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Finding spatial regularity in mosaic landscapes: two methods integrated

Ke-Ming Ma, Bo-Jie Fu, Xu-Dong Guo & Hua-Feng Zhou
Department of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O. Box 2871, Beijing 100085, P. R. China (E-mail: mkm@mail.rcees.ac.cn)

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Abstract

Two methods were employed to find spatial regularity in a complicated mountain landscape of Beijing, China on the basis of functional and structural affinities. The first approach applied Affinity Analysis based on species composition to landscape. The mosaic diversity of the landscape was 3.5298>3, which means the study landscape is complex and controlled by multiple environmental gradients. These landscape types were divided into 3 parts according to the mean affinity values of 0.2143 and 0.7857 (0.5 ± 1 SD). Modal sites are the central types of the landscape, which include a zonal broad-leaved forest of the region and a conifer plantation replacing the former. Outliers are found in the highest altitude and the lowest, both have few species in common with the above two modal types. The remaining landscape types are intermediate sites, which are transitional between modals and outliers, broadly distributed throughout mountain environments. Neighbor types have more species in common than those more widely separated, which probably distributed adjacently in space or in similar quality habitat. The other method employed is the new TWINSPAN analysis by substituting spatial neighboring data of landscape types for species composition data. It clearly divided the landscape types into three groups, i.e., subalpine, middle and low mountain groups, which were correlated with altitude, as well as influenced by human disturbance. The new TWINSPAN classification method is more reliable in finding spatial gradient of patchy landscapes than affinity analysis; however, affinity analysis is useful in finding species diversity pattern and the importance of landscape types in a region. Integrating advantages of the two methods could supply complete and reliable information on how landscape types are distributed in space, which environmental gradient dominates the spatial distribution of the landscape types, as well as where important and unusual types are located.

Introduction

It has been recognized that regional pattern often determines, and usually constrains finer scale ecological conditions (Turner 1989; Caley & Schluter 1997). Once patterns are detected, we can seek to discover the process determinants of pattern, and the mechanisms that generate and maintain these patterns (Levin 1992).

A region usually consists of many land use types, whereas each land use type contains a great deal of patches. The interactions among land use types are complicated not only because of the environmental heterogeneity and succession history, but also human disturbance and management (Forman & Godron 1986; Krummel et al. 1987; Forman 1995). The spatial patterns observed in landscapes are resulted from complex interactions between physical, biological, and social forces. Especially human disturbances remarkably alter the flows of materials, energy and species among different landscape patches, and the resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement (Krummel et al. 1987; Turner 1989), as well as in the diversity of species composition. For example, because of human occupation and exploitation effect, forest landscapes of the Donglingshan Mountain region, Beijing, China have been seriously fragmented (Chen 1997). Therefore it is significant to find spatial regularity of landscape types in a fragmented landscape for ecosystem management.

However, current landscape pattern analysis mainly focuses on the spatial geometry (Haines-Young 1999), scaling properties (Turner & Gardner 1991; Levin 1992) and spatial autocorrelation (Legendre & Fortin 1989; Rossi et al. 1992) of landscapes. Haines-Young (1999) argues that it is limited at least three aspects. First, much of it is confined to landscapes that have a distinct spatial structure. What happens in landscapes where gradients rather than patches predominate? Second, while we are beginning to understand the consequences of pattern, we also need to understand what factors control the development of landscape pattern itself. This is important in a management context, when we seek to influence the development of landscapes. Finally, while biophysical models can be helpful for planning in landscapes where people rather than nature are the dominant force? Unfortunately, few approaches are available to describe these properties, especially the gradient distribution of landscape types and its relationship with environmental factors in region (Turner & Gardner 1991; McGarigal & Marks 1993; Haines-Young 1999). This task remains as a challenge to landscape pattern analysis.

In reality, there are two kinds of data on landscape types that can be used to summarize the spatial regularity of a landscape. These are functional data, including the species composition; and structural data, the spatial neighboring or pattern metrics of landscape types.

Correspondingly, two kinds of methods exist to approach the above problem. One is the classification or ordination method in community ecology based upon species composition data (Gauch 1982). This method can indirectly find the spatial regularity of vegetation and its correlation with environmental gradients in a region on the basis of species composition measured in plots. It has a long history of development and application in community ecology with diverse ordination and classification methods to select (Gauch 1982; ter Braak 1987, 1988; Knox & Peet 1989; Palmer 1993; Zhang 1995). Affinity analysis, a complement to community ordination, has been applied in landscape ecology as well (Scheiner 1992). On the basis of species composition of landscape types, affinity analysis could reveal the species relationships of landscape types and pattern diversity. This relationship between local and regional diversity has been paid more and more attentions in recent studies (Caley & Schluter 1997; Ma et al. 1999). However, reliable species composition data on broad scale landscapes is quite difficult to collect because it is impossible to sample an entire region under sampling effects remain a serious problem to this challenge (Lobo et al. 1998). Thus the information supplied by these methods cannot be relied on all the time. Although there are still some problems existed, a new development, combining remotely sensed data with field survey (Lobo et al. 1998), has shown a cogent bright future.

