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EFFECTS OF ENVIRONMENTAL FACTORS ON SPECIES DIVERSITY AMONG THE PLANT COMMUNITIES IN THE MOUNT LAO NATURE RESERVE, SHANDONG PROVINCE OF CHINA

WEI LI[1], JINMING YANG[1], HAIFANG LI[1] AND CUIPING ZHANG[1]*

[1]*Qingdao Agricultural University, Qingdao, Shandong 266109, P.R. China*
[*]*Corresponding author's email: zcp116@126.com*

Abstract

As species diversity plays a key role in ecosystem stability and vegetation restoration, this study investigated the relationship between soil properties and species diversity in the Lao Nature Reserve, Shandong Province of China, which has remained poorly understood to date. Forty vegetation sites (30 m × 30 m) were examined in the Lao Nature Reserve. Soil moisture, soil organic matter, total nitrogen, soil available potassium, soil available phosphorus, pH, and plant communities were accessed for each site. Two-way indicator species analysis (TWINSPAN) and canonical correspondence analysis (CCA) were used to depict the relationship among the plant communities and soil properties. Species accumulation curves indicated that samples from these 40 permanent sites were statistically sufficient for analyzing the species composition. TWINSPAN analysis showed that the forest communities could be classified into nine types. A negative relationship was detected between the plant diversity, the soil water content, and pH. The species diversity index for these communities were differentially affected by soil factors. CCA results indicated the influences of site factors on the distribution and composition of plant communities. Our study provides the theoretical basis for the management and protection of the Nature Reserve in the future.

Key words: Species diversity; Plant community; Soil properties; Mount Lao Nature Reserve.

Introduction

Species diversity is the simplest and most effective way to describe plant community (Molina *et al*., 2015; Rosenzweig, 1995; Chongbang *et al*., 2018). It plays a key role in ecosystem stability and vegetation restoration. Plant species' diversity is closely related to soil properties, geographical conditions, land cover, micro-landforms, and meteorological environments. An in-depth study of species diversity can be beneficial not only to learn about richness and the degrees of variations or evenness of species in a habitat but also to understand the relationship between different geographical conditions and biological communities (Zhang, 2000; Iturrate *et al*., 2016). The soil is indispensable for the occurrence and development of the plant communities, whereas these plants, in turn, are capable of affecting the soil's properties and fertility. Studying the relationship between soil features and the composition diversity of the plant communities has always been one of the hot topics in ecology research (Xiao *et al*., 2008). To reveal the interrelationships among biodiversity and soil factors, studying how the characteristics of plant community biodiversity vary with soil factors would be essential. At present, many studies have been carried out focusing on the relationship between soil properties and plant community diversity. Yang studied the effects of soil characteristics on biodiversity in the lower basin of the Tarim River and indicated that plant communities showed a change from mixed-species communities to single-species community corresponding to the changes of plant species diversity indices. Moreover, the organic matter, nitrogen, phosphorus, potassium, and other changes in the soil have a particular impact on plant species diversity (Yang *et al*., 2008). Wang used stepwise regression to study the relationships between plant species' diversity and soil environmental factors in the Bird Island area of Qinghai Lake. The results showed that there were some differences in the influence of soil factors on the plant community species diversity in different regions (Wang *et al*., 2007). Sahu has quantitatively analyzed the tree species diversity concerning the soil nutrient status in three sites of the sacred forest ecosystem along the Niyamgiri Hillrange, Eastern Ghats, and India, and found that species' diversity was positively correlated with organic carbon and phosphorus and negatively with nitrogen, electrical conductivity, and pH and the soil nutrient status of the three forest types was related to tree species diversity (Sahu *et al*., 2012). Other studies showed that the site factors, especially the altitudinal gradient that results in the gradient effects of various environmental factors, have an important influence on the distribution patterns and diversity of species (Sally, 1999). Therefore, it is of great importance to study the biodiversity patterns along the altitudinal gradient (Tang *et al*., 2012). In different research scales and different regions, plant diversity has different distribution patterns along the altitudinal slope (Rohde, 1992). Species' diversity in plant communities reaches the maximum at medium altitudes, but it was also believed that it is not related to an altitudinal gradient or even negatively correlated with elevation (Tang *et al*., 2012; Zhu *et al*., 2004; Lomolino, 2001; Abbas *et al.,* 2017). Long demonstrated that diversity asymptotically increases and positively correlates with increased soil fertility, and the total phosphorus value is predicted to be a vital soil factor that affects successional rate during tropical vegetation recovery processes (Long *et al*., 2012).

At present, many studies have been carried out at home and abroad around the relationship between soil traits and plant community diversity. Soil nutrients have impacts on community properties, such as vegetation cover, tree density, biomass, and species composition and competition (Girona *et al*., 2018). Some hypotheses suppose that habitat heterogeneity controlled species richness gradients through local and regional species turnover (Shmida *et al*., 1985; Ricklefs, 1985), and the rate of species replacement increased with soil fertility (Paoli *et al*., 2006) and decreased with successional age (Prach, 1993). However, before these findings and assumptions can be verified, more work needs to be conducted on the interaction of soil nutrients with vegetation development (Prach, 1993; Prach *et al*., 2007; Dybzinski *et al*., 2008).

