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Forest and population structure and regeneration dynamics of relict *Dipentodon sinicus* in southwestern China

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ABSTRACT: *Dipentodon sinicus* is an extant relict plant of East Asia. It is a small deciduous broad-leaved tree, the sole surviving representative of the *Dipentodonaceae*. We investigated forest features, population structure, and regeneration dynamics of forest stands containing this species in Caojian Forest Station of Yunnan Province and Yushe National Forest Parks of Guizhou Province, southwestern China. We identified six forest types: *Carpinus kweichowensis-Liquidambar formosana-Lithocarpus glaber-Dipentodon sinicus* forest (Type 1); *Illicium simonsii-Salix matsudana-Schima khasiana-Dipentodon sinicus* forest (Type 2); *Dipentodon sinicus* forest (Type 3); *Dipentodon sinicus-Schima khasiana* forest (Type 4); *Dipentodon sinicus-Tetracentron sinense* forest (Type 5); *Pterocarya macroptera* var. *delavayi-Tetracentron sinense-Populus yunnanensis-Salix matsudana* forest (Type 6). Among the six forest types, *D. sinicus* forest (Type 3) had the lowest values in species richness, Shannon-Wiener and Simpson's diversity indices. The maximum age of *D. sinicus* was 54 years, reaching 34 cm DBH, with 14 m maximum height. Its frequency distribution in DBH-and age-class displayed a sporadic pattern in various forests. Its regeneration was more active in *D. sinicus* forest (Type 3), *Dipentodon sinicus-Tetracentron sinense* forest (Type 5), and *Carpinus kweichowensis-Liquidambar formosana-Lithocarpus glaber-Dipentodon sinicus* forest (Type 1) than that in the other forests (Types 2, 4 and 6). *D. sinicus*' growth rate generally fluctuated from 1.15 to 5.62 mm/year. Its regeneration modes were seedlings and sprouts. Its seedling establishment depends on forest gaps formation by disturbances. It is clear that the population persistence of *D. sinicus* was maintained in habitats where natural disturbances were frequent.

KEY WORDS: Age structure, *Dipentodon sinicus*, Forest features, Habitat, Population structure, Regeneration, Species diversity.

INTRODUCTION

In the Pleistocene, the climate of East Asia was milder and the glaciations were weaker than in Europe and North America. This region displays high endemism and has an extraordinarily high proportion of elements of relict flora (Qian *et al*., 2003; Manchester *et al*., 2009; Tang *et al*., 2018). Southern East Asia has an exceptionally high diversity of vascular species (Mutke and Bartholott, 2005). The center of the origin and diversification of angiosperms could be considered as southern East Asia and tropical Asia (e.g. Takhtajan, 1969; Wolfe, 1975; Lidgard and Crane, 1990). Southwestern China has been identified as a center of long-term stable refugia harboring a high richness of relict plant species (Tang *et al*., 2018). As such, the region is recognized as a global biodiversity hotspot (Myers *et al*., 2000) having a priority for conservation as a Global 200 ecoregion (Olson and Dinerstein, 2002). Several high profile relict plants of global significance occur in the region, including *Ginkgo biloba*, *Taiwania cryptomerioides*, *Davidia involucrata*, *Tetracentron sinense*, etc. However, biodiversity values of forests in southwestern China had been eroded by an expanding human population that relied on these forests for the harvesting of timber and fuel-wood. Current knowledge of the ecology and habitats of many relict plant species across the distribution areas is generally poor, creating great uncertainty regarding abundance and distribution of these relict species. Now, there is a pressing need to understand the ecological requirements of relict plant species, as seen in the following examples.

Dipentodon sinicus is a small deciduous broad-leaved tree. It is the sole survivor of the family in Dipentodonaceae (Ma and Bartholomew, 2008). Its phylogenetic position is that of sister to *Tapiscia* (Tapisciaceae) (Peng *et al*., 2003). It is sparsely scattered in southwestern China, northern Vietnam and northern Myanmar. Its distribution center is in Yunnan and Guizhou (Fig. 1). It is a rare and vulnerable species (Wang and Xie, 2004), ranked as a second-grade protected species in China. Populations are generally scant. The ratio of seed-setting was very low with a number of 4.31% (Zhang *et al*., 2017), though this species has high genetic diversity (h_T = 0.902) and high genetic differentiation (N_{ST} = 0.987 and G_{ST} = 0.948)

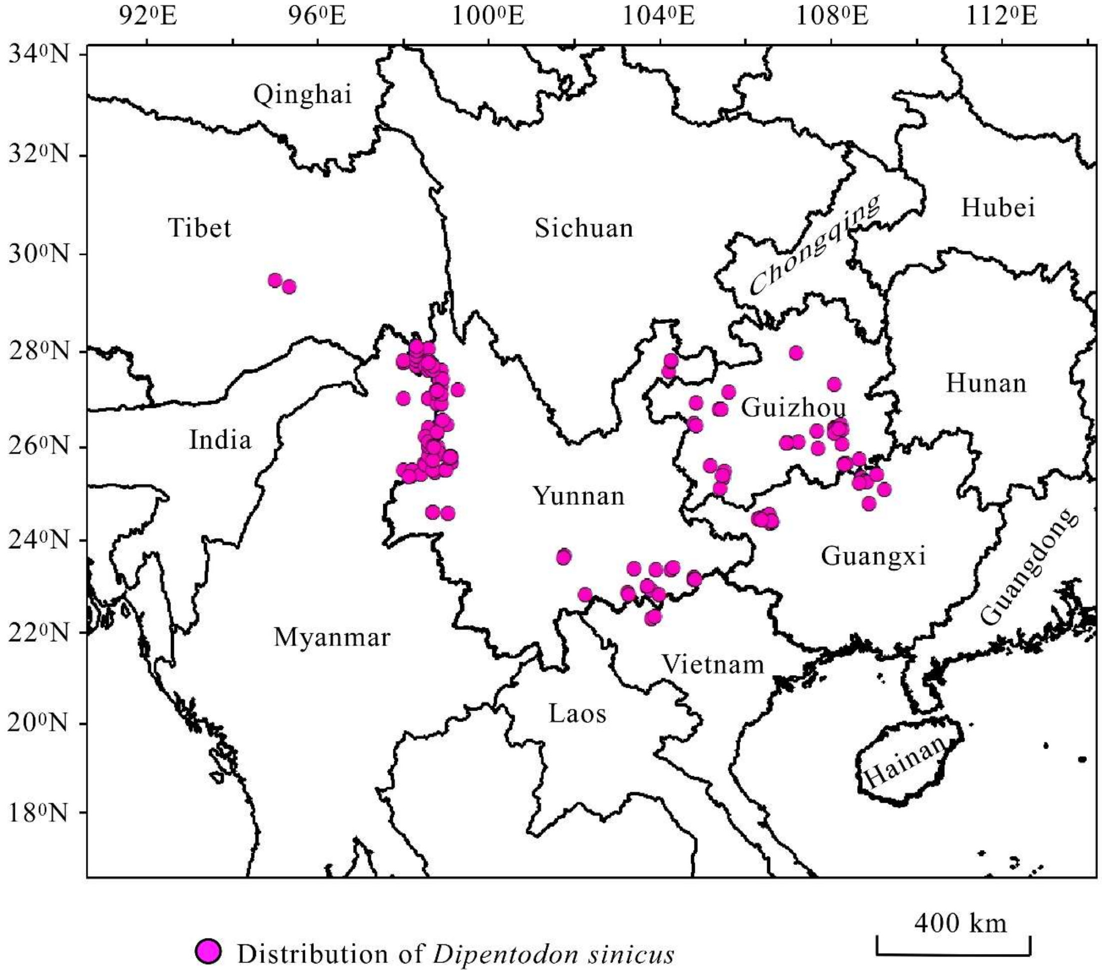

Fig. 1. Present distribution of *Dipentodon sinicus* in East Asia. Data sources: http://www.cvh.org (Retrieved October 5, 2018), and our field observations from this study.

