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FLORISTIC ANALYSIS OF THE WANDA MOUNTAIN IN NORTH EASTERN CHINA

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Abstract

The plants of the Wanda Mountain area were investigated between 2009 to 2013. The results show that Wanda Mountain has 95 families of seed plants distributed in 334 genera and 705 species. A geographical component analysis shows that in addition to a small number of cosmopolitan species, cold, temperate and tropical species account for 14.9%, 77.3% and 4.4% of the total species, respectively, indicating that the flora of the Wanda Mountains exhibits a significant temperate nature and includes a small number of tropical components and certain cold components. In addition, the Wanda Mountains show a remarkable level of endemism and are geographically related to other regions in East Asia, particularly Japan. Furthermore, the Wanda Mountains present a complicated species composition, with a total of 14 distribution patterns and 10 variants. The coefficient of similarity between the flora of the Wanda Mountain area and the flora of the Changbai Mountain area is 43.1%, and the coefficient of similarity between the flora of the Wanda Mountain area and the flora of the Lesser Xingan Mountain area is 49.2%, indicating that the plants of the Wanda Mountain area are more common to those of the Lesser Xingan Mountain area.

Key words: Flora, Seed plant, Coefficient of similarity, Geographical components, Comparison of the similarity.

Introduction

Since the 1950s, the numbers and quality of forests in China have been decreasing at an accelerating rate (Li, 2004), and the habitats of more than 60% of species have been threatened (Fu *et al*., 1995). Under such circumstances, fully understanding data on floristic units has become the chief task in the conservation of plant diversity (Takhtajan, 1986).

As an important component of the floristic region of northeastern China, the flora of the Wanda Mountain area is generally considered a part of the flora of the Changbai Mountains and has never been fully studied. In past decades, the Wanda Mountain area has drawn attention from very few researchers, and there has been no important plant conservation area established in this region. Even though the Wanda Mountains are generally considered to be part of the Changbai Mountains (Liu, 1955; Mitsuzo, 1971), the formation of the geology and the flora of the Wanda Mountains are different from that of the Changbai Mountains. Geologically, the Wanda Mountain area was formed through the development of the Mesozoic deep-sea sedimentary strata and is the only outcrop area composed of a Mesozoic deep-water mobile sedimentary formation in northern China; in addition, the Wanda Mountain region presents a very complex environment of sedimentary materials (Zhang & Zhang, 1999). In the Mesozoic, the interactions (subductions and collisions) between the Nadanhada area and the Pacific Plate formed the Wanda Mountains (Li & Zhang, 1997). In contrast, the main body of the Changbai Mountains was formed from volcanic eruptions in the Oligocene of the Paleogene period at the earliest (Wei *et al*., 2005). There is a significant difference in the geological environment between the Wanda Mountains and the Changbai Mountains. In terms of the flora, due to the multiple volcanic eruptions of the Changbai Mountains, the vegetation of these Mountains have been repeatedly altered by volcanic magma flows (Zhou, 1997). The formation of the floristic composition of the Changbai Mountains resulted from reshaping multiple times, and the flora of these Mountains came into existence approximately during the Tertiary (Fu *et al*., 1995). These volcanic eruptions had no impact on the plants of the Wanda Mountain area, located in the north of the Changbai Mountains, and the floras of the Wanda Mountains and the Changbai Mountains have undergone different development processes. In addition, differences in geological location, altitude and climate also resulted in differences between the floristic compositions of the Wanda Mountains and the Changbai Mountains. The Changbai Mountain area, located in the south, presents a warmer climate and higher precipitation (800-1,800 mm) (Fu *et al*., 1995). There is more plant exchange between the Changbai Mountains and the floristic region of northern China situated at relatively low latitudes. The Wanda Mountain area, located in the north, presents a colder climate and relatively lower precipitation (500-800 mm) (Jiang *et al*., 2005). There is an even greater difference in altitude between the Wanda Mountains and the Changbai Mountains: the average altitude of the Wanda Mountains is only approximately 300 m, and the highest peak of the Wanda Mountains is 854 m (Jiang *et al*., 2005), whereas the altitudes of the most of the Changbai Mountain area range from 700 m to 1,600 m, and the highest peak of the Changbai Mountains is 2,750 m (Fu *et al*., 1995).

However , we still do not fully comprehend the basic data on many important floristic units, such as the Wanda Mountain area, located in northeastern China. It is utterly necessary to comprehensively and systematically investigate the Wanda Mountains as an independent floristic unit to conserve plant germplasm resources and study the origin of the flora of this region.