The flora of the Lao Nature Reserve is typical of the representatives Jiaodong Peninsula of China. It is in a warm, temperate deciduous broad-leaved forest with plenty of plant species. The flora composition is somewhat complicated, and the forest coverage rate is above 90%. Among the endemic plants in Shandong Province, 28 species have been found in the Mount Lao Nature Reserve (Fan *et al*., 2003). Due to the uniqueness of plant species in the Mount Lao Nature Reserve, as well as the similarity of its vegetation in some extent to other regions in the Liaodong Peninsula, the Reserve has a prominent position and significance in the vegetation division not only in Shandong but also in China (Wang, 1984; Wang, 1994). To date, many studies on forest ecosystem in the Mount Lao Nature Reserve have been carried out, including flora investigation and distribution (Wang *et al*., 2001; Li *et al*., 2009; Huang *et al*., 2001) forest ecosystem service (Wang *et al*., 2012; Sun *et al*., 2006), Population characteristics and determination of biomass in the *Quercus Acutissima* forest community (Li, 1987), ornamental plants (Zhang *et al*., 2016) and rare and endangered species (Li *et al*., 2015). Zhang has reported that the altitudinal patterns of plant diversity in Mount Lao (Zhang *et al*., 2016). However, quantitatively studies on the classification of the forest community, ordination and its relationship with environmental factors have not been reported.

To quantitatively survey the relationship between species diversity and environmental factors at the Mount Lao Nature Reserve, we investigated comprehensively the species diversity of its vegetation and the relationship among vegetation distribution and environment, by using stepwise regression, two-way indicator species analysis (TWINSPAN), canonical correspondence analysis (CCA). We tested the following hypotheses: 1). The relationship between species diversity and altitude. 2) The relationship between species diversity and soil factors in the nature reserve on Mount Lao Nature Reserve. The ultimate aim of our findings will be helpful for to understand the spatial distribution pattern of forest community and the ecological adaptability of each species and provide evidence for forest management. Artificial tending and environmental protection, particularly at the elevation of about 300-600 m asl, are strongly recommended to increase species diversity in the future.

Materials and Methods

Study area: The Mount Lao Nature Reserve (latitude 36° 03’-36° 24’ N and longitude 120° 07’-120° 43’ E) is located near the coast of the Yellow Sea on the southern part of the Shandong Peninsula. The maximum distance between the north and the south is 40 km, whereas that between the east and the west is 46 km. The highest peak is known as “Laoding” up to 1132m above sea level. The Mount Lao Nature Reserve is a temperate monsoon continental climate, and the seasons changes and the monsoons’ advances and retreat are pronounced. Also, this area characteristically has abundant rainfall (annual average of 734.3 mm), moderate temperatures (average annual temperature of 11.9°C), and mild climate (on average frost-free for 179 days). The main body of the mountain consists of Mesozoic granite acidic rocks and eruptive basement rocks. The loosely structured soil is comprised of brown soil, alluvial soil, and salty soil, and is acidic or slightly acidic.

According to the structural, functional, and environmental characteristics of the ecosystem of the Mount Lao Nature Reserve, 40 plots (30 m × 30 m for each plot) of representative forest plant communities (Fig. 1) were selected in Jufeng, Taiqinggong, and Beijiushui. By utilizing a GPS system, the elevations, slope positions, aspects, and slopes of these plots were measured and recorded. In most parts of the Mount Lao Nature Reserve, the thickness of soil layer is not high. Therefore, we collected the soil samples from the top layers to determine the related parameters, such as the soil pH, the organic matter content, the total nitrogen content, available phosphorus and potassium, and soil water content (SWC). Besides the species, the abundance, the diameter at breast height (DBH), the height and the diameter of the crown of the trees with DBH ≥ 5cm were also recorded. Five 5 m × 5 m shrub areas were set up at the four corners, and the cross point of diagonal lines in each plot, and one 2 m × 2 m area in each shrub area was allocated as an herb area. These areas were used for recording the names, the abundance, the coverage, and the heights of shrubs and herbs.

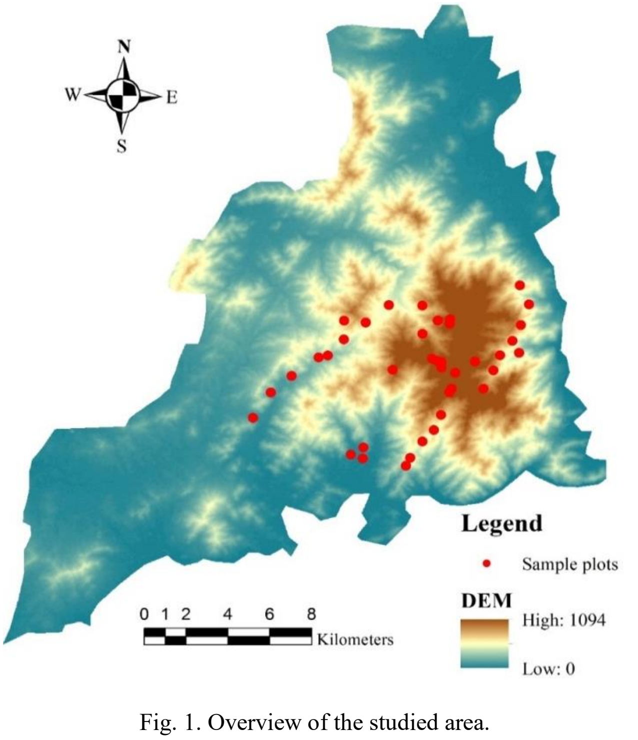

Fig. 1. Overview of the studied area.