(Yuan *et al*., 2008). However, there is virtually no ecological information available on this species, except for some preliminary studies on species composition and characteristics of *D. sinicus* communities in northeastern Yunnan (Su *et al*., 2014, 2015) and Guizhou (Lin *et al*., 2007; Lin *et al*., 2008a, b; Feng and Wei, 2017). To date, studies of forest and population structure, including size and age structure, growth rates, as well as regeneration of *D. sinicus* are not available. An understanding of forest features, population structure and regeneration of *D. sinicus* is crucial for its conservation. Based on our field survey in southwestern China, Caojian Forest Station and Yushe National Forest Park have the largest population sizes of *D. sinicus*. So the two areas afford an opportunity to study this species' community and population structure, as well as its regeneration dynamics in detail. We address the following questions: 1. What are the structural features of forests containing *D. sinicus* in Caojian Forest Station and Yushe National Forest Park? 2. What are the size structures of major species in various forests? 3. What are the growth trends of *D. sinicus* as based upon ring area and width data? 4. What are the age structure and regeneration dynamics of *D. sinicus*?

MATERIALS AND METHODS

Study area

The study was carried out in Caojian Forest Station (25º29′-26º04′ N, 98º58′-99º15′ E, 2300-3605 m asl) of Yunlong County, Yunnan Province, and Yushe National Forest Park (104º33′57″-104º53′09″E, 26º02′56″ ～ 26º28′56″N, 1700-2503 m asl) of Shuicheng County, Guizhou Province (Fig. 2). Both areas are located in the mid-subtropical zone of China. The climate is influenced by the Indian and East Asian summer monsoon, and the East Asian winter monsoon, with dry continental winds in winter and moist oceanic winds in summer. According to the weather station (26° 40' 40.8"N, 99° 7' 51.6"E, 2140 m asl) in Caojian Town, the mean annual temperature is 13.7ºC, while average monthly temperatures range from 6ºC in January to 19.1ºC in

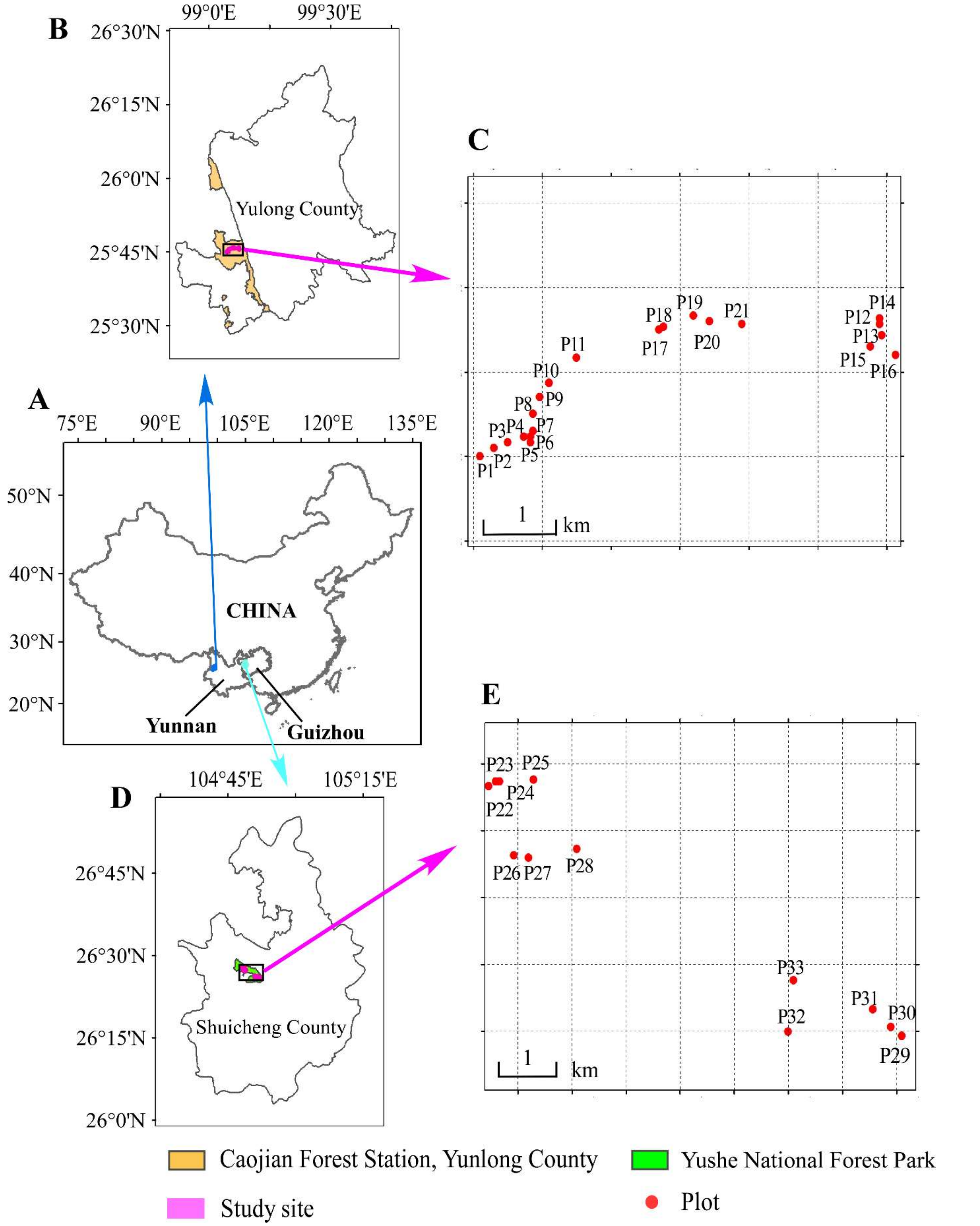

Fig. 2. The study areas and the locations of plots. **A**. Yunnan and Guizhou Provinces located in southwestern China. **B**. Caojian Forest Station in Yunlong County. **C**. Locations of 21 plots in Caojian Forest Station. **D**. Yushe National Forest Park in Shuicheng County. **E**. Locations of 12 plots in Yushe National Forest Park.

August. The mean annual precipitation is ca. 1400 mm. The rainfall increasing rate along altitudes is 28 mm /100 m. In Yueshe National Forest Park, the mean annual temperature is 12ºC, while average monthly temperatures range from -0.3ºC in January to 24.1ºC in August. The mean annual precipitation is 1379 mm. For both study sites, 80% of precipitation occurs during June to October. The monthly relative humidity is greater than 85% in Caojian Forest Station and 80% in Yushe National Forest Parks.

Data collecting and analysis

The forests in the study area are subjected to factors such as elevation, topographic situations and natural disturbances; thus, forests are structurally and floristically heterogeneous and the vegetation shows mosaic patches. We selected plots in each patch containing *D. sinicus* in the study area. During July-September 2017, we established 21 plots in Caojian Forest Station in Yunnan Province and 12 in Yushe National Park in Guizhou Province. Based on topography and accessibility, plot size was from 20 m x 20 m or 10 m x 40 m to 20 m x 30 m depending on the size of the patches and the maximum number of species.

