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Spatio-temporal pattern and rationality of land reclamation and cropland abandonment in mid-eastern Inner Mongolia of China in 1990–2005

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Abstract The Mid-eastern Inner Mongolia of China, a typical agro-pastoral transitional zone, has undergone rapid agricultural land use changes including land reclamation and cropland abandonment in past decades due to growing population and food demand, climatic variability, and land use policy such as the "Grain for Green" Project (GFG Project). It is significant to the regional ecology and sustainability to examine the pattern and its rationality of land use change. The processes of land reclamation and cropland abandonment were accessed by using land use change dataset for four periods of 1990, 1995, 2000, and 2005, derived from the interpretation of Landsat TM images. And then the rationality of land reclamation and cropland abandonment was analyzed based on the habitat suitability for cultivation. The results indicated that: (1) land reclamation was the dominant form of agricultural land use change from 1990 to 2005, the total cropland area increased from 64,954.64 km^2 in 1990 to 76,258.51 km^2 in 2005; However, the speed of land reclamation decreased while cropland abandonment increased around 2000. The Land Reclamation Degree decreased from 1995–2000 to 2000–2005, meanwhile, Cropland Abandonment Degree increased. (2) As for the habitat suitability levels, moderately and marginally suitable levels had largest areas where cropland was widespread. Pattern of agricultural land use trended to become more rational due to the decrease of land reclamation area in low suitable levels and the increase of cropland abandonment in unsuitable area after 2000. (3) The habitat suitability-based rationality analysis of agricultural land use implicated that the GFG Project should take cultivation habitat suitability assessment into account.

Keywords Land reclamation · Cropland abandonment · Habitat suitability for cultivation · Inner Mongolia · China

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Introduction

Land use change is a kind of human's response and adaption to resources demand to some extent;

however, ecological services such as ecological regulation and provision functions have been potentially affected by agricultural land use change (Foley et al. 2005). Land reclamation means that other land use types was cultivated for farming to meet food demand, and cropland abandonment means that the low-productivity cropland was given up for the ecological conservation or other aims, parts of that were due to the national ecological restoration policy such as the “Grain for Green” Project (GFG Project).

Land use change and its ecological effects were considered as significant issues of global environmental change and sustainable development (Turner et al. 2007). Land use change was always a key research topic in both past and current international research programs, such as Land Use and Land Cover Change (LUCC), and now contributing to Global Land Project (GLP 2005). The research object of GLP was the human–environment coupling system. The ecological effects of land use change should be examined from the aspect of integrated human-environment coupling system, especially for typical ecological ecotones where land was converted and modified rapidly and the effects of land use change on ecology and environment were prominent.

In China, agro-pastoral transitional zones have become hotspot regions for climate change and land use change studies because of the fragile ecology. With the changing of land cultivation policies and the increasing of cropland demand due to population growth, land reclamation and cropland abandonment were concurrent. Land reclamation was an important reason for desertification there (Fullen and Mitchell 1994; Zhang and Sun 1999). Meanwhile soil nutrients were easy to run out after cultivation of grassland (Liu and Tong 2005; Yang et al. 2005; Huang et al. 2007a, b). Much attention has been paid to land degradation and soil erosion of Inner Mongolia (d’Angelo et al. 2000; Ge et al. 2004; Shi et al. 2007) especially in the situations of climate variation uncertainty increasing. However, successive monitoring of agricultural land use change, and rationality analysis of land reclamation and cropland abandonment were still need to be improved (Wang et al. 2006; Chen and Rao 2008; Cao et al. 2009a, b).

Although the GFG Project has made a great progress, some studies indicated that the expansion of cropland and the shrink of grassland were almost inevitable (Dulamsuren et al. 2008). Especially since the Reform and Opening Up, rapid land use change has happened accompanied with rapid development of economy. Existed researches indicated that an obvious increase of cropland occurred in the 1990s, and the increasing at country-scale mainly derived from the reclamation of forest and grassland in Northern China, meanwhile, cropland abandonment existed (Liu et al. 2003). Land reserves for future cultivation were very limited in China; however, the reclamation continued. The present cultivation mainly occurred in fragile ecological areas and followed by sequent ecological degradation. Therefore, the exact depicting about the processes of land reclamation and cropland abandonment is significant for the decision making of land management and ecological protection.

Quantitative analysis of land reclamation and cropland abandonment, as well as the rationality of land use change could provide effective supports for regional ecological protection and sustainable development. The habitat suitability analysis was an effective method to measure the rationality of agricultural land use change especially land reclamation and cropland abandonment (Tugac and Torunlar 2007; Kurtener et al. 2008; Tseganeh et al. 2008).

This paper aimed to answer several questions: What were the characteristic of land reclamation in the agro-pastoral transitional zone in different periods? Did cropland abandonment occur at the same time with reclamation? Was the land reclamation rational since 1990? Whether was the GFG Project effective? This paper investigated the spatio-temporal change pattern of land reclamation and cropland abandonment in three stages (1990–1995, 1995–2000, and 2000–2005) based on the land use change dataset from remote sensing. The habitat suitability model was used for the rationality assessment of agricultural land use change. A comparison in the period before 2000 and that after 2000 was emphasized to find the possible effects from the GFG Project.

Materials and methods

Study area

The Mid-eastern Inner Mongolia locates between 115°13′–126°04′ E and 53°23′–45°24′ N in Northeast China (Fig. 1a) and encompasses five regions with a total area of 6.66×10^5 km^2, covers about 56% of Inner Mongolia. The study area had a population of 12.80 million and a food productivity of 1.23×10^7 T in 2007. And main crops include wheat, corn, soybeans, potatoes, sorghum, millet, etc. Greater Higgnan Mountains with an elevation of 700–1,700 m crosses from northeast to southwest (Fig. 1b) and is the dividing line for terrain, climates, and farming systems. The Nenjiang Plain and the West Liaohe Plain locate on the east of the Mountains and both the plains are important production areas for food and cash crops on the elevation of about 200–500 m; Hulun Buir Steppe and Xilin Gol Steppe locate on the west of the Mountains and are mainly for stockbreeding with the elevation of 550–1,000 m, and main grass types include *Stipa capillata* Linn., *Leymus chinensis* (Trin.) Tzvel, and so on. In addition, Hunshandake Sand locates in the southwest of the study area with a elevation of 800–1,200 m. Main climate types include semi-humid climate with annual precipitation of 500–800 mm in the east of the mountains and semiarid climate with annual precipitation of 300–500 mm in the west. Soil types have a significant transition from northeast to southwest, and fertile soils are distributed in the eastern part. Vegetation types also have a transition from east to west due to the increase of evaporation and the decrease of precipitation, that is, the xeric plants gradually increased (Fig. 2).

