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Full Length Research Paper

Ecological relations between forest communities and environmental variables in the Lishan Mountain Nature Reserve, China

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This study attempts to reveal the relationships between forest communities and environmental variables in the Lishan Mountain Nature Reserve, North China. The Lishan Reserve is located at E111° 05' 43" - 111° 56'29", N35ë 29' 07" - 35° 23'10", and is a part of Zhongtiao mountain range. Floristic and environmental data from fifty-eight quadrats, each of 10 × 20 m along an elevation gradient from 1400 to 2100 m were analyzed by TWINSPAN, DCCA and species diversity indices. Nine forest communities were distinguished by TWINSPAN, and they are all secondary vegetation. Forest units varied in accordance with altitudinal gradient. The results of DCCA showed that elevation and soil organic matter were the most important factors determining the spatial patterns of forest communities in the Lishan Reserve. Vegetation distribution was also significantly related to slope, aspect, soil N, P, Cu, Zn, pH and conductivity. The interaction between the examined environmental factors was obvious. Almost all environmental variables were significantly correlated with elevation and soil organic matter. The effects of soil Cu on forests was important in the studied area because Cu affects the effects of most other variables. Species richness increased linearly with the elevation, which is in contrast to the hump-shaped pattern of diversity-elevation relations. However, species heterogeneity and evenness followed the hump-shaped pattern with elevation. Besides elevation, slope was also a significant factor to species diversity in forest communities. Species diversity was negatively correlated with most soil variables except Cu. The interactions between species diversity and soil variables need more attention in future studies.

Key words: Forest conservation, canonical ordination, classification, topographic factors, soil variables, species diversity.

INTRODUCTION

The conservation of forest communities is one of the most important topics in ecology in the world (May, 1975; Dale, 1998; Martins et al., 1999; Loreau et al., 2001; Wang et al., 2003; Krestov et al., 2006), especially in the regions like Northern China where forests are limited in small areas of mountains (WU, 1982; Zhang, 1999, 2005). Species diversity in forests is also important in conservation management and is frequently used as a frequently used as indicator of stability of community systems (Magurran, 1988; Pausas, 1994; Tóthmérész, 1995). The relationships of community structure, composition and species diversity of forest with environmental factors have emerged as a central issue in ecological and environmental sciences. Among environmental variables, topography and soil are the most important factors affecting species and community variation. Many studies on the interaction between forest community and these factors have been reported (Tang and Ohsawa, 1997; Ojeda et al., 2000; Austrheim, 2002).

The variation in species diversity can be linked to several ecological gradients (Grime, 1979; Kessler 2001).

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Figure 1. The geographical position of the Lishan Nature Reserve in Shanxi Province of China.

Altitudinal gradient is well known as one of the causative factors shaping the spatial patterns of species diversity (Thomas et al., 2000; Brown, 2001; Wang et al., 2003).

The hypothesis of species and community diversity – elevation gradient had been tested many times and had become one important hypothesis in plant ecology (Lomolino, 2001; Kessler, 2001). The maximum diversity appearing at intermediate level of elevation (hump-shaped pattern) is one most common hypothesis in biodiversity studies (Kessler, 2001; Austrheim, 2002; Wang et al., 2003). However, there are still a number of notable exceptions to this pattern (Stevens, 1992; Pausas, 1994). Some authors argued that species diversity – elevation relation is largely depended on patterns of interactions among community, species and environmental factors (Olten et al., 1993; Lomolino, 2001; Brown, 2001) . Thus correlation analysis with more environmental variables in species diversity variation should be carried out. To protect the forest vegetation in the Lishan Mountains, the National Nature reserve, Lishan Mountain Nature reserve, was set up in the 1970s. Since then, studies on flora (Liu, 1984; Shangguan et al., 2000), vertical distribution of vegetation (Fu and Li, 1976; Zhang et al., 1997; Zhang et al., 2006) and plant resources (Liu, 1984; Fu and Zheng, 1994) have been carried out. Species functional groups and their relations in forests were analyzed recently (Zhang and Zhang, 2007). However, no studies were conducted on the interpretation of vegetation pattern associated with the major environmental factors and the variations of plant community structure, composition and species diversity. Quantitative analysis of vegetation data, such as classification and ordination, is an important approach to generate hypotheses with respect to vegetation and environment (Hill, 1979; Ter Braak and Smilauer, 2001; Zhang, 1995; Martin et al., 1999) . In the present work, we attempt to present a quantitative analysis of vegetation in relation to the major environmental variables by multivariate analyses, to test the hypothesis of the hump-shaped pattern of diversity-elevation relations in the Lishan reserve, and to elucidate the mechanism of vegetation –environment relationships in the Lishan Mountain Nature reserve.

Study area

The Lishan Mountain with the highest peak of 2358 m is located at E111º 05’ 43” - 111º 56 ’29 ”, N35º 29’ 07” - 35º 23 ’10”, and is a part of Zhongtiao mountain range in Southern Shanxi, China (Figure 1). It lies on the southern margin of the Loess Plateau and is on the transitional area from warm-temperate zone to subtropical zone (WU, 1982). The center part of this mountainous area is the National Nature Reserve, Lishan Mountain Nature Reserve that mainly protects the typical warm-temperate broad-leaved deciduous forests. The climate of this area is warm, temperate and semi-humid with continental characteristics and controlled by seasonal wind. The annual mean temperature is 13.3°C, the monthly mean temperatures of January and July are -0.5 and 27.5°C, respectively, and the annual accumulative temperature more than 10°C is 2100°C. The annual mean precipitation varies from 568 to 850 mm in this mountain, 70% precipitation occurring in July to September within a year. Along the altitudinal gradient, the average precipitations at 1350, 1600 and 2000 m are 545, 672 and 908 mm, respectively. Several soil types, such as cinnamon soil, mountain cinnamon soil, brown forest soil and mountain meadow soil can be found in this area. The study area, Zhuweigou, is the main valley in the Lishan Mountain Nature reserve. Its elevation varies from 1 400 to 2 358 m. Maximum area of the Lishan Reserve is covered with forests, and a small area close to the mountain top is covered with mountain shrub-lands and meadow. This study concerns all forest communities distributed from 1 400 to 2 100 m. The forests are secondary vegetation with frequent disturbance of grazing and felling for timber or fuel until the Lishan Mountain Nature Reserve was found in 1970s'.