Materials and Methods

Site description: The Wanda Mountains, located in the east of Heilongjiang Province, China, at the northernmost end of the Changbai Mountains, comprising an area of 78,400 km^2. The Nadanhada Range is the main range of the Wanda Mountains. The mountain body of the Wanda Mountains is composed of ancient granites. The northeast-southwest-trending Wanda Mountains extend from the Raoli River in the northwest to the Wusuli River in the east to Guokui Mountain in the south. The Wanda Mountains are the watershed between the Raoli River and the Muling River. Shending Mountain, the main peak of the Wanda Mountains, is at an altitude of 831 m and is located at the northernmost end of the mountains. Laotudingzi, the highest point of the Wanda Mountains, is located in the middle section of the Wanda Mountains and is at an altitude of 854 m. The forest region of the Wanda Mountains is a relatively flat low-hill region. Brown forest soil is the main soil type in the Wanda Mountains. The thicknesses of the soil layer generally ranges from 30 cm to 50 cm, and the soil presents moderate fertility. The Wanda Mountains exhibit an oceanic temperate monsoon climate with warm and humid summers and cold and dry winters. January is the coldest month, with a monthly average temperature of -19.4˚C. July is the hottest month, with a monthly average temperature of 21.1˚C. The annual precipitation is 500~800 mm, and the precipitation is concentrated from June to August. The annual average temperature is 2.4˚C; the absolute highest temperature is 36.6˚C, and the absolute lowest temperature is -42˚C. The frostless period lasts for 125~150 days. The annual accumulated temperature is approximately 2,300~3,000˚C (Jiang 2005).

Experimental treatment: From 2009 to 2013, we conducted a 5-year-long continuous investigation of the plants of the Wanda Mountain area to comprehensively and systematically analyze the seed plant flora of the Wanda Mountains. The forest-covered region of the Wanda Mountains, with an area of 12,000 km^2 (Fig. 1), was divided into 20 units of 25 km×25 km (Fig. 2), and 15 survey quadrats of 30 m×30 m were set up in each unit. There were a total of 300 quadrats. Communities with orderly forest forms and relatively homogeneous slopes were selected when setting up the quadrats to avoid slashes and large forest gaps resulting from human and natural disturbances. The quadrat surveys included surveys on the basic conditions of the quadrats and surveys on different plant types, including arborous plants, shrub plants and herbaceous plants. The applied quadrat survey methods were as follows. (1) Survey on arborous plants: the grid method was used to evenly divide the sample plot into 36 small quadrats of 5 m×5 m, and all of the tree species within each small quadrat were surveyed to determine their species and parameters such as height and diameter at breast height. (2) Survey on shrub plants: based on the uniformity principle, 10 small quadrats of 5 m×5 m were selected from the 36 quadrats that had been surveyed to obtain information on arborous plants (Fig. 3); the shrub plants within these 10 small quadrats were then surveyed to determine their species and parameters such as their average height, average crown diameter and average tuft size. (3) Survey on herbaceous plants: 1 small quadrat of 1 m×1 m was set up within each of the quadrats that had been surveyed to obtain information on shrub plants (there were a total of 10 quadrats; after each quadrat was delineated, a photograph of each quadrat was obtained from a position vertically above the quadrat; each photograph covered the entire area of the corresponding small quadrat, these photographs provided an important reference for the subsequent correction of coverage estimates); the herbaceous plants within these 1 m×1 m small quadrats were then surveyed to determine their species and parameters such as their abundance, height and coverage.

Floristic analysis: An inventory of the plants of the Wanda Mountains was made through field observations, specimen examinations (the herbaria whose specimens were examined included the Herbarium of the Institute of Botany of the Chinese Academy of Sciences (CAS) (PE), the Qinghai-Tibet Plateau Museum of Biological Specimens of the Northwest Institute of Plateau Biology of the CAS (HNWP), the Herbarium of the Kunming Institute of Botany of the CAS (KUN), the Herbarium of the Shenyang Institute of Applied Ecology of the CAS (IFP), the South China Botanical Garden Herbarium (IBSC), the Herbarium of the Xinjiang Institute of Ecology and Geography of the CAS (XJBI), the Herbarium of the Chengdu Institute of Biology of the CAS (CDBI), the Herbarium of the Lushan Botanical Garden of the CAS (LBG), the Specimen Collection Room of the Department of Biology of the Henan Normal University (HENU), the Herbarium of the Xishuangbanna Tropical Botanical Garden of the CAS (HITBC), the Herbarium of the Guangxi Institute of Botany of the CAS (IBK) and the Herbarium of the Guangxi Institute of Chinese Medicine and Pharmaceutical Science (GXMI)) and literature reviews (the literature that we examined include the Flora of China (Wu *et al*., 2003), the Flora of Heilongjiang (Zhou, 1986), Key of Plants of Northeastern China (Fu, 1995), the Flora Plantarum Herbacearum Chinae Boreali–Orientalis (Liu, 1959) and the Silva of Heilongjiang (Zhou, 1986). The standard classification for the areal types of the families and genera of seed plants of China proposed by Wu (1991) and Wu *et al.* (2003) was used. The results of the study conducted by Fu (Fu *et al*., 2003) were consulted for the classification of species distribution patterns.