The other method corresponds to structural data, for example, the spatial neighboring data of landscape types. Unfortunately, no gradient analysis method is currently available. The authors borrowed the TWINSPAN classification from community ecology by substituting spatial neighboring data of landscape types for species composition. The new TWINSPAN classification avoided the shortcomings of data source in typical community classification and can be easily used to directly disclose the emergent spatial characteristics of landscape types. Because broad scale landscape pattern analysis is supported by Geographical Information Systems (GIS) based upon maps or remotely sensed data, it is convenient to map a landscape and to get its statistical and spatial properties, which made this new method easy to apply.

Considering that typical community classification and ordination have already been carried out in the study area (Ma et al. 1997), this paper employed affinity analysis and the new TWINSPAN classification to identify spatial gradients in the mountain landscape. Three purposes of this study are, (1) to show how each method works in finding spatial regularity of the mountain landscape; (2) to compare the advantages and shortcomings of the two methods; and at last (3) to combine the two methods in order to supply a reliable and integrated description of spatial regularity to the study landscape. Toward these goals, the diversity of species composition and spatial pattern were measured to show the complexity of the study landscape.

Methods

Study area

The Donglingshan Mountain is an extension of Xiaowutaishan Mountains and belongs to the broader Taihangshan Mountains. The study area, Beijing Forest Ecosystem Research Station of the Chinese Academy of Sciences (40°00′ to 40°02′ N, 115°26′ to 115°30′ E) is located 100 km northwest of Beijing city, China. The altitudes of most mountainous areas are more than 1000 m above sea level, the highest peak being at 2303 m. Landforms are mainly of mountain erosion structure: slopes are steep (usually >30°) and streams are deep incised. Dominant soil type is brown earth fertile in organic materials (Huo 1989). The annual climate of the region includes a long cold winter with 160 days below freezing and a short growing season (135 days). Average annual precipitation is 500–650 mm, making this region a typical warm temperate-zone monsoon climate.

The zonal vegetation of Donglingshan Mountain region is warm temperate-zone deciduous broad-leaved forest (Chen 1997), including mainly oaks (*Quercus* spp.), mixed forests (e.g., *Tilia* spp., *Ulmus* spp., *Acer* spp., *Juglans mandshurica* and *Fraxinus rhynchophylla* etc.), birches (*Betula* spp.) and poplar (*Populus davidiana*). There are also some conifers, e.g., pine (*Pinus tabulaeformis*) and larch (*Larix principis-rupprechtii*) plantations (>30 yr) originated from deciduous broad-leaved forest, and some shrubs (e.g., *Prunus* spp., *Vitex negundo* var. *heterophylla*, etc.). The mountain landscape has been highly fragmented, it is impossible to find an obvious spatial gradient of landscape types.

Affinity analysis

A total of 10 typical vegetation types of this mountain landscape were chosen for this study from the overall 18 types of low to high elevation. They include 7 forests, *Betula dahurica (Bd), Betula platyphylla (Bp), Juglans mandshurica (Jm), Larix principis-rupprechtii (Lp), Quercus liaotungensis (Ql), Populus davidiana (Pd), Pinus tabulaeformis (Pt)*, 2 Shrubs, *Prunus ameniaca* var. *ansu & P. davidiana (P&P), Vitex negundo* var. *heterophylla (Vn)*, and subalpine meadow (*Sm*). Three repeat sampling plots were set up in the sites typical of each. The quadrat sizes of forest, shrub and grass types or layers were 20 × 20, 10 × 10 and 1 × 1 m^2, respectively. Within each forest or shrub plot, three grass layer quadrats were chosen. The number of species and corresponding coverage of tree, shrub and grass layer were separately measured. The number of species in each layer was determined, and species diversity was calculated using the Shannon index on the basis of species coverage ($Pi = i$ species cover/total layer cover). The altitude and slope exposure, steepness degree and position were recorded in all of the 10 types to examine if these gradients were correlated with the species diversities of landscape types.

Affinity analysis was carried out twice based on species presence/absence data of sample plot and landscape type respectively. In the first step, pairwise similarities for each subunit with others are determined to provide a measure that incorporates mean distance and dispersion of distance. For presence/absence data, Jaccard index (number of common species between two samples/(number of species in sample $a+$ number of species in sample $b-$ number of common species between the two samples)) proved to be a consistently good measure of similarity. In the second step, pairwise affinities among all subunits are computed. Affinity measures the relative distances of two subunits by use of a standard rank-sum statistic. In the final step, the mean affinity of each site is plotted against the mean similarity of each site (the affinity graph) and the slope of the line is computed to get mosaic diversity (for detailed procedures of affinity analysis please refer to Scheiner 1992).

