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SPATIAL DISTRIBUTION CHARACTERISTICS OF LICHENS IN FOREST OF DABIE MOUNTAIN, ANHUI PROVINCE, CHINA

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Abstract

Twenty-nine lichen quadrats were sampled in Yaoluoping national nature reserve. The data of three environmental factors, relative humidity, altitude and illumination, were collected. According to RDA results, the eigenvalue of canonical axis 1 and canonical axis 2 were 0.123 and 0.068, respectively, accounting for 82.9% of total eigenvalue of the first four axes. The first canonical axis mainly reported the change of environment variable humidity. *Peltigera neopolydactyla* had the highest positive correlation with humidity where as *Leptogium saturninum* and *Cladonia chlorophaea* had the highest positive correlation with altitude factor and illumination factor respectively. Spearman rank correlation coefficient test showed no significant negative correlation species-pairs ($p<0.05$). Fifty one species-pairs showed positive correlation ship. The distribution pattern is comprehensive response to environmental factors, of which environmental humidity, exactly availability moisture of lichens, has the greatest influence on it. Twenty-nine quadrats could be divided into six associations based on three environmental factors. There were no significant negative correlation species-pairs in the lichens, which might be due to small lichen individual, sparse distributing pattern and low interspecific competition ($p<0.05$). The bonding intensity of lichen interspecific relation-ship is a comprehensive response to available moisture and the type of substrates.

Key words: Terrestrial lichen; Redundancy analysis; Distribution characteristics; Interspecific relationship; Spearman rank correlation.

Introduction

Lichen is a composite organism of algae or cyanobacteria; however, it has a symbiotic relationship with the filaments of fungi, its primary habitat. Thus, the survival of lichen depends on the different substrates on which it grows. To The lichen clings to the substrate and derives parts of some nutrition and essential living conditions. Lichen life is diverse and its ecological width varies, which is located on the rock surface, soil or moss plexiform. Terrestrial lichens play an important role in soil conservation and maintenance of ecological balance on earth's surface. By investigating the ecological characteristics of terrestrial lichen in dense forests, we can gain several useful insights for the decomposition and composting of lichens. By investigating the relationship between the location of lichens and the environmental conditions in the coniferous forest, Markus *et al*., (2011) proved that the continuity of the opography and geographical characteristics of the location should be used to determine lichen distribution. Zedda *et al.*, (2011) comprehensively investigated the characteristics of lichens grown on different types of soil. They proposed that the morphological and structural characteristics of different types of lichens strongly depend on the prevalent environmental factors of their habitat. In the past 12 years (1995–2006), only three articles have been published on this topic in PNAS, Nature, and Science journals. In these articles, comprehensive investigation has proved that the proliferation of different types of lichens is closely related to ecology of that region (Fu *et al*., 2007). Furthermore, only a few reports have investigated about the ecology of lichen in China (Tumur *et al*., 2001; Li *et al*., 2007, 2015; Tumur & Abbas, 2009; Liu *et al*., 2011; Jiang *et al*., 2015).

In China, Dabie Mountains are located at the junction between the northern subtropical zone and the northern temperate zone. Thus, Dabie Mountains are located in the ecological transition zone. The ecosystem of this region is affected greatly by climate change caused by global warming. In the recent times, systematic taxonomic studies have been carried out to investigate the survival, growth, and proliferation of lichens in the forest ecosystem of Dabie Mountains (Wei, 1991; Wang *et al*., 2006; Wang & Zheng, 2009; Huang, 2008; Li & Wang, 2013). However, the spatial distribution of terrestrial lichen in Dabie Mountains has not been investigated till date. In this study, we performed ecological research methods that are conventionally used in carrying out studies of high plants, We selected the subtropical Yaoluoping National Natural Reserve in Dabie Mountains as the sampling site. The methods and means used in lichen ecology research are same as those used in studies of high plant ecology (Mueller, 2004). Here, we analyzed the species composition and spatial distribution characteristics of lichens on the ground surface. In this study, we analyzed the relationship between environmental factors, the quadrats, and the species as well as the characteristics of interspecific association. Moreover, we comprehensively investigated the following parameters in this study: the species composition characteristics of terrestrial lichen ecosystem in the subtropical forest of Dabie Mountain, and the distribution pattern of lichen along the habitat gradient. In this manuscript, we provide some basic information about the normal ecological function of the protected area and its maintenance, as well as the protection of the subtropical forest ecosystem in Dabie Mountain.

Material and Methods

Research area overview: The Yaoluoping National Natural Reserve is located at the junction of Anhui Province and Hubei Province; it is a watershed of the Yangtze River Basin and the Huaihe River Basin. The geographical range of this area is between 30° 57' to 31° 06' in north latitude, and 116° 02' to 116° 11' in east longitude. It is located at the junction of northern subtropical region and warm temperate region; the total area of this region is 123 km^2 (Fig. 1). The northern part of this area has low lying planes and the southeastern part of this area has high altitude plateaus and hills. The afforested areas of this zone are clearly demarcated as "protected areas". These areas are characterized by subtropical monsoon climate, with the air usually being mild and humid. In this region, January and July are the coldest and hottest months, respectively. The annual average temperature of this region is 11.5°C. In this region, monsoon season extends from June to August. Each year, the region receives heavy rainfall during monsoon. The average annual rainfall is about 1400 mm. The protected areas have mixed forest ecosystem: besides northern subtropical deciduous trees, we also observed evergreen broad-leaved plants. There are more than 2000 species of vascular plants. The forest coverage rate is over 90%. In this region, there are 13 species of protected plants, including *Emmenopterys henryi*.

