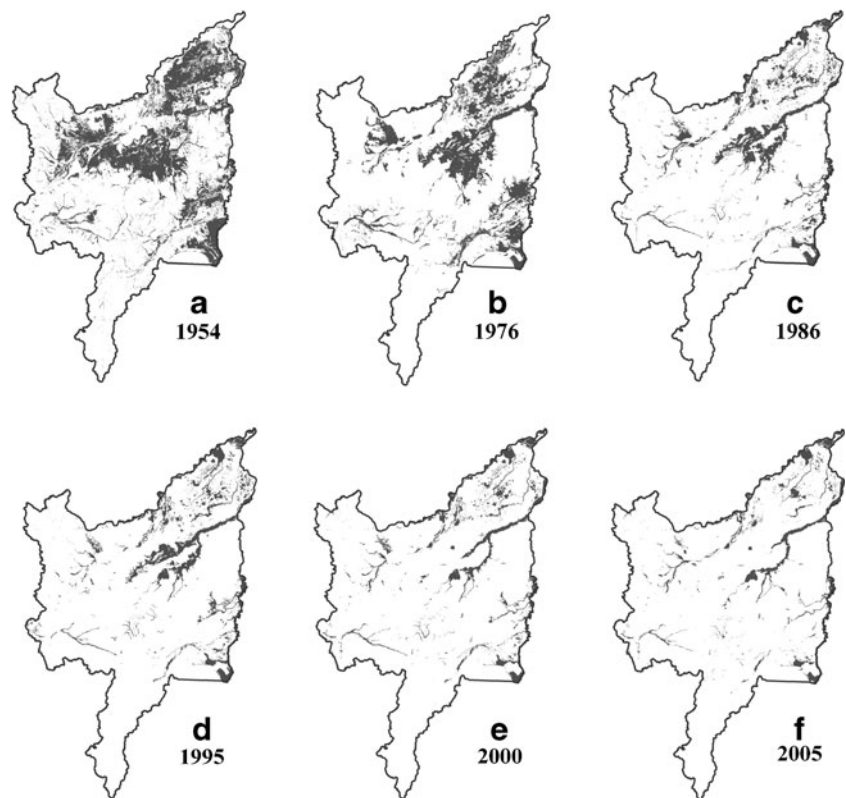
where  $DI$  is the dryness index;  $PET$  is potential evapotranspiration; and  $PPT$  is precipitation.

Linear regression analyses were performed to identify the relationships between marsh loss and cropland gain, and relationships between cropland area and total or agricultural population. Nonlinear asymptotic regression analyses were used to describe temporal trends of climatic factors. These statistical analyses were conducted using SPSS 10.0.

## Results

The progression of spatial change of marshes in the Sanjiang Plain is illustrated in Fig. 2, and specific data on temporal change of marsh area and change rate over the study period are listed in Table 1. In 1954, marshes were

**Fig. 2** Distribution of marshes in the Sanjiang Plain, China, in 1954 (a), 1976 (b), 1986 (c), 1995 (d), 2000 (e), and 2005 (f)



distributed widely in the middle and northern part of the study region, and many large patches existed. However, by 1986, marshes had been eliminated over large areas, and many formerly extensive patches disappeared. By 2005, large patches of marsh only remained in some nature reserves (Figs. 1 and 2). Over the 50 year period, a rapid loss of marshes was evident, and two distinct intervals, 1954–1986 and 1987–2005, were evident based on different characteristics of marsh loss and fragmentation.

Marsh area of the Sanjiang Plain decreased overall by 27,170 km<sup>2</sup> over the 50 year period. In 1954, marshes occupied about 32.4% of the overall area with an area of 35,270 km<sup>2</sup>. However, by 2005, the total marsh area decreased by about 77% to 8,100 km<sup>2</sup>, with an average loss rate of 543 km<sup>2</sup>/year. The greatest absolute losses of marsh area occurred between 1954 and 1976 (13,184 km<sup>2</sup>), and between 1977 and 1986 (8,193 km<sup>2</sup>). From 1987 to

2005, marsh losses declined. Losses of marsh area during 1987–1995, 1996–2000, and 2001–2005 were 1,744 km<sup>2</sup>, 2,560 km<sup>2</sup>, and 1,489 km<sup>2</sup>, respectively (Table 1). From 1954 to 1986, the net loss and loss rate of marsh area were 21,377 km<sup>2</sup> and 668 km<sup>2</sup> per year, respectively. In contrast, from 1987 to 2005, they were 5,793 km<sup>2</sup> and 305 km<sup>2</sup> per year, respectively.

