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Plant communities, species richness and life-forms along elevational gradients in Taibai Mountain, China

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Understanding the distribution patterns of vegetation, species richness and plant life-forms along elevational gradients can suggest important implications for developing optimal strategies for conservation of species diversity, sustainable managing and utilizing plant resources. We explored the relationships between vegetation, species richness and plant life-forms and the separate elevational gradients on the south slope and the north slope of Taibai Mountain. Eight plant communities were clearly identifiable on each slope and these communities presented zonal distributions along elevational gradients, however, the elevational ranges occupied by different communities had more overlaps at middle elevations (c. 2250 - 3350 m a.s.l.) than at two extremes. Three communities (*Quercus spinosa*, *Acer caesium* subsp. *giraldii* and *Carex capilliformis* var. *major* communities) were first found in the area. Total species richness demonstrated a significant hump-shaped relationship with elevations on both slopes. Overall, phanerophytes, geophytes and hemicryptophytes were the most dominant life-forms, while chamaephytes and therophytes were the rarest life-forms. Species richness of phanerophytes on the south slope and hemicryptophytes on both slopes exhibited a significant hump-shaped relationship with elevations, while that of therophytes on both slopes exhibited a significant reverse-hump-shaped relationship; Species richness of phanerophytes on the north slope declined with increasing elevation, however, that of chamaephytes and geophytes on both slopes increased with increasing elevations.

Key words: Elevational gradients, plant community, species richness, plant life-forms, Taibai Mountain.

INTRODUCTION

Taibai Mountain is located in the eastern mainland China, which is the highest mountain (3767.2 m a.s.l.) in the region and also the peak of the Qinling Mountain Range, whereas the Qinling Mountain Range is the climate demarcation line between the northern China and the southern China, and also the watershed between the Yellow River and the Yangtze River. Because of the particular location and huge elevation difference, Taibai Mountain has a complicated topography with different

aspects, slopes, valleys, and sharp and flat peaks. Accordingly, the diverse environmental conditions have resulted in diverse vegetation types and high biodiversity.

Taibai Mountain has a very high conservation value since it is home to many rare animals: *Ailuropoda melanoleuca*, *Ursus thibetanus*, *Neofelis nebulosa*, *Moschus berezovskii*, *Budorcas taxicolor*, *Naemorhedus goral*, *Ithaginis cruentus*, *Bhutanitis thaidina* and *Luehdorfia chinensis*, the above first 7 species are classified as endangered by the CITES (2011). This region also provides important habitats for many Chinese endemic plant species (*Larix chinensis*, *Abies chensiensis*, *Abies fargesii*, *Pteroceltis tatarinowii*, *Eucommia ulmoides*, *Kingdonia uniflora*, etc.) and species confined to Taibai

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Mountain (*Callianthemum taipaicum*, *Aconitum taipaicum*, etc.) (Wu et al., 1999, 2001, 2003). Some species such as *Taxus chinensis*, *Tetracentron sinense* and *Sinopodophyllum hexandrum* occurred in the region are classified by the CITES as endangered (CITES, 2011). Four most important rivers, known as Hei River, Xushui River, Shitou River and Bawang River, originated in the region are the important sources of agricultural water for Hanzhong Basin and Guanzhong Plain and domestic water for Xi'an – the most important city in northwest China. Although possessing both its ecological and economic importance, intensive studies on vegetation in this area have been conducted only in the recent 20 years due to the rugged topography and inaccessibility of the mountainous escarpment, and these studies mainly relate to several plant community types (Wang et al., 1990; Liu and Ling, 1995; Miao et al., 2004; Duan et al., 2007; Lin et al., 2008, 2009). Few studies have expatiated on the patterns associated with vegetation, species richness, as well as species richness of different plant life-forms along the entire elevational gradient (Ying et al., 1990), however, understanding these patterns may suggest important implications for developing optimal strategies for conservation of species diversity, sustainable managing and utilizing plant resources (Vetaas and Grytnes, 2002). Quantitative analysis techniques play a very important role in the study of vegetation (Mabry et al., 2000). By a quantitative classification method, the present study would present a quantitative depiction of vegetation in the south slope and the north slope of Taibai Mountain.

Variations in species richness are often linked to various environmental gradients (Huston, 1994; Wang et al., 2002; Sharma et al., 2009). Elevational gradients are one of the most commonly discussed determinative factors in shaping the spatial patterns of species richness (Lomolino, 2001; Chawla et al., 2008; Acharya et al., 2011). Studies on the variations in species richness along elevational gradients have at least resulted in five patterns: (i) a monotonic decline in species richness with increasing elevation (Mallen-Cooper and Pickering, 2008; Sharma et al., 2009); (ii) a hump-shaped relationship with the highest species richness at intermediate elevation (Grytnes and Vetaas, 2002; Nogués-Bravo et al., 2008; Brinkmann et al., 2009); (iii) a monotonic increase of species richness with increasing elevation (Baruch, 1984); (iv) the lowest species richness at intermediate elevation (Peet, 1978); and (v) no obvious relationship between species richness and elevation (Wilson and Sykes, 1988; Lovett, 1999), and these trends have been discussed in relation to different environmental variables (Körner, 2002; Grytnes, 2003b; Rahbek, 2005).

Based on the position of buds or regenerating parts in unfavourable seasons, Raunkiaer (1934) proposed a life-form classification system which resulted in five main life-form categories: phanerophytes, chamaephytes, hemi-cryptophytes, geophytes and therophytes. Obviously, plant life-forms reflect plants' adaptations to a multifactorial environment (Mera et al., 1999). Thus it is

expected that the species richness of hemi-cryptophytes and geophytes, with their buds protected below the soil surface to avoid the extremely harsh environmental conditions at high elevations (Carlsson et al., 1999), will exhibit increasing trends with increasing elevation, and declining trends for phanerophytes and chamaephytes. In addition, plant life-forms divide all species into several functional types, thus elevational patterns of species richness probably become more explainable by taking account of both species richness of different life-forms and total species richness (Pausas and Austin, 2001).

The aims of the study are to elucidate the relationship between vegetation and the separate elevational gradients on the south slope and the north slope of Taibai Mountain by analyzing

- (1) the spatial distribution patterns of vegetation and species composition, and
- (2) the variations in total species richness and species richness of different life-forms along the elevational gradients.

We also compare total species richness and species richness of each life-form between the two slopes.

MATERIALS AND METHODS

Study area

The study area, Taibai Mountain, is located in the junction of three counties (Mei County, Zhouzhi County and Taibai County), Shannxi province, China (107°19' - 107°58' E and 33°45' - 34°10' N) (Figure 1). Due to the huge elevation difference (the summit, 3767.2 m a.s.l.), the average annual temperature in the area changes in a wide range of 8.7 (1500 m a.s.l.) -2.5°C (3250 m a.s.l.) on the south slope and 11.0 (1250 m a.s.l.) - 1.1°C (3250 m a.s.l.) on the north slope (Tang and Fang, 2006). The average annual precipitation has an obvious difference between the two slopes, according to Houzhenzi climate station (107°50' E, 33° 46' N, 1260.0 m a.s.l.) and Taibai County climate station (107° 19' E, 34°02' N, 1543.1 m a.s.l.), 945.5 mm on the south slope and 751.8 mm on the north slope, respectively. The precipitation is mainly concentrated during July to September which account for c. 50% of the total.

This area is characterized by diverse landforms including fluvial landform (below 3300 m a.s.l.), quaternary periglacial landform and quaternary glacial landform (above 3300 m a.s.l.) (Xia, 1990). Diverse soil-forming factors (such as climate, biont, geology and geomorphy) and their complex combinations create diverse soil types, including mountain drab soil, mountain brown soil, mountain dark brown soil, subalpine forest-meadow soil and alpine meadow soil based on elevational gradient from low to high (Lei et al., 2001). Vegetation types of the study region include Montane Forest, alpine thicket and meadow. The study area below 1500 m a.s.l. on the south slope has relative high anthropogenic disturbances, nevertheless, it is in a rather primitive state mainly due to lack of roads that restrict human disturbances.

