ATTRIBUTES OF FOREST DIVERSITY IN THE YUNMENG MOUNTAIN NATIONAL FOREST PARK IN BEIJING, CHINA

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Abstract. The Yunmeng Mountain National Forest Park is close to Beijing city and is ecologically important for its citizens. Forty-two quadrats of 10 m × 10 m were established along an altitudinal gradient within the forest. Species composition and environmental variables were measured and recorded in each quadrat. TWINSPAN (Two-Way Indicator Species Analysis) and CCA (Canonical Correspondence Analysis) were used to analyze the relationships between forest types and environmental factors, and species diversity indices were used to analyze the pattern of species diversity in this park. The results showed that there were seven forest communities (formations); most of which were secondary natural forests, along with some plantations. Each forest type had its own characteristic composition, structure, function, and environment. The variation in forest communities was most significantly correlated with elevation and slope position but was also related to slope, aspect, soil depth, and litter depth. Species richness and diversity increased significantly along altitudinal and slope position gradients. The highest diversity appeared near the mountain summit. Elevation and slope position were key factors influencing forest distribution and species diversity. Effective management measures should be considered in this park.
Keywords: *forest conservation; forest classification; forest-environment relation; species diversity; mountain development*

Introduction

Variation in forest vegetation and species diversity and their underlying mechanisms form the basis for conservation of natural forests (Fetene et al., 2006, Muhumuza and Byarugaba, 2009; Zilliox and Gosselin, 2014). Mountainous regions are significant for nature conservation because in countries with limited protected areas, such as China, most natural forest communities are centralized in the mountains (Zhang et al., 2012). Beijing is the capital city of China, and its natural forests are very limited (Zhang et al., 2013). Therefore, these natural forests are especially important for providing ecological services to people living in such a large city (Muenchow et al., 2013).

A complex of factors determines the community composition, structure, and related species diversity of mountain forest vegetation (Schmidt et al., 2006; Korner, 2007; Luth et al., 2011). One important factor is altitude, which has a strong influence on the structure of the forest vegetation in most mountains of the world (e.g., Zhang, 2002; Hawkins and Diniz, 2004; Rahbek, 2005). Whether species diversity increases or decreases with increasing elevation or peaks at intermediate elevation depends largely on specific patterns of interactions among forest communities, species, and environmental factors (Lomolino, 2001; Brown, 2001; Korner, 2007). Changes in forest type and species diversity along altitudinal gradients have been studied frequently in plant ecology (Fetene et al., 2006; Otypkova et al., 2011), and most have found a ‘‘humped’’ distribution, with peak species diversity occurring near the middle of the

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gradient (Austrheim, 2002; Zhang et al., 2012). However, there are a number of exceptions to this pattern (Pausas, 1994; Zilliox and Gosselin, 2014).

Yunmeng Mountain, belonging to the western part of the Yan Mountain Range, is one of the most well-known, picturesque mountains in suburban Beijing, and the topography of the forest park is unique. It is the closest national nature-forest park to the city center of Beijing and is a famous eco-tourism site (Xiang and Zhang, 2009). Forest vegetation plays a significant role in local development, and it should be protected and utilized reasonably. A number of studies have been conducted in this geographical area, including studies related to floristic characteristics and plant resources (He et al., 1992), resources and evaluation of eco-tourism (Wang et al., 2004), restoration of degraded scrublands at lower elevations (Dai et al., 1990), and vertical distribution of tree species (Zheng et al., 2007). However, no studies have examined the association between major environmental variables and forest or species diversity in the Yunmeng Mountain Forest Park. This work studies forest and species diversity and their relationship to environmental variables. Our objectives were (1) to analyze the interdependencies among forest characteristics and environmental variables, (2) to identify the key environmental factors influencing forest composition and species diversity, and (3) to test the hypothesis that highest species diversity appears at intermediate elevation.

Materials and methods

Study sites

The Yunmeng Mountain National Forest Park is located at 116°40′- 116°50′E, 40°26′- 40°38′N in the north of Beijing City and is approximately 85 km from the city center. The park occupies a total area of 2,208 ha, and its main peak is 1,414 m.a.s.l. This area is deeply affected by the warm-temperate, subhumid Southeast monsoon. The annual mean temperature is approximately 10ºC, the mean monthly temperature of July is 25ºC, and the mean monthly temperature of January is -7ºC. The annual mean precipitation is 600-700 mm, and it increases with increasing elevation. Most rain (over 76%) falls from June through September. The main soil types are brown forest soil and drab soil.

The forest park has rich scenic resources, thick forests, and significant animal and plant diversity, including 711 species of plants. Vegetation is mainly secondary broad-leaved deciduous forest, with some plantations of coniferous forest. The Yunmeng Mountain Forest Park, with its unique topography, ponds, waterfalls, forests, and vivid landscapes integrates the functions of conservation and sightseeing through eco-tourism.

