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Effects of ecological restoration on carbon storage in the northern foot of Yinshan Mountain, Inner Mongolia

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Abstract

Explore the changes of ecosystem carbon storage under the background of ecological restoration, and provide an effective basis for achieving carbon neutrality. Taking the northern foothills of Yinshan Mountain in Inner Mongolia as the research area, the impact of the implementation of the Grain for Green Project on ecosystem carbon storage was quantitatively evaluated. This study combines the ArcGIS land use transfer matrix and the Carbon module in the InVEST model to study the impact of returning farmland to forest and grassland on the spatial and temporal changes of carbon storage in the northern foothills of Yinshan Mountain in Inner Mongolia from 2000 to 2020. (1) From 2000 to 2020, the area of returning farmland to forest and grassland in the study area was 638.83 km² and 219.26 km² respectively, accounting for 79.49% of the total amount of cultivated land transferred out. (2) From 2000 to 2020, the carbon storage in the northern foot of Yinshan Mountain in Inner Mongolia showed an overall increasing trend. As the project of returning farmland to forest and grassland entered the management and protection stage, the grassland area reached the highest value in 2015, so that the carbon storage reached a peak of 704.42 × 106 t in this year. (3) The key areas of the implementation of the Grain for Green Project in the study area are consistent with the spatial and temporal variation of carbon storage, which significantly improves the carbon sequestration effect in the study area. The carbon storage increased from 702.12 × 106 t in 2000 to 704.11 × 106 t in 2020, and the Grain for Green Project increased the carbon storage in the study area by 7.8 × 106 t. The above research results provide scientific basis for future research on carbon storage, provide strong data support for regional ecological restoration and realization of dual carbon targets, and provide important scientific reference for sustainable development.

Keywords

Grain for gree; land use change; carbon storage; Invest model.

1. Introduction

With the acceleration of industrialization and urbanization, human activities such as the burning of a large number of fossil fuels have led to a sharp increase in the concentration of greenhouse gases such as carbon dioxide in the atmosphere, triggering a series of environmental problems such as global warming [1,2]. The change of carbon storage is very important for regulating the global climate. As an important reservoir of carbon, the dynamic change of carbon storage in ecosystems has attracted wide attention [3]. Changes in land use patterns are one of the important factors affecting the carbon storage of terrestrial ecosystems [4]. Ecological restoration is to restore land that is not suitable for farming, such as sloping farmland and desertified farmland, to natural ecosystems such as forest land, grassland or wetland. This change in land use type will cause a series of changes in ecological factors such as vegetation and soil, which in turn will have an impact on carbon storage. In order to improve the ecological environment, prevent soil erosion and land desertification, many countries such as China have implemented large-scale ecological restoration projects [5,6]. China has implemented the project of returning farmland to forest and grassland since 1999, which is one of the largest ecological restoration projects in China and even in the world. The implementation of these projects provides a large number of practical cases and data basis for studying the impact of ecological restoration on carbon storage changes [7,8]. Accurate assessment of the impact of ecological restoration on carbon storage is of great scientific significance and practical value for understanding the carbon cycle process of terrestrial ecosystems, predicting climate change trends, and formulating reasonable ecological protection and climate change policies [9,10].

The northern foot of Yinshan Mountain in Inner Mongolia is located in the agro-pastoral ecotone in northern China [11]. It belongs to the arid and semi-arid zone and is a sensitive zone with extremely fragile ecosystem. Since the implementation of the project of returning farmland to forest and grassland in the study area, the spatial pattern of land use has changed significantly and has had a profound impact on carbon storage [12]. The northern foot of Yinshan Mountain in Inner Mongolia is the main dust source of Beijing and Tianjin, and it is also an important part of the sand control belt in northern China. This study is helpful to understand the process of ecosystem carbon cycle in the northern foothills of Yinshan Mountain, clarify the change law and mechanism of carbon storage in different ecosystems (such as grassland and forest land) after ecological restoration [13], fill the gap of regional carbon cycle research, and provide more accurate parameters for global carbon cycle model[14]. By studying the change of carbon storage, we can quantitatively evaluate the actual effect of the ecological restoration project on increasing carbon sinks and reducing carbon emissions, and provide a scientific basis for the adjustment and improvement of the ecological restoration policy in the region [15], so as to better achieve the goal of ecological protection and restoration. Accurately grasping the impact of ecological restoration on carbon storage in the region can provide an important reference for national and local governments to formulate strategies to address climate change, help to rationally plan land use, improve regional carbon sequestration capacity, and contribute to the achievement of carbon peaks and carbon neutrality goals [16]. At present, there are few studies on the change of carbon storage in the northern foot of Yinshan Mountain in Inner Mongolia. Carnegie-Ames-Stanford Approach (CASA) model [17] and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model [18] are mostly used in related fields at home and abroad. Among them, InVEST model is widely used by scholars in the estimation of carbon storage, which can realize the spatial distribution of carbon storage and reflect the relationship between land use change and carbon storage. Therefore, this study combined ArcGIS software and InVEST model to estimate the temporal and spatial variation characteristics of carbon storage in the northern foot of Yinshan Mountain in Inner Mongolia from 2000 to 2020, in order to reveal the impact of land use change caused by the Grain for Green Project on regional ecosystem carbon storage. It provides a reference for future research on ecosystem service functions in ecologically fragile areas [19]. It also provides theoretical support for the long-term stability and sustainable development of the ecological environment in the northern foothills of Yinshan Mountain.

