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TOPOGRAPHIC CONTROLS ON THE DISTRIBUTION OF INDIGENOUS RHODODENDRONS IN THE SOUTHERN SLOPE OF THE NANLING MOUNTAINS, SOUTH CHINA

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Abstract

Rhododendrons, one of the traditional flowering plants in China and overseas, are famous for their beautiful flowers. However, only a few indigenous Rhododendron plants are used for landscaping in China. To determine the ecological role of distribution of Rhododendrons, and analyse whether and how major topographic factors influence the distribution and growth of indigenous Rhododendrons, a total of one hundred and two plots (10 m × 10 m, 100 m^2) were laid out in the southern slope of the Nanling Mountains, South China (700–1900 m a.s.l.). We found that the topography affecting the Rhododendron species, i.e., *Rhododendron simiarum, R. cavaleriei, R. bachii, R. championae, R. kwangtungense R. fortune, R. chunii*., and there are different patterns among species. The richness and abundance of the seven indigenous Rhododendrons depaned on topographical gradient, greater higher elevation, intermediate slope steepness, convex slopes and shady aspect. By contrast, sunny habitats and habitat at low positions in the slope had fewer rhododendron plants. Non–parametric Kruskal–Wallis test and canonical correspondence analysis showed that altitude, position in the slope, slope shape and slope aspect had significant effects on the total abundance of Rhododendrons (p<0.05) compared with slope steepness. Indicator species analysis identified were indicative of altitude (four species), slope aspect (one species), position in the slope (one species), and slope shape (two species), respectively. The spatial heterogeneity of indigenous Rhododendron plants to topographic factors has significant implications for species conservation and potential for use in landscaping.

Key words: Indigenous Rhododendrons, Indicator species, Topographic, Landscaping.

Introduction

Determination of the environmental gradients that influence species richness, composition and biomass of plant communities is one of the most important issues in ecology (Körner, 2007). Topography is one of the most important factors affecting the tree growth performance (Sattler *et al.,* 2014) and distribution of trees in mountainous forests (Enoki, 2003), which also has been proven to be a strong regional predictor of above ground biomass accumulation in tropical forests (Alves *et al.,* 2010). The availability of accurate topographic information at different spatial scales is a limiting factor for relating to forest productivity (Laamrani *et al.,* 2014), and as a driver of cryptic speciation (Britton *et al.,* 2014).

Ericaceae are widely distributed in temperate and subarctic regions, also at high elevations in tropical regions. There were 22 genera and 826 species (524 endemic) have been found in China (Fang, 2005). The genus Rhododendron is the largest genus of Ericaceae that are widely spread in Asia, Europe, and North America. Sino-Himalaya Region is the largest centre of distribution for modern Rhododendron (Min & Fang, 1979). George Forrest collected large numbers of living and herbarium specimens of hitherto unknown species in Yunnan, China, to introduce to the western world (Geng, 2010). The genetic relationships among Rhododendron species were partially related to their taxonomic position, geographic distribution and morphological classification (Zhao *et al.,* 2015). Tree Rhododendron adapts to a wide range of habitats with different environmental conditions (Ranjitkar *et al.,* 2013). However, Rhododendron plants, are also serious invasive alien plants, can inhibit forest regeneration in several systems worldwide (Wurzburger & Hendrick, 2007). Using invasive shrub rhododendron as a case study, Harris *et al.,* (2011) integrated information on both the demographics and spatial dynamics within an individual–based, spatially–explicit model to investigate the invasion potential of shrub Rhododendrons in different habitats. Moreover, Rhododendron toxins was degraded during composting (Hough *et al.,* 2010). Rhododendrons are increasingly recognized as a keystone element in the Himalayan region, which provides the ecological stability, associated niche and community continuum (Singh *et al.,* 2009). Biodiversity conservation was recognised as a globally serious subject at the United Nations Conference on Environment and Development Earth Summit in June 1992 in Rio de Janeiro, Brazil (Hsu *et al.,* 2013). Biodiversity has become a major concern in landscape planning in the recent years (Morimoto & Yoshida, 2005). Hybrid Rhododendron plants, such as *Rhododendron pulchrum*, *Rhododendron pulchrum* var. *phoeniceum*, and *Rhododendron simsii,* are widely applied in parks, residential areas and street–side green spaces in China, with versatile application patterns presenting excellent landscape effects. However, indigenous Rhododendron plants are seldom applied in landscaping in China.