Statistical analysis

The coefficient of similarity between the plant species of different areas was calculated using the following equation:

$$s = \frac{c}{a+b+c} \times 100\% \quad \text{(Jaccard, 1901)}$$

where a represents the total number of species in area A; b represents the total number of species in area B; c represents the number of the species in both areas A and B; and s represents the coefficient of similarity. The list of the species of the Wanda Mountains was obtained through survey statistics. The lists of the species of the Lesser Xingan Mountain area (Cao & Li, 2007) and the Changbai Mountain area (Cao & Li, 2003) were obtained from the results of the studies conducted by Cao & Li (2003) and Cao & Li (2007).

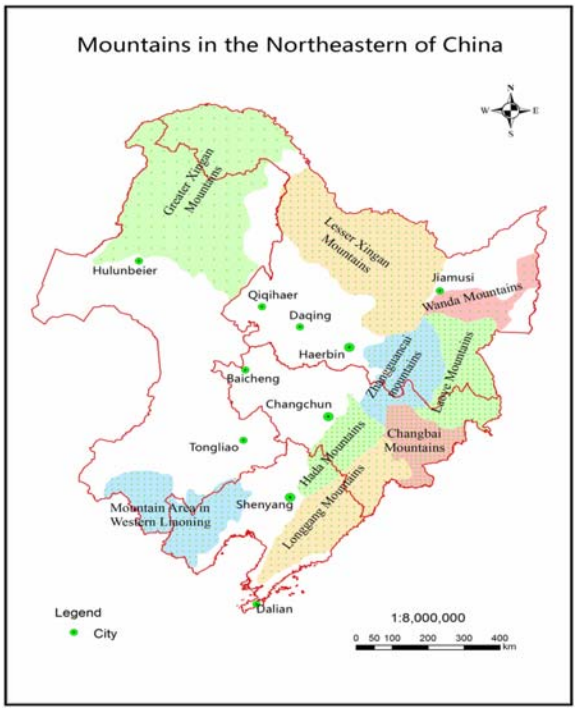

Fig. 1. The mountains distribution in the northeastern of China.

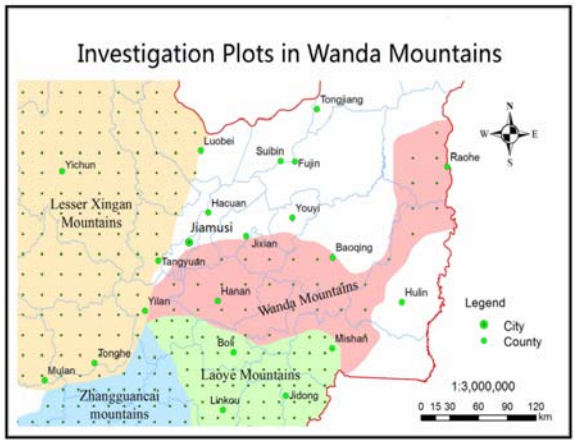

Fig. 2. Distribution of the survey areas and the survey units.

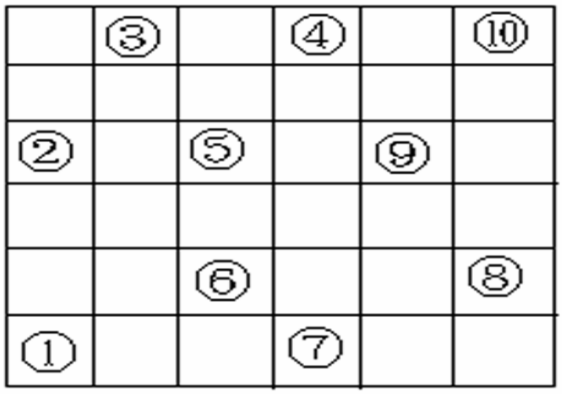

Fig. 3. Setup of the small shrub and herbaceous plant survey quadrats.

Results

Basic composition of the flora: There are a total of 95 families of seed plants, distributed in 334 genera and 705 species, in this area including 1 family of gymnosperms, which has 3 genera and 5 species, and there are 94 families of angiosperms, belonging to 333 genera and 700 species.

