Analysis of the effectiveness of landscape protection in the Liancheng National Nature Reserve, Gansu, China

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Research

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Abstract

Background

The rapid assessment of the effectiveness of landscape protection in nature reserves is of great significance for the scientific formulation of protection and management countermeasures for nature reserves and is also an urgent problem to be solved for the construction and management of nature reserves in China. Using high-resolution remote sensing image data, this study analyzes the landscape dynamics in the Liancheng National Nature Reserve (LNNR) and their driving factors since the reserve's promotion to the national level in 2005, and proposes a comprehensive evaluation method for the effectiveness of landscape protection in protected areas based on the Landscape Transfer Index (LTI), Protected Landscape Integrity Index (PLII), and Interfered Landscape Sprawl Index (ILSI).

Results

Between 2006 and 2019, the area of protected landscape—namely woodland, grassland, and water—in the LNNR decreased, while the area of interfered landscape such as residential land, industrial and mining land, and water conservancy facility land increased. The LTI was –0.14, and among the driving factors, the development of industry and mining, land use by indigenous inhabitants, and the development of the transport industry made the highest contribution to the landscape transfer tendency, being respectively 34.79%, 28.98%, and 17.30%. The PLII decreased from 82.7 to 68.7 and the ILSI increased from 26.61 to 26.68.

Conclusion

The effectiveness of landscape protection in the LNNR is low. Between 2006 and 2019, the overall quality of the landscape slightly decreased, the spatial pattern of the protected landscape became more fragmented, and the degree of human interference in the landscape increased; however, the scope of influence of human interference did not change significantly. These changes were mainly due to industrial and mining exploitation, land use by indigenous inhabitants, and road construction. However, despite the insignificant nature of these changes, they still require attention and timely remedial measures. The methodology proposed in this study may be applicable to the rapid assessment of the effectiveness of landscape conservation in various types of

nature conservation sites around the world.

Keywords

Landscape pattern, Human interference, Driving factors, Effectiveness of landscape protection, Liancheng National Nature Reserve

Introduction

Natural habitat loss and fragmentation are important threats to global biodiversity conservation (Chase et al. 2020; Sala et al. 2000). Studies have shown that the establishment of protected areas (PAs) can effectively curb the destruction of natural ecosystems, and this approach is a major component of biodiversity conservation (Li et al. 2020; Ma et al. 2012; Tang et al. 2011). In 2019, there were 261,200 PAs of various types in the world, covering 15.3% of the global terrestrial and freshwater environment (Maxwell et al. 2020). Analyzing landscape changes in PAs is an intuitive way to monitor and evaluate such areas. Scholars classify the landscapes in PAs into two categories according to their attributes, namely protected and interfered landscape(Zhang et al. 2014; Lindenmayer 2006; Chinese State Forestry Bureau 2008). The former mainly refers to natural landscapes but also includes some human-made landscapes that are beneficial to wildlife; the latter refers to the types of human-made landscape that cause interference and damage to natural ecosystems and wildlife habitats (Rovero et al. 2017; Richard et al. 2011; Lin et al. 2017). It is generally accepted that PAs are effective for the conservation of natural habitats (Rosas et al. 2017; Guo et al. 2017). However, some scholars have argued that the loss of wildlife habitat in some PAs due to increased anthropogenic interference has still not been effectively curtailed, questioning the conservation effectiveness of nature reserves (Fuller et al. 2010; Guadilla-Sáez et al. 2019). Therefore, it is highly necessary to scientifically assess the conservation effectiveness of PAs by monitoring the dynamic changes in the protected landscape.

In China, there are 11,800,000 PAs of various types, covering a total area of more than 1.8 million km^2 (Chen 2019). Among them, nature reserves occupy the largest area among the various types of PAs and are of fundamental importance for ecological conservation (Zhao et al. 2020). There are a total of 2750 nature reserves in China, covering a combined area of 1.47 million km^2, accounting for 15% of China's land area; of these, 474 are state-level nature reserves covering a total area of 980,000 km^2, accounting for 10% of China's land area (Wang 2019). Anthropogenic activities are prevalent in these national nature reserves; as of 2015, anthropogenic activities were present in 446 national nature reserves in China (Liu et al. 2020), and the level of such activities is expected to continue to increase as the population increases (Wittemyer et al. 2008). Furthermore, a comprehensive quantitative assessment of the landscape protection effectiveness of nature reserves in China has not been carried out, and how to scientifically and rapidly assess the landscape protection effectiveness of nature reserves following their establishment is an urgent problem for the construction and management of nature reserves.

In recent years, scholars in China and abroad have conducted a large number of studies on the dynamic changes of regional landscapes and their driving factors using a combination of remote sensing and GIS, based on theories related to landscape ecology (Cao et al. 2015; He et al. 2019; Su et al. 2011; Zheng et al. 2017). Most of these studies were conducted at large spatial scales using moderate-resolution (≥30 m) satellite image data. In nature reserves, under strict control measures, the landscape generally does not change to a large extent; however, smaller-scale anthropogenic activities that lead to landscape changes are common, such as the construction of water conservancy facilities, residential land use, and tourism service facilities. It is difficult to identify these activities with medium-resolution satellite imagery. With the development of remote sensing and geographic information systems, high-resolution satellite imagery has enabled researchers to accurately identify landscape changes in nature reserves at smaller scales (Cong et al. 2019; Cui et al. 2014; Song et al. 2016), providing the possibility to accurately assess the effectiveness of landscape protection in nature reserves.

Scholars in China have explored methods to assess the effectiveness of conservation in nature reserves from different aspects such as landscape, vegetation, plants, and animals (Guan et al. 2012; Liu et al. 2016; Jin et al. 2015; Xin et al. 2015). Additionally, based on the research results, forestry industry standards were issued (Chinese State Forestry Bureau 2014), providing a theoretical basis for research on the conservation effectiveness of nature reserves at the landscape level. However, research by Chinese and foreign scholars on the conservation effectiveness of nature reserves at the landscape level has mainly focused on changes in landscape dynamics, the impacts of human interference, and the effectiveness of habitat quality protection (Broadbent et al. 2012; Mehring and Stoll-Kleemann 2011; Guo et al. 2017; Long et al. 2014; Niu et al. 2003; Lin et al. 2019). These studies evaluated the conservation effectiveness of different types of nature reserves from different perspectives; however, a fast, effective, and universal method to evaluate the landscape protection effectiveness of nature reserves is lacking.

This study takes the Liancheng National Nature Reserve (LNNR) as the study area and uses high-resolution remote sensing image data from 2006 and 2019 to analyze the landscape change trend and its drivers from the perspective of landscape type change since the nature reserve was promoted to a national nature reserve in 2005; moreover, it proposes the use of the Protected Landscape Integrity Index (PLII) and the Interfered Landscape Sprawl Index (ILSI) to attempt to quantify the integrity of protected landscape and the influence range of human disturbance from the perspective of the landscape spatial distribution pattern. These methods were used to comprehensively evaluate the effectiveness of landscape protection in the LNNR since its promotion to a national nature reserve. The main objectives of this study are as follows: (1) To propose a method to rapidly assess the effectiveness of landscape protection in nature reserves; (2) to evaluate the effectiveness of landscape protection in the LNNR using this method; and (3) to propose countermeasures and recommendations for landscape protection management in the LNNR.

Data sources and research methods

Overview of the study area

The LNNR is located in the arid northwest of China, in Yongdeng County, Lanzhou City, and in the Tianzhu Tibetan Autonomous County, Wuwei City. It was established as a provincial nature reserve in 2001 and promoted to a national nature reserve in 2005. The geographical coordinates of the reserve are 36°32′54″~36°48′28″ N latitude, 102°35′57″~102°54′32″ E longitude; it covers a total area of 48,240 hm^2, of which, 14,440 hm^2 (29.93%) is the core zone, 13,333 hm^2 (27.64%) is the buffer zone, and 20,467 hm^2 (42.43%) is the experimental zone. The LNNR is located in the middle and lower reaches of the Huangshui River, a major tributary of the Yellow River. The LNNR is a forest ecosystem type nature reserve; the main object of protection is the *Sabina przewalskii* and *Picea crassifolia* forest ecosystem and the habitat of nationally protected wild animals and plants. The LNNR has a wide variety of vegetation, which can be divided into six vegetation types, 17 formation groups, and 28 formations, providing a good habitat for wild animals and plants to survive and reproduce. A survey of the LNNR found vascular plants from 91 families, 403 genera, and 1283 species, and terrestrial vertebrates from 24 orders, 66 families, and 220 species(Wang 2008). Its rich biodiversity and many rare and endangered species make the LNNR a rare-species gene pool, especially in the Loess Plateau region. Furthermore, the large areas of primeval forest in the LNNR, which are composed of *S. przewalskii*, *Picea wilsonii*, and *P. crassifolia*, make it an important forest and water conservation area in the upper reaches of the Yellow River. The LNNR is not only regionally representative but also has high conservation and scientific research value. As of 2019, there were 30,695 community residents living within the LNNR, distributed among 10 administrative villages and one community in two townships, mainly in the experimental zone of the reserve. These communities are subject to frequent human activities, which greatly threaten the protection and management work of the reserve.