The spatial distribution of high–elevation tropical forest patches is controlled by landscape–scale topographic characters (Coblentz & Keating, 2008). Topography can significantly alter microclimates and resource availability (Simonson *et al.,* 2014). Moreover, community–scale topographic factors, which also have great impact on species composition and diversity patterns of forest communities (Palmer & Dixon, 1990), significantly influence the distribution of understory species in the Nanling Mountains, with the magnitude of influence in the following order: elevation > slope aspect > slope steepness

(Ou *et al.,* 2009). The distribution of species play a key ecological role in forest communities. Understanding the relationship between topographic factors and species patterns is important for forest conservation and sustainable management.

In this study, we analyzed the ecological relationships between the distribution of Rhododendron plants and five topographic factors in the southern slope of the Nanling Mountains. The objectives of this study were to: 1) to reveal whether the topography affect the richness and abundance of Rhododendron species; 2) to ascertain the major topographic factors influence the distribution of indigenous Rhododendron; and 3) to determine whether the abundance of each species of Rhododendron vary in topographical gradient or not?.

Materials and Methods

Study area: The Nanling mountain (24º37′–24º57′N, 112º30′–113º04′E) range is located in southern China, straddling from west to east across the borders of Guangxi, Guangdong, Hunan, and Jiangxi provinces for more than 1000 km. It is a natural dividing line in southern China that separates the Yangtze River from the Zhujiang River. The Nanling National Nature Reserve, the largest Nature Reserve in Guangdong province (58400 ha), is located in the southern slope of the Nanling Mountains, with rugged topography and altitude ranging from 300 m to 1902 m at the summit of Shikengkong in Ruyang. On the average, annual temperature is 17.7 ℃, annual relative humidity is 84%, and annual precipitation is 1705 mm mainly occurring between March and August. The Nanling Mountains are the refugium of ancient tropical flora and the origin and key belts of temperate and subtropical plants in East Asia. A huge reservoir of biodiversity exists in the Nanling Mountains, with a record of 3760 vascular plant species (including subspecies levels), belonging to 268 families and 1306 genera (Xing, 2012).

Sampling design and plant census: Community monitoring plots were set along the elevation gradient based on the relative distribution of the indigenous Rhododendron plants in the southern slope of the Nanling Mountains. We studied the Rhododendron community in 102 plots (10 m × 10 m, 100 m^2) which were set along thirteen 120 m transects (700–1900 m a.s.l.) (Fig. 1). The total inventoried area was 1.02 ha. The plots were distributed over a 120 × 1200 m^2 area (≈14.4 ha). We identified all indigenous Rhododendron species in each sample plot using the available literature (Fang, 2005), and counted the number of stems, height, percentage cover or diameter at breast height (DBH) of all individuals including seedlings, juveniles and adults (Hao *et al.,* 2002).

We recorded the topographic factors on each plot. Slope steepness and slope aspect were measured using a professional forest compass (DQL-1, Harbin Optical Instrument Factory, China), whereas position in the slope and slope shape were determined by visual estimation. According to a general classification system from gentle to very steep, the slope degree of the sample plots ranged from 6.0° to 59.8° and were classified into five slope steepness groups. Where as slope aspect was initially divided into eight groups from the starting point of due north, namely, north aspect (338°–22°), northeast aspect (23°–67°), east aspect (68°–112°), southeast aspect (113°–157°), south aspect (158°–202°), southwest aspect (203°–247°), northwest aspect (248°–292°) and west aspect (293°–337°) in a clockwise direction (Olivero & Hix, 1998). As shown in Table 1, slope aspect was divided into sunny slope, semi–sunny slope, semi–shady slope and shady slope. The sunny slopes are south aspect, south west aspect and south east aspect, semi-sunny slopes are east aspect and west aspect, semi-shady are northwest aspect and northeast aspect, shady slopes are north aspect, respectively.