In studying the overstory of the forests, woody species inventory was carried out for all the individuals at least 1.3 m high in each plot. All were tagged with number tape, recorded with species name and whether living or dead, measured diameter at breast height (DBH) (including all main stems and sprouts) and tree height (H). Tree stems were classified into four types based on their vertical position, crown position, and height: canopy (20–28 m tall); subcanopy (8–20 m tall); and shrub layer (1.3–8 m tall). All woody species (from 5–60 cm tall for seedlings and 60–130 cm for saplings) occurring in the understory of each plot were identified, counted, and measured for height and percent cover.

We obtained 59 stumps cutting from the trunk base (above ground level at 0 m) of *D. sinicus* with varying DBHs in the study areas. Tree ages were determined using the LINTABTM 6 tree-ring station (RINNTECH). From this analysis, we were also able to determine ring widths and to calculate basal area increments (BAI). The following formula was used to calculate BAI: X-(X-1) where X is the basal area at year X (last year of growth) and X-1 is the basal area of the tree measured up to the year previous to X. BAI is used in forest growth studies because it provides an accurate quantification of wood production based on the ever-increasing diameter of a growing tree (Rubino and McCarthy, 2000).

Forests were classified using a floristic similarity dendrogram with Relative Sørensen and Group Average clustering [PCORD software (McCune and Mefford, 1999)]. Dominance was determined using a dominance analysis according to the relative basal area of each species (Ohsawa, 1984). The forests were named according to dominant species. Diversity was calculated for each forest stand using species richness (number of species), the Shannon-Wiener index (Pielou, 1969) and Simpson's diversity index (Lande, 1996). The proportion of total number of individuals was applied for calculating the diversity indices. Differences in species richness and diversity indices among habitats were analyzed by the non-parametric Kruskal–Wallis all-pairwise comparisons test, using Analyze-it software (Ltd., Leeds, United Kingdom).

The frequency distributions in the DBH- and age-class were classified into three patterns, namely inverse-J, sporadic and unimodal. The inverse-J pattern, having the highest frequency in small size and age classes with a gradual decrease in the number of individuals towards the large size and age classes, suggests that regeneration is active. The sporadic pattern with more than one peak in the size and age classes indicates regeneration varying by chance, depending on disturbance for gap regeneration. The unimodal pattern with a single peak in the intermediate or large size and age classes and/or few if any individuals in small size and age classes suggests weak regeneration.

RESULTS

Forest types, stratification and species diversity

The similarity dendrogram based on the vegetation data of 21 plots in Caojian Forest Station, Yunnan and 12 plots in Yushe National Forest Park, Guizhou is shown in Fig. 3a. Six distinctive forest types became evident: Type 1, *Carpinus kweichowensis-Liquidambar formosana-Lithocarpus glaber-Dipentodon sinicus* forest (deciduous and evergreen broad-leaved mixed forest) on steep slopes or in roadsides or stream sides in Yushe National Forest Park; Type 2, *Illicium simonsii - Salix matsudana-Schima khasiana-Dipentodon sinicus* forest (evergreen and deciduous broad-leaved mixed forest) in stream sides in Caojian; Type 3; *Dipentodon sinicus* forest (deciduous broad-leaved forest) in stream sides, or roadsides in Caojian and Yushe National Forest Park; Type 4, *Schima khasiana-Dipentodon sinicus* forest (evergreen and deciduous broad-leaved mixed forest) in stream sides or roadsides in Caojian; Type 5, *Dipentodon sinicus-Tetracentron sinense* forest (deciduous broad-leaved) in stream sides or roadsides in Caojian and Yushe National Forest Park; Type 6, *Pterocarya macropterai* var. *delavayi-Tetracentron sinense-Populus yunnanensis* forest (deciduous broad-leaved) by streams in Caojian.

Fig. 3b depicts the stratification of the six forest types. No trees over 20 m tall in the canopy layer were found in forest Types 1–4. In Type 1, *D. sinicus* absolutely dominated the shrub layer (1.3–8 m), though

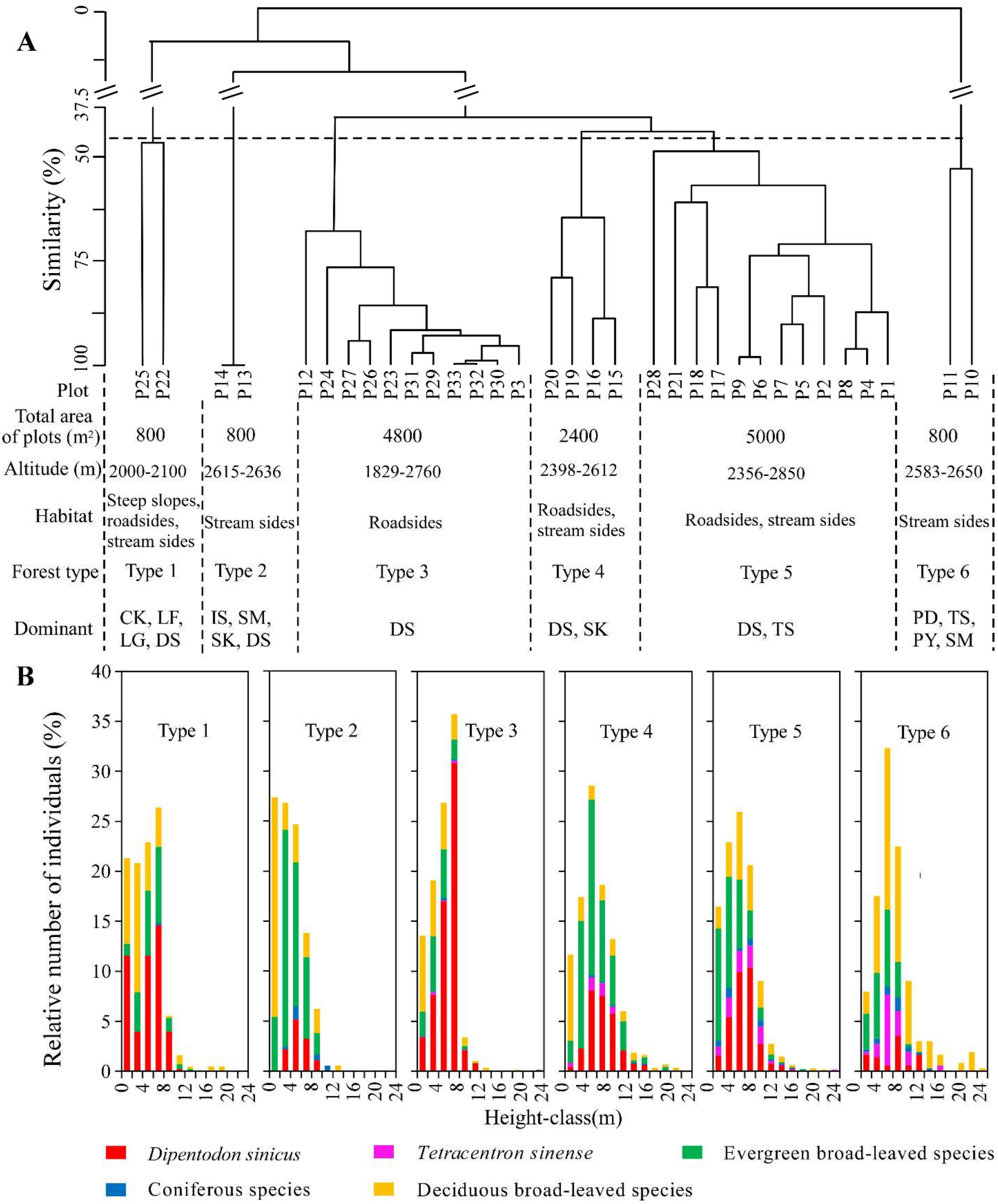

Fig. 3. Floristic dendrogram and forest stratification. **A**. Floristic similarity dendrogram and forest characteristics. **B**. Height-class frequency distribution of species (height ≥ 1.3 m). For species abbreviations in **A**: CK: *Carpinus kweichowensis*, LF: *Liquidambar formosana*, LG: *Lithocarpus glaber*, DS: *Dipentodon sinicus*, IS: *Illicium simonsii*, SM: *Salix matsudana*, SK: *Schima khasiana*, TS: *Tetracentron sinense*, PD: *Pterocarya macropterai* var. *delavayi*, PY: *Populus yunnanensis*.

