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RESEARCH ARTICLE

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Altitudinal patterns of the flora of seed plants of Dawei Mountain in Yunnan Province, south China

Abstract Altitudinal gradient incorporates multiple resource gradients, which vary continuously in different fashions. It is important to study the mountain floristic patterns along altitudinal gradients, which reveal the regular pattern of the flora along the environmental gradients, the changing trend of biodiversity patterns along the altitudinal gradient, and relevance of biological fitness. To explore the compositional characteristics and ecological significance of floristic patterns along altitudinal gradient in China National Nature Reserve of Dawei Mountain in the southeast of Yunnan Province, field investigations have been made to the flora along the two routes of the southwest slope and the northeast slope of the said reserve, including a vertical vegetation transect. Meanwhile, further investigations have also been made to the flora of Dawei Mountain, which has been accounted for in the literature, as *Flora Yunnan*, *The Seed Plant in Yunnan*, and so on. The structural characteristics of the flora and the altitudinal distribution pattern of its floristic components were analyzed. By applying systematic cluster analysis, the altitudinal position of the dividing line of floristic changes along altitudinal gradient was detected, and the effects of the montane climate on the vertical variation of floristic composition were studied. Conclusions were put forward. This paper can be summarized as follows: (1) The obvious boundary that differentiates tropical floristic elements is located at the altitude of approximately 1,500 m; it is reasonable to stipulate the boundary line between tropical rain forests and the evergreen broad-leaved forests. (2) The vertical vegetation spectrum made by cluster analysis shows that humid rain forests are below 700 m a.s.l, montane rain forests are between 700 and 1,500 m, monsoon evergreen broad-leaved forests are between 1,300 and 1,800 m, and montane mossy evergreen broad-leaved forests are above 1,800 m a.s.l. Nonrepresentative montane mossy dwarf forests (above 2,100 m) in the area are distributed in windward sides and in barren land on the mountain slopes.

Keywords Dawei Mountain, geographical elements, altitudinal gradient, cluster analysis

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1 Introduction

Plant distribution theory holds that the distribution zone of species is reflected by their developing process (Ochobbi, 1965). Mountainous areas not only reflect the natural geographical as well as biogeographical characteristics of the horizontal zone, but is also the ideal place for studying the specific biodiversity (Fang et al., 2004). It is the sanctuary of numerous species and the cradle of the new flora differentiation, and at the same time, the significant area of the global biodiversity study because of its highly differentiating habitats and relatively low human disturbance (Messerli and Ives, 1997; Kornor, 2000; Myers et al., 2000). The study of the formation of the biodiversity pattern is mainly the synthetic study of the relationship between the ancient and the modern bioenvironment and forest plants, forest community patterns, and forest landscape pattern, analyzing the forest biodiversity history and its relationship with the biological conditions (Rohde, 1992; Rosenzweig, 1992, 1995). National Nature Reserve of Dawei Mountain is situated at the northern edge of the tropical area. Owing to its special location, topography, long geological history, and highly differentiating habitats, Dawei Mountain has nurtured abundant plant resources with 188 families, 994 genera, 3,027 species, and varieties of seed plants. Its species density is as high as 19.69 species/km^2, becoming one of the areas richest in plant species in Yunnan Province. Apart from this, dense and tall humid rain forests —the most humid and hot in China—grow in this area (Wu, 1980; Wu and Zhu, 1987); the area has an elevation difference of 2,140 m, which constitutes a relatively complete vertical vegetation spectrum and becomes a critical place for the study of the relationship between vegetation and environment. In view of this, this article will discuss and analyze the basic characteristics of Dawei Mountain's floristic components and their distribution patterns along altitudinal gradient based on the field investigations and literature about the distribution of seed plants in Dawei Mountain.

