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Altitudinal distribution of seed plants in Foping and Changqing, Qinling Mountains, China

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To analyze the altitudinal distribution of seed plants in the central area (~590 km^2) of the Qinling Mountains (central China), supporting a giant panda population, we conducted floristic surveys at discrete altitude intervals and reviewed the data in published floras for the area. We found that there are 2031 species of seed plants in the study area, representing 694 genera and 148 families. These seed-plant species account for 59.1% of all those known from the Qinling Mountains and 7.6% of those found in China. The proportion of pantropical species decreases with increasing altitude, and above 2800 m a.s.l. tropical species do not exist. The proportion of northern-temperate plants increases with increasing altitude. The area accommodates predominately a mixture of Sino-Japanese and Sino-Himalayan forest-region species. A regression model predicted a theoretical boundary between the subtropical and warm-temperate zones at 530 m above sea level.

Introduction

The natural mountain ecosystems are highly variable, typically with discrete geographic and biological characteristics distributed along climate-driven horizontal zones or altitude gradients (White & Miller 1988, Fang *et al*. 2004, Fischer *et al*. 2011). Because mountain ecosystems are heterogeneous and relatively undisturbed by humans, they harbor a diversity of plant species, and are recognized as areas of speciation within endemic genera, also known as floristic regions (Körner 2000, Myers *et al*. 2000, Culmsee *et al*. 2011).

The Qinling Mountains in central China represent just such an isolated high mountain range, with relatively untouched ecosystems and a clear altitudinal zonation. Dividing the watershed of the Yellow and Yangtze Rivers, the Qinling Mountains traverse the middle of China east–west and separate the subtropical zone in the south from the warm-temperate zone in the north (He *et al*. 2009, Shen 2010). Because of their geographic location, the Qinling Mountains form an area of immense endemic biodiversity (Yu *et al*. 2006, Wang *et al*. 2010), containing a major portion of the vegetation types in China concentrated in a relatively small area. As such, they are a key region for floristic research.

Foping and Changqing are two national nature reserves located in the middle of the Qinling Mountains and they are the main habitats of the giant panda (Pan *et al*. 1988, Feng *et al*. 2009). They have become important for the

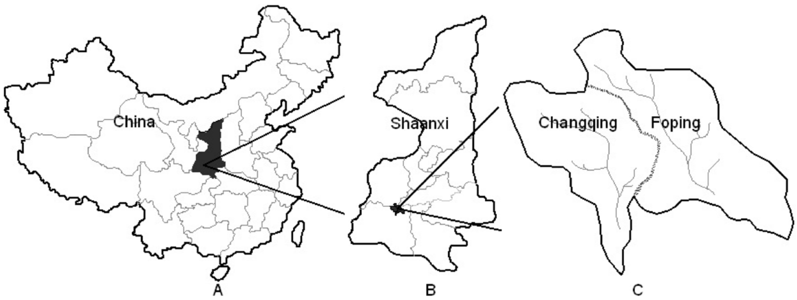

Fig. 1. Location of the study area. — **A**: Shaanxi Province in China. — **B**: Study area within Shaanxi Province. — **C**: Study area.

conservation of many rare and endangered plants and animals, and studies of the vegetation of this region are crucial to conservation efforts. Several previous studies have reported on the plant communities and species diversity of the region (Yue *et al*. 1999, Yue *et al*. 2000, Du *et al*. 2011, Zhang *et al*. 2011). However, there has been little information on the flora specific to the giant panda habitat in Qinling, and especially rare are quantitative analyses of elevation zones, vertical distribution patterns, and changes in the plant zones. Studies that focus on the altitudinal distribution of plants in the area would contribute to the understanding of the composition and structure of this floristic region and provide a baseline assessment of the biodiversity that supports the giant panda habitat.

In the present study, we conducted a field survey of the region and a search of the literature to document the seed plant species of the giant panda habitat, and then constructed distribution profiles of these plant species. Our purpose was to understand the altitudinal pattern of seed-plant distribution in the habitat and provide a theoretical basis for its conservation and artificial reconstruction.

Material and methods

Study area

The study area is located in the middle of the southern slope of the Qinling Mountains and encompasses the Foping and the Changqing National Nature Reserves (33°19´–33°46´N, 107°17–107°55´E). The area covers 59 146 ha (Fig. 1). Hanzhong City and Xi'an are located 158 km south and 215 km north, respectively, of the headquarters of the Foping Nature Reserve, and Xi'an is 300 km north of the Changqing National Nature Reserve. The forest coverage of the region is higher than 90%. The elevation ranges from 800 to 3174 m a.s.l.

