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Vegetation Patterns and Species Diversity Along Elevational and Disturbance Gradients in the Baihua Mountain Reserve, Beijing, China

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Vegetation and species diversity patterns in conservation areas near big cities are poorly known. These are important recreational areas used also for educational purposes. Therefore, investigations of local diversity patterns are urgently needed. The Baihua Mountain Reserve is close to the city of Beijing and is the northern end of the Taihang mountain range in north China. Sixty-one 10 × 20 m quadrats of plant communities were established along gradients for elevation (750–2043 masl) and disturbance (mainly due to tourism and agriculture). Data on species composition and environmental variables were measured and recorded in each quadrat. Two-way indicator species analysis and canonical correspondence analysis (CCA) were used to analyze the relationships between vegetation and environmental variables, while species diversity indices were used to analyze the pattern of species diversity. Twelve plant communities were found, mostly secondary forests with some plantations. These communities are representative of the vegetation in the mountains west of Beijing. Each community had a different composition, structure, and environment. The variation of plant communities was significantly related to elevation and disturbance and related to litter thickness, slope, and aspect. The cumulative percentage variance of species–environment relationships for the first 4 CCA axes was 89.6%. Elevation and disturbance intensity were revealed as the factors that most influenced community distribution and species diversity. Species richness, heterogeneity, and evenness all showed a ''humped'' pattern along elevational and disturbance gradients—the highest species diversity appeared in the middle elevation and under medium disturbance intensity. Recommendations regarding management measures are made.

Keywords: *Vegetation classification; vegetation–environment relationships; species diversity; nature conservation; human disturbance; China.*

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Introduction

Understanding vegetation and species diversity patterns is fundamental for conservation of natural areas; these patterns have frequently been the focus of ecological studies (Magurran 1988; Martins et al 1999; Loreau et al 2001; Fetene et al 2006; Muhumuza and Byarugaba 2009). Few natural areas remain near Beijing, China's capital (Xu and Zhang 2008; Xiang 2009). In this densely populated region, most natural plant communities are concentrated in biodiversity-rich mountainous regions, which provide important ecological services for the people living in the city and are therefore significant areas for conservation (Zhang 2005; Cui et al 2008).

A complex of factors determines the community composition and structure, and the related species diversity, of mountain vegetation (Kessler 2001; Schmidt et al 2006). One important factor is elevation (McVicar and Körner 2012), which has a strong influence on the structure of the vegetation in most mountains in the world (Brown 2001; Hawkins and Diniz 2004; Rahbek 2005; Zhang, Ru, et al 2006). Changes in species diversity along elevational gradients have been the subject of numerous studies (Lomolino 2001; Austrheim 2002; Fetene et al 2006); most of them found a "humped" distribution, showing peak species diversity near the middle of the gradient (Austrheim 2002; Zhang and Ru 2010). Bruun et al (2006) suggested that a humped pattern is especially likely to emerge when the elevational gradient corresponds to a productivity gradient and thus tested Grime's (1973) suggestion of a general productivity–diversity relationship. Bruun et al (2006) also noted a possible variation in natural disturbance and in disturbance due to grazing animals (Grime's [1973] "intermediate disturbance hypothesis"). However, scholars have found a number of exceptions to the humped pattern (Stevens 1992; Pausas 1994). Some have argued that whether species diversity will increase or decrease with increasing elevation or will peak at an intermediate elevation depends largely on specific patterns of interactions among plant communities, species, and environmental factors (Brown 2001; Lomolino 2001; Körner 2007). Further tests of the hypothesis in different mountains are needed (Kikvidze et al 2006; Zhang and Chen 2007).

The Baihua Mountain Reserve includes most of Baihua Mountain, which is part of the Taihang mountain range. It is the closest national nature reserve to Beijing's city center and is a popular destination for recreation (Xiang 2009; Xiang and Zhang 2009). Vegetation plays a significant role in local development, such as tourism, and should be protected and used with care in this reserve (Zhang 2005; Hammi et al 2010). Some studies related to floristic characteristics and plant resources (He et al 1992), resources for and evaluation of tourism (Xiang and Zhang 2009), and interspecific association of seed plants (Liu and Ren 1992) have been carried out in this area.

However, no studies to date have examined the variations of vegetation and species diversity associated with the major environmental variables in the area. Quantitative analysis of vegetation data, such as classification and ordination, is important to generate and test hypotheses with respect to vegetation and the environment (Podani 2000; ter Braak and Šmilauer 2002; Zhang 2004; Zhang and Zhang 2007). This study analyzed plant community composition and diversity and their relationships with environmental variables. Our objectives were (1) to analyze the interdependencies among community characteristics and environmental variables, (2) to identify the key environmental variable influencing plant community composition and species diversity, and (3) to test the humped distribution hypothesis—the hypothesis that the highest species diversity appears at the middle elevation and under medium disturbance intensity—for the Baihua Mountain Reserve.