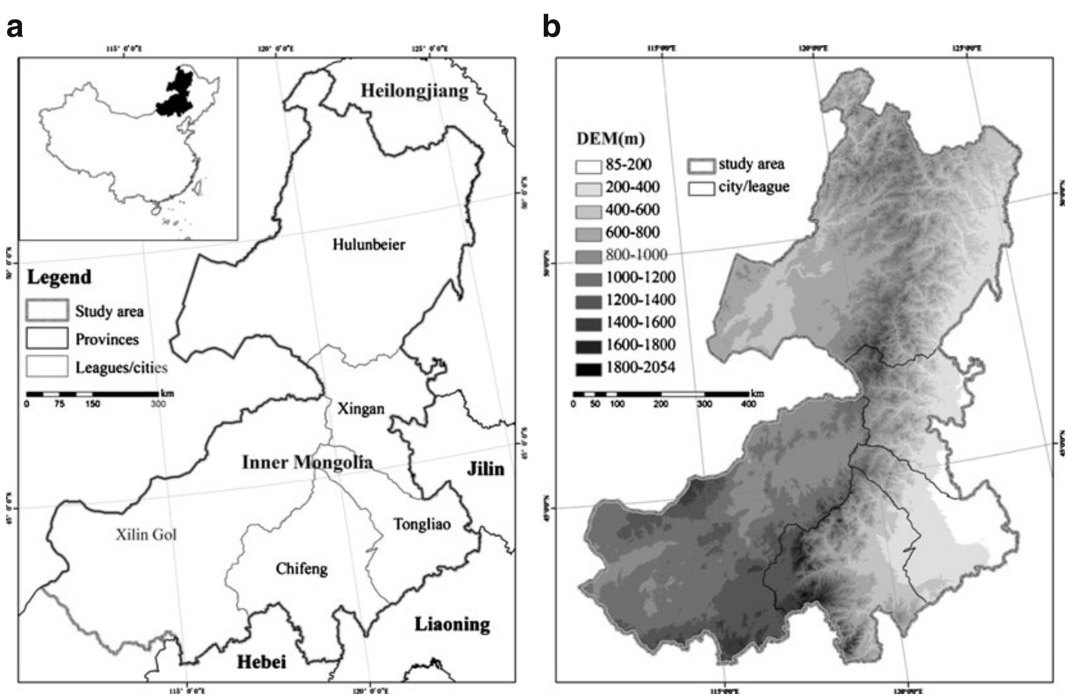

Fig. 1 **a** Study area (Mid-eastern Inner Mongolia) location in the Northeastern of China; **b** the elevation of study area

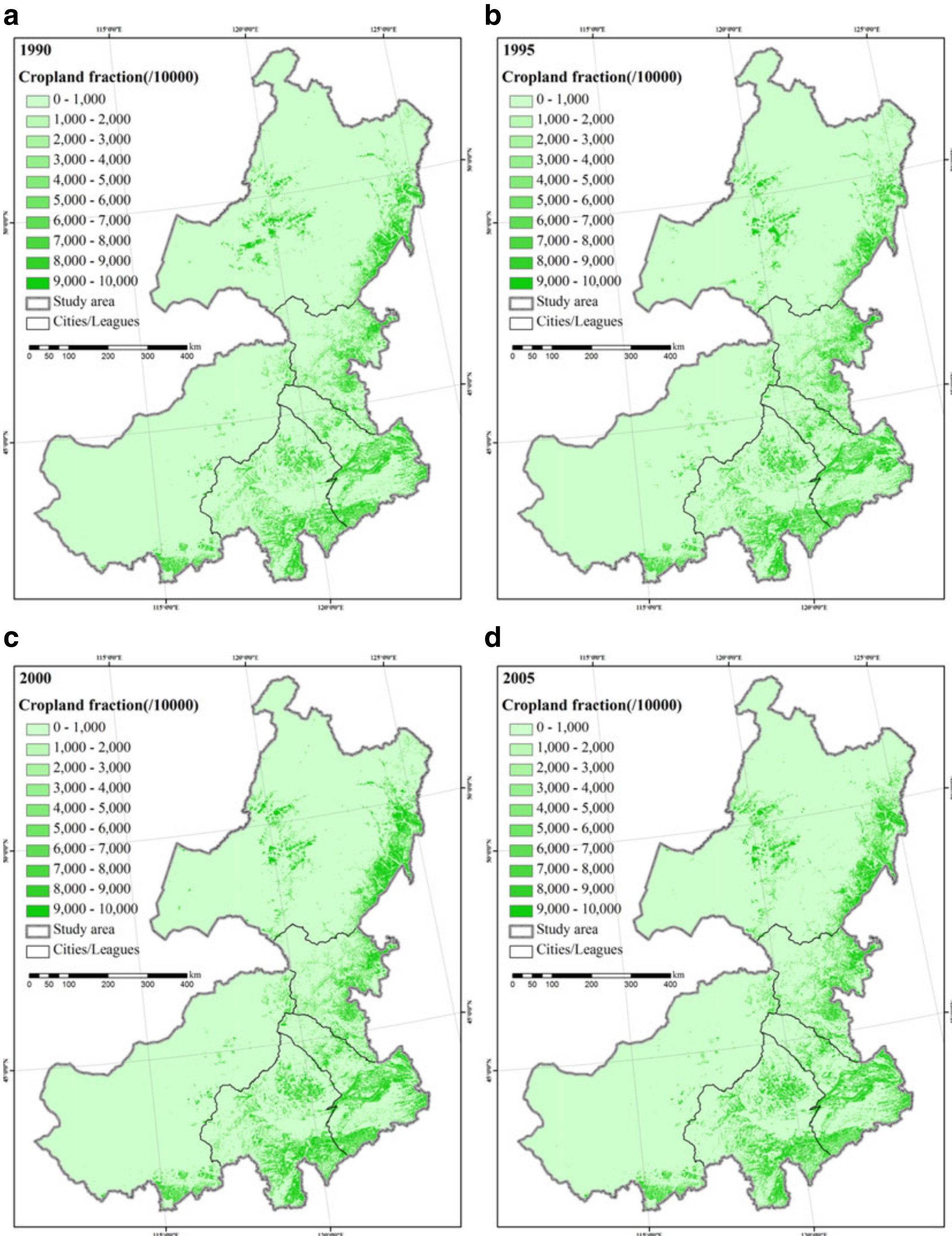

Fig. 2 Spatial distribution of cropland in four periods, grid values were area fraction numbers of cropland, for example, n means that there is an area of $n/10{,}000\ km^2$ in the certain grid of 1 km × 1 km

