Chin. Geogra. Sci. 2022 Vol. 32 No. 2 pp. 324−339
https://doi.org/10.1007/s11769-022-1269-1

Springer Science Press
www.springerlink.com/content/1002-0063

Stability of Land-use/Land-cover in National Nature Reserves of Jilin Province, China

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Abstract: National nature reserves are an important part of classification management on ecological protection in China. Taking the national nature reserves of Jilin Province as examples, this paper introduced the stability index by referring to the intensity model of land-use and land-cover change (LUCC), and analyzed the overall stability of land-use and land-cover (LULC) in the study area from the time interval level and land category level. The stability of LULC in different types of nature reserves was tracked and identified by extracting land-use change trajectory, and the land-use change trajectory was divided into three types: stable type, sub-stable type and unstable type. The impact of LUCC on regional ecosystem services was studied by using hotspot analysis and gravity center analysis. The results showed that: 1) The LULC in the study area was stable on the whole, and the proportion of stable land area reached 86.08%. The intensity of LUCC showed an increasing trend in recent 20 years, and the conversion of cultivated land and construction land was active in continuous time interval. 2) The stability of LULC in forest ecological reserves and wildlife reserves in the eastern part of Jilin Province was the highest, while that in inland wetland reserves and geological relic reserves in the central and western part of Jilin Province was lower. 3) The LUCC in national nature reserves not only changed the value of its own ecosystem service function, but also affected the ecosystem service function of the whole region. The combination of intensity analysis and land-use change trajectory was used to identify the characteristics of stability of LULC in nature reserves, which was conducive to deeply understand the process of LUCC in national nature reserves and provided reasonable suggestions for regional ecological protection.

Keywords: national nature reserves; land-use and land-cover change (LUCC); stability; intensity analysis; land-use change trajectory; ecosystem service value

Citation: SHANG Yi, WANG Dongyan, LIU Shuhan, LI Hong, 2022. Stability of Land-use/Land-cover in National Nature Reserves of Jilin Province, China. *Chinese Geographical Science*, 32(2): 324−339. https://doi.org/10.1007/s11769-022-1269-1

1 Introduction

Nature reserves play an important role in protecting biodiversity, safeguarding ecosystem health, and providing ecosystem services, livelihoods and sustenance to local communities (Lee and Abdullah, 2019). Since the 1870s, in response to the industrial revolution, European and American countries have established various types of reserve. Currently, nearly 250 countries or regions have established networks of nature reserves based on their local environmental characteristics (Chen et al., 2020). By 2016, 244 countries or regions had established 217 155 nature reserves, covering 19.80 million km^2 (or 14.7%) of land globally; between 2010 and 2016, the global protected area had increased by 16% (UNEP-WCMC and IUCN, 2016). As well as representing an effective strategy for biodiversity conservation across the globe, nature reserves can also be used to help ad-

Received date: 2021-09-10; accepted date: 2022-01-07
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 42071255)
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dress issues such as depleted water supplies and the need to improve human wellbeing and food security (Sobhani et al., 2021). In China, nature reserves are hubs of biodiversity conservation (Wu et al., 2018); however, since the late 1970s, economic reform and opening-up policies have led to a rapid rural-urban transition and large disparities in economic development across the country (Long et al., 2016). This rapid transition has imposed tremendous pressure on land, water and air quality, and has made natural resource management a requisite component of China's overall development strategy. Anthropogenic alterations to the landscape have increased as the human population rises, leading to detrimental changes in natural habitats (Martin and Root, 2020). Within this context, the designation of nature reserves has become a crucial policy vehicle for protecting areas of importance for wild flora and fauna in China (Wu et al., 2018). China's nature reserves are chosen based on biodiversity, natural beauty, resilience to natural disasters, cultural values and other ecosystem services (Gao, 2019). Since the establishment of the first nature reserve in 1956, China has built a large variety of reserves, 2750 in total, including 474 national nature reserves; they cover an area of about 1.47 million km^2, and account for 14.88% of the country's total land area (http://www.forestry.gov.cn/main/5462/20200521/154226923344835.html).

Nature reserves are key providers of ecosystem services, and are therefore crucial to human wellbeing and sustainable development (Chen, 2020). The capacity of a nature reserve to provide those services and conserve biodiversity is determined by the characteristics of its particular ecosystem, including its LULC (Hu et al., 2018a; 2018b). For some time, China has implemented strict control measures on nature reserves, and as a result reserves' LULC was relatively stable. However, the effects of human activity are hard to avoid. Anthropogenic interventions across the globe, driven by the exploitation of natural resources to keep pace with accelerated technological development and rapid population growth, with their associated demands for food, fiber and energy (Da Silva et al., 2021), have led to a decline in natural biomes and reduced the ability of nature reserves to provide ecosystem services. Exploring LULC in nature reserves is therefore crucial for effective environmental management and sustainability (Sobhani et al., 2021). Using sustainable LULC management practices to oversee nature reserves will promote continuity in ecosystem structures and processes, and help protect the world's natural capital (Petrosillo et al., 2013). Stable LULC can safeguard the ability of nature reserves to provide ecosystem services.

Studies on the LULC of nature reserves usually focus on three main questions: a) What is the spatio-temporal pattern of the LULC of the nature reserves? b) What are the drivers of any change in LULC? c) What is the projected LULC of nature reserves in the future? However, relatively few studies have explored the processes and patterns of LUCC in a study area from the perspective of LULC stability. LULC stability studies are usually based on transfer matrixes, but traditional methods of index analyses are not sufficient to reveal quantitative and systematic signals of LUCC (Huang et al., 2012). For example, a transfer matrix can not show whether the LULC in a nature reserve is stable or whether there is variability across different types of reserve. Moreover, it can not reveal which processes of LUCC have evolved naturally or arisen as a result of human agency (Yang et al., 2019). When applied to LUCC assessments, both single and composite indices disregard social and economic factors, and ignoring those factors degrades the effectiveness of nature reserves (Lee and Abdullah, 2019). To optimize the use of transfer matrix data, Pontius et al. (2004) have developed a method called intensity analysis, which analyzes the loss and gain of different LULC categories. Separate calculations are used to determine whether a large transition from category A to category B can be explained by an intensive process, whereby A gains systematically from B and/or category B loses systematically to category A (Huang et al., 2012). Intensity analysis is a mathematical framework that can express differences within a set of categories that exist at multiple time points. For example, an intensity analysis can indicate a change in land cover in one region during different time intervals (Pontius et al., 2017; Quan et al., 2020). Aldwaik and Pontius (2012) have improved the intensity analysis methodology, by proposing a framework that analyzes the intensity of LUCC at three different levels: interval level, category level and transition level. This can be used to identify the systematic and stationary characteristics of the LUCC process in a study area during a continuous time period.

The intensity analysis framework has been applied at different research scales. Huang et al. (2012) were the first to apply it in China, in a study of the process and pattern of LUCC in the Jiulong River Basin, the southeastern China, between 1986 to 2007. Subsequently, Sun et al. (2016) applied it to an analysis of the intensity and pattern of LUCC in Kunming, China, and explored the scope of its application. Since then, the research framework has been applied to LUCC information mining at an urban scale (Akinyemi et al., 2017; Yang et al., 2019; Quan et al., 2020; Niu et al., 2021). However, while the theory of intensity analysis is now well established, few studies have applied the methodology to nature reserves, in particular multiple nature reserves, and the framework has mainly been applied across regions with geospatial continuity.