Material and methods

Study site

The Baihua Mountain Reserve is located at 39°48′–40°05′N; 115°25′–115°42′E. It is the northern end of the Taihang mountain range in China (Figure 1) and 120 km west of Beijing's city center. It is an important ecological barrier against the dust storms from the western areas for Beijing and its residents. The climate of this area is temperate and semihumid, with continental characteristics, and is controlled by seasonal winds. The annual mean temperature is 7.0°C; the monthly mean temperatures of January and July are −7.8 and 21.1°C, respectively. The annual mean precipitation is 700 mm in this reserve, 70% of which falls from July to September. Several soil types—such as brown soils, mountainous brown soils, brown forest soils, and mountain meadow soils—can be found in the reserve (Huo 1989). The altitude varies from 750 to 2043 m. The total area of the reserve is more than 2300 ha (Huo 1989). The vegetation consists of secondary natural vegetation with widespread disturbance connected with grazing and logging of timber and firewood until 1980, when the national reserve was established (Cui et al 2008). Vegetation, mainly secondary forests, shrubland, and mountain meadows recovered well during the last 30 years, and today, the reserve is the main recreation destination for Beijing during the summer (Xiang 2009).

Data collection

Along the elevational gradient from 750–2043 masl, 26 sampling points separated by 50 m in elevation were set up, and 2–4 quadrats were established around each sampling point in July and August 2010. Species data were recorded in each quadrat. The quadrat size was 10 × 20 m, within which three 5 × 5 m quadrats were used to record shrubs and three 2 × 2 m quadrats were used to record herbs. The cover, height, and abundance of trees, shrubs, and herbs, as well as the basal area of trees, were measured in each quadrat. Plant height was measured using a height meter for trees and a ruler for shrubs and herbs. The basal diameter of trees (diameter at breast height) was measured using a caliper. A total of 171 plant species were recorded in 61 quadrats.

Elevation, slope, litter thickness, aspect, and disturbance intensity were also recorded for each quadrat. The elevation in each quadrat was measured using a global positioning system, the slope and slope aspect were measured using a compass meter, and the litter thickness was measured directly using a ruler (Zhang 2004; Zhang, Xi, et al 2006). The elevation, slope, and litter thickness were reading values. Aspect measurements were classified from 1 to 8 as follows: 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°); the greater the value, the more sunlight the quadrat received. The intensity of disturbance by human activities was evaluated on a scale of 1 to 5 based on number of tourists, distance from the nearest road, number of pieces of garbage, and trampling (1 = no obvious disturbance, 2 = weak disturbance, 3 = medium disturbance, 4 = heavy disturbance, and 5 = very heavy disturbance).

Data analysis

The importance value (IV) of each species was used in multivariate analysis of communities and species diversity. It was calculated using the following formula (Zhang 2004; Zhang, Xi, et al 2006):

$$IV_{tree} = \frac{(\text{relative density} + \text{relative dominance} + \text{relative height})}{3}$$

$$IV_{\text{shrubs and herbs}} = \frac{(\text{relative cover} + \text{relative height})}{2}$$

Relative dominance refers to species' basal area. The species data were the IVs of 171 species in 61 quadrats. The environmental data were values of 5 variables

