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Evaluation of Land Reclamation and Implications of Ecological Restoration for Agro-pastoral Ecotone: Case Study of Horqin Left Back Banner in China

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Abstract: The agro-pastoral ecotone has been recognized as the main distribution area of reserved land resource for cultivation. Accordingly, clarifying this assumption, as well as concerting land reclamation and ecological restoration, is important to ensure food security and environmental improvement in the agro-pastoral ecotone. We selected Horqin Left Back Banner (HLBB) as the subject of our case study. The landscape ecological security pattern of this area was determined using the minimum cumulative resistance model. Over-cultivation, quantity of reserved land resource for cultivation, and changes in landscape indexes before and after land use adjustment were then analyzed. Over-cultivation is a serious problem in the agro-pastoral ecotone. Reserved land resource for cultivation is less than that considered previously, and the area of reserved land resource for cultivation in HLBB only accounts for 11.50% of total uncultivated land. With regard to changes in landscape indexes, the adjusted land use pattern is effective for anti-desertification. The compensation standard for abandoned cultivated land should be improved and the comprehensive results of 'Grain for Green' should be evaluated to further implement ecological restoration in the agro-pastoral ecotone.

Keywords: land reclamation; ecological restoration; minimum cumulative resistance model; agro-pastoral ecotone; China

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1 Introduction

Food security is an important challenge worldwide (Godfray *et al.*, 2010), particularly in China. China accounts for only 8% of the world's arable land but is home to 19% of the world's population (Yang *et al.*, 2015). Furthermore, a large proportion of arable land in China is used for construction due to the rapid development of its social economy (Liu *et al.*, 2014). Consequently, food security in China has aroused international concern (Anderson and Strutt, 2014). To maintain food security, the Chinese government implemented the 'Cultivated Land Balance Policy' in 1996 to conserve a certain amount of cultivated land (Song and Pijanowski, 2014). This policy emphasized that cultivated land occupied by construction must be compensated by adding the same amount of cultivated land. Land reclamation was a major source of cultivated land, and cultivated land from reclaimed land accounted for 63.2% of the overall increase in cultivated land area from 2001 to 2008 (Zhou *et al.*, 2014).

The agro-pastoral ecotone is located southeast of the Inner Mongolia Plateau and northwest of the Loess Plateau of China; this area is characterized by agriculture

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and animal husbandry (Xu *et al.*, 2014). For a long period, the agro-pastoral ecotone has been recognized as the main distribution area of reserved land resource for cultivation that can be reclaimed into cultivated land (Liu *et al.*, 2003; Yi *et al.*, 2013). The literature on land reclamation mainly comprised studies on the natural characteristics of uncultivated land and ecological security was rarely considered. Natural characteristics of uncultivated land include soil property, topographic condition, and climatic condition (Zhang *et al.*, 2010; Dong *et al.*, 2011). The agro-pastoral ecotone is characterized by fragile eco-environments (Jiang *et al.*, 2005; Xu *et al.*, 2014). And it exhibits severe sandy desertification because of irrational land use, particularly land reclamation (Ge *et al.*, 2013; Xu *et al.*, 2014). Thus, ecological security must be emphasized in land reclamation evaluation. Accordingly, we studied the amount of reserved land resource for cultivation from the aspect of landscape ecological security patterns. The result of this work can provide evidence on whether the agro-pastoral ecotone can be regarded as the major distribution area of reserved land resource for cultivation.

To improve ecological and environmental conditions, several ecological projects have been implemented in the agro-pastoral ecotone, including the 'Great Green Wall' in 1978 (Wang *et al.*, 2010), 'Grain for Green' in 1999 (Xu *et al.*, 2006), and the 'Beijing and Tianjin Sand Control Program' in 2001 (Cao *et al.*, 2011). These projects have alleviated desertification to a certain degree and have improved the environmental condition in the area (Zhang *et al.*, 2012; Tan and Li, 2015). Research on ecological restoration has mainly focused on ecological restoration measures and their effects (Li *et al.*, 2009; Miao *et al.*, 2015), the influencing factors of ecological restoration efficiency, and measures for the sustainable development of ecological restoration (Cao *et al.*, 2011; Tan and Li, 2015). However, only a few studies have focused on the regional determination of ecological restoration. Moreover, uncultivated land has been reclaimed as cultivated land (Dong *et al.*, 2011). Uncultivated land with high vegetation coverage was prioritized for utilization because it was more fertile than that with low vegetation coverage. Reclaimed cultivated lands were abandoned after a few years because of the rapid depletion of fertility. Thereby causing a destructive circle: land reclamation > cultivated land degradation > cultivated land abandonment (followed by ecological restoration) > land reclamation (Yang and Li, 2000). Irrational land reclamation severely damages the eco-environment in the agro-pastoral ecotone. Thus, concerting land reclamation and ecological restoration in the agro-pastoral ecotone is critical to ensure food security and environmental protection.

