ANALYSIS OF SPATIO-TEMPORAL CHANGES IN THE LANDSCAPE PATTERN OF THE TAISHAN MOUNTAIN

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Abstract - Analyzing spatial and temporal changes in landscape patterns is an important aspect of landscape ecology. We used satellite imagery and ERDAS Image software, calculated landscape indices, and quantified landscape transformation processes to determine the nature and magnitude of landscape structural changes within an upland area of the Taishan Mountains in Shandong province, eastern China. We used digital image processing techniques to produce landscape classification maps from 1986 and 2001 Landsat images. Based on a geographic information system (GIS) and patch analyst program software (FRAGSTATS), landscape pattern indices were calculated, and the relationships between changes in landscape patterns and anthropogenic disturbances were further investigated. The results showed a significant decrease in *Pinus* forests, due mainly to the conversion to *Quercus* and mixed forests. Forest vegetation patches have become more fragmented, isolated, and much smaller since 1986. Changes in landscape structure were significantly associated with anthropogenic disturbances, although the strength of the association differed throughout the study zone. A larger proportion of bare substrate on steep slopes will damage the health of the mountain ecosystem, in all likelihood, and upland clearing will lead to longer term potential for land degradation.

Keywords - Landscape structure, Landscape change, Mountain Tai, Anthropogenic disturbances.

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1. Introduction

Landscape ecology incorporates the study of biological, physical, and societal causes and consequences of spatial variation in landscapes. Landscape structure is determined by complex interactions of physical, biological, political, economic, and social factors. Most landscapes have been influenced by anthropogenic disturbances, and the resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement (Turner, 1989). Landscapes differ structurally in their distribution of species, energy, and materials, and therefore differ functionally in the flow of species, energy, and materials among the elements (Forman and Godron, 1986). Forest landscapes are unique environments and valuable natural resources, they have particular spatial configurations and values, and conserve a wide variety of productive, protective, and aesthetic functions (Malanson,1993; Boulinier *et al.*, 2001; Thoms and Sheldon, 2000; Forman, 1997). However, anthropogenic activities, such as agriculture, livestock husbandry, tourism, transportation, and industry, can alter or degrade forest environments. In addition, the continuous misuse of these resources can lead to further ecological problems and economic losses. Therefore, it is necessary to protect these areas through restoration, rehabilitation, or conservation programs (Armando *et al.*,2002; Harper *et al.*, 1999). Although several studies have reported changes in landscape conditions (Beavis *et al.*, 1999; Li *et al.*,2003; Wang *et al.*,2003), they have seldom used a quantitative analysis of spatio-temporal changes in the landscape structure of famous tourist areas. In this research, Tai Mountain, an international natural and culture heritage protected zone, was selected as the study site. The objective of study was to analyze and assess the nature and magnitude of the

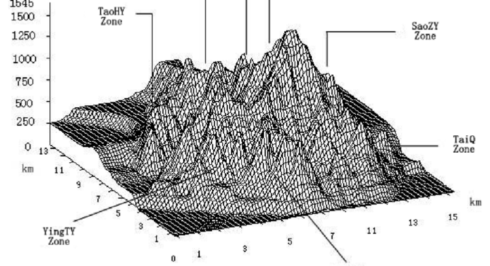

Fig. 1 – The Taishan mountain study area

landscape structural changes in the Taishan Mountains from 1986 to 2001.

2. Study area

The Taishan Mountains of eastern China constitute a famous world natural heritage protected zone and national forest park. The area covers 116.11 km^2; 85.2% and 8.7% of the soils in the area are brown soil and bare stone, respectively. The topography of the Luzhong uplands, at an elevation of 145 m-1545 m, encompasses most types, varying from steep hills (mainly in the center) to flat uplands (mainly in the southern parts). Based on different landforms and the distribution of valleys and catchments, the area was divided into eight zones: the Bashan, Sancha, SaoZY, and FuYsi zones belonged to the natural landscape area, while the ZhuLs, TaoZY, YingTY, and TaiQ zones belonged to areas that had been disturbed by anthropogenic causes (Fig.1). Forest vegetation is the predominant landscape type on Tai Mountain, covering ca. 81.0%. Several species occupy about 92.9% of the forested area, including *Pinus spp.*, *Quercus spp.*, *Robinia pseudoacacia*, and *Platycladus orientalis*. The other main landscape covers are mixed forest (2.27%), economic (plantation) forest (1.62%), abandoned land (2.29%), shrubs (3.28%), bare rocky substrate (2.28%), water (2.30%), residential settlements (3.33%), and roads (2.29%). Activities in the Taishan Mountains principally consist of tourism, horticulture, crop cultivation, and cattle grazing, and this area faces a tourist population of about 160,0000 every year. With the development of tourism and an increasing number of tourists visiting the area, anthropogenic disturbances are affecting the balance of the forest ecosystem more and more severely.