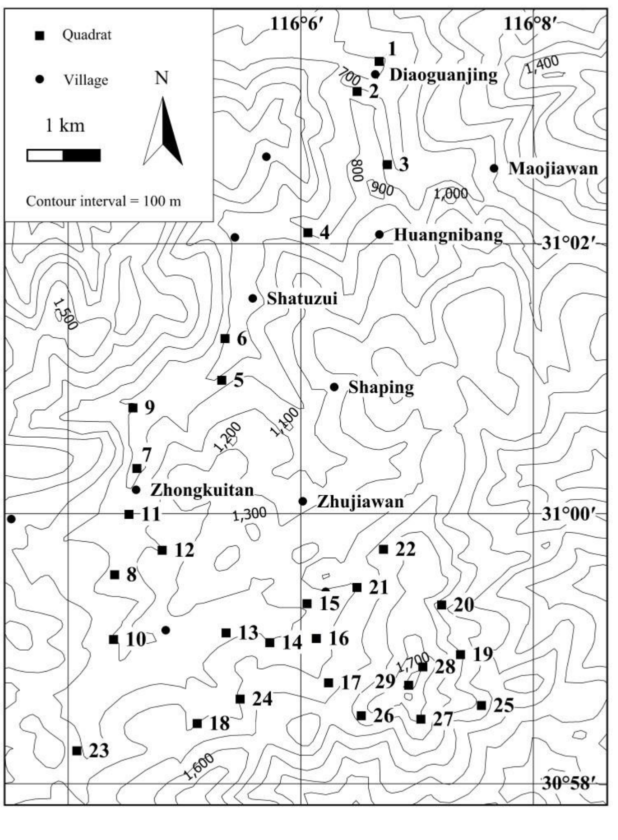

Fig. 1. Study area and quadrats setting.

Research methods: The survey was conducted on the minimum community area, which was calculated by Fu's *et al*., (2008) method. Along the elevation in different habitats, we demarcated 29 quadrats; each quadrat had dimensions of 1 m ×1 m (Table 1, Fig. 1). The different types of species and the total number of lichens were surveyed in each quadrat. The ecological indices were recorded, and the relative frequency (F_r) of species was calculated. We used Hauck's method to measure the quadrat coverage and to calculate the relative lichen coverage (*Cr*) (Hauck *et al*., 2001). A temperature and humidity meter (Testo 608-H2, *Germany*) was used to measure humidity of this region. A GPS instrument (Garmin 550T, USA) was used to measure elevation, latitude, and longitude data of this region. An illuminance meter (Tes1330A, China) was used to measure illumination of this region.

Data analysis: In each of the quadrats, we analyzed the environmental data and species data by Canocco 4.5 software (Microcomputer Power, USA, 2002). Using this software, we analyzed data pertaining to the following environmental parameters: humidity, altitude, and illumination. We determined the actual growth of lichens in this region by substituting important values of species data in this formula:

$$IV = (F_r + C_r)/2.$$

Species matrix was determined through natural logarithmic conversion. The resultant data files were plotted with CanoDraw software, and the sorted results were represented by a double sequence diagram. Different communities of lichen were sorted using the following parameters: Results of redundancy analysis (RDA), Shannon-Wiener diversity index, Whittaker similarity index, and the natural environment characteristics of field observation (Mason, 1983; Wang 1987; Inga & Jannus, 2003).

Spearman's rank correlation coefficient was used to check the correlation significance of species pairs (Zhang & Shangguan, 2000; Zhang 2004); the formula of rank correlation coefficient is as follows:

$$r_{S(i,j)} = 1 - \frac{6\sum_{k=1}^{n} d_k^2}{n^3 - n} \quad (1)$$

where, $d_k = x_{ik} - x_{jk}$; x_{ik} and x_{jk} are the rank of species *i* and *j* in quadrat *k*, respectively.

Community diversity is expressed in terms of Shannon-Wiener index (Wang, 1987), which is defined by the following formula:

$$H' = -\sum_{1}^{s} P_i \ln P_i \quad (2)$$

The community similarity index was calculated by Whittaker index (Whittaker, 1972), which is defined by the following formula:

$$I = 1 - 0.5\left(\sum_{i=1}^{S} |a_i - b_i|\right) \quad (3)$$

Spearman's rank correlation coefficient was determined using SPSS 19 software (IBM, USA).

Table 1. Locations and ecological indexes of 29 quadrats.