Data collection

Based on a general investigation, 15 sampling points, each separated by 50 m in elevation, were set up along an altitudinal gradient between 750 and 1401 m.a.s.l. Two to four quadrats around each sampling point were established along the contour line. The quadrat size was 10 m × 10 m. The cover, height, abundance, and basal area for tree species and the height and cover for shrubs and herbs were measured and recorded in each quadrat. Plant height was measured using a clinometer for trees and a steel tape measure for shrubs and herbs. The basal diameter of trees was measured using a caliper and was used to calculate basal area. A total of 102 plant species were recorded in 42 quadrats.

Six environmental variables were measured and recorded for each quadrat: elevation, slope, aspect, slope position, soil depth, and litter depth. Elevation was determined with

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a GPS, slope and slope aspect were measured using a compass meter, soil depth was measured with a penetrometer, and litter depth was measured using a ruler (Zhang et al., 2013). Elevation, slope, soil depth, and litter thickness were continuous variables. Slope position was classified from 1 to 5, representing hill ridge, upper, middle, lower location, and valley bottom, respectively. Aspect measurements were classified from 1 to 8 in the following way: 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°), and 8 (157.6°-202.5°).

Data analysis

The Importance Value (IV) of each species was calculated and used in multivariate analyses of forest communities and species diversity. The importance value was calculated by the formula (Zhang et al., 2013):

$$IV_{Tree} = (\text{Relative abundance} + \text{Relative dominance} + \text{Relative height})/3$$

$$IV_{Scrubs\ and\ Herbs} = (\text{Relative cover} + \text{Relative height})/2$$

Dominance was defined as a species' basal area. In statistical analyses, species were represented by their importance values in the 42 quadrats. The environmental variables were represented by values for elevation, slope, aspect, slope position, soil depth, and litter depth in the 42 quadrats.

The TWINSPAN (Two-Way Indicator Species Analysis) classification and CCA (Canonical Correspondence Analysis) ordination method (ter Braak and Smilauer, 2002) were used to identify forest community types and to analyze their relationship to environmental variables. TWINSPAN and CCA were calculated using the computer programs TWINSPAN (Hill, 1979) and CANOCO (ter Braak and Smilauer 2002), respectively.

Three species diversity indices, one for species richness, one for species diversity, and one for species evenness, were used to assess diversity (Zhang, 2011). These indices were calculated as:

Species number (as an index of richness): $D = S$

Shannon-Wiener index: $H' = -\sum P_i \ln P_i$

Pielou evenness index: $E = \dfrac{H'}{\ln(S)}$

where P_i is the relative importance value of species i, $P_i = N_i/N$, N_i is the importance value of species i, N is the sum of importance values for all species in a quadrat, and S is the species number present in a quadrat.

Regression and correlation analyses were used to assess the relationship between species diversity and environmental variables.

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Results

Forest community diversity

Based on importance values, TWINSPAN classified the 42 quadrats into seven clusters, representing seven forest communities (forest formations) (*Fig. 1*). The variation among forest communities was clear and was related to ecological gradients; elevation increased from formation I through VII (*Fig. 1*) (Hill, 1979; Zhang, 2011). The name and major characteristics of the seven communities are described below.

