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Monitoring of vegetation changes based on RS monitoring in Changbai Mountain Nature Reserve

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Abstract. High vegetation cover helps maintain the ecosystem's stability and reduces the risk of soil erosion and natural disasters. Vegetation restoration is essential for the ecological value of Changbai Mountain Nature Reserve. In this study, the interannual changes in vegetation cover in Changbai Mountain Nature Reserve, China, from 2013 to 2022 were studied in depth based on Landsat remote sensing data and land use transfer matrix. The study includes interannual dynamic changes in vegetation types, quantitative analysis of interannual changes in surface vegetation types, and the land use transfer matrix analysis. In addition, the drivers of dynamic changes in vegetation types were analysed. The research indicates a notable advancement in ecological restoration within Changbai Mountain Nature Reserve between 2013 and 2022. There was a substantial reduction in the extent of barren land, which predominantly transitioned into grass and woodland areas. In particular, the year 2022 exhibited a significant increase in grassland area when compared to 2013, with a remarkable expansion of 27.18 square kilometers, primarily concentrated in the central-eastern sector of the study area. The findings of this investigation serve as a valuable scientific foundation for guiding ecological preservation and management decisions within Changbai Mountain Nature Reserve, contributing to a deeper comprehension of the evolving patterns in vegetation cover.

Keywords: Changbai Mountain Nature Reserve, remote sensing monitoring, vegetation cover, ecological protection.

1. Introduction

Globally, vegetation cover in nature reserves profoundly impacts ecological balance, species diversity, ecosystem services and industrial development. High vegetation cover helps maintain ecosystems' stability and reduces the risk of soil erosion and natural disasters. Vegetation is closely related to the surrounding environment and is very sensitive to changes in the ecological environment[1]. Furthermore, people often speculate on the changes in the regional ecological environment based on the growth status of vegetation, so monitoring the changes in vegetation from the temporal and spatial scales is of great significance for revealing the changes in the ecological environment and evaluating the ecological quality of the region [2, 3]. As a primary producer in the ecosystem, the vegetation cover directly reflects the structure and function of the ecosystem [4, 5]. In recent years, with the continuous development of remote sensing technology, the combination of remote sensing and vegetation sample survey has become the primary method to study the dynamic changes of regional vegetation.

Changbai Mountain Nature Reserve is located in northeastern China, with a unique geographic location that includes a variety of alpine ecosystems. Due to the economic development and population growth in the region, anthropogenic factors have significantly impacted the disturbance and restoration of the vegetation in the Changbai Mountain region, and the vegetation in the region has changed significantly over twenty years [6].

The Chinese government attaches great importance to the Changbai Mountain Nature Reserve and regards it as a valuable natural heritage. Since the establishment of the Changbai Mountain Nature Reserve, natural resources have been protected by national laws and regulations. The initial changes in vegetation types were relatively small until the impact of Typhoon No.15 in 1986 caused severe damage to the original forest. Since then, the changes in vegetation types in the following two decades have been dominated by vegetation restoration in the area [7].

Steadily advancing in the protection and management of protected areas and continuing to polish the bottom of high-quality development as the goal [8], China has taken a series of measures to reduce the adverse impacts on the environment. Meanwhile, in order to obtain essential information on ecosystem changes, scientific research and ecological monitoring are applied to nature reserves, which is conducive to designating more effective conservation strategies.

Remote sensing technology plays a vital role in the research. Different ranges of remote sensing bands (visible, near-infrared, thermal infrared, microwave) have been used for soil remote sensing studies. Any band range has its advantages and limitations [9]. RS is capable of providing high spatial and temporal resolution data for tracking seasonal and inter-annual changes in vegetation and assessing the health of vegetation. It has the advantages of multi-source data fusion, wide-coverage, real-time data acquisition and quantitative analysis. In addition, time-series monitoring can be used to analyse long-term trends in surface features, which is essential for studying issues such as local microclimate change.

However, high-resolution remote sensing data still need to be fully utilised by academia. Surveys of forest resources are still relatively cursory, and the classification of different types of forests needs to be sufficiently accurate and detailed. In addition, although studies on inter-annual and intra-annual forest changes have been conducted in the Changbai Mountain region, these studies are usually isolated and need more comprehensive linkages, failing to elucidate the relevant issues fully.