Table 1 Index of habitat suitability for cultivation

Aspects	Indicators	Suitability level			
		High	Moderate	Marginal	Unsuitable
Climate	Precipitation (mm)	>400	200–400	150–200	<150
	AAT10 (°C)	>2,500	1,800–2,500	1,600–1,800	<1,600
	Wind speed in spring (m/s)	<3.3	3.3–3.8	3.8–4.3	>4.3
Topography	Slope (°)	<6	6–15	15–30	>30
	Aspect	Flat, southern, eastern, western, southwestern, southeastern	Northeast, northwest	North	None
Soil	Soil fertility	>3.5	2.5–3.5	1.5–2.5	<1.5

Data

Land use data

Considering the possible inaccuracy from statistical data because of some institutional factors (Frolking et al. 1999; Seto et al. 2000; Frolking et al. 2002), land use data derived from remote sensing were more effective and reasonable to some extent. Land use data of this study was derived from Data Center for Resources and Environmental Sciences of Chinese Academy of Sciences which has realized the successive monitoring for every five years since the late 1980s (henceforth referred to as 1990) (Liu et al. 2003, 2005). Land use types included six main kinds of farmland, forest, grassland, water body, built-up area, and unused land, and the classification accuracies of land use data in the four periods were all over 92%, and the remote sensing images for updating land use maps were consistent in the imaging season (Liu et al. 2003, 2005, 2010).

The land-use raster data with area proportion information and without precision decrease were used by an effective fusion method of spatial data. The data processing contained several steps: firstly, a standard vector "fishnet" with the cells of 1 × 1 km was built; secondly, land use vector map and the "fishnet" were intersected and each cell was partitioned into several parcels according to different land use kinds, the area of certain land use type in cells was collected according to the cell ID; then the results of overlay were divided into several layers of different land use types; and finally every layer was converted into grid raster with each grid including area proportion information (Liu et al. 2003).

Climatic, topographical, and soil data

Climate, soil, and topography were chosen as main control aspects for habitat suitability evaluation of cultivation. And the sub-class indicators of the three aspects were chosen as shown in Table 1. Climatic indicators contained Annual Accumulated Temperature Above 10°C (AAT10), annual precipitation and wind speed of spring, all which were derived from the meteorological station data and spatially interpolated into raster grids using ANUSPLINE software (Hutchinson 2002) based on the method of thin plate smoothing splines, and the method took into account elevation in the process of interpolation. Topographical factors included slope and aspect that were acquired from the DEM grid data with a resolution of 90 m × 90 m, and then the data were resampled into 1 km × 1 km.

Soil data in this study was from the Second National Soil Survey of China, the related materials and data were collected and analyzed by the Institute of Soil Science, Chinese Academy of Sciences.[1] The single-factor evaluation criteria of soil organic matter (SOM) and soil total

[1]The data of Spatial distribution of National soil chemical properties with 1:4,000,000 was digitalized by the group of Dongsheng Yu and Xuezheng Shi in 2007 and shared in the Data Sharing Infrastructure of Earth System Science, China.

nitrogen (STN), soil total phosphorus (STP), and soil total kalium (STK) were designated according to certain criteria for the fertility qualification, and then the single-factor fertility was synthesized with weighted sum for the comprehensive fertility evaluation of soil. The formula for calculation was as follows:

$$\text{Soil} = \text{SOM} \times 0.15 + \text{STN} \times 0.15 + \text{STP} \times 0.3 + \text{STK} \times 0.4 \quad (1)$$

where SOM, STN, STP, STK are the scores of SOM, STN, STP, and STK, respectively, and Soil is the score of comprehensive fertility evaluation.

Methods

Statistic analysis of land reclamation and cropland abandonment

There are indeed two kinds of cropland changes including land reclamation and cropland abandonment separately; however, there is only one result of "increase" or "decrease" in statistic results. The statistic result of cropland was equal to the combination of "land reclamation" and "cropland abandonment." The two types of land use changes were shown as follows.

$$S_2 = S_1 + \Delta S = S_1 + \Delta S_{\text{cul}} - \Delta S_{\text{dec}} \quad (2)$$

where S_2 was the cropland area in the later period; S_1 was the initial area at the beginning; ΔS_{cul} was the area of land reclamation and ΔS_{dec} for land abandonment. The quantity and spatial distribution of ΔS_{dec} and ΔS_{cul} could be acquired by spatial analysis, and $\Delta S = \Delta S_{\text{cul}} - \Delta S_{\text{dec}}$ was the result of traditional statistical change.

Land Dynamic Degree Model (Liu and Buheaosier 2000) was considered as a typical and effective model to measure land use change. Because agricultural land use changes contain two states of land reclamation and cropland abandonment, Land Dynamic Degree Model for cropland could be divided into two categories: "Land Reclamation Degree" (LRD) and "Cropland Abandonment Degree" (CAD) separately for measurements of land reclamation and cropland abandonment. As follows,

$$\text{CAD} = (\Delta S_{\text{dec}}/S_1)/T \times 100\% \quad (3)$$

$$\text{LRD} = (\Delta S_{\text{cul}}/S_1)/T \times 100\% \quad (4)$$

where *CAD* was Cropland Abandonment Degree defined as the conversion-out rate of cropland in certain period and ΔS_{dec} was the abandonment area of cropland; *LED* was Land Reclamation Degree of cropland defined as the exploitation rate for cultivation and ΔS_{cul} was the reclamation area; S_1 was the cropland area at the beginning; and T was the study period with year as unit usually. The indicators of *LRD* and *CAD* in different stages could indicate the characteristics of regional agricultural land use change.

Rationality analysis of agricultural land use change based on habitat suitability for cultivation

Niche theory provided an important implication for the study of cropland suitability. And the existed researches proved that the method could play an important role especially in land use management (Wang 2007; Wang et al. 2007). The cropland of status quo was designated into certain levels of suitability levels according to the niches for plant growth. This paper adopted the model of habitat suitability for cultivation to investigate the rationality of land reclamation and cropland abandonment, and finally provided supports for decision making of ecological security and agricultural development.