Data analysis

Species accumulation curve: The species accumulation curve, which describes the cumulative number of species along an increased sample size, is a powerful tool for understanding species composition and predicting species richness in plots and is widely used in biodiversity and community surveys. It is also used to judge the adequacy of the sample size and estimate the species' richness (Li, 2011). Using a first-order folding knuckle index (Jackknife1), the desired species richness (Sp) was obtained as follows (Heltshe *et al*., 1983): Sp = So + f1 (N-1) / N. In this formula, the number of observed species, the number of species in each plot, and the number of plots are represented by So, f1, and N, respectively. Species accumulation rate analysis was performed on Sp samples, and the cumulative curve of species was 100 random cumulative results, which were completed by Estimates software (Oksanen *et al*., 2015).

Values of importance: For each plot, the importance of trees, shrubs, and herbs were calculated by using following formulas (Ma *et al.,* 1994):

Tree importance (%) = (relative density + relative dominance + relative height) / 3,
Shrubs and Herbs Important Value (%) = (Relative Coverage + Relative Height) / 2.

Species diversity: The formula for calculating the diversity index (Ma *et al.,* 1994) is as follows:

Species richness in the Patrick Index: R = number of species present in the plot:

$$\text{Shannon index: } H' = -\sum_{i=1}^{s} P_i \ln P_i$$

$$\text{Simpson index: } D = 1 - \sum_{i=1}^{s} P_i^2$$

$$\text{Pielou's index: } E = \frac{H'}{\ln S}$$

where: P_i is the importance of species i

The plots were classified by using TWINSPANand grouped into different community types, then the calculating and plotting of the diversity indices were finished by using Excel. The analysis of the correlation and regression among species' diversity index and soil factors, as well as the descriptive analysis of soil nutrients, were conducted by using Spss software. The ordinations on community distribution and soil factors were performed by using Canoco 5.0 and plotted with Cano-Draw (Ter *et al.,* 1998).

Results

Species accumulation curve: We used all plant species (trees, shrubs, and herbs) from the 40 sampling plots to create the species accumulation curve. As shown in Fig. 2, as the number of plots increased, the species accumulation curve rose sharply and then flattened, indicating adequate sampling for data analysis.

TWINSPAN quantitative classification: According to the classification and nomenclature of plant communities, the 40 plots were classified by TWINSPAN. The plant communities in this area can be divided into nine categories (Fig. 3).

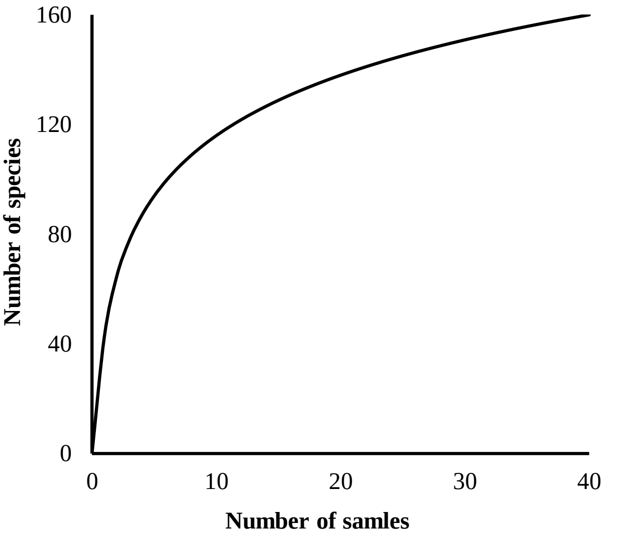

Fig. 2. Sample-based species accumulation curves.

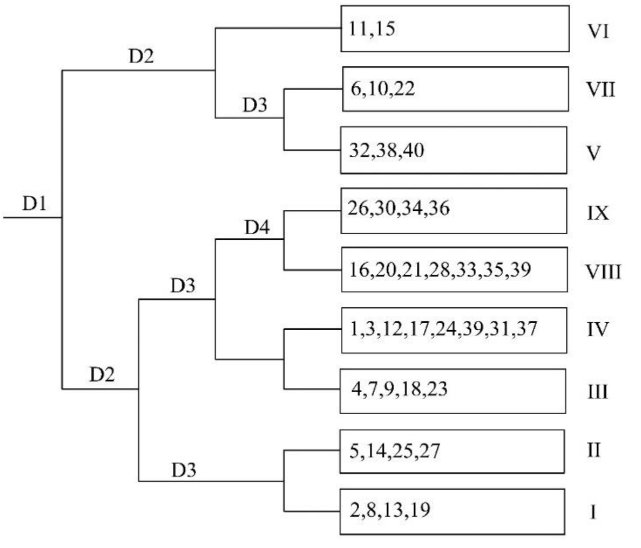

Fig. 3. Dendrogram of the TWINSPAN classification of 40 plots in the Mount Lao Nature Reserve.