Analysis of the components of the families: According to the statistical analysis of the results, there are a total of 95 families of wild seed plants in the Wanda Mountain area, which can be classified into large families (containing more than 31 species), relatively large families (containing 11 to 30 species), medium families (containing 6-10 species), small families (containing 2-5 species) and single-species families (containing only 1 species). There are 5 large families in the Wanda Mountain area: the Compositae including 70 species; Cyperaceae including 51 species; Ranunculaceae including 45 species; Rosaceae including 37 species; and the Gramineae including 32 species. There are 12 relatively large families, such as the Labiatae including 26 species; Leguminosae including 26 species; Scrophulariaceae including 26 species; Saxifragaceae including 25 species; Caryophyllaceae including 23 species; and Liliaceae including 23 species. There are a total of 10 medium families, such as the Trapaceae including 10 species; Caprifoliaceae including 10 species; Primulaceae including 8 species; Papaveraceae including 8 species; and Violaceae including 8 species. There are a total of 10 small families, such as Aceraceae including 5 species; Crassulaceae including 5 species; Pinaceae including 5 species; Euphorbiaceae including 4 species; and Celastraceae including 4 species. There are 29 families represented by single species such as Fagaceae and the Moraceae.

There are a total of 27 large, relatively large and medium families in this flora, which only account for 28.4% of the total plant families. The genera that belong to these 27 families account for 72.5% of the total genera, and the species account for 79.1% of the total species, indicating that the large, relatively large and medium sized families constitute the main composition of the genera and species in this area. There are a total of 68 small and single-species families in this flora, which account for 71.6% of the total families in this region. However, the small and single-species families contain only 92 genera and 147 species, which account for 27.5% of the total genera and 20.9% of the total species in the flora, respectively, indicating that the small and single-species families (Table 1) constitute the main body of the families in this flora.

Statistical analysis of the genera: There are 3 large genera (containing more than 10 species) of seed plants, 17 medium genera (containing 6-10 species), 124 small genera (containing 2-5 species) and 190 single-species genera (containing only 1 species) in the Wanda Mountain area.

Table 1. Group statistics of the seed plant families of the Wanda Mountain area.

		Large families (No. sp. >31)	Medium families (No. sp. 6-30)	Small families (No. sp. 1-5)
Family	No. % the flora	5 5.3%	22 23.10%	68 71.60%
Genera	No. % the flora	94 28.1%	148 44.30%	92 27.60%
Species	No. % the flora	235 33.3%	323 45.90%	147 20.80%

Table 2. Statistics for the composition of the seed plant genera and the corresponding species of the Wanda Mountain area.

		Large genera (No. sp. >10)	Medium genera (No. sp. 6-10)	Small genera (No. sp.1-5)
Genera	No.. % the flora	3 0.9%	17 5.1%	314 94.0%
Species	No. % the flora	64 9.1%	119 16.9%	522 74.1%

Table 3. Areal types of the seed plant families of the Wanda Mountain area.

Areal types of the families	No. of families	%	No. of genera	%	No. of species	%
1 Cosmopolitan	46	48.4%	244	73.1%	512	72.6%
2 Pantropic	16	16.8%	24	7.2%	38	5.4%
2-2 Trop. Asia-Trop. Afr.-Trop. Amer. (S. Amer.)	2	2.1%	2	0.6%	3	0.4%
2S Pantropic especially S. Hemispher	2	2.1%	2	0.6%	2	0.3%
3 Trop. & Subtr. E. Asia & (S.) Trop. Amer. disjuncted	1	1.1%	3	0.9%	4	0.6%
6d S. Afr.	1	1.1%	1	0.3%	1	0.1%
8 N. Temp.	8	8.4%	22	6.6%	47	6.7%
8-4 N. Temp. & S. Temp. disjuncted	14	14.7%	31	9.3%	84	11.9%
8-5 Eurasia &Temp. S. Amer. disjuncted	1	1.1%	1	0.3%	1	0.1%
9 E. Asia & N. Amer. disjuncted	2	2.1%	2	0.6%	2	0.3%
10 Old World Temp.	1	1.1%	1	0.3%	10	1.4%
14 E. Asia	1	1.1%	1	0.3%	1	0.1%

There are a total of 20 large and medium genera, including 183 species. The large and medium genera account for 6.0% of the total genera, and the species that belong to these genera account for 26.0% of the total species in this area. The large and medium genera and the species that belong to these genera account for relatively small proportions of the total genera and total species in this flora. A total of 314 small and single-species genera in this flora include 522 species. The small and single-species genera account 94.0% of the total genera, and the species that belong to these genera account 74.1% of the total species. However, the small and single-species genera constitute the main composition of the genera of this flora (Table 2).

