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MULTIVARIATE ANALYSIS OF THE ENDANGERED MEDICINAL SPECIES *Cercidiphyllum Japonicum* COMMUNITIES IN THE SHENNONGJIA RESERVE, CENTRAL CHINA

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HIGHLIGHTS

TWINSPAN and PCA were very effective in the analysis of relationship between community and environment.

Eight *Cercidiphyllum japonicum* communities were identified in the Shennongjia Nature Reserve.

Elevation and slope were key environmental factors influencing community distribution.

Species diversity was quadratically and negatively correlated with elevation.

The effective management is needed for conservation of *C. japonicum* populations and communities.

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ABSTRACT

Conservation for endangered medicinal plant species is important and urgent. *Cercidiphyllum japonicum* is an endangered and nationally protected medicinal plant species. We use multivariate methods to study ecological relations of C. japonicum communities in the Shennongjia Nature Reserve, Central China. Fifty-eight 10 m x 20 m quadrats of *C. japonicum* communities were randomly set up along an altitudinal gradient. Data for species composition and environmental variables were measured and recorded for each quadrat. Two-way indicator species analysis (TWINSPAN) and canonical correspondence analysis (CCA) was used in analyses. Moreover, species diversity indices were used to analyze the relationships between species diversity and environmental variables. The results showed that there were eight types of *C. japonicum* communities. Each community had its own compositional, structural and environmental characteristics. Variation of *C. japonicum* communities was significantly correlated to elevation and slope. Community variations were also related to aspect and litter thickness. Elevation and slope were revealed as important factors that influence community distribution and diversity. Species diversity showed a quadratic and negative correlation with elevation. The importance values of *C. japonicum* also showed a quadratic and negative correlation with species diversity. For conservational purposes, species diversity should be maintained within a reasonable range.

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INTRODUCTION

Multivariate analysis methods have been used increasingly for ecological investigations since the 1950s. Ordination and classification are effective techniques for multivariate analyses of community structure in vegetation ecology (Zhang, 2011). The objective of ordination and classification is normally to generate hypotheses about the relationships between the composition of vegetation, community types and the environment or other factors which determine it (ter Braak and Smilauer, 2002). The results of ordination and classification might be used as a tool in, for example, conservation management of the studied vegetation (Hill, 1979). There were various ordination and classification methods available in plant ecology.

Many studies have demonstrated that the conservation of endangered species and their environments is becoming urgent (Luijten et al., 2000; Lindborg and Ehrlen, 2002; Reddy et al., 2013; Sproull et al., 2015). Estimates of current and future extinction rates suggest that we will lose double-digit percentages of the existing species on Earth in the new century (Pimm and Askins, 1995). Many plant species are already listed as endangered (Orians, 1993; World Conservation Monitoring Center, 1992). Widespread research on endangered plants, including their taxonomy, genetics, evolution, reproduction, and conservation management, has been performed. However, the conservation of endangered medicinal species remains insufficient (Reisner et al., 2013; Cullotta et al., 2015).

Cercidiphyllum japonicum Sieb. Et Zucc. (Cercidiphyllaceae) is a deciduous tree species and is an endangered and nationally protected medicinal species (Guan, 1979). Due to its high value for spices, medicine, and timber (Liu, 2009), it has been disturbed and damaged by human economic activities. *Cercidiphyllum japonicum* is mainly distributed in subtropical mountainous regions, e.g., Hubei, Sichuan, Hunan, and Guizhou provinces in China; the Shennongjia region is one of its distribution centers in China. *Cercidiphyllum japonicum* communities generally occur on both sides of valleys and mountain creeks. The maintenance of biological diversity is important for the conservation of *Cercidiphyllum japonicum* and its communities. Some studies on, e.g., *Cercidiphyllum japonicum* distribution range, breeding, medicinal chemistry, and seedling establishment in the natural community have been performed (Liu, 2009; Fu et al., 2012). However, relationships between *Cercidiphyllum japonicum* communities and environmental variables and species diversity have not been studied. In the present study, we use multivariate analysis methods to assess the variations in *Cercidiphyllum japonicum* communities with environmental gradients in the Shennongjia Reserve, identify the important environmental variable influencing plant communities, and test the hypothesis that the highest species diversity appears at medium elevations.

MATERIAL AND METHODS

Study area

The Shennongjia Nature Reserve is located at 109° 59'- 110° 58' E, 31° 15'-31° 57' N in the western part of Hubei Province, China (Figure 1). Its elevation varies from 500 m to 3,105.4 m; the mountaintops are higher than 1,500 m. This area is deeply affected by the southeast subtropical monsoon, characterized by abundant precipitation and a moderate mean temperature. The annual mean temperature decreases with altitude from approximately 13.8°C at 460 m to 7.4°C at 1,700 m. The mean monthly temperature is higher than 25°C in summer, while the mean monthly temperature is lower than -4°C in winter. Moreover, annual mean precipitation is 1,219.93 mm, increasing with elevation. Most rain falls from May to October (Zhang et al., 2015). The soil in the Shennongjia Nature Reserve also changes with altitude. The soil changes in the order of red-yellow soil, mountain yellow soil, mountain yellow-brown soil, mountain brown soil, mountain dark brown meadow soil and mountain gray-dark brown soil from the bottom to the summit (Zhang CM et al., 2005). The vegetation also changes with elevation: evergreen broad-leaved forest exists under 900 m, mixed evergreen and deciduous broadleaved forest exist between 900 and 1,500 m, deciduous broad-leaved forest are present between l,500 and 2,000 m, mixed conifer and deciduous broadleaved forest can be found between 2,000 and 2, 600 m, and subalpine conifer forest and subalpine shrubs and meadows exist above 2,600 m (Zhang et al., 2015).