Sampling design and data collection

The field investigation was carried out from July through September 2009 and July through October 2010. One transect was constructed on each slope of Taibai Mountain along elevational gradients, which

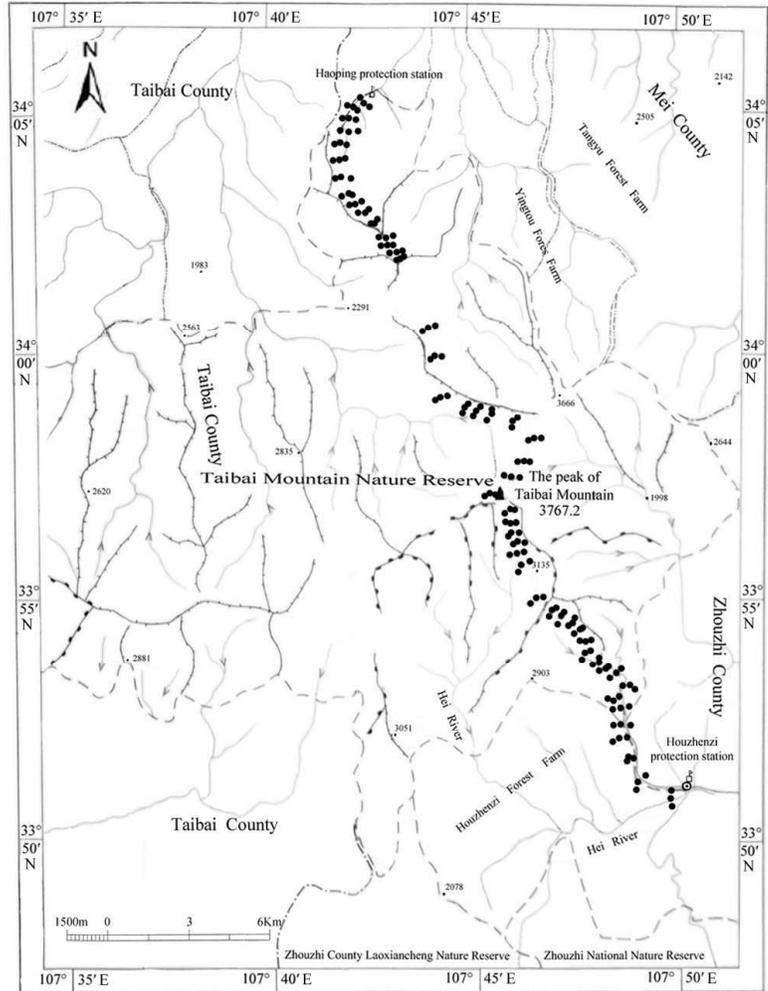
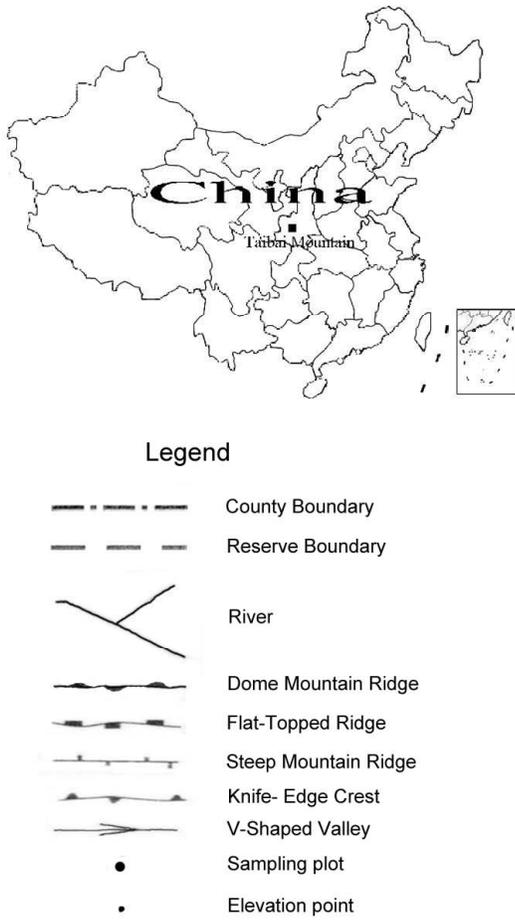


Figure 1. Location of the study area.

had an elevation span from c. 1350 to c. 3750 m a.s.l. and c. 1250 to 3650 m a.s.l. on the south slope and the north slope, respectively. Three plots were sampled at approximately 100 m (fluctuating up and/or down by 20 m at a given elevation) elevation intervals and a total of 75 plots in each transect were surveyed on each slope (Figure 1). Data were collected in nested plots with outer dimensions of 20 m × 20 m (for trees). A subplot (10 m × 10 m) was set up in the center of each plot, and was used to investigate shrub and herb. Every species name was recorded and its canopy cover was estimated. Canopy cover estimates were made by viewing the whole plot or subplot from four vantage points (the midpoint of each side of plot or subplot) to make estimates of percent cover for dominant or common species. The plot or subplot was then examined thoroughly for lower cover or infrequent species (Magee et al., 2008). Two meter tapes were used diagonally in the plot or subplot to improve estimation precision. Elevation of each plot was determined by Magellan eXplorist GPS500.

Data analysis

In order to explore plant community types, hierarchical clustering analyses were separately performed on the south slope and the north slope based on data of species relative cover in each plot

(species relative cover = individual species cover in a plot / the sum of all species cover in the plot × 100). Relative Sorensen distance and flexible-β linkage were selected in the clustering analyses (β = 0.25) (McCune and Grace, 2002). In order to minimize the “noise”, only those species that were found in no less than three plots or subplots were used in the clustering analyses (McCune and Grace, 2002). For clustering analysis, a key issue is to determine the dendrogram of cluster analysis be pruned at an appropriate level that represents a compromise between homogeneity of the groups and the number of groups (McCune and Grace, 2002). The Indicator Species Analysis (ISA) technique (Dufrière and Legendre, 1997) can be used to resolve the problem. ISA indicator values depict the percent of perfect indication of each species for each group based on combined relative abundance and relative frequency (McCune and Grace, 2002). The sum of the species significant indicator values for each clustering level can be as a criterion to determine the final classification hierarchy because when this value is decreasing, the clustering method does not explain anything more (Dufrière and Legendre, 1997). Species were considered significant indicator species if P ≤ 0.05 through Monte Carlo tests, 4999 randomizations.

Total species richness and species richness of each life-form (five life-forms were distinguished according to Raunkiaer’s system, that is, Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes

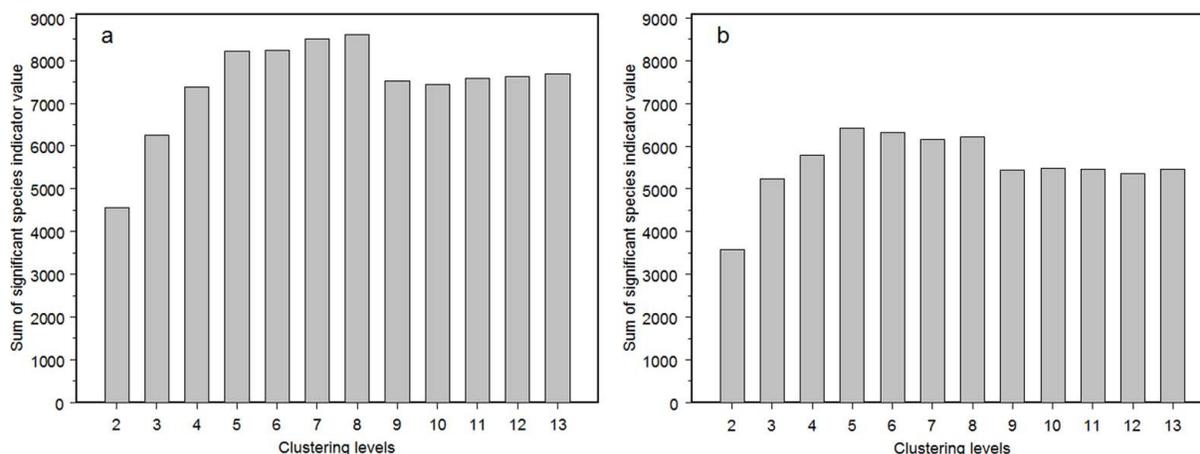


Figure 2. The sum of all the species significant indicator values for each clustering level is used to determine the appropriate endpoint of the clustering procedures. An abrupt decline at 9-group level for both the south slope (a) and the north slope (b) suggests 8 groups are an appropriate division for each slope.

and Therophytes (Raunkiaer, 1934)) were related to elevation on each slope by means of a Generalized Linear Model (GLM; McCullagh and Nelder, 1989). When the response variables are count data, they are expected to have Poisson distributions, and log-link functions can be used to link the expected response to the explanatory variables (McCullagh and Nelder, 1989). The explanatory variable used in this study was elevation. GLM is a parametric model, its first- or second-order polynomials is restricted to be linear or symmetrically unimodal, so any complex patterns that total species richness and species richness of different life-forms change with elevations will in most instances not be detected. Therefore a non-parametric model, Generalized Additive Model (GAM; Hastie and Tibshirani, 1990), which can describe more complex patterns, was used to evaluate whether any trends in the data that could not be captured by GLM. To depict the relationships between total species richness, species richness of each life-form and elevations, six different models were established, two with GLM (a first-order and a second-order polynomial), four with GAM (a cubic smoother spline using three, four, five and six degrees of freedom, respectively) (Hastie and Tibshirani, 1990). Then *F*-tests were used to evaluate the significance of the deviance explained by a first-order polynomial against null model (that is, null hypothesis), if it was significant, to test the significance of the additional deviance explained by a second-order polynomial against the first-order polynomial; if significant again, to test the significant of the deviance explained by a GAM model with three degrees of freedom against the second-order polynomial, and the like, and eventually selected the best model (Grytnes, 2003a).