2 Study site

National Nature Reserve of Dawei Mountain lies to the south of the North-Tropic of Cancer, east longitudes 103°20′–104°03′, north latitudes 22°35′–23°07′, with a total territory of 153.7 km^2. The Dawei Mountain where the reserve is located, is situated to the southeast of the central Yunnan lake basin and at the western edge of the southeast Yunnan Karst plateau, viewing Ailao Mountain through Honghe, a mountain formed by the cutting of the Nanxi river, Xinxian river, and Honghe river, with Honghe and Nanxi rivers flowing through its southwest side and northeast side respectively. The highest peak, Dajian Peak has an elevation of 2,365 m, the second highest mountain, Dawei Mountain, 2,345 m, and the lowest, 225 m in the area. Because of the barrier of the surrounding high mountains with only the narrow Honghe valley mouth (76.4 m elevation) in its southeast leading to the north bay of Vietnam, it becomes the only place that is affected most profoundly by the southeast tropical monsoon with warm and humid currents in the whole Yunnan Province. This area has ample rainfall and heat, hot and rainy in summer, warm, humid, and foggy in winter with an average annual temperature of 22.6°C, 15.2°C in the coldest month (January) and 27.7°C in the hottest month (July), the lowest multiannual average 5.8°C, with 8,246.2°C of annual accumulated temperature above 10°C and no frost through the year. The mouth, deep down the valley, receives an average rainfall of 1,777.7 mm. With the increase in elevation, the temperature drops and there is orographic rain, as much as 2,649.5 mm. The plateau lateriti soil, red soil, yellow soil, and yellowish brown soil are distributed along the altitudinal gradient, among which yellow soil has the widest distribution area, accounting for 85% of the total reserve. Vegetation such as humid rain forests, montane rain forests, subtropical monsoon evergreen broad-leaved forests, montane mossy evergreen broad-leaved forests, montane top mossy shrubs, and so on are distributed from low elevation to high elevation peak.

The Nature Reserve of Dawei Mountain is located in a disjuncted mountain, which is in the south margin of the slope of Yunnan plateau slanting toward the south and the transitional zone between the flora of organism in the tropical zone on the north verge of the penisular southeast Asia subtropical zone and the one in mid-Yunnan plateau subtropical zone, as well as the joint between the two components in east Asia near the south point of the "Tanaka Line" (Li and Li, 1992). This area is of great scientific and practical importance for the study on vegetation geography, plant flora geography, and biodiversity protection. Scholars worldwide have been visiting it to collect and study plant specimens since the nineteenth century, whose achievements are mainly reported in monographs such as *Flora Yunnan* and *The Seed Plants in Yunnan*. Experts and scholars organized by the Southwest Forestry College have carried out a comprehensive investigation on National Nature Reserve of Dawei Mountain since 1997.

3 Study methods

3.1 Seed plants and their altitudinal distribution

The study began from both the southwest slope and the northeast slope of the reserve. The virgin forest in the low-altitude humid rain forest has been damaged because of the constant agricultural activities and logging, and sparsely scattered forest could be found only in some steep valleys. Therefore, in the study: (1) routes were investigated and specimens collected to obtain plant species existing between the low elevation of 300 m and the Dajianding Peak of 2,356 m; (2) from 800 m to Dajianding Peak, with an interval of 50 m, sample patterns were collected in 400–1,000 m^2 quadrats, owing to the disturbed topography and changed community structure, to obtain plant specimens emerging between 800 and 2,356 m; (3) references such as *Yunnan Flora*, *Flora China*, and *The Seed Plants in Honghe Region of Southeast Yunnan* (Shui, 2003) were used in addition to the specimens collected above 300 m in Dawei Mountain. Accordingly, the seed plants and their altitudinal distribution were confirmed and a database of the seed plant flora was established, including distribution patterns of families and genera, elevations, habitats, life patterns, leaf shapes, and so on (Wu, 1991).

The number of plant species correlates directly with investigation range and the habitats involved owing to the seriously disturbed topography of Dawei Mountain and the high heterogeneity of environmental space; so the analysis was conducted by integrating samples collected from different slopes at the same elevation.

