Quantitative classification and ordination of forest communities in Pangquangou National Nature Reserve

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Abstract: Quantitative analysis of ecological relationships between vegetation and the environment has become an essential means in the field of research of modern vegetation ecology. In this article, based on data from 84 quadrates, forest communities in this reserve were investigated using TWINSPAN, DCA and DCCA. The results will be helpful in the construction and development of Pangquangou National Nature Reserve. Using TWINSPAN, the forest communities were classified into seven types. The distribution pattern of vegetation reflects the comprehensive influence of environments. The results of DCA and DCCA clearly reflect the relationship between the pattern of forest communities and environmental gradients. The ordination result of DCCA indicates that altitude is more important than other environmental factors because the change of altitude gradient will lead to changes in the temperature and humidity gradients. The first of the DCA ordination axes indicates the humidity gradient, and the second indicates the temperature gradient. All these results show that the main factors restricting the distribution of communities in this reserve are temperature and humidity. The ecological meaning of the ordination axis in DCCA is much clearer than that in DCA, and the species-environment correlation of DCCA is more obvious than DCA. The first DCCA axis indicates the altitude gradient among the communities, while the second is the gradient in aspect and slope among the communities. DCCA ordination can simultaneously express similarities of species and environment. Therefore, the quadrat location in the DCCA ordination figure is much closer than in the DCA.

Key Words: Pangquangou; National Nature Reserve; forest community; TWINSPAN; DCA; DCCA

1 Introduction

Since the 1980s, vegetation pattern study has been one of the most important aspects of modern vegetation ecology. Quantitative analysis, especially quantitative classification methods and ordination techniques, has been widely used to indicate the ecological relationships between vegetation and the environment. Nature reserves aim to protect particular species, while ecosystems protect special ecological relationships within the reserve.

Pangquangou Nature Reserve, established in 1986, is located in the middle of Luliang Mountains. Its peak, Xiaowen Mountain, is 2 831m above sea level. The main protected objects in this reserve are *Crossoptilon mantchuricum* and a cold temperate coniferous forest. Many previous studies of this nature reserve have focused on the flora, biomass, and scrub diversity. However, relatively few studies have examined the spatial pattern of vegetation and its ecological relationship with the environment. Studying the vegetation distribution pattern is a basic aspect of the design and management of nature reserves.

The objectives of this study are to (1) examine the spatial distribution pattern of forest communities and (2) analyze the ecological relationships between these communities and their environment. We thus aim to improve management and restoration decisions in Pangquangou National Nature Reserve in order to maintain a healthy and sustainable habitat for *Crossoptilon mantchuricum* and cold temperate coniferous tree species.

1.1 Study site

The field work was carried out in Pangquangou National
Nature Reserve (37°45′–37°55′N, 111°22′–111°33′E, 1 600–2 500m above sea level) within a total area of 10 443.5hm² in western Shanxi, China. The climate is cold, the annual mean temperature is 3–4 ℃ and annual precipitation is about 700mm. The growing season lasts approximately 105 days. Soil types ranging from the upper to the lower level are mountain brown soil, mountain alfisol cinnamon soil and mountain cinnamon soil.

Based on the system of national vegetation regionalization, the basal zone of this area is classified as a warm temperate deciduous broad-leaved forest region. With the elevation rising, the vegetation zones are respectively deciduous broad-leaved forest, needle-broad-leaved mixed forest, cold-temperate coniferous forest and sub-alpine scrub-pearl. Among them, a cold-temperate coniferous forest consisting of Larix principis-rupprechtii forest and Picea spp. (P. Meyeri and P. wilsonii) forest is dominant, while Crossopon manchuricum also inhabit this area.

1.2 Sampling

In order to study the characteristics of the various cold-temperate coniferous forest communities, sample plots (each 20m×20m) were set up in different elevation zones and aspects and each plot was subdivided into 4 (10m×10m), 8 (2m×2m) and 8 (1m×1m) quadrats for tree, shrub and herb layers, respectively. There are a total of 21 sample plots with 84, 168 and 168 quadrats for trees, shrubs and herbs.

Vegetation at each sample plot was identified in terms of species, height, coverage and abundance. The abundance of trees and shrubs was measured by numbers in the quadrats, while herbaceous abundance was estimated by a five-grade species, height, coverage and abundance. The abundance of 84, 168 and 168 quadrats for trees, shrubs and herbs.

To establish an environmental data matrix, aspect data were transformed to eight classes: starting from east (0°) and turning clockwise, with every 45° was counted as an interval, 1 (247.5°–292.5°), 2 (292.5°–337.5°), 3 (302.5°–247.5°), 4 (22.5°–337.5°), 5 (167.5°–202.5°), 6 (22.5°–67.5°), 7 (112.5°–167.5) and 8 (67.5°–112.5°)[5,11].