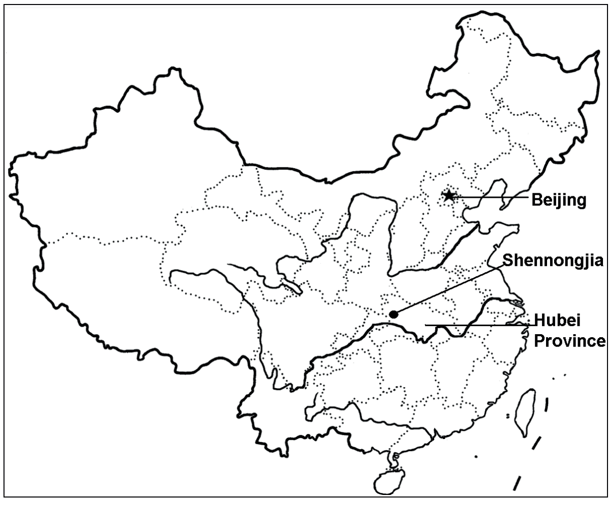

FIGURE 1 The geographical location of the Shennongjia Nature Reserve, Hubei Province, Central China.

Sampling design

Based on a general survey of *Cercidiphyllum japonicum* population and communities (Tree picture see Figure 2), fifty-eight 10 m × 20 m quadrats were set up along the altitudinal gradient between 1,350 - 2,050 m. Species name, cover, height, basal diameter and individual abundance for tree species and name, individual or tussock abundance, cover and height for shrubs and herbs were recorded in each quadrat (Zhang et al., 2013). Plant height was measured using a height-meter for trees and a ruler for shrubs and herbs. The basal diameter of trees was measured using a caliper; the diameters were used to calculate the basal area (Zhang et al., 2015). In total, 138 plant species were recorded in 58 quadrats.

FIGURE 2 The studied tree picture of *Cercidiphyllum japonicum* in the Shennongjia Nature Reserve, Hubei Province, Central China.

Elevation, slope, aspect and litter thickness for each plot was also recorded. The elevation of each plot was measured using a GPS, the slope and slope aspect was measured using a compass meter, and the litter thickness was directly measured with a ruler (Zhang et al., 2013). The elevation, slope and litter thickness were absolute values, while the aspect measurements were classified from 1 to 8 in the following manner: 1 (337.6°-360°, 0°-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 aspect and sunlight available is positively correlated (Zhang et al., 2015). Tree cover and herb cover were treated as biological variables related to structure, composition and distribution of *Cercidiphyllum japonicum* communities.

Data analysis

The importance value of each species was calculated and used as data in multivariate analysis of communities and species diversity. The importance value was calculated using the formula 1 and 2 (Zhang, 2011):

$$IV_{Tree} = (\text{Relative cover } + \text{Relative dominance } + \text{Relative height})/3 \quad [1]$$

$$IV_{Scrubsand\ Herbs} = (\text{Relative cover} + \text{Relative height})/2 \quad [2]$$

The dominance referred to species basal area. The species data included importance values of the 138 species in 58 quadrats. Environmental variables included elevation, slope, aspect, litter thickness, tree cover and herb cover in each quadrat.

Three species diversity indices, i.e., one for species richness, one for species heterogeneity, and one for species evenness, were used to calculate diversity values (Pielou, 1975; Zhang, 2011). These indices included: Species number (as a richness index), *D* = *S;* Shannon-Wiener heterogeneity index, (3) Pielou evenness index (4). The Spearman correlation and regression were used to analyze the relationships between species diversity and environmental variables.

$$H' = -\left(\sum P_i \ln P_i\right) \quad [3]$$

$$E1 = \frac{(H')}{(\ln(S))} \quad [4]$$

Multivariate methods

TWINSPAN classification

Here we use Two-Way Indicator Species Analysis (TWINSPAN) because it is a most common classification method in plant ecology and it provides useful and reasonable ecological results (ter Braak and Smilauer, 2002). TWINSPAN is a polythetic divisive technique (Hill, 1979). The data are first ordinated by correspondence analysis (CA). Then those species that characterize the correspondence analysis axis extremes are emphasized in order to polarize the quadrats. The procedure of TWINSPAN analysis is as follows.