Quadrats	Humidity %	Altitude (m)	Illumination (Lux)	Quadrats	Humidity %	Altitude	Illumination (Lux)
1	22	680	15340	16	27	1280	13320
2	39	700	13600	17	26	1320	18810
3	11	780	10710	18	50	1300	7240
4	18	800	11280	19	46	1400	8400
5	24	920	14180	20	43	1380	12440
6	19	900	13310	21	12	1300	13600
7	10	970	9260	22	54	1420	15630
8	38	1050	15050	23	33	1250	18520
9	28	1000	15920	24	36	1300	19390
10	31	1100	9260	25	44	1350	12150
11	41	1050	19680	26	35	1550	19970
12	30	1100	13020	27	34	1600	6650
13	16	1150	7520	28	21	1680	13310
14	22	1200	9840	29	13	1700	22000
15	32	1210	12450				

Results and Discussion

In total, 20 lichens and 9 genera were present in 29 quadrats. Table 1 presents environmental index of each of the 29 quadrats. Table 2 presents the distribution of lichens in each quadrat.

Analysis of Redundancy analysis results: Redundancy analysis (RDA) was performed using the linear model of direct gradient analysis. According to the results of RDA analysis, eigen values of the first canonical axis and the second canonical axis were 0.123 and 0.068, respectively. These eigen values accounted for 53.29% and 29.4% of the total eigen values of first four canonical axes. Using the relationship between canonical axes of environmental factors and species, we found that the correlation coefficient between the first canonical axis and species was 0.873. Similarly, the correlation coefficient between the second canonical axis and species was 0.805. The correlation coefficient between environmental factors and the canonical axis of species, and the correlation coefficients between environmental factors and canonical axis of environment were shown in Table 3. Thus, we found that RDA analysis reflects the relationship between environmental factors and lichen quadrat.

By analyzing the data presented in Table 3 and Figure 2, we found that there was negative correlation between the first canonical axis and the three environmental factors: humidity, altitude, and illumination. The negative correlation coefficients were -0.8319, -0.1424, and -0.3188 for the following respective parameters: i) the first canonical axis and humidity, ii) the first canonical axis and altitude, and iii) the first canonical axis and illumination. This indicates that the first canonical axis mainly reflects changes in humidity. From left to right of the canonical axis, the moisture content, altitude, and light intensity of each quadrat reduced gradually. Illumination was negatively correlated with the second canonical axis, with the correlation coefficient being -0.7499 between illumination and the second canonical axis. Humidity was positively correlated with the second canonical axis, with the correlation coefficient being 0.3571 between humidity and the second canonical axis. Similarly, altitude was positively correlated with the second canonical axis, with the correlation coefficient being 0.5069 between altitude and the second canonical axis. From the correlation coefficient values, we infer that the second order axis mainly depicts the variation in intensity of illumination. From the bottom to the top of canonical axis, we noticed the following variations for different parameters of different quadrats: the light intensity was gradually decreased for the various quadrats, but the altitude and humidity content were gradually increased in the various quadrats. From the double sequence diagram and correlation coefficients, we infer that the distribution of lichen is affected by humidity. From the point of view of the first canonical axis, the quadrats falling into the quadrant I and quadrant VI were mostly distributed in the forest stone and bare stone surface; these quadrats showed the lowest water retention capacity. Apart from 28th quadrats, the quadrats falling into the quadrant I were primarily located at a moderate altitude (970-1300 m), where the light intensity was low. The quadrats in quadrant VI were very similar to quadrats in quadrant I in the substrate, as both these quadrats were made of exposed stone or bare soil. Moreover, the ambient humidity in both these quadrats (quadrant I and quadrant VI) was almost the same. However, the quadrats in quadrant VI were mostly at low altitude (except quadrat 29), so it received high illumination. The quadrats falling into quadrant II and quadrant III were mostly growing on moss or soil under the cover of forest where the environment shade was better than that observed in quadrant I and quadrant IV. Moreover, the water holding capacity of such substance was stronger in quadrats II and III than that observed in quadrats I and IV. The humidity was similar in quadrats II and III; however, the humidity of these quadrats was higher than those of I and IV quadrats. Furthermore, there were conspicuous differences between various conditions of quadrats in quadrant II and quadrant III: the former were at a higher altitude, with weak intensity of illumination; In contrast, the latter were located at a lower altitude, and it received high illumination.

Table 2 Lichen species and their distribution and number in each quadrat.

