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Wetland Distribution Prediction Based on CA–Markov Model under Current Land Use and Protection Policy in Sanjiang Plain

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Abstract: The conflict between grain production and wetland resource protection in plain wetland is prominent. Understanding the future impacts of current land use policies on wetlands is the key to rationally evaluating and adjusting these policies. Therefore, the objective of the research was to predict the potential distribution of Sanjiang plain wetland under the current land use and protection policy using remote sensing images and CA Markov models. Methodologically, Landsat TM remote sensing images of the Sanjiang Plain (2010–2020) were used to extract wetland distribution based on object-oriented methods, and the characteristics and patterns of wetland change caused by the land use and protection policies during this period were analyzed. A CA–Markov model was used to predict the potential distribution of Sanjiang Plain wetland in 2030, 2040, 2050, and 2060. Then, we summarized the advantages and disadvantages of current land use policies and put forward adjustment measures. The results indicate that during 2010 and 2020, the wetland area of Sanjiang Plain decreased by 22.34%. The conversion ratio of wetland to non-wetland type (mainly farmland) in the first half and the second half of the decade was 46.41% and 15.31%, respectively, and the decrease in wetland showed an obvious slowing trend. The spatial distribution prediction in future showed that the wetland area will continue to decline in 2030, and the decline will basically stop in 2040. Finally, the proportion of wetland area will remain at 8.68% of the total area of Sanjiang Plain, with that of some counties and cities less than 5%. It is concluded that, although the current land use policies in Sanjiang Plain can effectively slow down the wetland area shrinking and stabilize the spatial pattern, a very low proportion of wetland area in some areas will make it difficult for the wetland ecosystem to exert ecological functions and ensure regional ecological security. The wetland conservation managers should adjust the current land use policies according to relevant requirements of farmland protection policies and restore the areal proportion and spatial pattern of wetland in order to help with regional sustainable development.

Keywords: wetland change prediction; wetlands in China; regional sustainable development; SDG targets

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1. Introduction

Wetlands are natural or artificial, perennial or seasonal waterlogging areas and waters, with significant ecological functions, including the sea area where the water depth is not

more than six meters at low tide [1]. Wetlands have important ecological functions, such as water conservation, climate regulation, soil and water conservation, water purification, and biodiversity maintenance, and can directly provide the food and raw materials necessary for human production and life [2]. However, in the context of global change, wetlands at different scales are facing various ecological problems. The continuous area decreases and functional degradation of wetlands [3–5]. have serious impacts on global ecological security and economic and social development. Since 1970, the global wetland area has decreased by 35%, and wetland is the most threatened ecosystem, disappearing three times faster than forest ecosystem. Land use change is the biggest driving force for the degradation or disappearance of inland wetlands [6]. In recent years, large-scale urban construction, agricultural reclamation, and other human activities have caused the fragmentation of wetland ecosystem and the degradation of ecosystem service functions, which have seriously threatened regional ecological security, food security and sustainable social and economic development [7–10]. Rational evaluation and timely adjustment of land use policies to ensure the normal functioning of wetland ecosystem are of great significance for wetland protection and regional sustainable development.

With the deepening and expansion of research on the relationship between economic development and land use, scholars have conducted a series of studies on the impacts of land use change on wetlands, providing technical support for promoting the simulation and prediction of wetland distribution. Based on a Markov model and remote sensing data, foreign scholars have done a lot of research on the relationship between land use/land cover, the environment, and climate. Some studies predicted the land use/land cover changes and further assessed and modeled the impacts of wetland land cover changes on water provision and habitat quality ecosystems [11–15]. Also, the future land use prediction results of the CA–Markov model were used to predict the water quantity, sediment yield, and water balance [12]. In China, the CA–Markov model and remote sensing images were mainly applied for the change and prediction of all types of land uses in administrative or basin areas with wetland as the main ecosystem [16–18]. The above studies have confirmed the practicability of the land use prediction model in reflecting social and economic development policies and their impacts on land use change, indicating it is a powerful way to simulate and forecast land use change under certain policies.

However, at present, most of these studies focus on the spatio-temporal changes and driving factor analysis of lake and coastal wetlands [13–15,19–23]. Few studies have been conducted on the simulation and prediction of marsh wetland, which is greatly affected by agricultural reclamation. The applicability of the model in the complex area with agricultural development and wetland protection conflicts, and the future impacts of current land use policies on the area are still unclear. When wetland reduction will stop and whether the current land use and protection policies are effective still need further study.

Sanjiang Plain is a wetland biodiversity hotspot and national ecological function area with global significance in China [24,25] It is an important node on the international migratory bird migration channel, named “Northeast Asia-Australia” [26]. At the same time, it is also an important grain production base with very important ecological, economic, and social values. However, the conflict between agricultural development and wetland protection here is prominent [4,27]. The health of wetland ecosystem in Sanjiang Plain is of great significance to local social stability and development, regional ecological security, and the economic development of our country [28,29]. In this paper, we propose a hypothesis that land use and protection policies in Sanjiang Plain will remain unchanged in the coming decades. Based on this assumption, we intend to take Sanjiang Plain as the research area, to analyze the impact of current land use policies on the changing trend of marsh wetlands that are affected by agricultural development. Our general objective is to predict the future changing trend of the wetlands in 2030–2060 in Sanjiang Plain by combining with the region’s historically changing rules of the wetlands. The specific objectives are determining whether the wetland area reduction will stop and putting forward suggestions for adjusting land use policies for the sustainable development of agriculture-affected wetlands.