In this paper we used national nature reserves in Jilin Province, China as our study area. This study has applied the intensity analysis framework to discontinuous geographic space, and identified the LULC stability characteristics of the study area. Because there are numerous and varied LULC types within the national nature reserves in Jilin Province, we have applied a stability index based on the intensity analysis to compare the intensity of LUCC within the Jilin national nature reserves with the intensity of LUCC of Jilin Province. The objectives of this study were to: 1) identify LULC stability at two levels, time interval level and land category level; 2) classify the stability of the nature reserves by analyzing the trajectories of LUCC; 3) explore the regional ecological effects of LUCC in the national nature reserves based on ecosystem service value (ESV). The combination of intensity analysis and land-use change trajectory was used to identify the characteristics of stability of LULC within the national nature reserves of Jilin Province, and then used ESV to examine the regional ecological effects of the LUCC process, with a view to providing a scientific basis for the rational development and utilization of nature reserves and regional ecological protection.

2 Materials and Methods

2.1 Study area

With a typical temperate continental climate, Jilin Province has a complex and diverse natural geography, including plains, hills and mountains transitioning from west to east. To the west there is a grassland ecological region, in the middle of Songliao Plain, and to the east a secondary vegetation and virgin forest ecological region (Chen et al., 2020). Within the overall area there are 24 national nature reserves (Fig. 1), covering a total area of 12 449.77 km^2. There are eight forest ecological reserves, eight inland wetland reserves, four geological relic reserves, three wild animal reserves and one wild plant reserve (Released by the Ministry of Ecological and Environment of the People's Republic of China in 2018). For this study, the wild animal and wild plant reserves were grouped together as wildlife reserves. In re-

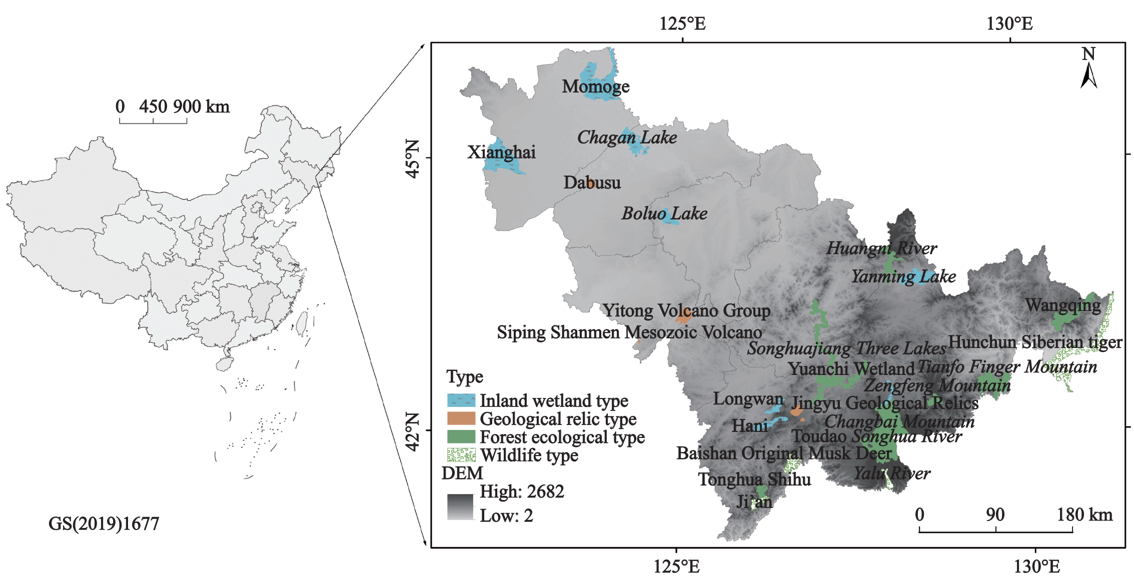

Fig. 1 Location of the Jilin Province, China

cent years, with a rapidly developing social economy, the area of important ecological land in national nature reserves in Jilin Province has been decreasing (Chen et al., 2020). It is therefore important that managers study the patterns of LUCC within nature reserves in order to formulate appropriate protection policies.

2.2 Data sources

The boundary vector data for the Jilin nature reserves were obtained from the Resource and Environment Science and Data Center website (http://www.resdc.cn/). Raster data for the LULC of the nature reserves in 2000, 2010 and 2020 came from the Global Land Cover website (http://www.globallandcover.com/). The original data were geometrically corrected, mosaiced and clipped. Following an established land-use classification system (Costanza et al., 1997; Xie et al., 2003; 2008; 2015; Chen and Li, 2019), the original LULC data were grouped into seven categories (forest land, grassland, wetland, water, desert, cultivated land and construction land) using an ArcGIS platform. In addition, the LULC data were uniformly mapped using the projection of krasovsky_1940_Albers. Socio-economic data were obtained mainly from Jilin Statistical Almanacs (http://tjj.jl.gov.cn/).

2.3 Research methods

2.3.1 Land-use transfer matrix

For the land-use transfer matrix (Table 1), the rows represent land-use categories for time node T_1, and the columns represent land-use categories for time node T_2. Category 1, 2, 3, 4 represent the different land categories; S_{ij} represents the area of category i that has been converted into category j over a period of time; S_{ii} represents the area of categories that have not changed during the time period T_1–T_2; S_{i+} represents the total area of category i at time node T_1; S_{+i} represents the total area of category i at time node T_2.

Table 1 Land-use transfer matrix

T_1	T_2				
	Category 1	Category 2	Category 3	Category 4	Total
Category 1	S_{11}	S_{12}	S_{13}	S_{14}	S_{1+}
Category 2	S_{21}	S_{22}	S_{23}	S_{24}	S_{2+}
Category 3	S_{31}	S_{32}	S_{33}	S_{34}	S_{3+}
Category 4	S_{41}	S_{42}	S_{43}	S_{44}	S_{4+}
Total	S_{+1}	S_{+2}	S_{+3}	S_{+4}	

2.3.2 Land-use stability analysis

A transfer matrix can reflect the LUCC process, but it can not provide information about the stability and systematic patterns of the process (Yang et al., 2019). An intensity analysis can be used to describe the process and patterns of LUCC at three levels (interval, category and transition) from top to bottom, which does provide information on the mechanisms of LUCC. However, the geographical space occupied by national nature reserves in Jilin Province is not continuous, and the processes and mechanisms of LUCC in nature reserves in different regions can be significantly different. Therefore, based on the intensity analysis framework, this study introduces the stability index, which compares the intensity of LUCC in regional areas (the natures reserves, or study area) with that of the overall area (Jilin Province as a whole), and identifies the stability characteristics of LULC in the regional areas at the level of interval and category. The stability of each nature reserve is then determined using a trajectory analysis of change in LULC.