Doing CA analysis and taking the first CA axis, the quadrats are divided into two groups by breaking the ordination axis at centroid *y,* where y_j is the ordination score for quadrat *j*, *N* is the number of quadrat.

$$\bar{y} = \sum_{(j=1)}^{N} \frac{(y_j)}{N} \quad [5]$$

The quadrats are divided into two groups, negative group A_1($y_j \leq \bar{y}$), and positive group A_2($y_j > \bar{y}$).

The quadrat division is refined by a reclassification using species which have maximum value in indicating the poles of the ordination axis. Calculating indicator values for species, where *D*(*i*) is the indicator value for species *i*, N_1 and N_2 refer to the numbers of quadrat in groups A_1 and A_2 respectively, $n_1(i)$ and $n_2(i)$ refer to the numbers of quadrat species *i* present in groups A_1 and A_2 respectively.

$$D(i) = \left| \frac{(n_1(i))}{(N_1)} - \frac{(n_2(i))}{(N_2)} \right| \quad [6]$$

$$i = 1, 2, \ldots \quad P \quad [7]$$

Selecting several species with maximum indicator values as indicator species, each of them is awarded -1 or 1 score (x_i) based on their dominance in group A_1 or A_2. Summarizing quadrat indicator score according to the presence of indicator species in each quadrat, where Z_j is the indicator score for quadrat *j*, X_i is indicator score for indicator species *i*, and *m* is the number of indicator species. The quadrats are divided into two groups by breaking indicator score gradient near its middle.

$$Z_j = \sum_{(i=1)}^{m} x_i \quad [8]$$

Comparing the two classifications and adjusting the misclassification in the indifference zone. The first division is finished.

The division process is then repeated on the two quadrat subsets to give four clusters, and so on, until each cluster has no more than a chosen minimum number of quadrat (Hill, 1979, Gauch, 1982). TWINSPAN calculation was performed using the WinTwins 2.3.

CCA ordination

There are many ordination methods. Here we use Canonical Correspondence Analysis (CCA) because it a most used and high-effective technique in the analysis of ecological relations between plant community and environmental variables. CCA is to relate the ordination axis to the environmental variables by multiple regressions of the quadrat score on the environmental variables, wheere y_j is ordination score for quadrat *j*, b_0 is the intercept and b_k is the regression coefficient for the environmental variable *k*, U_{kj} is the value of environmental variable *k* in quadrat *j* and *q* is the number of environmental variable. Note that the quadrat scores *z* are estimated from the species data first; the regression coefficients *b* are estimated next. The species data are thus related to the environmental variables via the ordination axis. The procedure of CCA is as follows (9).

$$y_j = b_0 + \sum_{(k=1)}^{q} b_k U_{(kj)} \quad [9]$$

Starting with arbitrary, but unequal, initial quadrat score y_j.

Calculating species score by weighted averaging of the quadrat score, where z_i is the score of species *i*, y_j is score of quadrat *j* given at the first step, X_{ij} is abundance value of species *i* in quadrat *j*, and *N* is the number of quadrat.

$$z_i = \frac{\left(\sum_{(j=1)}^{N} x_{(ij)} y_j\right)}{\left(\sum_{(j=1)}^{N} x_{(ij)}\right)} \quad [10]$$

Calculating new quadrat score by weighted averaging of the species score, where y'_j is calculated score of quadrat *j*, and *P* is the number of species.

$$y'_i = \frac{\left(\sum_{(i=1)}^{P} X_{(ij)} Z_j\right)}{\left(\sum_{(i=1)}^{P} x_{(ij)}\right)} \quad [11]$$

Obtaining regression coefficients by weighted multiple regressions of the quadrat score on the environmental variables. The weights are the quadrat totals.

Calculating new quadrat score by equation 9.

Centering and standardizing the quadrat score. This step is same as in correspondence analysis (CA) (ter Braak and Smilauer, 2002).

Stopping on convergence, i.e., when the new quadrat scores are sufficiently close to the quadrat score of the previous iteration, the calculation is stopped. The second axis can be extracted as in correspondence analysis by adding a step that makes the trial quadrat score uncorrelated with the first axis. Calculation of CCA analysis was performed by use of the CANOCO 4.5 (ter Braak and Smilauer, 2002) computer program.

RESULTS

TWINSPAN classification

TWINSPAN classified 58 quadrats into 8 groups, representing 8 *Cercidiphyllum japonicum* communities. The names and the main composition of the 8 communities are as follows: I. Comm. *Cercidiphyllum japonicum* + *Rhododendron auriculatum* – *Indocalamus longianritus* – *Trifolium pretense*. The total community cover was 85%; the tree, shrub and herb cover were 80%, 5% and 35%, respectively. The common species in the community were *Piospyros kaki*, *Cornus controversa*, *Juglans cathayensis*, and *Oxalis corniculata*. II. Comm. *Cercidiphyllum japonicum* + *Pterocarya insignis* – *Symplocos paniculata* – *Oxalis corniculata*. The total community cover was 83%; the tree, shrub and herb covers were 77%, 6% and 38%, respectively. The common species in the community were *Prunus vaniotii*, *Paris polyphylla*, *Trifolium pretense*, and *Carex tristachya*.