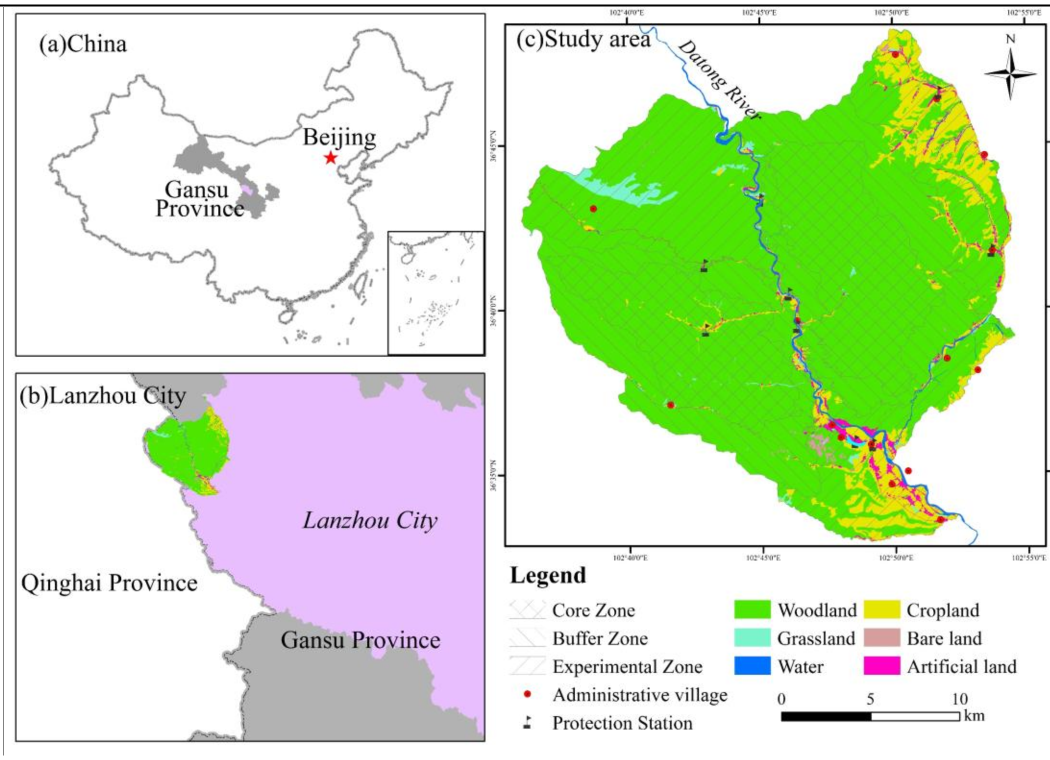

Figure 1 Location map of the Liancheng National Nature Reserve (LNNR)

Data sources

Two sets of remote sensing images of the study area were collected, one acquired in 2006 (resolution: 2.5 m) and the other in 2019 (resolution: 2 m). Socio-economic data for the LNNR were obtained from the survey statistics of the Chinese Nature Reserve Authority.

Data processing

Remote sensing image processing and landscape classification

Using the ENVI 5.1 software (L3Harris Geospatial, Boulder, Colorado, USA), the two image series were processed with geometric correction, multi-band blending, panchromatic sharpening and cropping. The protected area was divided into 10 primary landscape types and 21 secondary landscape types (Table 2) based on the Chinese Land Use Classification Standard (GB/T 21010-2017). The accuracy of the decomposition results was assessed using a field survey, and the attribute accuracy and boundary accuracy of the decomposition results for 2006 and 2019 were found to be greater than 97% (Table 1), which meets the accuracy requirements (Cong et al. 2019; Cui et al. 2014; Song et al. 2016).

Table 1 The results of the accuracy analysis of the landscape classification in the Liancheng National Nature Reserve (LNNR)

Remote sensing image acquisition	Total number of	Number of samples	Sampling rate	Number of correct	Attribute accuracy	Number of correct	Boundary accuracy

year	patches			attributes		boundaries	
2006	1901	471	25%	464	98.51%	468	99.36%
2019	1971	381	19%	372	97.64%	370	97.11%

The 21 secondary landscape types were classified into protected, interfered, and neutral landscapes based on the attributes of the land use/land cover (LULC) types (Table 2): protected landscapes include natural forest, artificial forest, shrub forest, grasslands, and river water surface; interfered landscape include agricultural land, mining land, industrial land, roads, hydraulic architecture, urban residential land, detached houses, rural residential land and other construction land. Neutral landscape includes bare land and bare gravel land. Ecological levels were assigned to the different types of landscapes using the golden divide method (Table 2), in which threshold values of 0.62 and 0.38 were used to divide the given interval. A higher assigned value indicates a higher ecological level. Interfered landscapes have negative values, and larger absolute values indicate a higher level of anthropogenic interference. Neutral landscapes are assigned a value of 0 (Zhang et al. 2014).

Table 2 The assigned landscape types and ecological levels in the LNNR

Primary landscape type	Secondary landscape type	Landscape classification	Ecological level	Primary landscape type	Secondary landscape type	Landscape classification	Ecological level
Woodland	Shrub forest	Protected landscape	0.62	**Bare land**	Bare land	Neutral landscape	0
	Artificial forest	Protected landscape	0.38		Bare gravel land	Neutral landscape	0
	Natural forest	Protected landscape	1	**Other construction land**	Other construction land	Interfered landscape	-0.62
Grassland	Grassland	Protected landscape	0.62	**Water conservancy facility land**	Ditches	Interfered landscape	-0.62
Cropland	Cultivated land	Interfered landscape	-0.38		Hydraulic architecture	Interfered landscape	-1
	Agricultural facility land	Interfered landscape	-0.62	**Water**	River water surface	Protected landscape	1
Industrial and mining land	Mining land	Interfered landscape	-1		Ponds	Interfered landscape	-0.38
	Industry and storage land	Interfered landscape	-1	**Residential land**	Urban residential land	Interfered landscape	-0.62
Traffic facility land	Highways	Interfered landscape	-1		Detached house	Interfered landscape	-0.62
	Bridges	Interfered landscape	-1		Rural residential land	Interfered landscape	-0.62
	Railway land	Interfered landscape	-1				

Landscape transfer matrix

The intersection module of ArcGIS was used to calculate the geometric intersection in 2006 and 2019. Landscape type vector maps were used to statistically derive the area change of each landscape type between different periods and generate the landscape transfer matrix. To clearly demonstrate the changes in landscape pattern, the networkD3 package for R was used to draw the landscape transfer matrix Sankey diagram, and the area change rate of each landscape type was also calculated.

Landscape Transfer Index

The Landscape Transfer Index (LTI) can directly reflect the overall trend of landscape type change. According to the ecological level assigned to each landscape type, the LTI of the LNNR was calculated based on the landscape transfer matrix using the following formula:

$$I_T = \frac{\sum_{\mathrm{i}=1}^{\mathrm{m}} \sum_{\mathrm{j}=1}^{\mathrm{n}} S_{i \to \mathrm{j}} \left(D_j - D_i\right)}{S_T} \times 100$$

where I_T is the landscape transfer index; *m* is the number of landscape types in the previous period; n is the number of landscape types in the current period; $S_{i \to \mathrm{j}}$ is the area in which landscape type i was converted to landscape type j; S_T is the total area of the nature reserve; and D_i and D_j denote the assigned ecological levels of landscape types i and j, respectively.

The LTI has values between –200 and 200; positive values indicate that the landscape and ecological conditions of the area have improved and negative values indicate that they have deteriorated, with larger absolute values indicating greater change and vice versa.

Protected Landscape Integrity Index

In this study, the fragmentation index and the edge effect index were used to comprehensively characterize the degree of integrity of the protected landscape in the LNNR using the following formulae:

$$I_F = 1 - \sum_{j=1}^{n} \left(\frac{S_j}{\sum_{j=1}^{n} S_j} \right)^2$$

$$I_E = \sum_{j=1}^{n} \left[\frac{S_j}{\sum_{j=1}^{n} S_j} \cdot \frac{2\lg(0.25P_j)}{\lg S_j} \right]$$

$$I_I = \sqrt[3]{\frac{\sum_{j=1}^{n} S_j}{S_T} \cdot (1 - I_F) \cdot (2 - I_E)} \times 100$$

where I_F is the fragmentation index of the protected landscape, reflecting the overall fragmentation of all protected landscapes, and has values of between 0 and 1; S_j is the area of the jth protected landscape mosaic patch; n is the total number of protected landscape mosaic patches; I_E is the edge effect index of the protected landscape; P_j is the perimeter of the jth protected landscape mosaic patch; I_I is the integrity index of the protected landscape; and S_T is the total area of the LNNR.