3.2 Vertical gradient analysis of the geographical components of seed plants

The study area was divided at every 100 m elevation, the percentage of worldwide distributed genera in the total genera (T1) was calculated; the percentage of the genera of the remaining 14 distributions, namely Pantropic (T2), Tropical Asia and Tropical America disjuncted (T3), Old World Tropics (T4), Tropical Asia and Tropical Australiasia (T5), Tropical Asia to Tropical Africa (T6), Tropical Asia (T7), North temperate (T8), East Asia and North America disjuncted (T9), Old World Temperate (T10), Temperate Asia (T11), Mediterranea, West Asia to Central Asia (T12), Central Asia (T13), East Asia (T14), genera endemic to China (T15), Vietnam to Southwest China (T7.4), Burma, Thailand to Southwest China (T7.3), Sino-Himalaya (T14.1), Sino-Japan

(T14.2), percentage of noncosmopolitan genera (T2–T15), and the ratio of the number of temperate genera to the number of tropical genera (T_w/T_r) was also shown in the article.

3.3 Cluster analysis of floristic elements of seed plants

Based on the analysis of vertical gradients, the dividing line of geographical elements of seed plants along altitudinal gradient in Dawei Mountain was discussed and detected to provide the basis for the division of the vertical vegetation zones there. A systematic cluster analysis was performed to analyze the percentage of each elevation area of 994 seed plant genera in each altitudinal distribution pattern and the percentage of the number of the species in distribution pattern genera (Yang and Lu, 1981; Tang, 1986; Xu, 1994).

Mean distance: The distance was determined by means of the shortest distance and the longest distance. Lustering G_p and lustering G_q were combined to G_r, so that the distance between G_r and any of the lustering G_i could form the following formula:

$$D_{ir} = \sqrt{\frac{1}{2}D_{ip}^2 + \frac{1}{2}D_{iq}^2 - \frac{1}{4}D_{pq}^2}$$

and the Euclid distance is

$$d_{ij} = \sqrt{\sum_{t=1}^{p}\left(X_{it} - X_{jt}\right)^2} \quad (i, j = 1,\ 2, ..., n)$$

where D_{ip}, D_{iq} and D_{pq} are respectively the distance between G_i and G_p , G_i and G_q, and G_p and G_q.

4 Results and analysis

4.1 Altitudinal gradient patterns of seed plant floristic elements

According to Shen et al. (2001), the geographical components in a flora zone are not only a reflection of history and interrelationship between this zone and other zones in the world, but also a response to the local environment (or climate). An analysis of the relevance between geographical components of seed plants and vertical gradients in Dawei Mountain is shown as follows.

4.1.1 Distribution patterns of elements in tropical zone

All elements in the tropic zone (T2–T7) decrease along the rise of elevation, which coincided with their properties but with an obviously different decreasing rate. Between 300 and 1,300 m, Tropical Asia elements remain at 32%, but the percentage drops sharply above 1,300 m, which indicates that this height is the boundary for most Tropical Asia (T7) elements. Between 300 and 1,500 m, the elements of Tropical Asia and Tropical Australasia (T5) and Tropical Asia to Tropica Africa (T6) change little in their percentage, but they decrease linearly above 1,500 m. Elements in Pantropic (T2), Tropical Asia and Tropical America disjuncted (T3), and Old World Tropics (T4) have a tendency of dropping along altitudinal gradients without obvious disjointed points but with obvious differences of the proportion between 300 to 2,300 m. Pantropic elements (T2) drop form 25.5% to 21.0% along the rise of the elevation; whereas Old World Topics (T4) from 13.0% to 7.0%, and Tropical Asia and Topical America disjuncted (T3) from 4.2% to 2.1%. The distribution of tropical elements along altitudinal gradients shows that the obvious boundary differentiating tropical floristic elements is located at the elevation of 1,500 m in Dawei Mountain.

