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The spatial–temporal dynamic characteristics of the marsh in the Sanjiang Plain

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Abstract: Using the methods of combining landscape ecology with GIS spatial analysis, this paper analyses the dynamics of the marsh landscape structure of the Sanjiang Plain in the past 20 years, furthermore, taking Fujin County, located in the north of the plain, as an example, analyzes the conversion between marsh and other land use types. It is shown that the marsh in the Sanjiang Plain decreased greatly in the past 20 years, but the trend has begun to reverse. The marsh area decreased by 51.33% from 1980 to 1996, whereas it decreased by 4.19% from 1996 to 2000. The fragmentation of the marsh increased; the number of the patches increased by 326 from 1986 to 1996, whereas it only increased by 18 patches from 1996 to 2000. It is obvious that the speed of patches number diminished and the marsh fragmentation decreased, which shows that the reclamation of the marsh converted from the fragmentation to the brim in a large area of the marsh. The reclaimed marsh has mainly converted to paddy field and dry land. Large-scale reclamation in the Sanjiang Plain influences its natural environment directly: the climate of the region turns from cold and wet to warm and dry, which makes the marsh both in the low-temperature northern part and in the deeply stagnant eastern part suitable for further agricultural development.
Key words: marsh; spatial and temporal dynamics; wetland management; landscape change; remote sensing
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1 Introduction

The wetland ecosystem is the latest one understood by humans and it is the most seriously damaged ecosystem (Williams, 1991). The Sanjiang Plain, located in northeast China, is the largest concentrated area of freshwater wetland in China. Since the 1950s, large-scale reclamation of the marsh in the Sanjiang Plain has been started. According to statistics, the natural marsh has lost about 80% of its total area. The marsh resources in the Sanjiang Plain decreased greatly and the spatial distribution layout is seriously disturbed. As a result, the marsh function and the natural ecosystem in the Sanjiang Plain has become worse and worse. According to the prognostication, if the marsh decreases at the same speed as recent years, the natural marsh in the Sanjiang Plain will disappear within 20 years. Therefore, more attention is paid to the marsh loss and gain in the Sanjiang Plain by the local government and marsh experts. Liu and Zhao have expounded the influence of large-scale reclamation on the marsh resources in the Sanjiang Plain (Zhao, 1999; Liu, 1995), and proposed that the aggravation of natural conditions such as the rise of air temperature and the drop of precipitation naturally quicken the speed at which the marsh area is decreasing. Liu explored the changes of main land cover types by using RS and taking the typical area as an example (Liu, 1996), and concluded that among the natural conversions in the Sanjiang Plain, the marsh and forest decrease most greatly. The above-mentioned studies describe the dynamic characteristics from different profiles, but because of lack of the necessary temporal and spatial dynamic data of the

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whole area (Briassoulis, 2001), it is impossible for earlier researchers to further strengthen the quantitative calculation. In order to analyze the marsh dynamics of the whole plain, this paper uses the wetland database of the Sanjiang Plain, which was obtained by remote sensing interpretation. At the same time, in order to quantitatively calculate the temporal and spatial characteristics of the marsh in the Sanjiang Plain, our analysis is based on the methods of landscape ecology and those of the GIS spatial analysis.

GIS and landscape ecology provide a useful way of describing landscapes both spatially and temporally and have proven to be particularly useful for understanding vegetation structure or patterns in landscapes across the world (Diane, 2002).

By combining the quantitatively calculations of the landscape ecologic structure and GIS spatial analysis to study the dynamics of land use and cover change, we can further understand such problems as the natural resource dynamics in landscape and the region scale and the environment management, and the elements that influence the landscape caused by human beings (Chen and Fu, 1996). It can provide valuable materials for the rational management of the environment. This field has become the core of landscape dynamic study and has become the direction for further development. With the combination of the quantitative calculation of landscape ecologic structure with GIS spatial analysis, we not only quantitatively recognize the temporal and spatial dynamic characteristics of the marsh in the Sanjiang Plain, the largest freshwater marsh in China, but also further understand the process of the dynamic change of the marsh (Turner, 1989; Gustafson, 1998), and propose practical measures for the sustainable development of the marsh.