III. Comm. *Cercidiphyllum japonicum* + *Euptelea pleiospermum* – *Indocalamus longianritus* – *Cardamine leucantha* + *Carex tristachya*. The total community cover was 80%; the tree, shrub and herb covers were 75%, 8% and 30%, respectively. The common species in the community were *Prunus vaniotii*, *Fagus engleriana*, *Tetracentron sinense, Paris polyphylla,* and *Ophiopogon japonicus*. IV. Comm. *Cercidiphyllum japonicum* + *Tetracentron sineme* – *Indocalamus longianritus* – *Carex tristachya*. The total community cover was 85%; the tree, shrub and herb covers were 70%, 10% and 40%, respectively. The common species in the community were *Euptelea pleiospermum*, *Indocalamus longianritus*, *Paris polyphylla,* and *Chrysosplenium macrophyllum*.

The V. Comm. *Cercidiphyllum japonicum* + *Acer buergerianum* – *Machilus microcarpa* + *Aucuba chinensis* – *Cardamine leucantha*. The total community cover was 75%; the tree, shrub and herb covers were 70%, 8% and 40%, respectively. The common species in the community were *Zelkova Schneideriana*, *Quercus oxyodon*, *Prunus vaniotii*, *Indocalamus longianritus*, *Euonymus alatus*, *Lonicera pampaninil*, and *Ophiopogon japonicus*. VI. Comm. *Cercidiphyllum japonicum* – *Acer buergerianum* + *Lonicera pampaninil* – *Cardamine leucantha*. The total community cover was 70%; the tree, shrub and herb covers were 68%, 8% and 35%, respectively. The common species in the community were *Angelica pubescens*, *Prunus vaniotii*, *Indocalamus longianritus*, *Chrysosplenium macrophyllum,* and *Carex tristachya*. VII. Comm. *Cercidiphyllum japonicum* + *Cronus japonica* – *Lonicera pampaninil* – *Cardamine leucantha*. The total community cover was 70%; the tree, shrub and herb covers were 65%, 9% and 25%, respectively. The common species in the community were *Cornus controversa*, *Kerria japonica*, *Tetracentron sinense*, and *Cardiocrinum giganteum*. VIII. Comm. *Cercidiphyllum japonicum* + *Eupetlea pleiospermum* – *Lonicera pampaninil* – *Aconitum henryi* + *Angelica pubescens*. The total community cover was 70%; the tree, shrub and herb covers were 67%, 10% and 30%, respectively. The common species in the community were *Angelica pubescens*, *Betula luminifera*, *Lonicera pampaninil,* and *Cardamine leucantha*.

The change of communities along elevation gradient is clear. Environmental variables, such as elevation, slope, aspect and litter thickness, vary obviously among communities. The main environmental characteristics of the communities are listed in Table 1.

TABLE 1 The environmental characteristics of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve, Central China.

Communities	Elevation (m)	Slope (°)	Aspect	Litter thickness (cm)
I	1380-1570	20-45	S	5-10
II	1400-1670	20-40	S, NW	2.5-10
III	1650-1690	40-55	S	6.5-10
IV	1520-1839	45-550	N, SE	6-8
V	1410-1815	25-35	S, NE	7-15
VI	1540-1820	35-60	S	10-15
VII	1650-1870	50-60	S, NW	10
VIII	1950-2030	40-55	N, NE, SE	5-10

CCA ordination

The Monte Carlo permutation test in the CCA ordination indicated that the eigenvalues for the first canonical axis and for all canonical axes examined were significant ($P < 0.001$) (ter Braak, 1986). The eigenvalues for the first four axes were 0.324, 0.270, 0.225 and 0.117; species-environment correlations for the first four axes were 0.931, 0.856, 0.875 and 0.895. These indicated that the CCA analysis performed well in describing relationships between *Cercidiphyllum japonicum* communities and environmental variables (ter Braak and Smilauer, 2002; Zhang, 2011).

The canonical eigenvalues indicated separation along the measured environmental gradients. The distribution of *Cercidiphyllum japonicum* communities was significantly correlated with most environmental variables in the Shennongjia Reserve (Table 2, Figure 3). The first CCA axis was significantly correlated with

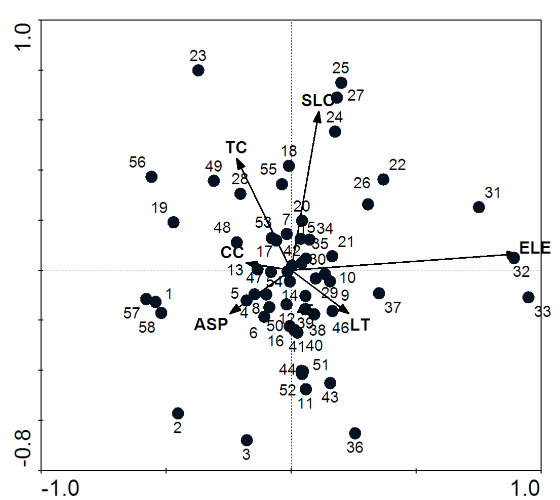

FIGURE 3 CCA ordination Bi-plot of the 58 quadrats and six environmental variables of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve, Central China. The numbers refer to the quadrat number.