Community I: *Pinus densiflora* + *R. pseudoacacia* - *Briar rose* + *Magnoliaceae* - *Mangliese* community (plots #2, #8, #13, and #19).

This community was mainly located on the shady and semi-shady hillsides with an elevation of 324-518 m asl. The dominant tree in this community was *P. densiflora*, and the primary accompanying species were *R. pseudoacacia*, *Alnus sibirica*, *Ailanthus altissima,* and *Castanea mollissima*. Among shrubs, the dominant species included *Rosa multiflora*, *Indigofera kirilowii*, *Lespedeza bicolor*, *Zanthoxylum simulans,* and *Sophora japonica*. *Miscanthus* *sinensis* was the dominant species among herbs in this community, and its primary accompanying species were *Spodopogon sibiricus*, *Kalimeris indica*, *Sanguisorba officinalis,* and *Thalictrum aquilegifolium*.

Community II: *P. thunbergii* + *Q. acutissima* - *Betula platyphylla* + *L. bicolor* + *Ulmus pungens* + *Potentilla anserine* community (plots #5, #14, #25 and #27).

This community was mainly located in the shady and semi-shady hillsides at 315-438 m asl. The dominant trees in the community were *P. thunbergii* and *Q. acutissima.* These species were accompanied by *Q. aliena* and *R. pseudoacacia*. The dominant shrubs were *Symplocos paniculata* and *L. bicolor*, whereas the major accompanying species were *Cerasus japonica*, *Sapium japonicum*, and *Spiraea fritschiana*. Regarding herbs, the dominant species were *U. pumila* and *P. chinensis*, accompanied by *Themeda japonica, Artemisia argyi, Hemistepta lyrata, and Spodiopogon sibiricus.*

Community III: *P. thunbergii* + *R. pseudoacacia* - *L. bicolor* + *C. japonica* - *Deyeuxia arundinacea* community (plots #4, #7, #9, #18 and #23).

The community was mainly located in the sunny and semi-sunny hillsides of 152-359 m. The dominant trees in this community were *P. thunbergii* and *R. pseudoacacia*, whereas the primary accompanying species were *A. cremastogyne*, *Styrax japonicus*, and *P. densiflora*. The dominant species in the shrub layer were *C. japonica* and *L. bicolor*, accompanied by *I. kirilowii*, *Pueraria lobata*, and *Smilax china*. The dominant species in the herb layer was *D. arundinacea*, and the primary accompanying species were *S. officinalis*, *Hemerocallis citrina* and *S. sibiricus*.

Community IV: *P. thunbergii*-*L. bicolor* +*C. japonica* -*T. aquilegifolium* +*Clematis heracleifolia* community (the plots #1, #3, #12, #17, #24, #29, #31 and #37).

The community was mainly located in the sunny and semi-sunny hillsides along 72-314 m asl. The dominant tree in this community was *P. thunbergii*, and the primary accompanying species were *A. cremastogyne* and *Sorbus alnifolia*. The dominant shrubs were *C. japonica* and *L. bicolor,* and the primary accompanying species were *Viburnum opulus, I. kirilowii,* and *Deutzia hamata.* The dominant herbs were *T. aquilegifolium* and *C. heracleifolia,* accompanied by *Pennisetum alopecuroides, H. citrina,* and *Saposhnikovia divaricata.*

Community V: *Larix kaempferi* - *L. bicolor* + *Lindera obtusiloba* - *Echinochloa crusgalli* + *M. sinensis* community (plots #16, #20, #21, #28, #33, #35 and #39).

This community was mainly located on the sunny and semi-sunny hillsides of 589-873 m asl. The species richness of this community in different areas was significantly different. The dominant species in the tree layer in was community are *L. kaempferi,* accompanied by *S. alnifolia, Q. acutissima,* and *Rhus chinensis.* The dominant species in the shrub layer were *L. obtusiloba* and *L. bicolor,* whereas the primary accompanying species were *Stephanandra incisa, S. china,* and *C. japonica.* The dominant species in the herb layer was *E. crusgalli,* and its primary accompanying species were *M. sinensis, Carex callitrichos,* and *Athyrium niponicum.*

Community VI: *L. kaempferi* + *S. incisa* + *L. obtusiloba* – *C. hexapetala* community (plots #26, #30, #34 and #36).

The community was mainly located on the semi-shady hillside of 682-975 m. The dominant tree species was *L. kaempferi,* primarily accompanied by *P. tabuliformis, S. alnifolia,* and *Diospyros lotus.* The dominant species in the shrub layers were *S. incisa* and *L. obtusiloba,* mainly accompanied by *Vitex negundo, I. kirilowii,* and *C. japonica*. The dominant species in the herb layer was *C. hexapetala*, and the primary accompanying species were *Panicum bisulcatum, Aster ageratoides, S. sibiricus,* and *S. officinalis.*

Community VII: *S. alnifolia* + *R. chinensis* - *S. incisa* + *S. fritschiana* - *Adiantum capillus-veneris* community (plots #32, #38, and #40).