2 General situations of nature, society and economy of the study area

The Sanjiang Plain lies in the northeast of Heilongjiang Province (43°49'55"-48°27'40"N, 129°11'20"-135°05'26"E) with a total area of 108,900 km^2 (Figure 1). It is a low alluvial plain of three rivers: Heilong, Songhua, and Wusuli. It is high in the southwest and low in the northeast. The climate in the area belongs to the temperate humid and subhumid continental monsoon climate. The mean temperature is below −18℃ in January, and 21-22℃ in July. The frost-free period is 120-140 days. Annual precipitation is 500-650 mm, mainly concentrating in May to September, making up 80% of the year's total. Most of the rivers in the area have the characteristics of the river in the marsh plain: the slight fall and large channel curve coefficient. The types of the plants belong to Changbai flora, mainly meadow and marsh vegetation. There are 23 counties in the area (Figure 2), with a population of 7.8 million, among which 53.4% is agricultural population. Agriculture is its main industry, and cultivated land covers about 1,1400 km^2. According to the statistical data, the accumulated yield of grain and bean is about 704.25 billion kg, being one of the commodity grain bases in China (Chen and Ma, 1997).

3 The study method

3.1 The flow of the technology

The spatial-temporal wetland database is the basis of this study. We study the whole of the Sanjiang Plain's landscape structure with the interpreted 1:200,000 Landsat MSS marsh map in 1980 and the 1:100,000 Landsat TM marsh maps of the Sanjiang Plain in 1996 and in 2000. With the consideration of accuracy conformity and data comparison, we processed three-date data sets with reference to the accuracy of

Figure 1 Location of the Sanjiang Plain

the smallest scale, 1:200,000, by eliminating the small polygons with an area less than 0.01 km² in the data from 1996 and 2000, and then we made an Albert projection for the date from these three dates. After that, the marsh landscape parameters were calculated at regional scale of the whole area, and marsh landscape models were built. Using these models, we analyzed the structural pattern of the landscapes in the Sanjiang Plain. In order to further understand the marsh dynamics and the conversion of the decreased marsh to other land use types, we used Fujin County as an example to make further analyses using land use maps at scale of 1:100,000. These maps were attained through remote sensing interpretation of Landsat TM images in 1986, 1996, and 2000.

Figure 2 Location of Fujin County

3.2 The model of the spatial change pattern of the marsh

With reference to the methods of population geography, the spatial change of the marsh is studied here. We calculated the distributed period of marsh patches, latitude and longitude, respectively, next to be multiplied by the area of the patch, then to accumulate the above results, divided by the whole marsh area in the Sanjiang Plain. The centroid of the marsh distribution can be calculated by the following formula (Wang and Bao, 1999):

$$X_i = \sum_{i=1}^{n}(C_{ti} \times X_i) \Big/ \sum_{i=1}^{n} C_{ti}$$

$$Y_i = \sum_{i=1}^{n}(C_{ti} \times Y_i) \Big/ \sum_{i=1}^{n} C_{ti}$$

where X_i and Y_i stand for the longitude and latitude, respectively, of the distribution centroid of the marsh in year t and C_{ti} stands for the area of the patch i.

By comparing the centroid of the marsh distribution of the three-date data set, we can find the spatial change laws of the marsh distribution.

4 Analysis on landscape dynamics of marsh in the Sanjiang Plain

4.1 The analysis of the area change and marsh fragmentation

Figure 3 is the dynamic distribution histogram showing the marsh area and the number of the marsh patches. As shown in the figure, the marsh area decreases greatly. The marsh area in the Sanjiang Plain was 19,450.95 km² in 1980, whereas it was 9,069.52 km² in 1996. Within 16 years from 1980 to 1996, the marsh area decreased by 51.33%, whereas in the time period of 1996 to 2000, it decreased by only 4.19%. This means that a large amount of marsh was lost. The number of the patches increased greatly, especially in the period of 1986 to 1996; the marsh patches increased by 326, and on the whole increased by 20.38 annually. In 1996 to 2000, the increase in speed of marsh fragmentation slowed down notably, to only 4.5 patches per year. The density of the patches increased from 0.04 patches/km² in 1986 to 0.12 patches/km² in 2000. The largest patch area and the biggest patch perimeter increased first and then slowly decreased. Compared with that of 1980, the area of the biggest patch in 1996 decreased by 65.37%; the perimeter decreased by 52.47%. The total perimeter, the smallest area, the smallest perimeter, and the average perimeter of the patches have a decreasing trend on the whole. The change of marsh in the period of 1980 to 1996 is great, whereas from 1996 to 2000, it is insignificant (Table 1). All of these show that the fragmentation of marsh is very severe, especially in the period from 1980 to 1996. Figure 4 illustrates the distribution of landscapes in 1980, 1996, and 2000. From these maps, we can see that the continuous marsh patches in 1980 were reclaimed into small area, the fragmented marsh landscape.