TABLE 2 Inter-set correlation coefficients and canonical coefficients of environmental variables with CCA axes in *Cercidiphyllum japonicum* communities in the Shennongjia Reserve, Central China.

Environmental variables	Inter-set correlation coefficients				Canonical coefficients			
	Ax	Ax 2	Ax 3	Ax 4	Ax	Ax 2	Ax 3	Ax 4
Elevation	0.845***	0.055	-0.303*	0.187	0.955***	-0.067	-0.357**	0.158
Slope	0.104	0.543***	0.505***	0.213	0.116	0.784***	0.466***	0.138
Aspect	-0.228	-0.148	-0.072	0.033	0.013	-0.412***	-0.293*	0.017
Litter thickness	0.215	-0.149	0.526***	-0.035	0.239	-0.112	0.557***	-0.098
Herb cover	-0.167	0.024	-0.105	0.848***	-0.142	-0.609***	0.232	0.127
Tree cover	-0.202	0.382**	-0.464***	0.384**	-0.196	0.970***	-0.522***	-0.321*

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

elevation, the second CCA axis correlated with slope and tree cover, the third CCA axis correlated with litter thickness, slope and tree cover, and the fourth CCA axis correlated with herb cover (Table 2). The altitudinal gradient from left to right is very clear in Figure 3, increasing gradually along the gradient. The communities on the left, e.g., Comm. *Cercidiphyllum japonicum* + *Rhododendron auriculatum* — *Indocalamus longianritus* — *Trifolium pretense* and Comm. *Cercidiphyllum japonicum* + *Pterocarya insignis* — *Symplocos paniculata* — *Oxalis corniculata,* were typically distributed in the hills at low elevations. The communities on the right, e.g., Comm. *Cercidiphyllum japonicum* + *Eupetlea pleiospermum* — *Lonicera pampaninil* – *Aconitum henryi* + *Angelica pubescens,* were distributed in comparatively higher hills. Elevation and slope were important environmental variables for *Cercidiphyllum japonicum* communities. The canonical coefficients, which represent the regression coefficients between CCA axes and environmental variables produced in the CCA analysis, show similar relationships of environmental variables with vegetation and species (Table 2).

The environmental variables were somewhat correlated with each other (Table 3). Elevation was negatively correlated with aspect and litter thickness was positively correlated with aspect. Tree cover was significantly correlated with aspect and herb cover.

Species diversity

Spearman correlation and regression analyses show that species richness and heterogeneity were significantly correlated with elevation. However, the correlation of species evenness with elevation was not significant (Figure 4). Species diversity changed following a decreasing quadratic curve along the altitudinal gradient (Figure 4). The effects of slope, aspect and litter thickness on species diversity were not significant.

Importance value is a most important indicator of species abundance, roles and survival status. The importance value of endangered species *Cercidiphyllum japonicum* may reflect the results of its conservation. Its importance values were significantly correlated with species richness, heterogeneity and evenness. However, their relations were negative quadratics (Figure 5).

DISCUSSION

Variation of *Cercidiphyllum japonicum* communities was apparent in the Shennongjia Reserve. TWINSPAN successfully distinguished them as different vegetation communities. Eight communities were representatives of the general *Cercidiphyllum japonicum* communities in southern and southwestern China (Wu 1980). These communities were secondary vegetation, following destruction of the original subtropical broad-leaved

TABLE 3 Spearman correlation coefficients between environmental variables in *Cercidiphyllum japonicum* communities in the Shennongjia Reserve, Central China.

Environmental variables	Elevation	Slope	Aspect	Litter thickness	Herb cover	Tree cover
Elevation	1	-	-	-	-	-
Slope	-0.039	1	-	-	-	-
Aspect	-0.281*	0. 111	1	-	-	-
Litter thickness	-0.04	0.162	0.289*	1	-	-
Herb cover	0.076	0.097	0.142	0.016	1	-
Tree cover	0.090	-0.031	0.260*	-0.065	0.646***	1