The value of I_I ranges from 0 to 100, with larger values indicating less fragmentation of the protected landscape mosaic, weaker edge-effect strength, and greater landscape integrity, and vice versa.

Interfered Landscape Sprawl Index

The Interfered Landscape Sprawl Index (I_S) was used to characterize the degree of dispersion of the spatial distribution of the interfered landscape and the intensity of edge effects in the LNNR in order to evaluate the extent of anthropogenic interference in the reserve. This index was calculated according to the following formulas:

$$P_{ij} = \frac{E_{ij}}{E}$$

$$I_S = -\frac{\sum_{i=1}^{m}\sum_{j=1}^{n} P_{ij}\, ln\, P_{ij}}{\ln(\mathrm{m}+\mathrm{n})} \times 100$$

where P_{ij} is the ratio of the common boundary length (E_{ij}) between the i-th interfered landscape mosaic patch and the j-th mosaic patch for all other types of landscape (including protected and neutral landscapes) to the total common boundary length (E) between all interfered landscape mosaic patches and other landscape mosaic patches; m is the total number of interfered landscape mosaic patches; and n the total number of mosaic patches for all other types of landscape.

The value of I_S ranges from 0 to 100; the larger the value, the more dispersed the distribution of interfered landscape, the greater the edge effect, and the greater the extent of anthropogenic interference.

Classification of drivers of landscape change

To analyze the causes of landscape changes in the LNNR, the landscape change patches in different periods were extracted using the ArcGIS topological analysis module. According to the actual situation of the LNNR obtained through past field investigation and image processing, the direct driving factors of each landscape patch change were qualitatively classified and the direct driving factors leading to landscape change were classified into nine categories (Table 3).

Table 3 The results for the direct drivers of landscape patch changes in the LNNR between 2006 and 2019

Driving factor	Description	Main conversion type
Natural disturbance	Landscape changes as a direct result of purely natural disturbances (e.g., landslides)	Woodland→Bare land
Land use by indigenous inhabitants	Landscape changes as a direct result of new housing, agricultural reclamation, etc.	Bare land→Cropland Bare land→Residential land

Population displacement	Landscape changes as a direct result of house demolitions, abandonment of cultivated land, etc.	Residential land→Bare land Cropland→Bare land / Grassland
Development of industry and mining	Landscape changes as a direct result of the construction of industrial and mining facilities, (e.g., ore mining)	Woodland→Bare land Bare land→Industrial and mining land
Development of the water and hydropower industry	Landscape changes due to the construction of dams, hydropower plants, and other hydroelectric facilities	Water→Water conservancy facility land / Bare land Bare land / Cropland→Water
Development of agricultural industry	Landscape changes as a direct result of the construction of agricultural facilities (e.g., farms and grow houses)	Cropland→Other construction land
Development of transport industry	Landscape changes as a direct result of road construction, road hardening, etc.	Woodland / Bare land→Traffic facility land
Development of tourism industry	Landscape changes as a direct result of the construction of amusement parks, observation decks, and other tourism services	Woodland→Bare land / Other construction land
Ecological restoration	Landscape changes as a direct result of conservation works (e.g., ecological restoration) carried out by authorities in the protected area	Bare land→Woodland

Results

Changes in landscape area

The LNNR has three main types of protected landscapes (forest land, grassland, and water) and six types of interfered land (cropland, residential land, traffic facility land, water conservancy facility land, industrial and mining land, and other construction land). The results show that, between 2006 and 2019, the total area of protected landscapes in the reserve decreased from 42,505.59 hm^2 (88.25% of the reserve's total area) to 42,456.16 hm^2 (88.15%) (Table 4). Woodland occupies the largest area among all landscape types in the LNNR, and its area decreased from 41,325.16 hm^2 (85.80% of the reserve's total area) in 2006 to 41,292.32 hm^2 (85.73%) in 2019, a decrease of 32.84 hm^2. In the same period, the grassland area decreased from 771.03 hm^2 (1.6% of the reserve's total area) to 760.86 hm^2 (1.58%), while the water area decreased from 409.4 hm^2 (0.85% of the reserve's total area) to 402.98 hm^2 (0.84%). That is, between 2006 and 2019, the areas of all types of protected landscapes in the reserve decreased slightly, and the annual rate of change in area was small (Table 4). In the same period, the area of interfered landscape in the reserve increased from 5526.36 hm^2 (11.47% of the reserve's total area) to 5546.71 hm^2 (11.52%). Of the various types of interfered landscape in the LNNR, cropland accounts for the largest area, and decreased from 4808.01 hm^2 (9.98% of the reserve's total area) in 2006 to 4773.51 hm^2 (9.91%) in 2019. During the same period, all other types of interfered landscape also increased in area to varying degrees, with residential landscape experiencing the largest percentage of area expansion of any type of interfered land, increasing continuously from 462.38 hm^2 in 2006 to 488.45 hm^2 in 2019. Water facility landscape experienced the fastest area expansion of any interfered landscape type, with a mean annual change in area of 5.54%.

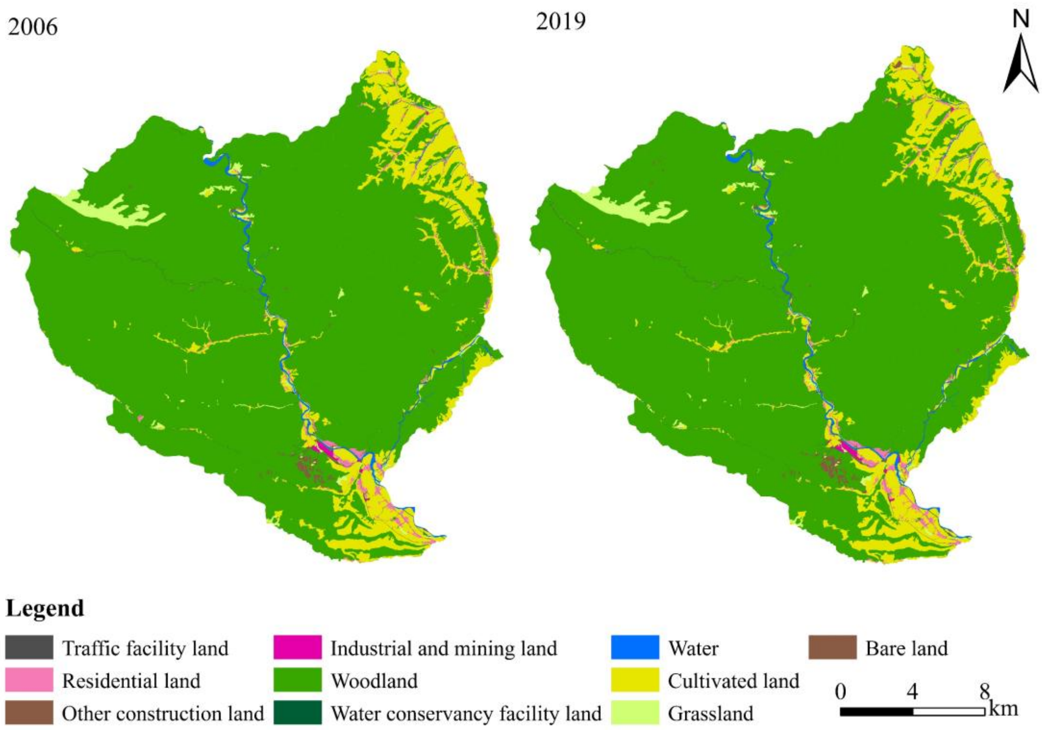

Figure 2 The distribution of landscape use types in the LNNR in 2006 and 2019

Table 4 Changes of landscape use types in the LNNR between 2006 and 2019

Landscape type	2006		2019		Area variation ratio
	Area (hm^2)	Proportion* (%)	Area (hm^2)	Proportion* (%)	(% · a^{-1})
Woodland	41,325.16	85.80	41,292.32	85.73	-0.01
Grassland	771.03	1.60	760.86	1.58	-0.10
Water	409.4	0.85	402.98	0.84	-0.12
Bare land	132.84	0.28	161.92	0.34	1.68
Cultivated land	4808.01	9.98	4773.51	9.91	-0.06
Residential land	462.38	0.96	488.45	1.01	0.43
Traffic facility land	182.14	0.38	189.21	0.39	0.30
Water conservancy facility land	7.67	0.02	13.19	0.03	5.54
Industrial and mining land	52.91	0.11	60.27	0.13	1.07
Other construction land	13.25	0.03	22.08	0.05	5.13

* Refers to the proportion of the total area of the LNNR.