2. Methodology

2.1. Study Site

Sanjiang Plain is located in the northeast of Heilongjiang Province (Figure 1). Its geographical coordinates are 43°49′55″ to 48°27′40″ N and 129°11′20″ to 135°05′26″ E. The administrative area includes 23 counties (cities) under Jiamusi City, Hegang City, Shuangyashan City, Qitaihe City, and Jixi City et al. The Sanjiang Plain is a low plain formed by the Heilongjiang, Songhua, and Wusuli Rivers. Its wetland distribution is concentrated and it is the plain wetland the largest area in Northeast China. The total area of Sanjiang Plain is about 10,890,000 hm^2. It is a temperate, humid, and semi-humid continental monsoon climate with a warm and short summer and a cold and long winter. Sanjiang Plain is mainly a diving swamp; there are also a considerable number of peat swamps, with a thick grass-roots layer, generally up to 30–40 cm thick, distributed in a large area of fertile black soil. Sanjiang Plain is also a key area for grain producing in China. The main land use types are wetland, cultivated land, forest land, grassland, construction land, and unused land. Sanjiang Plain wetland is rich in biodiversity resources [30].

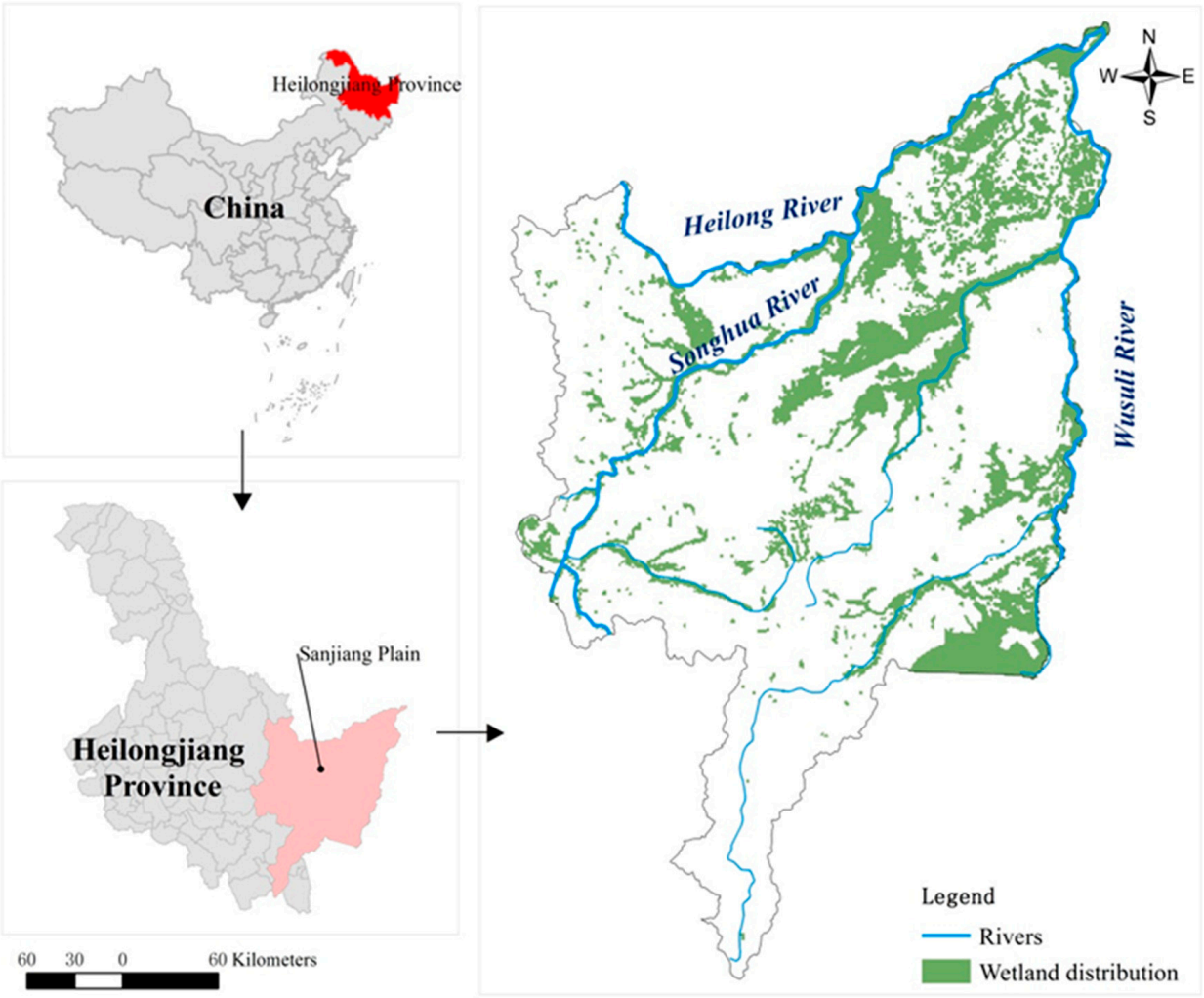


Figure 1. The location of the study area [30].