Statistical analysis of the dominant families and genera: A dominant family refers to a family that contains relatively more (genera) species and is a typical family in a particular area. A dominant family or dominant families constitute the main body of the flora of an area. The compositions of dominant families and dominant genera can reflect the nature, characteristics and origin of the flora of a particular area.

Plant families in the Wanda Mountain area such as Compositae, Cyperaceae, Ranunculaceae, Rosaceae, Gramineae, Labiatae, Leguminosae, Scrophulariaceae, Saxifragaceae, Liliaceae, Caryophyllaceae, Salicaceae, Umbelliferae, Orchidaceae and Polygonaceae include relatively more plant species compared with other families, and are the dominant families of this area. These dominant families are of great importance to studies on the origin of the species and the flora of this area.

The types of dominant genera are also a factor that has an important impact on the flora. For instance, the genus *Carex* includes 21 species, such as *Carex amgunensis*, *Carex atrata*, *Carex augustinowiczii*, *Carex brownii*, *Carex callitrichos*, *Carex cryptocarpa* and *Carex egena*; and the genus *Salix* contains 15 species, including *Salix matsudana*, *Salix triandra*, *Salix pentandra*, *Salix myrtilloides* and *Salix raddeana*. These dominant genera have an important impact on the distribution of plants and the characteristics of the flora in this area.

Statistics and analysis of the geographical components of the families, the genera and the species

Statistics and analysis of the geographical components of families: According to the classification method proposed by Wu *et al*. (2003), the 95 families of seed plants found in the Wanda Mountain area are classified into 8 distribution patterns and 12 variants (Table 3).

There are 46 plant families in the Wanda Mountain area that exhibit a cosmopolitan distribution pattern, which account for a relatively large proportion – 48.4% – of the total plant families in the Wanda Mountain area. The genera and species that belong to these 46 plant families also account for relatively large proportions of the total genera and the total species. There are 244 genera that belong to these 46 plant families, which account for 73.1% of the total genera in this area, and there are 512 species that belong to these 46 plant families, which represent 72.6% of the total species. There are only 22 families in this area that exhibit a tropical distribution pattern (types 2-7), which account for a small portion – 23.2% – of the total families. There are 32 genera that belong to these 22 families, which represent a relatively small portion – 9.6% – of the total genera. There are 48 species that belong to these 22 families, which account for a relatively small portion – 6.8% – of the total species. Compared with the families that exhibit a tropical distribution pattern, there are relatively more families – a total of 27 families – that exhibit a temperate distribution pattern (types 8-14), which account for 28.4% of the total families. There are 58 genera that belong to these 27 families, which account for 17.4% of the total genera, and there are 145 species that belong to these 27 families, which represent 20.6% of the total species (Table 3).

Statistics and analysis of the geographical components of the genera: The difference between two genera is ancient and stable. However, an investigation of the distribution characteristics of the genera in a particular area is beneficial to understand the nature and characteristics of the flora of such an area (Fu, 1995). According to the areal types of the genera of seed plants in China proposed by Wu (1991), the 334 genera of seed plants found in the Wanda Mountain area are classified into 14 distribution patterns and 25 variants. There are a total of 14 variants in the Wanda Mountain area.

Compared with the families, there are relatively fewer plant genera – a total of 59 genera – that exhibit a cosmopolitan distribution pattern, which account for only 17.7% of the total genera. There are 179 species that belong to these 59 genera, which account for 25.4% of the total species. Compared with the families, there are also fewer plant genera – a total of 36 genera – that exhibit a tropical distribution pattern, which account for 10.8% of the total genera. There are only 56 species that belong to these 36 genera, which account for 7.9% of the total plant species in the Wanda Mountain area. Compared with the families, there are relatively more plant genera – a total of 239 genera – that show a temperate distribution pattern, which account for 71.6% of the total genera. There are 470 species that belong to these 239 genera, which account for 66.7% of the total species, indicating that the plant genera in the Wanda Mountain area exhibit a typical temperate distribution pattern (Table 4).

Statistics and analysis of the geographical components of the species: According to the areal types of the seed plant species found in northeastern China (Fu *et al*., 2003), the 705 seed plant species are classified into 22 distribution patterns and 41 variants.

There is a relatively small number of species in the Wanda Mountain area that exhibit a cosmopolitan distribution pattern, which only account for 2.9% of the total species. There are many species that exhibit a temperate distribution pattern. The species that exhibit a China-Japan distribution pattern account for the greatest number of species – totaling 118 species, followed by the species that exhibit an Old World temperate distribution pattern – totaling 56 species. In addition, there are more than 20 species that represent the following distribution patterns: a temperate Asian distribution pattern, a northeastern China distribution pattern, a north temperate distribution pattern, an East Asian distribution pattern, a northeastern Siberian distribution pattern, a northeastern China-northern China distribution pattern, a northeastern China-central and northern Japan distribution pattern, a north temperate-Arctic distribution pattern, a northeastern China-Russian Far East distribution pattern and a Siberian distribution pattern. Sub-cold-cold, temperate and tropical species account for 14.9%, 77.3% and 4.4% of the total species, respectively (Table 5).