3. Methods

Quantifying landscape structure constitutes the basis for studies of landscape function and change (McGarigal and Marks, 1994). Based on ERDAS images, the GRID module of ARC/INFO, and ArcView 3.2 Spatial Analyst software, satellite images and other thematic maps were pre-processed, displayed, and analyzed. The 1986 and 2001 images of study zone were classified using spatial masking and supervised classification techniques, respectively. Twelve classes were determined for each image: *Pinus spp.*, *Quercus spp.*, *Robinia pseudoacacia*, *Platycladus orientalis*, economic forest, mixed forest, shrubs, bare rocky substrate, settlements, abandoned land, water, and roads. The digital elevation model (DEM) was acquired from a vector relief map, a landuse map, and a digital forest reserve database. A slope gradient and slope exposure map generated from the DEM was used to analyze the relationship between hypsography and landscape element changes. Some data sets were rasterized so that the analysis could be implemented in tandem with the landscape maps derived from the satellite images. Accurate boundaries in a forest landscape are often difficult to distinguish due to indistinct forest vegetation corridors that often have different longitudinal structures as well as transverse structures. In this paper, statistical measures describing the landscape configuration and composition were used to quantify landscape structure and its changes. The analysis of irregular patches is an extension of the ArcGIS system to generate landscape indices, and includes patch analysis functions using avenue codes as well as an interface with the FRAGSTATS spatial pattern analysis program (McGarigal and Marks 1994; 1995; Forman R T T & Godron, 1986; Li H & Reynolds, 1993; O'Neill, 1998).

Based on GIS, An attempt was made to analyze eight zones with the two-period images of comparative data in order to examine the effects of anthropogenic disturbances on changes in landscape patterns. By comparing the different landscape pattern indices of two-period, we could determine if the anthropogenic disturbance zone had a more complex structure than the natural landscape zone. In the spatial pattern analysis, landscape elements changed with the effects of environmental and anthropogenic disturbances, the ecological importance of these changes and disturbances are discussed. Lastly, the relationships between landscape pattern changes and anthropogenic driving factor were further analyzed.

4. Results and Discussion

4.1. Changes in landscape patches

The landscape changes observed in the Taishan Mountains, which had mixed forests, shrubs, and settlements throughout 1986-2001, consisted mainly of a large decrease in the areas of *Pinus* and *Platycladus orientalis* forests, and an increase in the areas of *Quercus spp.* and *Robinia pseudoacacia* (Tab.1, Fig.2). Forest vegetation decreased by about 1.60 km^2 over the 15-year period, and coverage decreased from 82.1% to 80.7% of the landscape. The area covered by *Pinus* and *Platycladus orientalis* fore-

sts also decreased within the 15-year study period. *Pinus* coverage decreased by about 8.33 km^2, an average of about 0.56 km^2 per year, and the area of *Platycladus orientalis* decreased by 3.24 km^2, down 18.1% from 1986 (Tab.1). The 2001 data showed that the area of *Quercus spp*. and *Robinia pseudoacacia* was 33.8 % of the total 116.11 km^2, up from 26.7% in 1986. Other types of landscape cover, i.e., shrubs, bare rocky substrate, settlements, and roads, also increased within the 15-year period, by 20.6%, 11%, 35.0%, and 22.5%, respectively. In contrast, the areas covered by abandoned land, economic forest, and water were reduced in 2001 relative to 1986, a change of 47.9%, 24.8%, and 24.7%, respectively.
The number of patches increased from 445 to 503 patches, a change of 12.6%, and patch elongation decreased significantly from 0.53 to 0.51 (Tab.2). The shape index values for all 1986 and 2001 zones were >1 in the whole study area, indicating that most landscape patches were irregularly shaped. We observed no significant changes in the shape index values in the natural landscape zone over the study period. In the natural landscape zone, the 2001 patches were slightly less irregular in shape than the 1986 patches (a change from 1.35 to 1.38; Tab. 2), and changes in the number of patches were also fairly modest in the natural landscape zone (from 191 to 208 patches). However, in the anthropogenic disturbance zone, the shape index value increased from 1.39 to 1.45, and the number of patches changed from 254 to 293. Thus, patch shape became more complex with the increase in patch numbers.