METHODS

Sampling and laboratory treatment

Along the elevation gradient of 1400 - 2100 m in Zhuweigou valley, 8 transects separated by 100 m in altitude were set up. These transects were cutting across the valley and oriented along the contours. Four to eight quadrats along each transect were established randomly and the number of quadrats for each transect is depended on vegetation heterogeneity. Species data were recorded in each quadrat. The quadrat size was 10 × 20 m, in which three 4 × 4 m and three 2 × 2 m small quadrats were used to record shrubs and herbs respectively, and to calculate frequency. The cover, height, basal area, number for trees, and the cover, height, abundance for shrubs and herbs were measured in each quadrat. The cover of plants was estimated by eye, and the heights were measured using height- meter for trees and using ruler for shrubs and herbs. The basal diameters of trees were measured using calipers and were used to calculate basal areas. Altogether 160 plant species were recorded in 58 quadrats. Elevation, slope, aspect and the depth of litter for each quadrat were also measured and recorded. The elevation for each quadrat was measured by altimeter, the slope and aspect measured by compass meter and the depth of litter measured by ruler directly. Eight classes of aspect of 1 (337.6 - 22.5°), 2 (22.6 - 67.5°), 3 (292.6 - 337.5°), 4 (67.6 - 112.5°), 5 (247.6 - 292.5°), 6 (112.6 - 157.5°), 7 (202.6 - 247.5°), 8 (157.6 - 202.5°) were used in the analysis (Zhang, 2004) . Five soil samples to a depth of 20 cm in each quadrat were taken using soil cylindered core sampler, and were thoroughly mixed and then one quarter was collected and taken to laboratory for chemical analysis. Soil samples were dried at 70°C and analyzed in the School of Environmental and Resources Science laboratories, Shanxi University. Soil pH, conductivity, organic matter, total nitrogen, total phosphorus, K, Cu, Mn, Zn were measured as soil variables. These variables were selected because some of them, such as N, P, K, organic matter, are the most important nutrient elements, and some of them, such as micronutrient elements Cu, Mn, Zn, have uneven-distribution in the study area (LIU, 1992). A 1:2.5 ratio soil to distilled water suspension was used to measure pH and conductivity using a Whatman pH sensor meter and a conductivity meter, respectively. Total nitrogen was estimated using Kjeldahl extraction, and total phosphorus was measured via the HCLO4-H2SO4 colorimetric method (molybdovanadate method). The organic matter was measured using the method of K2Cr2O7 – capacitance. The K, Cu, Mn, Zn were measured using an Atomic Absorption Spectrophotometer.

Data analysis

We used importance value of each species as data in community analysis and calculation of diversity indices. The importance value was calculated by the formulas (Zhang, 1995):

IV Tree = (Relative cover + Relative dominance + Relative height)/3

IV Scrub and Herbs = (Relative cover + Relative height)/2

The relative dominance refers to species basal area. The species data matrix is the importance values of 160 species in 58 quadrats. The environmental data matrix is the values of twelve variables, nine soil factors plus elevation, slope and aspect, in 58 quadrats.
There are many methods for classification and ordination in plant ecology. The two-way indicator species analysis (TWINSPAN) and detrended canonical correspondence analysis (DCCA) were used to analyze the variation of communities and their relationships with environmental variables, because these are the most common and effective techniques in community analysis with available software (Zhang, 1995) . The calculation of TWINSPAN and DCCA were carried out by computer program of TWINSPAN (Hill, 1979) and Canoco (Ter Braak and Smilauer, 2001), respectively. There are plenty of indices for measuring species diversity in ecological literature (Pielou, 1975; Zhang, 2004; Tóthmérész, 1995). We employed three species diversity indices, one for species richness, one for species heterogeneity, and one for species evenness. They are: Species number (as a richness index) D = S; Shannon-Wiener heterogeneity index H' = - PilnPi; Pielou evenness index E = (-PilnPi)/lnS. Where Pi is the relative importance value of species I, Pi = Ni/N, where Ni is the importance value of species I, N the sum of importance values for all species in a quadrat, S the species number present in a quadrat (Pielou, 1975, Zhang 1995).

The Pearson regression and correlation methods were used to analyze the relationships between species diversity indices and environmental variables.

RESULTS

Community classification

TWINSPAN classified 58 quadrats into 13 clusters at the last division (Figure 2). We chose a suitable classification level and got 9 groups, representing 9 forest communities (Figures 2 and 3). The community name and its quadrat composition are shown in Figure 2.

The structure and environmental characteristics of the nine communities varied greatly (Table 1). The relationships between species and these communities can be seen clearly from TWINSPAN results (Figure 3). The ecological gradients can be found from Figure 3 as well, that is, the elevation decreases from left to right, correspondingly, the temperature increases and the water-conditions decrease from left to right of Figure 3. The communities vary from hygrophilous and cryophilous types, such as *Betula albo – sinensis* + *Salix pseudotangii* + *Pinus armandi* forest and *B. albo – sinensis* + *Populus davidiana* forest, to thermophilous types, such as *Pinus tabulaeformis* forest. The same ecological gradients can be found from top to bottom of Figure 3. The species vary from humidity-liking species to dry-tolerant species from top to bottom. The variation of community and species is also correlated with aspect, slope, anthropogenic factors etc.