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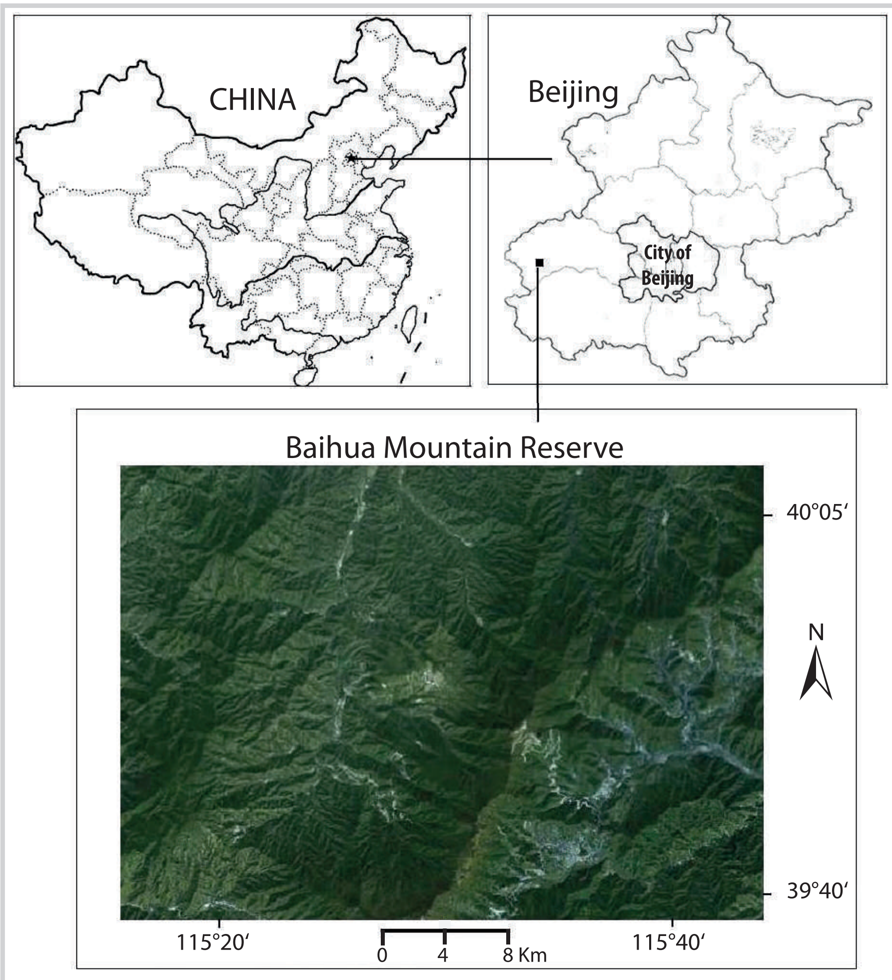
FIGURE 1 Location of the Baihua Mountain Reserve, Beijing, China. Map uses the World Geodetic System 1984 coordinate system. (Map by Jin-Tun Zhang)



(elevation, slope, aspect, litter thickness, and disturbance) in 61 quadrats.

A two-way indicator species analysis (TWINSPAN; Hill 1979) and a canonical correspondence analysis (CCA; ter Braak and Šmilauer 2002) were conducted to identify plant communities and to analyze their relationships with environmental variables. The calculation of TWINSPAN and CCA were carried out by the computer programs TWINSPAN (Hill 1979) and CANOCO (ter Braak and Šmilauer 2002), respectively.

Three species diversity indices, one for species richness, one for species heterogeneity, and one for species evenness, were used to calculate diversity values as follows (Shannon and Wiener 1949; Pielou 1975; Zhang 2004):

$$\text{Species number (as a richness index): } D = S$$

$$\text{Shannon-Wiener heterogeneity index: } H' = -\sum P_i \ln P_i$$

$$\text{Pielou evenness index: } E1 = \frac{H'}{\ln(S)}$$

where P_i is the relative IV of species i, $P_i = N_i/N$, N_i = the IV of species i, N = the sum of IVs for all species in a quadrat, and S = the number of species present in a quadrat (Pielou 1975; Zhang 2004).

Regression analyses were performed to establish the relationships between species diversity and environmental variables.

Results

Vegetation patterns

TWINSPAN classified the 61 quadrats into 12 clusters representing different plant communities (Figure 2; for the characteristics and composition of the 12 communities, see *Supplemental data,* Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-11-00042.S1). The variation of communities was clear and related to ecological gradients:

I. Comm. *Spiraea pubescens.* This is a subalpine shrubland community distributed from 1850 to 2025 m

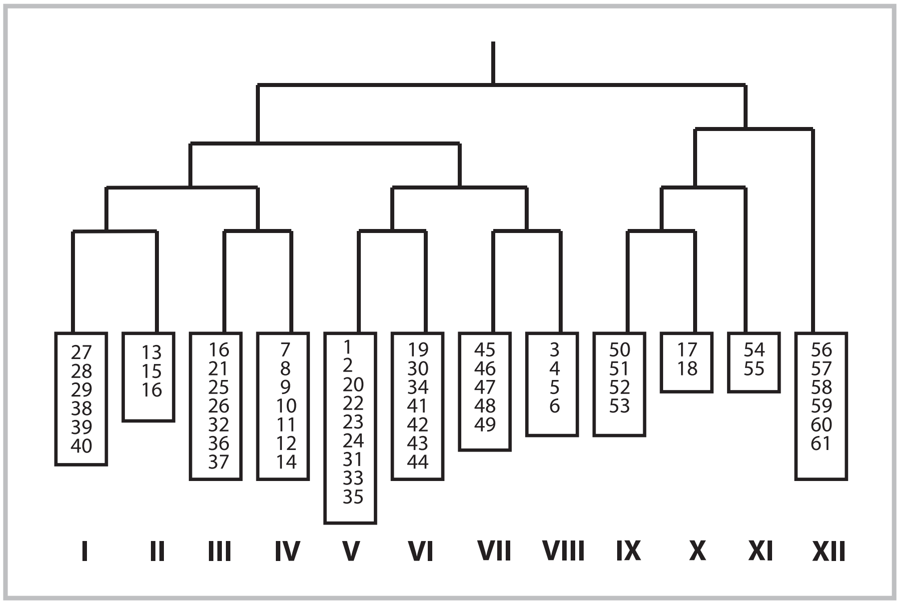


FIGURE 2 Dendrogram of TWINSPAN results for 61 samples of plant communities in the Baihua Mountain Reserve, Beijing, China. Roman numerals I–XII refer to the 12 communities, and Arabic numbers refer to quadrats. Elevation decreases and disturbance intensity increases from left to right.

in hills with a sunny slope of around 30–40° and brown forest soil. Its disturbance intensity is weak.

II. Comm. *Betula dahurica* + *Betula platyphylla*. This is a secondary forest community distributed from 1750 to 1800 m in hills with a shady or semishady slope of around 35–40° and brown forest soil. Its disturbance intensity is weak.

III. Comm. *Larix principis-rupprechtii*. This is a mixed community of secondary and planted forest distributed from 1500 to 2000 m in hills with a shady or semishady slope of around 20–30° and brown forest soil. Its disturbance intensity is weak to medium.

IV. Comm. *B. platyphylla*. This is a secondary forest community distributed from 1900 to 2040 m in hills with a shady or semishady slope of around 25–40° and brown forest soil. Its disturbance intensity is weak to medium.

V. Comm. *Quercus wutaishanica*. This is a secondary forest community distributed from 1350 to 1700 m in hills with a shady, semishady, or semisunny slope of around 25–40° and brown forest soil. Its disturbance intensity is medium.

VI. Comm. *Populus davidiana* + *L. principis-rupprechtii*. This is a mixed community of secondary and planted forest distributed from 1250 to 1600 m in hills with a shady, semishady, or semisunny slope of around 20–40° and brown forest soil. Its disturbance intensity is medium to heavy.

VII. Comm. *Pinus tabuliformis*. This is a planted forest community distributed from 1200 to 1400 m in hills with a sunny or semisunny slope of around 20–25° and brown forest soil. Its disturbance intensity is medium to heavy.

VIII. Comm. *Juglans mandshurica*. This is a mixed community of secondary and planted forest distributed from 1250 to 1400 m in hills with a sunny or semisunny slope of around 20–25° and brown forest soil. Its disturbance intensity is medium to heavy.

IX. Comm. *Hippophae rhamnoides* + *Spiraea trilobata*. This is a secondary shrubland community distributed from 1100 to 1200 m in hills with a semisunny slope of around 10–20° and brown or mountain cinnamon soil. Its disturbance intensity is heavy.

X. Comm. *Prunus armeniaca*. This is a secondary shrubland community distributed from 900 to 1150 m in hills with a semisunny slope of around 10–35° and mountain cinnamon soil. Its disturbance intensity is heavy to very heavy.

XI. Comm. *Vitex negundo* var. *heterophylla*. This is a secondary shrubland community distributed from 750 to 900 m in hills with a sunny or semisunny slope of around 20–35° and mountain cinnamon or cinnamon soil. Its disturbance intensity is very heavy.

XII. Comm. *Carex lanceolata* + *Sanguisorba officinalis* + *Polygonum viviparum*. This is a mountain meadow community distributed around 1800 m in hills with a sunny or semisunny slope of around 10° and mountain meadow soil. Its disturbance intensity is heavy.

