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FOREST LANDSCAPE PATTERN DYNAMICS OF LUONING COUNTY IN HENAN PROVINCE AND ITS DRIVING FORCES

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ABSTRACT: With the help of ARC/INFOR and ERDAS software, based on the information from forest resources distribution maps and TM images, four indices were chosen to analyze spatial pattern changes of forest landscape of Luoning County, Henan Province from 1983 to 1999. The results showed that: 1) The number and total area of patches were rapidly increased with time changes. The fragmentation degree of the landscape was increasing greatly. 2) The area of some forest patch types, especially shrub forest, economic forest, *Populus* spp. forest, *Quercus* spp. forest, sparse forest, deserted grassland etc. had been greatly changed. 3) The fragemation degree of each forest patch type became greater from 1983 to 1999. 4) The transition probabilities of deserted forest, economic forest, *Pinus tabulaeformis* forest, *Populus* spp. forest exceed 85%, *Robinia pseuoacacia* forest, deserted grassland, 65% and *Quercus* spp. forest, non-forest, shrub forest had smaller ones, which were 26.5%, 29.1% and 45.3%, respectively. The main transition trends of various patches were non-forest and *Quercus* spp. forest. During the course of transition, the types that 50% of area was remained were *Quercus* spp. forest, non-forest and shrub forest. According to above analyses, the main driving forces, such as the management policies, market economy factors and influences of human activities etc. were brought out.

KEY WORDS: forest; landscape pattern; driving forces; Luoning County

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1 INTRODUCTION

Forest landscape pattern is a spatial arrangement and combination form of various forest landscape elements, which are different in sizes and shapes. It is not only the detailed embodiment of forest landscape heterogeneity, but also the result of all kinds of ecological processes in different scales (WANG, 1995). The distribution, form and constitution of forest resources, and the transformation of energy flow, material cycle, and species migrating in the forest are made and affected by forest landscape pattern (XIAO *et al.*, 1997; HONG *et al.*, 1994). It has a close relationship with the abilities of anti-disturbance, restoration, stability and biodiversity of forest ecosystem (FU, 1995). The forest landscape pattern is in development, and today's pattern resulted from the past landscape flows including various kinds of ecological processes of nature, society and economy. By analyzing the landscape pattern changes at different times, the landscape ecological processes of forest were reflected, the succession mechanism and law in forest landscape were revealed, the variation tendency of the forest landscape in the future was predicted, and realized the sustainable utilization of forest resources at last (OLSSON and AUSTRHEIM, 2000; REID *et al.*, 2000; PAN and DOMONG, 1999; NAGASAKA and NAKAMURA, 1999).

Driving force analysis is an important aspect of LUCC (Land Use/Cover Change) study (WANG *et al.*, 2001). Forest landscape, as an important land-use type, takes an important position in studying mountain region and basin's LUCC because forest coverage influences environmental change in mountain areas and basins directly. Consequently the changes of the forest landscape pattern have been paid much attention to by

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numerous scholars (JIANG *et al*., 2002; YANG *et al*., 2001; JIAN and LI, 2001; SHAO, 1991). However the traditional studies on forest landscape pattern changes were most limited to quantitative analysis, and lacked the mechanism analysis of the changes. Therefores, this paper took Luoning County, in the middle reaches of the Yihe River and the Luohe River in Henan Province, as an example, with the help of ARC/INFOR and ERDAS software, based on the information from forest distribution maps and TM images from 1983 to 1999, analyzed the changes of the forest landscape pattern from 1983 to 1999, and probed into the possible reasons of the change in many aspects, such as the management policies, the industrial structure of forestry and human disturbances, etc.