Landscape metrics of marsh classes in 1954, 1976, 1986, 1995, 2000, and 2005 are listed in Table 2. The number of marsh patches decreased substantially from 4,996 in 1954 to 1,489 in 1986. From 1987 to 2005, the rate declined, with the number of patches decreasing from 1,489 to 1,116. Patch density decreased from 0.044 to 0.014 per 100 ha during 1954–1986, and from 0.014 to 0.010 per 100 ha during 1987–2005. From 1954 to 1986, area-weighted mean patch fractal dimension decreased from 1.30 to 1.21 and from 1987 to 2005, it only decreased from 1.21 to 1.20.

**Table 1** Marsh area of the entire Sanjiang Plain (108,829 km<sup>2</sup>) from 1954 to 2005 and areal changes during different periods

Year	Marsh area (km <sup>2</sup> )	% of total area	Period	Change in marsh area (km <sup>2</sup> )	% change
1954	35269.8	32.4	1954–1976	−13183.7	−37.4
1976	22086.1	20.3	1977–1986	−8192.8	−37.1
1986	13893.3	12.8	1987–1995	−1744.2	−12.6
1995	12149.1	11.2	1996–2000	−2560.3	−21.1
2000	9588.9	8.8	2001–2005	−1488.7	−15.5
2005	8100.2	7.4	1954–2005	−27169.6	−77.0

**Table 2** Landscape metrics for marsh in the Sanjiang Plain from 1954 to 2005. NP: number of patches; PD: patch density (/100 ha); AWMPFD: area-weighted mean patch fractal dimension; LPI: largest patch index (%); MPS: mean patch size (ha); PSCV: patch size coefficient of variance