This work presents a case study of Horqin Left Back Banner (HLBB) from the perspective of ecological security patterns. It aims to: 1) verify whether the agro-pastoral ecotone is the main distribution area of reserved land resource for cultivation, 2) identify landscape ecological security patterns in HLBB and calculate the areas of reserved land resource for cultivation and abandoned cultivated land for ecological restoration, and 3) provide the implications of ecological restoration for the agro-pastoral ecotone.

2 Materials and Methods

2.1 Study area

Horqin Left Back Banner (HLBB) (42°40′N–43° 42′N, 121°30′E–123°42′E) is a county in Inner Mongolia that is located in the agro-pastoral ecotone (Fig. 1). HLBB has a temperate continental monsoon climate. The average annual precipitation is 428 mm, which is mainly concentrated in July–September (accounting for 70% of the total). Sand-driving windy days (average wind velocity is higher than 5 m/s in one day) can reach up to 40 days in one year and are concentrated during winter and spring when vegetation coverage is low. Topography is characterized by sinuate sand dunes, flat sand lands, and plains. Topographic features include connections among fixed, semi-fixed, and moving sand dunes, and alternating distributions of undulating sand dunes and marshy lands. Aeolian sandy soil is the main soil type in the area, accounting for 68.9%. The area of uncultivated land was 76 449.01 ha in 2012 including other grass land, inland beach, sandy land, saline land, and alkaline land. The main crop is spring maize, and its planting area accounted for 86% of all sown areas in 2013. The numbers of sheep and cattle were 467 800 and 401 300 in 2013, respectively.

HLBB is a part of Horqin Sandy Land, which is the largest sandy land in China in terms of area. Sandy desertification is the prominent eco-environmental problem in HLBB. Sandy desertified land in HLBB reached 7042 km^2 in 1996, accounting for 61.3% of its total land

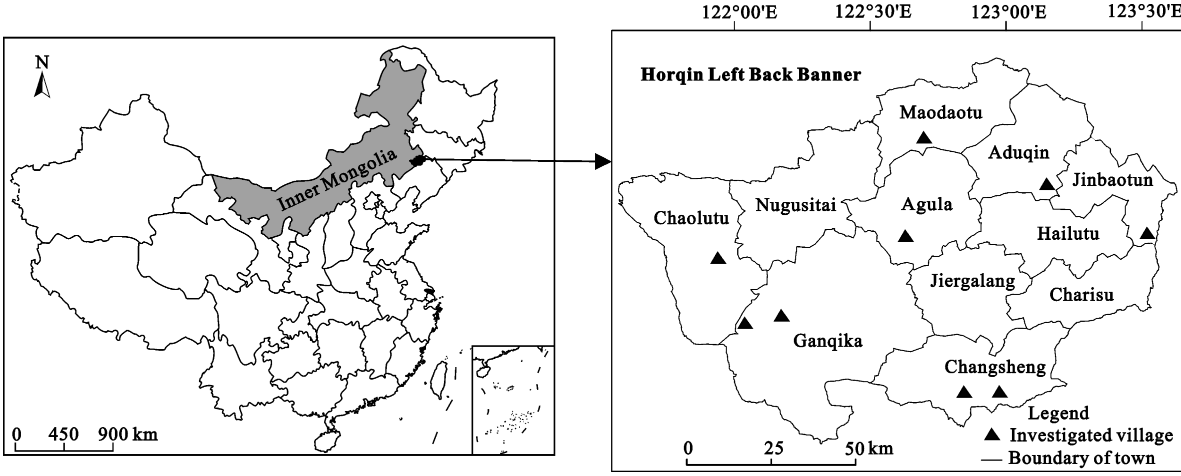

Fig. 1 Locations of Horqin Left Back Banner (HLBB) and the investigated villages

area. From 2001 to 2010, sandy desertified land accounted for an average of 38.7%. Extensive land use is the significant driving force of sandy desertification, particularly during windy days. First, precipitation in HLBB is relatively high at nearly 420 mm because of the transition location of the area from semi-humid region to arid region. Furthermore, the spring maize growth period coincides with the concentrated period of rainfall. Thus, natural precipitation can satisfy the water demand of spring maize growth to a considerable extent. Second, HLBB has abundant land resources and its population density has reached 35/km^2 in 2013. Accordingly, farmers adopt extensive cultivation to increase grain production. The cultivated land area increased from 112 000 ha in 1986 to 210 000 ha in 2011. The grain sown area increased from 85 000 ha in 1987 to 186 100 ha in 2011.