In addition, paired *t*-tests were used to test whether there were significant differences in total species richness and species richness of each life-form between the south slope and the north slope, the pairs of plots sampled at the same elevations on both the slopes, that is, 1350 to 3650 m a.s.l.

PC-ORD version 5.0 (McCune and Mefford, 2005) was used to perform clustering analysis and ISA and construct Figure 3. Other relevant statistical analysis and the constructions of Figures 2, 4 and 5 were done with the statistical program *S-PLUS* 8.0 for Windows (Anonymous, 2007).

RESULTS

A total of 402 species in 75 plots on the south

slope belonging to 71 families and 365 species in 75 plots on the north slope belonging to 63 families were identified. The families represented by the highest number of species on the south slope successively were Compositae (12.2%), Rosaceae (9.2%), Liliaceae (6.2%), Ranunculaceae (5.2%) and Saxifragaceae (4.7%), and comparatively on the north slope were Rosaceae (11.0%), Compositae (9.0%), Saxifragaceae (6.6%), Liliaceae (6.0%) and Ranunculaceae (4.9%) successively.

Plant communities

The sum of the species significant indicator values on both the south and the north slopes abruptly decreased at the clustering level nine groups (Figure 2), which suggested eight groups for each slope were appropriate clustering level. The resulting cluster analysis dendrograms had 1.85% chaining for the south slope, 2.69% for the north slope, and both were cut with 50% of the information remaining, resulting in eight forest groups, respectively (Figure 3). The general characteristics of the eight plant communities for each slope identified are summarized (Table 1) and briefly depicted below. The plant communities were named based on their most dominant species.

Plant communities on the south slope

Group S1: *Pinus tabulaeformis* community - This group containing 6 plots was distributed at an elevation of 1346 to 1449 m a.s.l. (except for the plot S25, which was distributed at an elevation of 2139 m a.s.l.). The plots were dominated by *P. tabulaeformis*, *Castanea seguinii* and *Corylus heterophylla* with the mean relative cover per plot 37.4, 13.6 and 4.0%, respectively. Although *Carex*

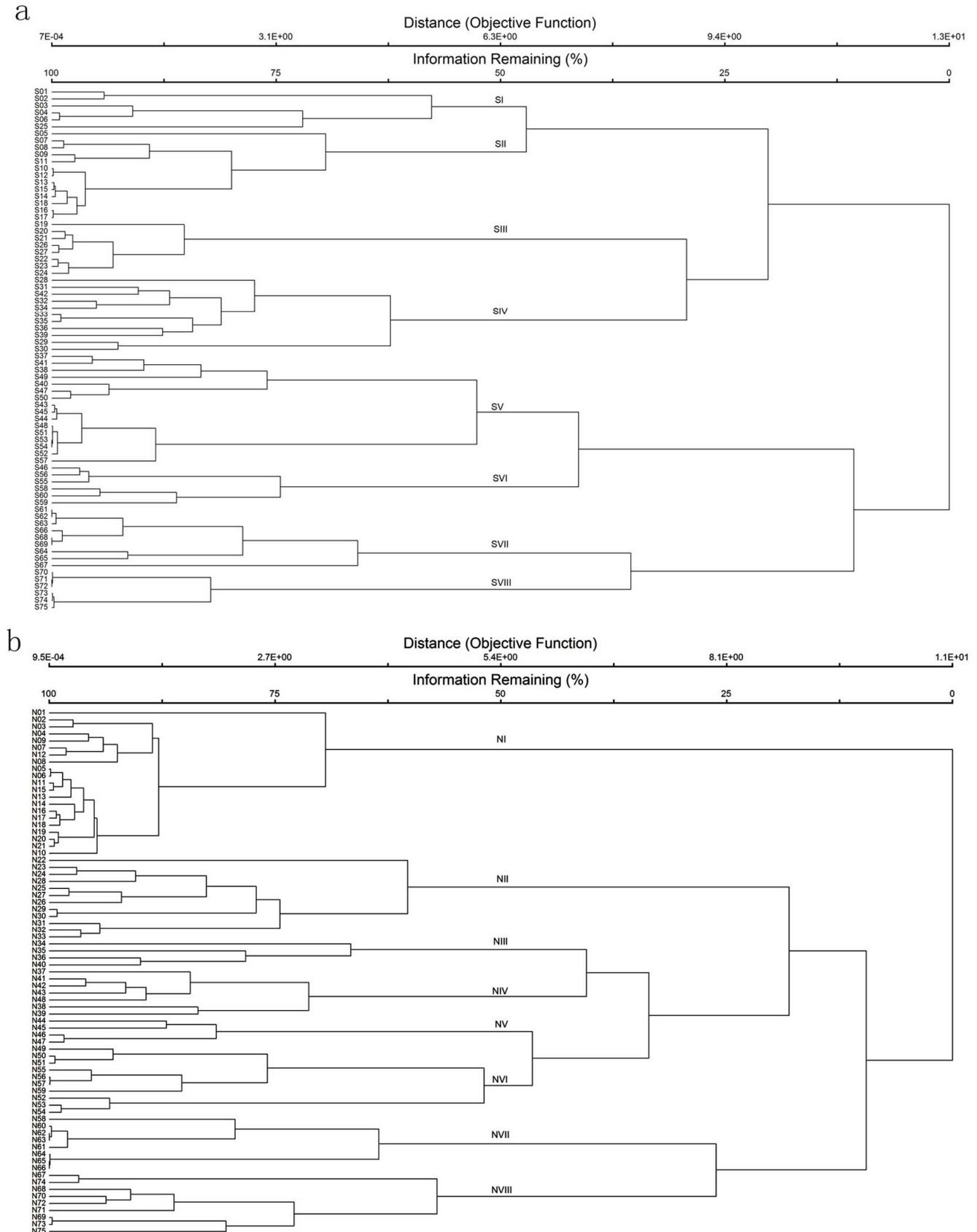


Figure 3. Dendrogram of each 75 plots on the south slope (a) and the north slope (b) of Taibai Mountain produced by cluster analysis using relative Sorensen distance and the flexible- β linkage group method.