species	Growth from	Quadrats																												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
S1	Foliose	0	0	0	0	0	0	0	0	0	0	0	0	38.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	Fruticose	0	0	0	0	56.5	0	0	0	55.5	0	17	29	0	0	0	0	0	0	0	0	0	0	0	100	0	24	0	0	0
S3	Fruticose	0	0	0	0	0	0	0	0	0	0	30	0	0	54	100	0	0	0	0	0	0	0	0	0	0	67	0	0	0
S4	Fruticose	0	25	0	12.5	0	0	0	0	33.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S5	Fruticose	0	0	0	0	43.5	0	0	0	0	0	26	42	0	46	0	0	27	0	0	0	0	0	32	0	0	0	0	0	0
S6	Fruticose	0	4	0	2	0	0	0	0	11	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S7	Fruticose	0	0	0	0	0	0	0	0	0	0	16	29	0	0	0	0	73	0	0	0	0	0	30	0	0	0	0	0	0
S8	Fruticose	100	34.5	0	17.2	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	38	0	0	0	0	0	0
S9	Foliose	0	0	6.5	3.3	0	0	0	36.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27.5	0	0	0	0
S10	Foliose	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	46.5	0	0	0	0	0	46	9	0	0	0
S11	Foliose	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	53.5	46.5	0	0	0	0	0	0	0	0	0
S12	Foliose	0	0	0	0	0	0	0	15	0	0	11	0	0	0	0	0	0	0	0	53.5	0	0	0	0	0	0	0	0	0
S13	Foliose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54.5	0	0
S14	Foliose	0	0	0	0	0	0	0	27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	26.5	0	0	0	0
S15	Foliose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	45.5	0	0
S16	Foliose	0	0	30.5	15.2	0	0	28.5	0	0	0	0	0	47.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
S17	Fruticose	0	0	0	0	0	77	38	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0
S18	Fruticose	0	0	0	0	0	23	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S19	Foliose	0	36.5	29.5	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1	0	0	0	0	0	0	39.5	100
S20	Foliose	0	0	33	16.5	0	0	14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	41.9	0	0	0	0	0	0	44.5	0
Total		1	4	4	4	2	2	4	4	3	1	5	3	3	2	1	1	2	1	2	2	3	1	3	1	3	3	2	3	1

Names of lichen species 1. *Anzia opuntiella*; 2. *Cladonia chlorophaea*; 3. *C. cariosa*; 4. *C. cornuta*; 5. *C. pyxidata*; 6. *C. rappii*; 7. *C. rei*; 8. *C. squamosa*; 9. *Heterodermia speciosa*; 10. *Leptogium saturninum*; 11. *Lobaria pseudopulmonaria*; 12. *L. retigera*; 13. *Peltigera degenii*; 14. *P. neopolydactyla*; 15. *P. polydactyla*; 16. *Phaeographyscia erythrocardia*; 17. *Stereocaulon japonicum*; 18. *S. sorediiferum*; 19. *Xanthoparmelia orientalis*; 20. *X. protomatrae*

Table 3. Correlation coefficient matrix of environmental factors and RDA ordination axes.

	Canonical axes of species				Canonical axes of environment			
	AX1	AX2	AX3	AX4	AX1	AX2	AX3	AX4
Humidity	-0.7263	0.2875	0.1160	0.1818	-0.8319	0.3571	0.1607	0.3931
Altitude	-0.1244	0.4081	0.5342	-0.1933	-0.1424	0.5069	0.7404	-0.4179
Illumination	-0.2783	-0.6037	0.4018	-0.0744	-0.3188	-0.7499	0.5569	-0.1610

From the species-environment double sequence diagram (Fig. 3), the most closely positive correlation species with respect to humidity was *Peltigera neopolydactyla*, whereas *Stereocaulon japonicum*, *S. sorediiferum* and *Xanthoparmelia orientalis* showed the most negative correlation with humidity. Furthermore, *Leptogium saturninum* was most positively correlated with elevation. *Cladonia chlorophaea*, *C. pyxidata*, *C. rei* and *C. squamosal* had positive correlation with illumination (Fig. 3). The results of RDA indicate that the distribution of lichens was a comprehensive response to environmental factors. For example, the species *C. rei* had the strongest positive correlation with light intensity; its population distribution was highest in the 11th quadrat as the illumination intensity was high in this quadrat. Furthermore, the population distribution of *C. rei* was moderate in the 12th quadrat, where the illumination intensity was moderate. The species *C. rei* was not found in the quadrat 29, where the illumination intensity was the highest. The population distribution of *P. neopolydactyla* was most closely related with humidity. Table 2 summarizes the population distribution of *P. neopolydactyla* in the 6, 22 and 25th quadrats; each of these quadrats have sharp different levels of humidity. Figure 3 illustrates the population distribution of *P. neopolydactyla* species in the these three quadrats; the humidity levels are sharply different in the quadrats.

Lichen community ordination: From the results of the ordination chart (Table 2, Fig. 3), we found that there were six associations of lichen in the 29 quadrats (Fig. 2). To distinctly classify the lichen population into six associations, we performed field investigation: in 29 quadrats, we carefully observed and recorded the ecological environment required for the proliferation of different species of lichen.

Community A: They were observed in 10 quadrats, where the type of soil and mass was conducive for their living and sustenance. The species of genus *Cladonia* were observed in these quadrats, and some lichen had lobes with larger foliage (Table 2). In total, we observed 918 lichen individuals, and they were classified into 11 species. It accounted for 55.0% number of species and 51.7% of lichen individuals of total lichens in the study. The diversity index is the highest (1.862) of all the six associations. In associations A, all the species had a positive correlation with illumination intensity. Moreover, most species of this community had a negative correlation with elevation (Fig. 2). The community elicited a concerted response to the environmental factors of each quadrat. The environmental factors conducive for the growth of lichen population were as follows: high illumination, medium and low altitude, and high humidity levels. In this community, *C. chlorophaea* was the predominant species of fruticose lichen. On the other hand, *Lobaria pseudopulmonaria* was the dominant species of foliose lichen in this association.