It is of special and important significance to study the impact of ecological restoration on the change of carbon storage in the northern foothills of Yinshan Mountain in Inner Mongolia from 2000 to 2020.This period covers the key period of China 's ecological restoration policy from start to continuous promotion and achieved initial results. By studying this period, we can comprehensively evaluate the long-term impact of the ecological restoration policy on carbon storage changes in the northern foothills of Yinshan Mountain in Inner Mongolia, and

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understand the effect and evolution trend of policy implementation. The period from 2000 to 2020 is an important stage for the ecological environment in the northern foothills of Yinshan Mountain in Inner Mongolia to change from relatively fragile to gradual restoration and improvement. During this period, the ecological restoration project was implemented on a large scale. Studying this period helps to reveal the dynamic changes of carbon storage in the ecosystem from damage to recovery under human intervention. Studying the impact of ecological restoration on carbon storage in the northern foothills of Yinshan Mountain in Inner Mongolia during this period can better understand the role and response mechanism of regional ecosystems in addressing climate change. The research in this period can accumulate rich scientific data, provide a basis and comparative basis for subsequent research on a longer time scale, and help to further explore the long-term relationship and internal mechanism between ecological restoration and carbon storage changes.

2. Overview of the study area

The northern foot of Yinshan Mountain in Inner Mongolia is located in the central part of Inner Mongolia Autonomous Region. It is adjacent to Ulan Buh Desert and Kubuqi Desert in the west, Hunshandake Sandy Land in the east, Yinshan Mountain in the south, and desert grassland in the north. Between 109°15′-116°56′E, 40°45′-43°23′N. The terrain gradually decreases from south to north, with an average altitude of 1600 m. The annual average temperature in the study area is 1.5 ~ 3.7 °C. Among them, the temperature is the highest in July, with an average temperature of 17.1 ~ 20.7 °C. The lowest temperature is in January, with an average temperature of – 14.2 ~ – 16.1 °C. The highest temperature between years can reach more than 30 °C, and the lowest temperature is below – 40 °C. The average annual precipitation is 200 ~ 400 mm, and gradually decreases from east to west and from south to north. From east to west, the study area is composed of 10 banners and counties from Duolun County of Xilinguole League to Darhan Maoming 'an United Banner (including Baiyun Obo mining area) of Baotou City, with a total area of about 73399.93 km^2. see Figure 1.

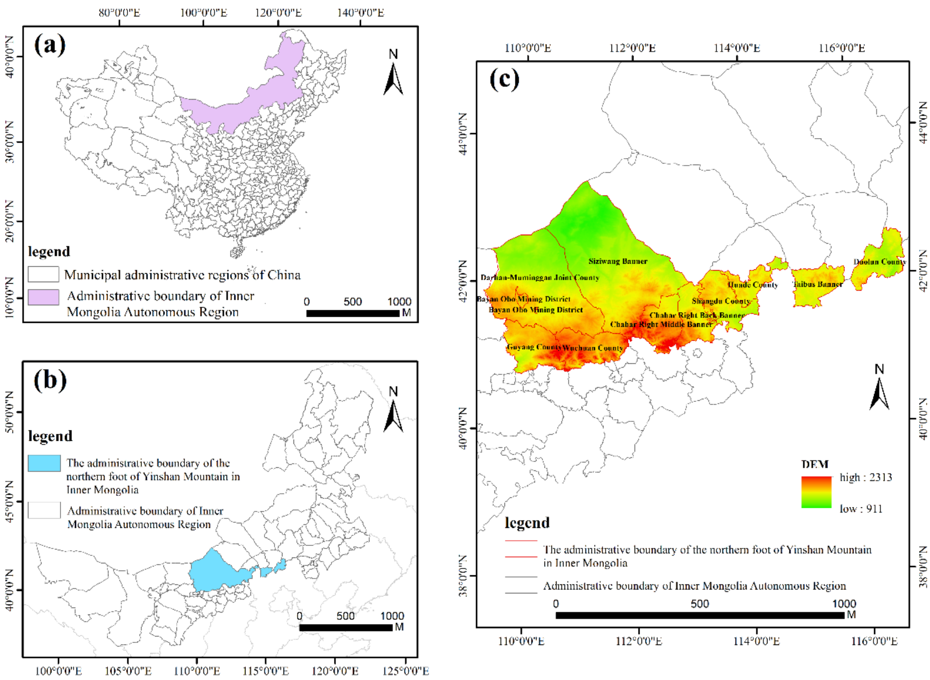

Figure 1. Overview of the study area: (a) map of China; (b) is the administrative boundary of Inner Mongolia Autonomous Region (c) It is the county-level administrative boundary of Yinshan Beilu Banner in Inner Mongolia.

3. Data Sources and Research Methods

3.1. Data source

The data of land use types in the northern foot of Yinshan Mountain in Inner Mongolia mainly include five land use / cover type data and carbon density parameters in 2000,2005,2010,2015 and 2020. Land use data were downloaded from the United States Geological Survey. The data in 2000,2005 and 2010 were mainly landsat TM data, and the data in 2015 and 2020 were landsat8 data with a resolution of 30 m. According to the standard of ' land use classification ' and the acquisition of carbon density parameters, land use is divided into six categories: cultivated land, forest land, grassland, water area, construction land and unused land. The DEM data were downloaded from the USGS (Https : / / www.usgs.gov) website. Carbon density data are obtained through remote sensing monitoring and literature review. Due to the differences in the calculation methods of carbon density and the results obtained by different scholars, in order to avoid large differences in data, this paper only selects the literature with similar climatic conditions and geographical locations in the study area as a reference [20-22]. The aboveground biomass, underground biomass, soil organic carbon and dead organic carbon density of various land use types were obtained.

3.2. Research methods

In this study, the land use transfer matrix was used to analyze the overall situation of land use transfer in the study area. The InVEST model was used to estimate the carbon storage and evolution characteristics of the study area. Combined with the above two methods, the spatial pattern change of land use and the evolution characteristics of carbon storage in the study area over the years were revealed.

3.2.1. Land use transfer matrix

The land use transfer matrix is a process to reveal the change of land use area and the direction of circulation in the study area [23], and can clearly show the dynamic information of the area change of each category in different years [24]. Based on this, this study estimates the impact of land use change on regional carbon storage.