Affinity analysis provides important information on two aspects of a landscape, (1) the assemblage of landscape subunits, and (2) the mosaic diversity. It was found that the mean affinity was constrained to 0.5, and 0.5 ± 1 SD (Standard Deviation) can objectively define those sites that are either modal or outlier sites (Scheiner 1992). Thus, the points in an affinity graph can be subdivided into three parts: modal sites (affinity $> 0.5+1$ SD), intermediate sites ($0.5-1$ SD $\leq$ affinity $\leq 0.5+1$ SD) and outliers (affinity $<$ $0.5-1$ SD). The relative distance of subunits within the overall landscape reveals the commonness or rarity of types in a landscape. The mosaic diversity (m) metric integrates all the information of affinity analysis to describe landscape pattern diversity. It is a function of two properties of species pattern: variation in species richness among communities and variation in commonness or rarity among species (evenness). Different ranges of m reflect different properties of a landscape pattern. Values of $m < 1$ indicate a disconnected landscape consisting of groups of sites that are similar within groups but with very few species shared among other groups. Values of m in the range of 1–3 indicate a simple landscape dominated by one or a few gradients. And values of $m > 3$ indicate a complex landscape with either many ecological gradients or no particularly strong gradients (Scheiner 1992).

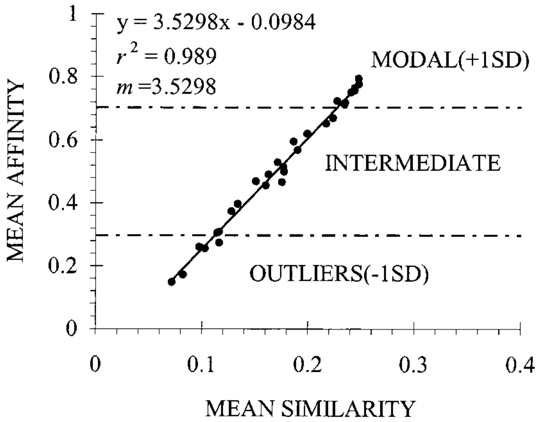

Figure 1. Affinity analysis on sample plots of landscape types in Donglingshan mountain region, Beijing, China. Where the landscape types are *Lp (Larix principis-rupprechtii), Pt (Pinus tabulaeformis), Bp (Betula platyphylla), Bd (Betula dahurica), Pd (Populus davidiana), Jm (Juglans mandshurica), Ql (Quercus liaotungensis), P&P(Prunus ameniaca* var. *ansu & P. davidiana), Vn (Vitex negundo* var. *heterophylla),* and *Sm* (subalpine meadow). The sample plots are $Sm-1$, $P\&P-2$, $Vn-1$, $Sm-2$, $Sm-3$ (outliers), $Jm-1$, $P\&P-3$, $Vn-2$, $Vn-3$, $P\&P-1$, $Pd-3$, $Bd-1$, $Bp-2$, $Bp-3$, $Bp-1$, $Jm-3$, $Pt-1$, $Jm-2$, $Lp-3$, $Pt-2$, $Pd-1$, $Bd-3$, $Lp-1$ (intermediate sites), $Pd-2$, $Pt-3$, $Lp-2$, $Ql-2$, $Bd-2$, $Ql-3$ and $Ql-1$ (modal sites) from the low affinity to the high.

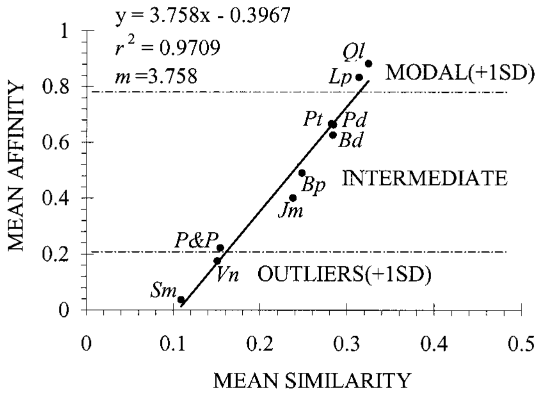

Figure 2. Affinity analysis on landscape types in Donglingshan mountain region, Beijing, China. Where the landscape types are *Sm* (subalpine meadow), *Vn (Vitex negundo* var. *heterophylla*) (outliers), *P&P (Prunus ameniaca* var. ansu & P. davidiana), Jm (Juglans mandshurica), Bp (Betula platyphylla), Bd (Betula dahurica), Pd (Populus davidiana), Pt (Pinus tabulaeformis) (intermediate sites), Lp (Larix principis-rupprechtii) and *Ql (Quercus liaotungensis)* (modal sites) from the low affinty to the high.