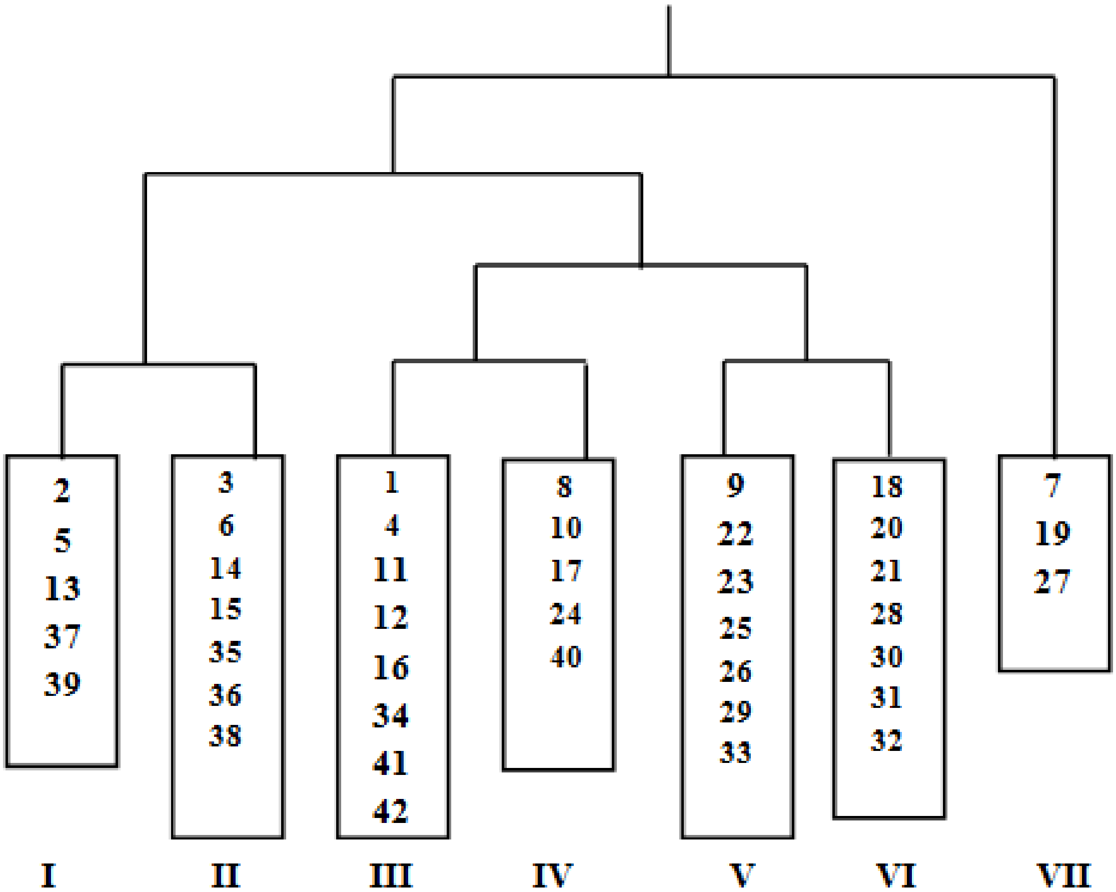

Figure 1. *The dendrogram of TWINSPAN results for the 42 forest quadrats in the Yunmeng Mountain Forest Park in Beijing, China. Roman numerals I - VII refer to the seven forest formations; Arabic numbers in rectangles refer to quadrat number.*

I. Form. *Pinus tabulaeformis.* This is a planted forest formation, distributed in patches from 780 to 1205 m, on hills with sunny slopes of 25 – 38°, and brown forest soil. The soil depth is 20-45 cm, and the litter depth is 3-5 cm. Disturbance intensity is medium. The forest community has a total cover of 85%, a tree layer cover of 70%, a shrub layer cover of 40%, and an herb layer cover of 35%. Common species in the tree layer include *Juglans mandshurica*, *Popolus cathayana*, and *Quercus mongolica.* Common species in the shrub layer include *Spiraea trilobata*, *Leptopus chinensis, Rhamnus parvifolia,* and *Vitex negundo* var. *heterophylla.* Common species in the herb layer include *Calamagrostis arundinacea*, *Carex rigescens*, *Artemisia lavandulaefolia*, and *Aconitum kusnezoffii*.

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II. Form. *Juglans mandshurica.* This is a secondary natural forest formation, distributed from 790 to 1200 m, on hills with sunny, semi-sunny, and semi-shady slopes of 10 – 39°, and brown forest soil. The soil depth is 25-70 cm, and the litter depth is 3-6 cm. Disturbance intensity is medium. The forest community has a total cover of 90%, a tree layer cover of 75%, a shrub layer cover of 50%, and an herb layer cover of 65%. Common species in the tree layer include *Fraxinus rhynchophylla, Quercus mongolica, Ulmus pumila, Acer truncatum*, and. *Tilia mongolica.* Common species in the shrub layer include *Deutzia parviflora, Philadelphus pekinensis, Corylus mandshurica, Spiraea trilobata, Lespedeza bicolor,* and *Leptopus chinensis.* Common species in the herb layer are *Rabdosia japonica, Dioscorea nipponica, Carex rigescens, Aconitum nagarum, Circaea quadrisulcata, Spodiopogon sibiricus, Ostericum sieboldii,* and *Artemisia lavandulaefolia*.

III. Form. *Fraxinus rhynchophylla + Acer truncatum + Tilia amurensis.* This is a secondary natural mixed forest formation, distributed from 1170 to 1320 m, on hills with semi-sunny, shady, and semi-shady slopes of 10 – 45°, and brown forest soil. The soil depth is 30-60 cm, and the litter depth is 3-7 cm. Disturbance intensity is heavy. The forest community has a total cover of 85%, a tree layer cover of 75%, a shrub layer cover of 40%, and an herb layer cover of 60%. Common species in the tree layer include *Quercus mongolica, Betula dahurica, Syringa pekinensis, Celtis bungeana, Popolus davidiana*, and. *Tilia mongolica.* Common species in the shrub layer include *Myripnois dioica, Syringa pubescens, Spiraea trilobata, Lespedeza bicolor,* and *Euonymus alatus.* Common species in the herb layer include *Adenophora wawreana, Carex lanceolata, Artemisia lavandulaefolia, Rabdosia japonica, Dioscorea nipponica, Carex rigescens, Circaea quadrisulcata, Calamagrostis arundinacea, Ostericum sieboldii,* and *Agrimonia pilosa.*