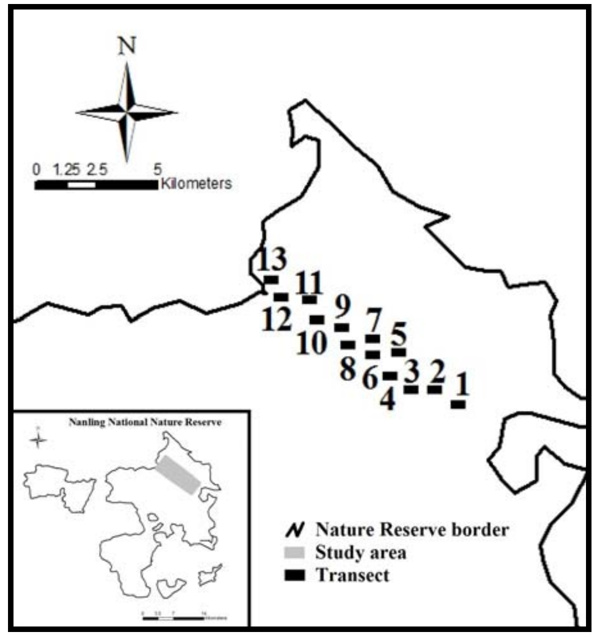

Fig. 1. Nanling National Nature Reserve. The light grey shaded rectangle on the inset indicates the location of the study area, and the black shaded rectangle indicates the location of transects.

Statistical data analysis: Two datasets were constructed based on data collected from the 102 plots. The first dataset consisted of Rhododendron plants. The second dataset comprised a quantitative environmental data matrix, including five topographical factors, (i.e. altitude, slope steepness, slope aspect, position in the slope and slope shape). Non–parametric Kruskal–Wallis test were used to analyse the differences in Rhododendron plant distribution between groups. Kruskal–Wallis test was carried out using Statistica version 8.0. All tests were performed at $p<0.05$. Canonical correspondence analysis (CCA) was performed to investigate the relationships between Rhododendron plants distribution and topographical factors. A Monte Carlo permutation test based on 999 random permutations was conducted to test the significance of the eigenvalue of the first canonical axis. CCA was carried out using CANOCO 4.5. Indicator species of indigenous Rhododendron in the Nanling Mountains were sieved using indicator species analysis (ISA). It was computed using the Dufrene and Legendre method to calculates the IV values (Su *et al.,* 2012).

Table 1. Measurements and variables of the study.

Measurement and variable	Variable coding
Altitude	1 = 700–900 m, 2 = 1000–1200 m, 3 = 1300–1600 m, 4 = 1700–1900 m
Slope steepness	1 =5.0°–15.0°, 2 =15.1°–25.0°, 3 =25.1°–35.0°, 4 =35.1°–45.0°, 5 =45.1°–59.8°
Slope aspect	1 = Sunny, 2 = Semi–sunny, 3 = Semi–shady, 4 = Shady
Position in the slope	1 = Upper, 1 = Middle, 1 = Lower
Slope shape	1 = Convex, 1 = Flat, 1 = Concave

Table 2. Number of stems in plots of seven indigenous Rhododendrons, and mean (± S.E.) of average basal area and average height of these species at the southern slope of the Nanling Mountains in South China.

Species	No. of stems	No. of plots	Average basal area (cm^2)	Average height (m)
Rhododendron simiarum Hance	205	24	44.7±3.2	3.7±0.1
Rhododendron cavaleriei Levl.	173	42	39.6±3.1	6.5±0.2
Rhododendron bachii Levl.	154	35	24.1±2.5	5.7±0.2
Rhododendron championae Hook.	57	26	67.5±10.7	5.7±0.4
Rhododendron kwangtungense Merr. et Chun	27	5	23.5±3.4	6.1±0.3
Rhododendron fortunei Lindl.	13	5	9.7±1.0	2.4±0.1
Rhododendron chunii Fang	3	3	35.2±4.8	4.7±0.7