TWINSPAN classification

The vegetation map of the study area was digitized into a GIS. The neighboring types and the correspondent perimeters were calculated. The spatial neighbor diversity of each landscape type was measured using Shannon index, where P_{ij} = neighboring length between type i and j/total perimeter of type i.

The TWINSPAN analysis of community classification (Hill 1979) was used to characterize the regional gradient of the mountain landscape by substituting spatial neighboring data of landscape types for species composition. For this analysis, the landscape types were regarded as ‘samples’ and their neighboring types were regarded as ‘species’ separately. The neighboring length was regarded as the attributes of ‘species’. Finally, the result according to ‘samples’ (landscape types) of the TWINSPAN classification was accepted, and the one according to ‘species’ (neighboring landscape types) was rejected.

Results

Affinity analysis on landscape types

Species diversity and environmental factors

Table 1 shows the number of species and Shannon index in the tree, shrub and grass layers in each landscape type of the mountain region. In all the types, tree species were few (5–13), whereas shrub and grass layers usually contained many more species, separately 13–30 and 36–69. Total species in the entire type ranged from 53–102. Species richness relationships in all the types were tree<shrub<grass layer, except shrubs without tree layer, and meadow without shrub and tree layers. As with species number, Shannon Index values differed among the three layers and agreed the regularities of species richness.

Environmental factors (altitude, slope exposure, steepness and position) were very different in the landscape types studied in this region (Table 2), which were distributed within altitudes of 895 to 2050 m above sea level, both on shady and sunny slopes between 0 and 45 deg, they covered all types of slope positions. The distribution of the 10 selected types showed some correlation with altitude, but no distinction among the other three factors. Moreover they do not appear to dominate the spatial distribution of species diversity: our data suggest that species diversity distribution has no obvious relationship with any single environmental factor in this mountain region (Tables 1 and 2).

Table 1. Species diversities of the main landscape types of Donglingshan mountain region, Beijing, China.

Code	Landscape type	Species number				Shannon index		
		Tree layer	Shrub layer	Grass layer	Total	Tree layer	Shrub layer	Grass layer
Bd	*Betula dahurica*	7	29	36	72	0.999	2.682	3.224
Bp	*Betula platyphylla*	7	21	65	93	0.987	1.981	3.520
Jm	*Juglans mandshurica*	6	27	69	102	0.966	2.634	3.730
Lp	*Larix principis-rupprechtii*	13	30	54	97	1.558	2.718	3.604
P&P	*Prunus ameniaca* var. *ansu & P. davidiana*	–	22	56	78	–	2.499	3.389
Pd	*Populus davidiana*	5	26	55	86	0.586	2.728	3.554
Pt	*Pinus tabulaeformis*	6	23	55	84	1.009	2.361	3.228
Ql	*Quercus liaotungensis*	8	27	41	76	0.779	2.539	3.316
Sm	subalpine meadow	–	–	53	53	–	–	3.174
Vn	*Vitex negundo* var. *Heterophylla*	–	13	41	54	–	1.793	3.203

Landscape type assemblage and mosaic diversity

Figure 1 shows the result of affinity analysis on the 30 plots sampled from the 10 landscape types of Donglingshan mountain region. The correlation coefficient r^2 of 0.9897, $P < 0.01$, suggests a statistically significant linear correlation. The mosaic diversity was 3.5298>3, meaning the landscape was complex and determined by multiple environmental gradients or no particularly strong gradients according to Scheiner (1992). The sample plots in the affinity graph can be divided into three parts: modal sites, intermediate sites and outliers. But no assemblage of landscape types was found in the affinity graph based upon the data of sample plot level.

Therefore affinity analysis on the landscape type level was carried out, for which only 10 points were available (Figure 2). The affinity analysis empirically demanded that data points should be more than 30 to ensure a reliable result (Scheiner 1992). Actually there are only 19 types in the mountain landscape, the demand could not be satisfied anyway on landscape type level. Therefore t-test was carried out in order to ensure the affinity analysis on landscape type level acceptable. The correlation coefficient r^2 of 0.9709, $P < 0.01$, suggests a statistically significant linear correlation. The mosaic diversity of 3.758 (larger than 3) means again that the landscape was complex and determined by multiple environmental gradients or no particularly strong gradients in the mountain region, which corroborates the former affinity analysis on sample plot level. Anyway, the value of 3.5298 from sample plot level was chosen for the mosaic diversity of the mountain landscape in order to ensure the mosaic diversity metric to be robust.

The landscape types in the mountain region can be clearly divided into three parts as well according to Figure 2. Modal sites: Ql and Lp are the central types of the whole landscape. They have greatest mean similarity and mean affinity with others, high species diversity and many common species, they are generally equivalent to the zonal types. The type Ql is found on the upper and moderately steep (31–35°), sunny slopes. Lp is also found on steep (0–33° slope), sunny and shady slopes with middle slope position (Table 2). These two types are a zonal broad-leaved forest (Ql) and a conifer plantation (Lp) originated from the former (Chen 1997).