Nature of the seed plant flora of the Wanda Mountains: Evidently, the seed plant flora of the Wanda Mountains exhibits a temperate nature. The families presenting the most species and genera include the families with a cosmopolitan distribution, those with a temperate distribution with a primary temperate distribution pattern and those with a temperate disjunct distribution containing species with a disjunct distribution. There are no endemic genera in this flora. However, there are 14 endemic species, indicating that the Wanda Mountain area exhibits significant endemism. The endemism of the Wanda Mountain area is manifested in the following observations. First, the seed plant flora of the Wanda Mountains is related to those of the most regions of the world to some degree, but primarily to those of Northern Hemisphere regions, particularly other East Asian regions. More than half of the species of the Wanda Mountain area are also found in other East Asian regions. The seed plant flora of the Wanda Mountains is most closely related to that of Japan, indicating that the flora of Japan was historically closely related to the flora of the Wanda Mountain area before Japan was separated from the Asian continent. Second, the flora of the Wanda Mountain area is related to the temperate floras of the Eurasian and North American continents. A total of 200 species components of the Wanda Mountain area (more than 1/4 of the total temperate components of the Wanda Mountain area) are related to the species components of the Eurasian and North American continents. These species of the Eurasian and North American continents might be closely associated with the gradual southward migration and evolution of the northern temperate plants since the climate became cold from the late Tertiary to the Quaternary as well as the south-north and east-west migrations of plants caused by multiple glacial advances and retreats. Third, the flora of the Wanda Mountain area is related to that of the Arctic: nearly 1/10 of the species of the Wanda Mountain are related to species from the Arctic, which were evidently closely associated with the climate change and advances and retreats of plants caused by multiple glacial periods since the Quaternary. In addition, the flora of the Wanda Mountain area is also related to the floras of tropical Asian, African, Australian and American regions to some degree: 12.6% of the genera and 3.3% of the species of the Wanda Mountain area are related to those of the tropical Asian, African, Australian and

American regions, which provides a vestige and proof of the relationship between the historical development of the Wanda Mountain area and the aforementioned tropical regions. The flora of the Wanda Mountain area is weakly related to those of other regions, such as western dry regions.

Comparison of the flora similarity between the Wanda Mountain and the Changbai Mountains and the flora similarity between the Wanda Mountain and the Lesser Xingan Mountains: In terms of families, genera and species, the coefficients of similarity between the Lesser Xingan Mountains and the Wanda Mountains are all slightly higher than the coefficients of similarity between the Changbai Mountains and the Wanda Mountains (Table 6). In terms of families, there is no significant difference between the coefficient of similarity between the Lesser Xingan Mountains and the Wanda Mountains and the coefficient of similarity between the Changbai Mountains and the Wanda Mountains. In terms of genera and species, there is a slight difference between the coefficient of similarity between the Lesser Xingan Mountains and the Wanda Mountains and the coefficient of similarity between the Changbai Mountains and the Wanda Mountains. The coefficient of similarity between the plant species of the Wanda Mountains and the plant species of the Changbai Mountains is 43.9%, whereas the coefficient of similarity between the plant species of the Wanda Mountains and the plant species of the Lesser Xingan Mountains is 50.1%.

Discussion

Composition of the plant flora of the Wanda Mountains: The Wanda Mountains have an area of less than 80,000 km^2. However, the families, genera and species in this floristic area account for 82% of the families, 58% of the genera and 40% of the species of the floristic region of northeastern China. Thus, the floristic area of the Wanda Mountains is an important area of plant diversity in northeastern China.