4.2 Analysis on the spatial change of marsh in the Sanjiang Plain

Transforming the above-mentioned centroid coverage of the marsh patches to ground coordinate, then calculating the distribution centroid of the marsh patches in 1980, 1996, and 2000, which are 46.91°N, 132.71°E, 46.85°N, 132.68°E, and 46.90°N, 132.65°E, respectively. We can see that from 1980 to 1996, the centroid of the marsh patches offset southward 0.06°, and westward 0.03°, so offset to southwest by 7,054 m on the whole in this period. From 1996 to 2000, the centroid of the marsh patches offset northward 0.05° and westward 0.03° further, so offset to northwest by 6,013 m on the whole in this period. As a general analysis, the centroid of the marsh in the Sanjiang Plain moved from the northeast to the southwest from 1980 to 2000, which shows that the developing speed in the northeast is slightly high. When comparing the dynamic patterns of different landscapes or the same landscape, the characteristics of the influencing factors should be taken into consideration (O'Neill *et al.*, 1996; Riitters *et al.*, 1996; Wu, 1998). The offset of the centroid of the marsh distribution reflects the influence of the climate change on the spatial pattern of marsh reclamation.

Table 1 The dynamics of marsh area and patches in the Sanjiang Plain

	1980	1996	2000
Area (km^2)	19450.95	9466.22	9069.52
Number of patches	746	1072	1090

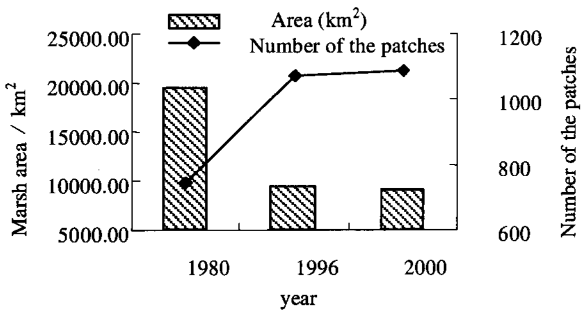

Figure 3 The dynamic change of the marsh in the last decades in the Sanjiang Plain

5 Analysis of land use/cover conversion of landscape in the Sanjiang Plain

Before 1950, the Sanjiang Plain was in virgin condition. From 1955 to 1987, the marsh was extensively reclaimed. We can understand the impacts of the human activities on the loss and gain of the marsh in the Sanjiang Plain. Here we take Fujin County as an example, to comparatively analyse the interpreted Landsat TM image data of three different periods of 1986, 1996, and 2000. Fujin County, with a land area of 8,485.69 km^2, is located in the central and

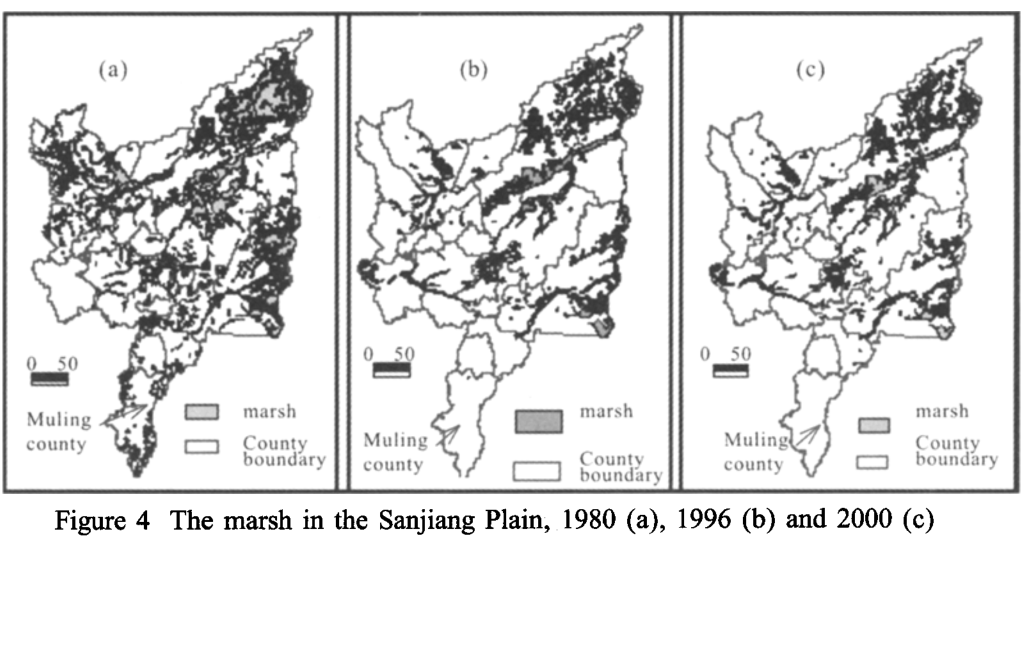

Figure 4 The marsh in the Sanjiang Plain, 1980 (a), 1996 (b) and 2000 (c)