The natural and ecological conditions in Mid-eastern Inner Mongolia were taken into account for habitat suitability for cultivation excluding socioeconomic factors, included: (1) climatic conditions: thermal and moisture conditions were two important aspects of climatic conditions. AAT10 was the indicator of thermal condition, and precipitation was the indicator of moisture condition because the farmland in the study area was mainly rain-fed. And soil erosion restricted agricultural development to a great extent especially in spring when the farmland was hardly covered by vegetation, while the land can be covered with vegetation in summer and autumn, and covered with snow or frozen earth surface in winter; all these covers provide protection to avoid wind erosion. Spring wind was an important factor for soil erosion due to the relationship between wind speed and soil erosion (Breshears et al. 2002; He et al. 2006); (2) topographical conditions included slope and aspect; however, the elevation was not chosen as an indicator; and (3) soil conditions, including SOM, STN, STP, and STK, were considered to be major determinants and indicators of soil fertility (Al-Kaisi et al. 2005; Huang et al. 2007a, b).

The criteria for suitability levels were designated by means of the consultations from several experts and existed studies (Wang et al. 2007). The suitability level for certain indicators was shown in Table 1. The suitability of certain indicator in every grid was evaluated into four levels: "highly suitable" (S1), "moderately suitable" (S2), "marginally suitable" (S3) and "unsuitable" (N). The cropland suitability decreased from S1 to N.

The principle of "Liebig's law of the minimum" was considered for the comprehensive evaluation of habitat suitability, that is, the suitability of every parcel was controlled by limiting factors instead of the available or fruitful resources and factors. The designation of ecological suitability for cultivation was completed in GIS with the following formula, the suitability rested with the lowest suitability levels of all the factors.

$$X = \mathrm{MIN}\,(x_i) \tag{5}$$

where X was the comprehensive habitat suitability level, x_i was the habitat suitability level of the single factor i.

Results

Spatio-temporal characteristic of land reclamation and cropland abandonment in Mid-eastern Inner Mongolia

Changes of cropland in four periods

Grassland was the dominant land use type in the Mid-eastern Inner Mongolia, followed by forest, and cropland accounted for only around 11% of the total study area in 2005. However, the quantity of cropland was more than 1/18 of total cropland area all over the country. Therefore, it played an important role in the regional and national food security, and it was also greatly significant on account of its sensitive ecology. Table 2 showed that cropland had a clear trend of increase.

From 1990 to 2005, land reclamation was distinct. The total area of cropland increased from 64,954.64 to 76,258.51 km^2, with an increase of 17.4%. Among the three stages of 1990–1995, 1995–2000, and 2000–2005, the largest area increase occurred during 1995–2000, with a net increase of 6,886.12 km^2. All the cities and leagues underwent successive increases in all the stages expect for Hulun Buir League with a slight decline in 1990–1995. In 1990, Chifeng City had the largest area of 17,242.80 km^2 among all the cities; however, the city with the largest cropland area in 2005 was Hulun Buir League with 20,375.80 km^2 (Table 2).

Alternation between land reclamation and cropland abandonment

1. Comprehensive analysis of study area in four periods
   For the whole study area, land reclamation has always been the dominant type since 1990. In 1990–2000, the amount of land reclamation area reached rapidly to 14,037.25 km^2; however, the reclamation quantity decreased to 2,780.39 km^2 in 2000–2005 (Table 3).
   In the whole study area, 670.01 km^2 of cropland was converted out in 1995–2000; however, the cropland abandonment area

Table 2 The areas of cropland in the study area (Unit: km^2)

City	1990	1995	2000	2005
Chifeng	17,242.80	18,718.00	19,663.40	20,215.60
Hulun buir	16,700.50	15,582.30	19,869.30	20,375.80
Xing'an	10,148.90	11,930.10	12,117.50	12,534.00
Tongliao	15,380.10	16,439.30	17,590.80	17,344.70
Xilin Gol	5,482.34	5,561.67	5,876.49	5,788.41
Total area	64,954.64	68,231.37	75,117.49	76,258.51

Table 3 Land reclamation areas (Unit: km^2) and Land Reclamation Degree (LRD, %) in Mid-eastern Inner Mongolia

Stages	Land reclamation							
	From forest		From grassland		From unused land		Total	
	LRD	Area	LRD	Area	LRD	Area	LRD	Area
1990–2000	0.37	2,397.71	1.69	10,951.89	0.11	687.48	2.16	14,037.25
1995–2000	0.77	2,619.27	1.17	3,995.52	0.18	615.44	2.12	7,230.22
2000–2005	0.07	252.56	0.55	2,075.14	0.12	451.89	0.74	2,780.39

increased rapidly to 1,552.21 km^2 after 2000 with the GFG Project as the possible dominant driving force. As for land use change speed, the *LRD* of cropland decreased from 2.12% in 1995–2000 to 0.74% in 2000–2005. Meanwhile, *CAD* increased from 0.20% to 0.41% (Table 4). That is, the speed of reclamation shrank since 1995, both grassland and forest reclamations decreased obviously. Meanwhile, the cropland abandonment speed increased after 2000.

2. Transition between cropland and grassland
   The land reclamation was mainly derived from grassland instead of forest or others. The area from grassland was 10,951.89 km^2 before 2000, and the land reclamation decreased after 2000, then reached to 2,075.14 km^2 in 2000–2005. However, the cultivation from grassland was still a dominant land use change way. The opposite conversion from farmland to grassland was faster in the 5 years after 2000 than the 5 years before 2000, and the conversion area increased from 505.69 km^2 in 1995–2000 to 1,310.22 km^2 in 2000–2005 (Tables 3 and 4). The total conversion area of 1990–2000 for grassland was 2,721.14 km^2, there were large areas of land reclamation and cropland abandonment in 1990–1995. The driving forces and reasons of land use change were complex, the ecological protection consciousness of people and cropland protection policy was not strong yet before 1995, so rapid land use transitions happened extensively.
3. Transition between cropland and forest
   The reclamation from forest was the prominent type in the transitions between cropland and forest, concentrated in the period of 1995–2000 with an area of 2,619.27 km^2. Then, the reclamation from forest decreased rapidly into 252.56 km^2 after 2000. Meanwhile, the area of cropland conversion for forest increased from 103.06 km^2 in 1995–2000 to 136.45 km^2 in 2000–2005 (Tables 3 and 4). The conversion from cropland to forest was also obvious in 1990–1995 likely due to natural factors, the conversion for forest since 1995 was due to the effects of the GFG Project in China to a great extent.
4. Transition between cropland and built-up land or unused land
   The transition from cropland to built-up land concentrated on the period of 2000–2005 with the area of 57.88 km^2, and the contrary transition was limited and nearly inexistent. The unused land was cultivated rapidly in 1995–2000, and the reclamation speed decreased after 2000 (Tables 3 and 4).