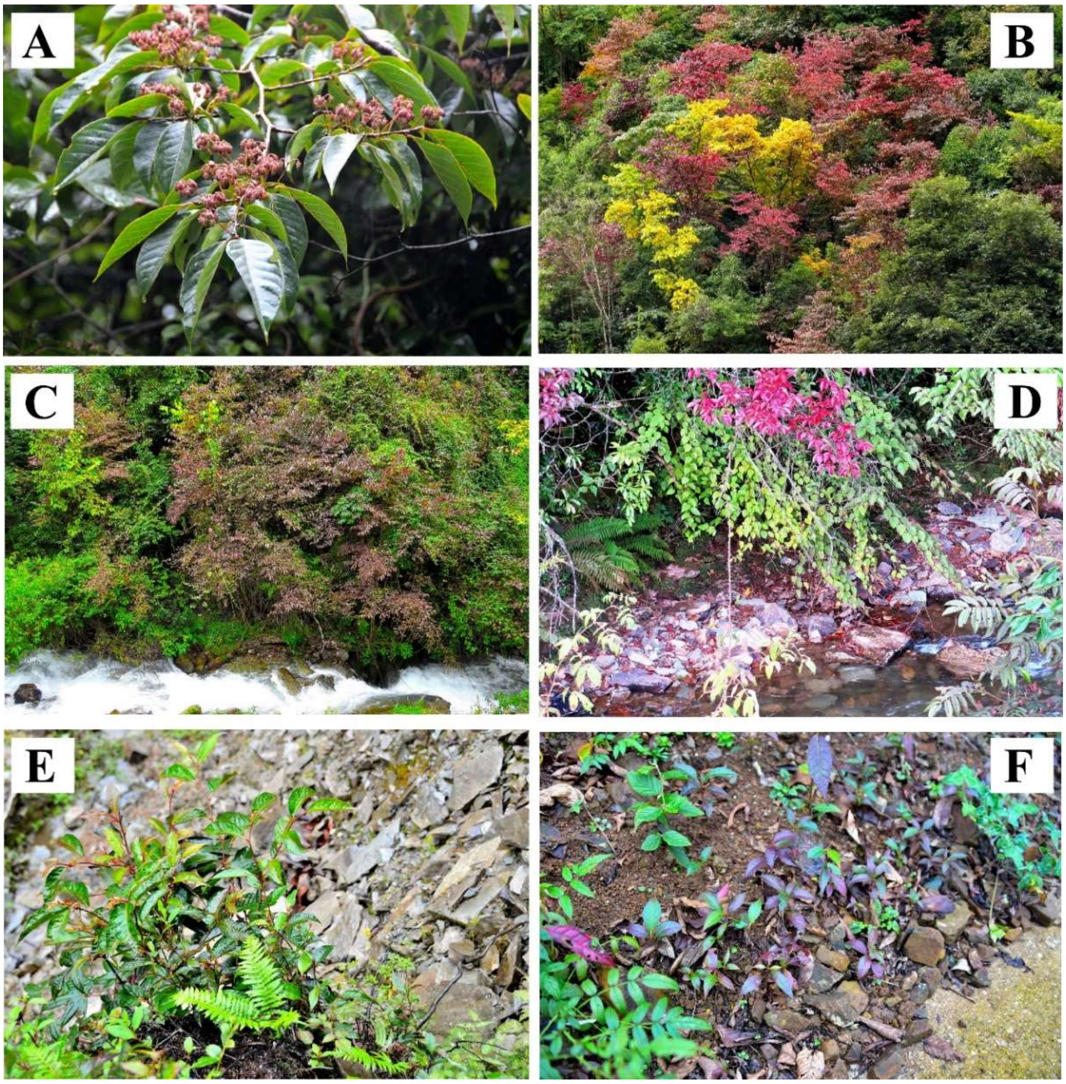

Fig. 4. *Dipentodon sinicus* and its forests and habitats. **A**. Foliage and fruits of *D. sinicus*. **B**. A forest dominated by *D. sinicus* (red leaves) on a mountain slope in Caojian Forest Station. **C**. *D. sinicus* along a steep slope beside a stream. **D**. *D. sinicus* (red leaves) and *Tetracentron sinense* (green leaves) coexisted by a stream side in Caojian Forest Station. **E**. *D. sinicus* saplings on a scree slope in Caojian Forest Station. **F**. *D. sinicus* seedlings in a disturbed roadside in Yushe National Forest Park.

some individuals of *D. sinicus* reached 10 m. Deciduous broad-leaved *Liquidambar formosana* and *Carpinus kweichowensis* reached 20 m and 15 m in the canopy and subcanopy respectively, while evergreen *Lithocarpus glaber* reached 12 m in the subcanopy layer. However, the coverage of canopy and subcanopy layers was very low (30%). In Type 2, evergreen broad-leaved *Illicium simonsii*, *Schima khasiana* and deciduous broad-leaved *Salix matsudana* co-dominated with *D. sinicus* in the shrub layer. Only a few individuals of those species reached 14 m. In Type 3, *D. sinicus*' maximum height reached 12 m. It overwhelmingly dominated the subcanopy and shrub layers. In Type 4, though a few individuals of *D. sinicus* reached 14 m in the subcanopy, most individuals of *D. sinicus* were found in the shrub layer. In *Dipentodon sinicus-Tetracentron sinense* forest (Type 5), *D. sinicus* dominated the subcanopy and shrub layers, while *Tetracentron sinense* and some other deciduous species were found in the canopy layer. In Type 6, *D. sinicus* was present in both shrub and subcanopy layers but it was not one of the dominants. *Pterocarya macropterai* var. *delavayi, Tetracentron sinense, Populus yunnanensis* and S*alix matsudana* co-dominated this forest (Type 6).

These forests were generally confined to subtropical area at 1,800–2850 m above sea level (asl), with the majority of records between 1,800–2700 m asl. At a finer scale, it was strongly associated with other relict plants such as *Tetracentron sinense* and *Pterocarya macropterai* var. *delavayi* along streams, cliffs and landslide-prone sites. *D. sinicus* and its representative forests and its habitats are shown in Fig. 4A–F.