(1) Interval level

Time interval was used to identify the stability characteristics of the study area's LULC. Equs. (1) and (2) calculate the intensity of LUCC for each time period, and the uniform intensity of LUCC during the entire study period, respectively. Equ.(3) calculates the stability index for the study area for a defined time period.

$$S_t = \frac{\left\{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right]\right\} / \left[\sum_{j=1}^{J}\left(\sum_{i=1}^{J} C_{tij}\right)\right]}{Y_{t+1} - Y_t} \times 100\% \quad (1)$$

$$U = \frac{\sum_{t=1}^{T-1}\left\{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right]\right\} / \left[\sum_{j=1}^{J}\left(\sum_{i=1}^{J} C_{tij}\right)\right]}{Y_T - Y_1} \times 100\% \quad (2)$$

$$E_t = \frac{S_{at}}{S_{At}} \quad (3)$$

where C_{tij} is the amount of land transferred from the initial land category i to the final land category j for the time interval $[Y_t, Y_{t+1}]$; S_t is the intensity of LUCC for the time interval $[Y_t, Y_{t+1}]$; U is the uniform intensity of LUCC for the entire study period; E_t is the stability index for the study area during period t; S_{at} is the intensity of LUCC for the study area during period t; and S_{At}

is the intensity of LUCC for the whole province during period t. If $S_t = U$, it indicates that the LULC during the defined time period is constant; if $S_t > U$, it indicates that there is rapid LUCC; if $S_t < U$, it indicates that LUCC is slow. If $0 < E_t \leq 1$, it indicates that the intensity of LUCC for the study area is less than or equal to the intensity of LUCC in the province as a whole, i.e. the study area's LULC is stable; if $E_t > 1$, it indicates that the intensity of LUCC for the study area is greater than the intensity of change in the province as a whole, i.e. the study area's LULC is actively changing.

(2) Category level

Category level was used to identify the stability characteristics of different land categories within the study area. Equs.(4) and (5) calculate the intensity of gain and loss, respectively, of different land categories for a defined time period. Equ. (6) calculates the stability index of a category level within the study area.

$$G_{tj} = \frac{\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right] / (Y_{t+1} - Y_t)}{\sum_{i=1}^{J} C_{tij}} \times 100\% \quad (4)$$

$$L_{ti} = \frac{\left[\left(\sum_{j=1}^{J} C_{tij}\right) - C_{tii}\right] / (Y_{t+1} - Y_t)}{\sum_{j=1}^{J} C_{tij}} \times 100\% \quad (5)$$

$$E_{tj} = \frac{G_{atj}}{G_{Atj}} \quad \text{or} \quad E_{tj} = \frac{L_{atj}}{L_{Atj}} \quad (6)$$

where G_{tj} is the intensity of gain of category j for the time interval $[Y_t, Y_{t+1}]$; L_{ti} is the intensity of loss of category i for the time interval $[Y_t, Y_{t+1}]$; E_{tj} is the stability index of category j for period t within the study area; G_{atj} is the intensity of gain of category j; L_{atj} is the intensity of loss of category j; G_{Atj} is the intensity of gain in overall area; and L_{Atj} is the intensity of loss in the overall area. If the intensity of gain or loss of a certain land category is greater than the uniform LULC intensity for that time period, the gain or the loss of that land category is rapid, otherwise it is slow; $0 < E_t \leq 1$ indicates that the land category is stable, while $E_t > 1$ indicates that the land category is changing active.

(3) Trajectory analysis

By using statistical spatial analysis of the LUCC trajectory for the study area, we can identify the spatial-temporal characteristics of LUCC for a defined time period (Mertens and Lambin, 2000; Gutman et al., 2004; Van Der Laan et al., 2018; Wang et al., 2020). A change in direction in the time series can be represented by different codes, the letters or numbers of each code representing the land-use categories during different time periods. Based on the land-use classification system for the study area, '1' represents 'forest land', '2' represents 'grassland', '3' represents 'wetland', '4' represents 'water', '5' represents 'desert', '6' represents 'cultivated land', and '7' represents 'construction land'. Because there are fewer than 10 categories, the trajectory codes for each category can be calculated using the following formula, in the 'Raster Calculator' mode within ArcGIS (Liu et al., 2017):

$$T_{ij} = (G_1)_{ij} \times 10^{n-1} + (G_2)_{ij} \times 10^{n-2} + \cdots + (G_n)_{ij} \times 10^{n-n} \quad (7)$$

where T_{ij} is the trajectory code from raster i to j; n is the number of time nodes; and G_1, G_2, . . ., G_n are the land category codes for each time node. When the number of

Table 2 Identifying the direction of land conversion

Primary transfer type	Secondary transfer type	Example	Explanation
Stable	Continuously stable	111	The initial, middle and final time periods are represented by forest land
	Dynamically stable	121	The initial and final time periods are represented by forest land, and the middle time period is represented by grassland
Sub-stable	Change during the earliest stage and stability in the later stages	122	The initial time period is represented by forest land, and the middle time and final time period are represented by grassland
	Change during the latest stage and stability in the earlier stages	112	The initial and middle time periods are represented by forest land, and the final time period is represented by grassland
Unstable		123	The initial time period is represented by forest land, the middle time period is represented by grassland, and the final time period is represented by wetland

land categories is more than 10, a trajectory code is usually replaced by a letter.

Based on the spatial statistics of the land-use transfer trajectories, a change in direction can be divided into three primary types of transfer (stable, sub-stable and unstable), and then divided further into secondary types of transfer (Table 2).

2.3.3 Hot-spot analysis

Hot-spot analysis has been widely used to explore the spatial heterogeneity of ESV (Chen et al., 2019; Zhang et al., 2020). Hot spots and cold spots represent statistically significant high-value spatial agglomerations and low-value spatial agglomerations, respectively, of ecosystem services. Equ. (8) calculates the G_i^* value of ESV. In order to facilitate interpretation and analysis, G_i^* is standardized by Equ. (9).

$$G_i^* = \frac{\sum_b^n W_{ab}(d) S_a}{\sum_b^n Sb} \tag{8}$$

$$Z(G_i^*) = \frac{G_i^* - E(Gi^*)}{\sqrt{Var(G_i^*)}} \tag{9}$$

where $W_{ab}(d)$ is the spatially weighted coefficient for the geospatial units a and b; S_a, S_b are the ESV for the geospatial units a and b; $E(G_i^*)$ is the mathematical expectation of G_i^*; $Var(G_i^*)$ is the variance of G_i^*. Typical probabilities are 0.01, 0.05 and 0.10; typical confidence intervals for the Z score are 90%, 95% and 99%, which lie between < -1.65 and > 1.65, < -1.96 and > 1.96, and < -2.58 and > 2.58, respectively. If the Z score is positive and significant, it indicates that the ESV or its variation for unit a and adjacent unit b is relatively high (higher than the average), i.e. it belongs to a hot-spot area. In contrast, if the Z score is negative and significant, it indicates that the ESV or its variation for unit a and adjacent unit b is relatively low (lower than the average), i.e., it belongs to a cold-spot area.