northern parts of the Sanjiang Plain (Figure 2).

5.1 Land use and land cover change in the typical study area

Table 2 The dynamic change of landscape index of marsh in two decades in the Sanjiang Plain

	1980	1996	2000
Total perimeter (km)	26769.72	21790.82	21312.64
Maximum area (km^2)	8773.42	3037.87	3141.37
Maximum perimeter (km)	5568.06	2646.55	2753.43
Minimum area (km^2)	0.03	0.01	0.01
Minimum perimeter (km)	0.80	0.44	0.44
Average area (km^2)	26.07	8.83	8.32
Average perimeter (km)	35.88	20.33	19.55

The comparison shows that, in Fujin County, except the marsh, the change of other land use/cover types, such as water area, residential area, grassland, forest, and other natural vegetation is not notable, whereas the land use types of paddy field and dry land change greatly. Figures 5 and 6 are histograms of land use dynamics of paddy area and dry land, respectively, in the area in Fujin County from 1986 to 2000. The paddy field area in 1996, up to 129.504 km^2, is more than twice as the area in 1986, whereas the paddy field area in 2000 is three times as that in 1986. Compared with the paddy field, the increase rate of dry land area is slight. The area of dry land increased 4.3% from 1986 to 1996, but decreased 0.9% from 1996 to 2000 (Figure 6). Because of the lower output of the dry land, some farmers have been adjusting their planting structures from dry land into paddy field.

5.2 The conversion of marsh to other land use/cover types in the typical study area

Using a GIS spatial overlay analysis, the conversion among land use types can be calculated (Kiensat, 1993; Jobn and Jack, 1995). With an Arc/Info 'INTERSECT' command, the decreased marsh area and its conversion from 1986 to 2000 in Fujin County are gained (Table 3). From Table 3, we can see that the decreased marsh was mainly converted to paddy field or dry land. There are 117 patches of dry land, area ratio up to 94.1%, reclaimed from natural marsh. Other 13 patches of paddy field, area ratio up to 5.82%, were reclaimed from natural marsh too. Only one piece of water area was converted from marsh, area ratio 0.08%. This means that the land use/cover conversion from marsh essentially resulted from agricultural activities.

Table 3 The area and patches of the land use types transformed from marsh in Fujin County

	Patches	Area (km^2)	Area ratio (%)
Lake	1	0.3252	0.08
Paddy field	13	23.3697	5.82
Dry land	117	378.1721	94.1

6 The mechanism of marsh dynamics in the Sanjiang Plain

6.1 The mechanism of marsh dynamics

(1) From the analysis on the marsh dynamics of the whole area in the Sanjiang Plain and the land use/cover conversion of marsh to other land use/cover change in the typical zone, it is concluded that the marsh in the Sanjiang Plain decreased substantially large scale in the past 20 years, and the marsh fragmentation increased, which shows that human activities are the radical reason for marsh loss in the Sanjiang Plain. The lost marsh was mainly converted into dry land and paddy field. The land use/cover condition in marsh distributed zone is directly influenced by the output of agricultural production (Guyer, 1997). Because of the high output of paddy

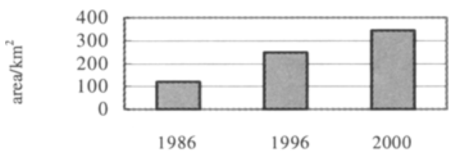

Figure 5 The histogram of paddy area in Fujin County

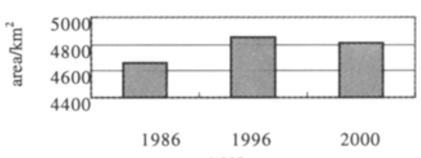

Figure 6 The histogram of dry land area in Fujin County

field, the speed of wetland reclamation into paddy field is higher than that to dry land in the Sanjiang Plain.