Luoning County lies in 34°5′–34°38′N, and 111°8′–111°49′E (Fig.1). Its total area is 2335.49km^2, in which the mountain area accounts for 72% of total area and the altitude is 276–2094m above sea level. The topographic types in the area are complicated, with Xiong'er Mountain stretching to south, Xiao Mountain lying in the northwest, and the Luohe River running from east to west. The climate of this region belongs to monsoon climate, with four clear seasons. The annual average precipitation is 613.6mm, and temperature 13.7℃. The soil types are mainly cinnamon soil, brown soil and meadow soil. Natural composition of vegetation belongs to North China Flora, mainly consisting of deciduous broad leave forests of warm-temperate zone, such as Fagaceae, Betulaceae, Salicaceae, Acer etc. The luxuriant natural secondary forest is located in the upside of Xiong'er Mountain and Xiao Mountain 1000m above sea level. In low mountain areas with an altitude less than 500m above sea level, the types of vegetation are simple, and the rate of the vegetation coverage varies greatly, with shrub and brushwood to be as the main types. In addition, the natural secondary forest and artificial economic forest are distributed in the form of patches. It is the main region of afforesting, because there are less cultivated lands but more deserted mountains. In hills and plains below 500m above sea level there are mostly the agriculture and forestry inter-distributive areas, and the vegetation is mainly the shelter forest for farmland and mud flat.

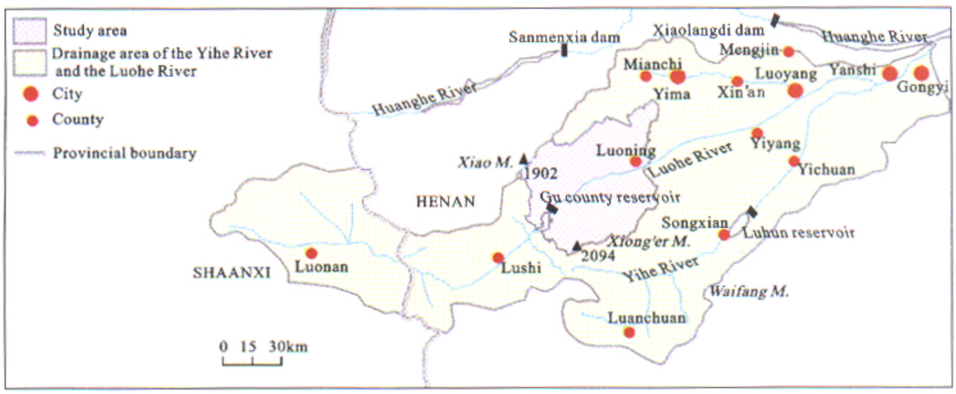

Fig. 1 The location of Luoning County

2 MATERIALS AND METHODS

2.1 Materials

The data used in this paper was derived from: 1) vegetation Type Maps of Luoning County in 1983 and 1999 from investigation in the field; 2) TM image (125/036) on May 4, 1999 provided by the Satellite Base of Remote Sensing of CAS; 3) the Digital Grid Topographic Maps on the scale 1:50 000 in 1975 provided by National Foundation Geographical Information Center; and 4) the data of the natural geography and forest resources changes of Luoning County obtained by the investigation in the field etc.

2.2 Methods

2.2.1 Disposal of image data

Through the data compound and interpretation as mentioned above, the maps of forest resources distribution pattern of Luoning County between 1983 and 1999 (Fig. 2) and the dynamics database of forest resources were gotten. Topographic map in 1975 were put into ARC/INFOR for vector graph conversion and were once again projected in ERDAS IMAGINE; then was sampled from TM image in 1999 and the forest