2.3.4 Gravity center analysis

The gravity center model is an important analytical tool for studying spatial variation in factors driving the processes of regional development (Zhang et al., 2020). During the process of decreasing or improving regional ecosystem service function, the center of gravity is constantly moving, which can be reflected in the spatial trajectory of change in ESV.

$$\bar{x} = \sum_{e=1}^{n} (m_{et} \cdot x_e) / \sum_{e=1}^{n} m_{et} \tag{10}$$

$$\bar{y} = \sum_{e=1}^{n} (m_{et} \cdot y_e) / \sum_{e=1}^{n} m_{et} \tag{11}$$

where m_{et} is the ESV of evaluation unit e at time t; x_e is the x coordinate of geographic center of evaluation unit e, $\bar{x}$ is the x coordinate of gravity center for ESV at time t; and y_e is the y coordinate of geographic center of evaluation unit e, $\bar{y}$ is the y coordinate of gravity center for ESV at time t.

3 Results

3.1 Land-use transfer matrix

Comparing the area covered by each land category, forest land had the highest total area, followed by cultivated land. From 2000 to 2020, the area of forest land and wetland decreased, forest land from 60.82% in 2000 to 58.06% in 2020, while wetland decreased by 0.28% (Table 3). During the 20 yr, the area of water, desert and construction land increased continuously, while the area

Table 3 Area and proportion of land-use categories in national nature reserves of Jilin Province, China for the years 2000–2020

Category	2000		2010		2020	
	Area / km^2	Proportion / %	Area / km^2	Proportion / %	Area / km^2	Proportion / %
Forest land	7572.35	60.82	7170.26	57.59	7228.21	58.06
Grassland	1284.96	10.32	1584.69	12.73	1429.82	11.48
Wetland	255.01	2.05	285.96	2.30	220.22	1.77
Water	738.13	5.93	740.48	5.95	886.09	7.12
Desert	231.55	1.86	238.38	1.91	272.07	2.19
Cultivated land	2301.57	18.49	2360.91	18.96	2313.37	18.58
Construction land	66.20	0.53	69.08	0.55	99.98	0.80

of cultivated land and grassland increased more dynamically.

Fig. 2 shows the transfer matrix of the study area from 2000 to 2020. According to the results, during 2000–2010, the transferred area was largest for forest land, represented mainly by conversions to grassland and cultivated land, and the conversion to cultivated land and grassland both exceeded 50 km^2. The scale of land transfer in 2010–2020 was higher than that of the previous decade, but, from the transfer matrix, it can be seen that for ecological land such as forest land, grassland, water and wetland, the gains and losses essentially mirrored each other, indicating that Jilin Province had implemented a balanced policy of occupation and compensation. The overall area of forest land and grassland increased during 2010–2020. Ecological restoration measures such as returning cultivated land to forest land (grassland) within the nature reserves played a positive role in the maintenance and restoration of the ecosystems in the study area.

3.2 Land-use stability analysis

3.2.1 Interval level

At the interval level, the rate of change was not uniform, as indicated in Fig. 3. The intensity of LULC for the study area increased significantly from 2000 to 2020. Compared with the uniform baseline, in 2000–2010 there was a slow change in land-use intensity, while in 2010–2020 there was rapid change. Similarly, the LULC of Jilin Province as a whole showed a slow change in intensity from 2000 to 2010, and rapid change from 2010 to 2020. Over the 20 years, the change in intensity was lower for the study area than for Jilin Province.

During 2000–2010, the stability index for the LULC in the study area was 1.04, while for Jilin Province as a

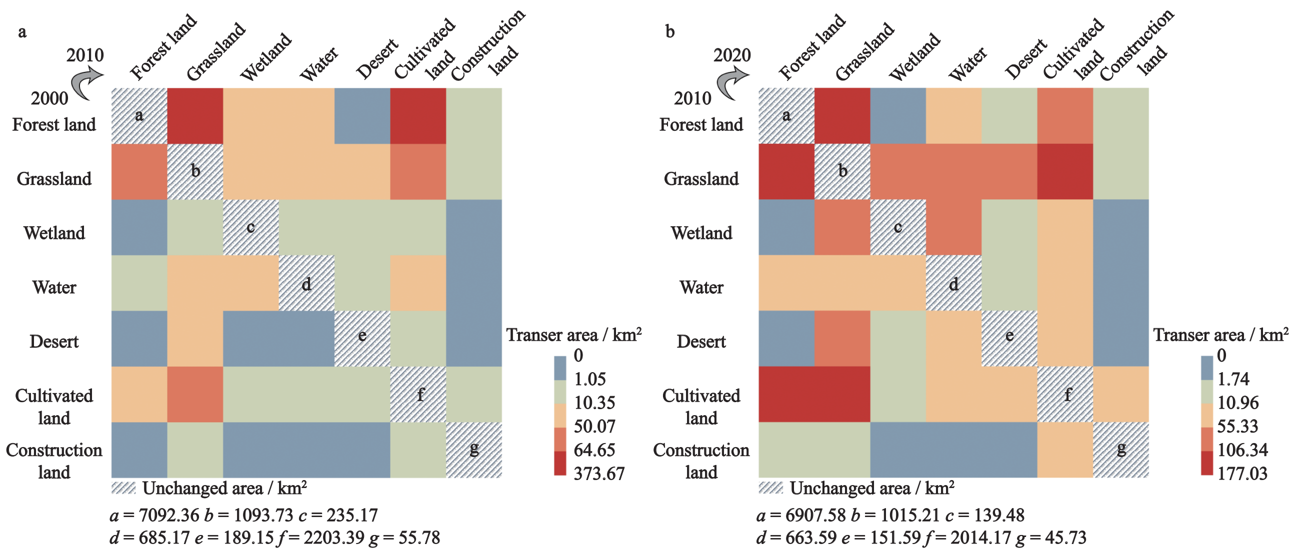

Fig. 2 The land-use transfer matrix in national nature reserves of Jilin Province, China for a. the years 2000–2010, b. 2010–2020

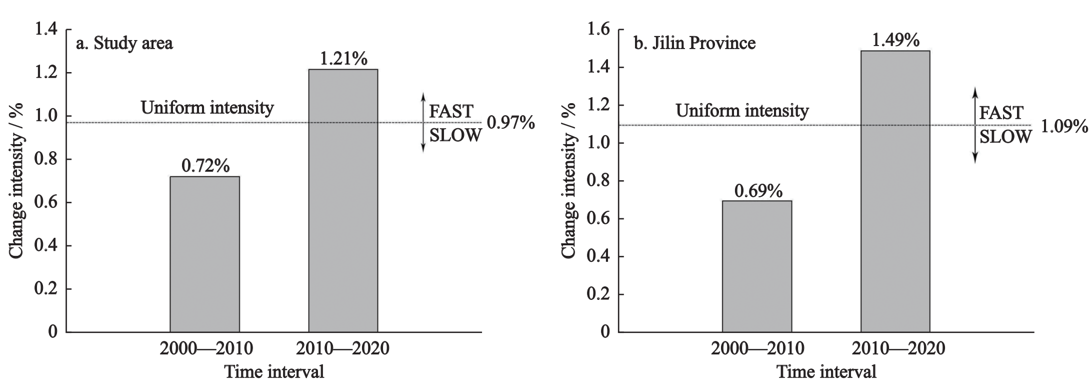

Fig. 3 Intensity of land-use change at the interval level in national nature reserves of Jilin Province, China during 2000–2020

whole it was slightly higher. And during 2010–2020, the stability index was 0.82. The change in LULC within the study area was relatively stable.