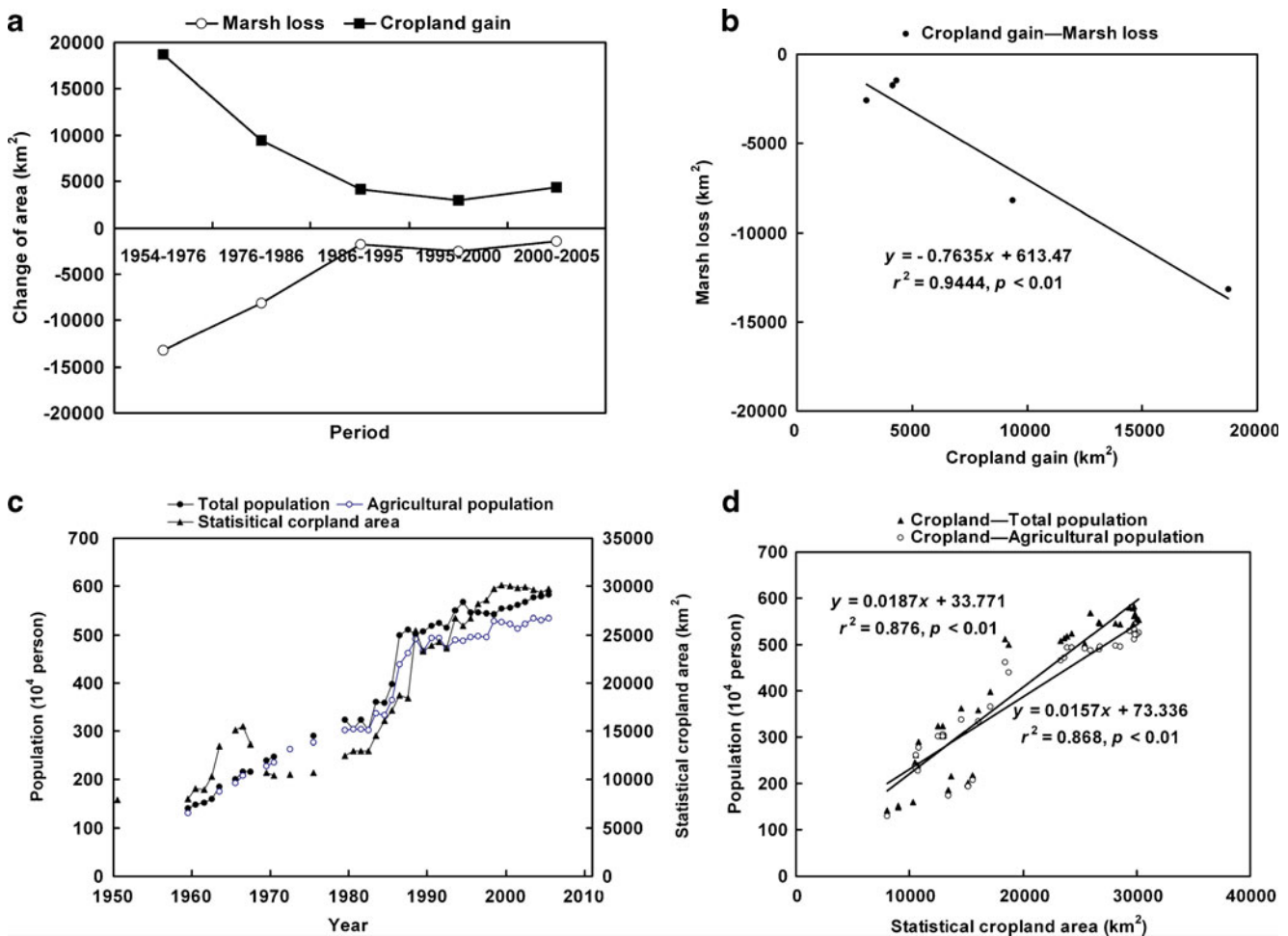
Year	NP	PD	AWMPFD	LPI	MPS	PSCV
1954	4799	0.044	1.307	17.592	734.9	3902
1976	1652	0.015	1.267	10.479	1336.9	2214
1986	1476	0.014	1.211	3.672	941.4	1213
1995	1390	0.013	1.208	3.063	874.1	1132
2000	1210	0.011	1.199	1.578	792.5	793
2005	1037	0.010	1.196	1.428	781.0	762

Differences between the two periods were also evident for LPI, MPS, and PSCV. From 1954 to 1986, largest patch index decreased from 17.59 to 3.67%, and from 1987 to 2005, it decreased from 3.67 to 1.43%. Mean patch size increased from 735 in 1954 to 1,336 ha in 1976, then decreased. Patch size coefficient of variance had a relatively

large decrease (from 3,902 to 1,213) from 1954 to 1986, and a relatively small decrease (from 1,213 to 762) from 1987 to 2005 (Table 2).

Figure 3a shows that, in concert with loss of marsh area during different periods (Table 1), changes in land use and human populations also occurred. Cropland area increased by 18,733, 9,382, 4,156, 3,004, and 4,328 km<sup>2</sup>, during 1954–1976, 1977–1986, 1987–1995, 1996–2000, and 2001–2005, respectively. Overall cropland area increased by 271% (Fig. 3c), and area of marsh loss was tightly correlated to the area of cropland gain ( $r^2=0.94$ ,  $p<0.01$ ) (Fig. 3b). The total population of the Sanjiang Plain increased from 1.41 million persons in 1959 to 5.83 million persons in 2005, a 313% change. The agricultural population increased by 311%, from 1.30 to 5.34 million persons over the same period. Cropland area linearly increased with total population ( $r^2=0.88$ ,  $p<0.01$ ) and agricultural population ( $r^2=0.87$ ,  $p<0.01$ ) (Fig. 3d).