Above all, comparing the two five years before and after 2000, *LRD* of cropland reduced,

Table 4 Cropland abandonment areas and Cropland Abandonment Degree (CAD, %) in Mid-eastern Inner Mongolia

Stages	Cropland abandonment							
	For forest		For grassland		For unused land		Total	
	CAD	Area	CAD	Area	CAD	Area	CAD	Area
1990–2000	0.05	333.14	0.42	2,721.14	0.01	47.12	0.48	3,136.30
1995–2000	0.03	103.06	0.15	505.69	0.02	60.24	0.20	670.01
2000–2005	0.04	136.45	0.35	1,310.22	0.01	47.66	0.41	1,552.21

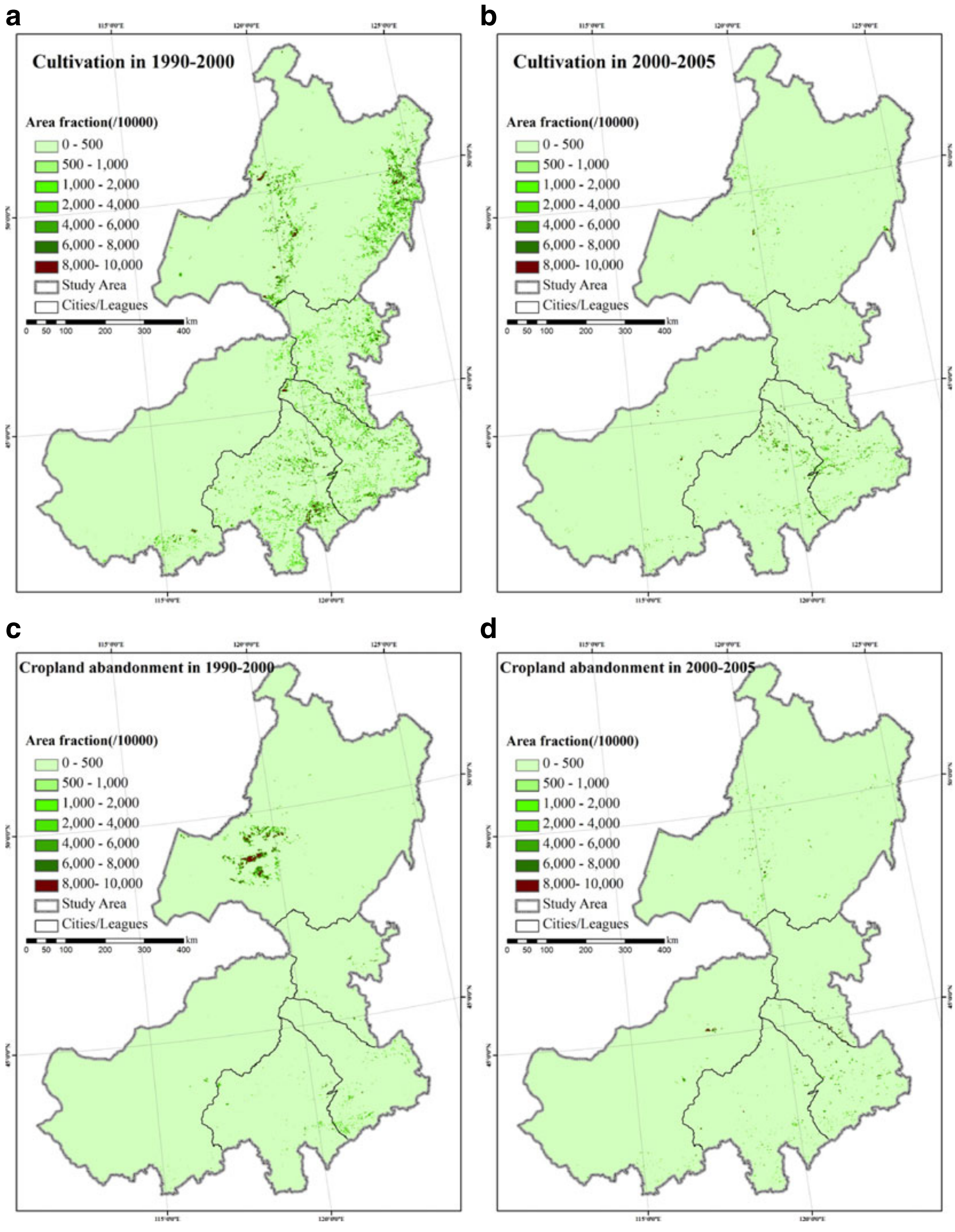

Fig. 3 Spatial distribution of land reclamation in **a** 1990–2000 and **b** 2000–2005; cropland abandonment in **c** 1990–2000 and **d** 2000–2005, the grid value had the same meaning with that in Fig. 2