2.2. Wetland Distribution Based on Remote Sensing Images

Landsat TM images of the same season with low cloud cover were selected for land use interpretation in the study area. The images were preprocessed by geometric correction and atmospheric precision correction, and Gaussian Kruger projection was adopted [31]. The interpretation method of remote sensing images is mainly supervised classification, and on

the basic of the classification results, manual visual interpretation is used for local modification. The region of interest (ROI) is drawn manually according to the interpretation marks. Supervised classification is performed using maximum likelihood classification. After verification, correction, masking, and reclassification, ENVI's clump and majority/minority analysis were used to process the classified images, and the maps were generated based on the field investigation data of this study [11,32,33]. According to the national standard land classification system, this paper divides the land uses of the study area into six categories: farmland, forest land, grassland, wetland, construction land, and unused land [34]. According to the results of indoor analysis combined with multiple field visits, data from 100 sample sites of various land use patches were randomly collected for verification, and the classification accuracy was higher than 85%. Finally, the wetland distribution was extracted from the land use interpretation results [35].

2.3. Spatio-Temporal Dynamics of Wetlands

In order to explore the changing process and characteristic of wetlands in Sanjiang Plain since 2010, this paper adopted the transfer matrix to quantify the wetland transformation during 2010–2015 and 2015–2020, based on the wetland distribution extracted from the remote sensing classification of different periods. The transfer matrix reflects the mutual transformation relationship between land use types and its dynamic process in a certain period of time in the region, showing the characteristics of land use structure change, including the information of the transfer-in and transfer-out of the area of each land type [12,36]. The basic form of the transition matrix can then be expressed as follows:

$$S_{ij} = \begin{bmatrix} S_{11}\,S_{12} & \cdots & S_{1n} \\ S_{21}\,S_{22} & \cdots & S_{2n} \\ \vdots\ \ \vdots & \cdots & \vdots \\ S_{n1}\,S_{n2} & \cdots & S_{nn} \end{bmatrix} \quad (1)$$

In Formula (1), S represents the area of different land use types, S_{ij} represents the area of land type i transformed into land type j before the transfer, i, j (i, j = 1, 2, …, n) respectively represent the land use types at the beginning and ending stages of the research transformation, and n represents the number of land use types. Each row of elements in the matrix represents the flow information of the beginning land type to the local ending type. Each column of elements in the matrix represents the source information of the ending land type transfered from the beginning type.

2.4. Prediction of Wetland Changing Trend

In this paper, the CA–Markov model was used to predict the future change of wetland in the Sanjiang Plain. The CA–Markov model is a prediction model based on the Markov chain, which is used to analyze and predict serial data [37]. This model combines Markov chains and the autoregressive integrated moving average model (ARIMA), which can better capture the dynamic change characteristics of time series and is widely used in land use prediction [38]. The CA–Markov model is a spontaneous random motion process, which determines the change trend of the overall state of the system through the initial probability of different states and the transition probability between states. The dynamic changes of land use have the nature of the CA–Markov process, which predicts the evolution from the initial stage of land use according to a stable transfer rate [39–42]. Therefore, the CA–Markov model yields good results for the quantitative description of land use prediction, and its formula is as follows:

$$S_{(t+1)} = P_{ij} \times S_{(t)} \quad (2)$$

In Formula (2), $S_{(t)}$ represents the land use state percentage vector at the initial time t, and $S_{(t+1)}$ represents the state probability vector at the time $t + 1$. P_{ij} is the state transition

probability matrix of the percentage of S_{ij} (Formula (1)) transition matrix, and satisfies: $0 \leq P_{ij} < 1$, and $\sum_{j=1}^{N} P_{ij} = 1$ ($i, j = 1, 2, \ldots, n$).

In the study, 2010 and 2015 are taken as nodes of different land use states, and 2015 is taken as the benchmark to predict land use states in 2020. The overall accuracy and kappa coefficient are calculated by comparing the prediction result with the actual value in 2020. The more the overall accuracy and kappa coefficient tend to be 1, the better the simulation accuracy. When the kappa coefficient is greater than 0.7, it indicates that the model accuracy reaches a satisfactory state in the statistical significance. The Kappa coefficient is calculated using the following formula:

$$K = \frac{P_o - P_e}{1 - P_e} \tag{3}$$

where P_o is the sum of the number of correctly classified samples for each class divided by the total number of samples and P_e is the overall classification accuracy.

$$P_o = \frac{\sum_{i=1}^{c} T_i}{n} \tag{4}$$

$$P_e = \frac{\sum_{i=1}^{c} a_i * b_i}{n^2} \tag{5}$$

C is the total number of categories, T_i is the number of samples that are correctly classified for each category, assuming that the real number of samples for each category is $a_1, a_2, \ldots, a_C$, and the predicted number of samples for each category is $b_1, b_2, \ldots, b_C$, the total number of samples is n.

The change prediction of wetlands in 2030, 2040, 2050, and 2060 is also based on the direction and rate of land type transfer from 2010 to 2015. And this paper used 2020 as the base year to predict the potential wetland distribution of Sanjiang Plain in the next few decades, so as to analyze the impact of current land use policies on future wetlands.

2.5. Wetland Conservation Priority Analysis

Using the proportion of existing wetlands as an evaluation index, the urgency of wetland restoration was analyzed [43]. In order to facilitate the implementation of a management and restoration plan, the administrative county was selected as the spatial unit of the wetland areal proportion calculation. According to the research conclusion of Delaney [44] on the rational proportion of wetlands in the flood plain (the proportion of wetlands that are beneficial to the function of wetland flood regulation and water quality improvement should be reached at 5~10%). The cities and counties in Sanjiang Plain were divided into three levels: high urgent restoration area (<5%), medium urgent restoration area (5–10%), and low urgent restoration area (>10%).