The temperate species of the Wanda Mountains account for 87.4% of the total species of these Mountains, which are similar to those of the floristic regions of northeastern China (81%) and the Changbai Mountains (88%) (Cao & Li, 2003). The Wanda Mountains are located at higher latitudes than the Changbai Mountains. However, the Wanda Mountains present fewer cold components (6.6%) than the Changbai Mountains (8.7%) (Cao & Li, 2003), evidently due to the fact that the Wanda Mountains exhibit relatively lower altitudes (mean altitude: 300 m) (Jiang, 2005), which are detrimental to the preservation of cold components, whereas the Changbai Mountains exhibit relatively higher altitudes (700-2700 m) (Fu, 1995), and relatively more cold components have been preserved in high-altitude areas. There is a clear relationship between the flora of northeastern China and the floras of tropical regions. The fossil record shows that in the past, there was a relatively large number of tropical plants distributed across the floristic region of northeastern China, and the distribution areas of these tropical plants gradually migrated southward as a result of climate change. Nevertheless, there are still some tropical components that have been preserved in the floristic region of northeastern China. The Changbai Mountains are located at lower latitudes than the Wanda Mountains. In addition, the Changbai Mountains exhibit more plant exchange with the floristic region of northern China located at even lower latitudes. However, the Wanda Mountains exhibit a significantly higher tropical composition (6%) than the Changbai Mountains (3.3%) (Fu, 1995), which may be due to the repeated volcanic eruptions of the Changbai Mountains, which resulted in a relatively young floristic region and a loss of a relatively large number of tropical components. The area impacted by the volcanic eruptions of the Changbai Mountains did not extend to the Wanda Mountains, resulting in the preservation of a relatively large number of tropical components in the Wanda Mountains.

Table 4. Areal types of the seed plant genera of the Wanda Mountain area.

Areal types of genera	No. of genera	%	No. of species	%
1 Cosmopolitan	59	17.7%	179	25.4%
2 Pantropic	19	5.7%	29	4.1%
3 Trop. Asia &Trop. Amer. disjuncted.	1	0.3%	1	0.1%
4 Old World Tropics	6	1.8%	11	1.6%
4-1 Trop. Asia. Africa (or E. Afr., Madagascar) & Australasia disjuncted	2	0.6%	5	0.7%
5 Tropical Asia &Trop. Australasia	2	0.6%	2	0.3%
6 Trop. Asia to Trop. Africa	4	1.2%	4	0.6%
7 Trop. Asia (Indo-Malesia)	2	0.6%	4	0.6%
8 North Temperate	104	31.1%	242	34.3%
8-2 Arctic-alpine	1	0.3%	1	0.1%
8-4 N. Temp. & S. Temp. disjuncted. ("Pan-temperate")	30	9.0%	67	9.5%
8-5 Eurasia & Temp. S. Amer. disjuncte	2	0.6%	4	0.6%
9 E. Asia &N. Amer. disjuncted	27	8.1%	41	5.8%
10 Old World Temperate	31	9.3%	52	7.4%
10-1 Mediterranea. W. Asia (or C. Asia) & E. Asia disjunct ed	4	1.2%	4	0.6%
10-2 Mediterranea & Himalaya disjuncted	1	0.3%	1	0.1%
10-3 Eurasia &S. Africa (Sometimes also Australasia) disjuncted	3	0.9%	8	1.1%
11 Temp. Asia	10	3.0%	17	2.4%
12-1 Mediterranea to C. Asia & S. Africa, Ausrealasia disjuncted.	1	0.3%	2	0.3%
12-2 Mediterranea to C. Asia&Mexico to S. USA. disjuncted	1	0.3%	2	0.3%
13 C. Asia	3	0.9%	3	0.4%
14 E. Asia	13	3.9%	17	2.4%
14(SH) Sino-Himalayan (SH)	1	0.3%	1	0.1%
14(SJ) Sino-Japanese (SJ)	7	2.1%	8	1.1%

Table 5. Areal types of the seed plant species of the Wanda Mountain area.

Areal types of species	No. of Species	%
1 Cosmopolitan	21	3.0%
2 N. Temp.-Arctic	25	3.5%
2-1 Old World Temp.-Arctic	13	1.8%
2-2 Asia-N. Amer.-Arctic	2	0.3%
2-3 Asia Temp.-Arctic	4	1.0%
3 Siberia	23	3.3%
3-1 E. Siberia	38	5.4%
4 North Temp.	43	6.1%
4-1 N. Temp.-S. Temp.	2	0.3%
5 Old World Temp.	57	8.1%
6 Asia-N. Amer.	7	1.0%
6-1 E. Asia-N. Amer.	6	0.9%
7 Temp. Asia	56	7.9%
8 E. Asia	41	5.8%
8-1 E. Asia-Australasia	1	0.1%
10 Sino-Japan	119	16.9%
10-1 N. E. China-C. & N. Japan	28	4.0%
10-2 China-Japan-Mongolia Steppe	5	0.7%
11 E. China	16	2.3%
11-1 E. to W. China	1	0.1%
12 N. E. China-N. China	34	4.8%
12-1 N. E. China-N. China-Mongolia Steppe	3	0.4%
14 N. E. China	54	7.7%
14-1 N. E. China-Far East Russia	24	3.4%
14-2 N. E. China-Dshuria	19	2.7%
14-3 N. E. China-Daxing'anling	4	0.6%
14-4 N. E. China- Mongolia Steppe	2	0.3%
15 N. China	1	0.1%
15-2 N. China -Mongolia Steppe	2	0.3%
16-1 Daxing'anling-Far East Russia	4	0.6%
18 Altai-Mongolia-Dahuria	3	0.4%
19 Dahuria- Mongolia	12	1.7%
21 N. E. China Plain	1	0.1%
22 N. Temp. -Trop.	3	0.4%
22-1 Old World Temp. -Trop.	4	0.6%
22-2 Asia & N. Amer. &Temp.-Trop.	2	0.3%
22-3 Asia Temp.-Trop	17	2.4%
24 Trop. Asia, Africa & S. Amer.	1	0.1%
25 Old World Trop	1	0.1%
26 Trop. Asia-Trop. Australasia	2	0.3%
27 Trop. Asia-Trop. Africa	1	0.1%