4.2. Landscape type changes

The landscape in 2001 was dominated by forests (80.7% of the total area), followed by shrubs (5.5%), settlements (4.5%), bare rocky substrate (3.6%), roads (2.8%), water (1.7%), and abandoned land (1.1%). The area of the forest landscape registered a 1.4% decline over

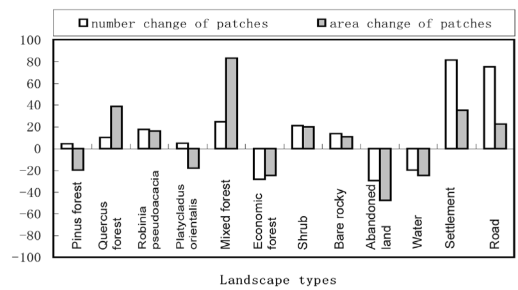

Fig. 2 – The changes of landscape type patches in study region from 1986 to 2001

Tab. 1 - Landscape patches variables in the study area from 1986 to 2001.

Landscape type	1986 year Patches number	Area (km^2)	2001 year Patches number	Area (km^2)	Ratio of patch variable Number variation (%)	Patch area variation (%)
Pinus	88	41.904	92	33.576	+4.5%	-19.9%
Quercus	79	14.372	87	19.920	+10.1%	+38.6%
R.pseudoacacia	62	16.64	78	19.332	+17.7%	+16.2%
P. orientalis	65	17.892	68	14.652	+4.6%	-18.1%
mixed forest	37	2.635	46	4.827	+24.3%	83.2%
economic forest	14	1.884	10	1.417	-28.6%	-24.8%
shrub	18	5.286	23	6.374	+21.1%	+20.6%
bare rocky	22	3.814	25	4.235	+13.6%	+11.0%
abandoned land	17	2.657	12	1.295	-29.4%	-47.9%
water	15	2.675	12	2.013	-20.0%	-24.7%
settlement	16	3.862	29	5.215	+81.3%	+35.0%
road	12	2.657	21	3.254	+75%	+22.5%
Total	445	116.11	503	116.11	12.8%	

15 years. This loss occurred mainly through the clearing and disappearance of patches, and the small variation was explained by a substantial reduction in *Pinus* and *Platycladus orientalis*, with a concurrent increased coverage of *Robinia pseudoacacia*, *Quercus*, and mixed forest. *Pinus* forests declined by 19.9%, resulting in increased fragmentation (i.e., patch number increased but patch size decreased). The area covered by *Platycladus orientalis* decreased by 18.1%; however, *Robinia pseudoacacia* and *Quercus* coverage increased, respectively, by 38.6% and 16.2%. Mixed forest area increased by 83.2%, a change caused mainly through large-scale conifer plantations and afforestation of broad-leaved forests. During the study period, human settlements and road areas showed increases of 35.0% and 22.5% in the study area; this increase was due, mainly, to many new government sponsored housing projects, as well as to the development of tourism. Neither of these developments led to an increase in forested areas by way of compensation. Shrubs (20.6%) and bare rocky substrate (11.0%) increased substantially during the study period. The area of abandoned land, economic forest, and water showed big declines, down 47.9%, 24.8%, and 24.7%, respectively, although the changed area was small relative to the total study area. There was a substantial increase in the number of patches, as well as an increase in area, for most landscape types during the study period. The big increase in patch numbers during the study period was due to the appearance of new patches. Conifer forests (*Pinus* and *Platycladus orientalis*) showed a large fluctuation in area, although with a general increasing trend in the number of patches. This result was explained by the increased patch number and area loss between 1986 and 2001. The change in mixed forest coincided with an increase in both the number of patches and in patch size from 1986-2001. The changes in each of the landscape types were reflected at the landscape level by an increase in the total number of patches and a decrease in area, or by a decrease in the number and area of patches. This fragmentation led to an increased diversity of landscape categories. Changes in landscape patterns from 1986-2001 showed two main trends: (1) transformation of *Pinus* forest to *Quercus* forest and mixed forest, and (2) replacement of *Robinia pseudoacacia* by shrubs and settlements. Transitions during the 1986-2001 period were characterized by further increases in settlements at the expense of tourist areas, and also by changes in land use, from abandoned lands to roads and settlements.