3.2.2 Category level

Fig. 4 shows the results of the intensity analysis at the category level. From 2000 to 2010, the largest increase in scale and intensity was seen for grassland gain, both within the study area and in Jilin Province as a whole. Grassland appeared to affect forest land more intensively than the other land categories. From 2010 to 2020, the intensity of gain and loss for each land category increased. The intensity of grassland gain decreased, while the intensity of grassland loss increased. Desert showed the greatest intensity in gain and wetland showed the greatest intensity of loss. Compared with the previous decade, the intensity of gain and loss of cultivated land was faster than the uniform intensity of LUCC for the study area. During the overall study period, the scale of forest land transfer within the study area was the largest, while the intensity of overall LUCC was the smallest.

The stability index could be used to characterize the stability of each category during the study period (Table 4). There was active gain of cultivated land and construction land, and loss of cultivated land, construction land and desert, across the time period, while the other categories were relatively stable.

3.2.3 Trajectory of land-use change

We also identified the stability of LULC for each nature reserve using a statistically determined land-use change trajectory (Table 5).

Stable change accounted for 86.08% of the total area, of which continuously stable change accounted for 83.75%. Continuously stable forest land represented the largest area, with a high degree of aggregation, accounting for more than 50% of the overall area. This was mainly distributed in the east of Jilin Province (Fig. 5). The continuously stable cultivated land, grassland and desert were mainly distributed within the inland wetland reserves and geological relic reserves in the middle and west of Jilin Province. Compared with forest land, the degree of aggregation of cultivated land, grassland

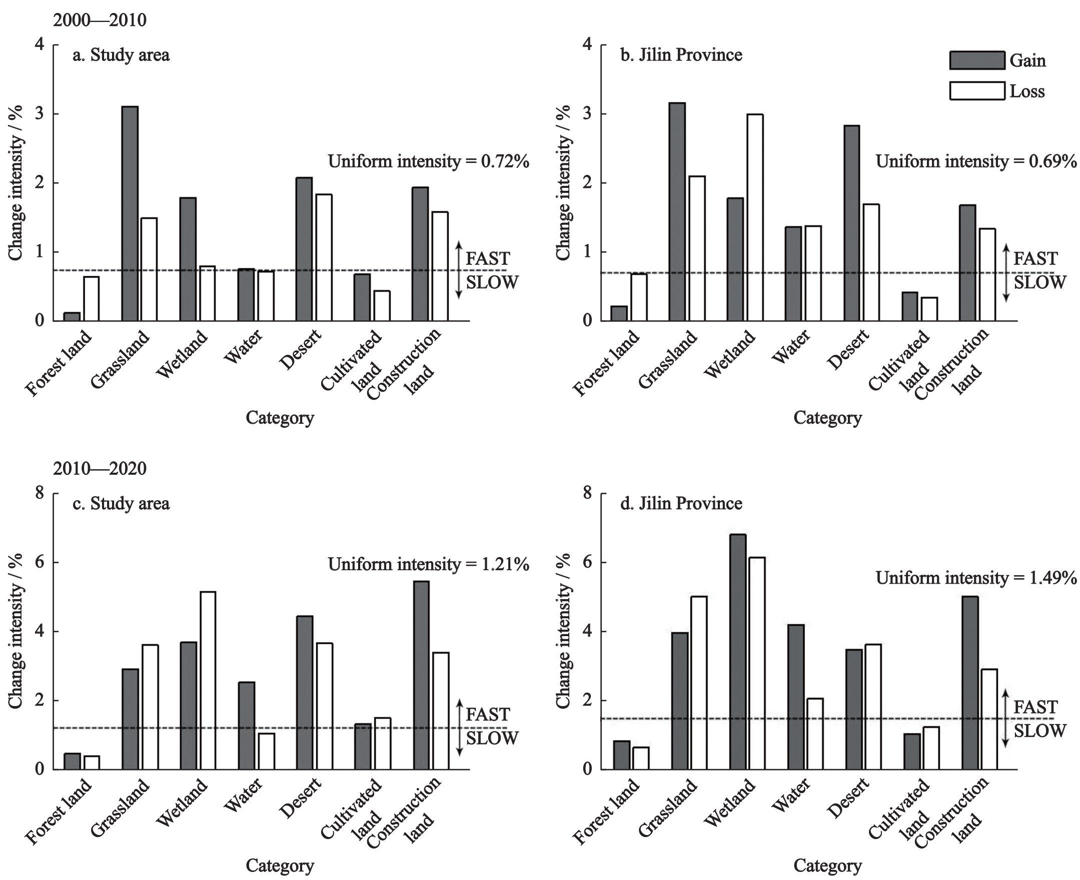

Fig. 4 Intensity of land-use change at the category level in national nature reserves of Jilin Province, China during 2000–2020

Table 4 Stability index at the category level in national nature reserves of Jilin Province, China during 2000–2020

Category	2000–2010		2010–2020	
	Gain	Loss	Gain	Loss
Forest land	0.50	0.93	0.53	0.56
Grassland	0.98	0.71	0.73	0.72
Wetland	0.99	0.26	0.54	0.83
Water	0.55	0.52	0.60	0.50
Desert	0.73	1.08	1.28	1.01
Cultivated land	1.62	1.25	1.25	1.18
Construction land	1.15	1.17	1.08	1.17

and desert was relatively low. The continuously stable wetland and water were mainly distributed within nature reserves with a water system passing through them. The area of continuously stable construction land was the smallest.

Dynamically stable type described land that changed land use during the middle time period but then reverted to the former land use during the later time period. This transfer direction was mostly distributed within fine patches in a small area, and may have been caused by short-term land occupation or an error in the land category classification during image processing. Dynamically stable forest land area was larger compared with the other land categories.

Sub-stable change accounted for 13.16% of the total area. It can be seen from Fig. 6 that the area that changed during the earlier time period and returned to a stable land use during the later time period stage was relatively small, and was represented mainly by the conversion of forest land into grassland. There was an increase in areas that remained stable during the early time period but then changed during a later time period; they were represented mainly by conversions into grassland. At the same time, wetlands within the western inland wetland reserves converted into grassland, and areas converted into cultivated land and water also increased greatly. Grassland and forest land were reclaimed as cultivated land to varying degrees, and conversion into water occurred mainly at boundaries where water, wetland and grassland intersected.