Therefore, the research objective of this paper is to conduct an in-depth study on the interannual vegetation changes in the Changbai Mountain Nature Reserve between 2013 and 2022 by combining Landsat remote sensing data and topographic maps. The specific studies in this paper include the interannual dynamic changes of vegetation types, the interannual changes of surface vegetation types (quantitative analysis) and the analysis of the land use transfer matrix. At the same time, this paper also analyses from the cause and ecological perspectives. It explores the drivers of dynamic changes in vegetation types in the context of the dynamic change characteristics of different vegetation types, their transformation relationships, and their associations with other land use types. This study will contribute to a more in-depth understanding of the trend of vegetation cover changes and provide scientific evidence to support conservation and management decisions in the Changbai Mountain Nature Reserve.

2. Data and methods

2.1. Overview of the study area

Jilin Changbai Mountain National Nature Reserve, situated in the southeastern part of Jilin Province, within the People's Republic of China, shares its southeastern border with the Democratic People's Republic of Korea. This reserve stands as one of China's most significant natural sanctuaries. The reserve's geographical coordinates span from an east longitude of 127°42′55″ to 128°16′48″ and a north latitude of 41°41′49″ to 42°25′18″. The study area stretches up to 80 kilometers from north to south and reaches a maximum width of 42 kilometers from east to west, encompassing a total area of 196,465 hectares. The primary areas of focus for protection within the reserve include temperate forest ecosystems, natural historical sites, and the preservation of rare plant and animal species.

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Figure 1 shows the geographical location of Changbai Mountain Nature Reserve. Changbai Mountain Nature Reserve has attracted much attention for its rich and diverse ecosystems and unique geomorphology and is also one of China's biodiversity hotspots. This area has a cold-temperate monsoon climate with long, cold winters and short, warm summers. Precipitation is unevenly distributed, with more precipitation in the mountainside and summit areas, while the valley areas are relatively dry.

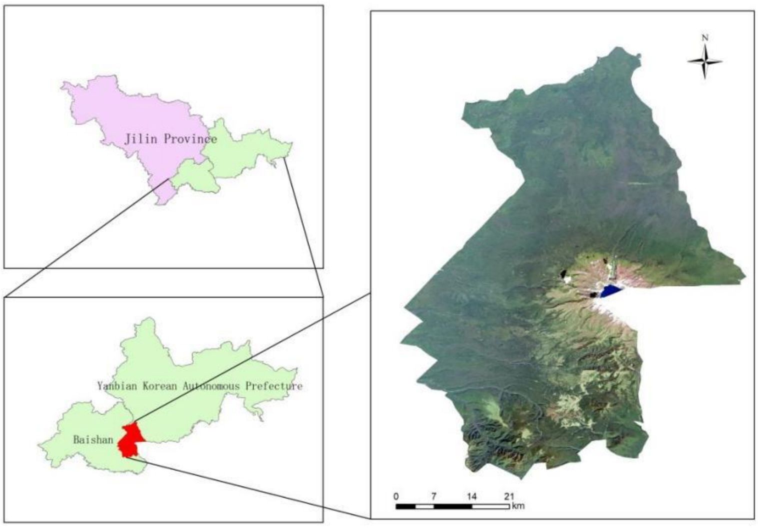

Figure 1. Geographic location of Changbai Mountain Nature Reserve.

Changbai Mountain is the highest mountain range in Northeast China and has the highest peak in Northeast China, the White Peak (2,691 metres). The area includes a variety of landforms and a rich diversity of vegetation types, and the study of its vegetation cover is an important aspect of the geography of the region. The lower elevation zones of the study area consist mainly of coniferous forests, including pine, fir, and spruce species. These forests are unique objects of study for geographers because of their importance for soil protection and water conservation. Vast alpine meadows can be found in the alpine areas, especially around White Top.

2.2. Data

The data source used in this study is mainly Landsat8 (http://eds.ceode.ac.cn/nuds/freedataquery) in the remote sensing data service system of the Chinese Academy of Space and Astronautics. The image coverage is generally 170*180km^2 for a 1-scene image, with a spatial resolution of 30m*30m. In this paper, 2-scene images of the study area in 2013 and 2022 were selected, as well as the geographic boundaries of Changbai Mountain Nature Reserve from the China Nature Reserve Specimen Resource Sharing Platform.