4.3. Landscape pattern changes

This study indicates that the landscape structure of the Taishan Mountains has significantly

Tab. 2 - Characteristics of patches in total study zone, anthropogenic disturbances(AD) region and natural (NL) region

	1986 year				2001 year			
Different region	Patches number	Density index	Patch elongation	Shape index	Patches number	Density index	Patch elongation	Shape index
Total region	445	3.8	0.53	1.36	503	4.3	0.51	1.41
NL region	191	3.0	0.57	1.35	208	3.3	0.55	1.38
AD region	254	4.8	0.49	1.39	293	5.5	0.45	1.45

Tab. 3 - Comparison of pattern change in total study zone, anthropogenic disturbances(AD) region and natural (NL) region

	1986 year				2001 year			
Different region	Diversity	Domin -ance	Fragment -ation	Dimen -sion	Diversity	Domin -ance	Fragment -ation	Dimen -sion
Total region	1.67	1.23	3.80	3.42	1.79	1.17	4.30	4.16
NL region	1.41	1.26	3.00	3.19	1.43	1.23	3.33	3.45
AD region	2.09	1.18	4.80	3.87	2.25	1.07	5.50	4.86

changed over the 15-year study period. While the 1986 landscape in the study area showed signs of human-induced fragmentation, the 2001 landscape was significantly more fragmented (especially in the anthropogenic disturbance zone). The changes occurring in the Taishan Mountain region from 1986 to 2001 consisted mainly of a large decrease in *Pinus* and *Platycladus orientalis* forests and significant increases in *Quercus spp.*, *Robinia pseudoacacia*, mixed forest, and shrubs. Predictions of landscape changes in the anthropogenic disturbance zone, based on socioeconomic variables, were mostly confirmed by data analysis, providing further evidence of the role of socioeconomic data in clarifying the dynamics of human-dominated landscapes (Parks 1991; LaGro and DeGloria 1992; Simpson *et al.* 1994; Farina 1998). The rate of loss of conifer forests has increased since 1986. This was probably due to large-scale conifer monocultures, disturbance by tourism, and urban development. The increase in patch number, together with the loss of mean patch area, suggest that large patches became isolated and broke up into small patches; thus, the landscape mosaic structure became more complex in the study zone. The variation in forested area from 1986-2001 could partly be explained by the shift in conifer forest to broad-leaved and mixed forest, as suggested by the number of partial transitions from forest vegetation to settlements and roads. Within the study period, approximately 3.33 km^2 of *Pinus* forest were converted, mainly, to *Quercus* and mixed forest, and approximately 1.13 km^2 of forest were converted, mainly, to residential areas and roads. This confirms the general trends in landscape pattern changes observed in the region and quantifies the magnitude of fragmentation of the forest vegetation. This analysis of forest patch changes related to anthropogenic disturbances raises some concerns.

The general trend, indicated by the landscape index analysis, was an increase in diversity values (from 1.67 to 1.79) and a decrease in dominance index values (from 1.23 to 1.17) in the study area. The quantitative comparison suggests that landscape structures were more complex in 2001. Landscape fragmentation values increased from 3.42 to 4.20, and the fractal dimension increased from 3.45 to 4.16. Landscape changes in the whole study zone were demonstrated by index changes both in the natural landscape zone and in the anthropogenic disturbance zone. In the natural landscape zone, fragmentation increased slightly, as indicated by values changing from 3.28 to 3.33, diversity values increasing from 1.41 to 1.43, the fractal dimension increasing from 3.22 to 3.34 (up 1.8%), and a dominance index value of 1.17. In contrast, in 2001 the anthropogenic disturbance zone had a much lower dominance index value (only 1.07) and higher diversity index and fragmentation index values, up 7.7% and 30.8%, respectively, from 1986. This indicates the general trend, namely, that values of diversity, fragmentation, and fractal dimension increased significantly in the anthropogenic disturbance zone and only slightly in the natural landscape (Tab.3). For example, only 0.4% (0.5 km^2) of the forested area was converted to residential and bare substrate in the natural landscape zone. This trend was due, in all likelihood, to increased tourism and transportation disturbances since the last century.

5. Conclusion

This study quantified the altered conditions of the forested landscape, changes that were mainly due to conversion to other landscape types. Forested areas have become more fragmented and are currently characterized by a proliferation of mixed forest patches. The management of forested areas, particularly in terms of rehabilitation and preservation, will benefit from information on spatio-temporal changes in landscape structure. The implementation of policies that will strictly limit vegetation clearing in forested areas could be adequately supported by the findings of this study. While more forest vegetation clearing occurred in the study zone, the proportional difference was not large enough to produce a strong correlation. Further studies over a longer period are necessary to develop a better understanding of the relationships between changes in landscape structure, human impacts, and other factors. However, the increasing proportion of forest vegetation cleared within the forest zone on steep slopes raises serious questions with regard to both the landscape health and the longer term potential for land degradation by upland clearing.

We have acquired landscape structure information that could be valuable in the management of mountain forests. The types of datasets, statistical approaches, mapping techniques, and spatial analyses implemented in this study could provide appropriate information for both the assessment and planning of landscape patterns. While our quantification of landscape structural changes was supported by GIS software, more indices relevant to landscape structural change analysis are needed to assess more complex landscape structural changes.

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