Relationship between vegetation patterns and environmental factors

CCA ordination of 61 quadrats and 5 environmental variables was carried out (Figure 3). The Monte Carlo permutation test indicated that the eigenvalues for all canonical axes were significant ($P < 0.01$). For the first 4

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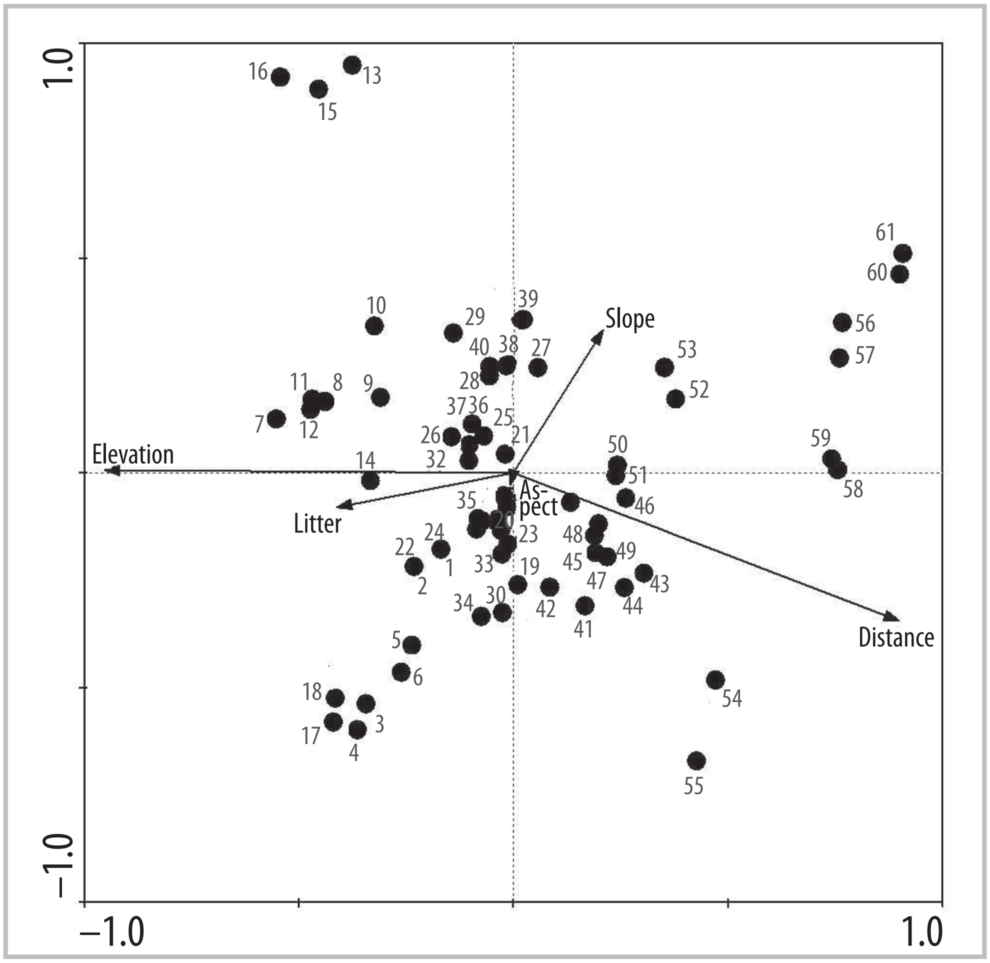
FIGURE 3 CCA ordination biplot of 61 quadrats and 5 environmental variables of plant communities in the Baihua Mountain Reserve, Beijing, China. The numbers refer to quadrats. Along the elevational and disturbance gradient (left to right), the elevation decreases and disturbance intensity increases gradually. The distribution of plant communities on the ordination map is related to environmental gradients. Communities on the left—such as *S. pubescens, B. dahurica* and *B. platyphylla, L. principis-rupprechtii,* and *B. platyphylla*—occur mostly in hills with high elevation and weak disturbance. Communities on the right—such as *V. negundo* var. *heterophylla, P. armeniaca,* and *H. rhamnoides* and *S. trilobata*—occur in lower hills with heavy disturbance. Communities in the central areas are in middle elevations with medium disturbance.



CCA axes, the eigenvalues were 0.606, 0.379, 0.284, and 0.236; the species–environment correlations were 0.967, 0.919, 0.914, and 0.880; and the cumulative percentage variance of species–environment relationship were 89.6%. This shows that the CCA performed well in describing relationships among species, communities, and environmental gradients (Zhang and Oxley 1994; Zhang 2004). The Monte Carlo permutation test also indicated that the species–environment correlations with the CCA axes were significant (ter Braak and Šmilauer 2002).

TABLE 1 Interdataset correlation coefficients of environmental variables with CCA axes in plant communities in the Baihua Mountain Reserve, Beijing, China.

Environmental variables	CCA axes			
	Axis 1	Axis 2	Axis 3	Axis 4
Elevation	−0.919***	0.005	0.271*	0.068
Slope	0.203	0.305*	0.691***	0.367**
Aspect	−0.007	−0.025	0.345**	−0.042
Litter thickness	−0.397**	0.073	0.086	0.791***
Disturbance	0.869***	−0.317*	−0.152	−0.053

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

TABLE 2 Correlation coefficients between environmental variables in plant communities in the Baihua Mountain Reserve, Beijing, China.