IV. Form. *Quercus mongolica.* This is a secondary natural forest formation, distributed from 1070 to 1360 m, on hills with sunny and semi-sunny slopes of 15 – 46°, and brown forest soil. The soil depth is 42-80 cm, and the litter depth is 4-7.5 cm. Disturbance intensity is medium. The forest community has a total cover of 90%, a tree layer cover of 70%, a shrub layer cover of 45%, and an herb layer cover of 55%. Common species in the tree layer include *Pinus tabulaeformis, Ulmus macrocarpa, Juglans mandshurica, Betula dahurica, Fraxinus rhynchophylla, Acer truncatum, Fraxinus rhynchophylla*, and *Popolus davidiana*. Common species in the shrub layer include *Spiraea trilobata, Euonymus alatus, Syringa pubescens, Lespedeza bicolor, Rhododendron micranthum,* and *Leptodermis oblonga.* Common species in the herb layer include *Carex rigescens, Adenophora wawreana, Carex lanceolata, Artemisia lavandulaefolia, Saussurea nivea, Aquilegia yabeana, Chelidonium majus, Clematis brevicaudata,* and *Rabdosia, japonica.*

V. Form. *Betula dahurica.* This is a secondary natural forest formation, distributed from 1190 to 1390 m, on hills with semi-sunny, semi-shady, and shady slopes of 35 – 47°, and brown forest soil. The soil depth is 28-59 cm, and the litter depth is 4-7.9 cm. Disturbance intensity is medium. The forest community has a total cover of 90%, a tree layer cover of 75%, a shrub layer cover of 35%, and an herb layer cover of 45%. Common species in the tree layer include *Betula dahurica, Popolus davidiana, Salix caprea, Betula platyphylla, Acer truncatum,* and *Quercus mongolica*. Common species in the shrub layer include *Abelia biflora, Spiraea trilobata, Corylus mandshurica, Euonymus alatus, Syringa pubescens,* and *Rhododendron micranthum.* Common species in the herb layer include *Carex siderosticta, Calamagrostis arundinacea, Aconitum*

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kusnezoffii, *Carex rigescens*, *Saussurea nivea*, *Aquilegia yabeana*, *Adenophora wawreana,* and *Clematis brevicaudata.*

VI. Form. *Popolus davidiana + Betula platyphylla.* This is a secondary natural mixed forest formation, distributed from 1200 to 1400 m, on hills with semi-sunny, shady, and semi-shady slopes of 20 – 44°, and brown forest soil. The soil depth is 25-62 cm, and the litter depth is 3-6.6 cm. Disturbance intensity is weak. The forest community has a total cover of 90%, a tree layer cover of 70%, a shrub layer cover of 40%, and an herb layer cover of 45%. Common species in the tree layer include *Betula dahurica*, *Larix principis-rupprechtii*, *Salix caprea*, *Fraxinus rhynchophylla,* and *Acer truncatum*. Common species in the shrub layer include *Corylus heterophylla*, *Deutzia hamata* var. *baroniana*, *Elsholtzia stauntonii*, *Corylus mandshurica,* and *Euonymus alatus.* Common species in the herb layer include *Agrimonia Pilosa, Calamagrostis arundinacea, Carex rigescens*, *Vicia gigantean*, *Circaea quadrisulcata*, *Spodiopogon sibiricus*, and *Adenophora wawreana.*

VII. Form. *Larix principis-rupprechtii.* This is a plantation forest formation, distributed from 1200 to 1414 m, on hills with shady and semi-shady slopes of 20 – 40°, and brown forest soil. The soil depth is 27-57 cm, and the litter depth is 4-8.2 cm. Disturbance intensity is weak. The forest community has a total cover of 99%, a tree layer cover of 80%, a shrub layer cover of 35%, and an herb layer cover of 45%. Common species in the tree layer include *Betula dahurica*, *Popolus davidiana*, *Betula platyphylla, Quercus mongolica, Tilia mandshurica,* and *Salix caprea*. Common species in the shrub layer include *Spiraea trilobata, Weigela florida*, *Abelia biflora*, *Corylus heterophylla*, *Euonymus alatus,* and *Deutzia hamata* var. *baroniana.* Common species in the herb layer include *Calamagrostis arundinacea, Carex rigescens*, *Phlomisum brosa*, *Saussurea nivea*, *Aquilegia yabeana*, *Convallaria majalis*, *Polygonatum odoratum*, *Phlomisum brosa*, *Adenophora divaricata,* and *Sedum aizoon.*

Forest communities and related environment

In the CCA ordination of 42 quadrats with six environmental variables (*Fig. 2*), the Monte Carlo permutation test indicated that the eigenvalues for the first canonical axis and for all canonical axes were significant ($P<0.01$). The species-environment correlations of the first four CCA axes were 0.919, 0.817, 0.913, and 0.855; and the cumulative percentage variance of species-environment relations for the first four CCA axes were 82.1 %; which showed that CCA performed well in describing relations among species, forest communities, and environmental gradients (Zhang, 2011). The Monte Carlo permutation test also indicated that the species–environment correlations with the CCA axes were significant (ter Braak and Smilauer, 2002).