Unstable change refers to continuous change between 2000 to 2020, and it represented the smallest area, accounting for only 0.76% of the total. The conversion of forest land to grassland and cultivated land accounted

Table 5 Trajectory of land-use change in national nature reserves of Jilin Province, China during 2000–2020

Primary transfer type	Secondary transfer type	Tertiary transfer type	Code / example	Area / km^2	Proportion / %
Stable	Continuously stable	Continuously stable forest land	111	6862.80	55.12
		Continuously stable grassland	222	724.11	5.82
		Continuously stable wetland	333	112.16	0.90
		Continuously stable water	444	632.63	5.08
		Continuously stable desert	555	129.38	1.04
		Continuously stable cultivated land	666	1927.22	15.48
		Continuously stable construction land	777	38.70	0.31
		Subtotal		10426.99	83.75
	Dynamically stable	Dynamically stable forest land	121	153.44	1.23
		Dynamically stable grassland	232	45.98	0.37
		Dynamically stable wetland	323	1.72	0.01
		Dynamically stable water	424	34.95	0.28
		Dynamically stable desert	525	15.69	0.13
		Dynamically stable cultivated land	626	34.92	0.28
		Dynamically stable construction land	727	3.25	0.03
		Subtotal		289.94	2.33
Sub-stable	Change during the earlier stage and stability in the later stages		122	510.36	4.1
	Change during the later stage and stability in the earlier stages		112	1128.09	9.06
Unstable			123	94.36	0.76

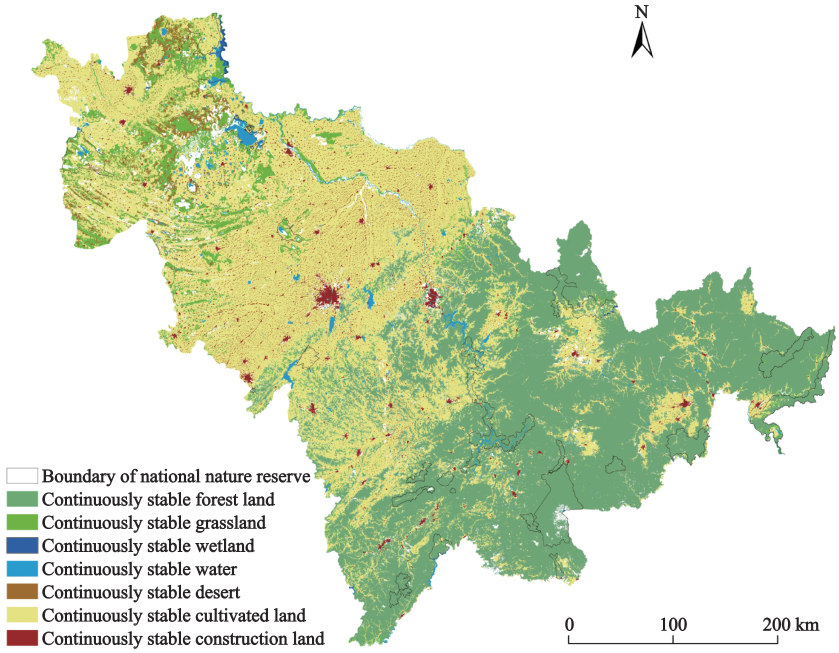

Fig. 5 Spatial distribution of continuously stable land use in national nature reserves of Jilin Province during 2000–2020

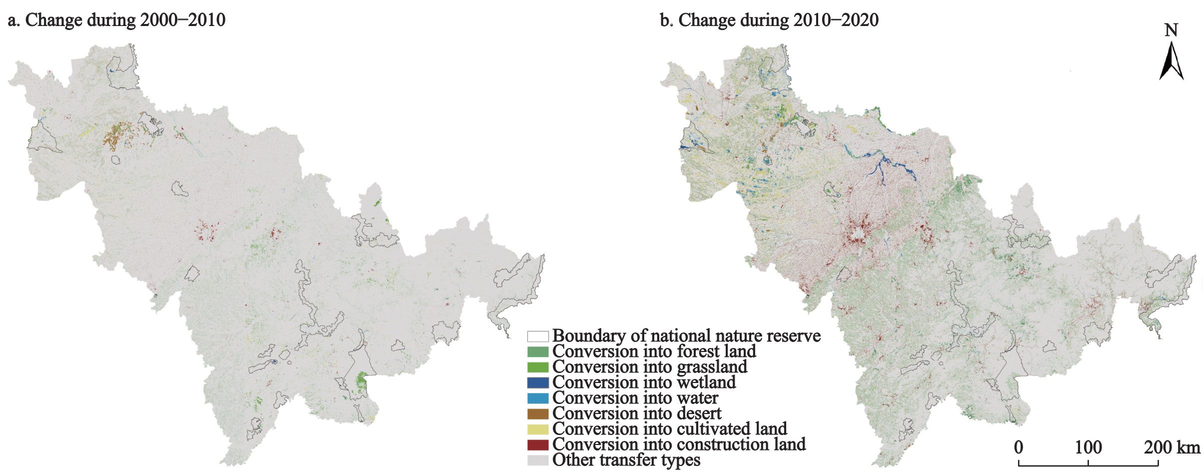

Fig. 6 Spatial distribution of sub-stable land-use change in national nature reserves of Jilin Province during 2000–2020

for the largest area, and was mainly distributed alongside water. The change in trajectory for grassland to wetland and water, and forest land to grassland and desert, also represented larger areas, and these were mainly concentrated in the Xianghai and Momoge reserves in the west of Jilin Province.

Overall, during the period 2000–2020, the LULC of the study area was relatively stable, with only 16.25% of area changing land category. Based on the proportion of continuously stable change across the total area of the nature reserves, the reserves could be divided into stable nature reserves (where the proportion was more than 90%), sub-stable nature reserves (where the proportion was between 80% and 90%) and actively changing nature reserves (where the proportion was less than 80%). Looking at the spatial distribution (Fig. 7), the actively changing reserves were mainly distributed in the central and western parts of Jilin Province; the forest ecological reserves and wildlife reserves were relatively stable, while the stability of inland wetland nature reserves and geological relic nature reserves was poor.

3.3 Impact of land-use change on regional ecosystem services

3.3.1 Hot spot analysis

Change in LULC can cause changes in the value of eco-

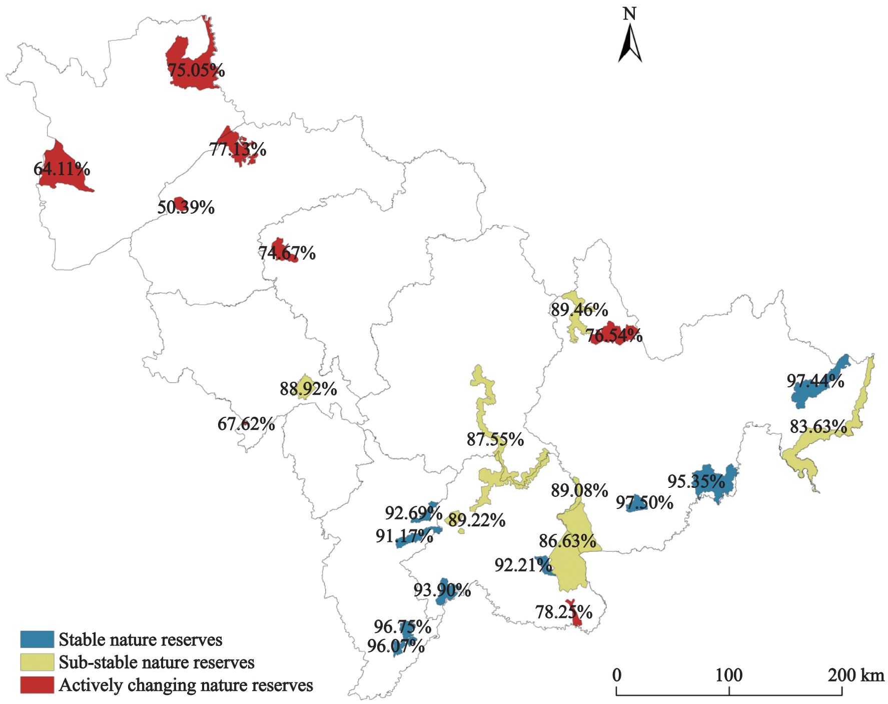

Fig. 7 Stable land-use in national nature reserves of Jilin Province, China during 2000–2020

system services (Wu et al., 2011; Eziz et al., 2012; Wang et al., 2014; 2021b). Based on the evaluation coefficient of Xie et al. (2008), the average value of ecosystem services (AESV) and its variation was calculated for the both the reserves and counties (cities, districts) in Jilin Province. Hot-spot analysis was then used to explore the impact of LUCC on the regional ecological functions of the reserves.