Using the proportion of potential wetland reduction as the evaluation index and the administrative county as the spatial unit, the potential threat of wetland was analyzed. According to the proportion of potential wetland reduction, the cities and counties in the Sanjiang Plain can be classified into three levels: high potential threat (reduction ratio > 4%), medium potential threat (reduction ratio 2~4%), and low potential threat (reduction ratio < 2%).

Wetland restoration priority was classified by combining the urgency of wetland restoration and the potential threat to wetlands. High urgency—high threat, high urgency—medium threat, and medium urgency—high threat are set as level 1 priority restoration areas (P1); medium urgent—medium threat is set as the level 2 priority restoration area (P2); and high urgency—low threat, low urgency—high threat areas are set to level 3 (P3). Medium urgency—low threat, low urgency—medium threat, and low urgency—low threat areas are set as level 4 (P4).

2.6. Statistical Analysis and Software Used

The relevant data, such as wetland slope, aspect, and topographic saturation, involved in this study were obtained through spatial analysis and deduction in the ARCGIS10.8 software. Excel, SPSS (Pearson correlation analysis), and the like were used to conduct data processing and statistical analysis on the wetland area of the Sanjiang Plain.

3. Research Results

3.1. Wetland Distribution Based on Remote Sensing Images

The results of wetland distribution extracted from interpreted land uses show that, from 2010 to 2020, the area of wetland had decreased from 1,501,300 hm^2 to 1,165,900 hm^2, and its proportion in the total area of Sanjiang Plain has decreased from 13.79% to 10.71% (Figure 2). In the past decade, the area of wetland had decreased by 335,400 hm^2, a decrease of 22.34% of the area in 2010. From 2010 to 2015, the wetland area decreased by 219,800 hm^2, a decrease rate of 2.92%, while from 2015 to 2020, the area of wetland decreased by 115,600 hm^2, a decrease rate of 1.80%. The decrease rate of Sanjiang Plain wetland in 2015–2020 significantly slowed down compared with that in 2010–2015.

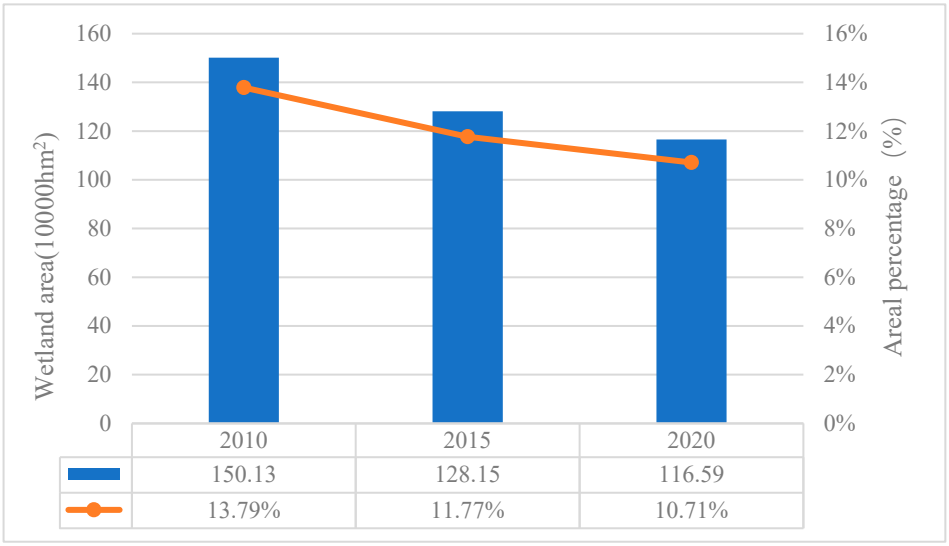


Figure 2. The wetland area and its proportion of the total area of Sanjiang Plain in 2010, 2015, and 2020.

From the perspective of spatial distribution (Figure 3), the wetland area in the Sanjiang Plain showed a significant decline from 2010 to 2015. The region of wetland loss was mainly distributed in the northeast of the Sanjiang Plain, covering the counties and cities of Naoli River basin and Tongjiang-Fuyuan basin. From 2015 to 2020, the distribution of wetland in the Naoli River basin remained basically unchanged, while some wetland areas in Tongjiang, Fuyuan, Hulin, and Mishan continued to decrease, but the decline was much smaller than that in 2010–2015.