Results

Species composition and distribution: In our 102 plots, we found 1,149 Rhododendron individuals, including 632 stems (Diameter at Breast Height, DBH> 3 cm), belonging to seven species (Table 2). *Rhododendron simiarum* had the highest abundance, whereas *Rhododendron cavaleriei*, *Rhododendron bachii* and *Rhododendron championae* were more widely distributed. All the Rhododendron plants in our plots were perennial evergreen woody plants, shrubs or small trees, in which the tallest tree (*R. championae)* was 16 m, whereas the shortest tree (*R. fortunei)* was only 1.8 m. In terms of the average height of rhododendron individuals, *R. cavaleriei* was the highest, whereas *R. fortunei* was the shortest. Regarding average basal area, *R. championae* was the biggest, whereas *R. fortunei* was the smallest. Basal area had significantly positive correlations with tree height (r = 0.4012, $p<0.001$). The species richness and abundance of Rhododendrons were greater in higher elevations, whereas fewer individuals were found at lower elevations (Fig. 2a). Moreover, species richness and abundance of Rhododendrons peaked at intermediate slope steepness (Fig. 2b). By contrast, sunny habitat and habitat at lower position in the slope and concave slope had fewer rhododendron individuals (Figs. 2c, 2d and 2e).

Relationship between topographic and Rhododendrons: Our study revealed that the total abundance of Rhododendrons was affected by altitude, position in the slope, slope shape, slope aspect, but not by slope steepness. Altitude had a significant effect on the total abundance of Rhododendrons. Total abundance was increased with elevation (Kruskal–Wallis test, $p<0.001$) (Fig. 3a). Multiple comparisons showed that the total abundance of Rhododendrons at 700–900-m was significantly lower than that at higher elevation. Similarly, the position in the slope had significant effect on the total abundance as well (Kruskal–Wallis test, $p<0.001$). Plots at the upper and middle positions in the slope had the higher total abundance than plots at lower position in the slope (Fig. 3b). Besides, slope shape had a significant effect on the total abundance of rhododendron (Kruskal–Wallis test, $p<0.001$), in which the concave slope had significantly lower total abundance as compared to convex slope and flat slope (Fig. 3c). In general, slope aspect had a significant effect on the total abundance of Rhododendrons (Kruskal–Wallis test, $p<0.001$). Plots at the sunny aspect had the lowest total abundance than plots at semi-sunny aspect and shady aspect (Fig. 3d). However, slope steepness did not significantly affect the total abundance of rhododendron in our plots (KW–H (4, 102) = 7.3135, P = 0.1202 for steepness).

In this study, the CCA results show the relationship between the abundance of seven rhododendron species and topographical variables ($p<0.001$) (Fig. 4). A Monte Carlo test based on 999 permutations found four significant canonical axes ($p<0.001$), in which the aggregate explained 24.8% variance in the species data and 99.6% variance of the species–environmental relation (Table 3). The first canonical axis had an eigenvalue of 0.636, and represented the topography–stand structure gradient. This canonical axis was significantly negatively correlated with altitude (r = –0.3185, $p<0.05$), and significantly positively correlated with slope steepness (r = 0.3123, $p<0.05$) and slope aspect (r = 0.2770, $p<0.05$). The second canonical axis had an eigenvalue of 0.402 and was significantly negatively associated with slope shape (r = –0.6499, $p<0.01$), altitude (r = –0.6129, $p<0.01$), and position in the slope (r = –0.5431, $p<0.01$) (Table 3).

ISA identified that indicator species that were indicative of altitude (four species), slope aspect (one species), position in the slope (one species), and slope shape (two species), respectively (Table 4). No indicator species was found for slope steepness ($p>0.05$). *R. kwangtungense* was indicative of middle–elevation, shade–tolerant slope aspect and flat slope shape. Similarly, the strongest indicator species of high elevation, *R. championae*, grew well in the concave slope. *R. fortunei* was an indicator species of the upper position in the slope (Table 4; Fig. 4).