Environmental variables	Elevation	Slope	Aspect	Litter thickness	Disturbance
Elevation	1				
Slope	0.043	1			
Aspect	0.163	−0.037	1		
Litter thickness	0.426**	0.219*	−0.157	1	
Disturbance	−0.920***	−0.012	−0.250*	−0.361**	1

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

The first CCA axis was significantly related to elevation, disturbance, and litter thickness, especially elevation and disturbance (Figure 3; Table 1); elevation had a negative correlation, and disturbance has a positive correlation. The second CCA axis is significantly correlated with disturbance. The third CCA axis relates to slope, aspect, and elevation, and the fourth axis relates to slope and litter thickness.

Some of the 5 environmental variables were significantly correlated with each other—for example, elevation and disturbance intensity, elevation and litter thickness, and slope and litter thickness (Table 2). Disturbance intensity decreased as elevation increased, because tourism density and agriculture activities decreased along that gradient.

Species diversity

Variations in species diversity are obvious in the reserve. Species richness varied from 9 to 24, heterogeneity varied from 1.60 to 2.55, and evenness varied from 0.68 to 0.96. We plotted species diversity indices against elevational and disturbance gradients because, based on the CCA analyses, they proved to be the 2 most important variables affecting the vegetation and species distribution in this area. Species richness, heterogeneity, and evenness all showed significant relationships with elevation and disturbance intensity (Figure 4A–C). All 3 first increased and then decreased with increasing elevation, reaching a maximum at 1500, 1550, and 1600 m, respectively. The highest species diversity appeared in the middle elevation; this suggests that elevation was important factor for species diversity. Similarly, species richness, heterogeneity, and evenness first increased and then decreased with increasing disturbance intensity, reaching a maximum at medium disturbance (Figure 4D–F).