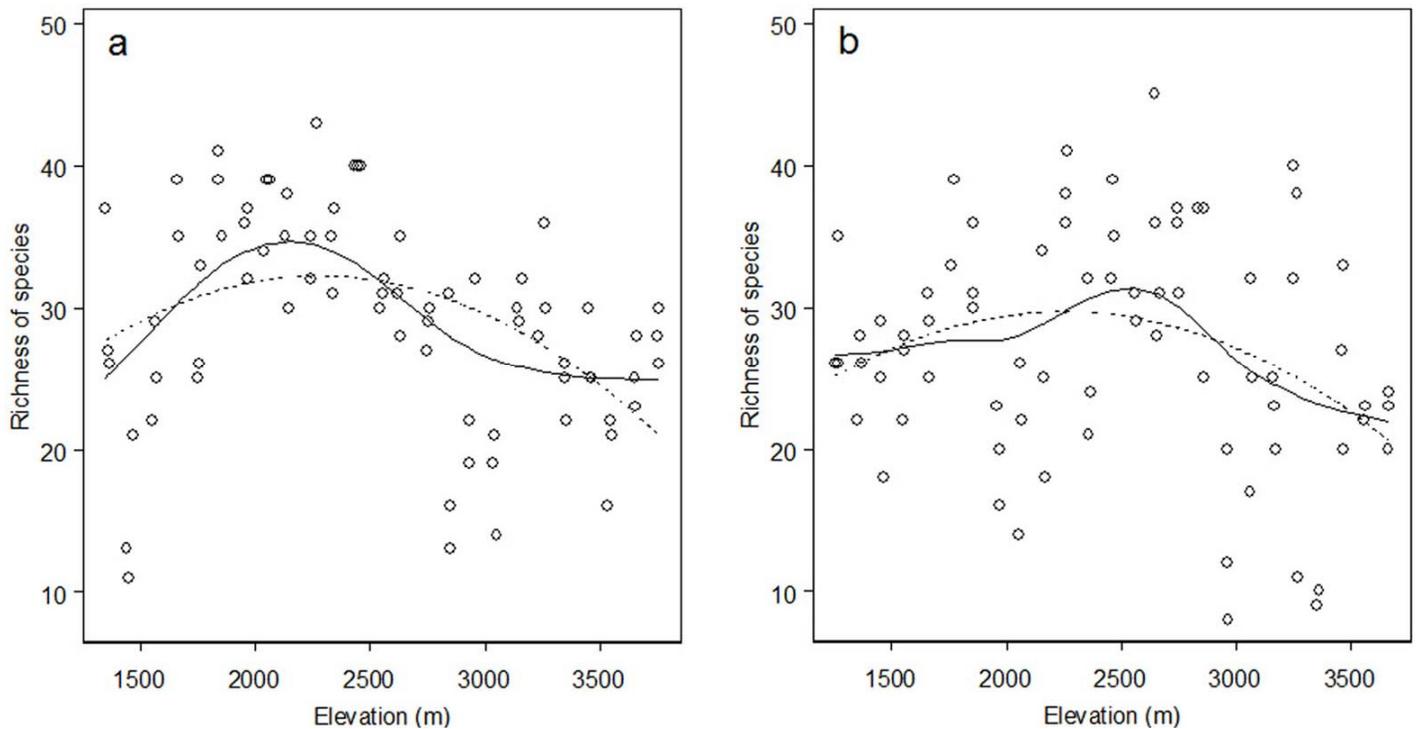


Figure 4. The plot-based species richness along the elevational gradients on the south slope (a) and the north slope (b) of Taibai Mountain. The broken and unbroken lines are based on the best GLM models (that is second-order polynomial) and the GAM models (that is cubic smooth spline with four and five degrees of freedom on the south slope and the north slope, respectively), respectively (for detail see Table 2).

lanceolata had a low relative cover (1.1%), it was found in every plot. On average, there were 25.3 species observed per plot. The plot S6 had the lowest species richness (only eleven species were found) in all the plots of the south slope.

Group SII: *Quercus aliena* var. *acutiserrata* community - This community was defined by 13 plots occurred at an elevation of 1470 to 1855 m a.s.l. *Q. aliena* var. *acutiserrata* (65.0% mean relative cover per plot) and *P. tabulaeformis* (8.0%) were the dominant species, and other species had low relative cover (each of them <3%). However, the shrubs such as *Lespedeza buergeri*, *Schisandra sphenanthera* and *Smilax stans* were present in most of the plots, and the herb *C. lanceolata* was the most common species which appeared in all the plots. The mean species richness per plot was 31.2.

Group SIII: *Quercus spinosa* community - This community was defined by 8 plots occupied at the elevations between 1956-2146 m a.s.l.. It was dominated by *Q. spinosa* (57.1% mean relative cover per plot) and *Populus purdomii* (14.4%). The trees *Pinus armandii* and *Carpinus shensiensis*, shrubs *Acanthopanax trifoliatum*, *Fargesia qinlingensis* and *Euonymus verrucosoides*, herbs *C. lanceolata* were the most common species which occurred in every plot although they had low

relative cover (3.1, 3.1, 0.3, 0.3, 0.1 and 1.9%, respectively). There were on average 35.3 species observed per plot in this community.

Group SIV: *Betula albo-sinensis* community - A total of 11 plots belonging to this community were located at elevations from 2240 to 2632 m a.s.l. *B. albo-sinensis* was the dominant species with a mean relative cover per plot 38.0%. *P. purdomii*, *Cerasus conadenia* and *A. fargesii* had high mean relative cover (10.4, 5.3 and 5.2%, respectively), but their frequencies of occurrence were very low (3, 1 and 4 plots, respectively). The species with low mean relative cover, such as *Rubus floosculosus*, *Philadelphus incanus* and *C. lanceolata*, were found in most of the plots. This community had the highest species richness with an average 35.5 species observed per plot.

Group SV: *A. fargesii*-*Betula utilis* community - The sixteen plots defining this group occurred from 2560 to 3148 m a.s.l. *A. fargesii* was the most dominant species with a mean relative cover per plot 50.9%, and *B. utilis* was the second most dominant species (24.8%). Common species in this community were *Lonicera szechuanica* (16 plots), *Viola biflora* (12 plots), *C. capilliformis* var. *major* (10 plots) and *Oxalis acetosella* subsp. *griffithii* (10 plots). On average, there were 26.1

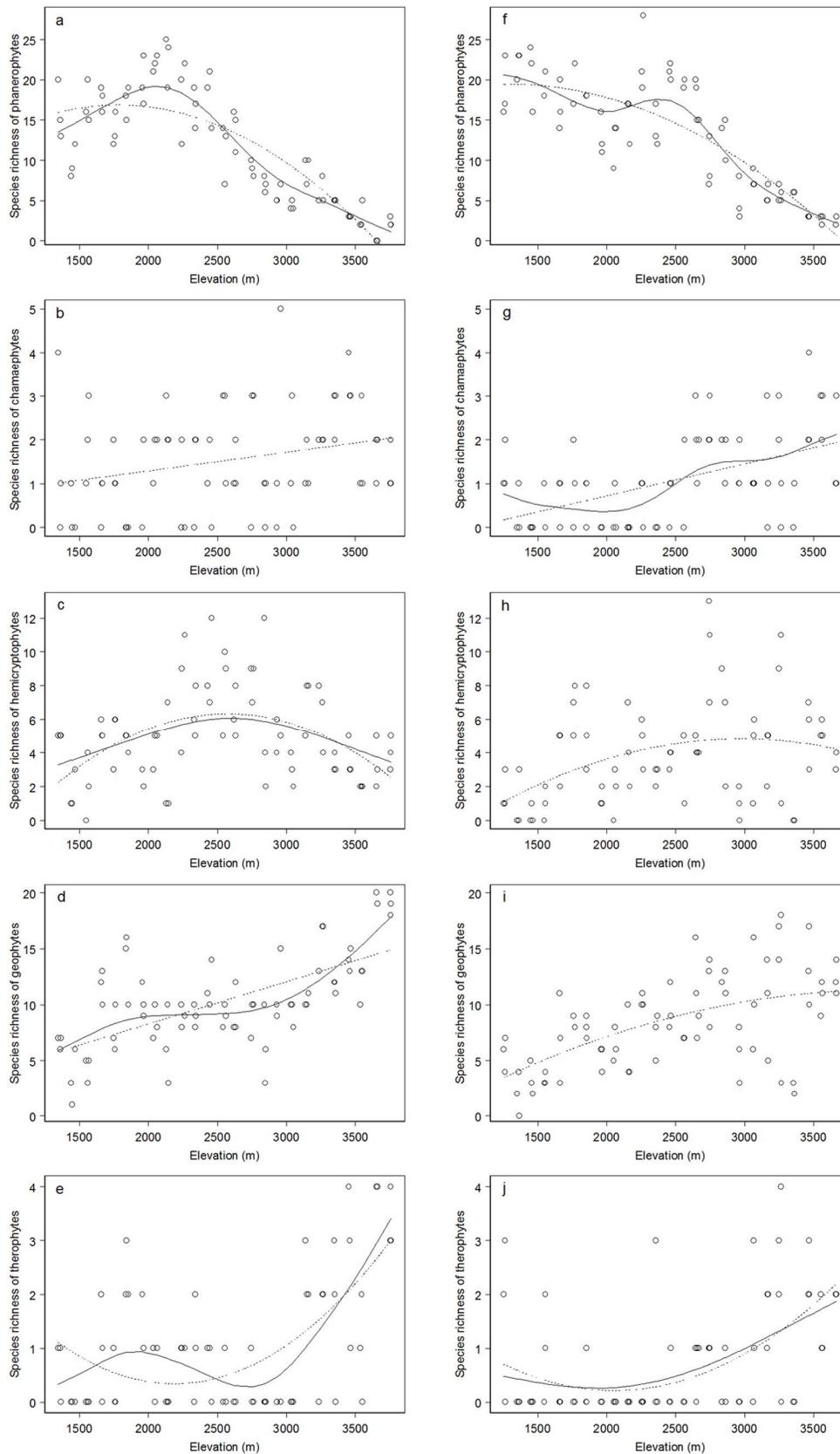


Figure 5. The plot-based species richness of different life-forms along the elevational gradients on the south slope (a-e) and the north slope (f-j) of Taibai Mountain. The broken and unbroken lines are based on the best GLM models and the GAM models, respectively (for detail see Table 4).

Table 1. Plant community types identified through classification on the south slope and the north slope of Taibai Mountain.