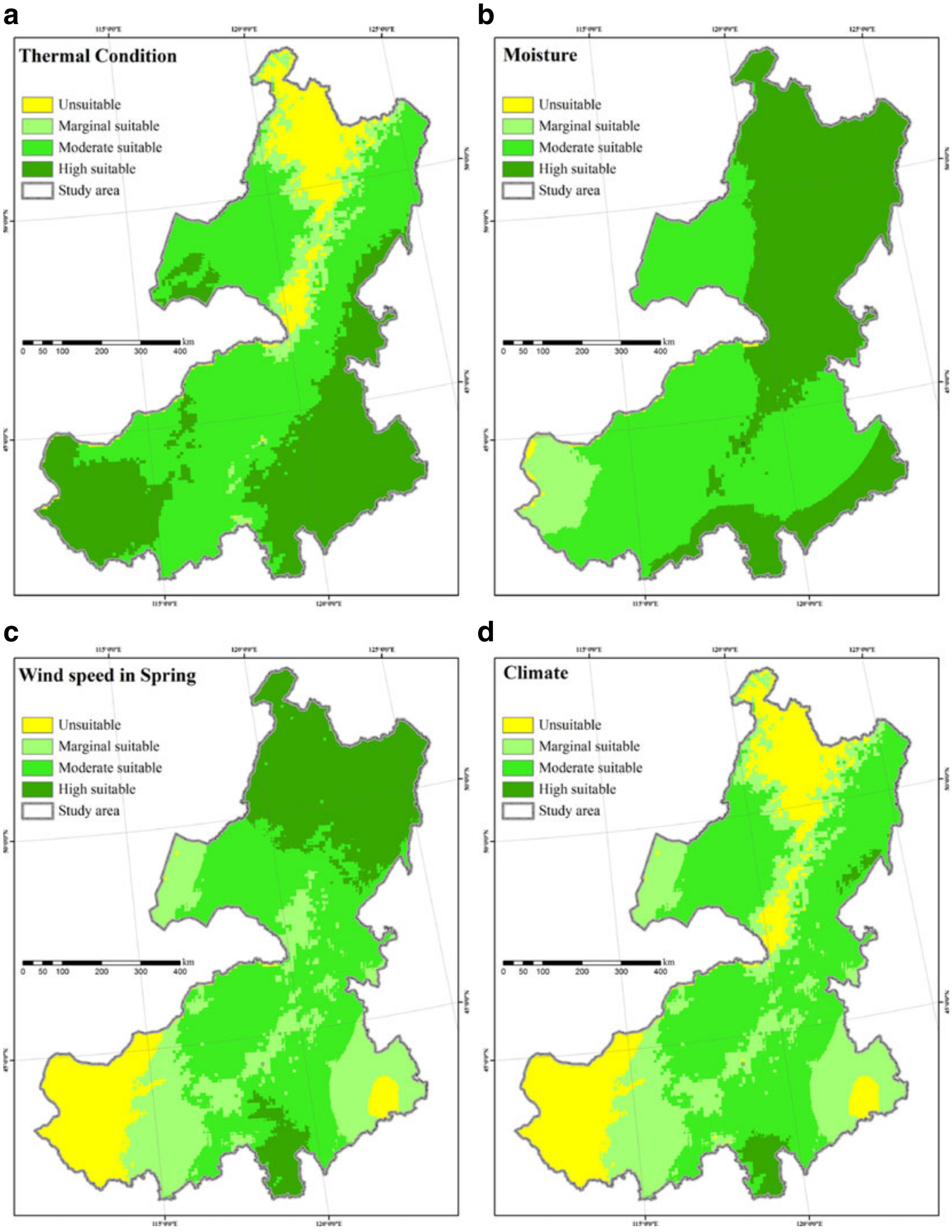

Fig. 4 Habitat suitability map based on climatic factors: **a** thermal condition, **b** moisture, **c** wind speed of spring, and **d** integrated climatic suitability

but *CAD* increased. Land reclamation was still dominant land use change type both before and after 2000. The total cropland quantity kept a successive increase with a decreasing speed. The transition between cropland and grassland was the most prevalent type all the time.

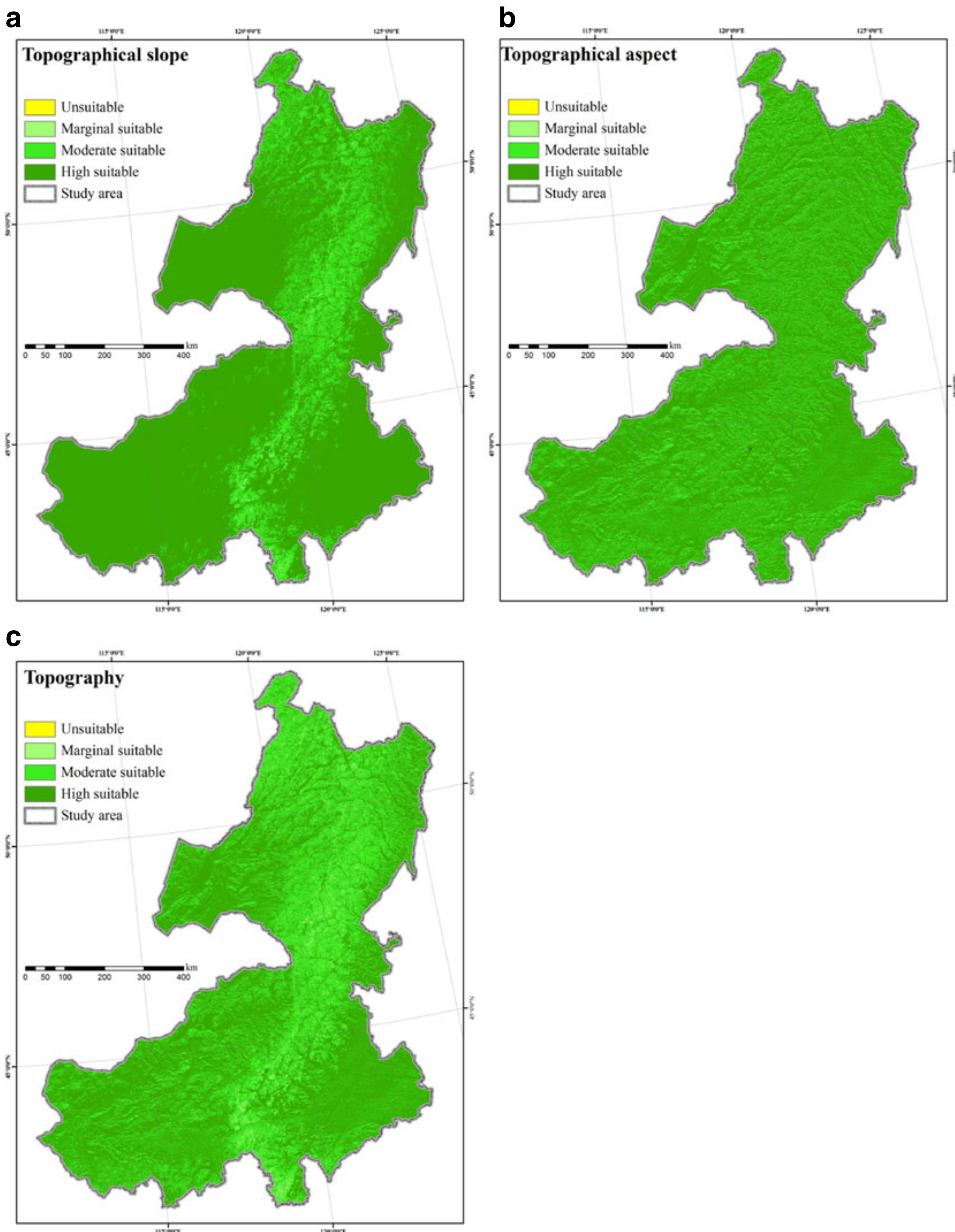

Fig. 5 Habitat suitability map based on topographical factors: **a** slope, **b** aspect, and **c** integrated topographical suitability

Spatial patterns of land reclamation and cropland abandonment

According to the administrative units, the study area was divided into several regions to explore the spatial diversity of land reclamation and cropland abandonment.