Over the 50 year period, climate in the Sanjiang Plain warmed significantly ( $r^2=0.49$ ,  $p<0.05$ ). *PPT*, which affects



**Fig. 3** Socio-economic driving forces associated with marsh loss from 1951–2005: **a** marsh loss and cropland gain; **b** correlation between marsh loss and cropland gain; **c** changes in total population,

agricultural population, and cropland area; **d** correlations between cropland area and total and agricultural populations

supplies of water for marshes, fluctuated over the 50 years, but did not exhibit a consistent trend ( $r^2=0.05$ ,  $p>0.05$ ). Estimated *PET* over the whole Sanjiang Plain increased significantly ( $r^2=0.29$ ,  $p<0.05$ ) over the 50 year period, which would have affected demand for water. However, no significant change of *DI* was observed ( $r^2=0.10$ ,  $p>0.05$ ) over the study period (Fig. 4).

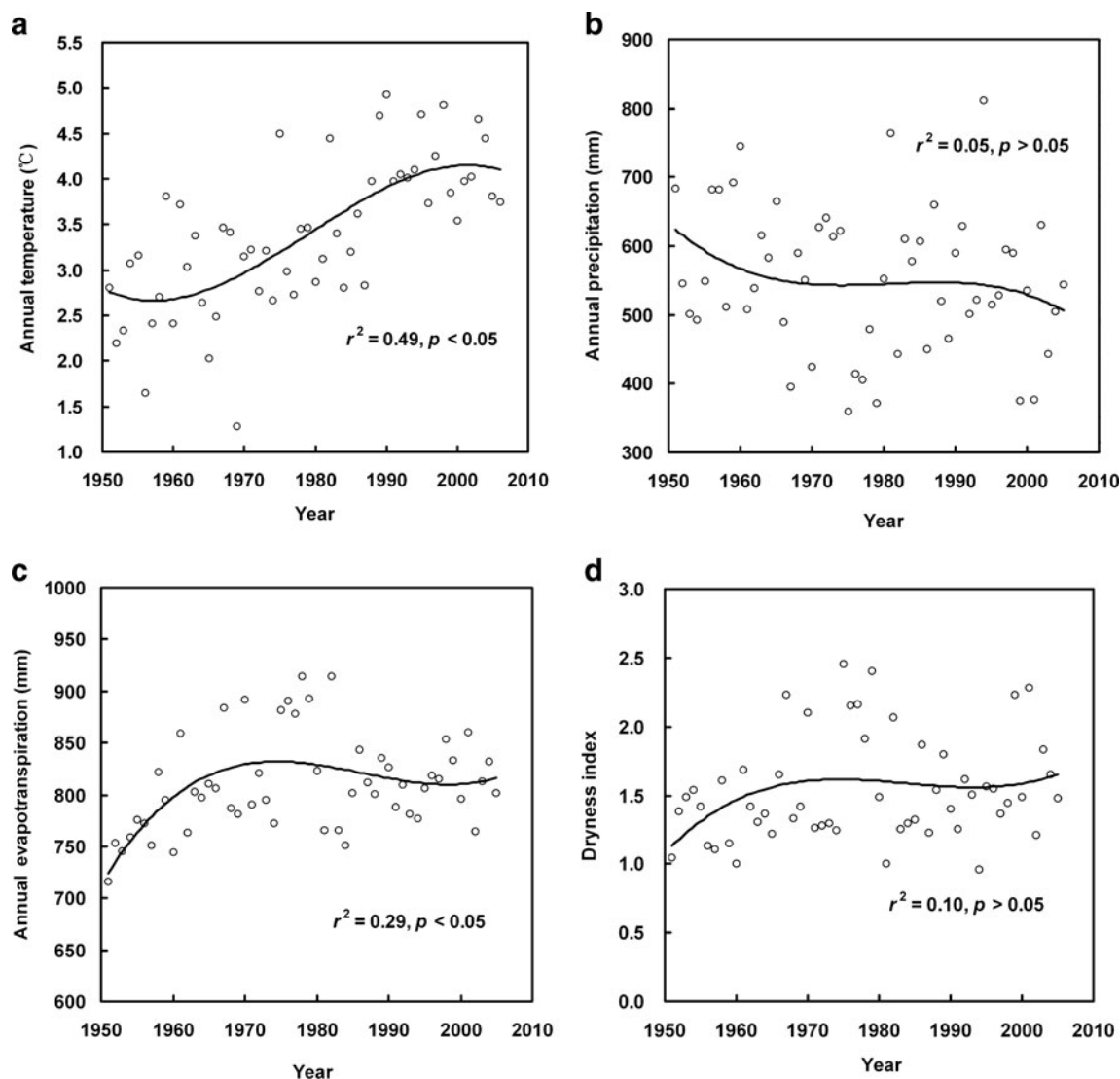
## Discussion

### Possible Anthropogenic and Natural Causes of Marsh Loss and Fragmentation

In the Sanjiang Plain, marsh area, number of marsh patches, and marsh patch density decreased considerably, especially

in the period 1954–1986 (Tables 1 and 2). Area-weighted mean patch fractal dimension declined continually because increasing human influence makes the shape of marsh patches simpler or more regular (Wang et al. 2009b). Largest patch index and patch size coefficient of variance decreased sharply from 1954 to 1986, but decreased gradually from 1987 to 2005, probably because the causes of marsh fragmentation differed between periods. Mean patch size increased from 1954–1976 because a large number of the smaller marsh patches were removed (with number of patches decreasing from 4799 to 1652). However, the mean patch size decreased from 1976 to 2005 because large marsh pieces were converted into smaller pieces.

Agricultural activities, especially cropland reclamation, have been major threats to freshwater marshes of the



**Fig. 4** Climatic change in the Sanjiang Plain from 1951 to 2005: **a** annual temperature; **b** annual precipitation; **c** annual evapotranspiration; **d** dryness index

Sanjiang Plain in the past. Cultivated land for grain production was developed at the expense of wetlands (Wang et al. 2006). Over the 50 year period, the net decrease of marsh area of 27,170 km<sup>2</sup> was concomitant with the substantial increase in cropland. During the period 1954–1986, marshes decreased and cropland area increased rapidly (Fig. 3b). However, over the period 1987–2005, the rates of marsh and cropland change slowed.