Relations of communities and environmental variables

We used DCA, CCA and DCCA to analyze the

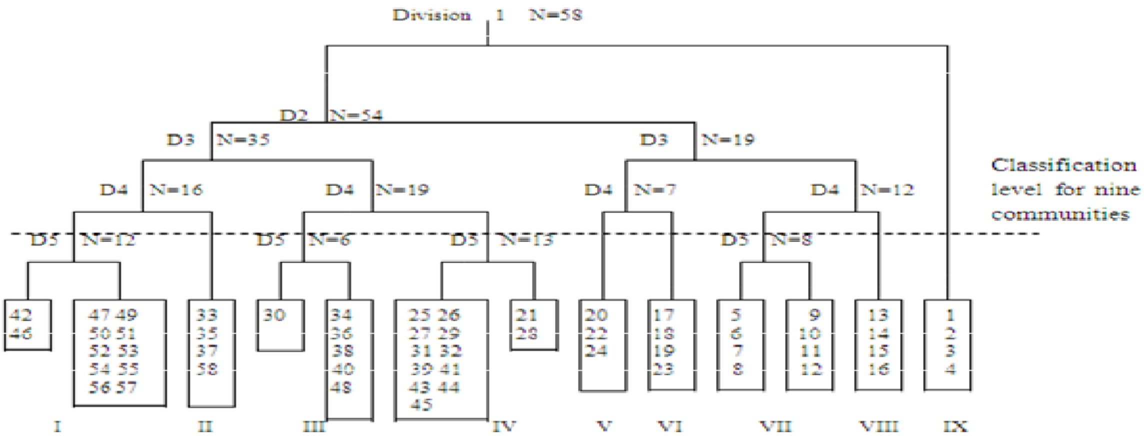

Figure 2. The dendrogram of the TWINSPAN classification of 58 quadrats in the Lishan Reserve, China. The numbers in the squares refer to quadrats. I - IX refer to nine communities. I Comm. *Betula albo-sinensis* + *S. pseudotangii* + *P. armand*i - *Abelia biflora* + *Spiraea pubescens* - *Thalictrum squarrosum* + *Polygonum* convolvulus; II. Comm. *B. albo-sinensis* + *P. davidiana* - *Philadelphus incanus* – *T. squarrosum* + *Cimicifuga foetida*; III. Comm. *Acer davidii* + *Q. liaotungensis* + *Acer mono* - *Lonicera chrysantha* + *Sorbaria sorbifolia* - *Dryopteris barbigera* + *Maianthemum bifolium*; IV. Comm. *A. davidii* + *Carpinus turczaninowii* + *Q. liaotungensis* – *P. incanus* - *Polygonatum odoratum* + *Saussurea japonica* var. *alata*; V. Comm. *A. mono* + *Juglans cathayensis* - *Sambucus williamsii* - *Achyranthes bidentata* + *Artemisia lavendulaefolia*; VI. Comm. *Toxicodendron verniciflum* + *C. turczaninowii* var. *stipulata* - Forsythia suspensa +Samnucus williamsii - Astilbe *chinensis* + *Saussurea japenica* var. alata; VII. Comm. C. turczaninowii var. stipulata + C. turczaninowii – F. *suspensa* - *Phlomis umbross* + *D. barbigera*; VIII. Comm. *J. cathayensis* – *F. suspensa* – *P. umbross* + A. *lavendulaefolia*; IX. Comm. *P. tabulaeformis* - *Vitex negundo* var. *heterophylla Patrinia heterophylla* + *Carex lanceolata var*. subpeditormis.

relationships between communities and environmental variables. Because they have similar results, only the results of DCCA ordination are displayed here. Figure 4 is the biplot of DCCA ordination of 58 quadrats with 12 environmental variables. Each quadrat can be assigned to one of the 9 communities produced by TWINSPAN.

The first DCCA axis (Eigenvalue = 0.651, $P<0.001$) is mainly an altitude gradient (a correlation coefficient of 0.866 with elevation) along which the elevation increases gradually from left to right, that is, the humidity and water-conditions in soils increase and the temperature decreases along the first axis from left to right. Therefore the communities on the left are usually distributed in low hills with comparatively dry and hot conditions, and that on the right distributed in the hills with high elevation. Besides elevation, the soil organic matter, N, Cu, pH and conductivity are also significantly correlated with the first DCCA axis. The second DCCA axis is mainly related to aspects and slope (with correlation coefficients of 0.594 and -0.530 respectively). In addition, soil Zn, N and elevation are important factors to the second DCCA axis (Figure 4). These relations can also be seen from canonical coefficients and correlation coefficients (Table 2). These ecological relations are also related to the interaction between environmental factors (Table 3). Figure 5 is the DCCA biplot of 18 tree species and 12 environmental variables. The DCCA axes have the same ecological gradients as Figure 4. Most of these species are dominant in the forests canopy layer, and their relationships with environmental variables also represent ecological relations between communities and environments.

Species diversity

Species richness shows a significant linear relationship, and species heterogeneity and evenness show a significant quadric relationship with elevation increasing (Figure 6). This suggests that elevation is an important factor for species diversity. Species richness increases with elevation, and species heterogeneity and evenness increase first, reach a maximum value and then decrease a little in the Lishan Mountain Nature reserve. The relationships between species diversity and other environmental variables are listed in Table 4. Species richness in community is negatively related to soil organic matter, Cu, Zn, K, N and pH. Species heterogeneity is positively correlated with slope, and negatively correlated with soil Zn, Mn, K and pH. Species evenness is also positively correlated with slope, and negatively related to aspect, soil Mn, Zn and K (Table 4).