Ordination results showed that the first CCA axis was significantly correlated with elevation, slope position, aspect, slope and soil depth and that elevation and slope position were the most significant factors related to the first CCA axis (*Fig. 2, Table 1*). Elevation had a positive correlation, and slope position had a negative correlation, with the first CCA axis. The altitudinal and slope position gradients were very clear (from left to right, *Fig. 2*), and along these gradients, elevation increased gradually, and slope position varied from valley bottom to hill ridge. The second CCA axis was significantly correlated with aspect, litter depth, soil depth, and slope position (*Fig. 2, Table 1*). The third CCA axis was correlated with soil depth, slope, litter depth, and aspect, and the fourth axis was correlated with aspect, slope, and litter depth (*Table 1*).

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Table 1. *Inter-set correlation coefficients of environmental variables with CCA axes in the Yunmeng Mountain Forest Park in Beijing, China*

	CCA 1	CCA 2	CCA 3	CCA 4
Elevation	0.810***	-0.147	0.243	0.204
Aspect	-0.427**	0.458**	0.304*	0.507***
Slope	0.549***	0.027	-0.530***	0.182
Slope position	-0.698***	0.291*	-0.204	-0.293*
Soil depth	0.469***	-0.337*	0.533***	0.007
Litter depth	0.258	-0.382**	-0.448**	0.303*

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

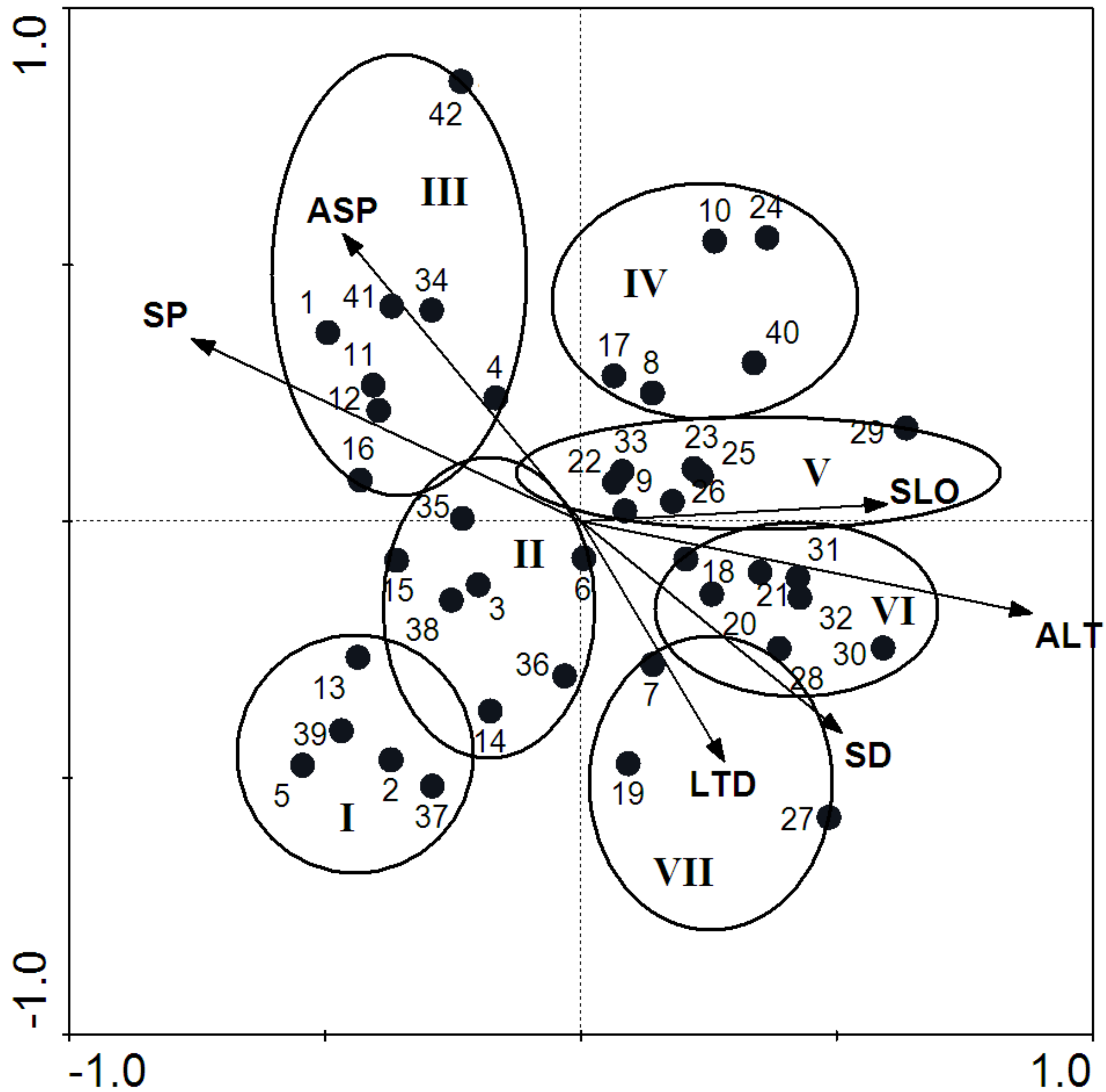

Figure 2. *CCA ordination biplot of the 42 forest quadrats and six environmental variables in the Yunmeng Mountain Forest Park in Beijing, China. ALT, ASP, SLO, SP, SD, and LTD refer to altitude, aspect, slope, slope position, soil depth, and litter depth, respectively. Roman numerals I - VII refer to the seven forest formations; Arabic numbers refer to quadrat number.*