To prevent desertification, the construction of the 'Great Green Wall' began in 1978 and is scheduled to be completed in 2050. Furthermore, the first round of 'Grain for Green' (completed in 2010) and the 'Beijing and Tianjin Sand Control Program' (completed in 2010) were implemented in HLBB. The 'Twelfth Five-year Plan of Forest of HLBB' indicated that 14 000 ha of cultivated land was converted into forest land and grass land in the first round of 'Grain for Green'. The 'Fifth Construction Plan of the Great Green Wall of HLBB' (2011 to 2020) forecasts that 1 040 000 ha of land will be intended for reforestation. The second round of 'Grain for Green' started in 2014 and will last until 2020. Hence, concerting land reclamation and ecological restoration in the agro-pastoral ecotone is urgently required.

2.2 Materials

The Chinese government conducted the second national land use survey from 2007 to 2009 and established a national land use database. Hereafter, this national land use database has been updated every year according to land use changes. Land use classification has 2 levels. For urban land use, 12 land use types are included in Level 1 and 57 land use types are included in Level 2. Land use types under Level 1 are cultivated land, orchard land, forest land, grass land, commercial/service industry land, industrial/mining and storage land, residential land, public management/service land, land for special uses, traffic/transportation land, water and water conservation facility land, and other uses of land. For rural land use, 8 land use types are included in Level 1 and 38 land use types are included in Level 2. Land use types under Level 1 are cultivated land, orchard land, forest land, grass land, town/village and industrial/mining land, traffic/transportation land, water and water conservation facility land, and other uses of land. The 2012 land use database of HLBB was collected from its Land and Resources Bureau. The Chinese government conducted the second national soil survey from 1979 to 1985, while HLBB completed its soil survey in 1984. Soil classification has 4 levels, namely, soil group, soil subgroup, soil genus, and soil local type. The soil database of HLBB from the Agricultural Bureau of HLBB was used in this study. Land use data and soil data were processed under the Xi'an_ 1980 coordinate system.

In addition, we also conducted field surveys in HLBB based on household on October 8–16, 2014 and July 20–31, 2015 to collect data about various aspects, such as areas of cultivated land, grass land, and forest land of households; plantation condition; profit in agriculture and animal husbandry; and implementation situation of the 'Great Green Wall' and the 'Grain for Green'. These surveys were completed via the participatory rural appraisal method and the investigated villages are shown in Fig. 1.

2.3 Methods

2.3.1 Minimum cumulative resistance model

A potential spatial pattern that consists of critical parts, positions, and spatial relationships always exists in a landscape and plays a key role in the ecological process. A potential spatial pattern is called a landscape ecological security pattern. A landscape ecological security pattern exhibits a relatively high efficiency in sustaining an ecological process (Yu, 1995). An ecological process refers to interactions among landscape units, and these interactions can be presented as a potential surface or a trend surface. A trend surface indicates the relationship between a landscape pattern and an ecological process. Simultaneously, the change in relationship is non-uniform and the turning points indicate the changes in an ecological process. Thus, turning points can be regarded as the change thresholds of an ecological process. Landscape ecological security patterns can be determined by conducting spatial analysis on the trend surface. An ecological process can be controlled efficiently via ecological security patterns. The minimum cumulative resistance model (MCRM) has been used to build the trend surface. This model has been applied to optimize land use patterns (Li *et al.*, 2013), protect biological habitats (Li *et al.*, 2014), and lay out the arrangement of rural settlements (Wu *et al.*, 2013). The first step in using MCRM is to determine the source zone that plays a key role in the given ecological process. Thereafter, the trend surface (the minimum cumulative resistance value) is constructed using Equation (1). Finally, landscape ecological security patterns can be confirmed according to the relationship between the minimum cumulative resistance value and land area.

Source zone: Source zone selection corresponds to a specific ecological process (Chen *et al.*, 2006), and a source zone can be recognized as the key land use type for regional ecological environments. Sandy desertification is the prominent eco-environmental problem in HLBB. Cultivated land is the most damaging land use type for vegetation coverage because tillage, harvest, and mechanical operations can all destroy the land surface and reduce vegetation growth. The main cause of sandy desertification is the reclamation of land suitable for forest land and grass land, but not for cultivated land (Cao *et al.*, 2004). After cultivation, soil nutrient is sharply reduced and soil particle size distribution becomes favorable to desertification (Su *et al.*, 2004; Zhao *et al.*, 2005). Thus, an over-cultivated land is abandoned and becomes desertified after a few years. By contrast, our field survey indicated that fertilization for sustainably used cultivated land was implemented by farmers and the amount of chemical fertilizers used was approximately 500 kg/ha. Therefore, cultivated land that was sustainably used maintained a sufficient amount of soil nutrients. Second, conservation tillage was adopted for the sustainably used cultivated land to protect cultivated land from wind erosion. Consequently, the sustainable use of cultivated land does not lead to desertification and is the best anti-desertification measure.