Table 6. Similarity coefficient between the Wanda Mountains and the Changbai Mountains and between the Wanda Mountains and the Lesser Xingan Mountains.

Coefficients of similarity	Families	Genera	Species
Wanda Mountains and the Changbai Mountains	85.7%	56.0%	43.1%
Wanda Mountains and the Lesser Xingan Mountains	96.0%	67.7%	49.2%

Comparison of the flora similarity between the Wanda Mountain and other regions: In terms of the classification of the plant sub-regions of northeastern China, the Wanda Mountain area is closer to the Changbai Mountains or the Lesser Xingan Mountains? Previously, researchers divided the floristic region of northeastern China based on the similarity of the species composition and floristic components, combined with the annual precipitation/annual evaporation (P/E) ratio (Liu, 1955; Liu, 1959; Mitsuzo, 1971), average temperature and the distribution of the main species (e.g., *Pinus koraiensis* and *Larix gmelinii*) (Mitsuzo, 1971). In this context, there were two representative viewpoints: some researchers believed that the Wanda Mountains were closer to the Changbain Mountain area (Liu, 1955; Liu, 1959), whereas others believed that the plants of the Wanda Mountain area were closer to those of the Lesser Xingan Mountains (Zhou, 1997).

The distribution of *Pinus koraiensis* is an important basis for determining the Manchurian floristic region (Mitsuzo, 1971). Based on the ratios of associated broad-leaved tree species to *Pinus koraiensis*, the Wanda Mountains appear to be closer to the Changbai Mountains (Anon., 1980), which is, however, contradicted by the

distribution of the genus Larix. *Larix gmelinii*, but not *Larix olgensis*, is distributed in the Lesser Xingan Mountain area. *Larix gmelinii* is distributed in most areas of the Wanda Mountains, and *Larix olgensis* is distributed in a few area of these Mountains. *Larix olgensis*, but not *Larix gmelinii*, is distributed in the Changbai Mountains (Wang, 1992), indicating that the Wanda Mountains are closer to the Lesser Xingan Mountains. In terms of floristic components, the Wanda Mountains are also closer to the Lesser Xingan Mountains. For instance, higher Siberian and Mongolian floristic compositions and a lower northern China floristic composition are found in the Lesser Xingan Mountain area and the Wanda Mountain area than the Changbai Mountain area. The similarity of the species composition is an important basis for dividing floristic regions. Previously, Zhou (1997) compared the similarity between the species of the Wanda Mountain area and the species of the Changbai Mountain area with the similarity between the species of the Wanda Mountain area and the species of the Lesser Xingan Mountain area and concluded that the similarity between the species of the Wanda Mountain area and the species of the Changbai Mountain area was higher than the similarity between the species of the Wanda Mountain area and the species of the Lesser Xingan Mountain area(Zhou, 1997). However, only a small area was selected from each mountain region as the representative area for comparison in Zhou's study (1997), and this study is deemed incomprehensive. After a comprehensive investigation, we have drawn a conclusion, differing from that of Zhou (1997), that the coefficient of similarity between the Wanda Mountains and the Lesser Xingan Mountains is higher than the coefficient of similarity between the Wanda Mountains and the Changbai Mountains, regardless of families, genera or species.

Conclusion

Based on the aforementioned analysis, the flora of the Wanda Mountains can be considered to exhibit a significant temperate nature and a small number of tropical components and certain cold components. The Wanda Mountains display a remarkable level of endemism and are extensively geographically related to other regions in East Asia, particularly Japan. In addition, the Wanda Mountains present a complicated species composition. The flora of the Wanda Mountains is closer to the flora of the Lesser Xingan Mountains but is different from the flora of the Changbai Mountain area. Further studies are necessary to understand the details and the genesis of this plant distribution pattern and to provide a basis for studies on the origins and evolution of these floras as well as the establishment of conservation areas.

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