The community was mainly located on the sunny hillsides of 583-1023 m asl. The dominant tree species was *S. alnifolia* mainly accompanied by *R. chinensis, S. japonicus,* and *Q. acutissima.* The dominant species in the shrub layers was *S. incisa* and the main accompanying species were *L. floribunda, S. fritschiana, S. china, and Euonymus oxyphyllus.* The dominant species in the herb layer was Adiantum capillus-veneris while the main accompanying species were *S. applanata*, *Gypsophila oldhamiana*, and *Rabdosia inflexa*.

Community VIII: *R. pseudoacacia* + *P. thunbergii* - *L. bicolor* + *I. kirilowii* – *H. citrina* + *C. callitrichos* community (plots #6, #10, #22).

The community was mainly located on the sunny and semi-sunny hillsides of 213-405 m asl. The dominant tree of this community was *R. pseudoacacia,* primarily accompanied by *P. thunbergii* and *Q. acutissima.* The dominant shrub species was *L. bicolor,* while the primary accompanying species were *Rubus crataegifolius, Albizia kalkora, Grewia biloba*, and *Q. acutissima.* The dominant species in the herb layer was *Paraixeris pinnatipartita*, while the primary accompanying species were *C. callitrichos*, *Commelina communis*, *Platycodon grandiflorus* and *Phytolacca acinosa*.

Community IX: *C. serrulata* – *S. japonicus* + *L. bicolor* - *C. callitrichos* community (plots #11 and #15).

The community was located on the sunny hillsides of 215-368 m asl. In this community, the dominant tree was *C. serrulata,* accompanied by *P. thunbergii, Diospyros lotus,* and *A. sibirica.* The dominant shrubs were *L. bicolor* and *S. japonicus,* while the primary accompanying species were *G. biloba, S. china,* and *C. japonica*. The dominant herb was *C. callitrichos*, and the primary accompanying species were *P. pinnatipartita, T. aquilegifolium,* and *Cleistogenes serotina*.

Relationship between the biodiversity of plant communities and soil properties

Biodiversity of plant communities: As shown in Figure 4, the curves of Shannon-Wiener index and Patrick richness index demonstrated almost the same changing trends. The highest index of species diversity (3.357) was observed in community II, which included four plots (#5, #14, #25, and #27). These plots, with less anthropogenic disturbance, showed a complex community structure with more vegetation ecotypes, more ecologically adaptive distributions, and relatively abundant species. Therefore the species diversity index was higher. Community VI, with the lowest species diversity index of 1.735, was composed of plots #26, #30, #34, and #36. The dominant species of this community was the Japanese larch (*L. kaempferi*). Its height and large canopy density, as well as the other adverse environmental factors (such as temperature, humidity, and light conditions), had adverse effects on other plants. Therefore the diversity index in this community was the lowest. In the plots below 300 m asl, the diversity index increased as the elevation rose, reaching the first peak at about 300m asl where the black pine (*P. thunbergii*) community dominated. After 300 m asl the diversity index slowly dropped, followed by another peak at the altitude of 600 m asl where the Japanese red pine (*P. densiflora*) and other trees dominate. At the elevation of ~940 m asl, the Japanese larch (*L. kaempferi*) became the most dominant species in the tree layer, even being the only arbor in some plots. In this community, since the temperature, humidity, and light conditions were not suitable for other lower plants, the diversity index was the lowest.

Correlation analysis between species diversity indices and soil factors: The correlation analysis of the six soil factors (Table 1) from nine communities showed that species diversity was more correlated to soil organic matter (SOM) content and total nitrogen (TN) content compared to other soil factors. SOM had a significantly negative correlation with the Simpson index (D) ($p<0.05$), whereas TN had a significant negative correlation with the Pielou evenness index (E) ($p<0.05$). The correlation coefficients were -0.743 and -0.836, respectively. However, the correlations between Patrick's richness index (R) or the Shannon-Wiener index (H) and soil factors were not significant.

According to Pearson's correlation coefficient analysis (Table 1), the relationship between species diversity indices and soil factors in the sample plot was different. As shown in Table 2, the stepwise regression analysis indicated that, among the Simpson indices (D), the content of SOM was the only one that entered the regression model with a significant correlation coefficient of 0.743 and a significant F test result ($p<0.05$). For the Pielou evenness index (E), TN was the only factor that entered the regression model, with a compound correlation coefficient 0.836 and a highly significant F test result ($p<0.01$). Besides, neither the Patrick index nor the Shannon index entered the regression model. Regression analysis and Pearson correlation coefficient analysis provided consistent results, suggesting that the species diversity indices of the communities were differentially affected by soil factors.