Area transfer between different landscape types

Between 2006 and 2019, the area of protected landscape types such as natural forest, shrub forest, grassland, and river water surface in the LNNR decreased. The conversion of protected landscapes was mainly in the form of area conversions out. As shown in the landscape transfer matrix (Table 6) and the landscape transfer Sankey diagram (Figure 3), natural forest was mainly converted to bare land and bare gravel land with 11.41 hm^2 and 6.86 hm^2, corresponding to proportions of 47.96% and 28.84%, respectively. Shrub forest was mainly converted to bare land and detached houses, with conversion areas of 4.40 hm^2 and 1.99 hm^2, corresponding to proportions of 34.24% and 15.49%, respectively. Grasslands were mainly converted to cultivated land and ditches, with conversion areas of 4.29 hm^2 and 2.19 hm^2, corresponding to proportions of 28.32% and 14.46%, respectively. River water surface was mainly converted to hydraulic architecture, mining land, and highways, with conversion areas of 1.49 hm^2, 3.72 hm^2, and 2.69 hm^2, corresponding to proportions of 12.58%, 31.42%, and 22.72%, respectively.

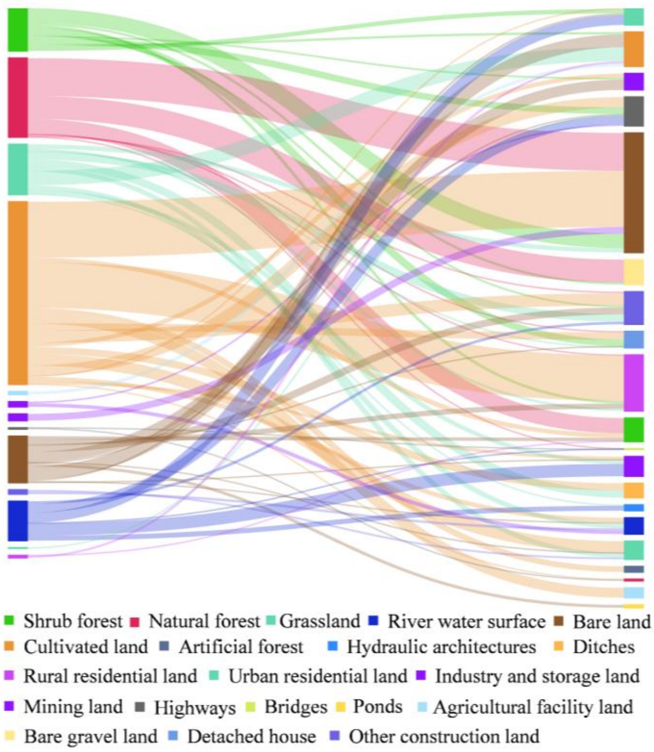

Figure 3 Landscape transformation Sanky map from 2006 to 2019

Additionally, between 2006 and 2019, the area of cultivated land in the interfered landscape in the LNNR decreased significantly. This cultivated land was mainly converted to bare land and rural residential land, with conversion areas of 16.84 hm^2 and 13.7 hm^2 and conversion rates of 30.63% and 24.92%, respectively. Furthermore, the areas of other types of interfered landscape, such as industry and storage land, hydraulic architecture, and highways, all increased to varying degrees. The industry and storage land in the protected area are ore processing workshops or ore dumps, which have mainly been converted from bare land, with a conversion area of 3.11 hm^2 and a proportion of 63.34%. The hydraulic architecture land is mainly used for dams or power stations, and has mainly been converted from river water surface, with a conversion area of 1.49 hm^2 and a transfer ratio of 85.14%. Highways were mainly converted from cultivated land and river water surface, with a conversion area of 3.16 hm^2 and 2.69 hm^2, accounting for 36.36% and 30.96%, respectively.

Moreover, the areas of the two types of neutral landscape, bare land and bare gravel land, increased significantly between 2006 and 2019, with bare land mainly being converted from natural forest and cultivated land, with conversion areas of 11.41 hm^2 and 16.84 hm^2, accounting for 31.72% and 46.82%, respectively. The bare gravel land is mostly distributed in the rocky hills on the west bank of the Datong River, and the main source of transfer is from natural forest, with a transferred area of 6.86 hm^2, corresponding to a conversion rate of 91.34%.

The calculated LTI of the LNNR is –0.14, indicating that the landscape of the reserve tended to deteriorate in general during 2006–2019.

Analysis of landscape transformation under different drivers

Between 2006 and 2019, the total area of changed landscape patches was 135.43 hm^2 and the total number of changed patches was 291 (Table 5). Seven of the nine driving factors were found to contribute negatively to the LTI (Figure 4), among which the absolute values of the LTI caused by the development of industry and mining, land use by indigenous inhabitants, and the development of the transportation industry were the highest, with contributions of 34.79%, 28.98, and 17.30%, respectively. With socio-economic development and population increase, the demand for construction land increased, and the number of landscape change patches caused by land use by indigenous inhabitants was the largest (135), with a total area of 37.8 hm^2. Land use by indigenous inhabitants was the largest driving factor of landscape area change and was also one of the main causes of the LTI decrease. In the experimental zone in the south of the reserve, there are large state-owned industrial and mining enterprises with a complete production line of ore mining, stockpiling, and processing built in the 1970s; this has caused some of the natural forest, shrub forest and water in the experimental zone of the reserve to degenerate into bare land or industry and storage land. The development of industry and mining has been the main driving factor for landscape deterioration in the reserve. There are 77 km of roads in the LNNR; the main transportation road in the reserve is provincial highway S301, which passes through the central experimental zone of the reserve, following the Datong River. From 2006 to 2019, 3.8 km of road reconstruction and expansion was carried out in the LNNR, mainly focusing on the

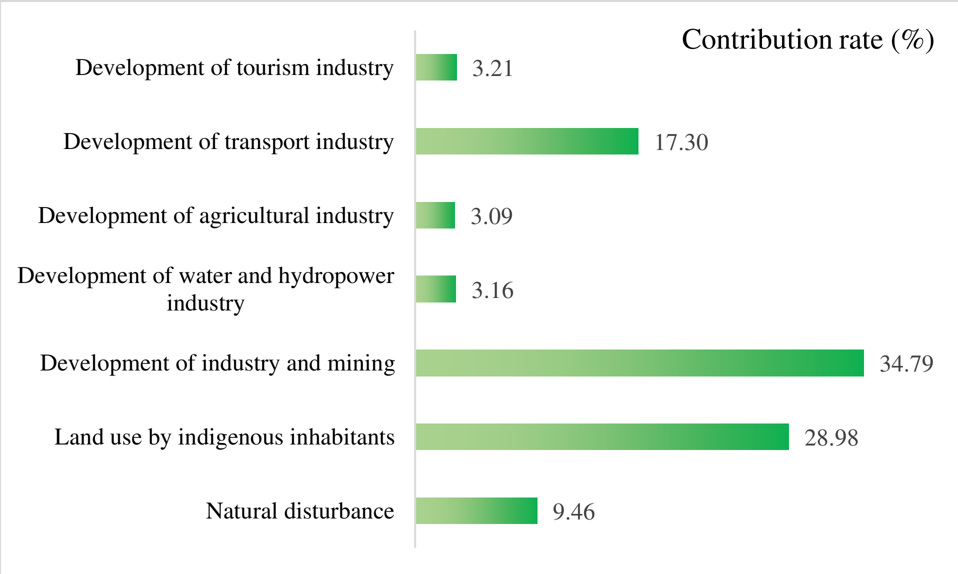

Figure 4 The contribution rate of different driving factors to the LTI

provincial highway S301, which transformed part of the shrub forest, water, and cultivated land along the Datong River into transportation land. Additionally, there are four hydropower stations in the reserve, all of which are located in the reserve's experimental zone; of these, two were newly built, and one was expanded, between 2006 and 2019. Water facility land is the landscape type that experienced the fastest change in LNNR during this period. However, the contribution of the development of the hydropower industry to the LTI decrease is insignificant (3.16%). This can be attributed to the fact that the construction of hydropower plants led to the conversion of protected landscapes (e.g., river water surface) into construction land, however, it also increased the water level, and consequently, patches with low assigned ecological levels along rivers (e.g., bare land and arable land) were converted into water lands, which have a higher assigned ecological level.