Plant community types identified by classification	Major constituent species	Indicator species	Species richness per plot (mean ± SD)
South slope			
Group SI: <i>Pinus tabulaeformis</i> community	<i>P. tabulaeformis</i> , <i>Castanea seguinii</i> , <i>Corylus heterophylla</i> , <i>Carex lanceolata</i>	<i>P. tabulaeformis</i> (68), <i>Magnolia multiflora</i> (63), <i>Eragrostis ferruginea</i> (60), <i>C. heterophylla</i> (59), <i>Rubia lanceolata</i> (50), <i>C. seguinii</i> (50), <i>Thalictrum brevisericum</i> (49), <i>Picrasma quassioides</i> (49), <i>Populus davidiana</i> (42), <i>Carpesium minus</i> (41)	25.3 ± 11.5
Group SII: <i>Quercus aliena</i> var. <i>acutiserrata</i> community	<i>Q. aliena</i> var. <i>acutiserrata</i> , <i>P. tabulaeformis</i> , <i>C. lanceolata</i> , <i>Schisandra sphenanthera</i>	<i>Q. aliena</i> var. <i>acutiserrata</i> (95), <i>Lysimachia christinae</i> (62), <i>Smilax discotis</i> (48), <i>Epimedium brevicornu</i> (46), <i>Deyeuxia langsdorffii</i> (45), <i>Thalictrum ichangense</i> (41)	31.2 ± 6.8
Group SIII: <i>Quercus spinosa</i> community	<i>Q. spinosa</i> , <i>Pinus armandi</i> , <i>Populus purdomii</i> , <i>C. lanceolata</i> , <i>Carpinus shensiensis</i> , <i>Fargesia qinlingensis</i> , <i>Acanthopanax trifoliatum</i>	<i>Q. spinosa</i> (99), <i>A. trifoliatum</i> (95), <i>C. shensiensis</i> (93), <i>Euonymus verrucosoides</i> (79), <i>Fraxinus mandschurica</i> (75), <i>Acer oliverianum</i> (66), <i>Rhamnus rosthornii</i> (63), <i>Celastrus orbiculatus</i> (63), <i>Ostrya japonica</i> (59), <i>P. purdomii</i> (56)	35.3 ± 3.2
Group SIV: <i>Betula albo-sinensis</i> community	<i>B. albo-sinensis</i> , <i>Rubus flosculosus</i> , <i>C. lanceolata</i> , <i>Philadelphus incanus</i>	<i>B. albo-sinensis</i> (83), <i>Torularia humilis</i> (70), <i>R. flosculosus</i> (69), <i>Zanthoxylum bungeanum</i> (57), <i>P. incanus</i> (56), <i>Phlomis umbrosa</i> (52), <i>Asarum sieboldii</i> (48), <i>Euonymus phellomanes</i> (46), <i>F. qinlingensis</i> (45), <i>Aruncus sylvester</i> (42)	35.5 ± 4.9
Group SV: <i>Abies fargesii</i> - <i>Betula utilis</i> community	<i>A. fargesii</i> , <i>B. utilis</i> , <i>Lonicera szechuanica</i> , <i>Carex capilliformis</i> var. <i>major</i>	<i>B. utilis</i> (66), <i>A. fargesii</i> (65), <i>Anemone exigua</i> (63), <i>L. szechuanica</i> (49), <i>Saussurea macrota</i> (44), <i>Ligularia dolichobotrys</i> (44), <i>Rubus pileatus</i> (44), <i>Chrysosplenium sinicum</i> (41), <i>Cardamine scaposa</i> (40)	26.1 ± 6.6
Group SVI: <i>Larix chinensis</i> community	<i>L. chinensis</i> , <i>L. szechuanica</i> , <i>C. capilliformis</i> var. <i>major</i> , <i>Carex capilliformis</i> ,	<i>L. chinensis</i> (98), <i>Notholirion hyacinthinum</i> (79), <i>C. capilliformis</i> (63), <i>Lonicera fargesii</i> (59), <i>Poa nemoralis</i> (54), <i>Fragaria gracilis</i> (40)	28.2 ± 7.9
Group SVII: <i>Rhododendron capitatum</i> community	<i>R. capitatum</i> , <i>Salix cupularis</i> , <i>Rhododendron deterile</i> , <i>C. capilliformis</i> var. <i>major</i> , <i>Anemone taipaiensis</i>	<i>R. capitatum</i> (95), <i>S. cupularis</i> (79), <i>Anaphalis nepalensis</i> (67), <i>Peucedanum praeruptorum</i> (67), <i>Spiraea alpina</i> (61), <i>Ajania remotipinna</i> (54), <i>Allium ovalifolium</i> (52), <i>R. deterile</i> (44), <i>Allium prattii</i> (43)	23.6 ± 3.9
Group SVIII: <i>C. capilliformis</i> var. <i>Major</i> community	<i>C. capilliformis</i> var. <i>major</i> , <i>Polygonum viviparum</i> , <i>Saussurea purpurascens</i> , <i>Anemone taipaiensis</i> , <i>Leontopodium giraldii</i> , <i>Swertia bifolia</i> , <i>C. capilliformis</i>	<i>Carex scabrirostris</i> (100), <i>Pedicularis decora</i> (100), <i>P. viviparum</i> (98), <i>Parnassia viridiflora</i> (94), <i>Lomatogonium carinthiacum</i> (92), <i>Melandrium apetalum</i> (91), <i>Rhodiola dumulosa</i> (87), <i>S. bifolia</i> (87), <i>L. giraldii</i> (84), <i>Anaphalis sinica</i> (84)	26.7 ± 2.5
North slope			
Group NI: <i>Quercus aliena</i> var. <i>acutiserrata</i> community	<i>Q. aliena</i> var. <i>acutiserrata</i> , <i>Dendrobenthamia japonica</i> var. <i>chinensis</i> , <i>C. shensiensis</i> , <i>Spiraea fritschiana</i>	<i>Q. aliena</i> var. <i>acutiserrata</i> (100), <i>Acer grosseri</i> (81), <i>Litsea moupinensis</i> var. <i>szechuanica</i> (66), <i>Dioscorea nipponica</i> (64), <i>C. orbiculatus</i> (56), <i>Crataegus wilsonii</i> (52), <i>D. japonica</i> var. <i>chinensis</i> (48), <i>S. fritschiana</i> (45), <i>A. ovalifolium</i> (43)	28.5 ± 5.0
Group NII: <i>Quercus wutaishanica</i> community	<i>Q. wutaishanica</i> , <i>Carpinus cordata</i> , <i>P. armandi</i> , <i>E. brevicornu</i> , <i>C. lanceolata</i>	<i>Q. wutaishanica</i> (100), <i>C. lanceolata</i> (83), <i>E. brevicornu</i> (79), <i>C. cordata</i> (67), <i>Smilax stans</i> (65), <i>P. davidiana</i> (45), <i>P. armandi</i> (42), <i>Rubus amabilis</i> (42), <i>Viola acuminata</i> (42)	26.1 ± 9.1
Group NIII: <i>Acer caesium</i> subsp. <i>Giraldii</i> community	<i>A. caesium</i> subsp. <i>giraldii</i> , <i>Cladrastis wilsonii</i> , <i>P. umbrosa</i> , <i>Acer caudatum</i> var. <i>multiserratum</i> , <i>L. fargesii</i> , <i>Viburnum betulifolium</i>	<i>A. caesium</i> subsp. <i>giraldii</i> (90), <i>C. wilsonii</i> (74), <i>Anemone cathayensis</i> (72), <i>A. caudatum</i> var. <i>multiserratum</i> (67), <i>L. dolichobotrys</i> (54), <i>P. umbrosa</i> (54), <i>Padus obtusata</i> (49), <i>Corylus ferox</i> var. <i>thibetica</i> (45), <i>L. fargesii</i> (45), <i>V. betulifolium</i> (44)	26.5 ± 4.9

Table 1. Contd.

Group NIV: <i>B. albo-sinensis</i> community	<i>B. albo-sinensis</i> , <i>C. capilliformis</i> var. <i>major</i> , <i>Pertya sinensis</i> , <i>P. umbrosa</i> , <i>Rosa omeiensis</i> ,	<i>B. albo-sinensis</i> (94), <i>P. sinensis</i> (59), <i>Kobresia myosuroides</i> (57), <i>Galium paradoxum</i> (57), <i>R. omeiensis</i> (54), <i>F. qinlingensis</i> (50), <i>P. purdomii</i> (43), <i>Triosteum pinnatifidum</i> (43), <i>Sanicula chinensis</i> (42)	35.3 ± 5.7
Group NV: <i>B. utilis</i> community	<i>B. utilis</i> , <i>P. sinensis</i> , <i>L. szechuanica</i> , <i>C. capilliformis</i> var. <i>major</i>	<i>B. utilis</i> (76), <i>L. szechuanica</i> (69), <i>Angelica tsinlingensis</i> (48), <i>S. macrota</i> (47), <i>Ajuga ciliate</i> (46), <i>Thalictrum petaloideum</i> (44), <i>Corydalis curviflora</i> var. <i>giraldii</i> (40), <i>A. sylvester</i> (40)	33.5 ± 2.9
Group NVI: <i>A. fargesii</i> community	<i>A. fargesii</i> , <i>B. utilis</i> , <i>L. szechuanica</i> , <i>Rhododendron purdomii</i> , <i>Cardamine macrophylla</i> , <i>C. capilliformis</i> var. <i>major</i>	<i>A. fargesii</i> (91), <i>C. scaposa</i> (55), <i>A. exigua</i> (51), <i>Cortusa matthioli</i> (49), <i>R. purdomii</i> (48), <i>Pseudostellaria heterophylla</i> (45)	28.0 ± 7.5
Group NVII: <i>L. chinensis</i> community	<i>L. chinensis</i> , <i>C. capilliformis</i> var. <i>major</i> , <i>C. macrophylla</i> , <i>Potentilla glabra</i>	<i>L. chinensis</i> (92), <i>P. glabra</i> (88), <i>Epilobium pyrricholophum</i> (44)	23.1 ± 12.6
Group NVIII: <i>R. capitatum</i> - <i>S. cupularis</i> community	<i>R. capitatum</i> , <i>S. cupularis</i> , <i>C. capilliformis</i> var. <i>major</i> , <i>Meconopsis quintuplinervia</i> , <i>Aconitum taipeicum</i> , <i>Polygonum viviparum</i> var. <i>angustum</i> , <i>Arenaria quadridentata</i>	<i>Ligusticum sinense</i> var. <i>alpinum</i> (99), <i>A. taipeicum</i> (99), <i>S. cupularis</i> (98), <i>A. quadridentata</i> (98), <i>M. quintuplinervia</i> (95), <i>R. capitatum</i> (95), <i>P. viviparum</i> var. <i>angustum</i> (94), <i>S. bifolia</i> (89), <i>Saxifraga gemmigera</i> (89), <i>Juncus bufonius</i> (88)	23.9 ± 4.0