It can be seen from Figs. 8, 9 that the location of high-value clusters of AESV were consistent with a more dense distribution of national nature reserves in Jilin Province, and areas with high concentrations of AESV fell between 2000 and 2020 were roughly consistent with areas of AESV reduction within nature reserves. Hence one could see that the AESV was generally higher in areas where there was a concentration of nature reserves with a high LULC stability. However, the ESV of nature reserves will change with LUCC, and the regional ecosystem service functions can also change to varying degrees.

3.3.2 Gravity center analysis

The ESV gravity center for Jilin Province was calculated for 2000, 2010 and 2020. Throughout the last 20 yr it has been located in Huadian City, indicating that the ESV in the eastern regions of Jilin Province was always higher than that in the central and western regions. The change in gravity center location from 2000 to 2020 indicated that it was moving eastward during the study period. The distribution of nature reserves in the eastern Jilin Province is dense, with stable LULC. With the expansion of construction land and cultivated land, ecological land has been continuously occupied, and the role of nature reserves in protecting regional ecosystems has become increasingly obvious.

4 Discussion

4.1 LULC patterns and processes based on stability analysis

In this study, the stability index is introduced to enable comparison of the intensity of LULC changes in nature reserves from the time interval level and land category level, which can reflect the multiple impacts on LULC changes, such as regional policies, social and economic development, in Jilin Province. At an interval level, the LULC stability index showed active change from 2000 to 2010, compared with stability from 2010 to 2020. During the period 2000–2010, large areas of land were converted from forest land to grassland in the Changbai Mountain National Nature Reserve, mainly as a result of tree felling for economic benefit. From 2010 to 2020, construction land expanded a lot in the central of Jilin

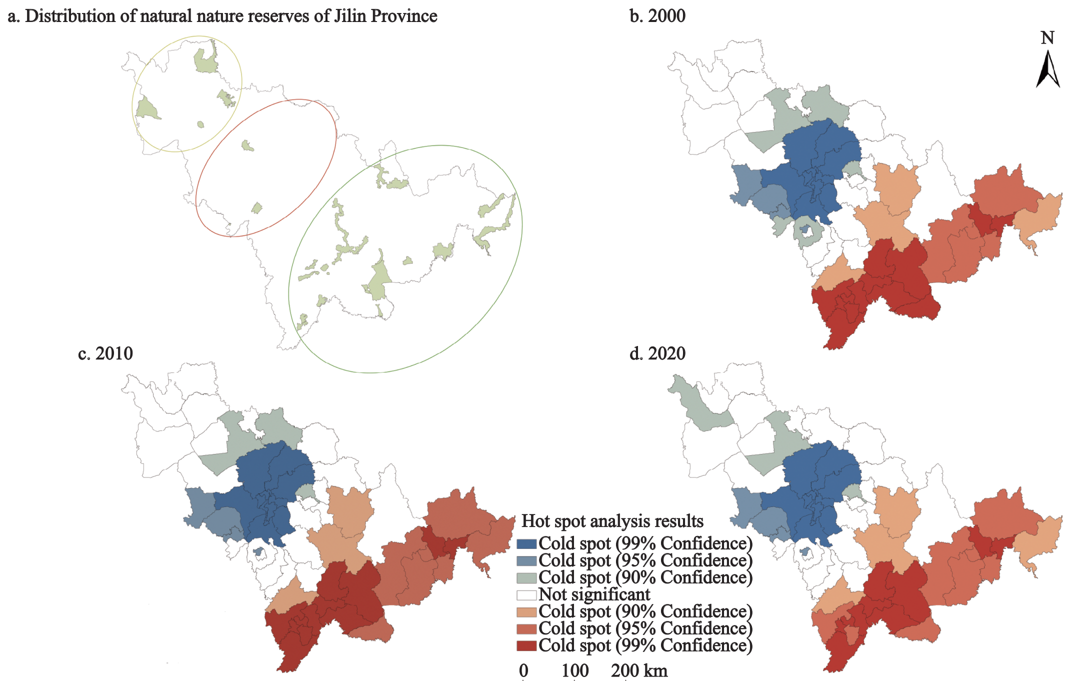

Fig. 8 Average value of ecosystem services (AESV) hot-spot analysis in Jilin Province, China during 2000–2020. Circle presents distribution density of natural nature reserves of Jilin Province

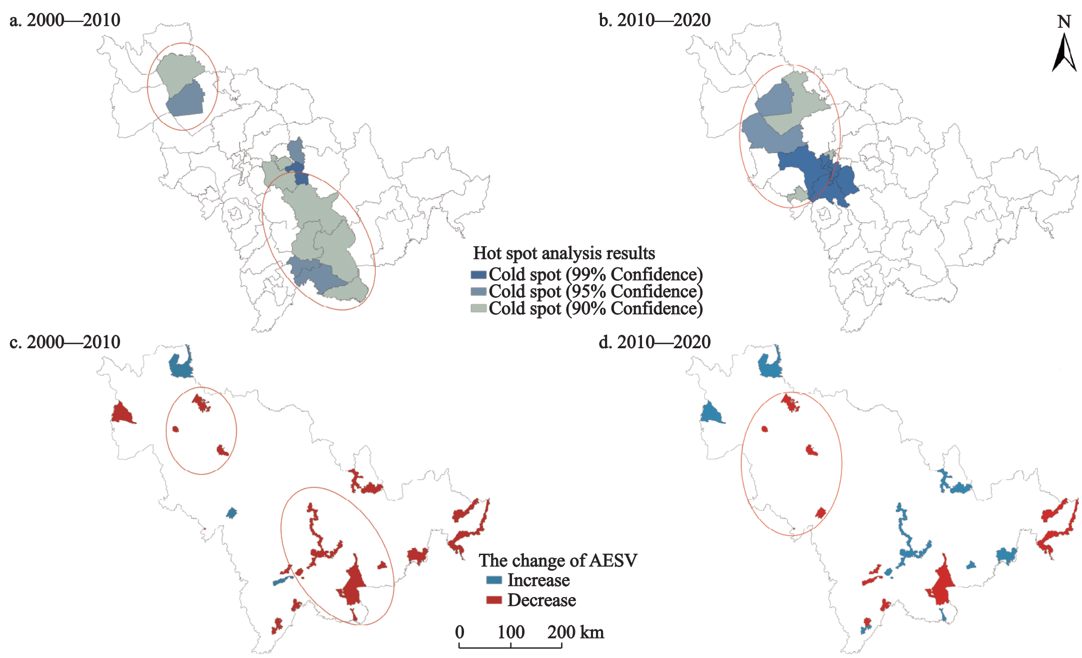

Fig. 9 Hot-spot analysis of Average value of ecosystem services (AESV) variation in Jilin Province and AESV changes within national nature reserves of Jilin Province during 2000–2020. Circle presents that the cold spot areas and the nature reserves with decreased AESV were consistent in spatial location