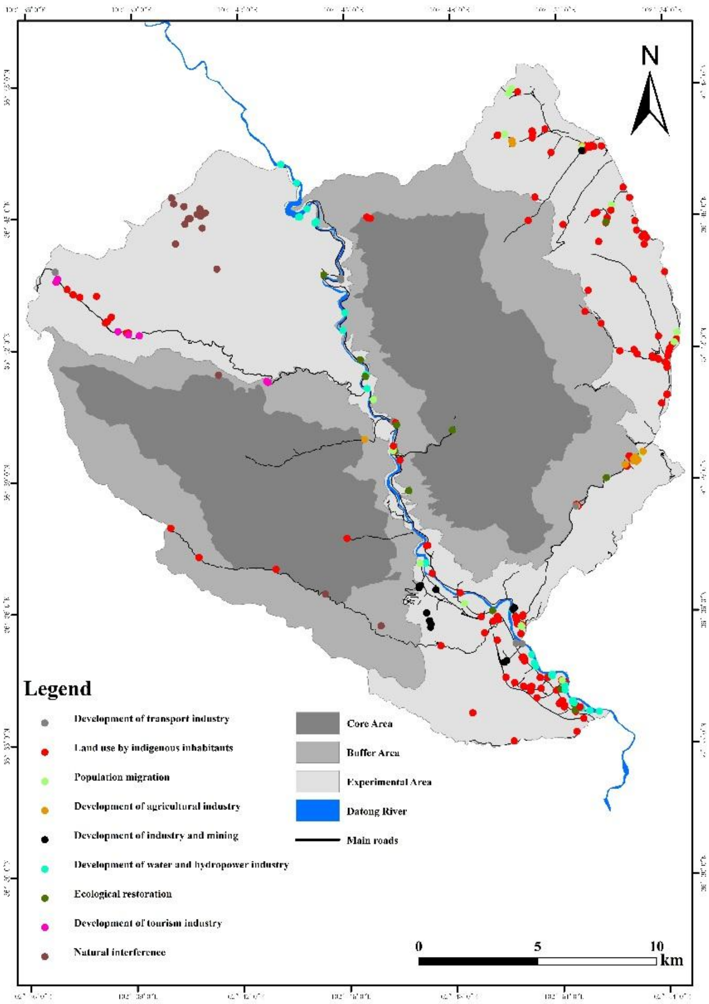

Figure 5 Spatial distribution of landscape change patches under different driving factors

Between 2006 and 2019, the LTI caused by population displacement and ecological restoration are positive, being 14.61×10^{-3} and 12.37×10^{-3}, respectively. The landscape change due to population displacement was mostly a shift from interfered to neutral landscape and did not prod uce a significant improvement in landscape quality. Although ecological restoration led to a significant improvement in landscape quality, the area of implementation is small. Therefore, the population displacement and the ecological restoration were not sufficient to compensate for the overall trend of poorer landscape quality due to other drivers.

Table 5 Values of the Landscape Transfer Index (LTI) under different driving factors

Driving factor	Patch area (hm^2)	Number of patches	Landscape transfer index ($\times10^{-3}$)
Natural disturbance	7.67	17	-15.40
Land use by indigenous inhabitants	37.80	135	-47.17
Population displacement	18.47	16	14.61
Development of industry and mining	26.45	28	-56.63

Development of water and hydropower industry	15.07	27	-5.14
Development of agricultural industry	7.03	11	-5.03
Development of transport industry	13.25	33	-28.17
Development of tourism industry	2.68	9	-5.22
Ecological restoration	7.02	15	12.37

Table 6 The area transfer matrix of second-level landscape types in the LNNR between 2006 and 2019

Unit：hm^2

2006–2019	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1				1.32	0.69			0.54	1.96			4.4	0.65	0.55						1.99	0.75
2																					
3	4.59									0.03		11.41	6.86	0.46						0.28	0.16
4					4.29		1.18					1.3		2.23	2.19	0.26	1.36		1.33	0.33	0.68
5	1.35	1.69	0.11	0.23		2.96	0.9	1.26	3.16			16.84		3.7	2.13		1.31		3.44	2.19	13.7
6					0.91																
7									0.45								1.08				
8												2.02									
9			0.35							0.01											
10																					
11																					
12	1.01			0.48	3.83		0.11	3.11	0.27					2.06			0.42	0.88	0.11	0.14	1.57
13																					
14																	0.73		0.56		
15																					
16																					
17				2.98			3.72		2.69	0.18				0.78		1.49					
18																					
19									0.16												
20																					
21	0.1				0.61																

*Note：1- Shrub forest; 2-Artificial forest; 3- Natural forest; 4- Grassland; 5- Cultivated land; 6- Agricultural facility land; 7- Mining land; 8- Industry and storage land; 9- Highways; 10- Bridges; 11- Railway land; 12- Bare land; 13- Bare gravel land; 14- Other construction land; 15- Ditches; 16- Hydraulic architecture; 17- River water surface; 18- Ponds; 19- Urban residential land; 20 Detached houses; 21- Rural residential land.

Table 7 The area transfer-out ratio of second-level landscape types in the LNNR between 2006 and 2019

Unit：%

2006–2019	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1				10.27	5.37			4.20	15.25			34.24	5.06	4.28						15.49	5.84
2																					
3	19.29									0.13		47.96	28.84	1.93						1.18	0.67
4					28.32		7.79					8.58		14.72	14.46	1.72	8.98		8.78	2.18	4.49
5	2.46	3.07	0.20	0.42		5.38	1.64	2.29	5.75			30.63		6.73	3.87		2.38		6.26	3.98	24.92
6					100.00																
7									29.41								70.59				
8												100.00									
9			97.22							27.78											
10																					
11																					
12	7.22			3.43	27.38		0.79	22.23	1.93					14.72			3.00	6.29	0.79	1.00	11.22
13																					
14																	56.59		43.41		
15																					
16																					
17				25.17			31.42		22.72	1.52				6.59		12.58					
18																					
19									100.00												
20																					
21	14.08				85.92																

*Note: Numbers refer to the same landscape types as in Table 6.

Table 8 The area transfer-in ratio of second-level landscape types in the LNNR between 2006 and 2019

Unit：%

2006–2019	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1			65.11		19.15							14.33									1.42
2					100.00																
3					23.91				76.09												
4	26.35				4.59							9.58					59.48				
5	6.68			41.53		8.81						37.08									5.91
6					100.00																
7				19.97	15.23							1.86					62.94				
8	11.00				25.66							63.34									
9	22.55				36.36		5.18					3.11					30.96		1.84		
10			13.64						4.55								81.82				
11																					
12	12.23		31.72	3.61	46.82			5.62													
13	8.66		91.34																		
14	5.62		4.70	22.80	37.83							21.06					7.98				
15				50.69	49.31																
16				14.86													85.14				
17				27.76	26.73		22.04					8.57		14.90							
18												100.00									
19				24.45	63.24							2.02		10.29							
20	40.37		5.68	6.69	44.42							2.84									
21	4.45		0.95	4.03	81.26							9.31									

*Note: Numbers refer to the same landscape types as in Table 6.

Protected landscape integrity

The PLII of the LNNR decreased significantly between 2006 and 2019, from 82.7 to 68.7, indicating that the integrity of the protected landscape of the LNNR decreased significantly during this period.

Between 2006 and 2019, the total area of the protected landscape mosaic in the LNNR decreased by 44.58 hm^2 (0.12%), from 42,505.59 hm^2 to 42,456.16 hm^2 (Table 9); additionally, the number of patches increased from 109 to 128, the fragmentation index increased significantly, from 0.22 to 0.57, and the edge effect index decreased slightly, from 1.18 to 1.15, indicating that the fragmentation of the protected landscape mosaic was the main reason for the reduced integrity of the protected landscape in the LNNR between 2006 and 2019. The main road network of the LNNR comprises the S301 provincial highway, in the central part of the experimental zone of the LNNR, the X137 county road, in the east of the LNNR, and a tourist road in the west of the Tulugou National Forest Park. In 2006, some road sections were narrow and not hardened, and did not form a sufficiently resistant surface, and therefore the protected landscape mosaic was not spatially completely cut away. Between 2006 and 2019, the reconstruction and expansion of roads resulted in a significant increase in the fragmentation of the protected landscape mosaic and a significant decrease in the landscape connectivity.

Table 9 A comparison of the landscape pattern indexes of protected landscape mosaics in the LNNR between 2006 and 2019

Year	Total Area (hm^2)	Number of Patches	Fragmentation Index	Edge effect Index	Connectivity Index	PLII
2006	42,505.59	109	0.22	1.18	2.74	82.7
2019	42,456.16	128	0.57	1.15	2.61	68.7

Note: PLII: Protected Landscape Integrity Index.

Interfered landscape sprawl

The ILSI of the LNNR was 26.61 and 26.68 in 2006 and 2019, respectively. The small change in the index over the study period indicates that the scope of influence of interfered landscape in the LNNR did not change significantly.