The intensive agricultural reclamation activity was associated with the increase in population and the concomitant requirement for grain after the founding of the People's Republic of China (Fig. 3b). As one of the important grain sources, the Sanjiang Plain needed to supply a large amount of grain to other regions (Wang et al. 2006). Similar losses of marshes from intensive agriculture also occurred in the Songnen Plain of Northeast China (Wang et al. 2005) and the Ruergai Region of the Tibetan Plateau of Northwest China (Yan and Wu 2005).

Patterns in marsh loss in the Sanjiang Plain were closely related to shifts in governmental policy. In the period from 1955 to 1960, a great number of retired veterans (about 81,500 people) entered the region to reclaim wetlands and wet meadows, and convert them into farmland with the aim of producing more food, according to the “Great Leap Forward” movement. As a result, cropland increased by 7,270 km<sup>2</sup>. In the period from early 1960s to 1977, 54,200 educated youth entered this region to conduct agriculture in response to the “Going to the Countryside and Settling in the Communes” movement, one of the important aspects of the “Cultural Revolution”. In this period, cropland increased by 6,060 km<sup>2</sup>. In the period from 1978 to 1985, the “Agricultural Modernization” policy promoted the use of advanced agricultural machinery, and as a result large modernized farms were built, causing an increase of 8,530 km<sup>2</sup> in cropland. In a fourth period from the mid-1980s to 2000, the “Comprehensive Agricultural Development Project” was implemented, and cropland increased by 10,400 km<sup>2</sup> (Cui and Liu 1999; Liu and Ma 2000; Na and Zhang 2004).

However, an increasing awareness of the important ecological functions of natural wetlands and the environmental consequences of wetland loss have motivated Chinese central and local governments to prohibit marsh reclamation in the Sanjiang Plain and to establish natural reserves. From 1985 to 2003, 17 reserves for wetlands (National or Provincial) were established in the Sanjiang Plain. Since 2005, the Chinese government has been implementing the National Wetland Conservation Program (NWCP) and the Degraded Wetland Restoration Program (DWRP), which aim to conserve natural wetlands and convert reclaimed low-yield croplands to natural wetlands.