On the contrary, Sm and Vn were two outliers in the mountain landscape. Both with lower mean affinity and mean similarity values than other types. The Sm was distributed in the highest altitude and the Vn was in the lowest (Table 2). With respect to species diversity, both were low in common species and have

Table 2. Environmental factors of the main landscape types in Donglingshan mountain region, Beijing, China

Code	Landscape type	Altitude(m)	Exposure	Slope degree	Slope position
Bd	*Betula dahurica*	1300–1460	shady	13–30	up
Bp	*Betula platyphylla*	1440–1730	shady/sunny	17–32	up
Jm	*Juglans mandshurica*	1150–1240	sunny	5	bottom
Lp	*Larix principis-rupprechtii*	1150–1210	sunny/shady	0–33	middle
P&P	*Prunus ameniaca* var. *ansu* & *P. davidiana*	1045–1160	sunny	30–42	up/middle
Pd	*Populus davidiana*	1200–1300	sunny/shady	5–20	middle/bottom
Pt	*Pinus tabulaeformis*	1160–1220	sunny/shady	27–45	middle
Ql	*Quercus liaotungensis*	1280–1325	sunny	31–35	up/middle
Sm	subalpine meadow	1650–2050	sunny/shady	14–39	top
Vn	*Vitex negundo* var. *heterophylla*	895–920	sunny	20–30	up/middle/low

little in common with the two modal landscape types of this region (Table 1).

The remaining landscape types were intermediate sites, with affinity values within 0.2143 and 0.7857 (0.5 ± 1 SD). These types were broadly distributed and occupied most of the area in the mountain landscape. Their species diversity has no obvious association and numbers of common species are moderate. These types are Pd, Pt, Bd, Bp, Jm and $P\&P$ from high to low affinity.

Figure 2 depicts the spatial order of species diversity of the mountain landscape types. Neighboring types have more species in common than those more widely separated. They are probably distributed adjacently in space or in similar topographic settings.

TWINSPAN classification on landscape types

Spatial neighboring diversity of landscape types

The landscape types of Donglingshan Mountain region varied significantly in neighboring types and the correspondent neighboring lengths, mainly 1 to 2 types (Table 3). Subsequently, the spatial neighboring of landscape types can be divided qualitatively into three kinds.

First, there is only one adjoining neighbor type. Their neighboring length is much higher than that with other types. For example, Rs (Residential) is only proximate with Fl (Farmland), their neighboring rate reached as high as 70.1 %, indicating the close relationship of residence to farmland. Other proximity associations belong to this category, Lp with Ql (46.3%), Pt with Ql (46.1%), Bc (*Betula costata*) with Sm (57.0%), as well as Pd with Ql (47.3%).

Secondly, closely neighboring with several types, no obvious dominant type existed, which implies a multiple neighborhood relationship. For Example, the boundaries of Po (*Platycladus orentalis*) with Fl (48.7%) and $P\&P$ (39.8%) are both high, but they are close. The other one is Ms (Mixed shrub) with Fl (48.4%) and Vn (39.3%).

The third category is between the first and second, closely neighboring with several types, but one or two of them show some extent of dominance. For example, Bd with Ql (41.8%), Bp (17.0%) and $P\&P$ (16.8%), where only Ql neighboring is dominant. This category included all of the remnant landscape types, *Bp, Ql, Mf* (Mixed forest), *Cj (Caragana jubata), Lb (Lespedeza bicolor), P&P, Vn, Ss (Spiraea spp.), Sm, Fl* and *Ao* (Apple orchard), which is the common spatial pattern in the landscape (Table 3).

The spatial neighboring diversities of the landscape types are much different in the mountain region. The order of Shannon index is $Bc < Ms < Vn < Bp < Ss < Po < Sm < Ql < Ao < Lp < Fl < Cj < P\&P < Pd < Lb < Mf < Bd < Pt < Rs$ (Figure 3). All of which were lower than Shannon index 2.940 at equal probability ($Pi = 1/19$), meaning that the ecological interactions of one type with another were quite different with the other neighboring types. This is accordant with the former category analysis results. The neighboring diversity of landscape types has the similar trend with that of the number of neighboring types, however weakly correlated with neighboring lengths (Figure 3). Therefore the number of neighboring types determined the neighboring diversity of landscape types. The spatial neighboring of the landscape types is diverse and com-

Table 3. Spatial neighboring property of the landscape types in Donglingshan mountain region, Beijing, China.