Between 2006 and 2019, the total area of interfered landscape in the LNNR increased by 20.35 hm^2 (0.05%), from 5526.36 hm^2 to 5546.71 hm^2, with an area conversion rate of 0.37%; additionally, the number of interfered landscape mosaic patches increased from 116 to 131 (Table 10). The degree of dispersion of the spatial distribution of the interfered landscape changed very little, and the increase in area occurred mostly in areas where there was originally a high concentration of interfered landscape; furthermore, the new patches were mostly small, which suggests that the control of the scope of influence of anthropogenic interference in the protected area of the LNNR was effective.

Table 10 A comparison of the Interfered Landscape Sprawl Index in the LNNR between 2006 and 2019

Year	Total Area (hm^2)	Area ratio	Number of Patches	ILSI
2006	5526.36	11.47%	116	26.61
2019	5546.71	11.52%	131	26.68

Note: ILSI: Interfered Landscape Sprawl Index.

Discussion

From 2006 to 2019, the area of protected landscape in the LNNR decreased and the area of interfered landscape increased; that is, the landscape in the reserve generally tended to deteriorate and the conservation effectiveness of the reserve was not significant. The implementation of major national natural forest resource protection projects promotes the development of natural ecosystems. In the LNNR, most of the protection project tasks were completed before the reserve was promoted to a national nature reserve in 2005, such as the natural forest protection projects, natural forest logging has been forbidden since 1998. Additionally, 446 hm^2 of sparse forest land and shrubbery land in the reserve were afforested between 1998 and 2005. From 2001 to 2005, a reforestation project of 703.5 hm^2 was completed in the eastern experimental zone of the reserve. Unfortunately, we do not have access to high-resolution remote sensing image data from the early days of the reserve to analyze the landscape changes resulting from these effective conservation measures. By 2005 (when the reserve was promoted to a national nature reserve), the proportion of forest landscape in the LNNR had already reached 85.8%, and subsequently, the implementation of various protection projects in the reserve mainly focused on hill closure for forestation. The decline in landscape quality that took place in the LNNR between 2006 and 2019 was mainly due to three reasons. First, there are large industrial and mining enterprises in the reserve, whose activities can cause great damage to the ecological environment (Dong 2008). In 2017, all of the mining enterprises in the LNNR stopped ore mining activities and jointly formulated a “mine vegetation restoration plan” together with the nature reserve management; this plan was implemented by 2018, however, ecological restoration is expected to take some time (Li 2004), and the effectiveness of vegetation restoration is not yet clear. Secondly, activities by indigenous residents, such as agricultural reclamation, settlement construction, and resource development have led to a reduction in the quality of the natural ecosystem in the LNNR (Mette 2014; Chen 2016; Cao et al. 2019). There are large numbers of indigenous residents in the LNNR, and these residents have a relatively concentrated distribution, mainly in the Liancheng town government seat in the southern part of the experimental zone and the Minle Township administrative villages at the eastern edge of the experimental zone. The frequent anthropogenic activities in the LNNR have placed great pressure on the protection and management of the reserve and have become an important reason for the decline of the overall quality of its landscape. Thirdly, the increase in population in the protected area of the LNNR has led to an increase in transport demand, and road construction has inevitably encroached on trees, shrubs, and water, resulting in a deterioration of landscape quality. Most of the PAs in China have a certain degree of human interference because of rapid population growth during the past few decades. However, the current management and protection strategies for PAs are not effective. Therefore, in PAs where habitat quality is declining, diverse ecological restoration projects should be selected, while for PAs that do not have conservation value, management measures should be adjusted in a timely manner to avoid further expansion of the scope and extent of interference.

The PLII can comprehensively reflect the degree of fragmentation, edge effect intensity, and spatial connectivity of wildlife habitats in PAs. This study uses changes in this index to evaluate the effectiveness of the protection of the integrity of the protected landscape in the LNNR. To calculate the index, it is necessary to delineate the protected landscape mosaic according to the real situation in different nature reserves. This is mainly achieved in two ways: First, it is possible to delineate the protected landscape mosaic according to the ecosystem type and protected objects of a specific protected area. For example, in this study, protected landscape types with a ecological level ≥ 0.38 were combined into a protected landscape mosaic, which included artificial woodland. Meanwhile, related studies showed that in the Wanglang National Nature Reserve, where giant pandas are the main protection object, artificial woodland is not a suitable habitat for the pandas (Yang et al. 2013). Second, when calculating the PLII, the interfered landscape which have not caused protected landscape separation can be merged into the protected landscape mosaic for analysis. For example, previous studies considered that transportation land types such as Class IV roads, forest roads, and rural roads do not form a substantial separation to protected landscape patches (Cui et al. 2018). Additionally, to ensure the accuracy of the calculation results, the protected landscape mosaic can be further integrated according to the distribution dynamic of protected objects. In summary, the PLII can be used to evaluate the integrity of protected landscapes, and its change value can be employed to assess the effectiveness of PAs for protecting major conservation objects and their habitats.

The ILSI directly reflects the spatial spread of interfered landscape, and this study uses changes in this index to evaluate changes in the effect of anthropogenic interference in the LNNR. For example, in this study, landscape types with an assigned ecological level ≤ -0.38 were combined into an interfered landscape mosaic, which includes cultivated land. A previous study showed that in Hanzhong, Shaanxi Province, cultivated land (paddy fields) is an important habitat for the crested ibis (*Nipponia nippon*) and green rice cultivation is thus of great significance to the conservation of this species (Liu et al. 2014). The interfered landscape mosaic can be adjusted according to the main object of protection and its sensitivity to various types of interference, and the ILSI can therefore be universally applied to evaluate and control the spread of human interference.

Based on the results of this study, we give the following recommendations to promote the protection effectiveness of protected areas: (1) Adjust the scope of PAs and functional areas as soon as possible, mainly by removing areas without protection value (e.g., towns, industrial and mining enterprises, and water conservancy and hydropower facilities) from PAs to avoid the interference of these areas in the assessment of the effectiveness of the landscape protection of PAs. Furthermore, for interfered landscape that cannot be withdrawn from the scope of PAs, scientific monitoring should be conducted to minimize the negative impact of this landscape on the main protection objects of nature reserves and their habitats; (2) Carry out the strict control and environmental impact assessment of the construction of facilities such as roads and hydropower stations in PAs to prevent the increased fragmentation of the protected landscape. At the same time, construct a protected area habitat corridor system to mitigate the decline in the connectivity and integrity of the protected landscape; and (3) obey the National Nature Reserve Regulation of China, follow the management routines of the LNNR strictly, and construct monitoring and response systems to the long-term management issues.

Conclusion

Using high-resolution remote sensing image data, this study analyzed the landscape dynamics and its drivers in the LNNR since its promotion to a national-level reserve; specifically, it evaluated the landscape protection effectiveness of the LNNR from 2006 to 2019 using the Landscape Transfer Index, Protected Landscape Integrity Index, and Interfered Landscape Sprawl Index. The following conclusions can be drawn:

(1) From 2006 to 2019, the area of protected landscapes—namely woodland, grassland, and water—within the protected area of the LNNR decreased, while the area of interfered landscape—namely residential land, industrial and mining land, and water conservancy facility land—increased, resulting in a decrease in the overall quality of the landscape and an increase in the degree of human interference in the reserve. These changes were mostly concentrated in the experimental zone of the protected area of the LNNR, and the main causes of the overall deterioration of the landscape were industrial and mining exploitation, land use by indigenous inhabitants, and the construction of transportation facilities. Although these changes are not obvious, they still require attention and timely remedial measures.

(2) During the same period, there was a decline in the integrity of the protected landscape mosaic in the protected area of the LNNR. This decline was mainly due to landscape fragmentation caused by road expansion and modification in the experimental zone of the protected area. It is necessary to mitigate the decline in the integrity of the protected landscape of the reserve by constructing ecological corridors and performing ecological restoration.

(3) The spatial distribution of interfered landscape in the LNNR did not change significantly between 2006 and 2019. The area of interfered landscape increased mostly in areas where such landscape was originally

concentrated, and the new patches were mostly small. These results suggest that the protected area of the LNNR is effective for controlling the scope of influence of human interference in the reserve.

This study proposes a comprehensive method for evaluating the landscape conservation effectiveness of PAs based on the LTI, the PLII, and the ILSI. This method has the potential to be applied to the rapid assessment of landscape conservation effectiveness in various types of protected area.

Declarations

Abbreviations

PAs: Protected Areas; LNNR: Liancheng National Nature Reserve; LTI: Landscape Transfer Index; PLII: Protected Landscape Integrity Index; ILSI: Interfered Landscape Sprawl Index.