Community B: This community was observed in three quadrats (Fig. 2), and it mainly included the species on moss that live on soil or stone. This community consisted of the following five species of genus *Cladonia*: *C. chlorophaea*, *C. cariosa*, *C. pyxidata*, *C. rei* and *C. squamosal*. All these species were fruticose lichens, with each individual being small in size; however, this community consisted of 291 individuals in total, which was a relatively large number. The number of species and individuals accounted for 25.0% and 16.4% of all quadrats, respectively. The diversity index of community B was 1.543. The habitat of community B was similar to that of community A; the Whittaker similarity index for the two communities (A and B) was 0.738, which was the highest among all communities. In community B, all the species of lichen exhibited a low correlation with light intensity (Fig. 2). The community B represents a comprehensive response of quadrats to adequate water environmental factors, higher elevation, and moderate illumination. In community B, the dominant species of lichen were *C. cariosa* and *C. squamosa*.

Community C: This community of lichen was observed in four quadrats; these quadrats had water-rich habitats, and this community of lichen mainly grew on moss on stony surface or under the shrub. The water holding capacity was better in these quadrats. Since the soil did not lose water easily, the micro-environment was conducive for the growth and proliferation of lichens in community C. Among the six communities of lichens, the community C was the most water-abundant. In this community, there were six species of lichen; however, the community consisted of only 39 individuals (Table 2). *Heterodermia speciosa*, *Leptogium saturninum*, *Lobaria pseudopulmonaria*, *L. retigera* and *P. neopolydactyla* were foliaceous lichen with large lobes. Only the species *C. rappii* was fruticose lichen in this community. Individuals were larger in size, and the biomass was higher; the species and individuals in community C accounted for 30.0% and 2.2% of all investigated quadrats, respectively. The diversity index of community C was 1.299. The lichen species in the community are positively correlated with humidity and altitude (Fig. 2). The community C exhibited a comprehensive response to the following environmental factors in a quadrat: adequate moisture, higher altitudes, and medium illumination. Under such combined conditions, the diversity tends to increase within the community. *L. pseudopulmonaria* and *L. retigera* were the dominant species in community C.

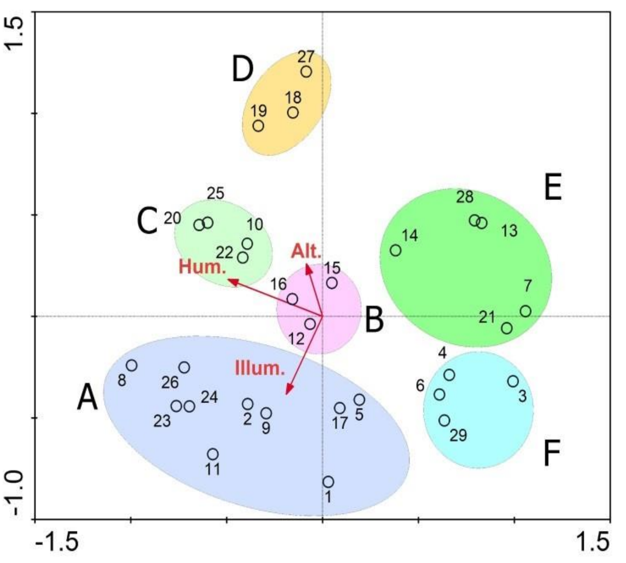

Fig. 2. RDA ordination of 29 quadrats and three environmental factors.

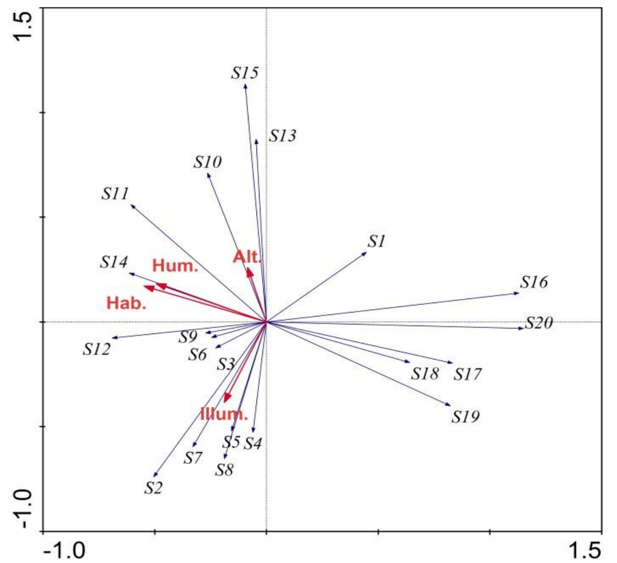

Fig. 3. RDA ordination of 20 species and three environmental factors.