CCA sorting: A matrix of environmental data was set up based on the six soil factors and elevations, and the species data matrix was established based on species' importance values. Then, CCA sorting was performed to sort the plant communities in the Mount Lao Nature Reserve. The results are presented in Table 3 and Fig. 5. Results suggested that the first and second CCA axes were significantly correlated with the environmental factors, as indicated by the eigenvalues of 0.344 and 0.281, with the species-environment correlations of 90.6% and 84.3%, respectively. In addition, the cumulative percentage variance of the species-environment relationship reached 57.4% at maximum. Therefore, these results may reflect the spatial distribution of plant communities.

Based on the first two sorting axes, a two-dimensional ordination chart was made. In this chart, first, the quadrant with arrows represents the positive and negative correlations between the environmental factors and the ordination sorting axis. Second, the distances between the arrows indicate the extents of the relationships between the environmental factors and the community distribution. Finally, the angle between the arrow connections and the ordination axes suggests the degrees of the correlations between the environmental factor and the ordination axis; the smaller the angle, the better the correlation. According to the CCA sorting diagram (Fig. 5) and Table 3, the first order axis of CCA was extremely significantly and positively correlated with altitude, and negatively correlated with soil water content. The correlation coefficients were 0.807 and -0.597, respectively. When the altitude increased gradually from left to right, the soil water content decreased gradually from left to right. The second order axis of CCA was significantly negatively correlated with pH ($p<0.01$), and along the second axe from top to bottom, other factors were not correlated with the ordination axis. The distances between the arrows indicated that the available phosphorus, total organic matter, and total nitrogen had little effect on the distribution of the communities, while elevation, soil moisture, and soil pH had greater effects. These results suggested that the distribution of the existing plant communities in the Mount Lao Nature Reserve was mainly affected by water, temperature, and soil pH. The range in elevation was 951 m asl, and the maximum difference of annual average temperatures was about 5.4°C, which was primarily determined by elevations (Wang, 2001). Nine community types produced by TWINSPAN are also shown in the CCA figure (Fig. 5) and were well dispersed along the first axis. From left to right, they were communities II, Ⅲ, VIII, and V. The remaining three communities, I, IV and IX, were distributed along the second axis from top to bottom. Notably, there were overlaps among communities I, IX, and IX to some extent.

Table 1. Correlation coefficients of diversity indexes and soil factors.

Diversity index	pH	Organic matter	Soil available potassium	Soil available phosphorus	Soil water content	Total nitrogen
Patrick index	0.325	0.539	-0.113	0.325	-0.235	-0.483
Simpson index	-0.165	-0.743*	-0.176	-0.318	0.323	-0.078
Shannon index	0.386	0.485	-0.104	0.384	-0.042	-0.281
Pielou's index	0.405	-0.541	-0.483	0.157	0.259	-0.836*

NOTES: * $p<0.05$; The same as below

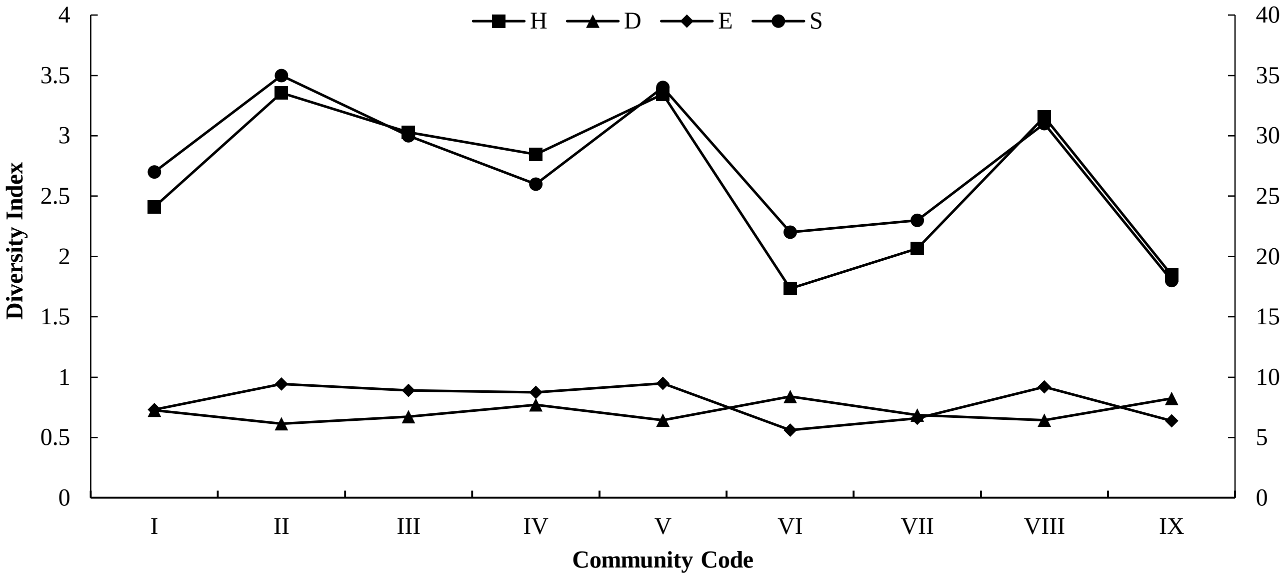

Fig. 4. Variation curve of species diversity of 10 communities in the Mount Lao Nature Reserve.