1. Spatial pattern of cropland abandonment
   Cropland abandonment occurred mainly in Hulun Buir League with an area of 2,464.38 km^2 in 1990–2000 (Fig. 3c), and the cropland abandonment area for grassland also concentrated on Hulun Buir League with an area of 2,424.14 km^2 at the same time; however, the area decreased after 2000. The transition area from cropland to forest mainly concentrated in Tongliao City with an area of 216.73 km^2 in 1990–2000, and then after 2000 the cropland abandonment in Hulun Buir League was significant and had the largest area of 322.74 km^2.
2. Spatial pattern of land reclamation
   The grassland was the largest source for land reclamation. Hulun Buir had an area of 3,537.94 km^2 converted into cropland in 1990–2000, distributed on both sides of Greater Higgnan Mountain (Fig. 3a), and that indicator shrank to 383.83 km^2 in 2000–2005 (Fig. 3b). All the leagues underwent sharp drops of grassland reclamation from 1990–2000 to 2000–2005; also the land reclamation areas of all the leagues from grassland decreased from 1995–2000 to 2000–2005 except for Chifeng, possible reason was that stricter ecological de-farming and farmland protection policy has been implemented in Chifeng in the end of 1990s, and also large population brought bigger demand for cropland after 2000.
   Land reclamation from forest had the largest area from Hulun Buir League because of its widely distributed temperate forests, and that was especially severe and reached 2,307.25 km^2 in 1995–2000 followed by Chifeng and Tongliao, and the deforestation decreased obviously after 2000 because of the GFG Policy.
   In addition, the unused land reclamation happened all the time, however, the reclamation

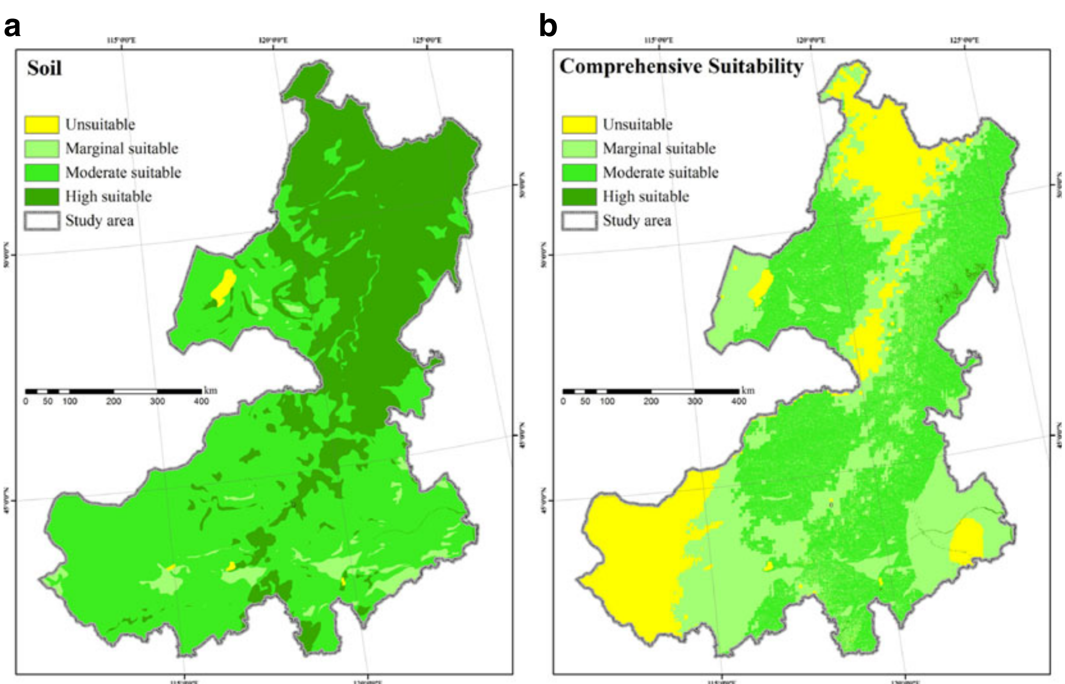

Fig. 6 **a** Habitat suitability map based on soil factor; **b** comprehensive habitat suitability map

Table 5 The area proportions (%) of different suitability levels for separate factors and comprehensive assessment

Aspects	Suitability levels			
	Unsuitable	Marginal	Moderate	High
Comprehensive	21.67	38.40	39.72	0.21
Topography	0.21	16.50	35.49	47.80
Soil	0.44	3.55	58.06	37.95
Climate	21.05	29.17	47.35	2.43

in unused land decreased after 2000 because the total quantity available for cultivation was limited and became less and less.

The rationality of land reclamation and cropland abandonment based on habitat suitability for cultivation

Habitat suitability for cultivation

1. Climatic suitability
   AAT10, precipitation, and wind speed of spring were representative indicators of thermal condition, moisture, and soil erosion, respectively. The result indicated that the climatic condition was unsuitable in the north and west parts, as well as the western of Xilin Gol and a small area in the southeast, while highly suitable areas were very limited and located in the east edge (Fig. 4d).
   The separate suitability of AAT10, precipitation, and wind speed of spring were shown in Fig. 4a–c. The restriction from thermal condition was prominent in the north of study area. The southeastern and southwestern parts of the study area were highly suitable in thermal condition; moisture condition was highly suitable in the middle, northern and southern parts, and a certain area in west was marginally suitable. So, we can conclude that the distributions of thermal condition and moisture were inconsistent (Fig. 4a, b). The pattern was disrupted by the indicator of wind speed in spring because the severe wind erosion happened in spring, especially in the southwestern and southeastern area (Fig. 4c).
2. Topographical suitability
   In general, topographical condition was better in the eastern plain than the middle and western regions (Fig. 5c). Topographical slope was shown in Fig. 5a and unsuitable area concentrated on the middle of the study area around Greater Higgnan Mountains. As for aspect, unsuitable area was dispersive distributed (Fig. 5b).
3. Soil suitability
   Highly suitable areas were distributed in the middle and north of the study area, and the marginally suitable area was dispersive in the south (Fig. 6a).
4. Comprehensive suitability
   The highly suitable area was hardly distributed only with an area of 0.21% (Table 5), and the moderately and marginally suitable areas were widely distributed. Unsuitable areas concentrated in the northern area along Greater Higgnan Mountains and partly in the southwest and southeast, while highly suitable area was hardly located in the eastern Hulun Buir (Fig. 6b).