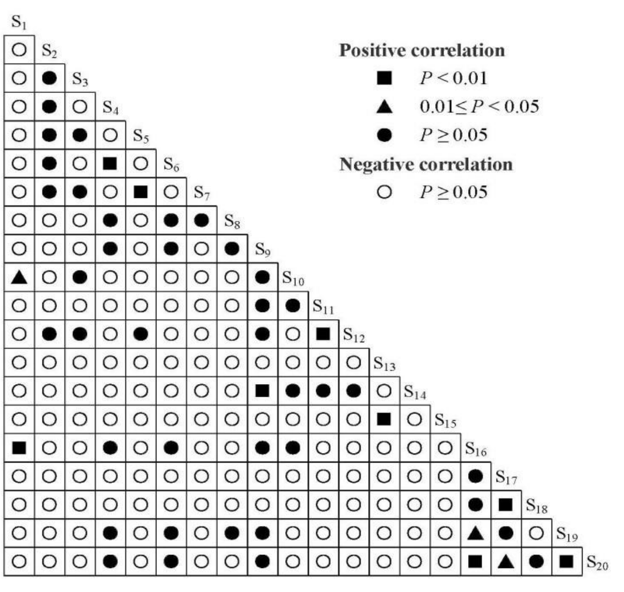

Fig. 4. Semi-matrix of Spearman correlation coefficients.

Community D: This community was observed in three quadrats. In community D, there were 4 species and 15 individuals. Since all the species (*Leptogium saturninum*, *L. pseudopulmonaria*, *P. degenii* and *P. polydactyla*) of the community D were foliaceous lichens, the diversity index (1.171) of community D was the lowest. This community had positive correlation with altitude and humidity, but negative correlation with illumination (Fig. 2). The community D was similar to community C, with the Whittaker similarity index being 0.205. The only difference between species of communities C and D was the fact that species of community D had adapted to less illumination intensity. In community D, the diversity tended to increase in the shady environment. The species *P. polydactyla* was dominant among all species of community D.

Community E: This community was observed in five quadrats; it consisted of foliaceous lichen and fruticose lichen. There were 318 individuals distributing in this community, which were classified into 9 species (Table 2). Species and individuals in community E accounted for 45% and 17.9% of all quadrats investigated, respectively. The diversity index of community E was 1.565. Community E was a typical representative of lichens living on stones. These lichens grow in quadrats having sparse coverage of shrubs; the shrub coverage has depleted due to human activities. Quadrat 28 had typical Alpine shrubs on bare rock surface, so only one species of lichens grew in this quadrat. The quadrats located on the stony surface were generally in a dry state; therefore, the water holding capacity of the substrate was poor, and the water availability of lichens was less. In these quadrats, *Leptogium saturninum* and *S. japonicum* were the dominant species of lichens.

Community F: A total of 192 individuals, 7 species, and 4 quadrats were included in this community (Table 2). The number of species and individuals accounted for 35% and 10.8% of all quadrats investigated, respectively. This community of lichens grew on a stone or bare stone. The community F was similar to the community E, with the Whittaker similarity index being 0.595. This value was only less than the Whittaker similarity index for communities A and B. But the species of community F proliferated in open area, where the water easily lost from the substrate. Therefore, the availability of water was very lack, and only the lichen species adapted to parched environment grew in such quadrats. With sparse rainfall, frequent droughts, and high illumination intensity, the habitat was more suitable for the proliferation of epilithic species. The ecological environment of quadrats 28 (community E) and 29 were similar in terms of altitude; however, the two quadrats were sharply different in terms of illumination and environmental water conditions. Within the community E, the species showed negative correlation with humidity and altitude; however, they showed positive correlation with low levels of illumination. Interestingly, *H. speciosa* was an exception, it was also distributed in community C, a community with high humidity. Such distribution pattern showed its adaptive features to various environment, the performance of a variety of habitat adaptation characteristics, ecological wide range. The dominant species in community F were *S. japonicum* and *X. orientalis*.

Interspecific association test: Interspecific association test is an important component of ecological research studies. By performing quantitative analysis of interspecific association, we determine the composition of species in the community. In addition, the relationship between species interdependence and restriction can be elucidated with these analyses. Spearman's rank correlation tests are non-parametric tests and they are completely applicable to community species, which are mostly subject to community distribution. In this study, Spearman's rank correlation test was performed on 190 species pairs. The analysis indicates that 139 species pairs had a negative correlation, and no significant negative correlation occurred among them ($p<0.05$). The remaining 51 species had positive correlation. Among these species, three species had a significant positive correlation ($0.01\leq p<0.05$), and 9 had very significant positive correlation ($p<0.01$, Fig. 4).