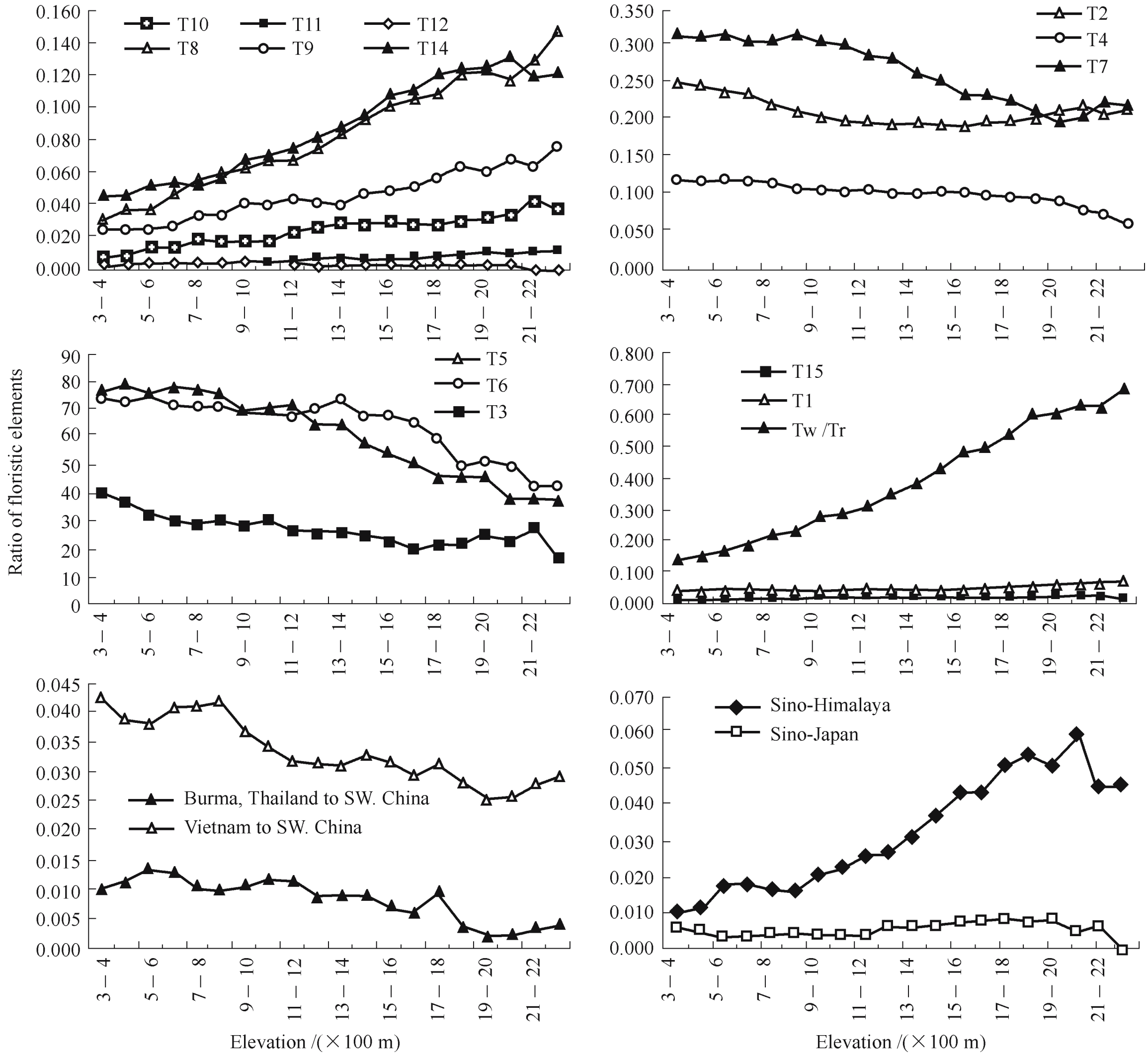
Besides, elements in Vietnam to Southwest China (T7.4) and Burma, Thailand to Southwest China (T7.3) in Topical Asia have similar changes along altitudinal gradients; the proportion of the Vietnam to Southwest China always dominates, almost four times that of Burma, Thailand to Southwest China, which indicated the close relationship between flora in Dawei Mountain and that in Vietnam to Southwest China.