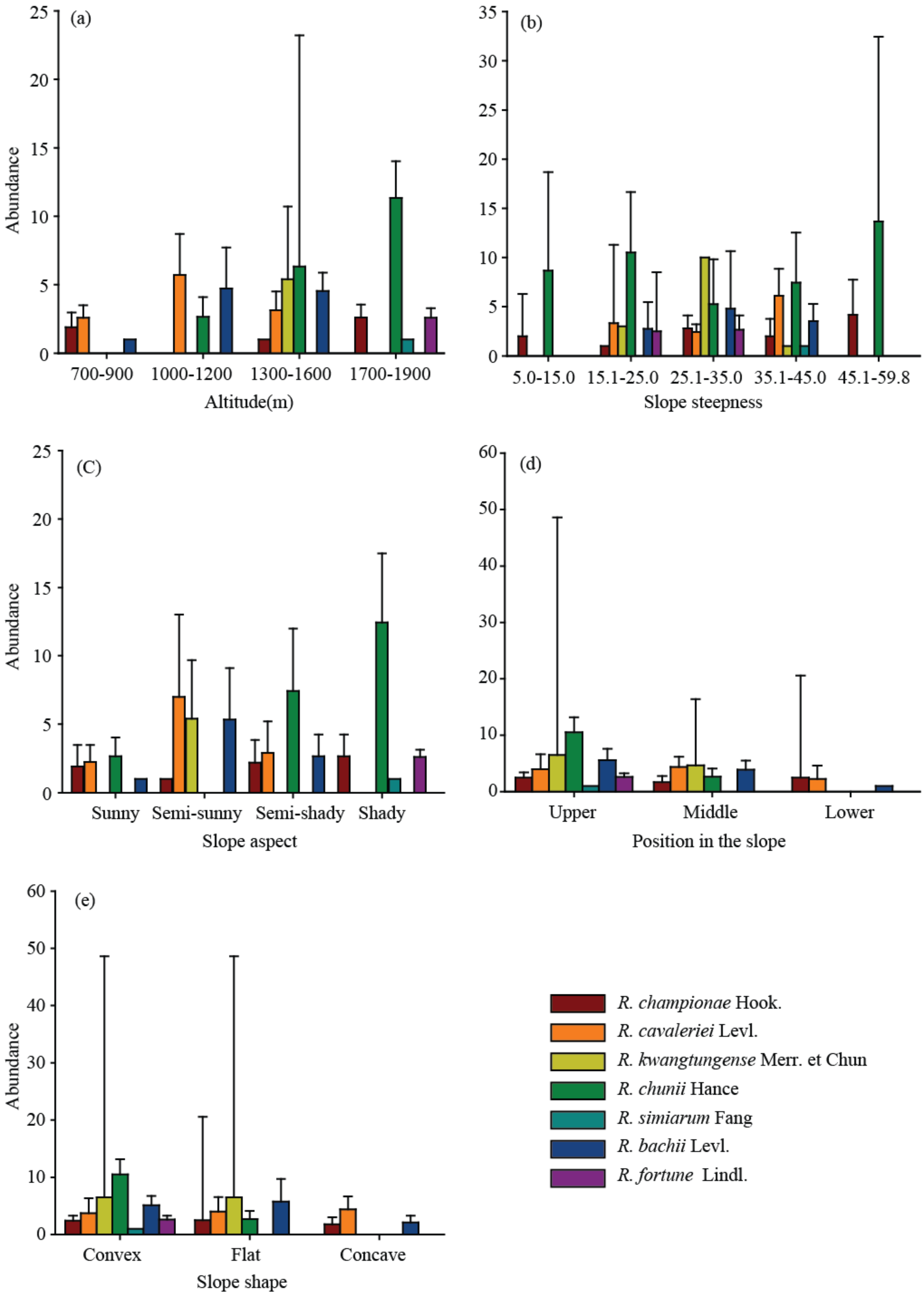

Fig. 2. Relationship between abundance of Rhododendrons and altitude (a), slope steepness (b), slope aspect (c), position in the slope (d), slope shape (e) in the Nanling Mountains, South China. The error bars represent the standard error.