Our field surveys indicated that paddy field and irrigated land were the highest ranking land use types in terms of soil fertility, water resource, and land infrastructure. The economic benefits of paddy field and irrigated land were also sufficient. In addition to paddy field and irrigated land, farmers have also persistently grown crops on top-quality dry cultivated land to increase their income. Thus, paddy fields, irrigated land, and top-quality dry cultivated land were included in sustainably used cultivated lands. Paddy fields and irrigated land were extracted from the land use database. For top-quality dry cultivated land, dry cultivated land with a slope of less than 6° was extracted from the land use database, and three organic soil genera with good soil fertility were obtained from the soil database. The three soil genera were black meadow soil, meadow bog soil, and peat soil. Thereafter, dry cultivated land with a slope of less than 6° and the three soil genera were overlaid to obtain top-quality dry cultivated land.

Trend surface: Income from cultivated land was higher than those from forest land and grass land. Hence, land always exhibits the tendency to be used as cultivated land. However, if land is over-reclaimed spatially, then the development of sandy desertification will be more likely induced.

Land use has a potential trend surface in spatial areas. The potential trend surface is mainly influenced by sandy desertification in HLBB. Moreover, different land use types have varying probabilities of sandy desertification. That is, different land use types have various resistance values for the development of anti-desertification in spatial areas. Thus, the trend surface (minimum cumulative resistance value) can be constructed with the sandy desertification probability of different land use types. Land with small minimum cumulative resistance values can be reclaimed into cultivated land because such values denote the low probability of sandy desertification from the perspective of spatial patterns.

Ge *et al*. (2013) studied the sandy desertification probability of different land use types in Naiman Banner (NB). NB and HLBB are adjacent counties, and both belong to Tongliao City in administration and Horqin Sandy Land in geolocation. Both banners are also located in the agro-pastoral ecotone. They are similar in natural conditions and socioeconomic characteristics. Accordingly, we have adopted the research results of this study as the sandy desertification probability of different land use types in HLBB. Sandy desertification probabilities of dry cultivated land, forest land, grass land, residential land and unused land are 0.63, 0.07, 0.23, 0.21 and 0.66.

$$MCR = f_{\min} \sum (D_{ijk} \times R_k) \tag{1}$$

MCR is the minimum cumulative resistance value and is calculated based on pixels. $f_{\min}$ denotes the minimum value of the cumulative resistance produced in different paths from unit *i* to source zone *j*. *f* is a function of the positive relation that indicates the relation of the cumulative resistance value for unit *i* in space to the distance from unit *i* to source zone *j* and the characteristics of the landscape base surface. D_{ijk} is the spatial distance across landscape *k* (land use type) from unit *i* to source zone *j*. R_k is the sandy desertification probability (resistance value) of landscape *k*.

2.3.2 Over-cultivation index

The over-cultivation index was calculated to analyze the over-cultivation condition in HLBB.

$$CI = (C - S)/S \tag{2}$$

where *CI* is the over-cultivation index, *C* is the area of cultivated land in 2012, and *S* is the suitable area of cultivated land according to the MCRM results.

2.3.3 Landscape index

The landscape index can highly concentrate landscape pattern information and reflect landscape features in structural composition and spatial allocation. Landscape indexes were calculated on the class level, including number of patches (NP), mean patch area (AREA_MN), coefficient of variation in patch area (AREA_CV), aggregation index (AI), and the splitting index (SPLIT), to reflect changes in landscape pattern before and after land use adjustment. NP can reflect changes in patch number. AREA_MN and AREA_CV reflect changes in patch area. AI can reflect patch aggregation condition. AI is small when patches are scattered and large when patches are connected. AI is between 0 and 100; a smaller value corresponds to a more significant land use fragmentation. SPLIT can reflect patch distribution condition. SPLIT increases as patches disperse.

$$NP = n \tag{3}$$

$$AREA\_MN = \frac{\sum_{j=1}^{n} x_{ij}}{n} \tag{4}$$

$$AREA\_CV = \frac{SD_i}{MN_i} \times 100\% \tag{5}$$

$$AI = \frac{g_i}{\max\_g_i} \times 100\% \tag{6}$$

$$SPLIT = \frac{A^2}{\sum_{j=1}^{n} x_{ij}^2} \tag{7}$$

where *n* is the number of patches of different land use types, x_{ij} is the *j*th patch area of land use type *i*, SD_i is the area standard deviation of land use type *i*, MN_i is the average patch area of land use type *i*, g_i is the number of like adjacencies between pixels of land use type *i* based on the single-count method, $\max\_g_i$ is the maximum number of like adjacencies between pixels of land use type *i* based on the single-count method, and *A* is the total area of land use type *i*.

