Trend surface analysis of forest landscape pattern in Guandishan forest region of Shanxi, China *

Guo Jin-ping, Xiao Yang, Zhang Yun-xiang

Department of Forestry, Shanxi Agricultural University, Taigu 030801, China

Xiao Du-ning **

Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110015, China

Abstract—Landscape pattern is a widely used concept for the demonstration of landscape characteristic features. The integral spatial distribution trend of landscape elements is interested point in the landscape ecological research, especially in those of complex secondary forest regions with confusing mosaics of land cover. Trend surface analysis which used in community and population ecological researches was introduced to reveal the landscape pattern. A reasonable and reliable approach for application of trend surface analysis was provided in detail. As key steps of the approach, uniform grid point sampling method was developed. The efforts were also concentrated at an example of Guandishan forested landscape. Some basic rules of spatial distribution of landscape elements were exclaimed. These will be benefit to the further study in the area to enhance the forest sustainable management and landscape planning.

Keywords: landscape pattern, trend surface model, uniform grid point sampling method, forest landscape, spatial distribution.

1 Introduction

Almost all of landscapes are spatially heterogeneous mosaics of land-cover or habitat (Forman, 1995). The spatial arrangement or spatial distribution of patches represents an aspect of landscape patterns (Xiao, 1997; Urban, 1987). There are many factors impacting the distribution pattern. In general, physiogeographical situation of land is the context of the landscape pattern. But the successional stage of landscape, disturbance and human activity are also important factors that need more careful research (Farina, 1995; O’Neill, 1989; Turner, 1987). Much more effort to explore the cybernetic mechanisms in the integral landscape is required before we can develop some practical principles for integrated decision making of landscape planning and management (Franklin, 1987). Improving the research on the spatial distribution pattern of landscape elements will be helpful for us to elucidate relationship and correspondence among disturbance, human activity and vegetation succession and landscape patterns.

As a special vegetation ordination method, trend surface analysis (TSA) was widely used in traditional ecological research to explore the physiogeographical distribution trend of populations or communities, or even just only a characteristic feature of the population in a definite area (Zhang, 1995; Yang, 1981). Due to the comprehensive effects of multiple factors, the physiogeographic spatial distribution trend are not always obvious and definite (Liu, 1994). By TSA, some of the factors partially activating could be eliminated. Then the systematically spatial dynamics of communities or populations and geographical spatial distribution trend can be definitely exclaimed. Therefore, TSA has ever been a useful quantitative method in traditional phyto-ecology, and well known as a large-scale pattern analytic method (Zhang, 1995). Although someone have expected that the method could be used in dynamic analysis of landscape pattern, but almost all of the practical technique problems in relation to this method have not resolved yet. They include spatial

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** The second author
sampling, ecological evaluation of elements, model analysis and ecological interpretation and so forth. There is not any report yet about the practical utilization of the method.

Because of geographic diversity and frequent human activity, forest landscape presented complex mosaic pattern in secondary natural forested region of North China. Controlled by ecological succession and disturbance regime, ecological processon is so active, landscape change is so diversified and elusive in forest landscape, that it is difficult to grasp the general trend and changing rules of spatial distribution of landscape elements (Liu, 1994). Very clearly, how can the TSA be effectively used to explore the forest landscape pattern and their dynamics is still a problem to be practiced and improved for the sustainable management and utilization of forest in this fragile region.

This paper intends to introduce the proposed technical routine to use the TSA, and presents the research results as an example of Guandishan forest region in Shanxi Province, North China. It is hoped that the results contribute to perfect the methodology in landscape ecological research, and at the same time, improve the principles for local forest management and landscape planning in the near future.

2 Study area

Guandishan Mountain is the distribution center of North-Chinese Larch (Larix Principis-rupprichtii) which distributed in forest remnants in rocky mountainous area, North China. Study area is situated at the middle section of Luliang Mountains. It includes Panguangou National Natural Reserve as the center, and six forest farms around it. The total area is 57200 hm². It has an inner-continental mountain monsoon climate. The altitude ranges from 1360m to 2838.7m. The annual mean air temperature is 4.2°C with relative humidity of 70.9%. The annual precipitation is 822.6 mm. The mountain soil originates from granite and gneissic granite of Archean Era. The main types of soil are sub-alpine meadow soil, mountain braunerde, mountain brown alfisol and mountain rubified soil.