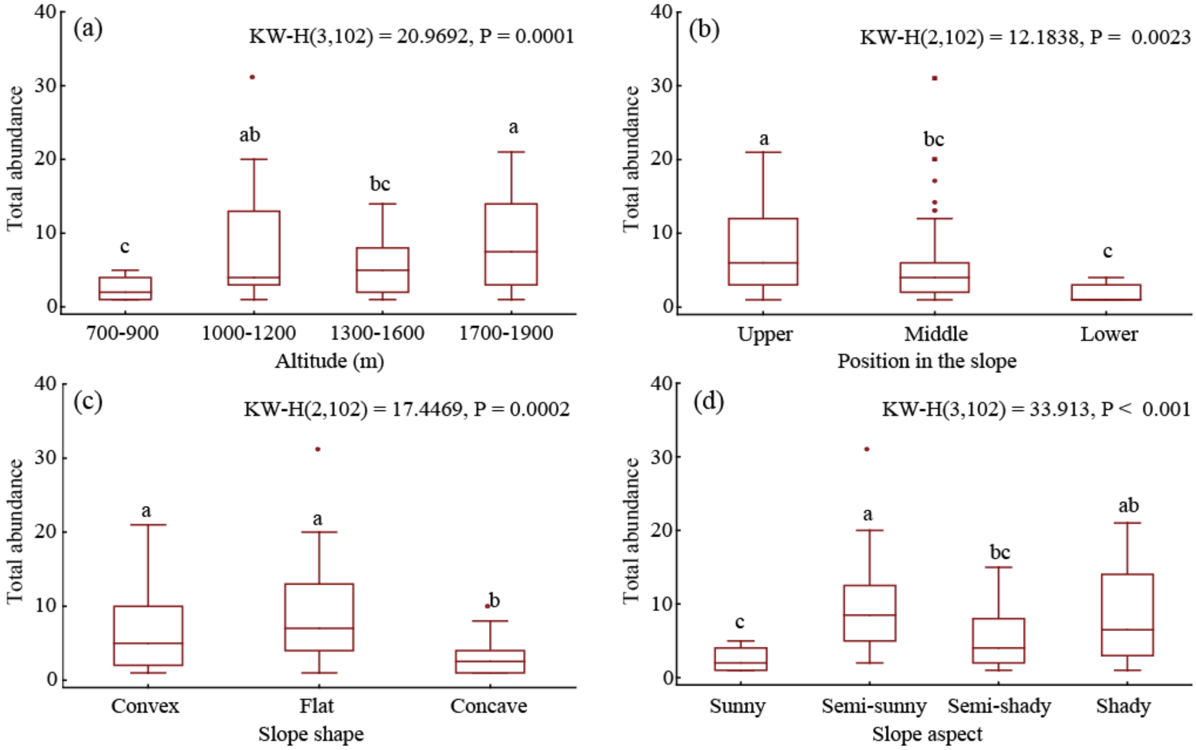

Fig. 3. Boxplots showing the Kruskal–Wallis test results for total abundance of Rhododendrons and altitude(a), position in the slope(b), slope shape (c), slope aspect(d) in the southern slope of the Nanling Mountains, South China. Different letters (a and b) in the graph show significant differences at the level of 0.05. The total abundance of Rhododendrons in our plots did not differ significantly with changes in slope steepness (p>0.05). The horizontal line in each box indicates the median, and the box endpoints indicate the 25th and 75th percentile values. The whiskers represent the non–outlier range. The circles and asterisks indicate the outliers and extreme values of rhododendron abundance, respectively.