The region has 310 vertebrate species, including the giant panda (*Ailuropoda melanoleuca*), takin (*Budorcas taxicolor*), golden snub-nosed monkey (*Rhinopithecus roxellana*), and crested ibis (*Nipponia nippon*). The 200 giant panda individuals account for 2/3 of all those in the Qinling Mountains. The region also has a great diversity of vegetation types: coniferous forest, broad-leaved forest, bamboo forest, and meadow. The forests are mainly dominated by the Chinese larch (*Larix chinensis*), Chinese pine (*Pinus tabulaeformis*), Chinese white pine (*Pinus armandi*), Bashan fir (*Abies fargesii*), oriental white oak (*Quercus aliena* var. *acuteserrata*), windbreak bamboo (*Arundinaria fargesii*), and arrow bamboo (*Fargesia qinlingensis*) forests.

Field work and data sources

We set up two principle transects, one in the Foping National Nature Reserve and one in Changqing. Each transect was 150 m wide. In each transect, we set up standard plots of 500 m^2, (20 × 25 m^2) for sampling; the altitude interval between plots was 100 m. We analyzed the plant communities in a total of 107 plots. We recorded the geographic coordinates, altitude, and the plant species found in each plot. We also consulted the floras published by Ren *et al*. (2002) and Liu and Zhang (2006) to supplement the plant species list and then constructed a floristic inventory database for the giant panda habitat in the Qinling Mountains.

Calculation of the balance point of floristic composition

We determined the floristic region for each species in our plant inventory database by consulting the classification of China's floristic distribution types by Wu (1991, 1993). Then for each of the 23 sampled altitude intervals, we recorded the number of species belonging to each floristic region (FR_1 to FR_{15}; *see* Table 1).

The flora transition value was calculated by dividing the sum of the species which have tropical distributions (FR_r) by the sum of the species which have temperate distributions (FR_w):

$$\frac{FR_r}{FR_w} = \frac{\sum_{i=2}^{7} FR'_i}{\sum_{j=8}^{14} FR'_j} \quad (1)$$

When $FR_r/FR_w = 1$, the flora is composed of equal numbers of temperate and tropical species. Therefore, the altitudinal interval with this transition value is the altitude of balance between representatives of these two flora elements.

Table 1. Floristic regions (FR) of the seed plants in the giant panda habitat of Qinling.

Code	Floristic regions	
FR_1	Worldwide	World element
FR_2	Pantropical	Tropical element
FR_3	Tropical Asia and tropical America	
FR_4	Old World	
FR_5	Tropical Asia to tropical Oceania	
FR_6	Tropical Asia to tropical Africa	
FR_7	Tropical Asia	
FR_8	North Temperate	Temperate element
FR_9	East Asia and North America	
FR_{10}	Old World Temperate	
FR_{11}	Temperate Asia	
FR_{12}	Mediterranean Sea, Western to Central Asia	
FR_{13}	Central Asia	
FR_{14}	East Asia	
FR_{15}	Endemic to China	China element

Results

In the study area, there were 2031 seed-plant species, representing 145 families and 694 genera (Table 2). Of those, 21 species were gymnosperms, belonging to 15 genera and 6 families, representing 46.7%, 65.2%, and 66.7% of the species, genera and families, respectively, of all the gymnosperms in Qinling, and 10.9%, 44.1% and 54.6%, respectively, of those in China. There were 2010 angiosperm species belonging to 679 genera and 139 families, representing 59.3%, 69.1%, and 73.9% of the species, genera and families, respectively, of all the angiosperms in Qinling, and 8.3%, 23.1%, 47.8%, respectively, of those in China.

Altitudinal patterns in seed-plant distribution

Distribution of tropical plants

The proportion of tropical plants in the flora decreased with increasing altitude (Fig. 2a). The

Table 2. Numbers of seed-plant families, genera, and species in the giant panda habitat of Qinling and in China.

Category	Family			Genus			Species		
	Study area	Qinling	China	Study area	Qinling	China	Study area	Qinling	China
Gymnosperms	6	9	11	15	23	34	21	45	193
Angiosperms	139	188	291	679	983	2946	2010	3391	24357
Total	145	197	302	694	1006	2980	2031	3436	24550