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \tag{1}$$

In the formula: S is area; n is the number of land use types before and after the transfer; ij (ij = 1,2,3,..., n) represents the land use types before and after the transfer; Sij denotes the area of the i-type land converted into the j-type land after the transfer.

3.2.2. 2.2.2 InVEST carbon storage model

Carbon storage in ecosystems mainly includes four basic carbon pools: aboveground biomass, underground biomass, soil carbon, and dead organic carbon [25]. Among them, aboveground biomass mainly includes carbon in all surviving vegetation above the surface [26]; underground biomass refers to the carbon present in the living root system of plants [27]. Soil carbon refers to the carbon in mineral soil and organic soil [28]; dead organic carbon represents carbon in litter and dead trees [29]. Using land use carbon density data combined with land use data, based on the Carbon module in the InVEST model, the carbon storage change in the northern foot of Yinshan Mountain in Inner Mongolia was evaluated. see Table 1.

$$C_i = C_{above} + C_{below} + C_{soil} + C_{deal} \tag{2}$$

$$C_{total} = \sum_{i=1}^{n} C_i \times S_i \tag{3}$$

In the formula: i is the land use type; C_i is the carbon density of land use type; C_{above} is the aboveground biomass carbon density; C_{below} is the underground biological carbon density; C_{soil} is soil carbon density; C_{deal} is dead organic carbon density; C_{total} is the total carbon storage of the ecosystem; n is the number of land use types, In this paper, n = 6; S_i is the area of land use type i.

Table 1 Carbon density parameters of different land use types (unit : (t / hm^2))

Carbon density (t · hm^2)	Above ground material	Underground material	soil	dead matter
cultivated land	4.00	25.60	80.70	0.72
woodland	4.80	42.40	115.90	0.18
grass land	2.50	18.20	74.60	0.45
waters	3.00	0.00	0.00	0.00
construction land	2.50	0.08	78.00	0.00
unutilized land	1.30	8.60	31.40	0.00

4. Results and analysis

4.1. Land use change

In 2020, the northern foothill area of Yinshan Mountain is mainly dominated by cultivated land, grassland and unused land, with an area of 1.57 × 10^4 km^2, 4.76 × 10^4 km^2 and 0.486 × 10^4 km^2, respectively, a total of 7.86 × 10^4 km^2, accounting for 92.8% of the total area. The second is forest land, construction land and water area, which are 2296.636 km^2,1969.404 km^2 and 943.928 km^2 respectively. According to the data of land use types during 2000-2020, among the six land use types, the grassland area is 4.75 × 10^4 km^2, accounting for 64.71% of the regional area, and the water area is 888.4 km^2, accounting for 1.2% of the regional area. From the perspective of change trend, during 2000 - 2020, the land use types in the northern foot of Yinshan Mountain have changed significantly due to the impact of ecological restoration projects. The main increase is grassland and construction land, and the decrease is mainly cultivated land and unused land. The increased areas of grassland and construction land are 515.19 km^2 and 342.1 km^2, respectively. In the past 20 years, the total area of cultivated land has decreased by 769.96 km^2, the total area of unused land has decreased by 481.58 km^2, and the forest land and water area have increased by 376.85 km^2. From the perspective of the transfer area of various land use types, from 2000 to 2020, the largest change in the northern foot of Yinshan Mountain in Inner Mongolia is the transfer between cultivated land and grassland. Among them, 880.49 km^2 of cultivated land and grassland are transferred to each other, followed by about 548.36 km^2 of unused land converted to grassland, another 219.26 km^2 of cultivated land and 130.44 km^2 of grassland converted to forest land, 182.25 km^2 of cultivated land and 190.88 km^2 of grassland converted to construction land. The area of cultivated land converted to grassland is as high as 638.83 km^2, the area of grassland converted to cultivated land is 241.66 km^2, and the area of water transfer is very small. Since the implementation of the project of returning farmland to forest and grassland, the northern foothills of Yinshan Mountain in Inner Mongolia has achieved certain results. The maximum effect period occurred in the early stage of the project from 2000 to 2005, mainly in the part of returning grass. Although the conversion area of returning forest is more than that of other types, it is not significant compared with the conversion area of cultivated land to grass. see Table 1. Figure 2. Table 3.

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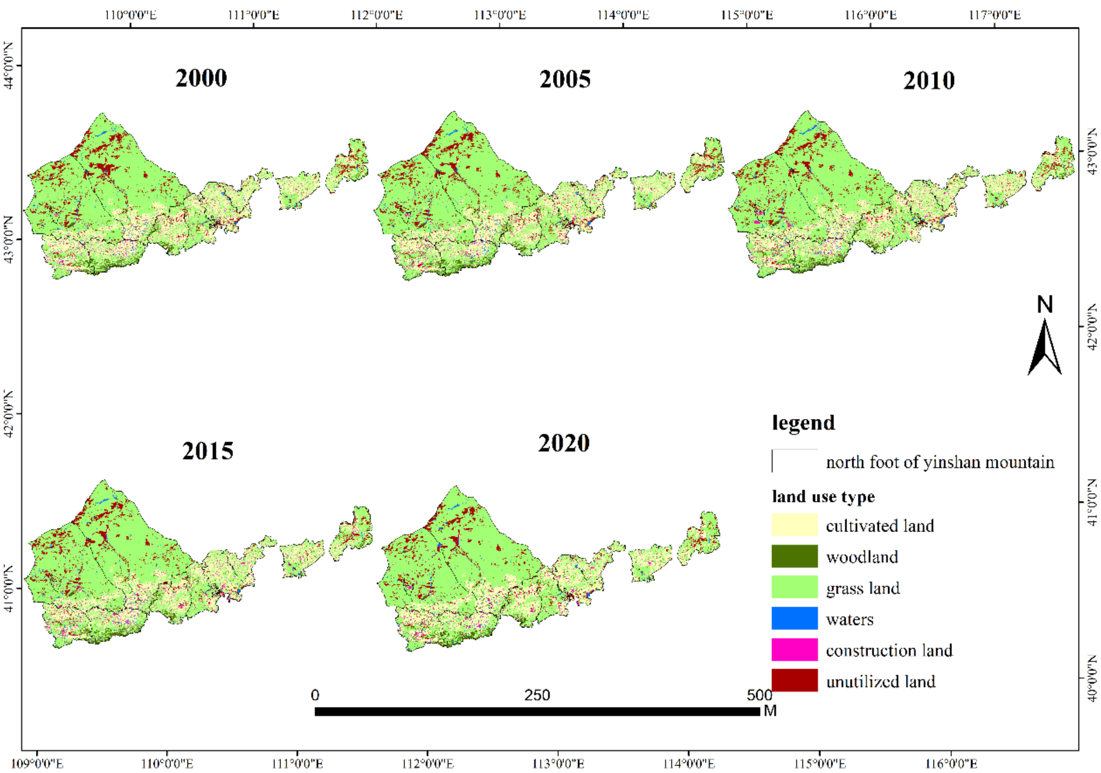