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The distribution of forest communities on the CCA ordination map was related to environmental gradients, e.g., forests on the left were usually distributed in lower hills, with lower slope position and valley bottom, such as Form. *Pinus tabulaeformis,* Form. *Juglans mandshurica* and Form. *Fraxinus rhynchophylla* + *Acer truncatum* + *Tilia amurensis*. Forests on the right were distributed in comparatively higher hills, with upper slope position and hill ridge, such as Form. *Quercus mongolica*, Form. *Betula dahurica,* Form. *Popolus davidiana* + *Betula platyphylla,* and Form. *Larix principis-rupprechtii.*

Some pairs of environmental variables, such as elevation and slope position, elevation and soil depth, slope and aspect, slope and slope position, and soil depth and slope position, were significantly correlated with each other (*Table 2*).

Table 2. *Correlation coefficients between environmental variables in the Yunmeng Mountain Forest Park in Beijing, China*

	Elevation	Aspect	Slope	Slope position	Soil depth	Litter depth
Elevation	1					
Aspect	-0.273	1				
Slope	0.329*	-0.367*	1			
Slope position	-0.940***	0.288*	-0.383**	1		
Soil depth	0.561***	-0.285	0.139	-0.551***	1	
Litter depth	0.263	-0.297*	0.328*	-0.225	0.074	1

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

Species diversity in forests

Species richness, diversity, and evenness showed significant variation within forests of the Yunmeng Mountain Forest Park. Species richness ranged from 11 to 20, the Shannon-Wiener index ranged from 1.129 to 2.114 and evenness ranged from 0.410 to 0.813. We plotted species diversity indices against altitudinal and slope position gradients, which were the two most important factors affecting forest and species distribution, based on the CCA analyses above. Species richness and diversity showed significant correlations with elevation and slope position (*Fig. 3, Table 3*).

Table 3. *Correlation coefficients of species diversity with environmental variables in the Yunmeng Mountain Forest Park in Beijing, China*

	Elevation	Aspect	Slope	Slope position	Soil depth	Litter depth
Shannon-Wiener index	0.401**	-0.134	0.176	-0.424**	0.376*	-0.056
Species evenness	0.075	-0.112	0.122	-0.072	0.194	-0.009
Specie richness	0.529**	0.086	-0.004	-0.453**	0.164	0.060

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

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Species richness and diversity (Shannon-Wiener index) increased gradually with increasing elevation, reaching a maximum close to the mountain summit, and decreased gradually as slope position varied from hill ridge to valley bottom. The correlations of evenness with these two gradients were not statistically significant, but the trends were similar to those for species richness and diversity. This finding suggests that elevation and slope position were the most important factors affecting species diversity in the Yunmeng Mountain Forest Park. Species diversity was also correlated with soil depth (*Table 3*).