1.3 Data analysis

A IVs matrix of 140×84 (species×samples) and an environmental data matrix were developed. Based on these two matrices, (1) forest communities were classified by a two-way indicator-species analysis (TWINSPLAN), (2) the spatial distribution pattern of forest communities was recognized by a de-trended correspondence analysis (DCA) and (3) the ecological relationships between the cold-temperate coniferous forest communities and their environment were analyzed by de-trended canonical correspondence analysis (DCCA). These calculations were carried out by CANOCO (Braak 1991) and TWINSPLAN (Hill 1979).

2 Results

2.1 TWINSPLAN classification

According to the fourth level for TWINSPLAN and the experience of traditional vegetation classification, 84 samples were classified into 7 associations types (Fig. 1). Each association group was named after dominant or indicator species[13]. The composition, structural characteristics and their environments of association groups are described in the following text.

(1) Association group I (Assoc. Larix principis-rupprechtii—Lonicer a chrysantha+Corylus mandshurica—Carex lanceolata+Equisetum pratense). Samples in this association group occurred at low elevations (1 800–2 060m), at a mid-slope position, and on northerly aspects. This group included quadrats: 1–4, 71–73 and 82–84. Larix principis-rupprechtii was the dominant species in the tree layer. Lonicer a chrysantha, Berberis amurensis and Cotoneaster multiflorus were the common species in the shrub layer. Betula platyphylla saplings were regenerating in the forest gaps.

(2) Association group II (Assoc. Larix principis-rupprechtii—Cornus bretschneideri—Carex lanceolata ). This group was present at low to moderate elevations (1 900–2 100m), on southerly aspects, and it included quadrats: 21–32 and 62. Larix principis-rupprechtii was the dominant species and Quercus liaotungensis companion species in the tree layer. The coverage of shrub was 60% and common species includes Cornus bretschneideri, Spiraea pubescens and Viburnum mongolicum. Two herbs were common in this group: Carex lanceolata and Galium boreale. A few Quercus liaotungensis saplings regenerated in the forest gaps.

(3)Association group III (Assoc. L. principis-rupprechtii+ Betula platyphylla + Populus davidiana—Spiraea pubescens —Carex lanceolata +Dendrantherma erubescens). This group occupied moderate to high elevations (2 000–2 340m) and on southerly aspects. Betula Plat yphylla, Populus davidiana and L. principis-rupprechtii appeared in this group. The coverage of shrub was 25%. Apart from Spiraea pubescens, there were several other scrub species, including Potentilla glabra, Rosa bella and Rubus idaeus. In the herb layer, the dominant species was Dendranthera erubescens and companion species were Cacalia hastate and Phlomis umbrosa.

(4) Association group IV (Assoc. L. principis-rupprechtii+ Picea sp.—Lonicer a chrysantha+ Ribes burejense —Carex lanceolata+Convallaria majalis). This group appeared at moderate elevations (1 900–2 100m) and on northerly aspects. Tree species were rich including L. principis-rupprechtii, Picea meyeri, Picea wilsonii, Betula platyphylla and Betula
albo-sinensis. The coverage of shrubs was about 20%, with common species being Lonicera chrysantha, Ribes burejense and Euonymus przewalskii. Carex lanceolata, Convallaria majalis, Vicia amoena and Maianthemum bifolium were common species in the herb layer. Many Picea meyeri saplings regenerated under the forest gaps.

(5) Association group V (Assoc. Picea wilsonii + L. principis-rupprechtii — Euonymus przewalskii + Carex lanceolata). This group occurred at moderate to high elevations (2,010–2,200m) on mid- to upper slopes, and on northerly aspects. Picea wilsonii was dominant in tree layer of the community, and L. principis-rupprechtii and Betula albo-sinensis were also present. The coverage of the shrub was 15% and dominant species was Euonymus przewalskii. In the herb layer, apart from Carex lanceolata, Allium senescens was also common. There were many Picea wilsonii saplings generating under the forest.

(6) Association group VI (Assoc. Picea wilsonii + L. principis-rupprechtii — Lonicera kungeana — Aconitum sinomontanum). This group appeared at high elevations (2,200–2,400m) on all aspects. Picea wilsonii was dominant and L. principis-rupprechtii was also present in the tree layer. The shrub species composition was relatively simple including Euonymus przewalskii and Lonicera kungeana. The coverage of moss was 15% and dead coverage did not decompose well.