The figures in parentheses behind each indicator species represent species indicator values, only those significant indicator species ($P < 0.05$) but also with an indicator value $\geq 40\%$ are mentioned for each plant community in the table. For simplicity, only the former 10 species with the highest indicator values are listed when there are more than 10 species meet these conditions in a community.

species observed per plot in this community.

Group SVI: *Larix chinensis* community - This community observed in 6 plots was distributed at the elevations between 2846 to 3265 m a.s.l. This elevation belt was also the upper limit of forest distribution on the south slope. *L. chinensis* (44.2%, mean relative cover per plot) dominated this community. *A. fargesii* and *B. utilis* with high mean relative cover (12.4 and 5.5%, respectively) occurred low frequencies, however, the herbs *C. capilliformis* var. *major* (9.3%) and *Carex capilliformis* (5.8%) were commonly distributed. Other species such as *L. szechuanica*, *Cardamine macrophylla* and *Heracleum moellendorffii*, with low mean relative cover (2.2, 0.6 and 0.3%, respectively), were found in most of the plots. On average, 28.2 species were observed per plot in this community.

Group SVII: *Rhododendron capitatum* community

- This shrub community involved in 9 plots occurred from 3350 to 3551 m a.s.l. *R. capitatum* was the dominant species with a relative cover 59.8%, other species with high relative cover were *Rhododendron deterile* (11.4%), *Salix cupularis* (9.5%) and *C. capilliformis* var. *major* (6.9%). *Anemone taipaiensis*, *Allium prattii*, *C. macrophylla* and *Ajania variifolia* with low relative cover (1.2, 0.6, 0.5 and 0.3%, respectively) were commonly distributed. This community had the lowest species richness on the south slope, in which 23.6 species were observed per plot.

Group SVIII: *C. capilliformis* var. *major* community - This community defined by 6 plots was an alpine meadow, which was distributed above c. 3550 m a.s.l. The species with the highest relative cover was *C. capilliformis* var. *major* (45.1%), and the following were *Polygonum viviparum* (11.9%) and *Saussurea purpurascens* (5.8%). Other species, such as *A. taipaiensis*, *Leontopodium giraldii*, *Swertia*

bifolia, *C. capilliformis* and *Ligusticum sinense* var. *alpinum* with low relative cover, occurred in all the plots of this community. On average, there were 26.7 species were observed per plot.

Plant communities on the north slope

Group NI: *Q. aliena* var. *acutiserrata* community - This group was defined by 21 plots from 1253 to 1856 m a.s.l.. *Q. aliena* var. *acutiserrata* was the absolutely dominant species with a high relative cover 67.1%. The relative cover of any other species was less than 3% in the community. *Dendrobenthamia japonica* var. *chinensis* and *C. shensiensis* were found more commonly at low elevations (<1550 m a.s.l.), and *Acer grosseri*, *Lindera obtusiloba*, *Litsea moupinensis* var. *szechuanica*, *Spiraea fritschiana* and *Dioscorea nipponica* were distributed commonly in the whole elevation zone.

Group NIII: *Quercus wutaishanica* community - The twelve plots defining this group were distributed at an elevation of 1960 to 2265 m a.s.l. *Q. wutaishanica* was the dominant species with a relative cover 52.6%, other species with high relative cover were *Carpinus cordata* (11.2%), *P. armandii* (6.6%) and *Populus davidiana* (5.6%). *Epimedium brevicornu*, *F. qinlingensis*, *C. lanceolata* and *S. fritschiana* with a common distribution but each of them had a low relative cover (1.8, 1.5, 1.0 and 0.4%, respectively). There were an average of 26.1 species observed per plot.

Group NIII: *Acer caesium* subsp. *giraldii* community - This group observed from 4 plots occurred at the elevations between 2356 and 2565 m a.s.l. *A. caesium* subsp. *giraldii* dominated this community with a relative cover (39.0%), however, plot N34 was an outlier in which *Padus obtusata* had the highest relative cover (52.5%). Other species contributing approximately 20% of the total cover were *Cladrastis wilsonii* (11.9%), *Phlomis umbrosa* (5.8%) and *Acer caudatum* var. *multiserratum* (2.6%). *Viburnum betulifolium*, *Lonicera fargesii*, *P. incanus*, *S. fritschiana*, *Anemone cathayensis* and *Sanicula chinensis* contributing low relative cover (each of them <2%) were found in all the plots. An average of 26.5 species per plot was observed in this community.

Group NIV: *B. albo-sinensis* community - This group containing 7 plots lied within an elevation belt of 2456 to 2746 m and was ranked highest in species richness per plot (35.3) on the north slope. The most important species in terms of relative cover were *B. albo-sinensis* (40.8%), *C. capilliformis* var. *major* (8.6%), *P. purdomii* (6.4%), *Pertya sinensis* (6.0%), *B. utilis* (3.7%), *Rosa omeiensis* (3.6%) and *A. caesium* subsp. *giraldii* (3.2%). Other species such as *P. umbrosa*, *F. qinlingensis*, *S. chinensis* and *Pseudostellaria heterophylla* were recorded in all 7 plots although they had low relative cover (2.7, 2.4, 0.4 and 0.1%, respectively).

Group NV: *B. utilis* community - A total of 4 plots belonging to this group were located at an elevation of 2651 to 2743 m a.s.l. On average, there were 33.5 species observed per plot. *B. utilis* was the most dominant species (53.0%, mean relative cover), other important species in this community were *P. sinensis* (5.9%), *L. szechuanica* (5.0%), *C. capilliformis* var. *major* (4.4%) and *P. umbrosa* (2.5%).

Group NVI: *A. fargesii* community - The ten plots belonging to this community occurred from 2836 to 3166 m a.s.l. *A. fargesii* was the most dominant species which contributed 60.8% of the total cover with other species *B. utilis*, *Rhododendron purdomii* and *Larix chinensis* altogether contributed an additional 20.1% of the total cover. The species *C. capilliformis* var. *major*, *L. szechuanica*, *C. macrophylla*, *Cardamine scaposa*, *Anemone exigua* and *P. heterophylla* with lower relative

cover occurred in most of the plots. On average, 28.0 species were observed per plot.

Group NVII: *L. chinensis* community - The eight plots involved in this community were distributed at an elevation of 3162 to 3362 m a.s.l. This elevation zone was the upper limit of forest distribution on the north slope. The dominant species were *L. chinensis* (47.8%), *R. deterile* (23.0%) and *C. capilliformis* var. *major* (17.1%), however, *R. deterile* was found only in three plots of an elevation around 3350 m. Other common species in the community were *C. macrophylla*, *Potentilla glabra*, *C. capilliformis* and *O. acetosella* subsp. *griffithii*. An average of 23.1 species per plot ranked lowest in species richness on the north slope.

Group NVIII: *R. capitatum*-*S. cupularis* community - This community, an alpine shrub-grass community appeared in 9 plots and occurred above 3450 m a.s.l.. *R. capitatum*, *S. cupularis* and *C. capilliformis* var. *major* were the most dominant species with the relative cover 27.8, 21.8 and 19.9%, respectively. Other species with lower relative cover (each of them <4%) such as *Meconopsis quintuplinervia*, *A. taipeicum*, *Polygonum viviparum* var. *angustum*, *Arenaria quadridentata*, *C. macrophylla* and *L. sinense* var. *alpinum* were widely distributed in all the plots. There were 23.9 species observed on average per plot.