Code	Landscape type	Number of neighbors	Total P (km)	Shannon index	Main neighbor types	Neighboring length (km)	Percent (%)
Rs	Resident	9	13.938	1.172	*Fl*	9.764	70.1
Lp	*Larix principis-rupprechtii*	3	20.210	1.566	*Ql*	9.358	46.3
Pt	*Pinus tabulaeformis*	9	19.282	1.697	*Ql*	8.888	46.1
Po	it Platycladus orintalis	5	13.346	1.077	*Fl*	6.502	48.7
					P&P	5.308	39.8
Bc	*Betula costata*	4	21.250	1.135	*Sm*	12.123	57.0
Bp	*Betula platyphylla*	12	174.908	1.640	*Ql*	74.800	42.8
					Sm	46.428	26.5
Bd	*Betula dahurica*	9	44.196	1.686	*Ql*	18.472	41.8
					Bp	7.492	17.0
					P&P	7.400	16.8
Pd	*Populus davidiana*	7	18.722	1.564	*QL*	8.850	47.3
Ql	*Quercus liaotungensis*	16	326.158	2.249	*Bp*	74.800	22.9
					P&P	66.138	20.3
					Lb	38.822	11.9
					Mf	38.198	22.9
Mf	mixed forest	13	95.892	1.900	*Ql*	38.198	39.8
					P&P	20.802	21.7
Cj	*Caragana jubata*	5	10.142	0.892	*Sm*	6.340	62.5
					Bc	3.136	30.9
Lb	*Lespedeza bicolor*	11	73.288	1.570	*Ql*	38.822	53.0
					Bp	14.174	19.3
P&P	*Prunus ameniaca* var. *ansu* & *P. davidiana*	15	181.020	1.986	*Ql*	66.138	36.5
					Vn	28.848	15.9
					Fl	25.240	13.9
					Mf	20.802	11.5
Vn	*Vitex negundo* var. *heterophylla*	11	165.332	1.467	*Fl*	89.518	54.1
					P&P	28.848	17.4
					Ss	15.896	9.6
Ss	*Spiraea* spp.	7	31.000	1.278	*Vn*	15.896	51.3
					P&P	8.274	26.7
Ms	mixed shrub	5	20.162	1.049	*Fl*	9.754	48.4
					Vn	7.912	39.2
Sm	subalpine meadow	12	127.760	1.860	*Bp*	46.428	36.3
					Ql	20.718	16.2
Fl	farmland	15	189.848	1.914	*Vn*	89.518	47.2
					P&P	25.240	13.3
Ao	apple orchard	3	4.596	0.674	*Fl*	3.422	74.5
					Vn	1.004	21.8

plex, hence we could find no obvious spatial pattern from the above results.

Spatial distribution of landscape types

Based on the number and length of the spatial neighboring types of each landscape type, the new TWINSPAN classification divided the landscape types into three groups, i.e., subalpine, middle and low mountain (Figure 4, also see Table 2 for the altitudes of the 10 main landscape types). The TWINSPAN classification result represented the spatial pattern of landscape types in this region. Broad-leaved deciduous forests, for example, *Ql, Bd, Mf, Pd* and so on, are

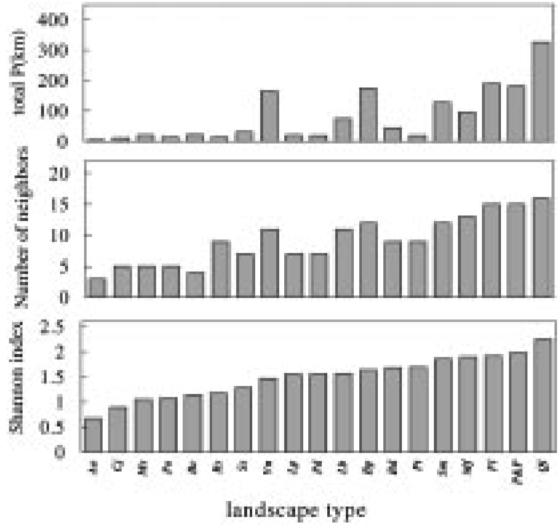

Figure 3. Spatial neighboring diversity and its correlation with the number of neighboring types and perimeters in Donglingshan mountain, Beijing, China. Where the landscape types are *Ao* (apple orchard), *Bc (Betula costata), Bd (Betula dahurica), Bp (Betula platyphylla), Cj (Caragana jubata), Fl* (farmland), *Lb (Lespedeza bicolor), Lp (Larix principis-rupprechtii), Mf* (mixed forest), *Ms* (mixed shrub), *Pd (Populus davidiana), P&P (Prunus ameniaca* var. *ansu & P. davidiana), Pt (Pinus tabulaeformis), Po (Platycladus orintalis), Ql (Quercus liaotungensis), Rs* (Resident), *Sm* (subalpine meadow), *Ss (Spiraea* spp.), *Vn (Vitex negundo* var. *heterophylla).*