3 Results and Analyses

3.1 Minimum cumulative resistance value and land use adjustment

Fig. 2 shows the trend surface of the minimum cumulative resistance value. A higher minimum cumulative resistance value corresponds to a higher probability of sandy desertification. From the MCRM results, the changing trend between the minimum cumulative resistance value and the number of cells (each cell is 30 m × 30 m) can be divided into three phases (Fig. 3): rapid increase, rapid decrease, and gradual decrease. Landscape ecological security patterns can be determined by the changing trend. When the minimum cumulative resistance value was below 250, the number of cells increased dramatically with increasing minimum cumulative resistance value. From 250 to 1080, the number of cells decreased rapidly with increasing minimum cumulative resistance value. From 1080 to the highest minimum cumulative resistance value, the change rate was slower than that of the previous phase.

In the first phase, that area of land that could be reclaimed into cultivated land increased dramatically because the sandy desertification probability was small. Thus, uncultivated land with a minimum cumulative resistance value of less than 250 was reclaimed into cultivated land. In the second phase, the number of cells decreased dramatically with the rapid increase in sandy desertification probability. This finding demonstrated that land suitable for cultivation decreased rapidly because of the rapid increase in sandy desertification probability. In the third phase, land exhibited the highest sandy desertification probability. Thus, land with a minimum cumulative resistance value higher than 250 was unsuitable for cultivation.

Cultivated land with a minimum cumulative resistance value higher than 1080 exhibited poor in natural conditions and presented the highest sandy desertification probability. The requirement to natural conditions for grass growth is low, and grass land is effective in sand dune fixation. Thus, cultivated land with a minimum cumulative resistance value higher than 1080 was abandoned and used as grass land. Cultivated land with a minimum cumulative resistance value between 250 and 1080 had a poorer natural condition than cultivated land with a minimum cumulative resistance value of less than 250, but had a better natural condition than cultivated land with a minimum cumulative resistance value higher than 1080. The requirement to natural conditions for forest growth lies between those of cropland and grass land. Accordingly, land with a minimum cumulative resistance value between 250 and 1080 can be used as forest land. However, our field surveys showed that income from animal husbandry accounted for a major part of household incomes in the area. Grass land can provide forage for animal husbandry. Furthermore, land conditions that satisfy the requirement for forest growth can generally also fulfill the requirement for grass growth. Hence, cultivated land with a minimum cumulative resistance value between 250 and 1080 was abandoned into either forest land or grass land. If the cultivated land was closer to grassland, then it was abandoned into grassland; if the cultivated land was closer to forest land, then it was abandoned into forest land.

Therefore, cultivated land with a minimum cumulative resistance value of less than 250 was suitable for

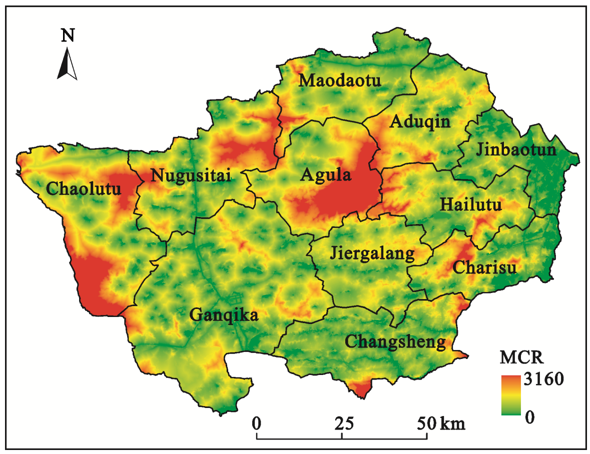

Fig. 2 Minimum cumulative resistance value (MCR)