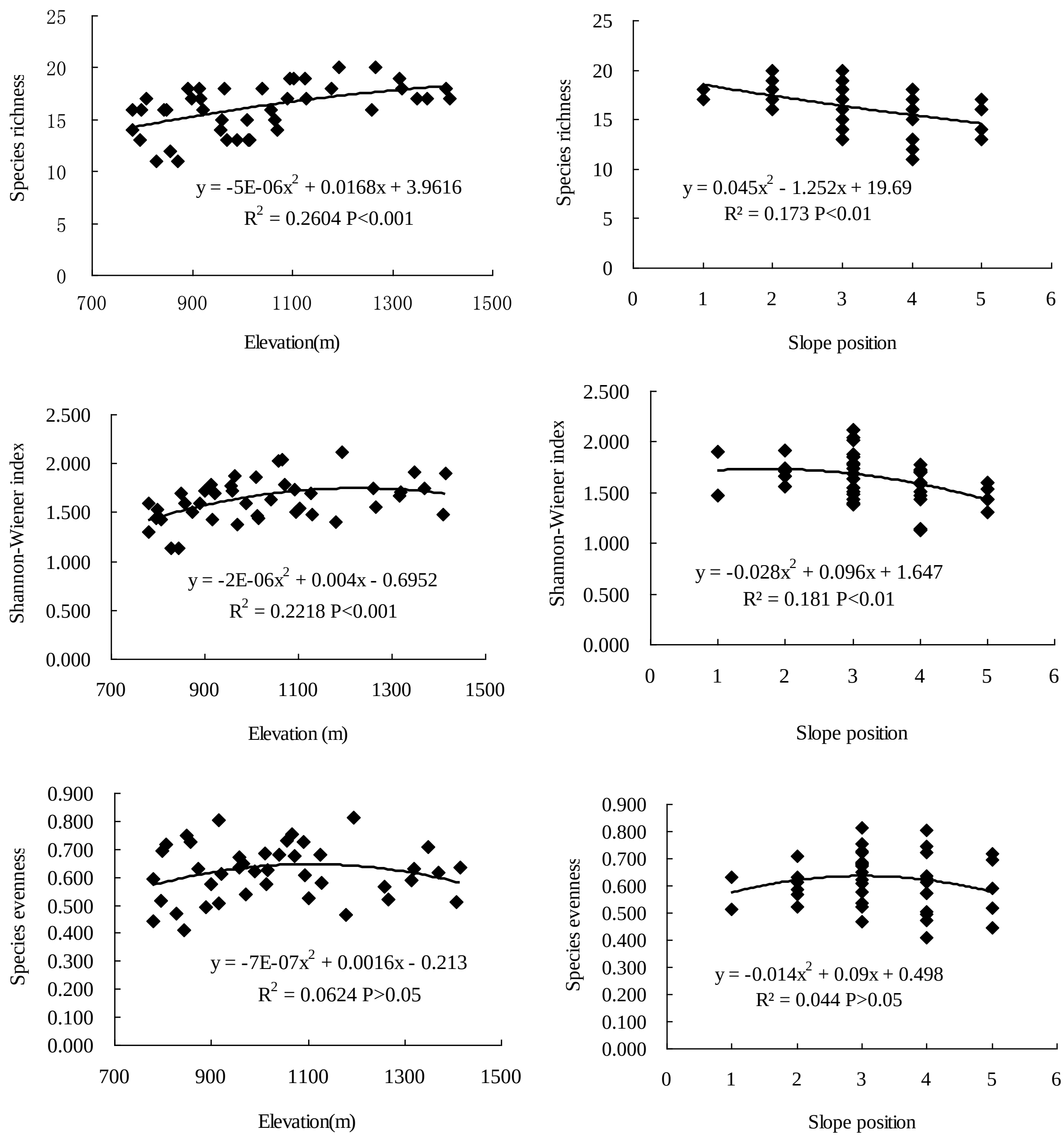

Figure 3. *Variation in species richness, diversity (Shannon-Wiener index) and evenness of forest communities along altitudinal and slope position gradients in the Yunmeng Mountain Forest Park in Beijing, China. Values of 1-5 for slope position represent the hill ridge, upper, middle, lower locations and valley bottom, respectively.*

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Discussion

Forest types and distribution pattern

Variation in forest communities (forest diversity) was apparent in the Yunmeng Mountain Forest Park, and TWINSPAN successfully distinguished them as different forest formations. The seven forest formations were representative of the general forest vegetation in this park, and they conform to the Chinese forest classification system (Wu, 1980; Zhang et al., 2013). Most formations were secondary forest vegetation, following destruction of the original warm-temperate broad-leaved deciduous forests and temperate coniferous forests (Dai et al., 1990), with the additions of some plantations (Zheng et al., 2007). The present work is the first systematic and quantitative classification of forest vegetation in the Yunmeng Mountain Forest Park. Dai (1990) described the vegetation in this park as only three formations, i.e., Form. *Vitex negundo* var. *heterophylla,* Form. *Spiraea trilobata*, and Form. *Quercus mongolica* (*liaotungensis*). The former two formations were shrublands in the 1980s, and they have been recovered to forest formations after nearly 30 years conservation (Zhang et al., 2013). The latter formation has been developed and enlarged distribution area in this park. These changes suggest that the conservation of plant species and forest vegetation has had significant effects on forest composition since the park was established (Cui et al., 2008). The seven forest formations recognized in this study belong to three vegetation types: warm-temperate broad-leaved deciduous forest, warm-temperate coniferous forest, and cold-temperate coniferous forest (Wu, 1980). These results correspond to forest descriptions of other mountains in Beijing, such as Baihua Mountain (Zhang et al., 2012) and Songshan Mountain (Suriguga et al., 2010). The Yunmeng, Baihua, Dongling, and Songshan Mountains are typical mountainous regions, and contain over 70% of the natural forests in the Beijing area; they therefore play a significant role in improving the city's ecological environment (Zhang et al., 2013).

The distribution of dominant species determined the forest differentiation and distribution along environmental gradient (Wu, 1980; Lomolino, 2001). The distribution of dominant species such as *Pinus tabulaeformis, Juglans mandshurica, Quercus mongolica, Larix principis-ruprechtii*, *Betula platyphylla*, and *Popolus davidiana,* play important roles in forest patterning in the Yunmeng Mountain Forest Park (Zheng et al., 2007). In addition to different dominant species, each of the seven forest formations has its own specific species composition, structure, function, and environment (Wu, 1980; Zhang et al., 2013). These forest formations are distributed predictably along an altitudinal gradient from lower to upper hills, in a reliable order: Form. *Pinus tabulaeformis,* Form. *Juglans mandshurica*, Form. *Fraxinus rhynchophylla + Acer truncatum + Tilia amurensis,* Form. *Quercus mongolica*, Form. *Betula dahurica*, Form. *Popolus davidiana + Betula platyphylla,* and Form. *Larix principis-rupprechtii.* These distribution patterns are determined by interactions among species, communities, and environment (Liu and Ren, 1992; Zilliox and Gosselin, 2014).