Species richness

Species richness had a statistically significant hump-shaped relationship with elevation on both the south slope and the north slope (Figure 4). The second-order polynomial statistically explained about 18% of the null deviance for the south slope and 9% for the north slope (Table 2). The statistically significant improvement were achieved by the GAM models with four degrees of freedom for the south slope and five for the north slope and the amount of deviance explained raised to approximately 40 and 19%, respectively. The GAM models depicted a more steep increase in species richness with elevation up to about 2050 m a.s.l., then a fast decrease to about 2850 m a.s.l. and a slowly descent above this elevation for the south slope (Figure 4a), and a gentle hump between c. 2050 and 2950 m a.s.l. for the north slope (Figure 4b). A paired *t*-test indicated that there was no significant difference in species richness between the south slope and the north slope (pairs of plots sampled from 1350 to 3650 m a.s.l., $t=1.94$, $P=0.0561$).

Species richness of different life-forms

Of five different Raunkiaer life-forms, phanerophytes with 144 species on the south slope prevailed (35.8%), followed

Table 2. Summary statistics of the regressions with species richness as response and elevation as predictor variables.

Model	Residual deviance	Test	F-value	Pr(F)
South slope				
Null	146.92			
p1	136.30	Null vs. p1	6.26	0.0146*
p2	120.46	p1 vs. p2	10.40	0.0019**
s3	95.24	p2 vs. s3	20.61	< 0.0001***
s4	88.86	s3 vs. s4	5.41	0.0232*
s5	84.95	s4 vs. s5	3.35	0.0714
s6	80.93	s5 vs. s6	3.53	0.0642
North slope				
Null	192.54			
p1	187.55	Null vs. p1	2.06	0.1554
p2	174.56	Null vs. p2	5.81	0.0184*
s3	167.34	p2 vs. s3	3.33	0.0723
s4	161.27	p2 vs. s4	3.10	0.0514
s5	155.12	p2 vs. s5	3.06	0.0337*
s6	149.08	s5 vs. s6	2.88	0.0936

The models used here refer to GLM with first- and second-order polynomial (p1 and p2, respectively) and GAM (with cubic smooth spline) with three to six degrees of freedom (s3 to s6). The Test column indicates which models were tested against each other and the *F*-value and *P*-value are associated with the test described in the Test column. The statistically best model is in bold. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 3. A comparison of species richness of each life-form between the south slope and the north slope of Taibai Mountain, n=72, df=71.

Plant life-forms	Species richness of different life form (mean \pm SD)		<i>t</i> -value	<i>P</i> -value
	South slope	North slope		
Phanerophytes	11.90 \pm 6.83	12.96 \pm 6.95	-1.66	0.1014
Camaephytes	1.53 \pm 1.17	1.04 \pm 1.04	2.88	0.0053**
Hemicryptophytes	4.96 \pm 2.70	3.92 \pm 2.95	2.59	0.0116*
Geophytes	9.87 \pm 3.89	8.40 \pm 4.18	3.24	0.0018**
Therophytes	0.94 \pm 1.17	0.69 \pm 1.00	1.83	0.0716

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

by geophytes with 134 species (33.3%). Hemicryptophytes were represented by 84 species (20.9%). Camaephytes and therophytes with 22 and 18 species were the rarest life-forms (5.5 and 4.5%, respectively). The percentage composition of different life-forms on the north slope had a similar characteristic with the south slope. Five life-forms phanerophytes, geophytes, hemicryptophytes, camaephytes and therophytes were represented by 149 (40.8%), 113 (31.0%), 72 (19.7%), 17 (4.7%) and 14 (3.8%) species, respectively. Paired *t*-tests determined the species richness of camaephytes, hemicryptophytes and geophytes on the south slope were significantly higher than on the north slope, but no significant differences for phanerophytes and therophytes (Table 3).

The species richness distributions of different life-forms along the elevation gradients on both slopes are presented in Figure 5. A statistically significant second-order polynomial relationship between species richness of different life-forms and elevation was found in three of the five life-forms on the south slope (phanerophytes, hemicryptophytes and therophytes), and the same relationship was also found on the north slope except for camaephytes (Table 4). Of them, the species richness of phanerophytes monotonously decreased with increasing elevation (Figure 5f), and that of geophytes monotonously increased with increasing elevation (Figure 5i) on the north slope, and that of phanerophytes and hemicryptophytes on the south slope and hemicryptophytes on the north slope presented hump-shaped relationships

Table 4. Summary statistics of the regressions with species richness of each life-form as response and elevation as predictor variables.

Plant life-forms	Null Dev	GLM model	GLM Res. Dev	GAM model	GAM Res. Dev.
South slope					
Phanerophytes	356.48	2 ($F = 101.41, P < 0.0001$)	70.88	5 ($F = 4.02, P = 0.0498$)	58.38
Camaephytes	80.13	1 ($F = 5.32, P = 0.0239$)	75.51	NS	-
Hemicryptophytes	108.90	2 ($F = 24.02, P < 0.0001$)	83.27	3 ($F = 5.13, P = 0.0275$)	78.29
Geophytes	131.51	1 ($F = 51.7, P < 0.0001$)	77.94	4 ($F = 4.44, P = 0.0391$)	60.90
Therophytes	119.38	2 ($F = 9.58, P = 0.0028$)	85.14	5 ($F = 4.22, P = 0.0440$)	68.38
North slope					
Phanerophytes	304.07	2 ($F = 45.39, P < 0.0001$)	75.81	6 ($F = 4.2, P = 0.0444$)	47.90
Camaephytes	87.84	1 ($F = 25.75, P < 0.0001$)	67.61	5 ($F = 4.37, P = 0.0407$)	55.87
Hemicryptophytes	182.03	2 ($F = 5.08, P = 0.0272$)	155.09	NS	-
Geophytes	163.85	2 ($F = 4.16, P = 0.0452$)	110.06	NS	-
Therophytes	108.66	2 ($F = 4.76, P = 0.0324$)	81.58	3 ($F = 5.88, P = 0.0199$)	75.19

The GLM and GAM model columns respectively indicate the statistically best model using their respectively given degrees of freedom. For the GLM models the F -value and P -value of each model in parentheses refer to a test against null model and for the GAM models the F -value and P -value refer to a test against the given GLM model. Dev = Deviance, Res. Dev = Residual Deviance, NS = not significant ($P > 0.05$).

with elevations, while that of therophytes showed reverse-hump-shaped relationships with elevations on both slopes. The species richness of chamaephytes and geophytes on the south slope showed significant linear relationships with elevations (Table 4 and Figure 5b, d), and so did chamaephytes on the north slope (Table 4 and Figure 5g).

The GAM models significantly improved all the fit over the GLM models barring chamaephytes on the south slope and hemicryptophytes and geophytes on the north slope (Table 4). For phanerophytes, the GAM models indicated a more steep hump between c. 1350 and c. 2950 m a.s.l. on the south slope (Figure 5a) and a small hump between c. 2050 and c. 3150 m a.s.l. on the north slope (Figure 5f). For geophytes on the south slope and chamaephytes on the north slope, the GAM models detected intricate curve relationships in species richness with elevations rather than the linear relationships indicated by GLM models (Figure 5d, g). The hump on the south slope (Figure 5c) and the reverse-hump on the north slope (Figure 5j) depicted by the GAM models for hemicryptophytes and therophytes became more gentle than described by the GLM models. A small hump between c. 1350 and c. 2750 m a.s.l. for therophytes on the south slope was captured by the GAM model but not by the GLM model (Figure 5e).