DISCUSSION

Forest communities

The forest varies significantly in composition. TWINSPAN successfully distinguished them into different forest types

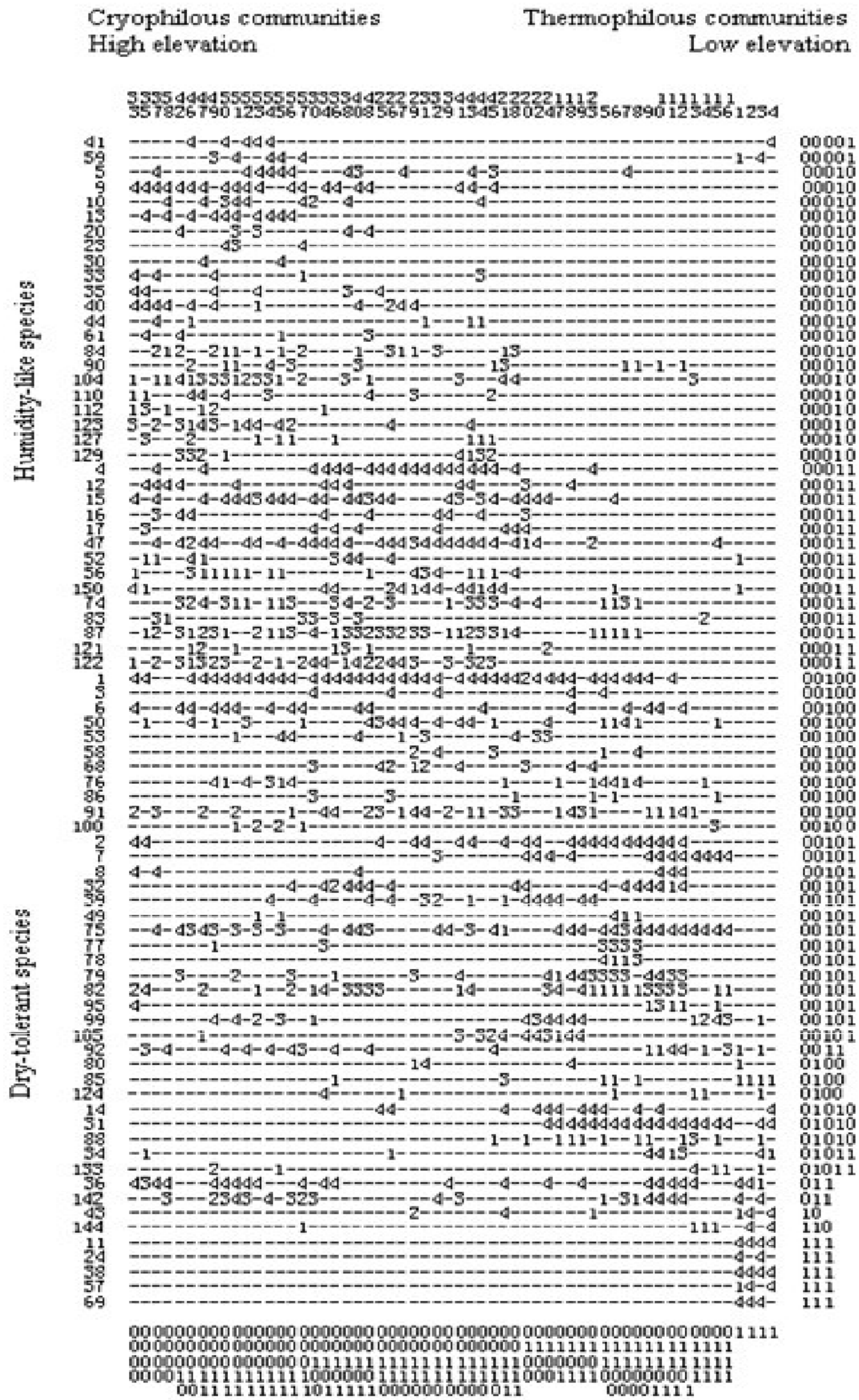

Figure 3. Two-way table of species and quadrats classification produced by TWINSPAN. The species number represents: 1.*Carpinus turczaninowii*; 2. *C. turczaninowii* var. *stipulate*; 3. *Ulmus lamellose*; 4. *Acer davidii*; 5. *Sorbus pohuashanensis*; 6. Q. liaotungensis; 7. Juglans cathayensis; 8. *Betula platyphylla*; 9 *Betula albo-sinensis*; 10. *Pinus armandi* ; 11. *Pinus tabulaeformis;* 12. *Salix pseudotangii*; 13. *Populus davidiana*; 14. T. verniciflum 15. *Acer mono*; 16. *Rhus chinensis*; 17. *Tilia mongolica*; 18. *Quercus aliena*; 19. *Staphylea*