Table 2. Stepwise multiple regressions between species diversity index and soil factor in Lao Mountain.

Diversity index	Stepwise regress model	Multiple correlation	Integration F
Simpson index	D=0.384-0.027 SOM	0.743	7.475
Pielou's index	E=1.142-0.674 TN	0.836	15.103

Table 3. The first 4 CCA soil axes and their component coefficients.

Environment factor	Axis1	Axis2	Axis3	Axis4
Elevation, ELE	0.807***	0.250	-0.109	0.151
Soil water content, SWC	-0.597**	-0.332	-0.372	-0.248
Soil available potassium, SAK	0.350	0.284	-0.391	-0.045
Organic matter, OM	-0.231	0.315	-0.321	-0.515**
Total nitrogen, TN	-0.327	-0.153	-0.499*	0.088
Soil available phosphorus, SAP	-0.328	0.265	0.136	0.294
pH	-0.226	-0.773**	0.236	0.016
Summary of CCA ordination				
Eigenvalue	0.344	0.281	0.176	0.135
Species-environment correlations	0.906	0.843	0.798	0.749
Cumulative percentage variance of species-environment relation (%)	31.9	57.4	76.4	89.0
Significance test Test of significance of all canonical axes		P=0.017		

*p< 0.05, **p< 0.01, ***p< 0.001

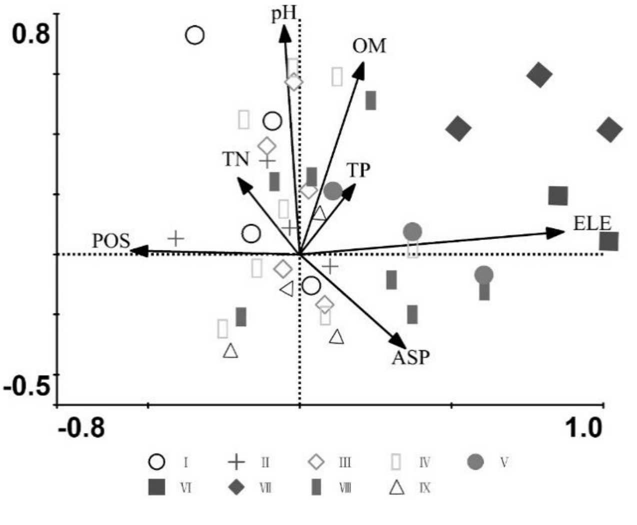

Fig. 5. CCA ordination diagram of 40 plots of forest community on Mountain Lao.

Discussion

Species diversity and its relationship with soil factors and elevation: By quantitative classification using TWINSPAN, the 40 plots of the forest community in the Mount Lao Nature Reserve were divided into nine communities, which included the Japanese red pine (*P. densiflora*), black pine (*P. thunbergii*), black locust (*R. pseudoacacia*), hill cherry (*C. serrulata*), and Japanese larch (*L. kaempferi*). As the main coniferous forest in the Jiaodong Peninsula and Mount Lao Nature Reserve, the black pine forest is distributed in the area of Mount Lao Nature Reserve from the foothills up to about 800 m asl above sea level, playing an important role in regulating the structure and function of the ecosystems. Therefore, the Japanese red pine is the primary type of forest community in the Mount Lao Nature Reserve. According to the characteristics of the shrub layer, the black pine forests were divided into three categories, including communities II, III, and IV. At the same time, there was one additional type of forest that was mixed with the black locust. In addition, Japanese larch and Japanese red pine were also widely distributed in the Mount Lao Nature Reserve, so black pines, Japanese larches, and red pines accounted for a certain proportion of forest community types.

In different research scales and different regions, the plant diversity has showed different distribution patterns along the altitudinal gradient. There are five common patterns, by which the diversity of plants behaves, with increasing altitude, 1) decreasing followed by increasing, 2) increasing followed by decreasing, 3) kept increasing, 4) kept decreasing, and 5) did not change apparently (Sahu, 2012). The species diversity of the Mount Lao Nature Reserve fluctuated along with the altitude gradientinal. At about 300 m asl, many species and a high variety of herbaceous plants were recorded due to the small trees and low canopy density, providing better light conditions for herbaceous species. Therefore, the first peak in plant diversity appeared there. At the elevation of about 600 m asl, the composition of the plant communities became more complicated. In this region, the most common trees were the black locust, Japanese red pine, arborvitae, and Korean mountain ash. In addition, there were Japanese snowbell, sawtooth oak, shrubby sophora, Chinese sumac, and Mongolian oak, as well as Japanese larch. Therefore, there were a lot of mixed forests in this area. But due to anthropogenic disturbances, the other trees were unable to dominate. In addition, the effects of temperature, humidity, and light conditionsled to a significant increase in different trees, shrubs, and herbs in the communities within this region. Because of these reasons, the community diversity index reached its maximum. At the elevation of about 900 m asl, the community diversity index was the lowest. The primary reason for this phenomenon was that the Japanese larch became the most dominant species in the arbor layer of this region and only this species was present in some plots. Because the temperature, humidity, and light conditions were not suitable for the growth of understory vegetation, the community diversity index reached its minimum. The trend of Simpson's dominance index was opposite to the Patrick's abundance index and Shannon-Wiener index. It reflects how important the dominant species was in the community to drive species diversity (Zhang *et al*., 2000). If one or more dominant species dominate the community, the Simpson dominance index is generally higher (Guo *et al*., 2005). The trend of the Pielou evenness index was different from the above three indices. The evenness index describes how evenly the different species in the community distribute; the more uniform the distribution, the higher the index. The evenness index is not related to the species to a certain extent and only reflects the quantitative relationship among different species (Laird *et al*., 2003). Therefore, the trend of the Pielou evenness index was different from other indices. The evenness index distributes gently with elevation, and the change range was not that big. Both the community development and the replacement rate are much stable and likely to be affected by the disturbance, hydrothermal conditions, and micro-habitats.