4.1.2 Distribution patterns of elements in temperate zone

The proportion of all elements in the temperate zone (T8–T14) increases along altitudinal gradients, which was identical to their attributes. East Asia (T14) elements account for the most, and the proportions of the elements in both North Temperate (T8) and Old World Temperate (T10) rise evidently along altitudinal gradients, but they increase slowly in both Temperate Asia (T11) and East Asia and North America disjuncted. The proportions of the elements in Mediterranea, West Asia to Central Asia (T12) and Central Asia (T13) markedly related to arid habitats are small or do not exist, which indicated the humid conditions of Dawei Mountain habitats historically. As a joint of two large elements in East Asia, Dawei Mountain is the combination of elements in both the east and the west (Li and Li, 1992); so elements in East Asia were the most special ones. East Asia (T14) maintained a strong tendency of rising along altitudinal gradients, and reached the peak at a range of 1,900–2,100 m, but its subdistribution, namely, Sino-Himalaya (T14.1) and Sino-Japan (T14.2) showed different patterns along altitudinal gradients, the former changing drastically, the latter slightly. The result might be related to southwest mountains in China that were raised to different degrees (Zhou and Ren, 1984) during Himalayan movement at the end of the third Ice Age. The movement created a condition for scattering southeast the elements in Sino-Himalaya flora along the medium-high mountains.

4.1.3 The distribution patterns of elements endemic to China

The proportion of elements endemic to China rose slightly along altitudinal gradients, which illustrated its relationship with temperate elements. At 1,100–1,300 m, it peaked, and dropped at 1,700–1,900 m. The comparatively low proportion might be the result of severe disturbance of protophytes.



T1, Cosmopolitan; T2, Pantropic; T3, Tropical Asia and Tropical America disjuncted; T4, Old World Tropics; T5, T. Tropical Asia and Tropical Australasia; T6, T. Tropical Asia to Tropical Africa; T7, Tropical Asia; T8, North Temperate; T9, East Asia and North America disjuncted; T10, Old World Temperate; T11, Temperate Asia; T12, Mediterranea, West Asia to Central Asia; T14, East Asia; T15, Endemic to China; T_w/T_r, The ratio of the number of temperate genera to the number of tropical and subtropical genera.

Fig. 1 The vertical distribution of the geographical elements of the flora of Dawei Mountain

4.1.4 The distribution patterns of the ratio of temperate elements and tropical elements

The ratio of the number of temperate genera to the number of tropical genera rose steadily along altitudinal gradients (Table 1), but it was less than 1 even near the mountaintop and the ratio turned out to be lower than 1 at an elevation of 300–350 m (peak) when the patterns of seed plant flora in the community were counted according to the sample data at different elevations. This clearly illuminated the tropical characteristics of Dawei Mountain flora, indicating that there was no flora equilibrium point in this area. Curves shown in Fig. 1 revealed fluctuation at various degrees off the general trend, which was clearly related to the water and heat conditions at different topographical positions.

4.2 Cluster analysis on flora

The analysis of the percentage of genera in different flora types changing along altitudinal gradients showed the gradient changes of the compositions of the floristic elements. It also meant that the changing characteristics of floristic element compositions could be used to detect the variation degrees of plant formation at environmental gradients. The number of genera in different flora types at different elevations and the number of species subordinated to them were counted, and their percentage in the total genera and total species subordinated to them was calculated. A systematic cluster analysis was performed at 20 different elevations to recognize the disjoint of the change of flora along altitudinal gradients and to identify the division lines among humid rain

Table 1 Comparison of several forest communities at different elevations and their T_w/T_r ratio

Community type	T_w/T_r*	Elevation /m	Exposure	Grade /(°)	Soil types	State	Site
Dipterocarpus tonkinensis, *Crypteronia. paniculata*, *Pometia tomentosa* Comm	0.12	820	E	30	Yellow latosol	Lot	Nuomi Village
Altingia excelsa, *Exbucklandia populnea* Comm.	0.12	1,000	EN	18		Frequent	
Rhodoleia parvipetala, *Nyssa sinensis*, *Nephium chryseum*, *Madchuca pasquieri* Comm	0.13	1,070	SW	20	Yellow latosolic red soil	Almost none	Weishan Laozhai
Eberhardtia aurata, *Lithocarpus megahylla*, *Macaranga henryi*, *Cryptocarya depauperata* Comm	0.15	1,360	E	15	Yellow latosolic red soil	Few	Zimuhe Gouqing
Rhodoleia paripetala, *Lithocarpus megalophyllus*, top *Cryptocarya densiflora* Comm	0.20	1,650	EN	25	Yellow soil	Less	Tiantou mounatain-
Lithocarpus harlandii, *Schima villosa*, *Eberhardtia tonkinensis* Comm	0.18	1,660	N	30	Mountain yellow soil	Less	Dawei Mountain
Lithocarpus harlandii, *Lindera latifolia*, *Mylitara laosensis* Comm	0.32	1,705	SE	15	Mountain yellow soil	Lot	Liugongli
Lithocarpus hancei, *Rehderodendron macrocarpus*, *Pygeum oblongum* Comm	0.24	1,870	WN	20	Yellow soil	Almost none	Bagongli
Lithocarpus spp., *Castanopsis hysirix*, *Rhodoleia parvipetalala* Comm	0.33	2,080		25	Yellow soil	None	Dawei Mountain Gouqing
Lithocarpus xylocarpus Comm	0.29	2 280		20	Yellowish brown soil	Almost none	Top of Dawei Mountain
Lithocarpus spp., *Rhododendron* sp., *Fargesia* sp. Comm.	0.64	2 300	SW, NE	35–50	Yellowish brown soil	Few	Dajian Mountaintop