holocarpa; 20. *Swida alba*; 21. *Cerasus polytricha*; 22. *Euodia rutaecarpa*; 23. *Crataegus kansuensis*; 24. *Cornus bretschneideri;* 25. *Koelreuteria paniculata*; 26. *Syringa reticulata* var. *mandshurica*; 27. *Pyrus betulaefolia*; 28. *Malus honanensis*; 29. *Hydrangea bretschneideri*; 30. *Celastrus orbiculatus*; 31. *Forsythia suspense*; 32. Lonicera chrysantha; 33. Lonicera hispida; 34. *Lonicera ferdinandii* 35. *Lonicera microphylla* 36. *S. pubescens* 37. *Spiraea trilobata*; 38. *V. negundo* var. *heterophylla*; 39. *Sambucus williamsii*; 40. *Abelia biflora;* 41. *Cotoneaster multiflorus;* 42. *Rubus crataegifolius;* 43. *Lespedeza bicolor*; 44. *Schisandra chinensis*; 45. *Cotoneaster acutifolius*; 46. *S. sorbifolia* 47. *P. incanus* 48. *Acanthopanax gracilistylus* 49. *Acanthopanax senticosus* 50. *Euonymus alatus* 51. *Euonymus nanoides* 52. *Ribes mandshuricum* 53. *Viburnum betulifolium* 54. *Viburnum schensianum* 55. Viburnum opulus var. calvescens 56. *Smilax china* 57. Rosa xanthina 58. Rosa davurica 59. Rosa bella 60. *Hydrangea bretschneideri* 61. *Berberis amurensis* 62. Syringa microphylla 63. Ribes bruejense 64. *Pyrus betulaefolia* 65. *Myripnois dioica* 66. *Daphne odora* 67. *Sophora flavescens 68*. *Rhamnus davurica* 69. *Elaegnus pungens* 70. *Celastrus orbiculatus* 71. *Elsholtzia stauntoni* 72. *Crataegus pinnatifida* 73. *Diospyros lotus* 74. Smilacina japonica 75. *P. umbross* 76. *Veratrum nigrum* 77. Paris verticillata 78. Triosteum pinnatifidum 79. A. chinensis 80. Cacalia hastata 81. *Cystopteris fragilis* 82. D. barbigera 83. Aquilegia viridiflora
84. *Vicia unijuga* 85. P. heterophylla 86. *Dioscorea nipponica* 87. *P. odoratum* 88. *Galium verum* 89. *Arisaema erubescens* 90. *Epimedium grandiflorum* 91. *S. japenica* var. alata 92. *Aconitum carmichaeli* 93. *Aconitum barbatum* 94. *Ajuga ciliata* 95. *Ligularia intermedia* 96. *Viola prionantha* 97. *Viola variegata* 98. *Viola biflora* 99. *A. lavendulaefolia* 100. *Artemisia argyi;* 101. *Artemisia brachyloba*; 102. *Pedicularis resupinata*; 103. *Thalictrum petaloideum*
104. *T. squarrosum* 105. *Achyranthes bidentata*; 106. *Rubia cordifolia* 107. *Senicula chinensis*
108. *Pimpinella thellungiana*; 109. *Hylotelephium verticillatum*; 110. *Polygonatum involucratum*; 111. *Pertya sinensis*; 112. *Polygonum convolvulus;* 113. *Lamium album* 114. *Carpesium cernuum* 115. *Glycine soja* 116*. Chrysosplenium pilosum*; 117. *Polygonatum verticilatum* 118. *Lactuca tatarica* 119. *Lonicera tragophylla* 120. *Kalimeris lautureana* 121. *Heracleum hemsleyanum* 122. *M. bifolium* 123. *Cimicifuga foetida* 124. *Sedum aizoon* 125. *Pyrrosia lingua* 126. *Lespedeza davurica* 127. *Cardamine tangutorum* 128. *Aster tataricus*; 129. *Angelica dahurica*; 130. *Paeonia obovata*; 131. *Convallaria keiskei*; 132. *Hypericum erectum*;
133. *Cirsium teo* 134. *Poa annua* 135. *Arundinekka hirta* 136. *Dendranthena lavandulifolium*; 137. *Polygonum viviparum*; 138. *Cynanchum ascyrifolium*; 139. Allium senescens; 140. Potentilla chinensis; 141. *Leontopodium leontopodioides*; 142. C. lanceolata var. subpeditormis
143. *Carex rigescens* 144. *Carex arnellii*; 145. Viola yedoensis 146. Iris tenuifolia 147. *Anemone tomentosa* 148. *Leibnitzia anandria*; 149. *Cleistogenes serotina*; 150. Geum *urbanum* 151. *Stellaria media*; 152. *Dendranthema cavandulifolium*; 153. *Vitis amurensis* 154. *Ixeris sonchifolia*; 155. *Duchesnea indica*; 156. *Akebia quinata*; 157. *Cacalia farfaraefolia* 158. *Clematis macropetala*.

(Figures 2 and 3). The nine communities are present in the Lishan Reserve (Zhang et al., 1997). They are almost all secondary forests, and Comm. IX including a part of planted trees of P. tabulaeformis near villages. The classification scheme of forest communities is reasonable according to the Chinese vegetation classification system (Wu, 1982). An altitudinal gradient in TWINSPAN diagrams (Figures 2 and 3) is clear which suggests that elevation is important in community differentiation. The effects of elevation on community variation are more obvious in high classification level (D4 in Figure 2). Four groups of forest, cold-temperate small-leaved and mixed forest (I, II), typical temperate broad-leaved deciduous forest (III, IV), temperate mixed broad-leaved deciduous forest (V, VI, VII, VIII, and warm temperate coniferous forest (IX), gradually changed along the altitudinal gradient. The first group is a vertical zonal vegetation type and the other three groups are zonal vegetation in this region (Zhang et al., 1997). Further differentiation of these groups into the nine communities is related to aspect, slope and micro topographic conditions because these factors varied greatly in mountains (Austrheim, 2002; Zhang et al., 2006; Krestov et al., 2006). In addition, human disturbance (grazing, traveling etc.) is an important factor affecting community variation, and an anthropogenic gradient related to elevation can be identified in the Lishan reserve. The lower the elevation, the more the disturbance, because low area is more close to villages. The relationships between communities and species composition are clear (Figure 3) and species variation is related to elevation, aspect, slope and human disturbances.

The age of the studied forests is between 60 and 80 years, and the effective conservation for these forests is only for the last 35 years (Shangguan et al., 2000). Therefore these forests are under succession, proceeding towards climax, Quercus forests (Wu, 1982; Zhang et al., 1997; Zhang, 2002). The types of forests are expected to change in the succession process.

Forest-environment relationships

Forests are usually closely related to the environmental variables (Liu, 1984; Ertli et al., 2004). DCCA results of this study support this point. Among environmental

Table 1. Structure of the nine forest associations in the Lishan Reserve, China.