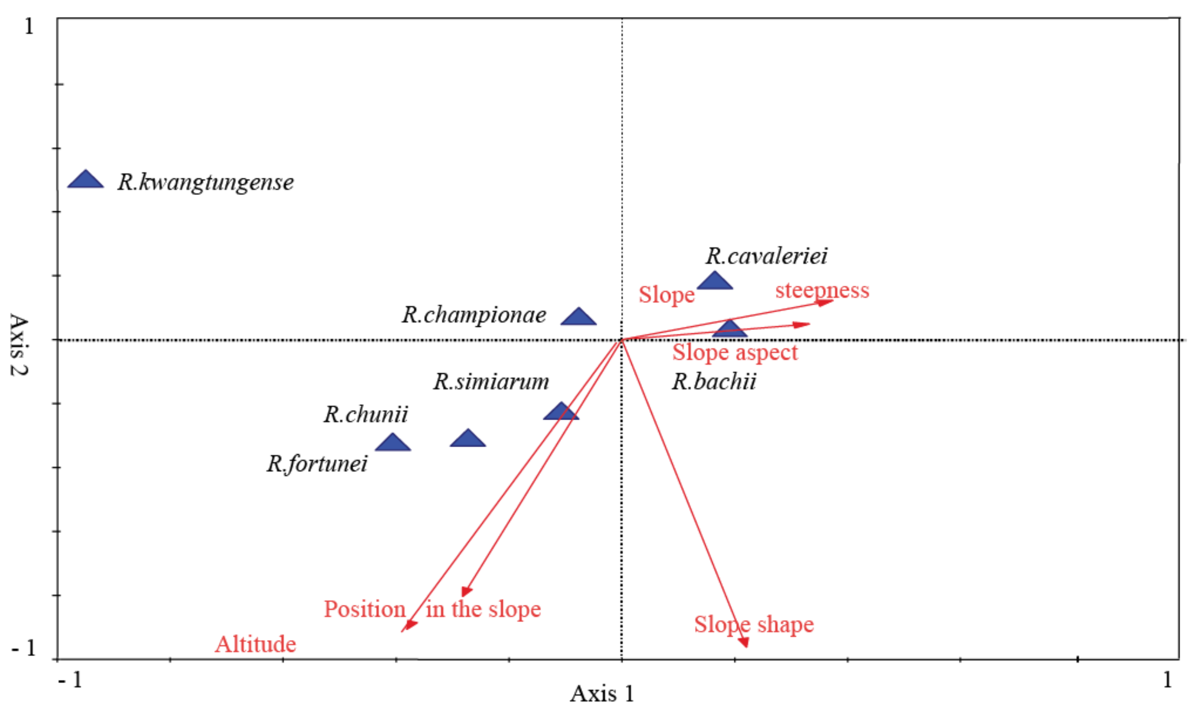

Fig. 4. Two–dimensional ordination diagram of canonical correspondence analysis (CCA) for seven species of Rhododendrons on 102 plots as constrained by five topographic variables in a subtropical mountain in Nanling, South China. The arrows represent the environmental variables. The length of an arrow indicates the strength of the correlation between the variable and axis.

Table 3. Summary and weighted correlation matrix of canonical correspondence analysis (CCA) for Rhododendrons in the southern slope of the Nanling Mountains, South China.

Attribute	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.636	0.402	0.035	0.012
Species–environment correlations	0.835	0.676	0.233	0.117
Cumulative % variance of species data	14.5	23.7	24.5	24.8
of species–environment relation	58.4	95,4	98.6	99.6
Intra–set correlations				
Altitude	–0.3185*	–0.6129**	0.0230	–0.0025
Slope steepness	0.3123*	0.0830	0.0280	–0.0884
Slope aspect	0.2770*	0.0338	–0.2101	–0.0115
Position in the slope	–0.2358	–0.5431*	0.0442	–0.0461
Slope shape	0.1850	–0.6499**	0.0271	–0.0050

Values at each treatment group followed by different letters are significantly different (*p<0.05, **p<0.01)

Table 4. Indicator Species Analysis (ISA) for Rhododendrons in the southern slope of the Nanling Mountains, South China based on topographic grouping variables. The topographic indicator species, *Rhododendron kwangtungense, Rhododendron championae, Rhododendron chunii* and *Rhododendron fortunei* were identified indicative of altitude, slope aspect, position in the slope and slope shape, respectively.