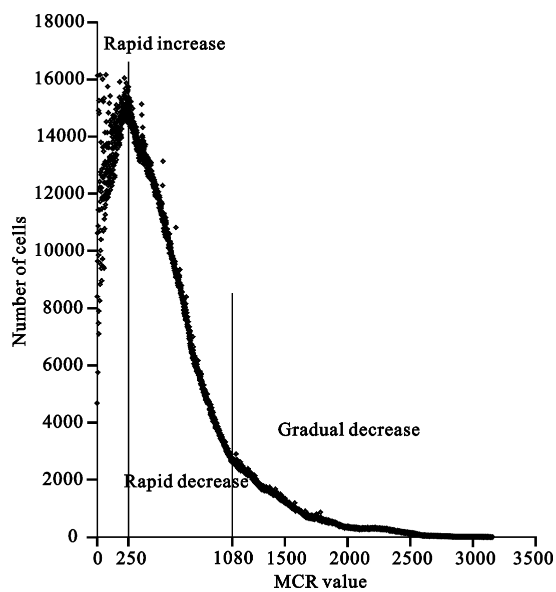

Fig. 3 Relationship between minimum cumulative resistance (MCR) value and number of cells

cultivation. Uncultivated land with minimum cumulative resistance values of less than 250 was reclaimed. By contrast, cultivated land with the minimum cumulative resistance value higher than 250 but less than 1080 was abandoned into forest land or grass land; cultivated land with a minimum cumulative resistance value higher than 1080 was abandoned into grass land (Fig. 4).

3.2 Over-cultivation analysis

In terms of the over-cultivation index, land was over-cultivated in HLBB and in the majority of its towns (Table 1). The over-cultivation index was generally 1.62 in HLBB, which indicated that 139 879.42 ha of its land was over-cultivated. This value was 1.62 times the suitable cultivated land area. Over-cultivation occurred in the majority of the towns in HLBB. Only three towns possess land that was not over-cultivated: Jinbaotun, Maodaotu, and Ganqika. All other lands in HLBB were over-cultivated. Agula presented the most serious over-cultivation problem, with an over-cultivation index of 15.49.

3.3 Analysis of reserved land resource for cultivation

Uncultivated land include other grass land, inland beach, sandy land, saline land, and alkaline land in HLBB. The uncultivated land is regarded as reserved land resource for cultivation ordinarily. Uncultivated land with minimum cumulative resistance values of less than 250 could be cultivated, whereas the others were unsuitable for cultivation, according to the MCRM results. The total area of the uncultivated land in HLBB was 76 449.01 ha (Table 2). By contrast, land that could be reclaimed into cultivated land was only 8792.31 ha, which accounted for 11.50%. For the towns, the percentages of reserved land resource for cultivation to the total area of uncultivated land were small. Five towns had a percentage of less than 10%, and three towns had a percentage of less than 15%. The area of uncultivated land in Agula was 10 988.37 ha, but the area suitable for cultivation accounted for only 0.18%. Among the 11 towns, only Changsheng and Jinbaotun exhibited relatively high percentages of 35.73% and 64.91%, respectively.

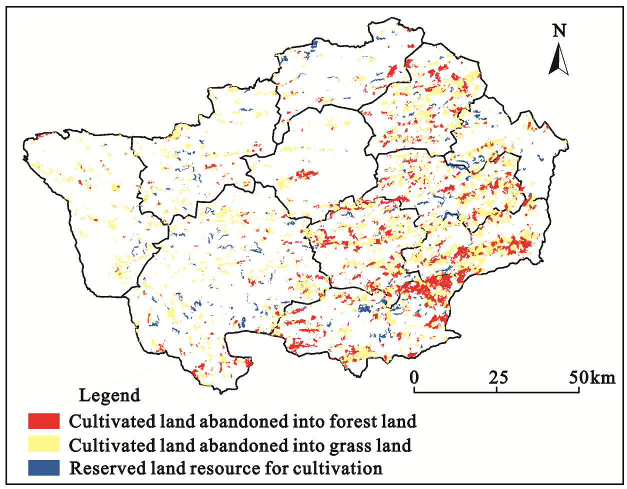

Fig. 4 Reserved land resource for cultivation and abandoned cultivated land

Table 1 Over-cultivation indexes of Horqin Left Back Banner (HLBB) and its towns

Town	Suitable cultivated land area (ha)	Over-cultivated land area (ha)	Over-cultivation index
Jinbaotun	17800.18	4963.57	0.28
Maodaotu	3181.73	2886.08	0.91
Ganqika	15646.06	14507.72	0.93
Changsheng	16745.52	22800.58	1.36
Charisu	13680.13	20476.33	1.50
Nugusitai	4042.25	7197.79	1.78
Chaolutu	3325.61	9500.83	2.86
Jiergalang	4100.60	15039.96	3.67
Aduqin	3639.16	13754.40	3.78
Hailutu	3356.30	17536.07	5.22
Agula	724.25	11216.08	15.49
HLBB	86241.80	139879.42	1.62