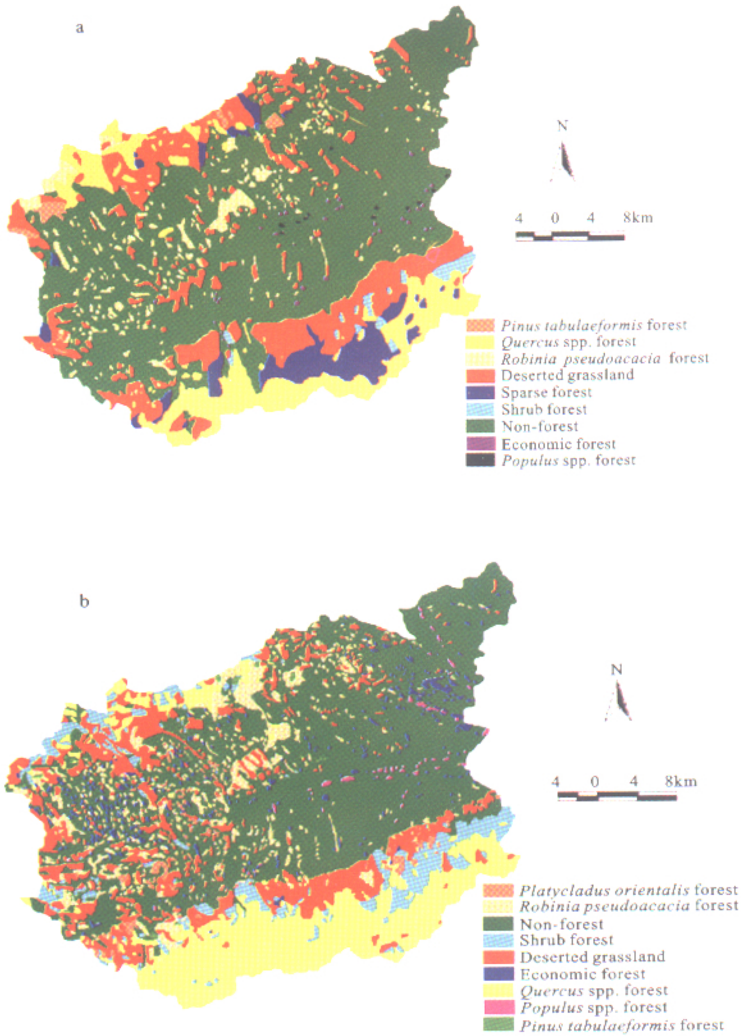

Fig. 2 The forest resources distribution pattern of Luoning County in 1983 (a) and 1999 (b)

resources map in 1983 were done with the projected topographic map as the geographic reference. We had linked and analyzed the raster and vector images in different spatial scales, times and projection systems, after DEM model generated from vector topographic map was input to the geography space database, receiving the data from forest resources distribution map in 1999 with supervised-classification which was sampled in TM image and input into GIS, and the vector graph conversion which was again sampled in forest resources distribution map and input into GIS.

2.2.2 Landscape indices

According to previous study (FORMAN,1995), landscape indexes were selected as follows:

(1) Patch number (*NP*), $NP=n_i$, includes the total number of patches of all landscape and the number of patches of a single type.

(2) Mean patch area (*MPS*), $MPS=\frac{1}{n_i}\sum_{j=1}^{n} a_{ij}$, is the most basic space characteristics of landscape patterns, and the foundation for calculating other space characteristics indices.

(3) Fragmentation index (*C*), $C=\sum n_i/A$, is to weigh the complexity of a landscape.

(4) Stability (*S*), $S=\frac{1}{m}\sum_{j=1}^{n} Pro_j$. The greater *S* value is, the stronger the forest landscape resistance to the change of natural environment and mankind interference.

In above formulas, n_i is the number of patches in the *i*th landscape type, a_{ij} is the area of the *j*th patch in the *i*th landscape type, *A* is the whole area of landscapes, *m* is the period, Pro_i is the probability of transforming to the same landscape type in the transformation matrix of the landscape.

3 DISCUSSIONS AND ANALYSES

3.1 Classification of Forest Landscape Elements

Forest landscape is a kind of natural scenery with forest vegetation as the prime part in the visual scope of people. The division of the landscape types of forest should regard the external characteristics of the forest landscape as the basis (JIAN and LI, 2001). The landscape dynamics classification system of forest should be set up according to the dominant composition of vegetation. On the basis of research purpose, the characteristics of research objects, and related national rules, the classification system not only reflects the former landscape types of forest, but also accurately denotes the evolvement of the latter type (Table 1).

In the dynamics classification of forest landscape, *Platycladus orientalis* forest was incorporated into *Pinus tabulaeformis* forest; economic forest only included *Phyllostachys glauca* forest in 1983, whereas in 1999 it included *Phyllostachys glauca* forest and other economic forests (such as apple forest and so on); the covering regions of *Themeda triandra* var. *joponica* meadow in 1983 and 1999 were referred to the wasteland of meadow; it was non-forest land that referred to the area except the above vegetation coverage.

3.2 Dynamics of the Forest Landscape Structure

The dynamics of the landscape structure was an important aspect of the forest landscape changes, and it was the space pattern of the elements that formed the landscape (WANG *et al.*, 1996). According to their important degree and function, landscape elements were divided into 3 types: patch, corridor and matrix. From the forest resources maps in 1983 and 1999, the matrix of landscape in 1983 was non-forest that had the largest area, in 1999 it was still non-forest land that occupied the absolute dominant position, but the area was decreased and more *Populus* spp. forest, *Platycladus orientalis* and *Robinia pseuoacacia* forest were distributed there. As for patch level, the total area of the patches of forest landscape was increased, and the amount of patches increased greatly from 556 to 1494. Patches of some types (such as sparse forest) disappeared, and new patch appeared (such as *Platycladus orientalis* forest), which made the fragment degree increased evidently.