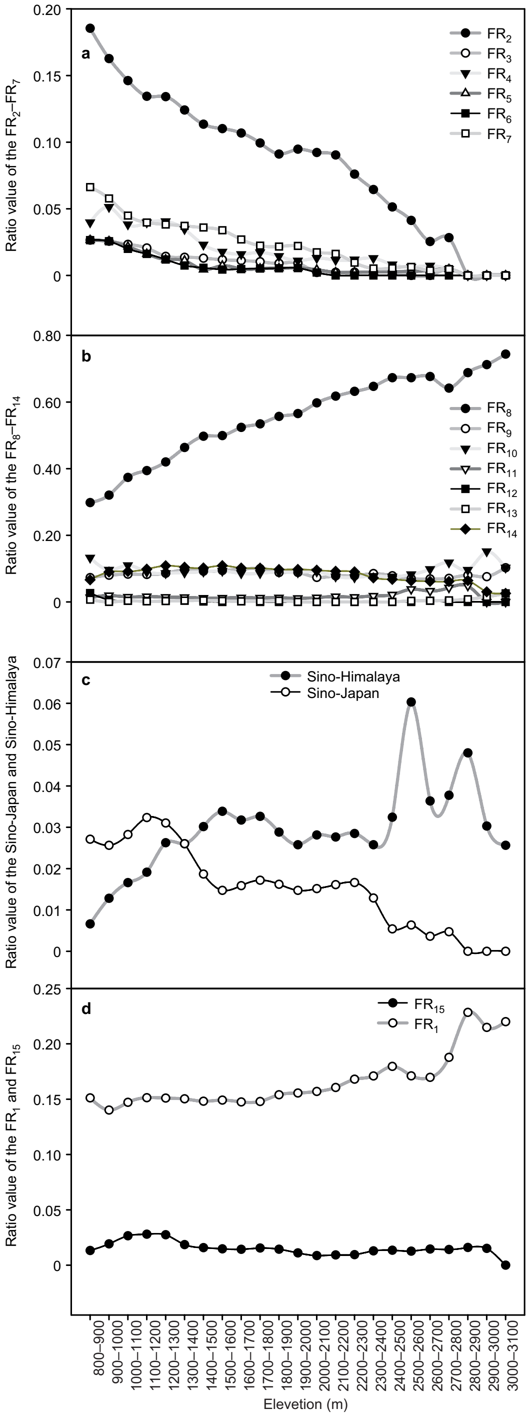

Fig. 2. Altitudinal distribution of seed plants in the giant panda habitat of the Qinling Mountains. *See* Table 1 for the abbreviations.

rate of decrease differed, however, among species of different subtypes of tropical distribution. The proportion of pantropical plants (FR_2) decreased from 18.5% to 0%, and the decrease between 800 and 1100 m, and 2100 and 2800 m a.s.l. was significant. There were only few species belonging to other tropical floristic regions (FR_3–FR_7), and the transition-value change with increasing altitude was smaller. FR_3 (tropical Asia and America) had the narrowest altitudinal range and disappeared at 2100 m a.s.l., while FR_2 (pantropical), FR_4 (Old World), and FR_5 (tropical Asia to tropical Oceania) had the widest ranges and disappeared only at 2800 m a.s.l. Above around 2800 m a.s.l. species of FR_2–FR_7 (tropical components) were absent, so this altitude is the boundary for tropical species.

Distribution of temperate plants

Plants of the northern-temperate floristic regions (FR_8) accounted for the major portion of temperate plants, and their proportion increased with increasing altitude (Fig. 2b) from 29.8% at 800 m a.s.l. to 74.4% at 3100 m a.s.l. The Sino-Japanese and Sino-Himalayan forest-region distribution types are subtypes of the East Asia floristic region (FR_{14}), and they have different altitudinal patterns. The species representing the Sino-Japanese forest region had a peak concentration at 1100–1200 m a.s.l., while the peak concentration for the species of the Sino-Himalayan forest region was between 2500 and 2600 m a.s.l. (Fig. 2c). The ratio of Sino-Japanese to Sino-Himalayan forest-region plant species decreased with increasing altitude. While Sino-Japanese species dominated below 1400 m a.s.l., Sino-Himalayan species were dominant above that altitude.

Species distributed worldwide compared with Chinese endemics

At each sampled altitude, the proportion of seed-plant species with a worldwide distribution (FR_1) increased with increasing altitude, from 15.1% at 800 m a.s.l. to 22.0% at 3100 m a.s.l. (Fig. 2d). The proportion of Chinese endemics (FR_{15}) was greatest between 1100 and 1200 m a.s.l.; the numbers were very small at all other

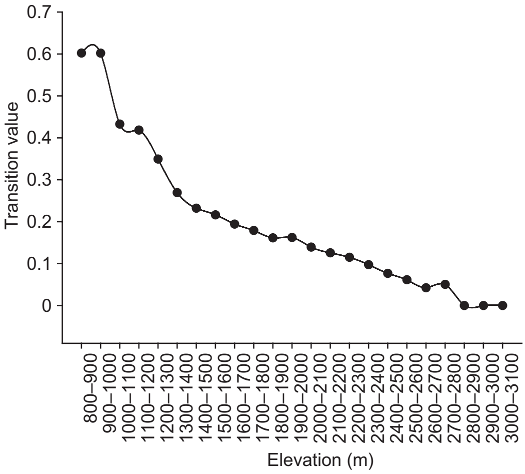

Fig. 3. Transition values (FR_r/FR_w) by altitude.