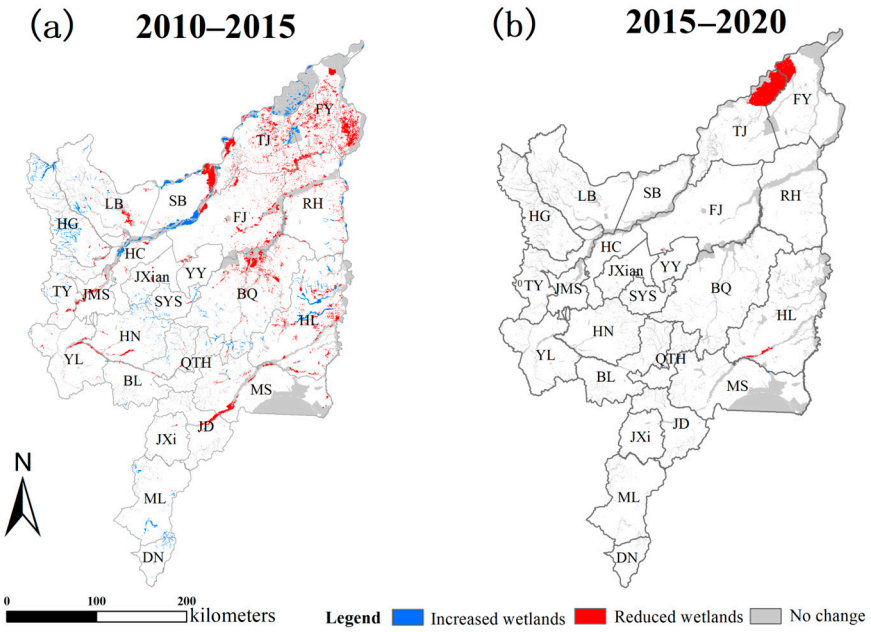


Figure 3. Distribution changes of wetland in Sanjiang Plain: (**a**) from 2010 to 2015, (**b**) from 2015 to 2020.

3.2. Spatio-Temporal Dynamics of Wetlands

According to the land use transfer matrix in Tables 1 and 2, 46.41% (from 2010 to 2015) and 15.31% (from 2015 to 2020) of all wetlands transferred and were converted to non-wetland types. From 2010 to 2015, wetlands were mainly converted to farmland, forest land, and grassland, accounting for 19.18%, 16.97%, and 10.09% of the total area of all transferred-out wetlands, respectively. From 2015 to 2020, wetlands were mainly converted to forest land and grassland, accounting for 6.01% and 7.18% of the total area of all transferred-out wetlands, respectively, while the conversion of farmland accounted for only 1.98%. In the two periods, 11.27% and 14.68% of non-wetland types were converted to wetlands. From 2010 to 2015, the main types of conversion from non-wetland to wetland were farmland and grassland, accounting for 15.42% and 13.33% of the total converted wetland area. From 2015 to 2020, the main types of conversion from non-wetland to wetland were farmland and forest land, accounting for 33.62% and 4.94% of the total area of all converted wetlands (Table 2).

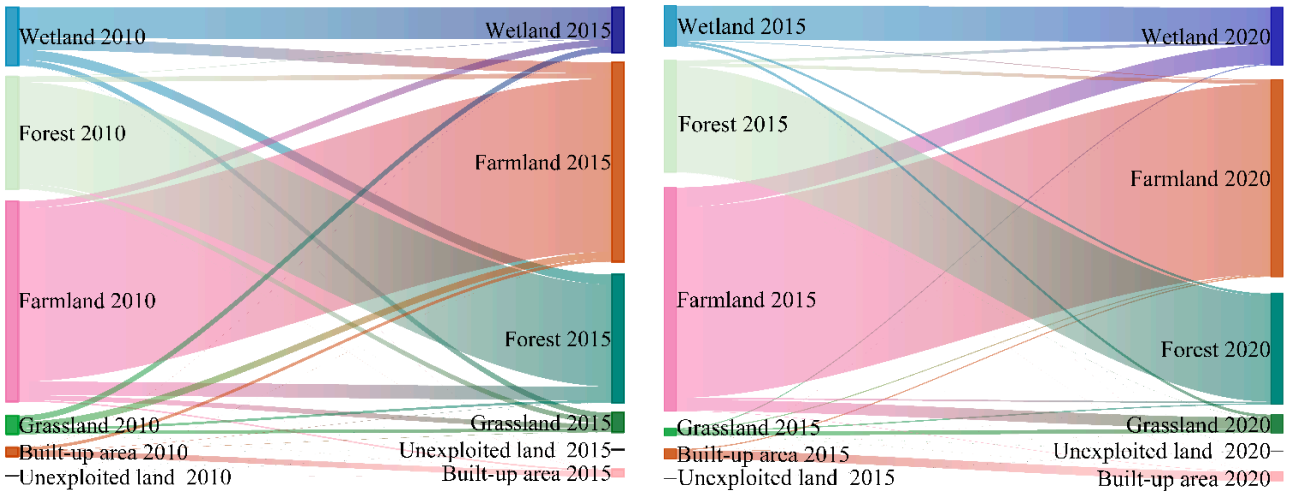
Table 1. The transfer matrix of land uses in Sanjiang Plain from 2010 to 2015. (Unit: 10,000 hm^2).

2010	2015						
	Wetland	**Farmland**	**Forestland**	**Grassland**	**Built-Land**	**Unused**	**Transerred-Land**
Wetland	85.45	30.59	27.06	16.08	0.28	0	74.01
Farmland	18.88	470.56	37.06	13.57	4.03	0.02	73.56
Forestland	1.53	13.55	277.15	13.69	0.27	0.02	29.06
Grassland	16.32	18.55	6.5	9.42	0.12	0.02	41.51
Built-land	0.26	8.47	0.8	0.66	15.23	0	10.19
Unused	0.00	0.11	0.06	0.05	0.04	0.08	0.26
Transerred-land	36.99	71.27	71.48	44.05	4.74	0.06	— —

Table 2. The transfer matrix of land uses in Sanjiang Plain from 2015 to 2020. (Unit: 10,000 hm^2).