Table 1 Forest Landscape elements classification system

	Temperate needle forest	Deciduous broad-leaved forest			Bamboo forest	Deciduous broad-leaved bush	Sparse forest	Meadow	Non-forest
	Temperate ever-green needle forest	Typical deciduous broad-leaved forest			Warm bamboo forest	Warm Deciduous broad-leaved forest	Sparse forest	Meadow in mountain and hill	Non-forest
1983	*Pinus tabulaeformis* forest	*Quercus* spp. forest	*Robinia pseuoacacia* forest	*Populus* spp. forest	*Phyllostachys glauca* forest	*Vitex negundo* var. *heterophylla+Zizyphus spinosus* bush	Sparse forest	*Themeda triandra* var. *joponica* meadow	Non-forest
1999	*Pinus tabulaeformis* forest; *Platycladus orientalis* forest	*Quercus* spp. forest	*Robinia pseuoacacia* forest	*Populus* spp. forest	*Phyllostachys glauca* forest; Economic forest	*Vitex negundo* var. *heterophylla+Zizyphus spinosus* bush		*Themeda triandra* var. *joponica* meadow	Non-forest

3.3 Dynamics of Forest Landscape

The spatial relationship among landscape elements was an important characteristic of the landscape patterns. By analyzing the spatial relationship among landscape elements, the characteristics, intensity and ways of interaction of several landscape elements, we could make the dynamics of forest landscape structure out.

3.3.1 Changes of patch area

The areas of forest landscape types, such as shrub forest, economic forest, *Populus* spp. forest, *Quercus* spp. forest, sparse forest, and deserted grassland, obviously changed from 1983 to 1999 (Table 2). The areas of shrub forest, *Robinia pseudoacacia* forest, economic forest and *Populus* spp. forest greatly increased, but the areas of non-forest land, sparse forest, deserted grassland and *Pinus tabulaeformis* forest were reduced to some extent.

3.3.2 Change of Fragmentation Degree of Patches

The fragmentation degree of landscape can be reflected by some indices, such as patch number, mean patch area, the largest and smallest area of patch etc. (Table 2). The number of all the types of patches had increased, especially *Robinia pseuoacacia* forest, economic forest and *Populus* spp. forest absolutely increased to large extent, others relatively increased to

Table 2 The forest patch indices of Luoning County in 1983 and 1999

		R. F	N. F	SH.F	D.G	E.F	S.F	*Pop*.F	*Pinus* F	Q.F	Total
Total area(ha)	1983	12032.9	137544.0	2511.7	39674.7	660.4	12419.9	260.2	2082.9	26423.9	233610.6
	1999	19604.4	116113.0	14411.0	32791.0	5706.4	0.0	4876.3	554.6	39559.3	233615.9
Maximum patch area(ha)	1983	1368.3	137171.4	1099.7	12372.9	33.5	7660.4	31.5	805.2	19145.6	137171.4
	1999	1885.6	112618.1	5433.5	5314.2	363.8	0.0	334.0	88.75	33068.2	112618.1
Miximum patch area(ha)	1983	4.3	39.4	44.6	0.1	9.1	40.5	13.7	11.42	0.4	0.1
	1999	4.3	1.0	2.1	1.1	3.1	0.0	4.0	2.8	9.2	1.0
Mean patch area(ha)	1983	45.6	34386.0	209.3	252.7	18.4	621.0	21.7	173.6	677.5	420.2
	1999	38.5	3870.4	160.1	108.6	18.6	0.0	32.7	24.1	482.4	156.4
Patch number	1983	264	4	12	157	36	20	12	12	39	556
	1999	509	30	90	302	307	0	151	23	82	1494

Note: R. F is *Robinia pseudoacacia* forest; N. F is non-forest land; SH. F is shrub forest; D. G is deserted grassland; E. F is economic forest; S.F is sparse forest; *Pop*. F is *Populus* spp. forest; *Pinus* F. is *Pinus tabulaeformis* forest; and Q. F is *Quercus* spp. forest.

some extent, but that of sparse forest had decreased to zero. At the same time, the average area of every forest type decreased except for *Populus* spp. forest, and the change of the largest and smallest area of all the types showed polarized phenomenon. The area of the largest patch of *Robinia pseuoacacia* forest, shrub forest, economic forest, *Populus* spp. forest and *Quercus* spp. forest increased quickly, but the smallest patch decreased. The maximum and minimum areas of other landscape patches were all decreased.