Community types	Elevation (m)	Slope (°)	Aspect	Total cover of community (%)	Mean coverage of tree layer (%)	Mean coverage of shrub layer (%)	Mean coverage of herb layer (%)	Mean coverage of mosses (%)	Mean thickness of litters (cm)
I	1800-2100	25	N	92	88	39	38	6	4
II	1900-2100	15	NE, NW, E, W	87	79	21	32	8	5.6
III	700-1920	15-25	N, NE	85	78	40	29	28	5.3
IV	1620-1920	15-25	N, NE, NW, E	92	87	31	31	16	4.4
V	1600-1620	20	N, NE	87	75	43	30	23	3.3
VI	1600-1620	20	N, NE	99	76	26	72	7	3.5
VII	1500-1510	15~20	E	96	89	49	58	25	5
VIII	1550	5	W, SE, SW	89	61	28	64	20	2
IX	1400	10	S	88	58	53	51	10	4

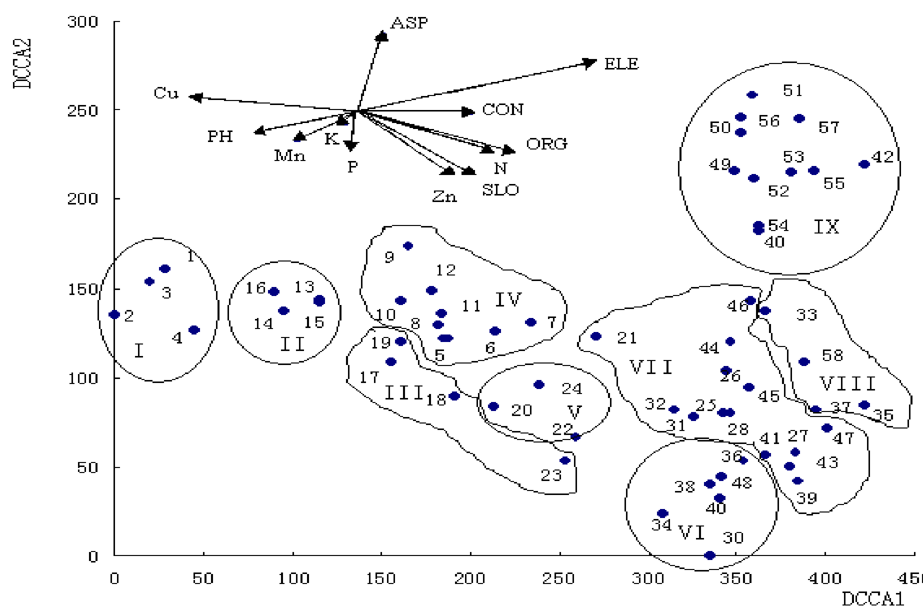

Figure 4. Two-dimensional DCCA ordination biplot of 58 quadrats and 12 environmental variables in the Lishan Reserve, China. 1, 2, …, 58 representing quadrat number; I, II, …, IX representing community types; ELE - elevation, SLO – slope, ASP – aspect, ORG - organic matter; CON - soil conductivity; PH, N, P, K, Cu, Mn and Zn refer to soil pH, total nitrogen, total phosphorus, K, Cu, Mn and Zn, respectively.

Table 2. Canonical coefficients and the correlation coefficients of environmental variables with the first three axes of DCCA

Environmental variables	Canonical coefficients			Correlation coefficients		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Elevation	0.792	0.316	0.183	0.866***	0.315**	0.019
Slope	0.185	0.119	-0.343	0.398**	-0.530***	-0.191
Aspect	-0.067	0.361	-0.247	0.048	0.594***	-0.038
pH	-0.004	0.062	-0.039	-0.403**	-0.144	-0.038
Organic matter	0.003	-0.085	0.035	0.575***	-0.356**	0.072
Conductivity	0.141	-0.024	-0.074	0.416***	-0.049	-0.081
N	0.168	-0.102	0.159	0.501***	-0.356**	0.255*
P	0.059	-0.092	0.267	-0.038	-0.254*	0.567***
K	0.001	0.126	-0.061	-0.068	-0.100	-0.248
Cu	-0.160	0.121	0.071	-0.645***	0.137	0.181
Mn	-0.099	0.067	0.181	-0.251*	-0.209	0.379**
Zn	0.172	-0.361	-0.052	0.375**	-0.523***	-0.172

* P<0.05, **P<0.01, ***P<0.001.

variables, elevation is the most important factor in relation to vegetation distribution pattern in the Lishan Reserve (Figure 4, Table 2). This is mainly due to the change of water-conditions along altitudinal gradient, that is, the water-conditions are improve with the elevation, because precipitation is a limiting factor to plant growth and distribution in this area (Zhang et al., 1997). Besides elevation, other topographic factors, such as slope and aspect, are also significant to spatial variation of plant communities, because aspect and slope also affect soil water conditions and temperature, and aspect further affects isolation in the communities (Lomolino, 2001; Krestov et al., 2006). This is identical to many studies of mountainous vegetation in other places in the world (Whittaker, 1960; Tang and Ohsawa, 1997;, Lomolino, 2001; Zhang, 2002; Wang et al., 2003).

The soil nutrients are key factors to plant growth and vegetation development (Liu, 1992; Brunner et al., 1999; Molles, 2002). The importance of nutrient factors in a community or a region depends on their amount anddistribution (Hou, 1982; Saarsalmi et al., 2001). Among soil variables in the Lishan Reserve, organic matter has the highest correlation with community distribution, for many nutrients are related to the amount of organic matter in soil (Wu, 1982; Zhang and Oxley, 1994), and the accumulation and amount of organic matter are strongly related to temperature and water-conditions in soils (Anderson, 1982; Wu, 1982; Zhang, 2002), because the degradation of soil organic matter is correlated with temperature and water-conditions (Molles, 2002). For the most important nutrient elements, soil N and P also have significant roles in affecting spatial vegetation pattern in the Lishan Mountains. This is due to uneven distribution of these two nutrients in this region (Liu, 1992). The relationship between forest and soil K is not significant, as nutrient K is sufficient in the soils in this area (Anderson, 1982; Zhang, 2002). For soil heavy metals, community variation is more significantly related to Cu and Zn, this may be due to the spatial distribution of these two metals being uneven, and they are not sufficient in some communities but they are too much to be toxic in some others (Liu, 1992). The Mn is also important to community distribution according to the correlation coefficients (Table 2). The role of soil pH and conductivity on forest communities is also significant in the Lishan Reserve, which may be related to elevation (Zhang and Zhang, 2007). The influences of vegetation communities on environmental variables, particularly on soil variables are also important, and this complicated inter-relationship can be illustrated by correlation and canonical coefficients (Tables 2 and 3).