Note: * T_w/T_r: The ratio of the number of temperate genera to the number of tropical and subtropical genera

forests, seasonal rain forests, montane rain forests, monsoon evergreen broad-leaved forests, montane mossy evergreen broad-leaved forests, and montane top mossy dwarf forests. The species in different floristic types and the total species at the same elevation were clustered and the result was shown in Fig. 2a and that of genera was shown in Fig. 2b.

1. There was an evident dividing live between elevation belt A4 (600–700 m) and A5 (700–800 m). It was reasonable to divide the vegetation of humid rain forests and montane rain forests in Dawei Mountain at the elevation of 700 m, which reflected the relationship between floristic structure, species composition, and vegetation types.

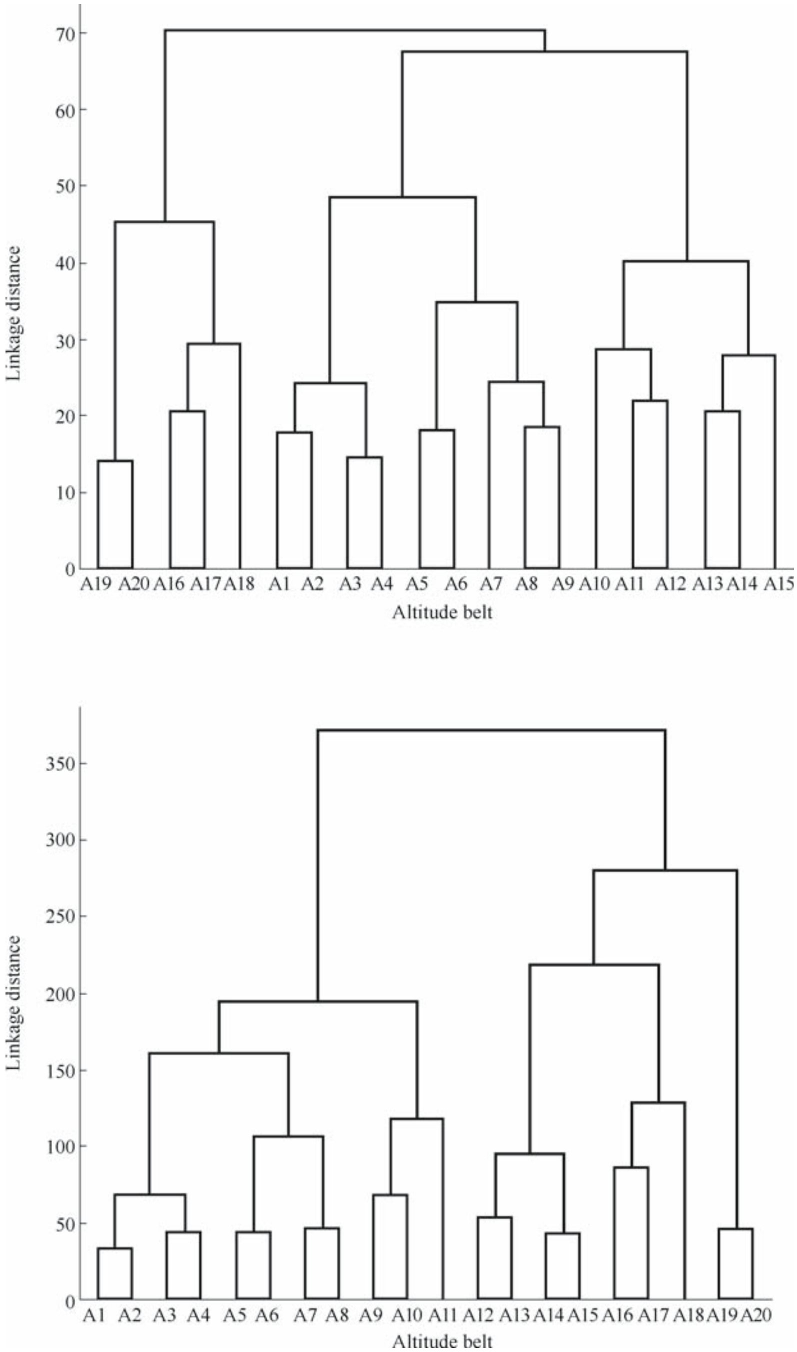
2. An obvious dividing line existed between elevation belt A12 (1,400–1,500 m) and A13 (1,500–1,600 m). The classification resulted in accordance with the vegetation classification principles, and the basis of Wu and Zhu (1987) also proved that the elevation of around 1,500 m was the upper boundary line of montane rain forests, which could be seen in Sect. 4.1 as well. Montane rain forests formed an obvious vertical belt in Dawei Mountain based on the field investigation, which belonged to upper boundary line (at an elevation of 700 m) of north tropical zone to summer foggy line (at an elevation of 1,000–1,100 m), the highest one at 1,300–1,500 m.