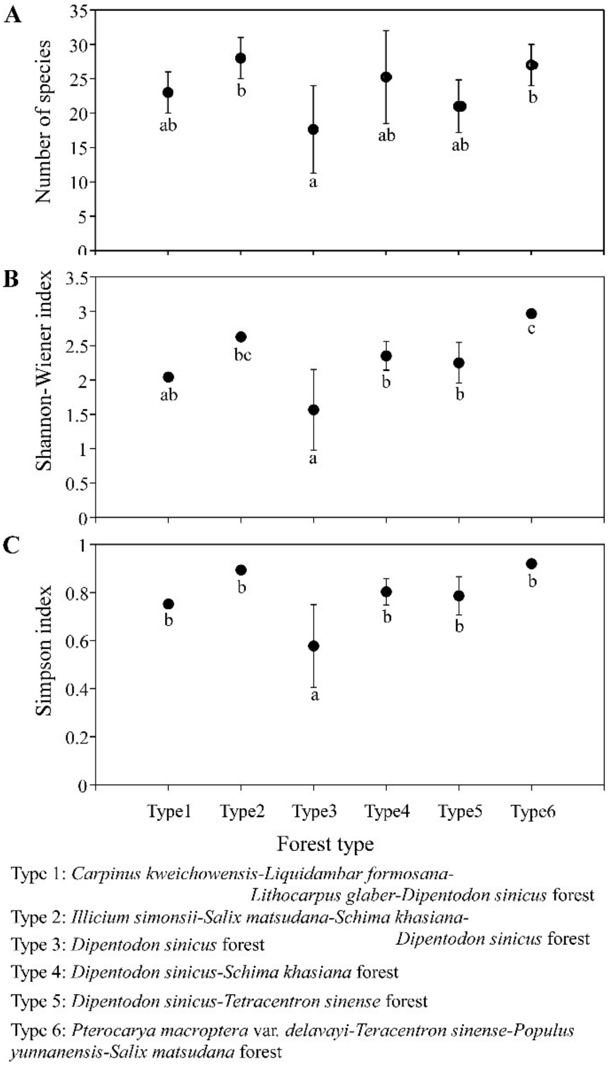

Fig. 5. Changes in species richness and diversity among the six forest types. **A**. Average number of species among plots of each forest type. **B**. Shannon-Wiener diversity index. The SD is 0.05, 0.01 and 0.05 for Type 1, Type 2 and Type 6, respectively. **C**. Simpson diversity index. The SD is 0.004, 0.002 and 0.002 for Type 1, Type 2 and Type 6, respectively. Forests having different letters differ significantly ($P < 0.05$). The bar indicates standard deviation.

The floristic composition of woody species in the six forest types is shown in Appendix. In total, 146 woody species comprised of 82 deciduous broad-leaved species, 62 evergreen broad-leaved and 2 coniferous species belonging to 83 genera in 43 families were recorded in the 33 plots (see Appendix). Among the 6 forest types, *D. sinicus* forest stand (Type 3) showed the lowest values in species richness (18), Shannon-Wiener index (1.57) and Simpson's diversity index (0.59) (Fig. 5A–C). Overall, *Illicium simonsii-Salix matsudana-Schima khasiana-Dipentodon sinicus* forest stand (Type 2) and *Pterocarya macropterai* var. *delavayi-Tetracentron sinense-Populus yunnanensis* forest stand (Type 6) tend to have higher species richness and diversity indices than the other types of forests (Fig. 5A–C).

Population structure and regeneration dynamics

Size structure of major species

The frequency distributions in DBH-classes of *D. sinicus* with dominant species in each forest type are shown in Fig. 6. In *Carpinus kweichowensis* - *Liquidambar formosana-Lithocarpus glaber* - *Dipentodon sinicus* forest (Type 1), *D. sinicus* trees were only found in small DBH-classes, with the maximum DBH of 18 cm. This species was continuously distributed between DBHs of 0–18 cm, with peaks in DBH classes of 0–3 cm and 6–9 cm. It showed a sporadic pattern indicating that its regeneration depends on forest gap formation. *Carpinus kweichowensis*, *Liquidambar formosana* and *Lithocarpus glaber* were in an unimodal pattern indicating absence of regeneration, with three large trees in 92 cm, 69 cm and 90 cm DBHs, respectively. In *Illicium simonsii-Salix matsudana-Schima khasiana-Dipentodon sinicus* forest (Type 2), *D. sinicus* and *Schima khasiana* were in a sporadic pattern with a peak in 3–6 cm DBH, then another peak within 15–21 cm DBH. *Illicium simonsii* showed an inverse-J pattern indicating an active regeneration, with many seedlings/saplings at a height of 30–130 cm (data were not shown in the graph), though it lacked individuals in the DBH class of 0–3 cm. *Salix matsudana* formed an unimodal pattern. In *D. sinicus* forest (Type 3), most trees of *D. sinicus* were found in a DBH class of 6–9 cm. No *D. sinicus* trees were found in a 27–30 cm DBH. Then a few *D. sinicus* trees appeared with DBH-classes of 31–36 cm. It formed a sporadic pattern. Some other major species in forest Type 3, such as *Quercus fabri* and *Illicium simonsii*, also had a sporadic pattern. In *Schima khasiana-Dipentodon sinicus* forest (Type 4), both dominant species, *D. sinicus* and *Schima khasiana*, had a sporadic pattern showing multi-peaks within their DBH ranges. In *Dipentodon sinicus-Tetracentron sinense* forest (Type 5), both *D. sinicus* and *Tetracentron sinense* were in a sporadic pattern. *D. sinicus* reached the maximum DBH of 34 cm, while the maximum DBH of *Tetracentron sinense* was 75 cm. In *Pterocarya macropterai* var. *delavayi-Tetracentron sinense-Populus yunnanensis* forest (Type 6), *D. sinicus* as an accompanying species and the three dominants, *Pterocarya macropterai* var. *delavayi*, *Tetracentron sinense*, and *Populus yunnanensis*, were discontinuously distributed within their DBH ranges. They were in a sporadic pattern. *D. sinicus* only reached 21 cm DBH, while *Pterocarya macropterai* var. *delavayi* attained a maximum DBH of 42 cm.