Fig.2 Land use type map of the study area from 2000 to 2020

Table 2 Land use area and proportion in the study area from 2000 to 2020

land use type	2000		2005		2010		2015		2020	
	area /km^2	proportion /%	area /km^2	proportion /%	area /km^2	proportion /%	area /km^2	proportion /%	area /km^2	proportion /%
cultivated land	16513.7	22.5	15995.1	21.8	15986.8	21.8	15722.5	21.4	15743.8	21.5
woodland	1994.3	2.7	2239.79	3.1	2197.8	3.0	2264.45	3	2296.6	3.1
grass land	47045.2	64.1	47501.4	64.7	47532.6	64.8	47669.3	65	47560.4	64.8
waters	869.5	1.2	864.53	1.2	881.5	1.2	882.57	1.2	943.9	1.3
construction land	1627.3	2.2	1665.92	2.3	1817.4	2.5	1943.09	2.7	1969.4	2.7
unutilized land	5345.5	7.3	5128.82	6.9	4950.0	6.7	4892.61	6.7	4863.9	6.6

Table 3 Land use transfer matrix of the study area from 2000 to 2020 (unit: km^2)

land use type	grass land	cultivated land	construction land	woodland	waters	unutilized land	grand total
grass land	46291.94	241.66	190.88	130.44	55.59	123.72	47034.23
cultivated land	638.83	15427.57	182.25	219.26	18.36	20.76	16507.03
construction land	19.70	28.9	1571.37	3.38	2.06	1.81	1627.22
woodland	34.40	15.22	5.98	1932.31	1.92	2.87	1992.7

waters	24.85	6.18	2.36	3.79	813.75	18.2	869.13
unutilized land	548.36	23.69	16.51	7	52.21	4696.1	5343.86
grand total	47558.09	15743.21	1969.35	2296.18	943.88	4863.46	73374.17

4.2. Carbon storage changes

This study is based on the land use type data and carbon density parameter table from 2000 to 2020 in the northern foot of Yinshan Mountain in Inner Mongolia (Table 1). Through the Carbon Storage and Sequestration module in the InVEST model, the temporal and spatial changes of carbon storage are obtained (Figure 3, Figure 4). The total carbon storage of the northern foot of Yinshan Mountain in Inner Mongolia in 2000,2005,2010,2015 and 2020 was 702.13 × 10^6 t, 704.11 × 10^6 t, 704.39 × 10^6 t, 704.42 × 10^6 t and 704.1 × 10^6 t, respectively. In the past 20 years, the carbon storage in the northern foot of Yinshan Mountain in Inner Mongolia has shown an overall increasing trend, with a total increase of 1.97 × 10^6 t, an average annual increase of 0.1 × 10^6 t, and an average annual growth rate of 18 %. Among them, the total carbon storage in the study area increased from 702.13 × 10^6 t to 704.42 × 10^6 t from 2000 to 2015, a total increase of 2.29 × 10^6 t in 15 years, but a total decrease of 0.32 × 10^6 t during 2015-2020, reaching a peak of 704.42 × 10^6 t in 2015. During the study period, the carbon storage of cultivated land and grassland in the northern foot of Yinshan Mountain in Inner Mongolia showed a reverse increase or decrease trend. From 2000 to 2015, the carbon storage of cultivated land decreased sharply, while the carbon storage of grassland increased gradually. From 2015 to 2020, the carbon storage of cultivated land gradually increased, and the carbon storage of grassland slowly decreased. However, in general, the carbon storage of cultivated land showed a sharp decline, with a decrease of 7.8 × 10^6 t. The carbon storage of grassland showed an overall increase, with an increase of 4.64 × 10^6 t, and the carbon storage of forest land also increased significantly, with an increase of 4.4 × 10^6 t, which was mainly attributed to the implementation of the project of returning farmland to forest and grassland. The carbon storage of construction land increased significantly, with an increase of 2.7 × 10^6 t. The change of carbon storage in water area was not obvious, but it increased significantly in 2010, with an increase of 0.37 × 10^6 t, and then tended to be stable. see Fig.3.