Grouping variable		Species name	IV	*P*
Altitude (m)	1300–1600	*Rhododendron kwangtungense*	14.3	0.0210
	1700–1900	*Rhododendron championae*	31.0	0.0010
	1700–1900	*Rhododendron chunii*	16.7	0.0090
	1700–1900	*Rhododendron fortunei*	20.8	0.0020
Slope aspect	Shady	*Rhododendron kwangtungense*	13.7	0.0210
Position in the slope	Upper	*Rhododendron fortunei*	11.4	0.0480
Slope shape	Concave	*Rhododendron championae*	22.4	0.0320
	Flat	*Rhododendron kwangtungense*	20.0	0.0020

No indicator species was found to be indicative of slope steepness (p>0.05)

Discussions

Topographic influence of rhododendron plants: Altitudinal belts are one of the most basic methods used in mountain vegetation research (Beals, 1969). Altitudinal effect on the composition and richness of montane plant assemblages are complex and involve different factors, including temperature, air pressure and precipitation (Krömer *et al.,* 2013). Biodiversity encompasses multiple levels of biological organisation. In different levels, species richness along the elevation gradient exhibits different distribution patterns (Mahdavi *et al.,* 2013; Ghazal, 2015). A consistent 'altitude concept' in comparative ecology is necessary, such as multivariate analysis of data from altitudinal gradients replicated across various regions contrasting in moisture regimes can assist in separating moisture from thermal effects (Körner, 2007). Studies pointed out that species richness peaks at lower and intermediate altitudes (Hao *et al.,* 2002). Our study demonstrated that species richness and abundance of rhododendron plants were greater in habitats of higher elevation, intermediate slope steepness, convex slopes, and shady aspect. By contrast, sunny habitats and habitat at lower positions in the slope had fewer rhododendron individuals. Among seven indigenous Rhododendrons in our study, *R. kwangtungense* was indicative of middle–elevations, shade–tolerant slope aspect and flat slope shape. *R. championae*, the strongest indicator species of high elevation, was also an indicator species of concave slope. *R. fortunei* was an indicator species of the upper position in the slope. Species used in vegetation restoration should be carefully selected based on local environmental characteristics (Zhang, 2013). This research can lead to a predictive understanding and potential management strategies for indigenous Rhododendrons in community–scale.

The ecological role of distribution of Rhododendrons: An earlier study found that elevation and slope aspect were important controls of palm species distribution in the Andes of north–western Ecuador, while small–scale topography was of little importance (Svenning *et al.,* 2009). Topographic gradient includes complex variables such as water, nutrients and disturbances. Species distributed on steep and concave slopes regenerate depending on disturbances such as landslides on unstable topography, whereas species distributed on ridges and upper slopes regenerate depending on the canopy gap. The total abundance of Rhododendrons was high on upper positions and convex slopes in the present study. Altitude, position in the slope and slope shape had greater impacts on the distribution patterns of rhododendron plants than slope steepness and slope aspect. This study revealed that a community could be affected simultaneously by several topographic factors. Therefore interactions and compensations among topographic factors should be considered when assessing the effects of a single topographic factor on the spatial patterns of rhododendron plants. This finding was probably due to the fact that ridges or upper positions of gentle slopes are relatively stable in terms of soil surface disturbance, as demonstrated previously by Tsujino *et al.* (2009), who explained the large basal area found on this type of topography.

Conclusion

This study demonstrated that the topography affecting the richness and abundance of indigenous Rhododendrons. Altitude, position in the slope, slope shape and slope aspect had greater impacts on the distribution patterns of rhododendron plants than slope steepness. The richness and abundance of seven indigenous Rhododendrons varying in topographical gradient, and there are different patterns among species. *R. kwangtungense* was indicative of middle–elevations, shade–tolerant slope aspect and flat slope shape. *R. championae*, the strongest indicator species of high elevation, was also an indicator species of concave slope. *R. fortunei* was an indicator species of the upper position in the slope. The spatial heterogeneity of indigenous rhododendron plants distribution to topographic factors in the southern slope of the Nanling Mountains reflected their bioclimatic adaptation and phenology, indicating significant implications for species conservation and potentials for use in landscaping.

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