The DCA, CCA and DCCA ordinations all described these ecological relationships clearly (Zhang, 2004). However, DCCA results with the high correlation coefficients with ordination axes (0.977, 0.921 and 0.888 for the first three axes respectively) are better than that of DCA (0.460, 0.320 and 0.097 for the first three axes respectively) and CCA (0.964, 0.881 and 0.828 for the first three axes respectively) in describing relationships between vegetation and environments (Zhang, 1994; Zhang and Oxley, 1994). The first DCCA axis is closely related to elevation, organic matter, N, Cu and so on, while the second DCCA axis is related to slope, aspect, elevation, Zn, N and so forth (Figure 4). The DCCA biplot further confirms that these factors are significant to vegetation development and distribution in the Lishan Reserve. The distribution patterns of communities and tree species in DCCA space are consistent to the ecological gradients reflected by the DCCA axes (Figures 4 and 5). Each community has its own distribution area and clear boundaries in DCCA diagram, which proves that TWINSPAN and DCCA produce consistent ecological

Table 3. Correlation coefficients between environmental variables in forests in the Lishan Reserve, China.

Variable	Elevation	Slope	Aspect	pH	Organic matter	Conductivity	N	P	K	Cu	Mn
Slope	0.020										
Aspect	0.260*	-0.552***									
pH	-0.432***	-0.046	-0.167								
Organic matter	0.300*	0.534***	-0.074	-0.166							
Conductivity	0.342***	0.052	0.001	-0.153	0.215						
N	0.231	0.504***	-0.002	-0.116	0.877***	0.190					
P	-0.183	0.172	0.020	-0.092	0.273*	-0.171	0.280*				
K	-0.168	0.108	-0.066	0.028	0.171	-0.067	-0.162	0.087			
Cu	-0.470***	-0.530***	-0.070	0.433***	-0.441***	0.093	-0.400**	-0.093	-0.058		
Mn	-0.343**	0.128	-0.095	0.329**	-0.053	-0.034	0.158	0.295*	0.031	0.090	
Zn	0.149	0.242*	-0.026	0.175	0.291*	0.249	0.207	0.014	0.315*	-0.243	0.175

* $P<0.05$, ** $P<0.01$, *** $P<0.001$.

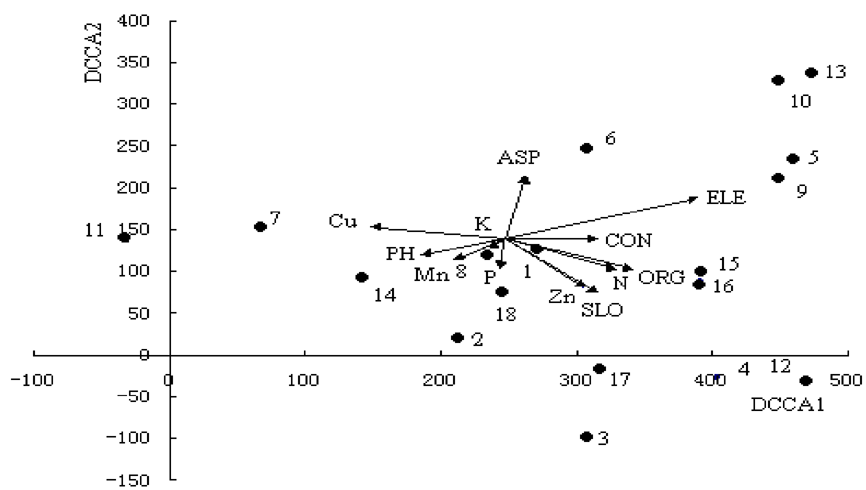

Figure 5. Two-dimensional DCCA ordination diagram of the main tree species and environment al variables in the Lishan Reserve, China. ELE - elevation, SLO – slope, ASP – aspect, ORG - organic matter; CON - soil conductivity; PH, N, P, K, Cu, Mn and Zn refer to soil pH, total nitrogen, total phosphorus, K, Cu, Mn and Zn, respectively. 1. *C. turczaninowii;* 2. *C. turczaninowii* var. *stipulate;* 3. *U. lamellose;* 4. *A. davidii;* 5. *S. pohuashanensis;* 6. *Q. liaotungensis;* 7. *J. cathayensis;* 8. *B. platyphylla;* 9. *B. albo-sinensis;*10. *P. armandi*; 11. *P. tabulaeformis*; 12. *S. pseudotangii*;13. *P. davidiana;* 14. *T. verniciflum;* 15. *A. mono*; 16. *R. chinensis;* 17. *T. mongolica;* 18. *Q. aliena.*