3.4 Stability of Patches

The stability of each patch can be shown through the transformation matrix among landscape patches. The results of calculation of the forest landscape dynamics transformation matrix in Luoning County from 1983 to 1999 was shown in Table 3. From Table 3, we could see that the transformation probability of sparse forest, economic forest, *Pinus tabulaeformis* forest, *Populus* spp. forest were all above 85%; and those of *Robinia pseuoacacia* forest, deserted grassland were more than 65%. But the transformation probability of *Quercus* spp. forest, non-forest, shrub forest were relatively lower, 26.5%, 29.1% and 45.3% respectively, the main transformation directions of all kinds of patches in the departments were non-forest land and *Quercus* spp. forest.

According to the definition of the stability degree (ZHAO, 1990) and Table 3, we could obtain such an order of stability degree of all forest types: *Quercus* spp. forest (74.5%) > non-forest land (70.9%)> shrub forest (54.7%)> deserted grassland (35%)> *Robinia pseudoacacia* forest (30.2%)> *Populus* spp. forest (15.96%) >*Pinus tabulaeformis* forest (6%)> economic forest (2.2%)> sparse forest (0%). There were only three kinds of patch (*Quercus* spp. forest, non-forest, shrub forest) could keep more than 50% of the areas unchanged while all other kinds of patches were transformed and changed obviously. As for the landscape, the relatively small patch had been changed greatly; from the respect of management pattern, we could find out that artificial destroying factors have a tremendous influence on the economic forest and very great problems still exist. The value of economic forest, *Pinus tabulaeformis* forest etc. could be fully realized if it kept relative space-time stability. If the space-time stability of forest landscape was greatly and frequently changed, it would lose the best economic benefits. So its construction and protection was still an arduous task.

3.5 Reasons of Forest Landscape Pattern Change

3.5.1 Reasons of forest landscape pattern structure change

Change of forest landscape structure of Luoning County was obvious from 1983 to 1999, the main reasons were as follows: 1) Even though the forest resources of Luoning County were abundant, the position of forestry in the Gross Domestic Product (GDP) was not important (Table 4). Furthermore the county's population was increasing constantly in the recent two decades, as the statistical data showed, 50 000 persons were added from 1983 to 1999. In order to guarantee the increasing grain demand of people, the conversion degree of the cultivated land was small. 2) The effective implement of forestry policy had protected the forest resources. For example, during 1991–2000, the restriction of forest cutting, conservation and forestation, made the destruction degree of the forest relatively low. According to calculation, the area of reserved forest of Luoning County added up to 140 980ha from 1983 to 1999. These factors prevented

Table 3 The transformation matrix of forest landscapes in Luoning County from 1983 to 1999

1983	1999							
	R.F	N.F	S.F	D.G	E.F	*Pop*.F	*Pinus* F	Q.F
R. F	30.2	39.2	9.5	14.0	1.7	2.1	0.4	2.7
N.F	7.7	70.9	1.6	9.8	3.6	2.2	0.1	3.2
SH.F	2.8	0.0	54.7	1.6	2.2	11.1	0.0	27.6
D.G	8.3	25.8	12.0	35	1.1	2.7	0.4	14.7
E.F	0.1	86.3	1.5	0.0	2.2	7.5	0.0	1.6
S.F	4.2	3.5	17.7	6.4	0.0	0.0	0.0	68.1
Pop.F	0.0	93.9	0.0	0.0	0.0	15.9	0.0	0.0
Pinus F	43.4	16.4	5.0	19.0	0.3	1.4	6.0	8.5
Q.F	1.7	4.0	10.0	8.9	0.1	0.4	0.2	74.5

Note: Every abbreviation's meaning is as same as that in Table 2

Table 4 Proportion of forestry productive value to Gross Domestic Product in Luoning County(%)

Year	1970	1980	1990	1995	1996	1997	1998
Proportion	4.5	6.4	10.1	11.12	14.83	7.6	7.61

effectively woodland areas from decreasing. 3) Driving by economic benefits, the constant change of forestry planting structure made the area and types of the forest change constantly. And 4) Forestation around houses, roads, villages and cultivated fields and the transformations of barren hill made the area of forest cover increase to a certain extent. At the same time, these activities strengthened the fragmentation degree of forest landscapes in the whole region.