(7) Association group VII (Assoc. L. principis-rupprechtii — Carex lanceolata). This group was found in the southerly aspects at an elevation above 2,500m. Species composition was very simple: one tree (L. principis-rupprechtii), a few shrubs (Lonicera ferdinandii, Euonymus przewalskii) and some herbs (Carex lanceolata, Cardamine tangutorum and Delphinium grandiflorum). The coverage of shrubs was 5%, while that of herbs was 80%.

2.2 DCA ordination

2.2.1 DCA ordination of quadrats

The structural and environmental characteristics of seven association groups in Pangquangou National Nature Reserve are provided in Table 1. The DCA ordination diagram of the 84 quadrats (Fig. 2) shows that each association has its own range and clear borderline, which reflects the ecological relationships between communities and their environments, and distribution pattern of forest communities in this area[14]. The first DCA axis represents a moisture gradient, that is, the moisture decreases from left to right along the first axis. The second axis clearly reflects a temperature gradient, that is, temperature gradually declines from the bottom to the top along the second axis. Along the diagonal of the ordination diagram, elevation increases from the lower left to the upper right.

Simultaneously, Fig. 2 displayed a distribution pattern of forest communities: Assoc group I, which appeared at low elevations and on gentle slopes, is located at the lower left and...
its environments are relatively warm and humid; however Assoc group Ⅶ, which occurred at high elevations and steep slopes, is situated on the upper right of Fig. 2 and its environments are characterized by dry and cold. Assoc groups Ⅱ and Ⅲ are located slightly higher than group Ⅰ. This is possibly due to the fact that altitudes and slopes rise. Group IV and group V are placed in the center of the DCA diagram. This suggests temperature and moisture in this elevation zone are adaptive for both mesophytic species *Picea meyeri*, *Picea wilsonii* (group V) and xerophytic species *Larix Principis-rupprechti*, *Betula platyphylla* and *Betula albo-sinensis* (group IV). This is consistent with the results of the TWINSPAN analysis presented earlier.

Assoc group Ⅰ and group Ⅱ (L. principis-rupprechti shrub forests) occupied the low elevation where habitats are warm and humid (Table 1, Fig. 2). The shrub coverage in these two groups is relatively high. The litter in their floors decomposes well, for example, at a thickness of only 2cm in group Ⅰ. In the middle of the mountain (altitude from 2 000 to 2 340m), L. principis-rupprechti, *Betula Platypilla*, and *Populus davidiana* mixed forests occurred on the southerly aspect, while *Picea* spp. occurs on the northerly aspect. The reason for this being that the water condition on the northerly aspect is better than in the southerly aspect. Thus *Picea* spp. can form mixed forest communities with deciduous broad-leaved tree species, such as Assoc group Ⅳ and Assoc group Ⅴ. On the top of the mountain (an altitude of 2 200 to 2 400m), *Picea wilsonii* and *L. principis-rupprechti* (Assoc group Ⅵ) mixed forest occupies the northerly aspect, but *L. principis-rupprechti* and *Carex lanceolata* (Assoc group Ⅶ) forest appears on the southerly aspects where habitats are dry and cold.

2.2.2 DCA ordination of dominant species

The DCA ordination diagram of the 18 dominant species shows their distribution pattern with the changes in the environmental gradient (Fig.3). Axis 1 (horizontal) is interpreted primarily as a moisture gradient based on the association of plants with implied-moisture regimes: species associated with mesic conditions, such as No. 3 (*Picea wilsonii*), No.7 (*Picea meyeri*) and No.10 (*Viburnum mongolicum*) occur on the left end, and species associated with xeric sites, such as No.6 (*Populus cathayana*) and No.8 (*P. davidiana*) on the right end. Axis 2 indicates a temperature gradient: plants associated with

![Fig.3 Two-dimensional DCA ordination diagram of the main species in Pangquangou National Nature Reserve](image-url)
warm conditions (No.2 and 11) on the bottom but plants associated with frigophilic conditions (No.12) on the top end. The diagonal of the ordination diagram reflects that species distribution varies along the elevation gradient; that is, the species (No.15 and 16) on the lower left of the diagram are mainly present in the low altitude zone, species (No.4 and 5) in the center are usually present at the middle elevation, and species (No.14 and 18) on the upper right are mainly present in the high altitude zone. *Larix Principis-rupprechtii* is the most widespread species, followed by *Spiraea pubescens* and *Lonicera chrysantha*. They are located around the center of the diagram. The distribution of species is influenced by elevation and aspect. This is in accordance with the results of quadrats DCA ordination described above.