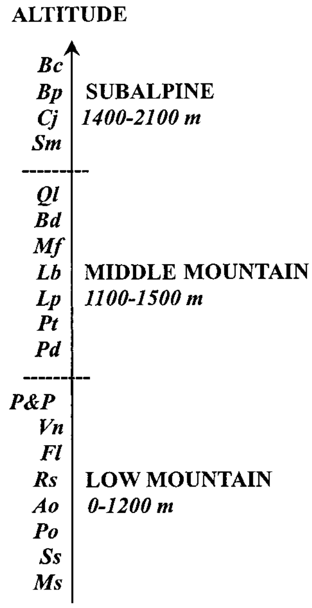

Figure 4. TWINSPAN classification on landscape types of Donglingshan mountain, Beijing, China. Where the landscape types are *Ao* (apple orchard), *Bc (Betula costata), Bd (Betula dahurica), Bp (Betula platyphylla), Cj (Caragana jubata), Fl* (farmland), *Lb (Lespedeza bicolor), Lp (Larix principis-rupprechtii), Mf* (mixed forest), *Ms* (mixed shrub), *Pd (Populus davidiana), P&P (Prunus ameniaca var. ansu & P. davidiana), Pt (Pinus tabulaeformis), Po (Platycladus orintalis), Ql (Quercus liaotungensis), Rs*(Resident), *Sm* (subalpine meadow), *Ss (Spiraea* spp.) and *Vn (Vitex negundo* var. *heterophylla).*

the typical forests in the study area, current landscape types are mainly the preservation or alteration of hem after anthropogenic disturbances (Chen 1997). They are distributed in the middle altitude of the mountain areas. Other types included in this group are two artificial coniferous types, *Lp* and *Pt*, and a shrub *Lb*.

The higher mountain areas were occupied by subalpine types *Sm, Cj, Bp* and *Bc*. Meanwhile the lower mountains were occupied by the low elevation types, plantation forests, shrubs and farmland, including *P&P, Vn, Fl, Rs, Ao, Po, Ss* and *Ms* (Figure 4).

This spatial gradient of the landscape types has close relationship with disturbance as well. Regarding the resident as the disturbance source, the disturbance intensity on landscape types would decrease with the distance from the resident. Figure 4 showed the resident was in the low mountain group, thus the disturbance intensity is high in the low altitude areas, and the reverse in the high altitude areas. Farmland and plantation forests, *Ao* and *Po* were the neighbors of the resident. Their spatial neighboring rates were high, therefore seriously managed by human. The farther neighbors were shrubs, *P&P, Ms, Vn* and *Ss*, all of which were the natural restored shrub types of zonal forests after disturbances in the low elevation area. Disturbance degree in the low mountain group is the highest.

On the other hand, in the subalpine group, *Bc* and *Sm* were far from the resident, which almost remained in natural states because of the low disturbance intensity. An exception is *Bp*, which was occasionally cut by high-mountain residents.

The *Ql*, which is the representative of zonal broad-leaved deciduous forest in this region, is located in the middle mountain group. The other typical forests in this group include *Bd*, *Pd* and *Mf*. The other two conifers (*Pt* and *Lp*) were the protected artificial types originated from *Ql*. And *Lb* was a natural restored shrub from zonal forests after disturbances. The disturbance degree is middle in the middle elevation region.

The spatial distribution of landscape types in Donglingshan mountain region was closely correlated with altitude, as well as influenced by human disturbance intensity.

Discussions

The spatial regularities of landscape types and species diversity are essential information for landscape conservation and management. However, few approaches are currently widely available for this kind of study. In order to enrich the analysis toward finding spatial patterns of complex landscape mosaics, this paper applied two methods, Affinity Analysis and TWINSPAN classification from community ecology; and two kinds of landscape level data, species composition and spatial neighboring data of landscape types, supplied both functional and structural information on the study landscape.

Unfortunately, the results of the two methods conflicted to each other on two aspects. (1) They found different spatial orders of landscape types in the same entity (Figures 2 and 4). (2) They detected different numbers of environmental gradients controlling the landscape. What are the reasons of the conflicts and which method can be trusted is a new problem need to be clearly differentiated before integrating them.

Comparisons of the two methods

Although both of the methods applied in this study belong to community classification and ordination, differences existed between them mainly on two aspects.

First and primarily, their goals are different. The application of the new TWINSPAN classification is to find a spatial gradient (1-dimension) of landscape types and its correlation with environmental factors. Whereas the affinity analysis is to identify how far is a landscape type from the center of the whole with respect to species diversity, and how many environmental gradients control the landscape pattern diversity (Scheiner 1992). Therefore, an affinity gradient of species diversity, which implies a 2-dimension mosaic pattern, might put two types with similar species diversity, however very different in environmental conditions together in affinity graph. For example, *Sm* is on the highest elevation of the mountain region, whereas *Vn* is on the lowest, they are put together in affinity graph (Figure 2) only because the similar number of common and rare species to the whole data set. Therefore, the order of landscape types in an affinity graph is a distance order on 2-dimensional space, hence the resulted mosaic diversity is a description to how many gradients control the spatial mosaic of species diversity in a 2-dimension space instead a 1-dimension landscape type gradient.