The satellite remote sensing data used in the latter part of this study is the resolution normalised vegetation index (NVI) daily synthetic data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the satellite and post-processed. The data were processed through radiometric calibration, cloud detection, atmospheric revision, surface anisotropy correction angle revision, gridded projection and maximum value synthesis.

2.3. Methodology

Remote sensing images of the region for 2013 and 2022 were compared to compare landscape changes using Landsat. Firstly, in this paper, the remote sensing image data Landsat8 OLI is radiometrically calibrated and atmospherically corrected based on ENVI to improve its accuracy. Then, based on the band synthesis method, it is subjected to true-colour synthesis so that it can help in the classification and identification of features in GIS and remote sensing applications, including but not limited to land cover, vegetation types and water bodies, to better observe the environmental changes in the Changbai Mountain Nature Reserve, such as the forest health, water quality, and soil condition, etc., to achieve the environmental monitoring within the site area. Finally, the detection of changes in classification is performed.

2.3.1. Wavebands. True colour bands are a method of accurately reproducing colour images by combining the three main colour bands, red, green and blue (RGB), simulating the human eye's perception of colour and making the image look lifelike and realistic. Synthetic bands are usually created by synthesising or combining data from different bands together to create new image bands that provide more information or improve the image for a specific application. This paper is based on the remote sensing image data Landsat8 OLI, radiometrically calibrated and atmospherically corrected in ENVI to make RGB=432 for true colour synthesis.

The choice of composite bands depends on the application and need, the commonly used composite bands are the Red, Green and Blue (RGB) composite bands, which combine data from the red, green and blue bands to create a colour image. Other composite bands include: infrared colour composite bands to highlight temperature differences in the image for thermal imaging and military use; high resolution multispectral composite bands for applications such as geological exploration, vegetation monitoring, and environmental monitoring; application-specific composite bands for detecting pollutants, farmland management, water resource monitoring, etc.; and PCA composite bands to reduce the dimensionality of the data and to highlight the main changes in the image.

2.3.2. Classification and change detection. The maximum likelihood classification method was used to classify the ENVI innovation ROIs of 2013 Landsat8 OLI, and 2022 Landsat8 OLI images in ENVI. Maximum likelihood classification is a statistical method that uses statistical information from known samples, in particular probability distribution models, to classify pixels in remotely sensed images. Its advantages include high accuracy, wide applicability and parameter estimation capabilities, but care needs to be taken to make strict assumptions about the data distribution.

Changes in grassland and bare land in the imagery were further detected by synthesising change maps between 2013 and 2022 based on the change detection tool in ENVI.

Use "Band Maths" in ENVI to perform band calculations to obtain a band ratio image. Calculate the 3/4, 5/4/ and 7/4 ratios in ENVI and then synthesise the colour bands via RGB=3/4, 5/4/ and 7/4.

3. Analysis of results

3.1. Classification results

Open the Landsat 8 OLI remote sensing imagery in ENVI software and employ the Maximum Likelihood Classification method within the Supervised Classification toolbox for overseeing the remote sensing image classification process. The outcomes of this classification are depicted in Figure 2a and 2b. The Landsat 8 OLI remote sensing images of the study area have been categorized into five distinctive land cover types, including woodland, grass, barren land, snow-covered areas, and bodies of water.

The classification results for the years 2013 and 2022 reveal that the predominant land cover in the study region is woodland, followed by barren land, with a limited extent of grass coverage. Bodies of water correspond to the Changbaishan Tianshan region. Woodland is predominantly concentrated in the northern, west-central, and southern regions of the map. Barren land, on the other hand, is primarily distributed in the central-eastern sector of the map, with sporadic patches observed in the southern region. Grassland can be identified in the central-eastern segment of the map, with occasional scattered areas in the southern portion.

Comparison of the two-year classification results showed that woodland had a slight increase in area in 2022 compared to 2013; grass had a more significant increase in area in 2022 compared to 2013,