Discussion

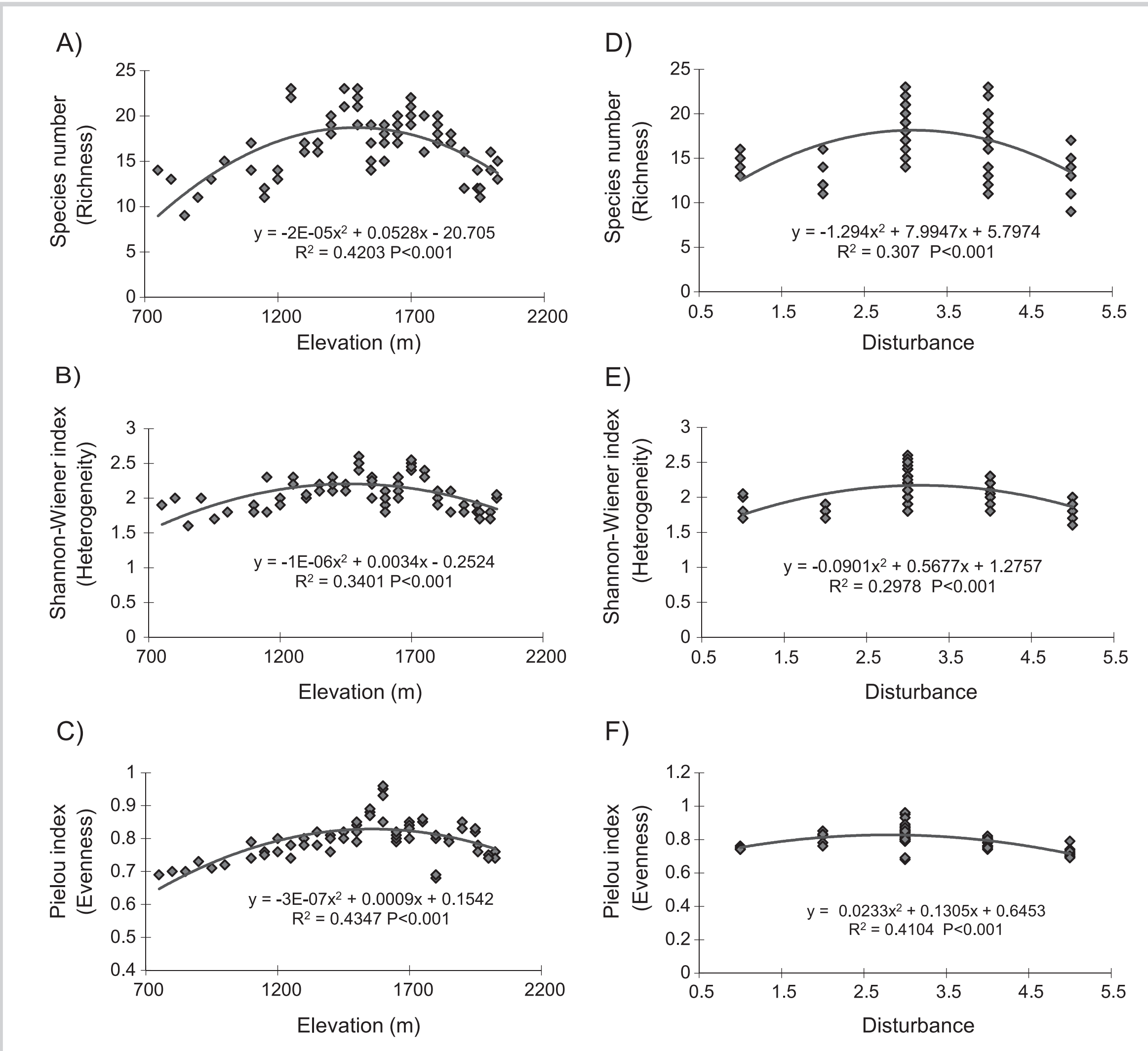
Vegetation patterns

The variation of plant communities was apparent; TWINSPAN successfully distinguished the different communities. The 12 communities were representative of the general vegetation in the reserve and conform to the Chinese vegetation classification system (Wu 1980; Huo 1989). Most of them consisted of secondary vegetation, following destruction of the original warm-temperate broad-leaved deciduous forests and cold-temperate coniferous forests (Xiang 2009), with some plantations in the 1950s (He et al 1992).

This study was the first systematic and quantitative classification of vegetation in the Baihua Mountain Reserve. Huo (1989) described this vegetation as comprising only 5 communities. The 12 communities recognized in this study were 12 vegetation formations (Wu 1980; Pan 1988). They belong to 6 vegetation types: warm-temperate broad-leaved deciduous forest, warm-temperate coniferous forest, cold-temperate coniferous forest, warm-temperate broadleaved deciduous shrubland, cold mountain shrubland, and mountain meadow (Suriguga et al 2010). Our results correspond to vegetation descriptions in other mountains in the Beijing area, such as Dongling Mountain (Huang and Chen 1994) and Songshan Mountain (Suriguga et al 2010). Baihua, Dongling, and Songshan Mountains, all west of Beijing, have more than 70% of the natural forest vegetation in the Beijing area, which has a significant role in protecting the city's environment (Huo 1989).

The distribution of dominant species determines vegetation differentiation and distribution along environmental gradients, such as the elevational gradient and the moisture gradient (Wu 1980; Zhang and Ru 2010). This is also true in the Baihua Mountain Reserve. Dominant species such as *L. principis-rupprechtii, B. platyphylla, Q. wutaishanica, P. davidiana, P. tabuliformis, J. mandshurica, H. rhamnoides, V. negundo* var. *heterophylla,* and *S. trilobata* play important roles in vegetation patterning in this reserve (Pan 1988; Kikvidze et al 2006; Zhang, Ru, et al 2006). In addition to dominant species, the indicator species of TWINSPAN divisions, such as *Veratrum nigrum, Polygonatum odoratum, Aconitum carmichaeli, Aster altaicus, P. viviparum, Artemisia japonica, Euphorbia esula, Dendranthema chanetii,* and *Maianthemum bifolium,* have proved important for community heterogeneity (Liu and Ren 1992). The herbaceous layer contributes more to species richness, but the tree layer contributes more to species evenness in communities in warm-temperate forests (Zhang, Ru, et al 2006). Herb richness is potentially sensitive to changes in

FIGURE 4 Changes in species richness, heterogeneity, and evenness along elevational and disturbance gradients in the Baihua Mountain Reserve, Beijing, China.



tree or shrub layer because of changes in light availability (Brinkmann et al 2009).