The forest stands in the area face to seriously disturbance of human activity, especially before liberation (1949), suffering from human induced fire and cutting. After that, government intensified administration. Forest farm and management bureau were set up to control the forest degradation. Before the middle of 1980s, the main tasks of forest farm in addition to forest stand reformation (generally replace early successional forest or wood land with coniferous plantation) are forest protection and reforestation. Forest fire, massive cutting by local villagers were effectively prevented except for fuel wood collection. These were benefit to the forest restoration. But in latter period, the control was relatively relaxed due to change of outside social and economical environment. Forest farms started to cut in small scale till now. The natural reserve was built in 1983, which turned out of primarily forest farm, for protecting secondary Larch forest ecosystem and Brown eared pheasant (Crossoptilon mantchuricum). It provided us an excellent place to promote some researches on the landscape patterns and their changes. There are seven types of vegetation, including sub-alpine brush, sub-alpine meadow, boreal coniferous forest, mountain broad-leaved forest, temperate coniferous forest, mountain brush, mountain meadow. Three types of forest vegetation are divided into 10 types of forest which dominated by different tree species (Table 1).

3 Method

3.1 Basic data

Topographic maps and remote sensing images taken at 4 temporal stages from 1959 to 1992 were collected as the basic information in the study area. They include forest maps, forest distribution maps, and forest resource archives in local forest farms were collected as assistant information. According to the criteria of forest landscape element classification (Table 1), by interpreting of the air photographs and correcting with assistant information, forest landscape mosaic maps of 4 stages were drawn respectively.
Table 1  Landscape element classification system and ecological potential value of the elements

<table>
<thead>
<tr>
<th>First level</th>
<th>Second level</th>
<th>Third level</th>
<th>Potential value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed forest</td>
<td>Boreal coniferous forest</td>
<td>Larix-forest</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Picea-forest</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Picea-larix-forest</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Mountain broad leaved forest</td>
<td>Larix-picea-forest</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Betula-larix-forest</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Temperate coniferous forest</td>
<td>Larix-broadleaved-forest</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Populus-betuliflorus</td>
<td>72</td>
</tr>
<tr>
<td>Artificial plantation</td>
<td>Artificial plantation</td>
<td>Tabulaeformis-broadleaved-forest</td>
<td>70</td>
</tr>
<tr>
<td>Open forest</td>
<td>Open forest</td>
<td>Tabulaeformis-forest</td>
<td>78</td>
</tr>
<tr>
<td>Brush</td>
<td>Brush</td>
<td>Broadleaved-tabulaeformis-forest</td>
<td>75</td>
</tr>
<tr>
<td>Meadow</td>
<td>Sub-alpine meadow</td>
<td></td>
<td></td>
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<tr>
<td>Mountain meadow</td>
<td>Mountain meadow</td>
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<tr>
<td>Cut-over-land</td>
<td>New cut-over-land</td>
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<td></td>
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<tr>
<td>Old cut-over-land</td>
<td>Old cut-over-land</td>
<td></td>
<td></td>
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<tr>
<td>Thin brush</td>
<td>Thin brush</td>
<td></td>
<td></td>
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<tr>
<td>Farmland</td>
<td>Bottom farmland</td>
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<tr>
<td>Slope farmland</td>
<td>Slope farmland</td>
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<tr>
<td>Abandoned farmland</td>
<td>Abandoned farmland</td>
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<tr>
<td>River</td>
<td>River</td>
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<tr>
<td>Residential area</td>
<td>Residential area</td>
<td></td>
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<tr>
<td>Others</td>
<td>Bear rocky area</td>
<td></td>
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<tr>
<td></td>
<td>Mining district</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Reservoir</td>
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</tr>
</tbody>
</table>

3.2 Digitizing topographic map and forest landscape maps

Supported by ARC/INFO, the topographic map and forest landscape maps mentioned above was digitized by process of "scanning (digitizing)-thinning-editing-building topological structure". Then the digitized layers of the maps were build in computer. It is required that the boundaries of all layers be consistent.

3.3 Building uniform grid sampling-point layer

With uniform TIC points, uniform grid sampling-point layer was built automatically by ARC/INFO to take sample for TSA model. The size of grid in grid layer was determined according to the average patch size of the landscape elements. After that, central points of the grids were taken and the grid lines were deleted. Then the topological structure of the temporary layer was built. By overlaying with the boundary layer of study area, deleting the points outside of the boundary and rebuilding topological structure of the layer, the uniform grid sampling-point layer was built for the study area.