### 2.2.3 DCCA ordination of quadrats

De-trended correspondence analysis (DCA) is perhaps the most widely used method of indirect vegetation ordination. But direct ordination of vegetation and environment is achieved with canonical correspondence analysis (CCA). CCA is a relatively new method in which the axes of a vegetative ordination are restricted to linear groups of environmental variables. DCCA is the combination of DCA with CCA. It has several advantages over the indirect ordination and is robust even when assumptions of multivariate normal data structure are violated. Multiple regression is used to determine the proportion of variation of each ordination axis explained by environmental variables. Therefore, DCCA is the newest method of direct ordination in international terms [15]. Both DCA and DCCA were calculated using CANOCO software.

The DCCA ordination diagram of 84 quadrats illustrates clearly the ecological relationship between the forests and environments (Fig. 4). The axis 1 of DCCA indicates an elevation gradient which increases from left to right, and the correlation coefficient between elevation and axis 1 is 0.881. Axis 2 of DCCA indicates the aspect and slope gradient, and aspect-axis 2, slope-axis 2 correlation coefficient is respectively 0.546 and 0.326. Therefore, altitude is more important than other environmental factors, because the change of altitude gradient will lead to changes in the temperature and humidity gradients.

Comparison of DCA with DCCA: the quadrat location in the DCCA ordination figure is much closer than in the DCA, the ecological meaning of ordination axis in DCCA is much clearer than that in DCA, and the species-environment correlation of DCCA is more obvious than DCA, but the eigenvalues in DCA are higher than those in DCCA (Table 2), thus DCCA reflects a species-environment correlation.

### 3 Discussion

Using the quantitative classification method (TWINSPAN) and ordination techniques (DCA and DCCA), the analyses presented in this article clearly describe the distribution pattern of forest communities in the study area.

Using TWINSPAN, the forest communities were divided into seven association groups. The distribution pattern of forest communities reflects the comprehensive influence of environments. Axis 1 of quadrats in DCA indicates the humidity gradient which decreases from left to right, and axis 2 represents the temperature gradient which gradually declines from the bottom up, and elevation increases from the lower left to the upper right. The ecological gradients indicated by species DCA ordination are similar to that of quadrats DCA ordination. The results of DCCA indicate that altitude is more important than other environmental factors, because the change of altitude gradient will lead to the changes of temperature gradient and humidity gradient. Axis 2 of DCCA indicates the aspect and the slope gradient.

According to the results of both classification and ordination, the distribution pattern of forest communities in this reserve is as follows: *L. principis-rupprechtii* shrub forests (Assoc group I and group II) occupied the low elevation where habitats are warm and humid; in the middle of the mountain (from an altitude of 2 000 to 2 340m), *L. principis-rupprechtii*, *Betula Platypilla* and *Populus davidiana* mixed forests (Assoc group III) occurred on the southerly aspect, but *Picea* spp. occurred on the northerly aspect. This is mainly

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**Table 2**  Eigenvalues and species-environment correlation coefficients for the first three axes of DCA and DCCA

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<th>Item</th>
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<th>Axis 1</th>
<th>Axis 2</th>
<th>Axis 3</th>
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<td>DCCA</td>
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<td>0.734</td>
<td>0.616</td>
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</tbody>
</table>

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**Fig. 4**  Two-dimensional DCCA ordination diagram of 84 quadrats in Panguquangou National Nature Reserve
due to the fact that water conditions on the northerly aspect are better than on the southerly aspect. This leads to the formation of deciduous broad-leaved coniferous forests, such as Assoc group IV and Assoc group V. On the top of the mountain (from an altitude of 2 200 to 2 400m), Picea wilsonii and L. principis-rupprechtii (Assoc group VI) mixed forest occupies the northerly aspect, but L. principis-rupprechtii and Carex. lanceolata (Assoc group VII) forest appears on the southerly aspects where habitats are dry and cold.

DCA compared with DCCA: the quadrat location in the DCCA ordination figure is much closer than in DCA, the ecological meaning of the ordination axis in DCCA is much clearer than that in DCA, and the species-environment correlation of DCCA is more obvious than DCA, but eigenvalues in DCA are higher than those in DCCA. This is due to the fact that DCCA ordination can simultaneously express similarities of species and environment. If classification is used together with ordination, DCA is better than DCCA.

The research results suggest that L. principis-rupprechtii is widely distributed in this nature reserve at an altitude from 1 600 to 2 500m. Picea spp. (P. meyeri and P. wilsonii) are mainly distributed in middle mountainous areas at an altitude from 2 000 to 2 350m where Crossoptilon mantchuricum inhabits, and therefore this area should be primarily preserved.

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References