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DIVERSITY AND DISTRIBUTION OF HIGH-MOUNTAIN MEADOWS ACROSS ELEVATION GRADIENT IN WUTAI MTS. (NORTH CHINA)

ABSTRACT: The Wutai Mountain Meadow Reserve, located at 112°50’–113°50’E, 38°30’–39°15’N, conserves the typical high-mountain meadows in North China. Eighty one plots (quadrates 2 m × 2 m) in 11 transects separated by 100 meters in altitude along an elevation gradient (2 000–3 058 m a.s.l.) were established. Species composition of plants, their abundance, coverage and height in each plot were measured and recorded. The environmental variable like slope, slope orientation, soil type, air temperature and humidity (yearly average values) were assessed. The multivariate analysis methods, TWINSPLAN for classification, and DCA and CCA for ordination, were used to analyze the relationships between meadow communities and environmental variables. The results showed that there are eight types of mountain meadow vegetation in the reserve. The distribution of meadow communities is related to elevation, slope, slope orientation, and soil-water conditions. The changes of species diversity ($H' = 1.5–2.5$) in communities are mainly related to elevation gradient, and also related to community coverage, slope and slope orientation.

KEY WORDS: mountain meadows, classification, ordination, species diversity, biodiversity conservation

Mountain vegetation has become a significant focus in studies of ecology and biodiversity conservation for a long period (Herben et al. 2003, Fossa 2004, Gerald 2004, Kurschner et al. 2005, Lovett et al. 2006). In China, mountainous regions are important in the conservation practice because most natural plant communities are occurring exclusively in mountains on limited areas (Wu 1982, Zhang 2005). There are many research papers on mountain meadows in the ecological literature, most of them focusing on grassland resources, productivity of plants and animals, responses of mountain meadow to climate changes, interaction between plant species, effects of grazing on grassland, and so forth (Frantisek et al. 2001, Sanz-Elorza et al. 2003, Daniel et al. 2003, Gerald 2004, Zhang and Zhang 2006). However, the study of ecological relations for mountain meadows in China is not sufficient (Zhang et al. 1998).

China has large areas of mountain meadows in its wide mountainous regions, most of them occurring in the western part of the country, such as Qilian Mountains, Tianshan Mountains, Qinghai-Tibet Plateau (Zhou 2001, Kurschner et al. 2005). Comparatively, the area of mountain meadows in North...
China is small. The largest and most typical mountain meadows in North China are occurring in Wutai Mountains. Some studies on meadow vegetation classification and description (Zhang 1989a, b; Zhang et al. 2006), distribution patterns of selected grass species (Zhang et al. 1998) and timberline development (Liu et al. 2002) have been carried out in the Wutai Mountain grassland area. In the paper, we present the changes of vegetation diversity of high-mountain meadows along the elevation gradient in the Wutai Mountain Meadow Reserve. The hypothesis that elevation in this region is the most significant for high mountain meadows and species diversity will be tested.

The Wutai Mountains with the highest peak of 3,058 m is located at 112°50’–113°50'E, 38°30’–39°15'N, and is a branch of Taihang Mountain range in Northeastern Shanxi, North China (Fig. 1). The Wutai Mountains have five-peaked mesa, and are sacred to Buddhists. It presents Manjusri, the Bodhisattva of Transcendent Wisdom, known in Chinese as Wenshu. The five-peaked mesa area above 1,600 m a.s.l. is the national natural reserve, the Wutai Mountain Meadow Reserve, which mainly protects the typical high-mountain meadow vegetation. The climate of this area is temperate and semi-humid with continental characteristics and controlled by seasonal winds (Zhang 1989a). According to 25-year average climatic records, the annual mean temperature is 6.4°C, the monthly mean temperatures of January and July are –18.3°C and 9.5°C, respectively. The frost-free period lasts only 130 days. The annual mean precipitation is 913.3 mm, which in the wettest year reached 1,120 mm, with 70% of the precipitation occurring from July to September. The annual average humidity is 68%. Vegetation varies from warm temperate deciduous
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broad-leaved forest dominated by *Quercus liaotungensis* Koiz. and *Betula platyphylla* Ssk., to temperate coniferous forest dominated by *Pinus tabulaeformis* Carr. and *Platycladus orientalis* (L.) Franco, cold-temperate coniferous forest dominated by *Larix prininis-rupprechtii* Mayr., *Picea wilsonii* Mast. and *Abies fabri* (Mast.) Craib, and further, to high-mountain meadows reaching the top of Wutai Mountains (Zhang 1989a). Several soil types, such as mountain cinnamon soil, brown forest soil and subalpine meadow soil can be found along the altitude gradient in this area (Liu 1992). The study area concerns all the meadow communities from 2 000 m to 3 058 m in the Wutai Mountain Meadow Reserve. Summer grazing is a common activity and the grazing intensity varies from 3.1 to 6.0 cattle per ha, decreasing with the increase of elevation (Zhang 1989b).