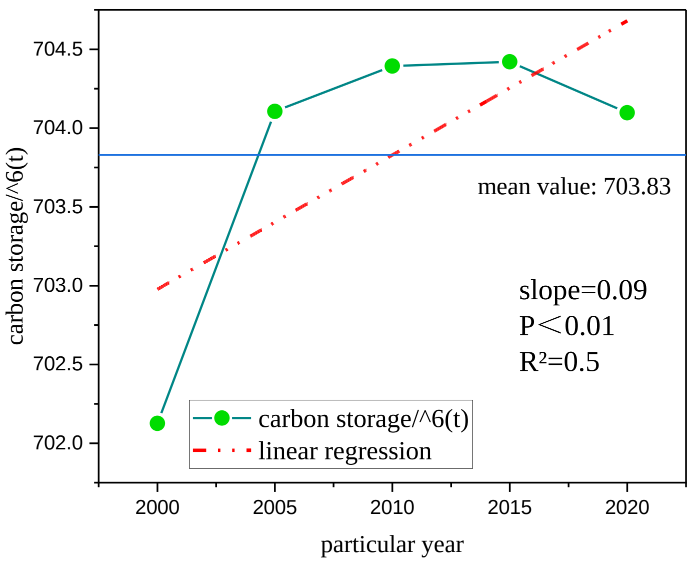

Fig.3 Spatial variation of carbon storage in the study area from 2000 to 2020

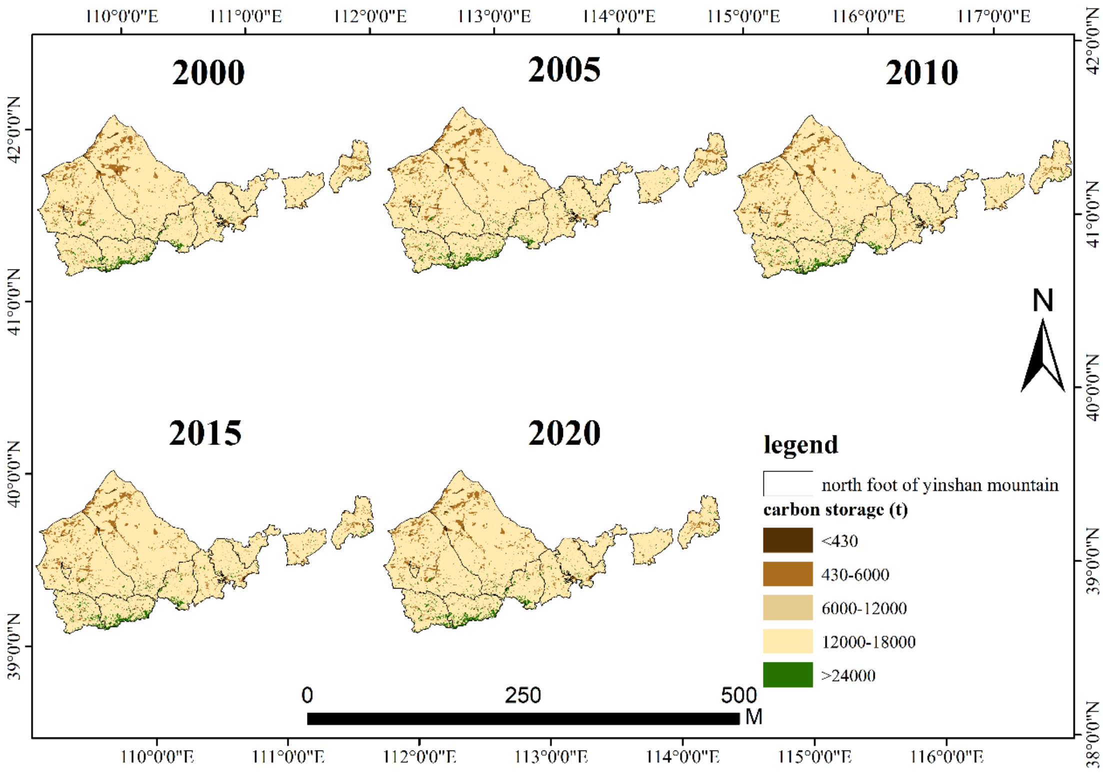

Fig.4 Changes in total carbon storage from 2000 to 2020

Table 4 Changes in carbon storage of various land use types

land use type	carbon storage×10^6 t				
	2000	2005	2010	2015	2020
cultivated land	183.1	177.44	177.07	174.61	175.3
woodland	32.75	36.73	35.97	37.06	37.15
grass land	451.12	455.42	455.22	457.17	455.76
waters	0.25	0.25	0.62	0.26	0.28
construction land	12.91	13.18	14.76	15.26	15.61
unutilized land	21.99	21.09	20.75	20.07	20.01

Figure 4 reflects the spatial change of carbon storage caused by the change of land use type in the study area during the implementation of the ecological restoration project from 2000 to 2020. The spatial distribution of carbon storage in the region is relatively stable and the area of carbon storage change is consistent with the ecological restoration area. The high value area of carbon storage in the study area is distributed in the south of Wuchuan County and the east of Guyang County, and the high value area of carbon storage is covered by forest land. The low value areas are scattered in Duolun County, Siziwang Banner and Darhan-Muminggan Joint County, which are mainly unused land. Since the implementation of the project of returning farmland to forest in the study area, returning farmland to forest and grass has enhanced the carbon sequestration capacity of the region and effectively enhanced the carbon sequestration capacity of the ecosystem in the region. see Figure4.

In general, the carbon sequestration function of the northern foot of Yinshan Mountain in Inner Mongolia increased first and then decreased slowly with the change of land use type during the study period, which was inseparable from the implementation of the project of returning farmland to forest and grass. The highest carbon storage in the study area is 2274.68 × 10^6 t of grassland, the lowest is 1.66 × 10^6 t of water area, the other are 887.52 × 10^6 t of cultivated land, 179.65 × 10^6 t of forest land, 103.91 × 10^6 t of unused land and 71.73 × 10^6 t of construction land. The carbon sequestration function in the study area was significantly correlated with land use change. Table 4.