The statistic results of the areas in individual and comprehensive suitability levels were shown

Table 6 The distributions of land reclamation and cropland abandonment in different suitability levels (km^2)

Suitability levels	Area	Land reclamation		Cropland abandonment	
		1990–2000	2000–2005	1990–2000	2000–2005
Unsuitable	139,529	205.17	69.26	17.40	60.89
Marginally suitable	247,226	4,823.46	1,398.42	877.73	704.40
Moderately suitable	255,721	8,981.62	1,350.97	2,254.52	773.66
Highly suitable	1,363	103.83	0.35	1.38	0.62

in Table 6. We could find that the moderately and marginally suitable areas covered 39.72% and 38.40%, respectively. There was 21.67% of unsuitable area, and the highly suitable area for cultivation was very limited (Table 5).

As for individual factors, the highly suitable area proportions for topographical and soil factors were larger than 37%; however, the comprehensive suitability was restricted by climate condition. They were not consistent spatially among different factors, especially the mismatching of thermal condition, moisture and spring wind existed. So the climatic conditions were the main control factors for cultivation.

The rationality of land reclamation and cropland abandonment based on habitat suitability

The areas of land reclamation and cropland abandonment in different suitability levels were calculated as shown in Table 6.

Land reclamation happened in all the four habitat suitability levels in 1990–2000, the reclamation area in moderately suitability level was the largest with 8,981.62 km^2; however, the reclamation of unsuitable area existed as well, with the area of 205.17 km^2. Then in 2000–2005, land reclamation shrank in all the suitable levels, and largest area of land reclamation occurred in marginally suitable area with 1,398.42 km^2, reclamation area in unsuitable area reached to 69.26 km^2. The reclamation reduced after 2000; however, reclamation in unsuitable and marginally suitable area still existed.

In 1990-2000, the cropland abandonment occurred with a large area of 2,254.52 km^2 in moderately suitable area. And it was rational to some extent that highly suitable cropland was hardly abandoned in the two stages. In 2000–2005, cropland abandonment area in moderately suitable level decreased into 773.66 km^2, and the cropland abandonment areas in unsuitable and marginally suitable levels were still large comparing with the period of 1990–2000.

The decrease of land reclamation in low suitability levels and the increase of cropland abandonment in unsuitable area after 2000 indicated that the agricultural land use pattern was improved to some extent.

Discussion

The effects of the GFG Project on cropland change

The GFG Project was a national campaign to convert low-yielding or unsuitable cropland into forest or grassland for the aim of ecological restoration (Peng et al. 2007; Xu et al. 2007; Cao et al. 2009a, b). The related issues of food security and ecological protection due to the project had been paid much attention (Long et al. 2006; Peng et al. 2007).

This study tried to give an assessment for the project based on a hypothesis that the conversion from cropland to grassland or forest was all from the GFG Project, and that hypothesis may amplify the actual effects of the project. The area converting cropland into forest or grassland was 1,446.67 km^2, including the area converted into grassland of 1,310.22 km^2 and that into forest of 136.45 km^2. *CAD* of cropland was 0.04% for forest and 0.35% for grassland in 2000–2005, and which was larger than the indicator of the five years before 2000.

The habitat suitability for cultivation can provide a significant implication for the GFG project. Cropland in unsuitable and marginally suitable levels should be abandoned or converted out firstly. However, the results showed that the GFG Project was also partly implemented in highly suitable cropland. At present, slope was taken as a common index in the operation of the GFG Project while other factors were ignored to some extent (Wang et al. 2007). The designation of habitat suitability for cultivation in this study could provide supports for the project, and the conversion sequence of cropland in the project could be determined according to the suitability levels.

Implication about the effects of land reclamation

The effects of the GFG Project have been discussed in above parts. However, how did land reclamation and cropland abandonment affect food productivity? Extensive reclamation was dominant type and rain-fed cropland increased remarkably. However, land reclamation may not bring out the increase of crop production because the crop yield of new reclamation area was low with low suitability. The total quantity of cropland increased; however, the high suitable cropland hardly increased.

Physical and chemical properties of soil have changed once the reclamation occurred (Chen and Duan 2009). The planting in the low suitable cropland give an impetus to land degradation, and then land abandonment happened again.

Uncertainty analysis

This study analyzed the land reclamation and cropland abandonment based on land use change data in the three periods of 1990–2000, 1995–2000, and 2000–2005, especially the comparison around 2000. However, there may be cropland conversion happening every year. Frequent turnovers occured because of the variability and fluctuation of climate change, farming strategy, etc. It is significant to show the consecutive inter-annual process of land reclamation or cropland abandonment with higher frequency of cropland change analysis.

The physical factors affecting cultivation can be divided into two categories: static ones and dynamic ones. Topographical factors were hardly changed as static ones, and AAT10, wind, and precipitation changed yearly as dynamic ones. Soil factors changed with a slow speed. Dynamic factors may make the suitability evaluation results changeable. In this study, all the factors were assumed hardly changed. That is, the mean of AAT10, wind speed in spring, and precipitation in 1988–2005 stood for the average climatic conditions of the study area, and we adopted the only soil data from the Second National Soil Survey of China. The possible effects of climatic and soil factor changes will be given more consideration in the future studies.

The criteria of habitat suitability from different crops and regions were different because of the crop's ecological demand and different ecological protection aims. The criteria in this study were uniform for the simplicity of the problem.

Conclusion

This study aimed to monitor the spatio-temporal pattern of agricultural land use change since 1990 in Mid-eastern Inner Mongolia and to evaluate the rationality of land reclamation and cropland abandonment based on the habitat suitability for cultivation.

Land reclamation was more acute than cropland abandonment during 1990–2005, and the total area of cropland increased. However, the speed of reclamation shrank since 1995, especially because of the GFG project for the aim of ecological restoration around 2000; land reclamation reduced rapidly. Meanwhile, cropland abandonment increased to 1,552.21 km^2 in 2000–2005 from only 670.01 km^2 in 1995–2000. Cropland area increased all the time with the pressures from growing population and food demand; however, the GFG Project did take effect in the restricting of land reclamation.

The total suitability level of cropland in the study area was relatively low; however, the situation of land use change was under improvement due to the implementation of the GFG Project. Cropland distribution in high suitability and unsuitable level was very limited, and the moderately and marginally suitable croplands were widely distributed. The climate conditions were the main control factors affecting cultivation. The habitat suitability assessment can provide an effective decision supporting for the implement of GFG Project.

The suitability changes of cropland were examined in this study. However, its impact on the crop productivity should be further investigated. The effects of land reclamation and cropland abandonment on food security should be assessed in depth. Spatial allocation of farmland based on the habitat suitability integrating both anthropogenic and natural factors is expected to be investigated in further study as well.

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