The interspecific association is due to the different environmental conditions of the community; species distribution is affected by environmental conditions of the community (Greig-Smith, 1983). The positive correlation pair indicates that the species have adapted successfully to similar ecological environment; there are niche differences between these species. In other words, these species have a close biological relationship (Zhang & Shangguan, 2000). Among the 12 significant positive correlation species pairs ($p<0.05$), the type of growth was same in most species pairs (Table 2, Fig. 4). The only exceptional species pair was *S. japonicum* and *X. protomatrae*. These Spearman rank correlation test species pairs with $p<0.05$ have a similar requirement for environmental factors. For example, both *S. japonicum* and *S. sorediiferum* (species-pair 17-18) were negatively correlated with humidity and had a low correlation with illumination (Fig. 3). The species pair *Anzia opuntiella* and *Phaeographyscia erythrocardia* showed highly significant positive association; these species pair are found either on a stone face or on the bark of trees. Both the species were in the quadrant I. The results of RDA analysis indicate that both these species have the closest relationship with community E (Figs. 2, 3). In the actual distribution, *A. opuntiella* was distributed in quadrat 13 in community E (6 individuals) and quadrat 4 in community F (4 individuals). The distribution of *Phaeographyscia erythrocardia* was wider than that of *A. opuntiella*, but it was still distributed in communities E (quadrats 7, 13, and 28) and F (quadrats 3 and 4); both the species *Phaeographyscia erythrocardia* and *A. opuntiella* coexisted in quadrats 4 and 13 (E); these quadrats had very similar environmental conditions and were attached to the same substrate of stone surface under forest. Therefore, the positive correlation between the two species was very significant. Both *L. pseudopulmonaria* and *L. retigera* (species pair 11-12) are large foliaceous lichens. By performing Spearman's rank correlation test, we detected a very significant positive correlation between *L. pseudopulmonaria* and *L. retigera*. By performing RDA analysis, both were categorized into quadrant II and III (left side of the first canonical axis). By performing community ordination, we observed that the species *L. pseudopulmonaria* was distributed in community A (quadrat 8), community C (quadrat 20), and community D (quadrat 19) (Figs. 2, 3). The species *L. retigera* was distributed in community A (quadrats 8, 10) and community C (quadrat 20), but there was no distribution of *L. retigera* in community D. In the two kinds of survival plots, the illumination intensity were very different and there was a large difference in altitude; however, the difference between environmental humidity was smaller for the two survival plots. Bith *L. pseudopulmonaria* and *L. retigera* are living on mosses. Because the water holding capacity of moss is very high, it creates a humid micro-environment that is conducive for lichens. In this environment, lichens get more water. As mentioned earlier, left side of the first canonical axis on the RDA represents a habitat with higher water content. Based on the above analysis, we infer that availability of water is an important factor that governs lichen distribution and interspecific association. By observing the distribution of other highly significant species pairs, we conclude that these species require similar environmental conditions to survive and thrive. Among these environmental factors, humidity (availability of water) plays an important role in the growth and proliferation of lichens. However, humidity was largely restricted by the nature of substractes (Mason, 1983).

By performing the pairing test, we found that only 139 species showed statistically significant result of $p\leq0.05$; they constituted only 6.3% of the total number of lichens. Thus, it was a relatively low result, indicating that the degree of competition between individuals was relatively low (Wang & Zhang, 2004). Guo *et al.*, (1947) found that woody plants were positively associated with species pairs, and that the species pairs had very similar characteristic traits, and niche differences were miniscule. A comprehensive study on woody plants was performed by Zhang *et al.*, (2006). They proposed that the following factors could lead to negative correlations: spatial crowding, spatial competition, allelopathy, and habitat requirements of different species (Zhang *et al*., 2006). Lichen is a special group in botany, which have low metabolic rate and slow growth; each individual (lichen) is small in size and they are dispersed in terms of distribution and growth (Mason, 1983). In this case, it is not easy to form a niche overlap of high value. At the same time, we also observed competitive exclusion between species. This may be the reason why there were few species pairs with significant correlation and significant negative correlation is absent. However, there are few reports on the relationship between individuals in the licensor category. Nevertheless, the way and mechanism governing the competition exclusion of lichens is not clearly understood till date. In plant studies, the size of sampling quadrats may affect the determination of interspecific association. The size and number of interspecific associations vary with the size of quadrats (Inga & Jannus, 2003; Zhang, 2004). Presently, research methods of lichen ecology are based on the methods of advanced plants, especially herbaceous plants and bryophytes. For subtropical forests, the quadrat setting of the size of lichens is not yet mature. Perhaps, this is another reason why significant correlations are fewer and significant negatively correlation is absent in this study.

Conclusion

Terrestrial lichens play an important role in the decomposition of litter and material circulation. According to the general consensus of ecologists, stone lichens play a vanguard role in primary succession. The distribution pattern of lichen species is affected by many factors. In this study, we found that the following environmental factors govern the distribution of lichen species: the combination of substrate type, humidity, altitude, and illumination. Amongst all these environmental factors, environmental humidity plays a pivotal role in the population distribution of lichen. All the observations were in complete agreement with the results of Whittaker similarity index. This indicates that RDA analysis was more suitable for sorting the different communities of lichens. Each individual (lichen) is small in size and these lichens are dispersed widely; therefore, the competition between species of lichen is very negligible. Thus, there is negative correlation between interspecific association analyses of species; however, no significant negative correlation is observed among these species. The biological relationship between lichen species completely depends on the availability of water to the substrate and lichen. However, we did not investigate whether the chemical composition of the substrate affects the population distribution of lichen; this relationship must be investigated in future studies. To perform lichen ecology research, we used all the unique methods and means that are normally used in high plant methods (Markus 2011). To determine the ecology that is most conducive for the growth and proliferation of lichen, it is imperative to explore the quadrat size, the importance value calculating method of lichen, and measurement methods. In most areas of Dabie Mountains, there is dense forest cover. Atmospheric pollution is low in this region due to dense forest cover. Lichens are an important type of ground cover plants, which are extensively found in this region. They are important as they play a pivotal role in conserving water and maintaining the ecological balance of the region, which is located at the junction of Yangtze River and Huaihe basin.