Wetland loss can be categorized as either: (1) direct loss resulting from land use conversion, or (2) indirect loss

resulting from the decline of wetland quality, particularly diversion of water from agricultural irrigation and channel drainage (Zhang et al. 2010). In the Sanjiang Plain, direct impacts on marshes were from agricultural exploitation, which turned marshes into agricultural lands through ditching, draining, tilling, and planting (Liu et al. 2004). Indirect impacts usually led to water loss from marshes, degrading them to grasslands. The indirect loss of wetlands from declining water supplies has also been reported by Li et al. (2007) in the West Songnen Plain and by Zhang et al. (2010) in the Northeastern part of the Sanjiang Plain.

In the Sanjiang Plain, temperature is a critical climatic variable that controls the distribution of crops. For instance, rice can only be cultivated in the places where the mean annual temperature is higher than 1°C (Liu et al. 2005b). Climate warming has enhanced crop growth, and stimulated the conversion of marshes into croplands. Because wetland systems are vulnerable to changes in the quantity and quality of water supplies, it is expected that continuing climate change will have a pronounced effect on wetlands through alterations in hydrological regimes (Erwin 2009). In the Sanjiang Plain, an increasing potential evapotranspiration is likely to result in conversion of marshes to grasslands or other landscape types.

#### Ecological Consequences of Marsh Loss and Fragmentation

Marsh loss and fragmentation in the Sanjiang Plain has significantly degraded ecosystem services, such as drought alleviation, flood retention, soil organic carbon storage, and biodiversity preservation. The frequency of droughts and floods in the study area has increased. Average intervals between extreme droughts and floods were 4.2 and 3.5 years, respectively, during the 1950–1970 period, but the intervals declined to 1.8 and 2.4 years during the 1971–1990 period (Liu and Ma 2002). To a large degree, the increased frequency and magnitude of flooding can be traced back to the conversion of marshlands to croplands. Reclamation dramatically reduced an important buffer for storm water retention and caused water levels of rivers to rise sharply during heavy rainfall (Liu 2007). Instead of percolating downward, much of the rainwater enters channels directly, carrying surface soil with it. Consequently, silt deposits have raised riverbeds substantially. Similar hydrological effects of wetland destruction and fragmentation have been identified in the coastal areas of the US (Turner and Yeleswarapu 1990), inland watersheds (Detenbeck et al. 1999), and semi-arid regions of Northeast China (Moiwo et al. 2010).

The role of wetlands in climate change has been a global focus in recent years. Wetlands store 25–30% of the soil organic carbon pool (Millennium Ecosystem Assessment 2005) despite only covering 5–8% of the land surface



(Mitsch and Gosselink 2007). Wetlands destruction or conversion into other land uses can release stored carbon, and contribute to the CO<sub>2</sub>-driven greenhouse effect (Keller et al. 2004). It was estimated that the conversion of marshland into cropland in the Sanjiang Plain over the period of 1950s–2000s resulted in soil organic carbon loss of 240 Tg (Huang et al. 2009).

Due to large-scale agricultural development, most marshes in the Sanjiang Plain are fragmented and isolated. Degradation of wetland functions have led to decreases in plant species richness, reductions in biological production, and increases in threats to endangered plants and animals, especially rare birds (Liu and Ma 2002; Liu et al. 2004). Areal loss, fragmentation, isolation, and patch shape change of marshes can affect nesting, foraging, and reproduction of waterfowl (Liu et al. 2007). Oriental storks require 3.2 km<sup>2</sup> as a minimum habitat area (Liu et al. 2007), and the number of marsh patches of this size has declined from 404 in 1954, to 310 in 1986, and to 210 in 2005. The population of Oriental storks in the Sanjiang Plain has decreased from 780 in the 1960s to 47 in the 1990s (Wang et al. 2006).

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