The relationship between plant community distribution and soil factors: Due to the broad range of elevation changes in the studied area, in addition to the shift in diversity index caused by soil factors, we considered the influence of altitude factors when performing the CCA analysis. Plant growth and development are substantially dependent on soil nutrient conditions since the differences in soil environment will lead to changes in species diversity. It has been shown that there is a significant correlation between soil fertility and plant species diversity in tropical regions (Xiao *et al*., 2008). Species diversity of plant communities increases with the increased soil fertility. Previous studies have also confirmed that the soil nutrients and plant diversity were positively correlated (Michael, 1996). Our results showed that the diversity of plant communities in the Mount Lao Nature Reserve increased with the decreased soil water content and pH, showing a negative correlation.

CCA analysis also required a combination of species and environmental factors. By plotting these factors, the relationship between community distribution and environmental factors was directly demonstrated. It will be beneficial for interpretation of the sorting axis and exhibition of the communities along the environmental gradient, and therefore become one of the most advanced techniques for the multivariate analysis of vegetation and environment (Zhang, 1992; Cajo *et al*., 1986).

In the present study, the first two axes of CCA explained the species-environment relationships, showing good ranking results. However, there are still some unexplainable parts, which may be due to measurement errors. In recent years, with the development of tourism, the Mount Lao Nature Reserve has become a hotspot for tourists and the plant communities were much disturbed by human activities. Therefore, the anthropogenic disturbance may have a profound impact on the distribution pattern of plant communities.

The Mount Lao Nature Reserve is a warm temperate deciduous broad-leaved forest vegetation in China's vegetation zone. Although the original vegetation no longer exists, currently there are broad, well-preserved secondary vegetation types and a variety of well-developed plantations. In addition, as the northernmost and southernmost distribution regions for Chinese fir and Korean pine (*P. koraiensis*), respectively, this area has a significant amount of black pine and Japanese larch forests, making it a meeting point for plants of both North and South China. Since the 1950s, many coniferous species such as Japanese larch, Chinese fir, black pine, and Huashan pine have been successively introduced. Since the original vegetation (natural pine forest) was cut down not too long ago, there were still a lot of seeds retained in the soil. In the absence of anthropogenic disturbances, these seeds may germinate and grow into adult plants, and then gradually form a mixed forest with the introduced species. Due to complex terrain and the impact of maritime climate, this region has a moderate temperature, abundant rainfall, relative humidity, and various microclimates. Therefore, its forest community composition and species diversity are very complex and may be affected by the natural and historical factors as well as human activities. In addition, the successional process of plant communities is influenced by various environmental factors such as altitude, slope, aspect, and soil properties. Thus, the quantitative classification by TWINSPAN and CCA analysis of forest communities in the Mount Lao Nature Reserve depicted well-established relationships between forest communities and the site factors. The composition and diversity of forest communities, along with the vertical variation of the altitudinal gradient, are of great significance to reveal the variation law of environmental gradient on biodiversity. This will help to better describe the spatial distribution pattern of these forest communities and provide a theoretical basis for forest protection and management.

Conclusions

The results indicated that the 40 plots were sampled very well (species accumulation curve) and the forest communities of the Mount Lao Nature Reserve can be divided into nine communities. The curves of the Shannon-Wiener index and Patrick richness index demonstrated almost the same changing trends. The curve of the relationship between plant species diversity and altitude were bimodal. Under the elevationof of 300 m asl, the diversity index showed an upward trend with the elevation increasing, reaching the first peak at 300 m asl. After that the diversity indices slowly descended, followed by an increasing trend, and reached the second peak at 600 m asl where red pine and other mixed forests dominated. At the altitude of 900 m asl, the diversity indices reached the minimum. The species diversity indices of the communities were affected differentially by soil factors. The diversity of plant communities in Mount Lao Nature Reserve increased with the decrease of soil water content and pH, indicating a negative correlation. The results of CCA indicated the influences of site factors on the distribution pattern of community types and species.

Better knowledge of the alterations of forest community composition and species diversity, along with the changes in soil factors and altitude, is of great significance. Revealing the law of environmental gradient of biodiversity will help understanding the spatial distribution pattern of the forest community and the ecological adaptability of each species. Additionally, it provides the theoretical basis for the management and protection of this area in the future. Finally, this type of studies accumulates necessary data for clarifying the distribution pattern of plant communities and diversity in this area.

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