(2) From the spatial-temporal distribution structure of the marsh in the Sanjiang Plain, the number of the marsh patches increased 326 pieces on the whole during the period from 1986 to 1996; 20.38 pieces increased each year. From 1996 to 2000, the patches increase rate slowed notably, to only 4.5 pieces per year. The reclamation of the marsh has converted to the rim of the existing marsh, not to the fragmentation of large piece of marsh. Because the existing large area of marsh only exists in the low flood plain called 'deep water marsh,' which is inundated most of the year, will be flooded in rainy seasons if being reclaimed, so it has not been normally tapped. However, the little inning exists yet, especially in the higher mesa, terrace wash, as well as the floodplain in high terrain for their comparative suitable development conditions. This kind of marsh is called "shallow water marsh," which can be cultivated after being reclaimed.

(3) The natural conditions in the Sanjiang Plain have greatly changed. According to our wetland database, the absolute humidity dropped by 50 mPa, the temperature from 1980 to 1997 rose 2℃. The trend of temperature rising far exceeds that in Northeast China (Liu, 2002). Precipitation decreases, and the amount of precipitation of each year radically changes. The function of "coldness and wetness" of marsh in the Sanjiang Plain has declined (Zhang, 2001). The radical climate change in the Sanjiang Plain can also be illuminated by the planting situation in the Sanjiang Plain. In the early 1980s, the crop suitable for plantation and being mainly planted was wheat; in the late 1980s, soybean; in the early 1990s, paddy; in the late 1990s, maize. Rivers are densely distributed in the northeast of the Sanjiang Plain, the marsh there was called "deep water marsh" in the past, because of the deep water existing on the marsh. The regional climate change turns "deep water marsh" into "shallow water marsh," thus making the marsh exclamation become easier. That is reason the centroid of the marsh in the Sanjiang Plain has moved to southwest.

(4) It can be seen from the spatial-temporal change of the marsh in the Sanjiang Plain was highly influenced by agricultural policies and the price of the agricultural product in the past 20 years. The reduction mainly occurred in the 16 years from 1980 to 1996, by 51.33% on the whole, by 3.41% each year. More than half of the original marsh was lost. Driven by market profits, local farmers exploited the marsh to enlarge arable lands because of the introduction of the family contracted responsibility system with remuneration linked to output and the lower price of agricultural production materials such as fertilizer, pesticide and seeds in the 1980s. The rate of the marsh reduction fell greatly from 1996 to late 2000, only decreasing by 4.19% totally, on an average, 1.05% per year due to the lower output of the dry land. But output of the paddy field is still high, thus making some marsh and dry land develop into paddy field. Market-oriented agriculture is more demanding of soil and water resources, and concerns about resource degradation are emerging (Brown and Shrestha, 2000), thus making the natural environment in the Sanjiang Plain deteriorate further.

6.2 The countermeasures of marsh protection

The loss of wetland can cause a significant decrease in their ability to perform their essential functions (Bedford and Preston, 1988). The marsh loss in the Sanjiang Plain has caused serious ecological problems. Therefore, marsh protection and restoration is imperative there. It is impossible for the marsh to get recovery naturally itself, and the scientific management of human beings on the marsh in the Sanjiang Plain is necessary. Here are some suggestions concerning about the management methods of the marsh in the Sanjiang Plain:

(1) Protecting the existing marsh and collecting fees from the land that was reclaimed from the former marsh. First, in order to protect the existing marsh in the Sanjiang Plain, the laws of wetland protection must be formulated and the related wetland education and protection should be further promoted. Second, the marsh dynamics should be periodically monitored and analyzed with the help of remote sensing, so the wetland managers could learn the

contemporary distributive conditions of the marsh in the Sanjiang Plain and establish the relative lash-up countermeasures. Third, it is suggested to charge 'marsh occupied fees' for the present land of dry land, paddy field, and construction that reclaimed after 1980 from the former marsh.

(2) Restoring the former marsh in the low-lying flood plain naturally. The agricultural output is usually low because of the frequent flood disasters happened in the drippy years for the land reclaimed from the former marsh in the low-lying flood plain. If stopping farming and leveling off the man-made dykes and the ditches that block the water flowage in these areas, the former marsh will be naturally restored.

(3) Restoring the former marsh that is important for the biology diversity. It is necessary to make a survey of the marsh that plays an important role in the biodiversity in the Sanjiang Plain. On the basis of the investigation, humans should restore the important marsh, if they cannot be renewed naturally as mentioned above.

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