4.3. Effect of returning farmland to forest (grass) on carbon storage change

The implementation of the project of returning farmland to forest and grassland has an important contribution to improving the carbon storage of the ecosystem. During the implementation of the project in the northern foot of Yinshan Mountain in Inner Mongolia, a large area of land use types in the region has been transferred, which has a great impact on the carbon storage of the ecosystem. It can be seen from Figure 5 that from 2000 to 2005, the conversion of farmland to forest was concentrated in Guyang County, and the conversion of farmland to grass was concentrated in the south of Siziwang Banner, Wuchuan County, Chahar Right Back Banner, Shangdu County, Huade County, and scattered in other areas. From 2005 to 2015, the intensity of returning farmland decreased, which was sporadically distributed in Shangdu County, Taibus Banner and Darhan-Muminggan Joint County. From 2015 to 2020, it was mainly based on returning farmland to grassland, which was stronger than the previous stage and distributed in each county of the study area. It can be seen from Table 5 that the contribution rate of carbon sink of returning farmland to forest and grassland in the northern foot of Yinshan Mountain in Inner Mongolia has increased significantly. During the study period, the total area of returning farmland to forest and grassland was 858.09 km^2.Among them, the area of returning farmland to forest and grassland was the highest, accounting for about 74.45% of the total area of returning farmland to forest and grassland. The carbon storage increased by 4.64×10^6 t, accounting for 51.33% of the total carbon storage of returning farmland to forest and grassland. The carbon storage of returning farmland to forest and grassland increased by 4.4×10^6 t, accounting for 48.67% of the total carbon storage of returning farmland to forest and grassland. see Figure 5. Table 5.

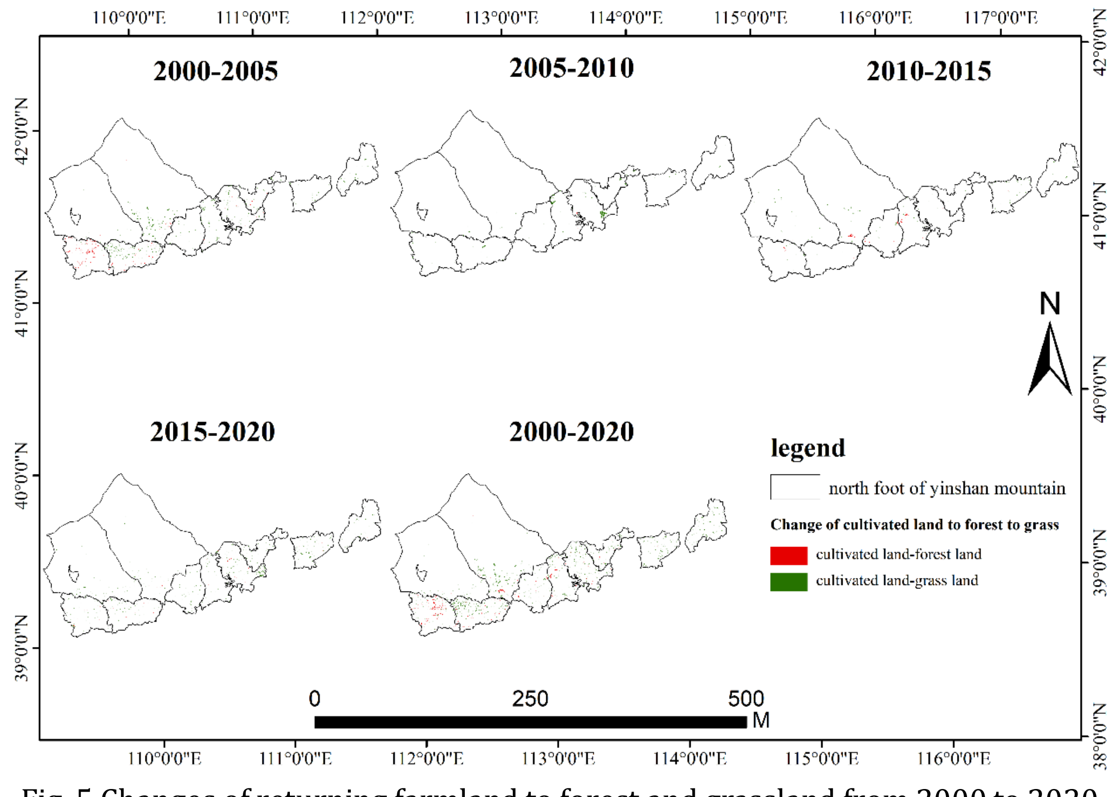

Fig. 5 Changes of returning farmland to forest and grassland from 2000 to 2020

Table 5 Changes in carbon storage of returning farmland to forest and grassland from 2000 to 2020

particular year	2000-2005	2005-2010	2010-2015	2015-2020	2000-2020
area of grain for green /km^2	158.23	7.4	59.01	25.36	219.26
Area of Returning Farmland to Grassland /km^2	430.57	176.65	116.26	277.66	638.83
Total area of de-farming /km^2	588.8	184.05	175.27	303.02	858.09
Contribution of carbon sink of returning farmland to forest /10^{6}t	3.98	-0.76	1.09	0.09	4.4
Contribution of carbon sink of returning farmland to grassland /10^{6}t	4.3	-0.2	1.95	-1.41	4.64
The total contribution of carbon sinks of returning farmland /10^{6}t	8.28	-0.96	3.04	-1.32	9.04