Table 2 Uncultivated land and reserved land resource for cultivation

Town	Uncultivated land (ha)		Percentage of reserved land resource for cultivation to total area of uncultivated land (%)
	Reserved land resource for cultivation	Uncultivated land unsuitable for cultivation	
Agula	19.73	10968.64	0.18
Chaolutu	227.92	5755.06	3.81
Aduqin	351.93	4378.04	7.44
Nugusitai	709.71	7460.58	8.69
Hailutu	820.42	7836.34	9.48
Maodaotu	1053.01	8625.84	10.88
Charisu	472.46	3527.06	11.81
Ganqika	2411.81	13881.64	14.80
Jiergalang	383.17	2169.28	15.01
Changsheng	1420.77	2556.08	35.73
Jinbaotun	921.38	498.14	64.91
HLBB	8792.31	67656.70	11.50

3.4 Landscape indexes before and after land use adjustment

The NP index decreased for cultivated land, thereby indicating that the patch number of cultivated land decreased (Table 3). Simultaneously, AI decreased, whereas SPLIT increased, which indicated that cultivated land became more dispersed in the spatial distribution. Moreover, the AREA_MN and AREA_CV indexes decreased, thereby indicating that the average area of cultivated land patches decreased. Large area cultivation is unsuitable for the agro-pastoral ecotone given that natural conditions change dramatically and the ecological carrying capacity is low in this region. By contrast, the cluster pattern of cultivation was suitable for this region. These changes demonstrated that cultivated land became more beneficial for anti-desertification.

First, the NP indexes for forest land and grass land decreased. Second, AI increased and SPLIT decreased, which respectively indicated that forest land and grass land became more aggregated. Third, the AREA_MN index increased, whereas the AREA_CV index decreased, thereby respectively indicating that the average areas of forest land and grass land increased. These changes in the landscape indexes of forest land and grass land also contributed to anti-desertification because large forest land and grass land could provide stable and effective protection against anti-desertification.

4 Discussion and Implications of Ecological Restoration

Relevant studies have verified that land was over-cultivated in the agro-pastoral ecotone in China (Wu, 2001; Zhang *et al.*, 2003; Zhao *et al.*, 2005). The result of the present study agrees with this conclusion and the investigation result. Our field investigation showed that the average contracted cultivated land area per capita was 0.53 ha, whereas that per household was 2.27 ha. Contracted cultivated land was top-quality land. Otherwise, the average actual cultivated land area per household was 2.78 ha. In particular, more land was reclaimed as cultivated land by households to increase cultivated

Table 3 Landscape indexes before and after land use adjustment

Land use pattern	Land use type	NP	AREA_MN	AREA_CV	AI	SPLIT
Before land use adjustment	Cultivated land	5587	40.48	1260.93	92.04	837.18
	Forest land	16978	10.42	1055.94	87.40	5910.65
	Grass land	5438	108.59	4423.17	95.52	9.77
After land use adjustment	Cultivated land	3968	23.95	823.02	89.20	7837.57
	Forest land	14954	14.66	1048.72	89.66	3439.45
	Grass land	4082	168.52	4326.32	96.20	5.65

Notes: NP is number of patches; AREA_MN is mean patch area; AREA_CV is coefficient of variation in patch area; AI is aggregation index; SPLIT is splitting index land area. Reclaimed land exhibited poorer quality than contracted cultivated land. First, natural rainfall can satisfy the water demand of spring maize growth to a considerable extent because precipitation is relatively rich and rainfall times coincide with the growth period of spring maize, which is the major crop in the agro- pastoral ecotone. Second, the ecotone has vast land resources with a low population density. Thus, farmers adopt extensive cultivation to increase cultivated land and grain production in case of agricultural drought years. Under extensive cultivation, grass land and forest land are reclaimed into cultivated land. The reclaimed cultivated land is then abandoned rapidly after several years because of rapid fertility depletion after reclamation. Farmers then reclaim other grass land and forest land. However, extensive cultivation is destructive to vegetation coverage (Sanders, 1986) and is the main driving force of sandy desertification (McClure, 1998; Tang *et al.*, 2008). Third, agricultural drought occurs as much as 9 years out of 10 during the spring maize growth period in the agro-pastoral ecotone because of rainfall fluctuations that characterized temperate continental monsoon climate. Once drought occurs, the vegetation coverage of abandoned cultivated land declined during summer. Thus, abandoned cultivated land is susceptible to soil erosion and sandy desertification during winter and spring, particularly in windy days. Therefore, the over-cultivation significantly affects the agro-pastoral ecotone.