Along the elevation gradient of 2 000–3 058 m, 11 transects separated by 100 meters in altitude were set up, and 6–8 plots (quadrates) of 2 m × 2 m in each transect were established randomly. The cover, height and abundance for all plant species were measured in each plot. The cover (%) was measured by eye, the height (cm) measured directly by using ruler, and the abundance by counting the number of individuals or tussocks. Altogether 78 plant species were recorded in 81 plots. Elevation, slope and slope orientation for each plot were also measured and recorded.

We used the Importance Value for each species as the data for community analysis and for calculation of diversity indices (Greig-Smith 1983, Zhang 1995). The importance value means here relative cover (measured as % of the species cover of the sum of cover of all species found in a quadrat) and relative height (measured as % of the species height of the sum of height of all species found in a quadrat) (Zhang 2004). The matrix of species data contains the importance values of 78 species in 81 plots. The matrix of environmental data consists of three variables (elevation, slope and slope orientation) measured in 81 plots.

The Two-way Indicator Species Analysis (TWINSPAN) (Hill 1979) and the Detrended Correspondence Analysis (DCA) (ter Braak and Šmilauer 2001) were used to analyze community variation (Zhang 1995). The Canonical Correspondence Analysis (CCA) was used to combine the species data with environmental variables. The calculation of TWINSPAN was carried out by computer program of TWINSPAN (Hill 1979), and the calculation of DCA and CCA were carried out by program of CANOCO (ter Braak and Šmilauer 2001).

We have applied three indices (Pielou 1975, Zhang 1995, Tóthmérész 1995) for measuring the community diversity: of species richness (D), of species diversity (H'), and of species evenness (E):

Species richness (species number) index:

\[ D = S \]

Shannon-Wiener biodiversity index:

\[ H' = -\sum P_i \ln P_i \]

Pielou evenness index:

\[ E = \frac{-\sum P_i \ln P_i}{\ln S} \]

Where \( P_i \) is the relative importance value of species \( i \), \( P_i = \frac{N_i}{N} \), \( N \) the importance value of species \( i \), \( N \) the sum of importance values for all species in a plot, \( S \) the number of species present in a plot (Pielou 1975, Zhang 1995).

The Pearson regression and correlation methods were used to analyze the relationships between species diversity indices and environmental variables.

The TWINSPAN clustered 81 plots into 8 groups, representing 8 high-mountain types of meadow vegetation. The meadow types and their composition are as follows (the plant nomenclature system – see Liu and Yue 2004) and their environmental characteristics are listed in Table 1.

**Type I – Caragana jubata + Potentilla nivea.** The total coverage of the community is around 90%. The most common is shrub species *Caragana jubata* (Pall.) Poir. Also the following occur: geophytes – *Potentilla nivea* L., *Polygonum viviparum* L., and *Sanguisorba officinalis* L. as well as sedge species – *Carex* spp. and *Kobresia bellardii* (All.) Degl.

**Type II – Polygonum viviparum + Potentilla nivea.** The total coverage of this community is around 90%. The common species in the community are geophyte species *Polygonum viviparum* L., *Potentilla nivea* L.,
Oxtropis coerulea (Pall.) DC., and Sanguisorba officinalis L. Sedge Carex spp., tussock grass Festuca ovina L. and Poa ianthina Keng as well as annual forb species – Anemone cathayensis Kitag. and Anaphalis hancockii Maxim are occurring in this community.

Type III – Kobresia pygmaea + Kobresia bellardii. The community coverage is around 95%. The common species in the community are sedge species – Carex lanceolata Boott, Kobresia pygmaea C. B. Clarke and Kobresia bellardii (All.) Degl. Geophyte species – Polygonum viviparum L., Pedicularis shansiensis Tsoong, Thalictrum petaloideum L., Gentiana macrophylla Pall., Ranunculus japonicus Thunb., and Taraxacum mongolicum Hand.-Mazz are occurring in this community.