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References

Fu, B.Q., F. Zhang and R.R. Gao. 2008. Ecological principles and methods. Science Press, Beijing.

Fu, W., Z.T. Zhao and S.Y. Guo. 2007. Progress of lichenology with special emphasis on the articles concerning lichens published in PNAS, Nature and Science in the Last Decade. *J. Fungal Res.*, 5: 176-182.

Greig-Smith, P. 1983. Quantitative Plant Ecology. 3rd edn. Blackwell Scientific Publications, Oxford. pp. 105-128.

Guo, Z.H., Z.D. Zhuo, J. Chen and M.F. Wu. 1997. Interspecific association in mixed evergreen and deciduous broadleaved forest in Lushan Mountain. *Acta Phytoecol. Sinica*, 21: 424-432.

Hauck, M., R. Jung and M. Runger. 2001. Relevance of element content of bark for the distribution of epiphytic lichen in a montane spruce forest affected by forest dieback. *Environ Pollution*, 112: 221-227.

Huang, M.R. 2008. Noteworthy species of Stereocaulon from China. *Mycosystema*, 27: 85-90.

Inga, J. and P. Jannus. 2003. Epiphytic and epixylic lichens species diversity in Estonian natural forest. *Biodiv. Conserv*, 12: 1587-1607.

Jiang, Z.Q., A. Abbas and A. Tumur. 2015. The saxicolous lichens diversity in Tumur Peak National Natural Reserve, Xinjiang. *J. Arid Land Res. Environ.*, 29: 82-86.

Li, N. and Y.L. Wang. 2013. Investigation of lichens in Dabie mountain. *Subtrop. Plant Sci.*, 42(3): 233-237.

Li, S., W.Y. Liu and L.S. Wang. 2007. Species diversity and distribution of epiphytic lichens in the primary and secondary forests in Ailao Mountain Yunnan. *Biodiv. Sci.*, 15(5): 445-455.

Li, S., W.Y. Liu and X.M. Shi. 2015. Responses of the distribution of four epiphytic cyanolichens to habitat changes in subtropical forests. *Chin. J. Plant Ecol.*, 39: 217-228.

Liu, H.J., M.R. Huang, Q.F. Wu and H.M. Li. 2011. An analysis on the altitudinal patterns of *Peltigera* in China. *Mycosystema*, 30: 955–964.

Markus, H. 2011. Site factors controlling epiphytic lichen abundance in northern coniferous forests. *Flora-Morphol. Distrib. Func. Ecol. Plants*, 206: 81-90.

Mason, E.H. 1983. The biology of lichens. Edward Arnold Publishers, Great Britain. pp. 97-158.

Mueller, M.G., F.G. Bills and S.M. Foster. 2004. Biodiversity of Fungi: Inventory and monitoring methods. Academic Press, Newyork.

Tumur, A, A. Abbas and A.N. Abdusalik. 2001. Primary study the minimal area of saxicolous lichen community of western Tianshan. *Arid Zone Res.*, 18: 66-68.

Tumur, A. and A. Abbas. 2009. Saxicolous lichen community structure and characteristics in mountainous area of southern Urumqi. *Mycosystema*, 28: 178-188.

Wang, B.S. 1987. Botany Communities. Higher Education Press, Beijing. pp. 217-233.

Wang, L. and J.T. Zhang. 2004. Interspecific association and correlation of dominant species of Lishan Mountain meadow in Shanxi Province. *Acta Bot Boreali-occidentalia Sinica*, 24: 1435-1440.

Wang, Y.L., R.J. Chai, Z.L. Xue and Y.H. Zheng. 2006. Lichens from Yaoluoping natural reserve. *J. Anhui Univ. Technol. Sci.*, 21: 67-69.

Wang, Y.L. and Y.H. Zheng. 2009. New record of lichens in Anhui Province. *Anhui Agri. Sci. Bull.*, 15: 55-56.

Wei, J.C. 1991. An Enumeration of Lichens in China. International Academic Publishers, Beijing.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon*, 21: 213-251.

Zhang, F. and T.L. Shangguan. 2000. Numerical analysis of interspecific relationships in an elaeagnus mollis community in Shanxi. *Chin. J. Plant Ecol.*, 24: 351-355.

Zhang, G.P., F. Zhang and W.M. Ru. 2006. Interspecific correlations among dominant populations of ligneous species in Mianshan Mountain of Shanxi. *Chin. J. Ecol.*, 25: 295-298.

Zhang, J.T. 2004. Quantitative ecology. Science Press, Beijing. pp100.

Zedda, L., A. Gröngröft and M. Schultz. 2011. Distribution patterns of soil lichens across the principal biomes of southern Africa. *J. Arid Environ*, 75: 215-220.

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