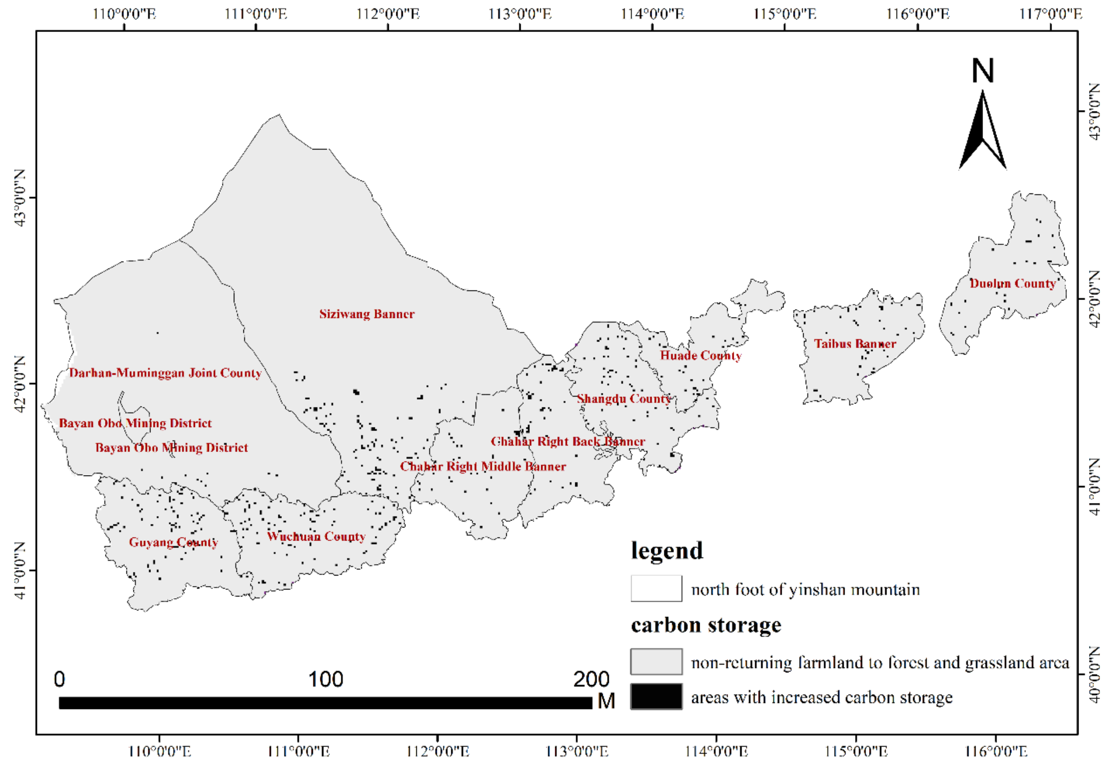

Fig.6 Changes of carbon storage in the area of conversion of farmland to forest and grassland from 2000 to 2020

From the analysis of the five research stages, 2000-2005 is the initial stage of the implementation of the project of returning farmland to forest and grass, which is also the most obvious stage of the effect, and also the stage of carbon storage growth in the study area. At this stage, the area of returning farmland to forest and grassland was 588.8 km^2, which promoted the increase of carbon storage in the study area by 8.28 × 10^6 t. Among them, grassland carbon storage contributed the most. The area of returning farmland to forest and grassland was about 430.57 km^2, and the contribution rate of carbon storage was 51.93 %. The area of returning farmland to forest was about 158.23 km^2, and the contribution rate of carbon storage was 48.07%. From 2005 to 2010, the intensity of returning farmland to forest and grassland gradually decreased. A total of 184.05 km^2 of returning farmland to forest and grassland was returned, mainly in the part of returning grass. The area of returning grass accounted for 95.98% of the total area of returning farmland. The contribution rate of returning grass to carbon sink was 79.17%, and the contribution rate of returning forest to carbon sink was 20.83%. From 2010 to 2020, the project of returning farmland to forest and grassland has entered the stage of management and protection, with a total of 478.29 km^2, which is still dominated by returning farmland to grassland, but the change rate of forest land is large and the carbon exchange rate is the highest. The area of returning grass accounted for 82.36% of the total area of returning farmland, the contribution rate of returning grass to carbon sink was 31.4%, and the contribution rate of returning forest to carbon sink was 68.6%. The carbon sink contribution rate of returning farmland to forest and grassland is also different in different periods.

Figure 6 reflects the change of carbon storage caused by ecological restoration from 2000 to 2020. It can be clearly seen that the increase of carbon storage is in the south of Siziwang Banner, the south of Darhan-Muminggan Joint County, Guyang County, Wuchuan County, Chahar Right Middle Banner, Chahar Right Back Banner, Shangdu County, Huade County, Taibus Banner and Duolun County. The area of carbon storage increased by returning farmland to forest and grass is 609.69 km^2, and the net carbon storage increased by 5.9 × 106 t. see Figure 6.

5. Discussion

5.1. Effects of ecological restoration on carbon storage

From 2000 to 2020, the area of returning farmland to forest and grassland in the northern foot of Yinshan Mountain in Inner Mongolia was 638.83 km^2 and 219.26 km^2, respectively, accounting for 79.49% of the total amount of cultivated land transferred out. This result shows that the state and local governments have implemented a series of policies for returning farmland to forests and grasslands, such as returning farmland to forests and grasslands [30], and encouraging farmers to return unsuitable land to forests and grasslands by providing subsidies, technical support, etc., to protect and improve the ecological environment. On the other hand, the northern foot of Yinshan Mountain in Inner Mongolia may face serious ecological problems, such as land desertification, soil erosion, soil fertility decline, etc., which reduces the production efficiency of cultivated land, and returning farmland to forest and grassland has become an inevitable choice to alleviate ecological pressure and restore the ecosystem. Third, with the adjustment of agricultural industrial structure, the economic benefits of traditional agricultural planting in some areas are not high, and the development of forestry, grass industry and related ecological industries may bring higher comprehensive economic benefits, prompting farmers to actively participate in returning farmland to forest and grass. Fourth, the progress of forestry, grass industry and other related technologies has improved the survival rate and ecological benefits of returning farmland to forest and grass, reduced the cost, made returning farmland to forest and grass more technically feasible, and promoted the large-scale development of this work.