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

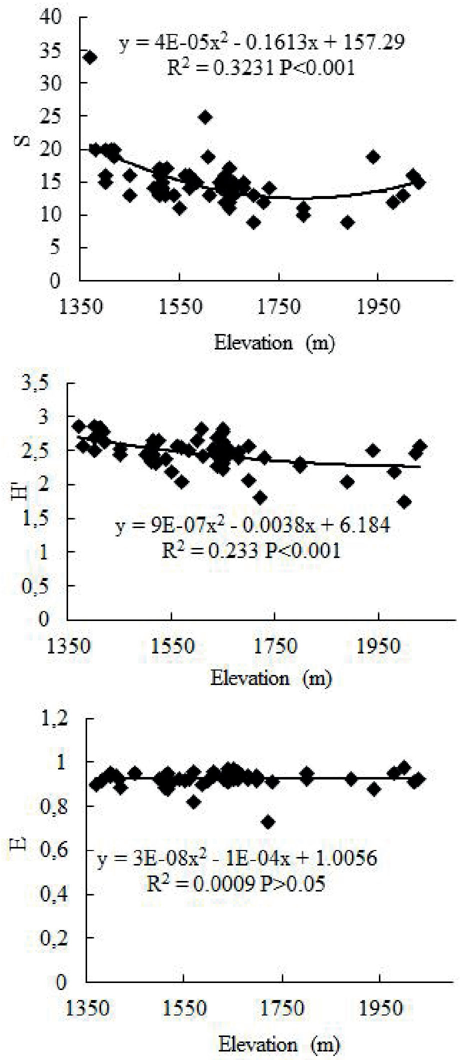

FIGURE 4 Variation of species richness, heterogeneity and evenness of *Cercidiphyllum japonicum* communities along an altitudinal gradient in the Shennongjia Reserve, Central China. S refers to species richness, H' to the Shannon-Wiener index, and E to species evenness.

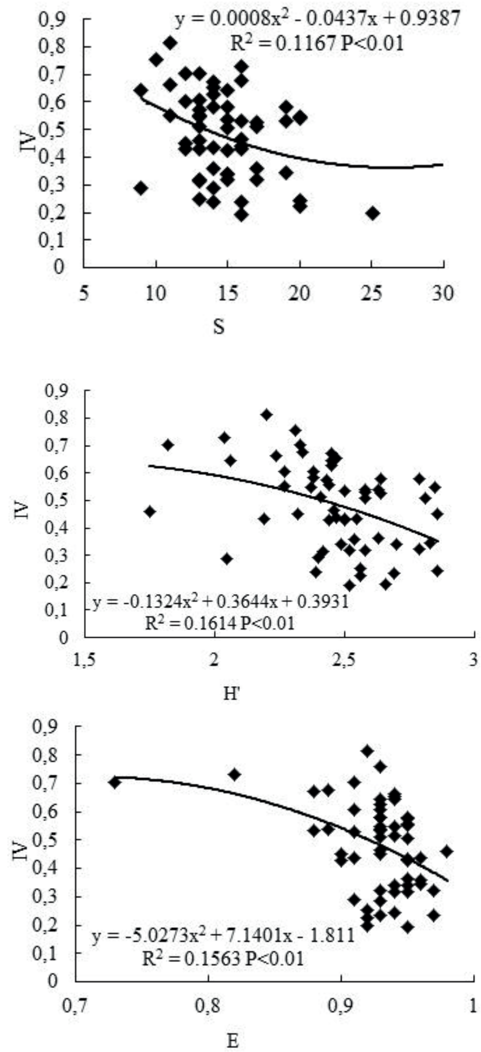

FIGURE 5 Regression analysis between importance values of *Cercidiphyllum japonicum* and species richness, heterogeneity and evenness in communities in the Shennongjia Reserve, Central China. IV refers to importance value, S to species richness, H' to the Shannon-Wiener index, and E to species evenness.

forests (Zhang et al., 2016). The present work is the first systematic and quantitative classification of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve. This is the basis for conservation of this endangered medicinal species and its communities (Reddy et al., 2013; Zhang and Shao, 2015). The structure and composition of the 8 communities were similar because they were all distributed on the sides near the bottom of mountain valleys or mountain creeks with similar environments (Reisner et al., 2013). The distribution of dominant species was determined for vegetation differentiation and distribution along environmental gradients (Ru and Zhang, 2012). This was also true for *Cercidiphyllum japonicum* communities in the Shennongjia Reserve. The distribution of dominant tree species, e.g., *Cercidiphyllum japonicum*, *Rhododendron auriculatum, Pterocarya insignis, Acer buergerianum Acer buergerianum, Euptelea pleiospermum, Tetracentron sineme,* and *Cronus japonica*, played important roles in the vegetation pattern of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve (Liu, 2009).

Plant community patterns are related to environmental factors that exhibit heterogeneity over space and time, e.g., climate, topography, soil, and human disturbances (Alexander and Millington, 2000; Zhang et al., 2013; Cullotta et al., 2015). Variation of *Cercidiphyllum japonicum* communities was closely related to elevation and slope in the Shennongjia Reserve. The aspect and litter thickness also showed some significant influences on plant communities because the environmental variables were correlated with each other in the studied communities (Meng et al., 2012). The change in *Cercidiphyllum japonicum* communities in CCA space clearly illustrated the relationships between plant communities and environmental variables (ter Braak and Smilauer, 2002). Each community had its own distribution area and was related to a special combination of environmental variables (Brinkmann et al., 2009; Sproull et al., 2015). The first CCA axis was primarily an altitudinal gradient, i.e., from left to right in the CCA ordination diagram; the elevation increased gradually. Elevation change leads to changes in, e.g., humidity, temperature, and soil type, which influence the community variations (Vittoz et al., 2010; Zhang et al., 2013). The second CCA axis was primarily a slope gradient, i.e., from bottom to top in the CCA diagram; the slope increased gradually. Elevation and slope are the important variables for *Cercidiphyllum japonicum* and its communities in the Shennongjia Reserve. Therefore, conservation of this species and its communities must consider these two factors (Reisner et al., 2013). In addition, tree cover was important for composition and structure of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve (Wu, 1980; Virtanen et al., 2010).