3. An elevation of 1,800 m—between the elevation belt A15 (1,700–1,800 m) and A16 (1,800–1,900 m)—divided evergreen broad-leaved forests into different subforests. In fact, at an elevation of 1,300–1,800 m south subtropical warm evergreen broad-leaved forests were distributed—monsoon evergreen broad-leaved forests, which were distributed at the far south latitude under the influence of monsoon climate. The tree types were mainly *Castanopsis* and *Lithocarpus* of Fagaceae, Theaceae, Magnoliaceae, Hamamelidaceae, Aquifoliaceae, and Symplocaceae. Above 1,800 m are mainly montane mossy evergreen broad-leaved forests, a special vegetation growing in a highly humid habitat in tropical mountains. Field survey also showed that montane mossy evergreen broad-leaved forests were distributed in humid habitats of 1,800–2,100 m elevation with warm and cool climate, foggy round the year. Its most distinct feature was that trees were mostly covered with thick and developed layers of moss. Nonrepresentative montane mossy dwarf forests (above 2,100 m) in the area were distributed in windward sides and barren land on the mountain slope. They could be considered as nontypical mountaintop mossy dwarf forests for their small-scale and limited seed plant species and less than 10 m community.

5 Conclusions

Generally, the flora in Dawei Mountain had tropical features without floral equilibrium. Its flora was closely related to that of Vietnam to Southwest China, and its small percentage of elements relevant to arid habitats revealed the humid geographical conditions of Dawei Mountain historically. Sino-Himalaya in East Asia (T14) maintained a strong tendency of rising along altitudinal gradients, which revealed that during Himalayan movement at the end of the third Ice Age a condition was created for the scattering of the elements toward southeast.

Both gradient analysis and cluster analysis indicated that there was an evident dividing line at an elevation of 1,500 m, which was the right line dividing Dawei Mountain into



(a): Based on the species composition of all genera; (b): Based on the areal-type composition of all genera. A1–A20: The vertical belts from.300–2,300 m elevation with an altitudinal interval of 100 m.

Fig. 2 Floristic dendrograms of 20 altitude delts of Dawei Mountain obtained by using different data

tropical rain forests and evergreen broad-leaved forests. The types of vegetation and boundaries along altitudinal gradients: humid rain forests were distributed below 700 m, montane rain forests between 700 and 1,500 m, monsoon evergreen broad-leaved forests between 1,300 and 1,800 m, and montane mossy evergreen broad-leaved forests above 1,800 m. Cluster analysis coincided with the traditional classification of vegetation.

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