Type IV – Carex spp. + Kobresia bellardii. The community coverage varies from 95 to 100%. The common species in the community are sedge species – Carex spp., and Kobresia bellardii (All.) Degl. Geophyte species – Potentilla nivea L., Polygonum viviparum L. and Thalictrum petaloideum L. as well as annual forb species – Anemone cathayensis Kitag. and Myosotis sylvatica Hoffm are occurring in this community.

Type V – Carex spp. + Polygonum viviparum. The community coverage is 90–100%. The common species in the community are sedge species Carex spp. The following species are occurring too: geophytes – Polygonum viviparum L., Potentilla nivea L., Sanguisorba officinalis L., Oxtropis coerulea (Pall.) DC., Taraxacum mongolicum Hand.-Mazz., Gentiana macrophylla Pall., tussock grass species Poa ianthina Keng, annual forb species Anemone cathayensis Kitag. and semi-shrub species Artemisia spp.

Type VI – Potentilla fruticosa + Artemisia spp. The community coverage is 90–95%. The common species in the community is short shrub species Potentilla fruticosa L. The other species are following: semi-shrub species Artemisia spp. sedge Carex spp., geophyte species – Potentilla nivea L., Polygonum viviparum L. and Gueldenstaedtia multiflora Bunge, tussock grass Festuca ovina L. and Koeleria cristata (L.) Pers., annual forb Anemone cathayensis Kitag.

Type VII – Potentilla fruticosa + Carex spp. The coverage is 90–95%. The common

Table 1. Environmental characteristics of I–VIII high-mountain meadow communities in the Wutai Mountain Meadow Reserve, North China.

<table>
<thead>
<tr>
<th>Vegetation types</th>
<th>Altitude range (m)</th>
<th>Slope orientation</th>
<th>Soil types</th>
<th>Temperature1 (°C)</th>
<th>Humidity1 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Caragana jabata + Potentilla nivea</td>
<td>2400–2600</td>
<td>N, NW</td>
<td>subalpine meadow</td>
<td>3–4</td>
<td>75–80</td>
</tr>
<tr>
<td>II Polygonium viviparum + Potentilla nivea</td>
<td>2400–2600</td>
<td>S, SW</td>
<td>subalpine meadow</td>
<td>3–4</td>
<td>70–80</td>
</tr>
<tr>
<td>III Kobresia pygmaea + Kobresia bellardii</td>
<td>&gt; 2800</td>
<td>S, SW, SN</td>
<td>alpine meadow</td>
<td>0–2</td>
<td>80–85</td>
</tr>
<tr>
<td>IV Carex spp. + Kobresia bellardii</td>
<td>2600–2800</td>
<td>N, NE</td>
<td>subalpine meadow</td>
<td>2–3</td>
<td>75–80</td>
</tr>
<tr>
<td>V Carex spp. + Polygonum viviparum</td>
<td>2200–2600</td>
<td>N, S, SW</td>
<td>subalpine meadow</td>
<td>3–4</td>
<td>70–75</td>
</tr>
<tr>
<td>VI Potentilla fruticosa + Artemisia spp</td>
<td>2000–2400</td>
<td>NW, SW</td>
<td>brown forest and mountain meadow</td>
<td>5–6</td>
<td>65–70</td>
</tr>
<tr>
<td>VII Potentilla fruticosa + Carex spp.</td>
<td>2000–2600</td>
<td>NW, SE</td>
<td>brown forest and mountain meadow</td>
<td>5–6</td>
<td>70–70</td>
</tr>
<tr>
<td>VIII Carex spp. + Poa ianthina</td>
<td>2400–2600</td>
<td>NE, NW</td>
<td>mountain meadow</td>
<td>3–4</td>
<td>70–75</td>
</tr>
</tbody>
</table>

1 yearly average values.
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species in the community is the short shrub *Potentilla fruticosa* L. The others are following: semi-shrub *Artemisia* spp. sedge *Carex* spp., geophytes *Sanguisorba officinalis* L. and *Polygonum viviparum* L., tussock grass *Koeleria cristata* (L.) Pers., *Festuca ovina* L. and *Poa ianthina* Keng.

Type VIII – *Carex* spp. + *Poa ianthina*. The community coverage varies from 95 to 100%. The most common species is the sedge *Carex* spp. The others are following: geophytes *Sanguisorba officinalis* L., *Potentilla nivea* L. and *Polygonum viviparum* L., tussock grass *Koeleria cristata* (L.) Pers. and semi-shrub species *Artemisia* spp.