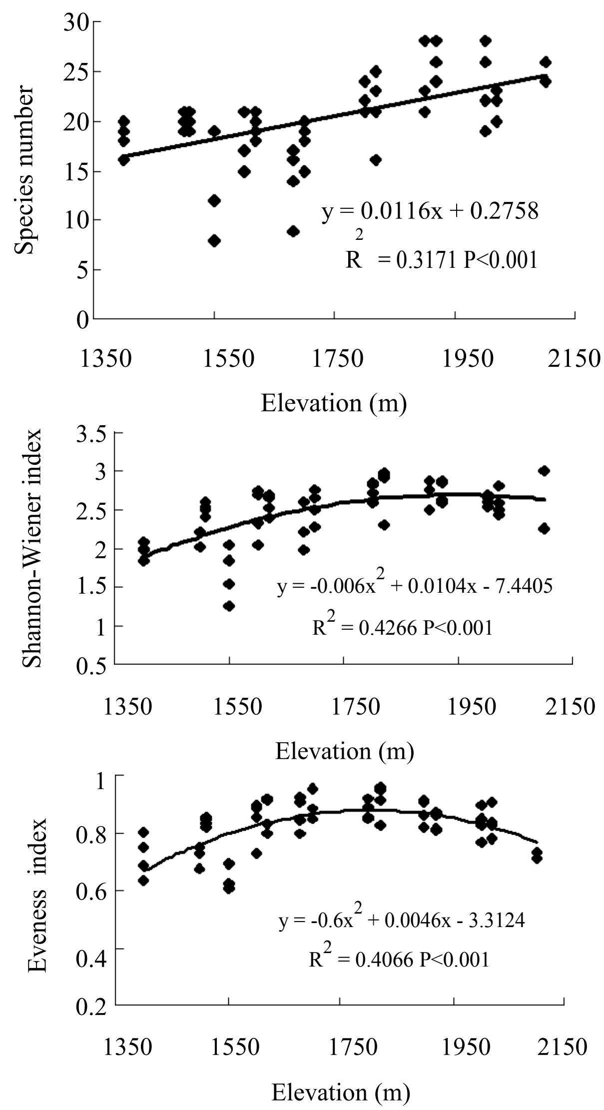

Figure 6. The variation of species diversity along the elevation gradient in the Lishan Reserve, China.

Table 4. Correlation coefficients between species diversity and environmental variables in Lishan Reserve, China.

Environmental variables	Species number	Shannon-Wiener index H'	Evenness E
Elevation	0.563***	0.597***	0.363**
Slope	-0.028	0.468***	0.723***
Aspects	0.068	-0.175	-0.346**
Soil pH	-0.293*	-0.252*	-0.174
Soil organic matter	-0.345**	-0.147	0.019
Soil conductivity	0.190	0.169	-0.048
Soil total N	-0.294*	-0.120	0.027
Soil total P	0.002	-0.057	-0.015
Soil total K	-0.281*	-0.385**	-0.346**
Soil Cu	0.369**	0.156	-0.028
Soil Mn	-0.146	-0.385**	-0.447***
Soil Zn	-0.610***	-0.570***	-0.367**

* P<0.05, **P<0.01, ***P<0.001.

relations of forests and environments (Zhang, 2004). In the DCCA biplot of quadrats, the cryophilous and hygrophilous communities and their dominant tree species appeared on the right area, and the thermophilous associations and their dominant species on the left area. This is mainly controlled by the altitudinal gradient (Tang and Ohsawa, 1997; Wang et al., 2003).

Interaction of environmental variables

All the ecological factors coexist and act simultaneously in communities and ecosystems (Zhang and Oxley, 1994; Tang and Ohsawa, 1997; Molles, 2002). These factors interact with each other, and this interaction is very complicated. In our study, almost all variables are correlated with elevation (Table 3), that is, the variation of elevation affects other environmental variables that further influence plants and vegetation. Therefore, the conclusion that elevation is the key factor to forests in the Lishan Reserve is reasonable (Zhang et al., 1997; Wang et al., 2003). The soil organic matter and N have significantly positive correlation and Cu negative correlation with slope. This suggests that slope is important to the distribution of main nutrient elements in forests, because slope affects the accumulation, degradation and eluviation of organic matter and nutrients. However, the role of aspect on soil nutrients is not apparent, and aspect may affect the isolation of communities which further affect vegetation pattern. For the soil variables, organic matter is significantly related to N, P, Cu, Zn and topographic factors, and is the most important soil variables in forests (Tang and Ohsawa, 1997; Martins et al., 1999), because the concentration of the most nutrients in soil depends on degradation of organic matter. Soil N is positively related to P which may be due to their similar source, and P is positively related to Mn. One notable phenomenon is that soil Cu is negatively related to all topographic factors and to soil organic matter and N, and positively related to soil pH. The effects of soil Cu on vegetation may result from its influence on other factors (Liu, 1992). This further proved the DCCA result that soil Cu is a significant factor in Lishan reserve.

Species diversity pattern

The relationships between species diversity and elevation in mountains have been tested frequently in plant ecology (Dale, 1998; Brown, 2001; Wang et al., 2002). Species richness has a significant linear relation with the altitudinal gradient in the Lishan Reserve. It increased with elevation, which is mainly due to the improvement of water -conditions along the altitude gradient from 1400 to 2100 m (Zhang et al., 1997). Species heterogeneity and evenness showed a hump-shaped pattern along altitudinal gradient, which is consistent with many other studies (Stevens, 1992; Lomolino, 2001; Zhang et al., 2006). The exception of species richness to the hump-shaped pattern of diversity-elevation relations may be interpreted as that the elevational gradient is not a full gradient of the Lishan Mountains and the subalpine shrubs and meadow are not included (Zhang et al., 2006; Zhang and Zhang, 2007). This study concerned forests communities with elevation from 1400 to 2100 m, and the mountain shrubland and meadow over the forest line (2130 to 2358 m) was not included. Species diversity is also significantly correlated with slope and aspect in the

Lishan Reserve. Species heterogeneity and evenness are positively correlated with slope, and evenness negatively correlated with aspects (Table 4).

Soil organic matter and nutrients are almost all negatively correlated with species heterogeneity, richness and evenness (Table 4), except for a positive relation between Cu and species richness. This may be due to the interactions between species, because the more the nutrient availability, the more possibility for certain species to prevail, which may affect other species. This may also depend on an interaction of litters, soil parent materials, and eluviation, and may be related to elevation, slope, aspect etc. (Anderson, 1982; Zhang and Oxley, 1994). The significant correlations between the examined factors (Table 3) show such interaction. This interaction will affect species diversity in forests. The effect pattern of soil variables on species diversity is uncertain, because there are no enough researches in the ecological literature on this topic (Zhang and Chen, 2007). More studies including empirical studies need further carry out in the future.

Species diversity is an important feature of forest community (Kessler, 2001) and the analysis on the relationships between species diversity and environmental variables can help us to understand the structure and ecological relations of communities (Zhang, 2004; Zhang and Chen, 2007). The combination of multivariate analysis and diversity analysis may become a more effective way in the study of plant communities.

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