Relationship between vegetation patterns and environmental factors

Vegetation patterns are determined by environmental factors that exhibit heterogeneity over space and time, such as climate, topography, and soil, as well as human disturbances (Alexander and Millington 2000). In the Baihua Mountain Reserve, the variation of plant communities was closely related to environmental factors, including elevation, disturbance intensity, litter thickness, slope, and aspect, among which elevation and disturbance were the most important. The change of plant communities in the CCA ordination space clearly illustrates the relationships between plant communities and environmental variables (ter Braak and Šmilauer 2002). Each community has its own distribution area with a specific combination of environmental variables (Dolezal and Srutek 2002; Zhang 2004; Brinkmann et al 2009). The first CCA axis was mainly an elevational gradient (from left to right on the CCA ordination diagram, elevation gradually decreased). Elevation change leads to changes in humidity, temperature, soil type, and other factors that influence the variation of communities (Zhang 2005; Kikvidze et al 2006; Vittoz et al 2010). The first CCA axis was also a disturbance gradient (from left to right of the CCA diagram, disturbance intensity increased gradually). Disturbance intensity was significantly correlated with elevation ($r = -0.920$), because disturbance from human activities was more frequent in low areas (Huang and Chen 1994; Xiang 2009).

Community variation was also closely related to other environmental factors such as litter thickness, slope, and

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aspect (Schmidt et al 2006; Zhang, Xi, et al 2006). Litter thickness was significantly positively correlated with elevation, possibly because litter decomposed more slowly as the mean temperature dropped (Zhang 2005). The effects of slope and aspect on vegetation were also significant, confirming the results of many other studies (Austrheim 2002; Lovett et al 2006; Zhang and Zhang 2007). Changes in slope and aspect may lead to changes in hours of sunshine, humidity, and temperature, all of which affect community development (Wu 1980; Virtanen et al 2010).

Species diversity

Species diversity is an important feature of community structure, and changes in it are used as an indicator of community dynamics (Hawkins and Diniz 2004; Körner 2007; Zhang and Dong 2010). Spatial variation in species diversity shows significant characteristics of vegetation patterns in the studied area (Zhang, Xi, et al 2006; Brinkmann et al 2009). Spatial variation in species richness, heterogeneity, and evenness was great in the reserve. This variation corresponded to changes in community structure, composition, and distribution and was related to environmental gradients (Kikvidze et al 2006; Littell et al 2010). Species richness, heterogeneity, and evenness were significantly correlated with elevation and disturbance. Elevation is a key variable affecting species diversity in mountains, as established in numerous studies (eg Rahbek 2005; Fetene et al 2006; Zhang, Ru, et al 2006; Muhumuza and Byarugaba 2009). Maximum diversity at an intermediate elevation has been the most commonly observed pattern (Kessler 2001; Austrheim 2002).

Though hundreds of studies on changes in species diversity along a disturbance gradient exist, the topic has only occasionally been studied in China (Xiang 2009; Hammi et al 2010). This study found that maximum diversity appears at an intermediate disturbance intensity, confirming the humped distribution hypothesis (Grime 1973; Bruun et al 2006). The pattern was similar to that of the effect of elevation on diversity, because disturbance was negatively correlated with elevation (Huang and Chen 1994; Zhang, Xi, et al 2006). Most villages and agricultural lands are in low areas (750–1100 m), where there is heavy disturbance; tourism is most active in the middle area (1200–1600 m), with medium to heavy disturbance; and disturbance decreases markedly above 1600 m. The change in diversity is mainly a result of the interaction of elevation and disturbance (Austrheim 2002; Zhang and Dong 2010). Species diversity was also related to litter thickness and slope: species richness was negatively correlated with slope ($r = -0.256$, $P < 0.05$), and evenness was positively correlated with litter thickness ($r = 0.34$, $P < 0.001$). All changes in species richness, heterogeneity, and evenness were significantly related to community variation and environmental diversity (Zhang and Zhang 2007; Brinkmann et al 2009).

Implications for management

This study found different vegetation types and plant communities along elevational and disturbance gradients. This pattern reflects particularly the effects of elevation, disturbance intensity, and landform on community composition and plant diversity. The plant communities, their composition, and their diversity identified in this study are typical for the mountains west of Beijing (Huang and Chen 1994; Suriguga et al 2010). These communities are important to the city and residents (Xiang and Zhang 2009). To manage these resources effectively, the following measures should be considered:

1. Plant species diversity should be treated as the main target of conservation in the Baihua Mountain Reserve. Birds, previously a strong focus of conservation efforts, can be more effectively protected if the vegetation is well conserved.
2. Disturbance must be controlled. Cropland should be partially returned to natural vegetation, and farm density should be reduced through resettlement away from the reserve at low altitudes. Tourist numbers should be limited, particularly from July to September, so as not to exceed the capacity of the reserve (Zhang 2005; Xiang 2009).
3. For some plant communities severely altered by disturbance at lower altitudes, active restoration measures such as soil conservation and tree planting should be carried out.

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Supplemental data

TABLE S1 Characteristics of communities identified by TWINSPAN in the Baihua Mountain Reserve, Beijing, China.

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