3.5.2 Reasons of forest landscape elements change

Analyzing the dynamics of forest landscape elements could expound forest landscape succession and expanding potentiality, explain the controlling factors and basic driving forces of landscape pattern formation and development, and explicate the role of human activities in landscape pattern change.

(1) Reasons of the main change in patch area. The area change of every patch type had direct relationship with the management policy and economic benefits. With the development of market economy, the forestry center changed the planting structure constantly and selected some kinds of forest which had relatively good economic benefits, such as economic forest, *Robinia pseuoacacia* forest, *Quercus* spp. forest. In order to meet market demand and gain greater economic benefits, the area of economic forest was enlarged. The economic forest and bamboo forest were the important sources of the output of forestry in Luoning County, which had a wide developing prospect. The increasing of the area of *Populus* spp. forest had a close relationship with the forestation around houses, roads, villages and cultivated fields. Since 1975, large amount of *Populus* spp. were planted in Luoning County, especially in 1999, the amount reached 2.29×10^6 individuals, occupying 91% of the total. At the same time, the area of deserted grassland, sparse forest decreased constantly because this county went on transforming the area to secondary forest. According to the statistical data, 4200ha of deserted mountains in the county had been transformed to secondary forest, and 6000ha of barren mountain had been planted.

(2) Reasons of patch fragmentation degree change. From above, we could see that the sparse forest had been transformed constantly to other types of forest or disappeared. There were direct relationship of forest areas (such as *Robinia pseuoacacia* forest, economic forest and *Populus* spp. forest, etc.) with economic benefits, the management policy of forest, and human activities. The low-quality woods, such as non-forestland were transformed constantly, and the forests with high economic benefit, such as *Robinia pseuoacacia* forest, economic forest, *Populus* spp. forest were planted on large scale, which made the maximum area of patch in the forest was increased and the minimum area in the forest was decreased. The increasing of patch numbers on a large scale made the average area of patches was greatly decreased, which reflected that the landscape fragmentation degree of the whole research area was increasing constantly.

4 CONCLUSSIONS

Through the analysis of the changes of forest landscape pattern, the basic laws and process of forest landscapes dynamics can be expound effectively, and the reasons of the landscape pattern changes can be revealed too.

(1) The number of the patches of forest landscape was very obviously changed in the study area, from 556 in 1983 to 1494 in 1999. Transforming of the low-quality woods constantly and planting of economic trees on a large scale, thus made the maximum area of patches in forest landscape increase, and the minimum area decrease. These reflected that the landscape fragmentation degree in the whole study area was increasing constantly.

(2) Along with the increasing of human interference intensity, the diversity of landscape declined, but dominant degree of landscape increased. The spatial characteristic of the human interference intensity and landscape succession could be reflected obviously. Even though the area of *Robinia pseudoacacia* forest, economic forest, *Quercus* spp. forest increased to some extent, the dominant patch type were still in the non-forest land and deserted meadow. So the areas of forestland should be increased by the forestry center in the light of local conditions in order to improve the coverage rate of forest. With the increasing of mankind interference intensity, the fragmentation degree of landscape was increased, but the landscape fragmentation was not contradictory with the increasing of dominant degree, because human conscious selection led to the fact that a lot of landscape elements disappeared. At the same time, the human activities made the natural landscape be divided into different kinds of landscape patches again.

(3) There were many factors influencing the change of forest landscape pattern. Even though this paper had analyzed the reasons of forest landscape change, it did not consider the natural factors (such as physiognomy, natural disaster, etc.) that influenced the changes of forest landscape pattern. And the change of landscape pattern under the background of various management conditions has not been discussed and the correlation degree between various kinds of factors and the forest landscape pattern dynamics had not been analyzed either. Those will be studied further.

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