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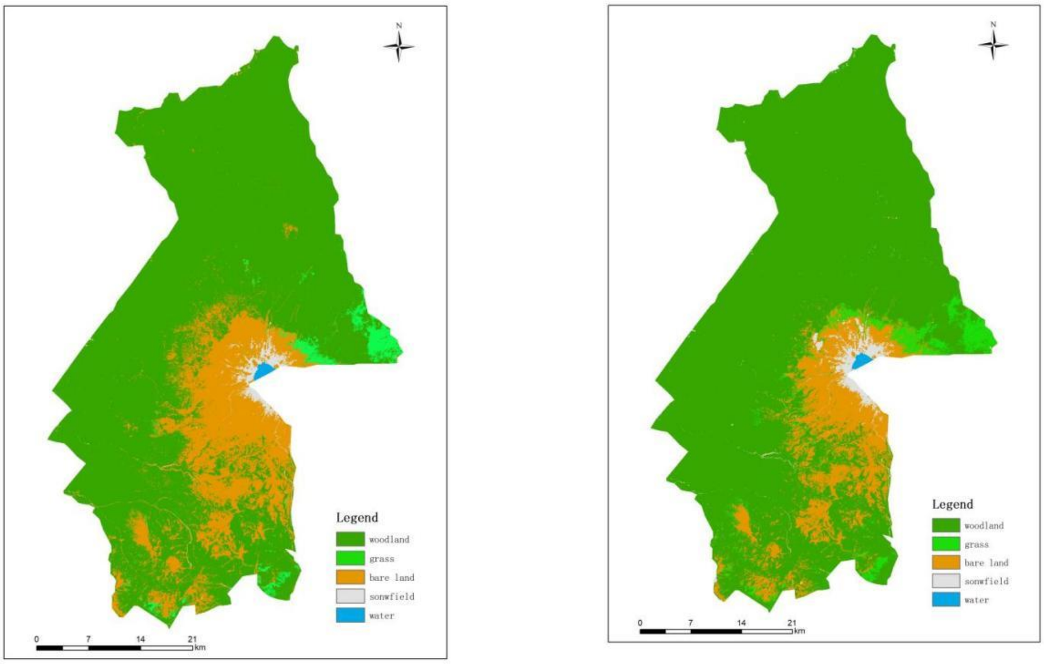
mainly in the east-central portion of the study area; bare land had a significant decrease in area in 2022 compared to 2013; snowfield had a slight increase in area in 2022 compared to 2013; and snowfield had a slight increase in area in 2022 compared to 2013. There was a slight increase in snowfield in 2022 compared to 2013, and no significant change in the water area between the two years. The reasons for the above changes may be that the state advocates ecological environmental protection from 2013 to 2022, the government invests more funds, afforestation, forestation, returning farmland to forests and grasslands, and increasing the area of reserve forests and forest plantations; the rise of the plantation forest industry, the increase of imported timber, and the total ban on logging in natural forests.



a.2013 b.2022

Figure 2. Distribution of vegetation cover in Changbai Mountain Nature Reserve.

3.2. Land-use transfer matrix

Table 1. Land use transfer matrix 2013-2020 (km^2).

2013-2022	Bare land	Grass	Snowfield	Water	Woodland	Total	Reduction
Bare Land	242.00	17.36	12.12	0.00	110.63	382.11	140.11
Grass	4.45	32.37	0.02	0.00	6.32	43.16	10.79
Snowfield	0.66	0.00	20.63	0.01	0.53	21.83	1.20
Water	0.00	0.00	0.12	3.61	0.00	3.73	0.12
Woodland	16.01	20.61	0.91	0.00	1472.63	1510.16	37.53
Total	263.11	70.35	33.80	3.62	1590.10	1960.98	
Increase	21.11	37.97	13.17	0.01	117.47		

In geography, a transfer matrix refers to a matrix that describes the interconnections between geospatial units, such as regions, countries, or ecosystems. It shows the probability distribution of connections or migrations from one geographic unit to another, helping researchers to analyse spatial interactions and

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trends. This is important for understanding resource flows, ecological migrations, and the evolution of geographical phenomena. Therefore, in this paper, the two-year classification results tif were converted into vector data, the area of each feature type was calculated in the attribute table, and finally, the land use transfer matrix was calculated. The results are shown in Table 1. The increase in Table 1 refers to the area of the feature transferred from other features in 2020 on top of the 2013 base; the decrease refers to the area of the feature transferred out to other features in 2020 on top of the 2013 base.

As indicated in Table 1, there was a notable decrease in the extent of barren land from 2013 to 2022, resulting in a total reduction of 199 square kilometers. The expansion in the barren land area primarily stems from the conversion of woodland areas, whereas the land transferred out of barren land is predominantly allocated to grass and woodland categories. The grassland area has grown by 27.18 square kilometers, and there has been an increase of 11.97 square kilometers in the snowfield area. The water-covered area has exhibited minimal change. In contrast, woodland area has experienced a substantial increase, with a cumulative growth of 79.94 square kilometers. This surge in woodland area is mainly attributable to the conversion of previously barren land, while the land transferred out of woodland is primarily allocated to barren land and grass categories.