2015	2020						
	Wetland	**Farmland**	**Forestland**	**Grassland**	**Built-Land**	**Unused**	**Transerred-Land**
Wetland	95.11	2.22	6.75	8.06	0.11	0.05	17.19
Farmland	53.62	526.52	4.21	31.36	1.06	0.02	90.27
Forestland	7.88	9.42	291.52	0.29	0.17	0	17.76
Grassland	2.77	2.65	3.70	11.17	0.12	0.10	9.34
Built-land	0.09	3.30	0.04	0.04	23.95	0.08	3.55
Unused	0.00	0.00	0.00	0.00	0.00	0.09	0.00
Transerred-land	64.36	17.59	14.7	39.75	1.46	0.25	— —

The transfer between wetland and other land use types showed that (Figure 4), in the first decade, the wetlands in Sanjiang Plain mainly tranfered into farmland, forest land, and grassland, and the reduction of farmland reclamation resulted in natural degradation to forest land and grassland. During this period, some farmland was also returned to wetland or forest land, and grassland was restored to wetland, increasing the proportion of wetland. In general, the conversion rate of wetland to a non-wetland type was significantly faster during 2010–2015. From 2015 to 2020, the conversion rate of wetland to non-wetland tended to be flat.



(**a**) (**b**)

Figure 4. Land uses transfer in Sanjiang Plain: (**a**) from 2010 to 2015, (**b**) from 2015 to 2020.

3.3. Prediction of Wetland Changing Trend

In this study, the land use data of 2010 and 2015 were used to predict the land use change of Sanjiang Plain in 2020. The kappa coefficient was 0.9567 and the real value was basically consistent with the simulated value, indicating the transfer matrix could be used for wetland prediction in this study area. The area of wetlands in Sanjiang Plain showed a further decline during the 30 years from 2030 to 2060. The reduced wetlands were mainly distributed in cities and counties of Fuyuan, Tongjiang, Luobei, Fujin, Baoqing, and Hulin (Figure 5). Compared with the reduced wetlands, the volume of increased wetlands is relatively small, mainly concentrated in the northwest and southeast of the Sanjiang Plain, which contains a large number of constructed wetlands, but the overall pattern of wetlands has not changed much.

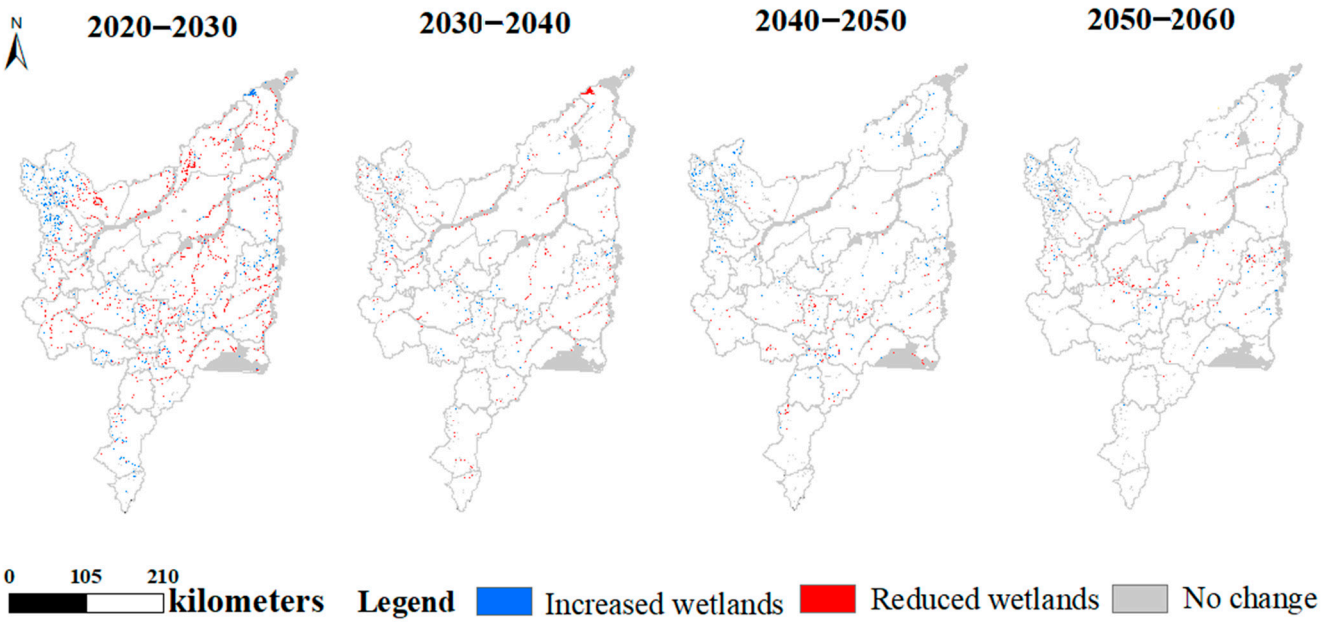


Figure 5. Spatial distribution of wetlands in Sanjiang Plain at different periods.