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Authors’ contributions

Z.H. designed the study, data preparation, analysis, and wrote the paper. Y.P. participated in the field investigation and provided suggestions for the method. R.W. participated in the data preparation and processing. B.Z. and N.L. participated in the remote sensing image interpretation and the accuracy calculation of the interpretation results. G.C. provided the project design and performed paper editing. All the authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

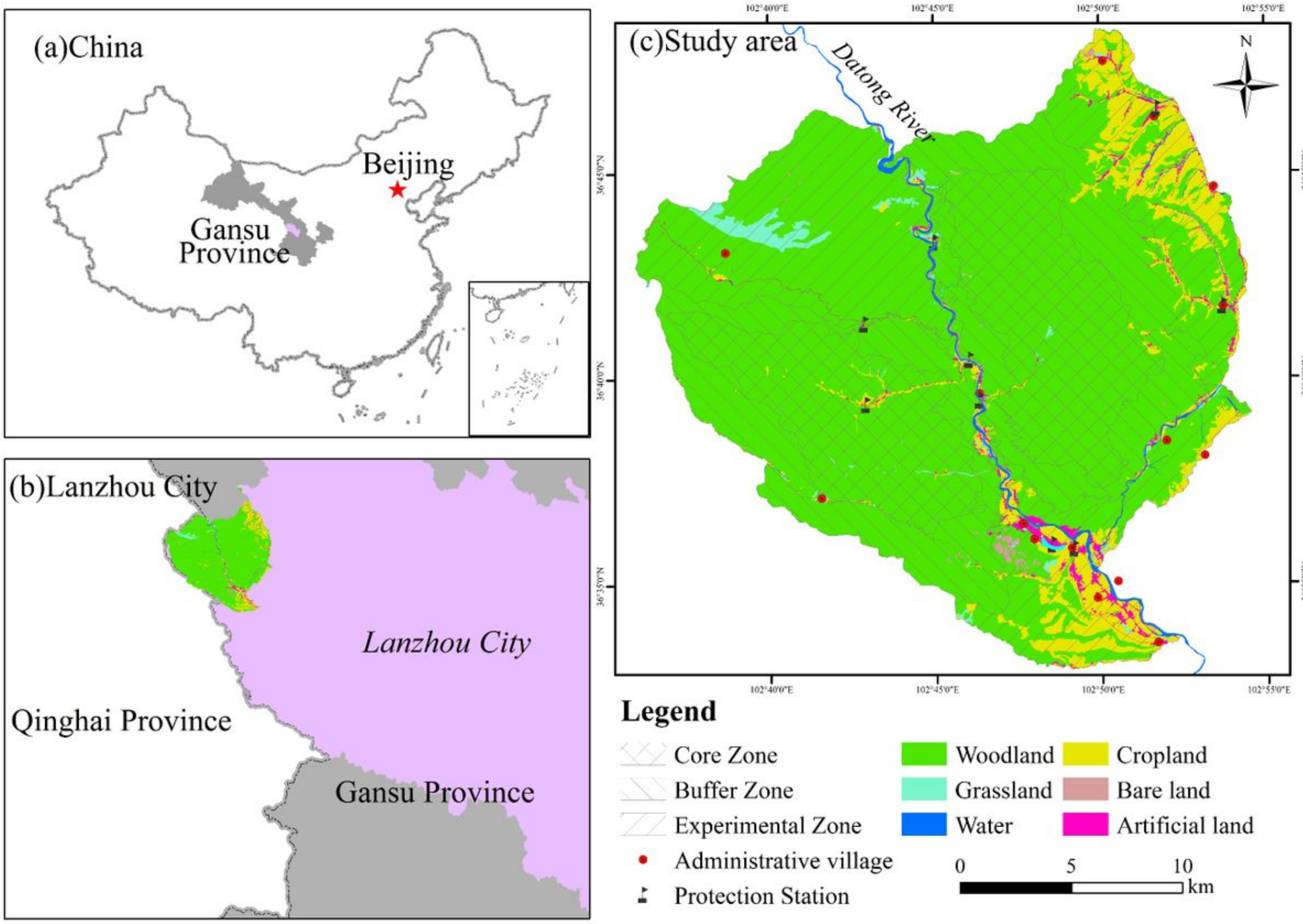

Figure 1

Location map of the Liancheng National Nature Reserve (LNNR). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

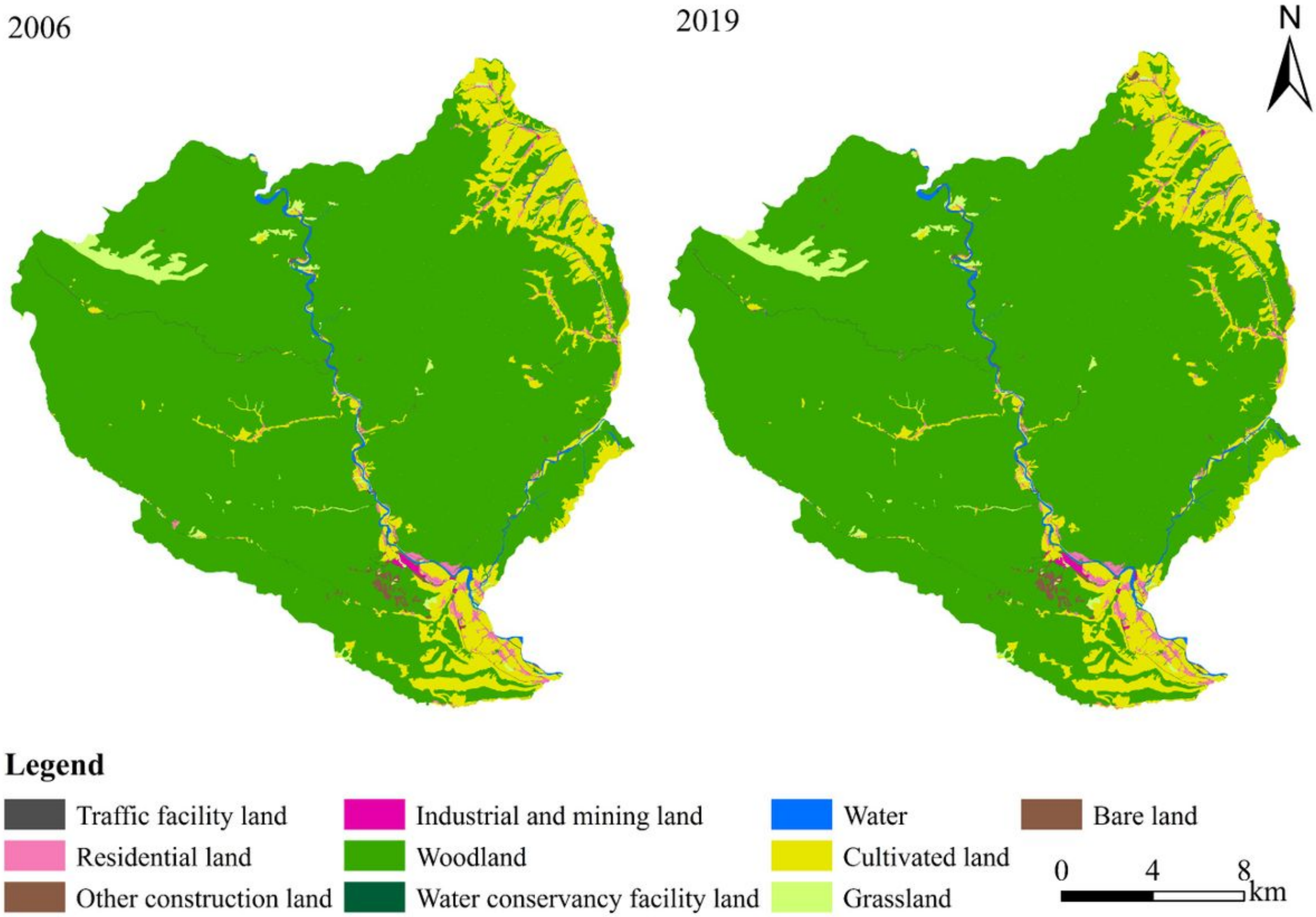

Figure 2

The distribution of landscape use types in the LNNR in 2006 and 2019. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