Secondly, the data sources are different. The data source of the present TWINSPAN classification is the number and length of spatially neighboring types, which is the spatial structural data. Meanwhile that of affinity analysis is species composition, which is functional data. This is also the important difference between the two methods. The result of functional data reflects the functional aspect of a landscape, meanwhile that of structural data reflects the structural aspect of the landscape, they are not necessary to agree with each other. Moreover a landscape type is determined using dominant species of dominant layer in vegetation. Therefore spatial neighboring data used in the new TWINSPAN classification actually described the spatially neighboring property of dominant species. However, the data used in affinity analysis, the species diversity, is just opposite to the dominance. Thus, the spatial distribution of species diversity must not be correlated to that of dominant species of landscape types, though they may have some relationships. The conflict existed in this study disclosed the disagreement of the structure with function and the dominance with diversity inside the mountain landscape. Therefore, it is significant to integrate the information of a landscape from the both aspects.

Integration of the two methods

Before integrate the two methods to describe the spatial regularity of the mountain landscape, we need to consider first which parts of the two results can be accepted and which need to be neglected.

Although affinity analysis can orderly arrange the 10 selected main landscape types in an affinity graph, we could not find this order is associated with any environmental factors. Which means the species diversity (functional) regularity of the landscape types it supplied, is not the practical distribution of the landscape in space. However, the result of the TWINSPAN classification (Figure 4) approximately agreed with those of observation and typical techniques of community classification and ordination (Ma et al. 1997), is the real structural description to the study landscape. Therefore, the new TWINSPAN classification is more reliable in finding spatial regularity in complicated landscapes and its correlation with environmental factors than affinity analysis. Although the new TWINSPAN classification tells us nothing more than that vegetation communities are distributed on an elevational gradient, it does make sense that the data it used based on GIS is easier to get than typical method, moreover it supplies a structural description rather than species composition to a vegetation.

Affinity analysis is also considered useful in describing pattern diversity of a landscape, since mosaic diversity metric can determine how complex is the landscape mosaics, and whether a landscape is gradient, or controlled by multiple environmental factors (Scheiner 1992). As for our study, the mosaic diversity value showed that there are many environmental gradients control the spatial pattern of species diversity (Figures 1 and 2). These gradients possibly include altitude, topographic settings, soil properties, light intensity, air moisture and temperature, and so forth, as well as human disturbance. It is the mixture of these multiscale factors that resulted in the present complicated spatial mosaic of species diversity. Analogous phenomena were also found in other mountain vegetations (Pinder III et al. 1997), and it is even popular in almost all the landscapes in the world. However, what do these gradients control is the species diversity pattern, not the spatial pattern of the landscape types, especially in those landscapes under severe human disturbance. We could not use functional data to express structural properties of a landscape when they did not agree with each other. Therefore the ecological meanings of the affinity analysis need to be carefully and exactly redefined based on its functional properties. However, affinity analysis supplied information on which type is typical and which is unusual, is helpful in finding important and special elements in a landscape.

Integrating the results of the above two methods is significant, which could combine information from both the functional and structural aspects of a landscape, and the advantages of the two methods. The detailed procedures should be: (1) to describe the spatial mosaic pattern of a landscape using the new TWINSPAN classification or other ordination method, finding out which environmental gradient mostly influenced the spatial pattern of the landscape; (2) to show which types are typical and which are unusual on the basis of affinity analysis, as well as how complex is the species diversity mosaics in space; and (3) by combing of the two approaches, we can understand more clearly how landscape elements are distributed, which environmental gradient controls the spatial distribution, and where important and unusual types are located, how the species diversity influenced by environmental factors. Thus, a landscape can be completely recognized on both structural and functional aspects. The spatial distribution pattern of a landscape found in this way is more reasonable and reliable than that of typical community classification and ordination using functional (species) data only.

Now we can conclude finally that the spatial pattern of the study landscape was controlled by altitude gradient, and influenced by disturbance intensity. Where *Ql* and *Lp* are the central types, equivalent to the zonal types, they are distributed in the middle mountain slopes. Outliers are *Sm* and *Vn*, which distributed in the top and low mountain areas. The remaining landscape types, *Pd, Pt, Bd, Bp, Jm* and *P&P*, are intermediate sites. They are distributed in the most of the mountain topographic settings and the more extensive types in the region. Neighbor types have more species in common than those more widely separated. This species diversity pattern was influenced by multiple environmental factors.

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