From 2000 to 2020, the carbon storage in the northern foothills of Yinshan Mountain in Inner Mongolia showed an overall increasing trend, and the carbon storage reached a peak of 704.42 × 10^6 t in 2015. It may be due to the following reasons. On the one hand, after returning farmland to forest and grass, newly planted trees and grasses continue to grow, and biomass continues to increase. A large amount of carbon dioxide is absorbed and fixed by photosynthesis [31], so that carbon storage continues to rise. In 2015, grassland growth reached a relatively stable and high level, making carbon storage peak. On the other hand, the increase of vegetation coverage reduces soil erosion, increases soil organic matter content, improves soil structure, facilitates soil microbial activity, and promotes soil carbon fixation and storage. Secondly, after entering the management and protection stage, the scientific

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management of the returning farmland area [32], such as reasonable irrigation, pest control, and prohibition of overgrazing, ensures the healthy growth of vegetation and is conducive to its full carbon sequestration [33].

The key areas of the implementation of the Grain for Green Project in the study area are consistent with the temporal and spatial variation areas of carbon storage, which significantly improves the carbon sequestration effect in the study area. The Grain for Green Project has increased the carbon storage in the study area by 7.8×10^6 t. This result may be due to the following three aspects. On the one hand, the implementation of the project of returning farmland to forest and grass may fully consider the local natural conditions and vegetation growth characteristics, and focus on the implementation of the area suitable for the growth of trees and grasses and the potential of carbon sequestration, so that the vegetation can grow well and exert the maximum carbon sequestration benefit [34]. On the other hand, in the key areas of the project implementation, the ecosystem has been reconstructed by returning farmland to forest and grassland. The new ecosystem structure is more reasonable [35], the biodiversity is increased [36], the synergy between the organisms is enhanced, and the carbon sequestration capacity of the whole ecosystem is improved. Secondly, in the process of project implementation, scientific and reasonable human intervention measures may be taken, such as reasonable selection of tree species and grass species, optimization of planting density and configuration methods, so that vegetation can better adapt to the environment and improve the efficiency of carbon sequestration.

5.2. Shortcomings and Prospects

The time span of the data in this study may not be long enough to fully and accurately analyze the long-term trends and laws of carbon storage after ecological restoration. At the same time, the spatial resolution of the data may be insufficient, and it is difficult to accurately reflect the differences in carbon storage under different terrain and soil conditions in the northern foot of Yinshan Mountain. Moreover, for some key basic data, such as soil background carbon content, there may be measurement errors or uncertainties. The InVEST carbon storage estimation model used in the research method may have certain limitations and cannot fully and accurately simulate the complex ecosystem and carbon cycle process in the region. The lack of mutual verification of multiple methods may lead to limited reliability of the research results. The analysis of the influencing factors of the change of carbon storage after ecological restoration may not be comprehensive enough, and the biological factors such as microbial activity, soil animals and the accidental factors such as fire, plant diseases and insect pests are not fully considered.

It is hoped that a long-term, continuous and high-resolution carbon storage monitoring system will be constructed in future research, and more comprehensive and accurate data will be obtained by combining satellite remote sensing, drones, ground monitoring stations and other means. Strengthen the synchronous monitoring of soil, vegetation and other elements, establish a database of multi-source data fusion, and provide data support for in-depth research. In terms of research methods, more advanced carbon storage estimation models that are more suitable for the characteristics of the ecosystem in the northern foot of the Yinshan Mountains are developed and applied, combined with process models and machine learning methods to improve simulation accuracy. Interdisciplinary research was carried out to comprehensively analyze the mechanism and influencing factors of carbon storage changes by using multidisciplinary methods such as ecology, soil science and meteorology.

6. Conclusion

Based on the implementation of the project of returning farmland to forest and grassland, this paper uses the Carbon module in the InVEST model and ArcGIS remote sensing technology to estimate the impact of land use change on carbon storage in the northern foot of Yinshan Mountain in Inner Mongolia from 2000 to 2020.

(1) From 2000 to 2020, the project of returning farmland to forest and grassland in the northern foot of Yinshan Mountain in Inner Mongolia has achieved remarkable results, and 858.09 km^2 of cultivated land has been converted into forest and grassland in 20 years. It accounts for 79.49% of other areas. The land use types in the study area are mainly cultivated land, grassland and unused land, and the sum of the three areas accounts for more than 93.32% of the total area. In addition, the area of cultivated land, grassland and unused land has changed greatly in the past 20 years. Among them, cultivated land and unused land have decreased by 769.9 km^2 and 481.6 km^2 respectively, and grassland has increased by 515.2 km^2. The most obvious change of land use type is cultivated land and grassland, about 880.49 km^2 between the two conversion.

(2) From 2000 to 2020, the carbon storage in the northern foothills of Yinshan Mountain in Inner Mongolia showed an overall increasing trend. With the project of returning farmland to forest and grassland entering the management and protection stage, the grassland area reached its peak in 2015. In the whole research stage, the carbon storage contribution rate of returning farmland to grassland was the highest, reaching 4.64%. This caused the carbon storage to peak at 704.42×10^6 t in this year.

(3) According to the combination of InVEST model and ArcGIS, the total carbon storage in 2000,2005,2010,2015 and 2020 is 702.13 × 106 t, 704.11 × 106 t, 704.39 × 106 t, 704.42 × 106 t and 704.1 × 106 t, respectively. It showed a significant upward trend and then a slow downward trend. The main reason for the enhancement of carbon sequestration function is the substantial expansion of grassland under the background of the implementation of the project of returning farmland to forest and grassland. The key areas of the implementation of the project in the study area are consistent with the spatial and temporal changes of carbon storage. The conversion of cultivated land to forest and grassland has significantly increased the carbon sequestration capacity of the study area. According to the model estimation, returning farmland to forest and grassland increased the research carbon storage by 7.8 × 106 t.

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