By 2030, the wetland area will be 1,007,200 hm^2 (accounting for 9.25% of the total area of Sanjiang Plain), and by 2040, 2050, and 2060, the wetland area will be stable at about 944,900 hm^2 (accounting for 8.68% of the total area of Sanjiang Plain). The area of wetlands will totally decrease by 221,000 hm^2 between 2030 and 2060 and remain stable by 2040 (Table 3).

Table 3. The predicted proportion of wetlands in Sanjiang Plain in 2030, 2040, 2050, and 2060.

Years	Wetland Area (10,000 hm^2)	Percentage (%)
2030	100.72	9.25
2040	94.49	8.68
2050	94.49	8.68
2060	94.49	8.68

3.4. Wetland Conservation Priority Analysis

A total of 19 counties and cities were considered in the wetland restoration priority analysis (excluding counties and cities with forest being the main landscape). As shown in Figure 6 and Table 4, the spatial distribution of existing wetlands in the Sanjiang Plain showed an uneven pattern. The proportion of wetlands in eastern counties and cities is relatively high, almost above 10%, and some counties and cities have reached more than 20% (Mishan City, Fuyuan County and Tongjiang City), while the proportion of wetlands in central and western counties is relatively low. The proportion of wetlands in Qitaihe City and Youyi County is less than 5%. In terms of restoration urgency, there are 2 counties with high urgency, 6 counties with medium urgency, and 11 with low urgency. And for potential threat, there are 5 counties with high potential threat, 11 counties with medium potential threat, and 3 counties with low potential threat.

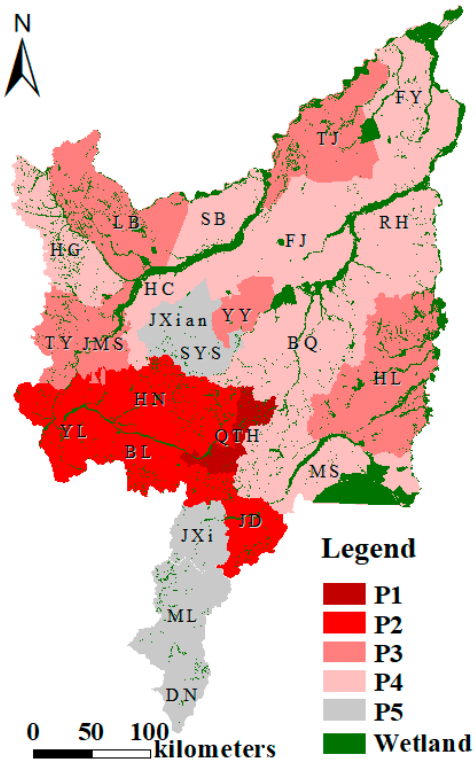


Figure 6. Wetland restoration priority in Sanjiang Plain. (P1: areas with the highest restoration priority; P2: areas with high restoration priority; P3: areas with moderate restoration priority; P4: areas with low restoration priority; P5: No need for wetland restoration).

Table 4. Wetland protection priority levels in Sanjiang Plain.

Priority Level	Counties and Cities (Abbreviation)	Including Counties and Cities	Existing Wetland Scale (%)	Urgency Level	Projected Proportion of Reduced Wetlands (%)	Potential Threat Level
P1	QTH	Qitaihe	4.27	high	3.65	middle
P2	HN	Huanan	5.69	middle	3.30	middle
	YL	Yi an	5.99	middle	3.13	middle
	BL	Boli	5.73	middle	2.87	middle
	JD	Jidong	6.21	middle	2.19	middle
P3	YY	Youyi	1.54	high	1.17	less
	TJ	Tongjiang	32.31	less	5.23	high
	LB	Luobei	10.82	less	4.01	high
	TY	Tangyuan	10.24	less	4.28	high
	HL	Hulin	15.89	less	4.20	high
	JM	Jiamusi	13.03	less	4.00	high
P4	HC	Huachuan	8.5	middle	1.77	less
	HG	Hegang	6.3	middle	1.76	less
	FJ	Fujin	12.46	less	2.12	middle
	MS	Mishan	28.34	less	3.18	middle
	SB	Suibin	18.61	less	3.43	middle
	FY	Fuyuan	40.27	less	3.44	middle
	RH	Raohe	12.75	less	2.79	middle
	BQ	Baoqing	11.37	less	3.44	middle

The priority levels of wetland restoration urgency and potential threats are shown in Table 4. Among them, there are 1 city belonging to P1, 4 counties belonging to P2, 6 counties and cities belonging to P3, and 8 counties and cities belonging to P4.

4. Discussion

In this research, we analyzed the changing spatio-temporal rules of the Sanjiang Plain wetland from 2010 to 2020, and predicted their potential changes in 2030, 2040, 2050, and 2060 under current land use policies. Our findings indicate that the CA–Markov model has applicability in the complex areas with agricultural development and wetland protection

conflicts; the current land use and protection policies are effective for alleviating wetland reduction, and the reduction will stop in 2040. The combination of the CA–Markov model with remote sensing images is often applied to the simulation and prediction of land use status at a certain time in the future. Aiming at the problem of substantial area reduction and functional degradation of wetlands in Sanjiang Plain at present, this study proposed a multi-period prediction framework to determine the stopping time node of wetland decline. On the basis of obtaining a large quantity of data, it strengthens the quantification ability and breaks through the limitations of previous single-timepoint prediction research. The results can also put forward suggestions for adjusting land use policies for the sustainable development of agriculture-affected wetlands.