The ordination analyses of species data were carried out by using DCA. Figure 2 is the scattered diagram of 81 plots in DCA ordination space. Distribution pattern of plots on DCA ordination diagram shows that the first DCA axis is mainly related to elevation and slope, and the second DCA axis is related to elevation and slope orientation. The altitude gradient from the left bottom to the right top is clear, along this gradient the elevation is decreasing gradually. The humidity and soil-water conditions decrease and the temperature increases – from the left bottom to the right top in the DCA ordination map (Table 1). The communities on the left bottom part are usually distributed in high area with comparatively humid conditions. These are: type III – *Kobresia pygmaea* + *Kobresia bellardii* and type IV – *Carex* spp. + *Kobresia bellardii*. And the communities which are located on the right top part are distributed in the hills with comparatively low elevation. These are: type VI – *Potentilla fruticosa* + *Artemisia* spp. and type VII – *Potentilla fruticosa* + *Carex* spp. The slope is decreasing from the left to the right along the first DCA axis. The slope orientation varies from semi-shady to semi-sunny, and to sunny slope along the second DCA axis. The plot composition for each meadow type is clearly showed in the DCA diagram, which further proves that the TWINSPAN classification is reasonable (Zhang 1995, ter Braak 1986).

The relationships between meadow vegetation and environmental variables were
Fig. 3. Changes of species diversity along the elevation gradient in high-mountain meadows in the Wutai Mountain Meadow Reserve, North China.
detectable when using CCA analysis. The first CCA axis is significantly related to the elevation and slope, and the second CCA axis is strongly correlated with slope orientation. This suggests that the meadow vegetation in the Wutai Natural Reserve is closely related to the elevation, slope and slope orientation. The significant relationship between meadow vegetation and environmental variables can be seen clearly from the correlation coefficients and canonical coefficients (Table 2).

The indices of species richness, biodiversity and evenness all showed a significant linear relationship with the elevation, and they increase with the increase of elevation between 2 100 and 3 050 m a.s.l. (Fig. 3). This suggests that species diversity is related to other factors connected with elevation like slope, slope orientation, humidity and soil-water conditions (Zhang et al. 1998). This pattern is similar to that of Qilian Mts. (West China) where plant species diversity is increasing from 1600 m to 2800 m, keeping stable from 2800 m to 3000 m, and then decreasing when elevation is over 3 000 m a.s.l. (Zhu and Zhang 2005).

These results are comparable to other studies in which the composition and distribution of mountain meadow communities are found to be closely related to the elevation gradients (Zhang 1989a, Stohlgren et al. 1997, Pucheta et al. 1998, Gavilan et al. 2002, Sanz-Elorza et al. 2003, Virtanen et al. 2003). From the left bottom to the right top of DCA ordination map, communities vary from comparatively high-cold-temperate type distributed in high mountains to cold-temperate type in middle mountains.

Elevation change leads to the change of humidity, temperature, soil conditions, which in turn influence the variation of meadow communities. The high-cold-temperate and cold-temperate meadows are the most unique communities in North China. From the ordination analyses (CCA and DCA), we can see that the community variation is also closely related to other environmental factors, such as slope orientation, slope and so forth. This is also a common point resulting from mountain vegetation studies (Pucheta et al. 1998, Zhang 2002).

The elevation between 2 000 and 3 000 m a.s.l. is the most significant variable influencing the variation of species diversity in the Wutai Mountain Natural Reserve. Species biodiversity, evenness and richness are all significantly related to this elevation range, i.e. they increase with elevation going up. This is, perhaps, due to the difference of grazing intensity, i.e. the grazing intensity is greater in low elevation area than that in high altitude (Pucheta et al. 1998, Zhang 2002, Matejkova et al. 2003). If the whole elevation gradient would be considered, the trend of changes of species diversity may be different (Fossa 2004, Zhu and Zhang 2005).

The composition of high-mountain meadow communities in the Wutai Mountains and their species diversity respond to environmental variables in similar way, so their conservation is important in this region.

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<table>
<thead>
<tr>
<th>Environmental variables</th>
<th>Correlation coefficients</th>
<th>Canonical coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axis 1</td>
<td>Axis 2</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.733</td>
<td>0.025</td>
</tr>
<tr>
<td>Slope</td>
<td>0.616</td>
<td>0.265</td>
</tr>
<tr>
<td>Slope orientation</td>
<td>0.311</td>
<td>0.672</td>
</tr>
</tbody>
</table>
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