Forest vegetation – environment relation

Forest composition, structure, and distribution pattern are usually related to environmental factors which exhibit heterogeneity over space and time, such as climate, topography, soil and disturbance (Alexander and Millington, 2000; Kikvidze et al., 2006; Korner, 2007). This is true in the Yunmeng Mountain Forest Park. The variation

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in forest communities was closely related to environmental variables, such as elevation, slope position, slope, aspect, soil depth, and litter depth, with elevation and slope position being the most important factors affecting forest formations in this park. The change of forest formations in CCA space clearly illustrated the relationship of forest communities to environmental variables (Brinkmann et al., 2009; Muenchow et al., 2013). Each forest formation had its own distribution area and was correlated with a specific combination of environmental variables (ter Braak and Smilauer, 2002; Zhang et al., 2012). The first CCA axis was primarily an elevational gradient, i.e., from left to right in the CCA ordination diagram, elevation increased gradually. Elevational change leads to changes in humidity, temperature, soil type, etc., which in turn influence forest formations (Vittoz et al., 2010; Otypkova et al., 2011). The first CCA axis was also a slope position gradient, i.e., from left to right in the CCA diagram, slope position varied gradually from valley bottom to hill ridge. Change in slope position also leads to change in humidity, temperature, soil type etc., which further influences the forest formations (Dai et al., 1990; Meng et al., 2012).

Forest variation was closely related to other environmental variables in the Yunmeng Mountain Forest Park, such as slope, aspect, soil depth, and litter depth. Changes in slope and aspect may lead to a change in hours of sunshine, in humidity or in temperature, which affects forest community development (Virtanen et al., 2010). The soil depth and litter depth are also important for providing nutrients to plants in forests (Austrheim, 2002). All environmental variables were interrelated, and they play a coordinated role in forest development (Zhang, 2011).

Species diversity

Species diversity is an important feature of forest composition and structure, and its change is frequently used as an indicator of forest dynamics (Muhumuza and Byarugaba, 2009). The spatial variation of species diversity corresponds closely to forest vegetation patterns in a region (Rahbek, 2005; Zhang et al., 2012). This spatial change of species richness, diversity and evenness was apparent in the Yunmeng Mountain Forest Park and corresponded to changes in forest structure, composition, function, distribution, etc., related to environmental variables (Littell et al., 2010; Zhang et al., 2011). Species richness and diversity were significantly correlated with elevation and slope position. Elevation and slope position, therefore, are key factors in influencing species diversity in this park. Elevation as a key factor affecting species diversity in mountainous areas has been demonstrated by many researchers (e.g., Fetene et al., 2006, Muhumuza and Byarugaba, 2009; Meng et al., 2012). The most commonly observed pattern is for diversity to be highest at intermediate elevations (Austrheim, 2002; Virtanen et al., 2010). The present study showed a different pattern, with species diversity was increasing gradually with increasing elevation, and reaching a maximum near the mountain summit. This pattern occurs because the altitudinal gradient from 750 m to 1414 m is shorter in the Yunmeng Mountains compared with other mountains, such as the Baihua and Songshan Mountains (Soriguga, 2012; Zhang et al., 2013). This pattern can be recognized as a part of a ‘‘humped’’ distribution curve (Brinkmann et al., 2009; Otypkova et al., 2011).

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Implications for management

The forest vegetation in the present study showed different forest formations within the Yunmeng Mountain Forest Park. These formations were secondary natural forests restored from destroyed warm-temperate deciduous forests, and degraded lands (Cui et al., 2008; Zhang et al., 2013). The restoration and conservation of forests have been effective over the past 30 years (Zheng et al., 2007), and as a result, vegetation reflects the effects of elevation, slope position and landform on forest composition, structure and diversity. The identified forest communities, compositions, and diversity are typical for the mountainous areas in Beijing (Suriguga et al., 2010). These forests are very important to the city and its citizens. During the last decade, eco-tourism has developed very quickly along with forest restoration and environmental improvement, and the disturbance to forests has correspondingly increased (Cui et al., 2008). This must be controlled, i.e., tourist numbers should be regulated in summer, according to the tourist capacity of this park (Wang et al., 2004; Zheng, 2007).

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APPENDIX

Electronic Appendix 1: Species Importance Value Data in the Yunmeng Mountain Forest Park in Beijing, China.

Electronic Appendix 2: Environmental data in the Yunmeng Mountain Forest Park in Beijing, China.

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