3.4 Sampling and building database

By overlaying topographical layer with sampling-point layer, and using DEM/DTM functions of GIS, geographic feature and topological data from all sample points were taken to build a relevant database. Respectively, overlay forest landscape layers with sampling-point layer to get forest landscape feature data from all sample points in each layer of succession stage. Linking the data with the database above, an integrated database for the TSA was ready.

3.5 Building trend surface model

Trend surface models were built for spatial pattern analysis by least-squares fitting with appropriate math function to simulate the data.

3.6 Analyzing model

Using professional knowledge, general rules revealed from the model analyzed and explained in effective style.
4 Results and discussion

4.1 Horizontal spatial distribution of landscape elements

Defining the longitude and latitude of sampling points as independent variables, and defining the potential value of the points as dependent variable, a trend surface model for horizontal spatial distribution of landscape elements was set up by least-square regression method. A trend surface model chart was drawn to show the simulation results (Fig. 2). For the convenient of comparison, the present distribution chart was drawn at the same time according to the potential values of sampling points (Fig. 1).

Comparing the two charts, it is obviously showed that the trend surface model is available to simulate the integral distribution trend of landscape elements, but partial differences are very significant. And the distribution trend is respondent to the topography. Therefore, at the scale of this study, the distribution trend is more likely the presentation of the controlling effect of topography to the landscape mosaic rather than that of geographical longitude and latitude. This stimulate further more analysis on the relationship between landscape mosaic and topographical features.

4.2 Impacts of altitude and slope aspect

Defining altitude and slope aspect as independent variables and potential value as dependent variable, a trend surface model was set up to analyze the impact of altitude and slope aspect onto the spatial distribution of landscape element (Fig. 3). For the advantage of analysis, the simulated potential values of north and south slope were selected typically and compared to illustrate the distribution pattern of landscape elements along the topographical gradients (Fig. 4).

In Fig. 3 and Fig. 4, it can be seen that the integral distribution trend of landscape elements along the altitude gradient is obviously presented. With the increasing of altitude, the differences of potential value among different sub-zones of altitude reduced. But, the differences among different slope aspects extended. And as a special case, the potential value at heliotropic (positive) slope is greater than that at heliophobic (negative) slope in the lowest altitude zone.

According to the potential values in different altitude zones, landscape element distribution pattern responding to the altitude and slope aspects can be seen from Fig. 4. In upper zone (above 2100m of altitude) at heliophobic slope, potential value ranges from 80 to 90. It is the zone in which boreal coniferous forest relatively concentrated. In upper-middle zone (1900m—2100m of altitude), corresponding with the mountain broad-leaved forest, the potential value ranges from 70 to 80, and at heliotropic slope the corresponding altitude range is higher than that at heliophobic slope. In middle zone (1600m—1900m of altitude), the potential value ranges from 55 to 70. And respectively, most of temperate coniferous forest distributed in this zone. But in fact, due to interpatch with non-forest land, especially of farmland and thinned brush, the potential values decreased
in the model. In lower zone (below 1600m of altitude), farmland and thinned brush are the dominant elements, the potential values are generally below 55.

![Spatial distribution model for landscape elements along gradient of slope and altitude](image1)

**Fig. 3** Spatial distribution model for landscape elements along gradient of slope and altitude

![Spatial distribution curves gradient of altitude in heliotropic and heliophobic slope](image2)

**Fig. 4** Spatial distribution curves gradient of altitude in heliotropic and heliophobic slope

Potential values of eight slope aspects were selected and presented in Fig. 5 for the comparison among different slope aspects. It showed that differences among slope aspects are significant in the case. The potential value at north slope is the highest, and that at southwest slope is the lowest. The order of potential values at different slope aspects from highest to lowest is north-northeast-northwest-east-southeast-west-south-southwest.

### 4.3 Impacts of slope gradient

Defining slope aspect and slope gradient as independent variables and potential value as dependent variable, a trend surface model was set up to elucidate the impacts of slope gradient to the distribution of landscape elements (Fig. 6). To highlight the effect of slope gradient, potential values in south and north slope aspects were selected and used to build an analysis chart (Fig. 7).