DISCUSSION

Plant community types and species composition

Our research indicated that respective eight plant communities were clearly identifiable on the south slope and the north slope of Taibai Mountain along elevational

gradients (Figure 3). Between the two slopes some differences were found among the community types and the elevation ranges of the same community. On the north slope, two communities occupy the elevation range of c. 1350-1850 m a.s.l. (that is, *P. tabulaeformis* community, c. 1350-1450 m a.s.l. and *Q. aliena* var. *acutiserrata* community, c. 1450-1850 m a.s.l.), while on the south slope, corresponding to this elevation range, only one community occurs (that is, *Q. aliena* var. *acutiserrata* community). *Q. spinosa* community dominates the elevation of c. 1950-2150 m a.s.l. on the south slope, while at the similar elevation of c. 1950-2250 m a.s.l. on the north slope, *Q. wutaishanica* community is dominant. The elevation range of occurrence of *B. albo-sinensis* community is c. 2250-2650 m a.s.l. on the south slope, while it is c. 2450-2750 m a.s.l. on the north slope. It is worth noting that the *A. caesium* subsp. *giraldii* community occurs in the elevation of c. 2350-2550 m a.s.l. on the north slope which has a large overlap with *B. albo-sinensis* community. The *A. fargesii*-*B. utilis* community occurring from c. 2550 m to 3150 m a.s.l. on the south slope is identified two separate communities (that is *B. utilis* community, c. 2650-2750 m a.s.l. and *A. fargesii* community, c. 2850-3150 m a.s.l.) by the hierarchical clustering analyses on the north slope (Figure 3). *L. chinensis* community occurs lower elevation range on the south slope (c. 2850-3250 m a.s.l.) than on the north slope (c. 3150-3350 m a.s.l.). The *R. capitatum* community (c. 3350-3550 m a.s.l.) and the *C. capilliformis* var. *major* community (above 3351 m a.s.l.) occurring on the south slope correspond to the *R. capitatum*-*S. cupularis* community on the north slope (above 3350 m a.s.l.). Of these communities, the *P. tabulaeformis*, *Q. aliena* var. *acutiserrata*, *B. albo-sinensis*, *B. utilis*, *A. fargesii*, *B. utilis*-*A. fargesii*, *L. chinensis* and *R. capitatum*

communities have been reported by previous dispersed studies (Wang, 1989; Wang et al., 1990; Liu and Ling, 1995; Fu and Guo, 1997; Lin et al., 2008, 2009), but the *Q. spinosa*, *A. caesium* subsp. *giraldii* and *C. capilliformis* var. *major* communities have not been reported. These findings indubitably are useful complements to the vegetation integrity of the area. Overall, the elevation ranges occupied by different plant communities have more overlaps at middle elevations (c. 2250-3350 m a.s.l.) than at two extremes on both slopes, which may suggest the existence of transitional belts among different plant communities located at the middle elevations. Similar results and observations have been reported by previous studies in other areas (Brooks and Mandil, 1983; Ghazanfar, 1991; Hegazy et al., 1998).

The species composition demonstrates great variations among different communities and even between the same sort of community on the south slope and on the north slope (Table 1). For example, the *B. albo-sinensis* communities on the two slopes only share 48 of 216 species (the total number of species occurred in the *B. albo-sinensis* communities on both slopes), which results in a low Sørensen similarity index (0.36) (Sørensen, 1948). Especially, of the important species (that is, species with a high relative cover or a common distribution) consisting of the *B. albo-sinensis* communities on both slopes, only *B. albo-sinensis* and *P. purdomii* are in common. Other communities such as *Q. aliena* var. *acutiserrata* and *L. chinensis* community show the similar features with the *B. albo-sinensis* community (Sørensen similarity indexes (Sørensen, 1948) of the two communities on the two slopes are both 0.42). These results are in agreement with previous studies in this area and other areas (Chen and Peng, 1994; Fu and Guo, 1994; Zhao et al., 2003). A variety of environmental factors, such as temperature, precipitation, soil properties and topography, have important effects on the distribution patterns of plant communities and species composition along elevational gradients which have been confirmed by many previous studies (Wang et al., 2002; Bornman et al., 2008; Brinkmann et al., 2009). Then some obvious environmental factors (human disturbances, soil, topography and temperature, etc.) observed in the fieldwork in this area may exist potentially important effects on the present results although we did not quantify them to perform an analysis. For example, the heavy human disturbances (that is. historical cutting of a large amount of vegetation due to the requirements of firewood, architectural and commercial materials) to the area below c. 1450 m a.s.l. on the south slope may result in establishments of secondary or artificial *P. tabulaeformis* community. A variety of Oak communities occurring at an elevation of c.1450-2150 m a.s.l. on the south slope and an elevation of c.1250-2250 m a.s.l. on the north slope probably relate to relative high temperature, gentle slopes and deep soil. The vegetation above c.2250 m a.s.l. may be more influenced by temperature and geomorphy.

Compared with *A. fargesii* community, the occurrence of *B. utilis* community always associates with higher stone cover of surface. The *L. chinensis* community and alpine shrub, shrub-grass and meadow are distributed on the quaternary glacial relic that is characterized by low temperature, strong wind, high solar radiation and shallow soil.

Species richness

The second-order polynomial models in GLM indicate significant hump-shaped relationships between the species richness and elevations with the peaks at the middle or near middle elevations on both slopes. However, the GAM models reinforce the peak values and significantly improved the goodness-of-fit that more truly reflect elevational species richness patterns (Figure 5 and Table 2). These results are in accordance with many previous studies (Grytnes and Vetaas, 2002; Nogués-Bravo et al., 2008). To explain species richness patterns along elevational gradients, many hypotheses have been proposed (reviewed by Brown, 2001; Lomolino, 2001), of which, the mass effect (or source-sink dynamics) is proved an effective scenario by numerous studies (Grytnes and Vetaas, 2002; Grytnes, 2003a). The mass effect probably creates a peak in species richness at the middle elevations because of the presence of hard boundaries (that is, dispersal barriers) which can result in more sink populations at the middle elevations due to the bidirectional receptions for sink populations from sources both above and below, however, only an unidirectional reception happens for the area locates at the highest or lowest gradient (Rahbek, 1997; Grytnes and Vetaas, 2002; Grytnes, 2003b). We have not made a direct test of the mass effect in the present study, however, we found numerous low-frequency species (here we conservatively consider a species is a low-frequency species when its plots of occurrence $\leq 10\%$ of total plots during a given elevational range) during a given elevational range which contribute most part of species richness, for example, on the north slope, low-frequency species contribute 132 of 215 species to the mid-elevational range of c. 2050-2950 m a.s.l. (with the highest species richness), and 105 of 164 species to the lower elevational range of c. 1250-1950 m a.s.l. and 51 of 113 species to the upper elevational range of c. 3050-3650 m a.s.l.. According to Grytnes et al. (2008), low-frequency species are more likely to belong to sink species, thus mass effect may play a potentially important role in the formation of the peaks in species richness at the middle or near middle elevations in the present study.

Grytnes's (2003a) study indicated that mass effect can cause peaks in species richness at the ecotones defined as forest-limit. In his study, five of seven transects demonstrated well the estimated maximum species richness above the forest-limit because the forest species

can survive in more open area while only a few alpine species are able to survive in shading conditions. However, we found that the peaks of species richness occurred far below forest-line, whereas relatively low species richness was presented around the forest-line, this probably because of the relative low canopy cover of *L. chinensis* community (56.5% on the south slope and 52.8% on the north slope) has less effect on several species which can grow well below and above the forest-line. Examples of such species include *C. capilliformis* var. *major*, *C. capilliformis*, *R. capitatum*, *A. variifolia*, *A. prattii* and *Polygonum viviparum*. This lack of increased species richness around forest-line ecotones has also been evidenced by Hofgaard (1997) and Odland and Birks (1999). These nonuniform conclusions may indicate the forest-line ecotones only play a partial role in shaping species richness pattern with elevation and they are probably strongly influenced by some environmental factors such as climate and land-use (Hofgaard, 1997; Kullman, 1998; Körner 2003). For example, Shrestha and Vetaas's (2009) study showed that species richness only has a small variation between the forest and open landscapes due to the grazing and browsing pressure in an arid trans-Himalayan landscape of Nepal.

Plant life-form

Different life-forms are regularly associated with special climate (Richkleeffs, 1973). Phanerophytes usually correspond to tropical climates; chamaephytes mainly relate to cold, dry climates; hemicryptophytes and geophytes mostly associate with cold, moist climates; and therophytes mainly associate with dry climates (Richkleeffs, 1973). These have been confirmed by many previous studies, for example, Wang et al. (2002) and da Costa et al. (2007) found that therophytes were the most dominant life-form in arid or semi-arid area. However, the present study area is basically a humid area (average annual precipitation 751.8 - 945.5 mm) and therefore, overall, chamaephytes and therophytes are the rarest life-forms, while phanerophytes, geophytes and hemicryptophytes are the most dominant life-forms. In detail, species richness of different life-forms exhibit various patterns along the elevational gradients (Figure 5), and these may implicate that elevational species richness patterns of different life-forms are determined by a variety of ecological factors or their combination (Lomolino, 2001; Brown, 2001). Due to the similar trends (Figures 4 and 5), phanerophytes and hemicryptophytes may play major roles in shaping elevational pattern of total species richness, while geophytes, chamaephytes and therophytes probably play opposite roles.

The plant-environment relationships are complex. The present study on the distribution patterns of vegetation, species richness and plant life-forms mainly relates to elevational gradients, however, elevation is a comprehensive reflection of multiple environmental factors. Many

previous studies on elevational patterns of vegetation, species richness and plant life-forms in other areas have been associated with temperature, rainfall, solar radiation, soil nutrient content, etc. and reach a lot of meaningful conclusions (Körner, 2003; Shrestha and Vetaas, 2009; Desalegn and Beierkuhnlein, 2010). Further study on the effects of these environmental factors on vegetation distribution, species richness and life-forms would improve understanding for the observed elevational patterns in the area.

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