Province, especially in Changchun City and Jilin City. Overall, changes accelerated across the two time intervals (Fig. 3). During this period, economic forces could be the major driver for LULC changes, which was indicated by the accelerating GDP in Jilin Province across the two time intervals across the two time intervals. With frequent LULC changes in Jilin Province, the intensity of LUCC in the study area also increased, but, compared with the whole province, the LULC of the study area was relatively stable. At the category level, the stability index indicated that conversion to construction land and cultivated land within the study area was active during 2000–2020. Growing market demands and price incentives for agricultural and forest products contributed to a rapid change in LULC. In the past 20 years, the cultivated land within the study area has increased by 11.80 km^2, and has spread into the interior of the central and western nature reserves. Fig. 10 shows that the increase in employed population in Jilin Province included considerable agricultural workers, which is consistent with the continuous increase in cultivated land area. Moreover, a large number of tourist facilities have also been built within nature reserves, causing a further increase in the total amount of construction land, and hindering the process of ecological restoration. And the LUCC will also change the ability of nature reserves and region to provide ecosystem services.

4.2 Regulating LULC changes for nature reserves by linking ecosystem services

Nature reserves provide large amount of ecosystem services, which are of great significance to maintain the regional ecological environment. On the contrary, the regional coordination of ecosystem services can further promote the conservation of nature reserves and regulate the LULC pattern rationally (Wang et al., 2022). Cultivated land reclamation, human-induced climate change, and conservation policies are predominant drivers of LULC change in nature reserves, which leads to successions in landscape pattern and ecosystem services. These factors have been widely confirmed in global studies (Thonfeld et al., 2020). Northeast China is the main grain producing area in China, and cultivated land within reserves has expanded significantly and led to the change of hot spots and gravity center of ecosystem services, which requires reasonable optimization and allocation in nature reserves. However, in recent years, implementation of policies for returning cultivated land to forest land and wetland has restricted further expansion of cultivated land. Ecosystem services are gradually used as a spatial decision-making tool in land use pattern optimization. By quantifying ecosystem service relationships, such as ecosystem service clusters and ecosystem service tradeoffs, the key areas for ecological protection can be identified and differentiated LULC schemes can be developed according to regional development demands. Therefore, linking ecosystem services and taking them as the optimization target to achieve LULC regulation pattern in nature reserves could be an effective way to improve regional ecological security and territorial space.

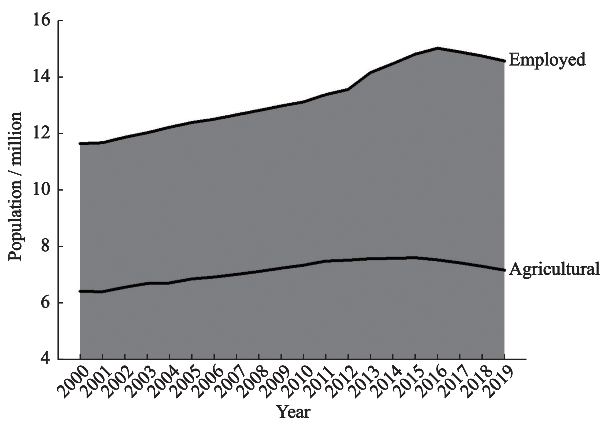

Fig. 10 The population size of agricultural and employed sectors in Jilin Province, China in 2000–2019

The intensity analysis framework provides a feasible way to reveal the comprehensive influence of natural and human factors on LULC. However, intensity analysis in this study involves different land categories across multiple nature reserves, and it is cumbersome applying this approach directly to the discontinuous geographical space of the study area. Using the trajectory of change, we can intuitively see the quantity and direction of LUCC in the study area, and determine the degree of stability of the reserves. However, based on the areas of converted land it is difficult to reveal trends and start to avoid particular types of change, and it is difficult to determine whether the LUCC is affected by natural factors or deliberate human actions. In further studies, different reserves with similar physical and geographical characteristics should be selected, to eliminate the influence of different natural factors, explore the tendency to land transfer within reserves at the level of conversion, and explain LUCC from the perspective of human agency. We need to express changes in intensity at different levels in time and space, and discuss the range of spatial change in order to improve the research framework.

4.3 Implications for national nature reserves conservation

In this study, we also selected national nature reserves from different regions of China to compare the processes and patterns of LUCC with Jilin Province's national nature reserves. We found that processes and patterns of LUCC had some common characteristics. From the results, we obtained the enlightenment to the protection of national nature reserves in China (Wan et al., 2015; Wang et al., 2021a; Xiao et al., 2021). Although both ecological and economic factors significantly affect the probability of designation and area allocated to local nature reserves, ecological factors are still the main determinant (Wu et al., 2018). Therefore, when using the resources of a nature reserve, we should follow the principles of zoning protection and prioritize the protection of its ecology, by strictly controlling cultivated land, prohibiting the unplanned encroachment of forest land and grassland by cultivated land, strengthening the protection of grasslands, and successfully returning cultivated land to forest land, grassland and wetland in core areas. By promoting protection of the reserves, we should be able to realize a coordinated improvement in both the environment and regional economy of nature reserves. In order to prevent further expansion of construction land, the regulation measures should be strengthened in nature reserves, and to expedite the reclamation of rural construction land and various industrial and mining areas currently located in the reserves. In addition, ecosystem services should be introduced into reserve management. Nature reserves play a crucial role in preserving and providing ecosystem services. ESV is indispensable when balancing the need for economic development and ecological protection, because it can clarify the ecological assets and values provided by nature reserves (Chen, 2020). Bringing ecosystem services into the management process for nature reserves can highlight the natural ecological advantages of the reserves, and help maintain an ecological balance while coordinating the development of regional economic growth.

5 Conclusions

A hierarchical LULC intensity analysis makes it easier to connect patterns in LULC with the processes of social and economic development, and helps researchers and managers understand more deeply the inter-relationships between humans and landscape. In this study, we built a stability index to measure the LULC changes in National Nature Reserves of Jilin Province and quantified their impact on regional ecosystem services. The main conclusions are as follows: 1) the proportion of stable land area was 86.08% in the study area, and the change in LULC intensity was lower for the study area than for Jilin Province, while the stability index was higher during 2000–2010 (1.04) than 2010–2020 (0.82). 2) the stability of nature reserves is higher in the eastern regions of Jilin Province, while change in the LULC of central and western reserves is more active; the LULC of forest ecological reserves and wildlife reserves is relatively stable, while the stability of inland wetland and geological relic reserves is relatively lower. 3) the LUCC intensity increased significantly during the 20 yr, while the conversion of grassland, wetland, water, desert and construction land was more rapid than cultivated land and forest land. 4) the spatial pattern of AESV was relatively stable during 2000–2020. The hot spots were distributed in the areas with concentrated national nature reserves in Jilin Province. National nature reserves are hugely important for the protection and maintenance of regional ecological functions. The LULC of nature reserves not only changes the value of ecosystem services, but also affects regional ecosystem services to varying degrees.

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