![Trend surface model for spatial distribution along gradient of slope and slope aspect](image3)

**Fig. 5** Comparison among eight slope aspects

![Trend curve at north and south slopes](image4)

**Fig. 6** Trend surface model for spatial distribution along gradient of slope and slope aspect

**Fig. 7** Trend curve at north and south slopes

Some general rules of landscape element spatial distribution are confirmed in the figures. While the slope gradient ranges below 16°, the potential value is increasing rapidly along with the rising of slope gradient. Otherwise, while the slope gradient ranges above 35°, it decreasing a little along with the rising of slope gradient. Between 16°—35° of slope gradient, variation of potential value
along with changing of slope gradient is very small. In fact, these patterns reflected two agents impacting the distribution of landscape elements. The first, mountain ridge, top and pass as topographical parts of mountain area, have gentle slope and generally unsuitable to wood vegetation because of micro-climate, soil water and other limitation, and generally dominated by shrub or meadow. The second, at slope foot or gully with relatively lower altitude, human activity is more frequent, cultivated patches and related landscape elements that have lower potential values predominated the landscape.

Furthermore, 4 models were set up for different altitude zones. Fig. 8, 9, 10 and 11 represent the upper zone, upper-middle zone, middle zone and lower zone, respectively.

From Fig. 8, it is clear that, in upper zone, at heliophobie slope and semi-heliophobie slope with slope gradient ranges from 8°—35° potential value are all above 85 with little fluctuation. This zone is predominated by boreal coniferous forest. From Fig. 9, it can be seen that, in upper-middle zone, all of potential value bellows 85. At heliophobie slope and semi-heliophobie slope or even semi-heliotropic slope, of that slope gradient ranges from 12° to 38°, potential values are higher than 70 with little variation along with changing of slope gradient.

In middle zone (Fig. 10), potential value of heliophobie slope increase along with rising of slope gradient till up to 35°, then decreased slowly. It reflected that, in this zone, human cultivation activity more frequently extended at the sections with gentle slope, forest cover mostly located at heliophobie slope with slope gradient above 25°. In lower zone (Fig. 11), controlled by human activity more widely in range of slope aspect and gradient, including farm cultivation, grazing, collecting fuel-wood and so forth, potential value is much lower than that in the other
zones. Due to more poor water condition in this zone (Xiao, 1998), the steeper the slopes are, the more conspicuous the differences of soil moisture are among different slope aspects. An integral trend is that the potential value at steeper heliotropic slope be higher than that at gentler heliotropic slope.

In sort, impacts of slope gradient to spatial distribution of landscape elements are obviously distinct in different altitude ranges in mountain area. Along with rising of altitude, difference of potential value in different ranges of slope gradient reduced. An integral trend in study area presented here in brief. While slope gradient ranges from 0°—16°, the smaller is the slope gradient, the lower is the potential value of land cover. While slope gradient ranges from 16°—35°, the potential value are higher and changes very little. Where as slope gradient is greater than 35°, along with the rising of slope gradient, potential value decreased more sharply.

5 Conclusion

Forest landscapes of secondary natural forested region in North China are highly heterogeneous mosaics. They are composed of relatively small patches of many forest types and other land cover types and different types of corridors. The mosaic is the integral result of environmental heterogeneity and human activity. Due to complexity of spatial distribution of landscape elements, it is difficult to grasp the integral spatial pattern hidden in complex mosaic. As the first step to reveal the cybernetic mechanism of forest landscape pattern, it is proved in this paper that trend surface analysis can be used in complex landscape pattern analysis to elucidate the basic characteristic features and general mechanism of landscape formation.

It is also proved that the approach to set up trend surface model provided in this paper is reasonable in technique, simple and practicable in data management and reliable of results. Supported by ARC/INFO (or other GIS software), sampling overall landscape by uniform grid sampling-point layer, database could be built and used to set up a multinomial model which is simple one of models in multiple variable statistic analysis, to simulate the spatial distribution of landscape elements.

In mountain secondary natural forested region of North China, at the scale of tens kilometers, the controlling effects of longitude and latitude to spatial distribution of landscape elements is much limited. Otherwise, the integral pattern is much more controlled by geographic characteristic features and disturbance regime comprehensively. Research results showed that, in study area, altitude, slope aspect and slope gradient was three basic factors in controlling spatial pattern of landscape as environmental context. At different altitude zone, the effect intensity of slope aspect and slope gradient was markedly different. The results provided in this paper can be used as a foundation for further study in related fields or disciplines, such as forest resource management and sustainable use, and especially in forest site classification, productively prediction and forest landscape planning.

References