The agro-pastoral ecotone has been recognized as the main distribution area of reserved land resource for cultivation, in which a large proportion of cultivated land can be provided (Liu *et al.*, 2003; Zhang *et al.*, 2010; Yi *et al.*, 2013). HLBB is rich in uncultivated land, with a total area of 76 449.01 ha. However, uncultivated land that could be cultivated was less, with a total area of 8792.34 ha, and accounted for only 11.50% of the uncultivated land. That is, uncultivated land in the agro-pastoral ecotone is unsuitable for widespread cultivation according to landscape ecological security patterns. This unsuitability corresponds to the fragile eco-environment of the agro- pastoral ecotone. In reality, over-cultivation has induced serious sandy desertification in the ecotone. Moreover, over-cultivation also brought serious eco-environmental problems in arid and semi-arid regions worldwide, including soil degradation (Sanders, 1986; Zhao *et al.*, 2005), vegetation deterioration (Hanafi and Jauffret, 2008), and sandy desertification (Lamchin *et al.*, 2016; Varghese and Singh, 2016). Some researchers have suggested that plants for biofuel production could be planted in the marginal land of drylands (Xue *et al.*, 2016). Thus, the assertion that reserved land resource for cultivation is rich in the agro-pastoral ecotone should be abandoned.

On the basis of the changes in the landscape indexes, the adjusted land use pattern became better in protecting against anti-desertification. However, such land use adjustment was considered only from the aspect of the eco-environment. If such adjustment will be implemented, then economic factors must also be considered. The average costs of spring maize plantation according to our field surveys are presented in Table 4, along with the yield of spring maize under dry climate condition. Thus, the profit for spring maize plantation was 7672.5 yuan (RMB)/ha. In the second round of 'Grain for Green', the compensation standards for cultivated land abandoned into forest land are 12 000 yuan/ha during the first year, 4500 yuan/ha during the third year, and 6000 yuan/ha during the fifth year. The compensation standards for cultivated land abandoned into grassland are 7500 yuan/ha and 4500 yuan/ha during the first and third years, respectively. The compensations are paid by the Central People's Government of China. In particular, average compensation standards are 4500 yuan/(ha·yr) for forest land for five years and 4000 yuan/(ha·yr) for grass land for three years. These compensation standards are significantly lower than the profit of spring maize plantations. In 2015, HLBB had a population of 408 900, with Mongolian accounting for 74.74%. First, our field surveys shows that Mongolian people have a low educational level and a low level of technology. Second, the non-agricultural industry is poor in the agro-pastoral ecotone. Thus, people have no opportunity to earn money from local non-agricultural industries and in other places. People have to make their living from agriculture (Ge *et al.*, 2015). Therefore, if cultivated land is abandoned for ecological restoration in the agro-pastoral ecotone, then the profit loss from maize plantation should be compensated by the local government. Simultaneously, wildlife habitat benefits, water quality benefits, air quality benefits, pesticide deposition, and government costs, have been studied in the 'Conservation Reserve Program' (Ribaudo *et al.*, 2001; Secchi *et al.*, 2009; Belden *et al.*, 2012), which was

Table 4 Costs and profit of spring maize plantation

Cost (yuan (RMB)/ha)				Profit	
Corn seed	Chemical fertilizer	Pesticide	Mechanical harvest	Yield (kg/ha)	Price (yuan (RMB)/kg)
450	1515	150	900	5625	1.9

conducted in 1985 in the United States (Claassen *et al.*, 2008). Thus, both the compensation standard and the comprehensive results of 'Grain for Green' should be evaluated for further development.

The agro-pastoral ecotone is a fragile eco-environmental region. This study evaluated the area of reserved land resource for cultivation from the perspective of landscape ecological security patterns. In the future, the natural characteristics of uncultivated land and ecological security should be simultaneously considered in the evaluation of reserved land resource for cultivation.

5 Conclusions

Landscape ecological security patterns in HLBB were determined using MCRM, and land use adjustment was conducted. From the MCRM results, over-cultivation, reserved land resource for cultivation, and changes in landscape indexes before and after land use adjustment were analyzed. The main conclusions of this study are as follows.

(1) Over-cultivation is serious and seriously affects the agro-pastoral ecotone. It is mainly attributed to extensive cultivation in the region, which in turn, contributes to sandy desertification.

(2) Reserved land resource for cultivation is less than that considered previously. The assertion that reserved land resource for cultivation is rich in the agro-pastoral ecotone should be abandoned.

(3) Land use pattern is effective in protecting against anti-desertification after land use adjustment. On the basis of the changes in landscape indexes, cultivated land becomes scattered in distribution, whereas grass land and forest land increase in area and become aggregated in distribution. Both changes are beneficial for anti-desertification.

(4) To further implement ecological restoration in the agro-pastoral ecotone, the compensation standard for abandoned cultivated land should be improved and the comprehensive results of 'Grain for Green' should be evaluated.

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