Species diversity was an important feature for community structure; its change was used as an indicator of community dynamics (Meng et al., 2012). Moreover, species diversity spatial variations were related to vegetation pattern characteristics in a region (Brinkmann et al., 2009). The spatial change in species richness, heterogeneity and evenness was clear in *Cercidiphyllum japonicum* communities in the Shennongjia Reserve. This change corresponded to the changes in, e.g., community structure, composition, and distribution, and related to environmental gradients (Zhang et al., 2005; Liu, 2009). Species richness and heterogeneity of *Cercidiphyllum japonicum* communities were significantly correlated with elevation. Species diversity decreased following a quadratic relationship with increased elevation. This further proved that elevation was an important variable affecting species diversity in communities (Muhumuza and Byarugaba, 2009).

The importance value of a species, including its relative cover, relative height and relative dominance (basal area), can reflect species growing status, position and likely roles in communities. Moreover, the importance value is an indicator of conservation effects for an endangered and protected species (Zhang et al. 2013; Reisner et al., 2013). The negative quadratic correlations of the importance value of *Cercidiphyllum japonicum* with species richness, heterogeneity and evenness show that communities with greater species diversity did not certainly benefit from the conservation of *Cercidiphyllum japonicum* and its communities (Lomolino, 2001; Zhang et al., 2013). Therefore, species diversity should be maintained in a reasonable extent for the conservation purpose of the studied species (Lomolino, 2001).

CONCLUSION AND SUGGESTIONS

The *Cercidiphyllum japonicum* communities in the present study had different vegetation types in the Shennongjia Reserve, mirroring the effects of key environmental variables, elevation and slope, on structure, composition and diversity. Aspect and litter thickness also had effects on community distribution and diversity. Conservation of populations and communities of *Cercidiphyllum japonicum* must protect these communities. A quadratic and negative correlation pattern of species diversity with elevation was revealed. For conservation of *C. japonicum*, species diversity in communities should be maintained within a reasonable range. To effectively manage the communities, the following measures should be considered: (1) *Cercidiphyllum japonicum* and its communities should be treated as the main targets for conservation in the Shennongjia Reserve. Felling for timber and collection for spices and medicines should be forbidden. (2) Traveling disturbance intensity must be controlled. The *Cercidiphyllum japonicum* communities were frequently disturbed because they appeared on the sides of the valley bottoms and mountain creeks, close to travel pathways. The tourist number should be controlled in summer. (3) *Cercidiphyllum japonicum* should be planted in suitable areas of 1,300 m to 2,400 m in the Shennongjia Reserve to promote the regeneration and development of *Cercidiphyllum japonicum* communities.

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REFERENCES

ALEXANDER. R.; MILLINGTON, A. **Vegetation Mapping: From Patch to Planet.** John Wiley and Sons, Chichester, 2000.

BRINKMANN, K.; PATZELT, A.; DICKHOEFER, U.; et al. Vegetation patterns and diversity along an altitudinal and a grazing gradient in the Jabal al Akhdar mountain range of northern Oman. **Journal of Arid Environments,** v.73, p. 1035-1045, 2009.

CULLOTTA, S.; PUZZOLO, V.; FRESTA, A. The southernmost beech (*Fagus sylvatica*) forests of Europe (Mount Etna, Italy): ecology, structural stand-type diversity and management implications. **Plant Biosystems**, v. 149, p. 88-89, 2015.

FU, L.G. **The red book of plants of China**. Science Press, Beijing. 1991.

FU, S.; HU, H.; ZHANG, Q. In vitro propagation of katsura tree (*Cercidiphyllum japonicum* Sieb. Et Zucc) an endangered plant in China. **African Journal of Biotechnology**, v.11, p. 14911-14919

GUAN, K.J. **Flora of China**. Vol. 27. Beijing, Sience Press, pp 22-24 (in Chinese), 2012.

HILL, M.O. **TWINSPAN-A Fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and atributes.** Ithaca: Cornell University, 1979.

LINDBORG, R.; EHRLEN, J. Evaluating the extinction risk of a perennial herb: demographic data versus historical records. **Conservation Biology**, v.16, p. 683-690, 2002.

LIU, M. Research development of endangered species, *Cercidiphyllum japonicum*. **Sichuan Forestry Design**, v. 3, p.18-22, 2009.

LOMOLINO, M.V. Elevation gradients of species diversity: historical and prospective views. **Global Ecology and Biogeography**, v.10, p. 3-13, 2001.

LUIJTEN, S.H.; DIERICK, A.; OOSTERMEIJER, B.; RAIJMANN, L.E.L. AND DEN NIJS, H.C.M. Population size, genetic variation, and reproductive success in a rapidly decling, self-incompatible perennial (*Arnica Montana*) in the Netherlands. **Conservation Biology**, v.14, p.1776-1787, 2000.