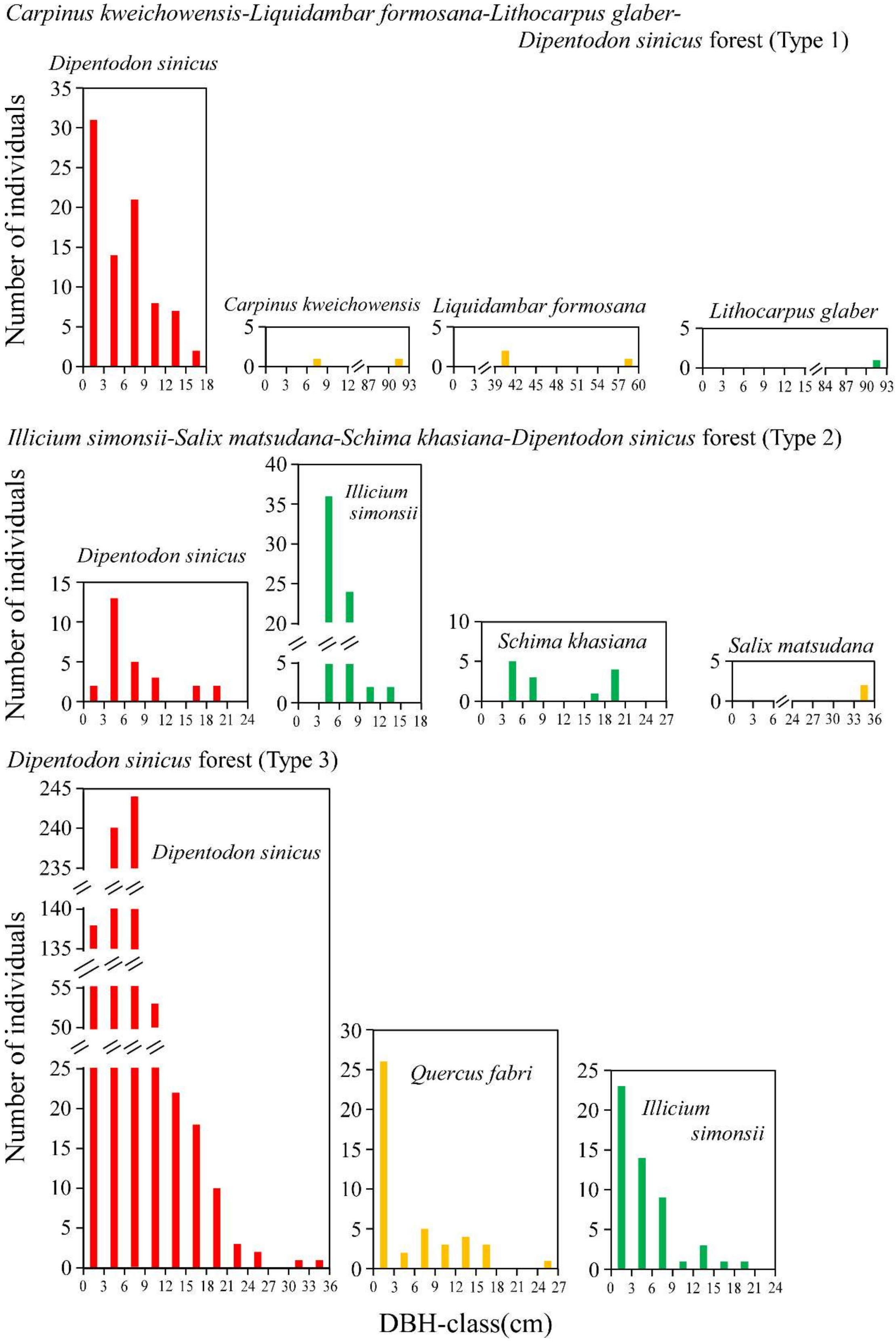

Fig. 6. DBH-class frequency distribution of major species in various forest types.

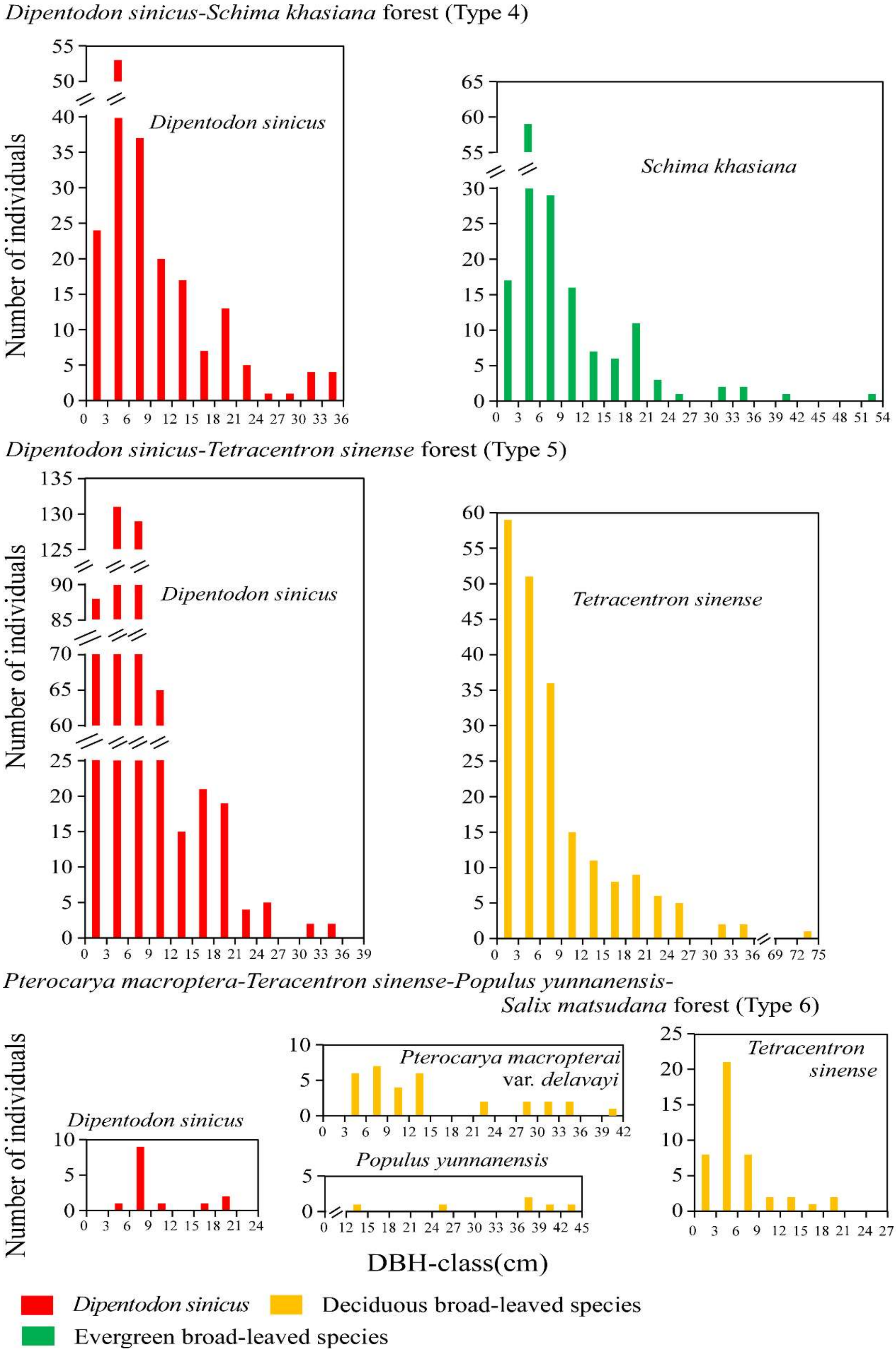

Fig. 6. (Continued) DBH-class frequency distribution of major species in various forest types.

Growth rate and age structure of Dipentodon sinicus

The relationship (y = 1.375x+8.212, R^2 = 0.78, n = 59) of DBH and age is shown in Fig. 7A. According to the ring width data, *D. sinicus* is a slow-growing species. Though the growth rate of radius (ring width) among the 59 samples varied between 1.15 and 5.62 mm/year, the trees had a relatively slow growth rate at 2.79 mm/year on average when they were under 6 years old. Then the growth rate increased and tended to be steady around 3.45 mm/year when the trees were 6–24 years old. At 24–39 years, the growth rate decreased to 2.61 mm/year on average. The growth rate fluctuated between 2.16–3.63 mm/year when the trees were over 40 years old (Fig. 7B). The basal area increment (BAI) indicated that the trees increased to 1400 mm^2 during the first 24 years, then stayed around the same level of 1400 mm^2 at 25–39 years. Finally the BAI fluctuated between 1500 mm^2–2300 mm^2 when the trees over 39 years (Fig. 7C).

Fig. 8 shows the age-structure of *D. sinicus* in various forest stands. In *Carpinus kweichowensis-Liquidambar formosana- Lithocarpus glaber-Dipentodon sinicus* forest (Type 1), *D. sinicus* only reached 27 years, with a peak at 6–9 years, and other sub-peaks were at 15–21 years. Seven seedlings were found in forest Type 1. In *Illicium simonsii-Salix matsudana-Schima khasiana-Dipentodon sinicus* forest (Type 2), ages of *D. sinicus* ranged from 9 to 30 years, the number of trees being rather limited. No seedlings were found. In *D. sinicus* forest (Type 3), there were more than 300 trees of 15–18 years old. Its maximum age reached 51 years, but no trees were found at the ages of 42–48 years. 1579 seedlings/samplings were found. In *Schima khasiana-Dipentodon sinicus* forest (Type 4), at the age-class of 12–18 years, the number of *D. sinicus* trees was relatively higher than those of the other age-classes. Its age reached 49 years, but no trees were found between 39–45 years. Seedlings/saplings did not appear in any plots of forest Type 4. In *Dipentodon sinicus-Tetracentron sinense* forest (Type 5), the number of *D. sinicus* trees had a peak at 15–18 years. Its age reached 54 years while no trees were found at ages of 42–48 years. 128 seedlings/saplings were observed. In *Pterocarya macropterai* var. *delavayi-Tetracentron sinense-Populus yunnanensis* forest (Type 6), *D. sinicus* scattered in a few age-classes. Less than 20 examples of *D. sinicus* were found; and no seedlings/saplings appeared in this type of forest. As a whole, the age-class data on *D. sinicus* for all the forest types indicate a sporadic pattern corresponding to its DBH-class structure. The highest number of *D. sinicus* trees were 15–18 years old. The largest number of seedlings/saplings was found in forest Type 3. The maximum age of *D. sinicus* was 54 years.