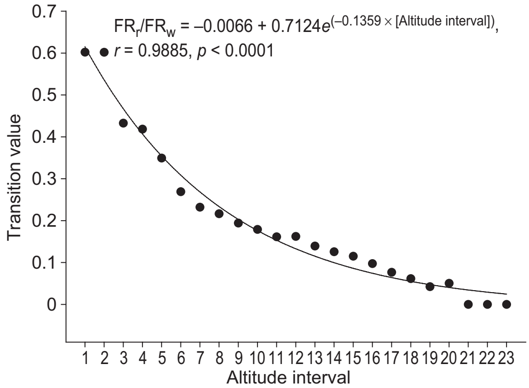

Fig. 4. Regression model of the association between transition values (FR_r/FR_w) and altitude.

altitudes, and at 3000–3100 m a.s.l. no Chinese endemics were found.

Balance point between tropical and temperate flora elements

The transition value (FR_r/FR_w) was < 1 throughout the entire altitudinal gradient (Fig. 3). Tropical species became fewer with increasing altitude. Thus, we found no floristic balance point between tropical and temperate flora elements in the study region.

To extrapolate such a balance point, we built a non-linear regression describing the association between FR_r/FR_w and altitude (Fig. 4), and calculated that the theoretical balance point between the tropical and temperate zones should be at 530 m a.s.l.

Discussion

The floristic composition of the giant panda habitat is a mixture of temperate and tropical plants, but dominated by the temperate ones. The highest altitude for the tropical species is 2800 m a.s.l. However there is no particular altitude that would definitively demarcate subtropical from warm temperate regions.

It is recognized that the wellbeing of the giant panda depends on all the vegetation within its habitat (Jian *et al*. 2011, Zhang *et al*. 2011). For the preservation of the giant panda population, studies of the vegetation of this region are crucially important. In this study, we found that plants with pantropical and northern-temperate distributions dominated the tropical and temperate zones, respectively, and their distribution patterns changed with altitude. These results agree with those of previous reports (Zhang 2002, Zhao *et al*. 2010).

The proportion of pantropical seed plants (FR_2) acutely decreased at altitudes between 800–1100 m and 2100–2800 m a.s.l. This may be because 800 m a.s.l. is on the border of the reserve region and human disturbance has been severe in this area, resulting in a serious lack of temperate components. As altitudes increased, human disturbance also decreased, and a large number of temperate components were intact. Furthermore, the proportion of pantropical plants (FR_2) decreased, and that of temperate plants (FR_8–FR_{14}) increased. The proportion of pantropical plants decreased rapidly at 2100–2800 m a.s.l.

In the temperate zone of the study region at 1400 m a.s.l., the proportion of plant species with a Sino-Japanese forest-region distribution was almost equal to that of plants with a Sino-Himalayan forest-region distribution. This indicates that 1400 m a.s.l. is the balance point between the species representing these two distribution types, which confirms that this region is the transitional zone between the Sino-Japanese and Sino-Himalayan forest regions (cf. Shen 2010).

The floristic region balance (transition) point is the altitude at which the proportion of plant species of temperate distribution, i.e., the temperate element, is the same as the proportion of plant species with tropical distribution. The altitude at which this occurs is also influenced by latitude (Feng & Xu 2008). The study area is characterized by a predominantly temperate flora and no floristic balance point. This result confirms that in China tropical plants dominate only below 30°N (cf. Zhu *et al*. 2007). Our study area is at 33°N in a mixed subtropical and warm-temperate zone. The southern slope of the Qinling Mountain range at 1300 m a.s.l. is the acknowledged north–south climatic boundary (Shen 2010). However, we found that the theoretical north–south floristic boundary is at 530 m a.s.l., but it does not exist in the study area.

Considering our data and observations, we conclude that the critical point for tropical plants is at 2800 m a.s.l., and 530 m a.s.l. is the theoretical balance point between the tropical and temperate zones. These limits are useful as dividing lines for the floristic patterns in the research area, and also provide the necessary theoretical foundation for plant diversity protection and restoration of the giant panda habitat. Floristic composition is influenced by many environmental factors such as temperature, water, and humidity, as well as altitude and latitude (Zhu *et al*. 2007), and their interactions are complex (Gaston 2000, Ruedas *et al*. 2006) in strict association with one another (Feng & Xu 2010). Thus, further studies should explain how these factors together affect the floristic patterns in this important region.

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