4. Discussion

Vegetation restoration in Changbai Mountain Nature Reserve has multiple social, humanistic and ecological values.

The social values mainly include afforestation, grassland restoration, habitat protection and biodiversity conservation. Reforestation restores forest cover by introducing locally adapted tree species, which helps to stabilise the soil, improve water quality, and provide feeding and habitat for wildlife. At the same time, habitat protection and biodiversity conservation are vital measures to protect wildlife and their habitats, promoting ecological balance.

Regarding human values, the restoration of vegetation in Changbai Mountain Nature Reserve helps maintain and strengthen the stability of the Changbai Mountain ecosystem. The growth of vegetation helps reduce soil erosion, improves water quality, reduces flooding, and provides foraging and habitat for various wildlife. These ecological benefits create a virtuous cycle that maintains a cultural balance between ecology and humans.

Most importantly, the ecological value of vegetation restoration to the Changbai Mountain Nature Reserve is immeasurable. It helps protect and maintain the area's ecosystem, maintain biodiversity, slow down land degradation, improve environmental quality, and provide sustainable ecological services. This not only helps to maintain the balance of nature but also helps to support sustainable development, promote ecotourism, and create economic value while ensuring that future generations will continue to enjoy the Changbai Mountain Nature Reserve as a precious natural heritage. Restoring forests and grasslands helps reduce the amount of carbon dioxide in the atmosphere and contributes to the mitigation of climate change. It also contributes to maintaining ecological balance to a certain extent, as climate change may adversely affect the ecosystem.

In conclusion, vegetation restoration has far-reaching significance in the Changbai Mountain Nature Reserve. It makes an essential contribution to the preservation of the ecological balance and biodiversity of this area [10]. In summary, vegetation restoration in Changbai Mountain Nature Reserve creates a virtuous cycle that brings wide-ranging benefits to the ecosystem and society by maintaining ecological balance, providing ecosystem services, attracting ecotourism, mitigating climate change, and continuous improvement and management. This virtuous circle helps to ensure that the natural resources and ecological balance of the Changbai Mountains can be protected and maintained in the future.

5. Conclusion

This paper compares the vegetation restoration status of Changbai Mountain Nature Reserve using Landsat data in 2013 and 2022. The research in this paper found that most of the surface cover in the study area is woodland, followed by bare land, with a small distribution of grass. From 2013 to 2022, the Chinese government has made significant progress in its advocacy and financial investment in

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national ecological environmental protection, especially in the ecological restoration of the Changbai Mountain Nature Reserve. The increase in grass in the study area in 2022 compared with that in 2013 was mainly in the central part of the study area. Meanwhile, the area of bare land decreased significantly in 2022 compared with 2013. Through the land use transfer matrix, the area of bare land decreased significantly from 2013 to 2022, with a total decrease of 199km, and the transfer out was mainly from grass and woodland. In addition, the grass area increased by 27.18km, mainly from woodland.

This is mainly due to the government's active promotion of projects such as afforestation, forestation, and returning farmland to forest and grassland, which has increased the area of reserve forests and created forests. In addition, the rise of the plantation forestry industry has reduced the pressure on natural forest logging, and the increase in imported timber has helped protect the integrity of the domestic ecosystem. Most importantly, the policy of a total ban on natural forest logging has provided solid support for the protection of ecosystems. Vegetation cover in the Changbai Mountain Nature Reserve has been significantly restored, essential for maintaining ecological balance, protecting endangered species and reducing the risk of natural disasters. Overall, these initiatives have contributed to ecological protection, ecosystem restoration, climate change response and the realisation of sustainable development.

Vegetation-coverage research shows China's significant 25% contribution to global greening. Vegetation is the link between water, soil and atmosphere, making it an important indicator of changes in anthropogenic factors.

The Changbai Mountain Nature Reserve is performing well regarding vegetation restoration. In the future, there is a need to maintain regulation, scientific research and innovation, publicity and education, and international cooperation to ensure sustainable ecological and environmental protection to maintain ecological balance, mitigate the impacts of climate change, and create a better future.

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