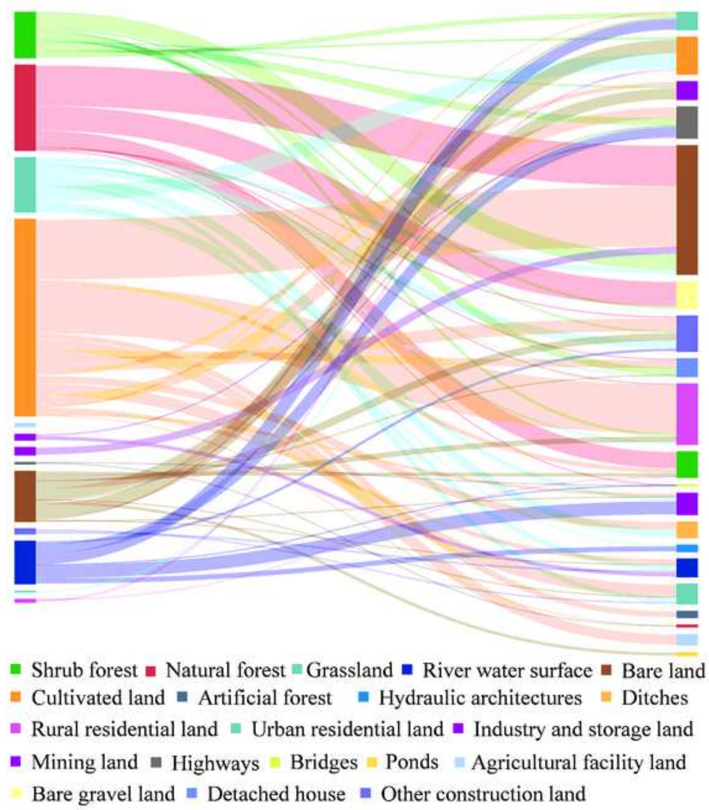

Figure 3

Landscape transformation Sanky map from 2006 to 2019

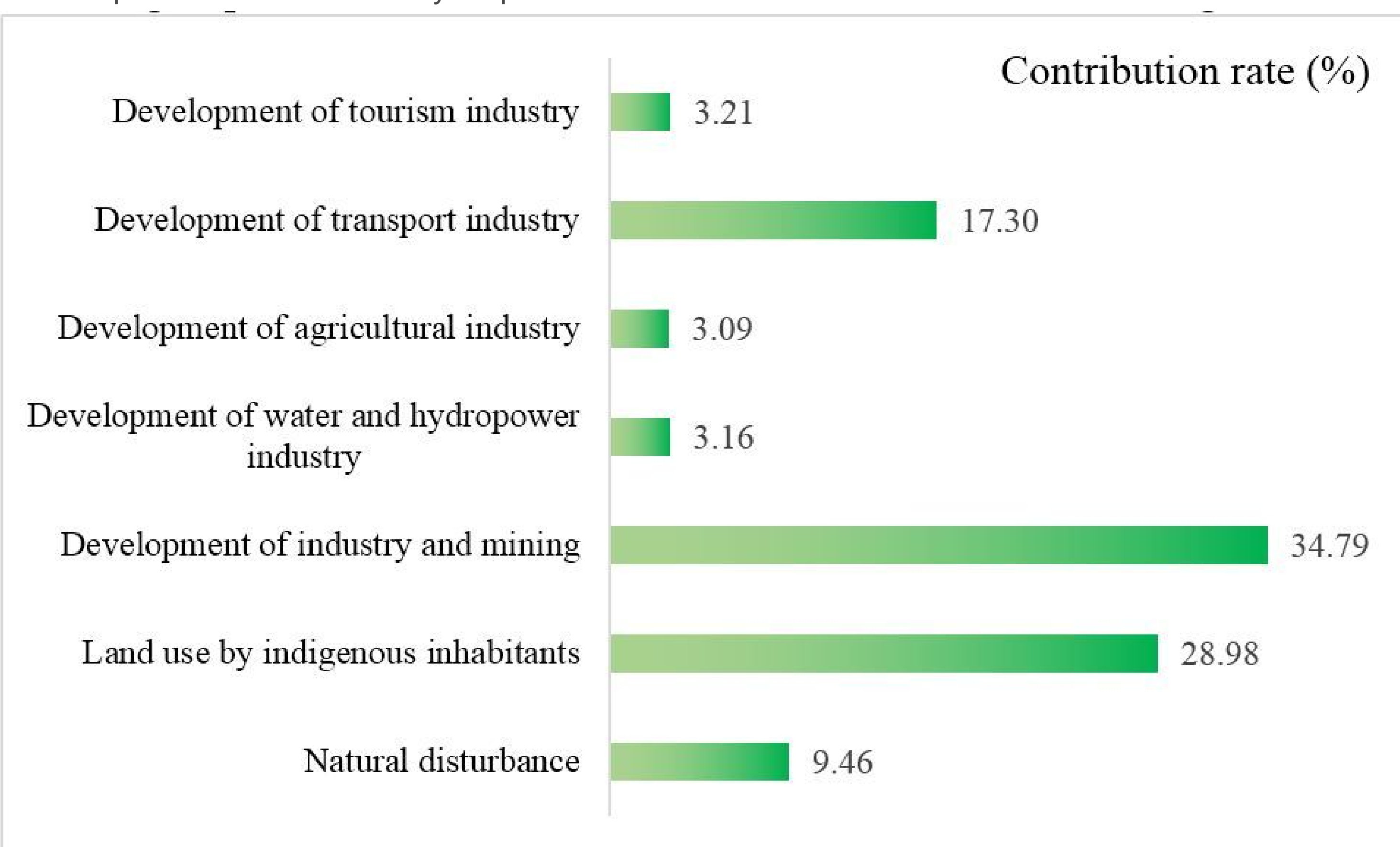

Figure 4

The contribution rate of different driving factors to the LTI

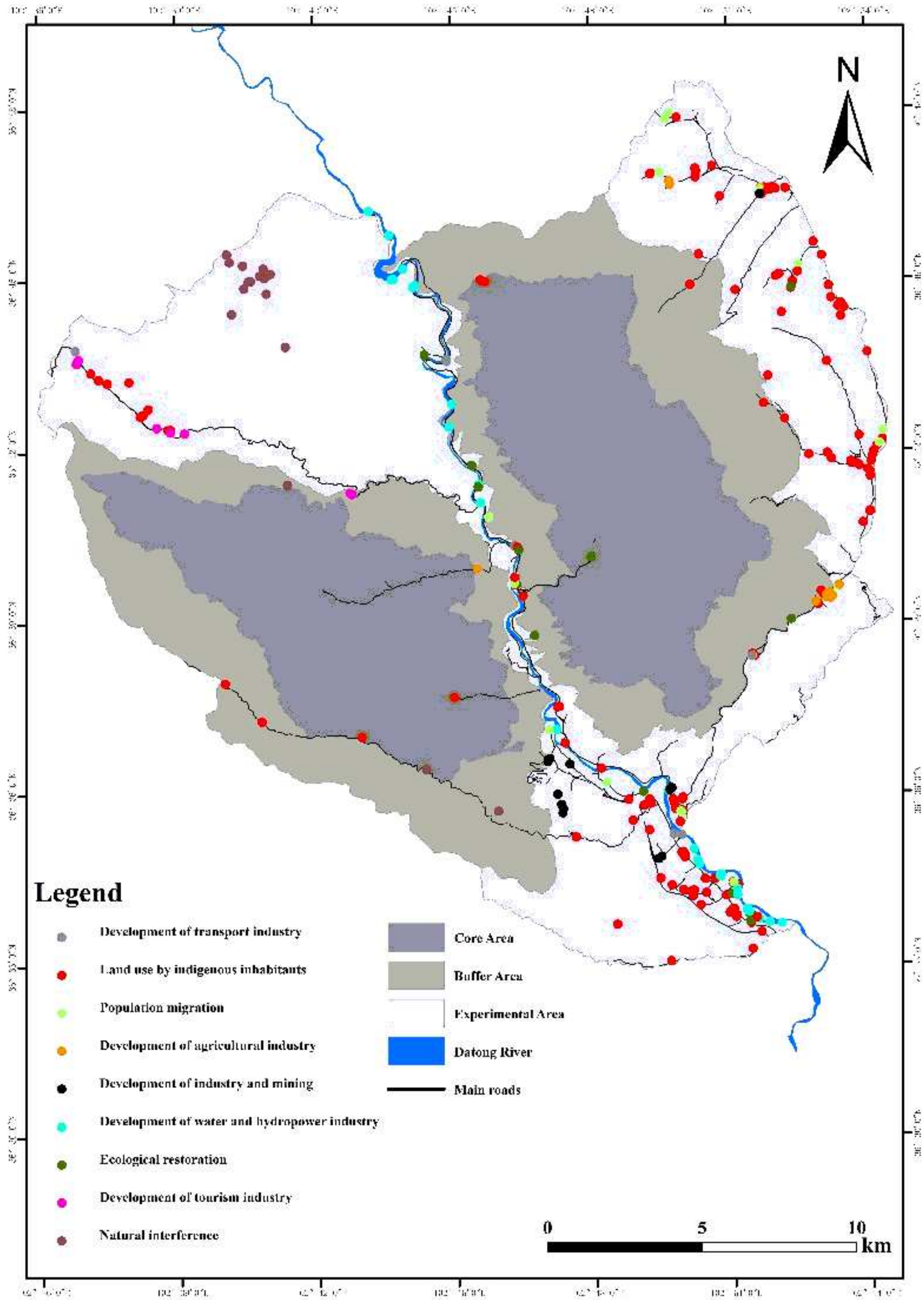

Figure 5

Spatial distribution of landscape change patches under different driving factors. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.