MENG, D.P.; ZHANG, J.-T.; LI, M. Diversity of woodland communities and plant species along an altitudinal gradient in the Guancen Mountains, China. **The Scientific World Journal**, V. 2012, Article, 2012.

ORIANS, G.H. Endangered at what level? **Ecological Application**, v.3, p.206-208, 1993.

PIELOU, E. C. **Ecological diversity**. London: Wiley, 1975. 165 p.

PIMM, S.L.; ASKINS, R.A. Forest loss predict bird extinction in eastern North America. **Proceedings National Academy of Sciences U.S.A**, v.92, p. 9343-9347, 1995.

REDDY, C.S; DEBNATH, B.; KRISHNA, P.H.; JHA, C.S. Landscape level assessment of critically endangered vegetation of Lakshadweep islands using geo-spatial techniques. **Journal of Earth System Science**, v. 122, p. 271-281, 2013.

REISNER, M.D.; GRACE, J.B.; PYKE, D.A.; DOESCHER, P.S. Conditions favouring *Bromus tectorum* dominance of endangered sagebrush steppe ecosystems. **Journal of Applied Ecology**, v.50, p.1039-1049, 2013.

RU, W.; ZHANG, J.-T. Ecological study of forests dominated by endangered species, *Taxus chinensis* var. *mairei*, in Shanxi of China. **Applied Ecology and Environmental Research**, v.10, n. 4, p. 457-470, 2012.

SPROULL, G.J.; QUIGLEY, M.F.; SHER, A.; GONZALEZ, E. Long-term changes in composition, diversity and distribution patterns in four herbaceous plant communities along an elevational gradient. **Journal of Vegetation Science**, v.26, p.552-563, 2015.

TER BRAAK, C.J.F. Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis, **Ecology,** v. 67, p.1167-1179,1986.

TER BRAAK, C.J.F.; ŠMILAUER, P. CANOCO **Reference Manual and User's Guide to Canoco for Windows.** Software for Canonical Community Ordination (version 4.5). Centre for Biometry Wageningen (Wageningen, NL) and Microcomputer Power (Ithaca NY, USA), 352 pp. 2002.

VIRTANEN, R.; LUOTO, M.; RAMA, T.; et al. Recent vegetation changes at the high-latitude tree line ecotone are controlled by geomorphological disturbance, productivity and diversity. **Global Ecology and Biogeography**, v. 19, : 810-821**,** 2010.

VITTOZ, P.; BAYFIELD, N.; BROOKER, R.; et al. Reproducibility of species lists, visual cover estimates and frequency methods for recording high-mountain vegetation. **Journal of Vegetation Science**, v. 21, p.1035-1047**,** 2010.

WORLD CONSERVATION MONITORING CENTER. **Global biodiversity**. Chapman & Hall, London.

WU, Z.Y. (ed) 1980. **Vegetation of China**. Science Press, Beijing, 1992.

ZHANG, C.M. CHEN, W.L.; TIAN, Z.Q.; XIE, Z.Q. Altitudinal pattern of plant species diversity in Shennongjia Mountains, central China. **Journal of Integrative Plant Biology**, v. 47, p.1431-1449, 2005.

ZHANG, J.-T.; MENG, D.P. AND RU, W.M. The ecological characteristics of the endangered species *Paeonia suffruticosa* var. *spontanea* in China. **Natural Areas Journal**, v.27, p.145-154, 2007.

ZHANG, J.T. **Quantitative ecology** (2nd edition), Beijing: Science Press. (In Chinese), 2011.

ZHANG, J.-T.; XU, B.; LI, M. Vegetation patterns and species diversity along elevational and disturbance gradients in the Baihua Mountain Reserve, Beijing, China. **Mountain Research and Development**, v..33, n.2, 170-178, 2013.

ZHANG, M.; XIE, Z. Q.; XIONG, G. M.; ZHANG, J.-T. Variation of soil nutrition in a *Fagus engleriana* Seem.-*Cyclobalanopsis oxyodon* Oerst. community over a small scale in the Shennongjia Area, China. **Journal of Integrative Plant Biology**, v.48, n.7, p. 767-777, 2006.

ZHANG, J.-T.; ZHANG, B.; QIAN, Z.Y. Functional diversity of *Cercidiphyllum japonicum* communities in the Shennongjia Reserve, central China. **Journal of Forestry Research**, v.26, n.1, p. 171–177, 2015.

ZHANG, J.-T.; SHAO, D. Attributes of forest diversity in the Yunmeng Mountain National Forest Park in Beijing, China. **Applied Ecology and Environmental Research**, v.13, n.3, p. 769-782, 2015.

ZHANG, J.T.; ZHANG, M.; MIAN, R. Effects of elevation and disturbance gradients on forest diversity in the Wulingshan Nature Reserve, North China. **Environmental Earth Science**, v.75, n. 10, p. 904, 2016.