Recruitment of Dipentodon sinicus

Abundant seedlings with heights lower than 30 cm were found in roadsides and on steep slopes or landslide sites. When seedlings were from 30–60 cm tall, the number of seedlings increased in the stream sides while it decreased in the other two habitats. More established saplings (90–130 cm) were found in stream sides rather than roadsides or steep slopes or landslide sites. No seedlings were found on gentle slopes with deep soils apart from roadsides. This indicates that *D. sinicus*' regeneration depends on disturbances and requiring open sites. Regeneration modes of *D. sinicus* included seedlings and sprouts. *D. sinicus* had very strong sprouting ability. Its sprouts were usually more than main stems (the ratio of sprouts to main stems = 1.18), while the other dominant species of the forest stands had the ratios less than 0.7 (Fig. 9).

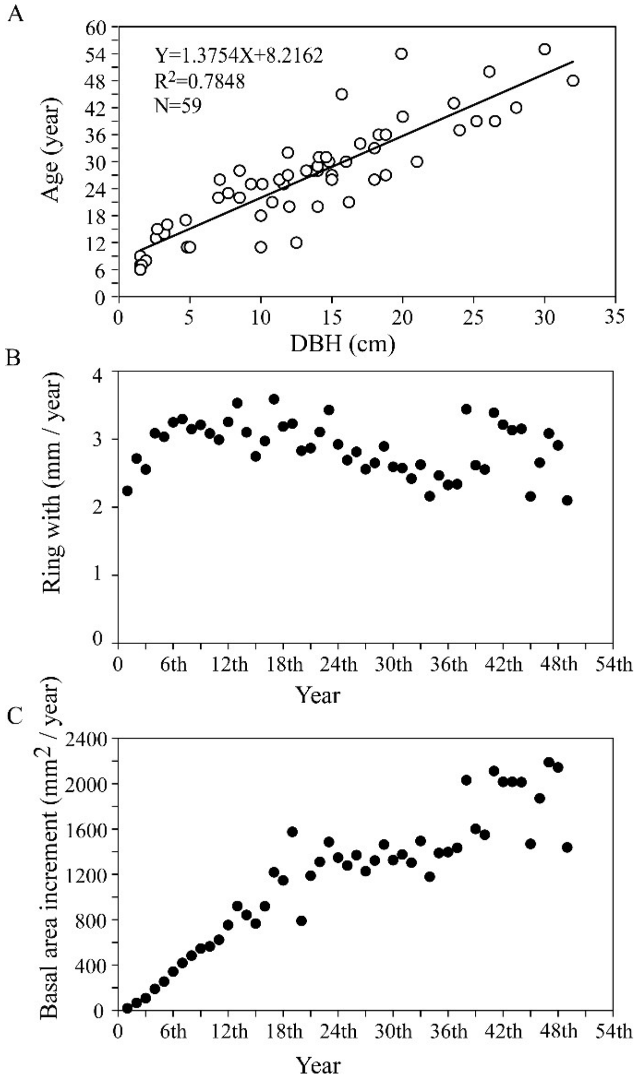

Fig. 7. Growth trends of *Dipentodon sinicus*. **A**. Relationships of age and DBH. **B**. The ring width. **C**. The basal area increment (BAI).

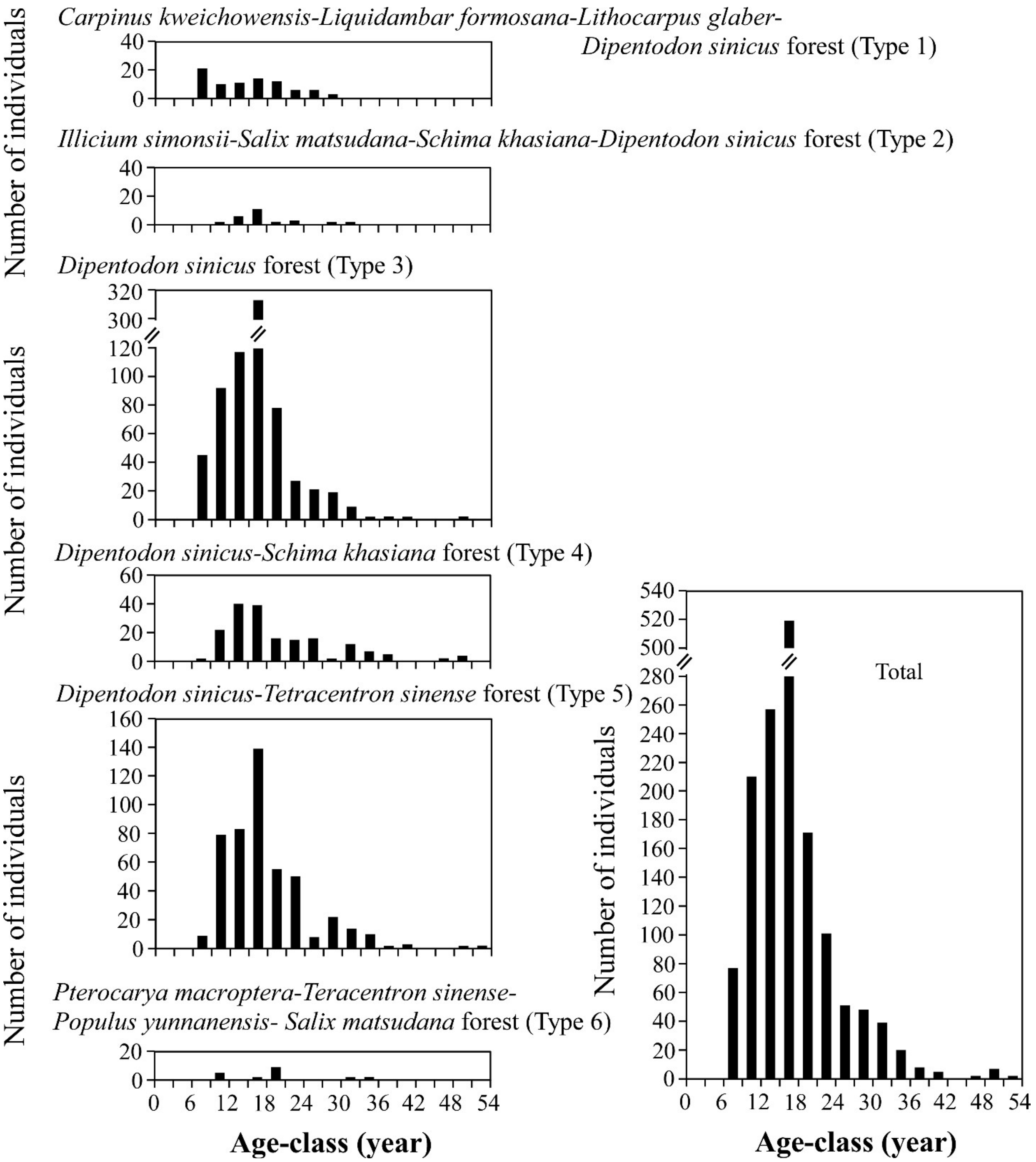

Fig. 8. Age-class frequency distribution of *Dipentodon sinicus* in the six forest types.