From 2010 to 2015, the wetland area decreased by 219,800 hm^2, a decrease rate of 2.92%, while from 2015 to 2020, the area of wetland decreased by 115,600 hm^2, a decrease rate of 1.80%.

The area changes of wetland during 2010 and 2020 showed that the wetland area in the Sanjiang Plain decreased gradually from 2010 to 2015, and the decline rate slowed down from 2015 to 2020, decreasing by 38.36%. The results of the wetland transfer matrix showed that, from 2010 to 2015, wetland mainly transferred to farmland, forest land, and grassland; and from 2015 to 2020, wetland also transferred to these land cover types, yet the conversion rate decreased by about 10%. During the first half and second half of the decade, 188,800 hm^2 and 536,200 hm^2 of farmland were returned to wetland, respectively, showing a slowing trend of wetland reduction rate from 2010 to 2020. This result is consistent with the expectation of the wetland protection and restoration actions and policies of the National Wetland Protection Project Plan (2002–2030) and ecological benefit compensation project [45,46]. By 2017, there were 17 wetland nature reserves with a total area of 1,007,400 hm^2 in Sanjiang Plain, including 6 international important wetlands, 9 national wetland nature reserves, and 8 provincial wetland nature reserves [47]. Heilongjiang Province started the compilation of the Heilongjiang Wetland Protection Plan (2016–2020), including 77 wetland parks, 87 provincial level or above wetland nature reserves and 9 wetland protection sites into the wetland protection system. According to the implementation of the project of returning farmland to wetland [48], from 2014 to 2020, the amount of returning farmland in Heilongjiang Province was 32,743.03 hm^2, accounting for 30.02% of the national total amount of returning farmland to wetlands. The implementation effects of the above wetland conservation and restoration projects have been verified in the results of wetland transfer in this study, indicating that recent land use policies and measures are effective for alleviating wetland reduction and degradation.

The prediction results obtained by the CA–Markov model showed a continuous slowing trend of wetland reduction rate from 2020 to 2030. A previous prediction study using the CA–Markov model also showed a continuous slowing trend and predicted the wetland reduction rate during 2011~2015 at 2.72% [23], which is consistent with the actual wetland reduction rate of 2.92%. The actual wetland reduction rate during 2016~2020 declined to 1.80%, indicating that the land use policies during this period were conducive to the alleviation of wetland resource loss. If the land use continues to develop according to the current policies, the wetland in Sanjiang Plain will stop decreasing and remain at 944,900 hm^2 by 2040. Our study further predicted the wetland reduction based on current land use and protection policies, providing more information for wetland conservation and management. However, two problems still exist, the long period of stopping wetland reduction (about 20 years) and the low proportion of wetlands in local areas (less than 5%, which does not reach the threshold of regional safety). In view of the above problems, this study suggests the following adjustment of land use policies: (1) to formulate wetland protection and restoration measures for different zoning and grading implementation priorities according to urgency and potential threat level. Counties and cities with wetland proportions reaching the safety threshold should be protected, while counties and cities with wetland proportions not reaching the safety threshold should be restored, and those counties and cities with a high priority should be included in the short-term wetland conservation

and utilization planning; (2) to improve the measurement accuracy of management and control, formulate quantitative conservation or restoration targets for wetlands at different spatial scales and ensure the normal functioning of the wetland ecosystem and regional ecological security; (3) to coordinate with policies and regulations related to farmland protection (Agriculture Law of the People's Republic of China, Land Management Law of the People's Republic of China, Regulations on Basic Farmland Protection, etc.) [49], and carry out wetland protection and restoration on the basis of maintaining basic farmland area as much as possible, in order to meet the needs of agricultural products for the future population and national economic development as well as the needs of regional security and sustainable development. In terms of general application of this study, it can provide technical support and an evaluation index reference for sustainable development goals (SDGs) at different scales.

Uncertainties inevitably exist in this study, even when the best available data are used. For example, the uncertainty related to data quality, including the quality of remote sensing images, and the quality of wetland distribution data, which is easily affected by the standards and methods used in the interpretation process. In addition, the land use change prediction model itself has uncertainty [50,51]. Climate change, especially rainfall, will also affect the spatial distribution results of wetlands, and thus generate errors in the prediction of land use change using CA–Markov model [52,53]. However, some errors caused by these uncertainties had made the model consistency test coefficient lower than 1, but the coefficient was still higher than 0.75, within the acceptable range of this study, and the results are relatively reliable. If remote sensing interpretation and modeling techniques are further improved in the future, we will use new techniques and models to refine the results.

It should be noted that wetland landscape patterns and connectivity are also important indicators affecting the degree of wetland degradation and the spatial pattern of wetland biodiversity at the regional scale [30,54–56]. Based on the simulation and prediction results of wetland landscape patterns and connectivity indicators, further assessment and prediction of wetland degradation and biodiversity conservation value need be conducted to provide references for wetland protection, management, and monitoring, which should be the focus of future research. In addition, in view of the problems of long-term, time consuming, and low area ratios of wetlands under the current land use policies, it is recommended to enhance the policies' enforcement, specificity, and scientific city, such as clarifying the protection and restoration targets of each city and county, and actively promoting the adjustment of agricultural planting structures to slow wetland reclamation and increase cultivated land resources. The reduction of natural wetland area and degradation of ecological functions should be reversed as soon as possible to ensure the sustainable development of the Sanjiang Plain.

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