DISCUSSION

Many relict plant species endemic to East Asia are habitat specialists and have specific regeneration niches (Tang, 2015; Tang *et al.*, 2018). *D. sinicus* found on unstable habitats including steep slopes, landslide sites, stream sides and roadsides shares ecological traits similar to many other relict plant species as exemplified by temperate deciduous broad-leaved *Davidia involucrata* found in scree slops on the Mt. Emei, Sichuan (Tang and Ohsawa, 2002), *Tetracentron sinense* found in deep ravines and on steep slopes in the Ailao Mountains, Yunnan (Tang *et al.*, 2013), *Euptelea pleiospermum* in riparian habitats with poor nutrients in the Shennongjia Mountains, Hubei (Wei *et al.*, 2010) and *Euptelea polyandra*, found in sites with repeated

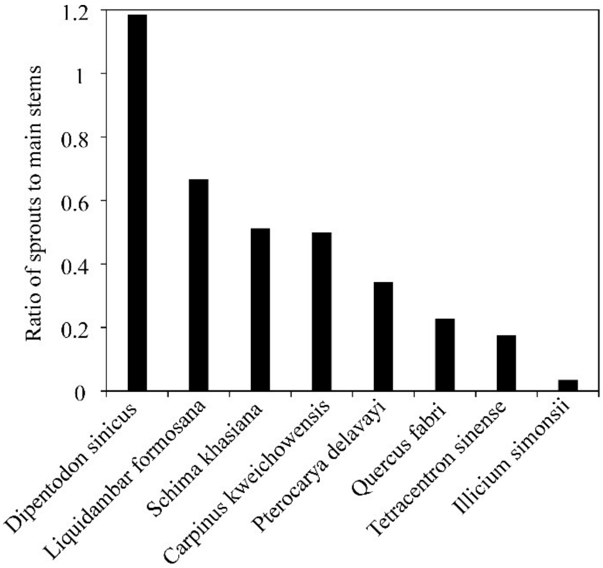

Fig. 9. The ratio of sprouts to main stems of *Dipentodon sinicus* and other dominant species in the forests studied.

ground surface disturbances in warm-temperate forests of the Chiba prefecture, Japan (Sakasi and Ohsawa, 1994), *Cercidiphyllum japonicum*, found in riparian habitats with frequent distrubance in Japan (Kubo *et al*., 2008); also coniferous *Metasequoia glyptostroboides* found on steep slopes and stream sides in deep valleys of Lichuan, Hubei (Tang *et al*., 2011), *Ginkgo biloba* favored rock crevices, limestone habitats in the Dalou Mountains, Guizhou (Tang *et al*., 2012), *Cathaya argyrophylla* found on steep slopes surrounded by cliffs on Mt. Jinfo, Chongqing (Qian *et al*., 2016), *Thuja sutchuenensis* found on steep limestone slopes in the Daba Mountains, Chongqing (Tang *et al*., 2015), *Taiwania cryptomerioides* found on riverbanks in deep valleys, on steep slopes, cliffs in the Gaoligong Mountains, Yunnan (He *et al*., 2015). All of those species' recruitments are restricted to local habitats with moderate disturbance regimes where competition usually is less intense and the regeneration potential of non-relict species is lower. Moreover, other relict trees, including *Tetracentron sinense* and *Pterocarya macropterai* var. *delavayi* grow along with *D. sinicu*s in the stream sides. *D. sinicus* has a ratio of sprouts to main stems similar to that of relict a small deciduous broad-leaved tree *Euptelea pleiospermum* (around 1.2). Besides seedlings/saplings' establishment, the abundant sprouting of relict species is also a key factor in their survival in an environment where damage to tree stems is frequent (Tang and Ohsawa, 2002; Tang, 2015). The deciduous broad-leaved relict species are confined to scree slopes, or steep slopes, or stream banks, or landslide-prone sites. Apart from more favorable light conditions, such as habitats generally have a rapid turn-over and replenishment of nutrient resources, which is beneficial for deciduous broad-leaved species, as they have a faster nutrient turn-over than evergreen broad-leaved species.

Though natural regeneration of this species is generally good, it becomes vulnerable because of human activities, such as cutting the trees for fuel and habitats fragmentation and loss. For effective conservation and management of this relict species, we emphasize that saplings on roadsides, being especially vulnerable, should be saved to the extent practicable.

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Appendix. Floristic composition of woody species (height ≥ 1.3 m) of the 6 forest types containing *Dipentodon sinicus*. Dominant species are indicated by boldface.

Range of altitude (m)	2000-2100	2615-2636	1829-2760	2398-2612	2356-2850	2583-2650
N. of plots	2	2	11	4	12	2
Total plot area (㎡)	800	800	4800	2400	5000	800
Species	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)
Deciduous broad-leaved						
Carpinus kweichowensis	**18.50**		0.003			
Liquidambar formosana	**17.71**		0.30			
Dipentodon sinicus	**13.70**	**9.72**	**62.75**	**27.79**	**25.81**	2.93
Quercus fabri	**9.61**		3.24			
Ilex micrococca	3.49		0.09			
Styrax japonicus	0.36		0.01			
Ilex fragilis	0.24				0.37	
Symplocos ramosissima	0.19		0.05		0.09	
Corylus heterophylla var. *sutchuenensis*	0.16		1.03		0.03	
Dendrobenthamia japonica var. *chinensis*	0.15		1.18		0.03	
Litsea cubeba	0.10		0.48			
Rhus chinensis	0.06		0.02		0.02	
Viburnum dilatatum	0.05		0.05		0.14	
Eurya impressinervis	0.04					
Gmelina chinensis	0.04					
Betula alnoides	0.02		1.72	2.49	0.40	
Viburnum betulifolium	0.02		0.003			
Evodia austrosinensis	0.02		0.01			
Hypericum monogynum	0.001	0.21	0.03	0.08	0.001	
Rosa sericea	0.001		0.0002			
Salix matsudana		**10.41**	0.73	0.10	3.60	**9.40**
Litsea pungens		**9.65**	0.02	0.29	0.11	0.24
Sorbus folgneri		5.33	1.18	2.24		
Lithocarpus confinis		4.82	1.80	2.41	0.01	
Cinnamomum bodinieri		2.43			0.01	
Corylus ferox		1.55		0.03	0.89	0.04
Acer buergerianum		1.30	0.13	0.45	0.31	0.09
Berberis diaphana		0.18	0.02		0.01	
Daphne odora		0.12		0.001	0.11	0.03
Acer oliverianum		0.005	0.96	1.75	7.59	2.50
Tetracentron sinense			1.10	1.60	**15.09**	**22.51**
Betula albosinensis			1.07		0.86	1.36
Cyclobalanopsis gambleana			0.76		0.01	
Alnus nepalensis			0.63	0.60		
Magnolia campbellii			0.60		0.56	2.70
Pterocarya macropterai var. *delavayi*			0.55			**23.87**
Premna crassa			0.53			
Padus racemosa			0.52	2.56	1.19	4.92
Decaisnea insignis			0.51			0.13
Styrax grandiflorus			0.40			
Nothopanax delavayi			0.31	0.07	0.47	
Cerasus clarofolia			0.21			
Swida macrophylla			0.17			
Magnolia wilsonii			0.11			
Sorbus aronioides			0.07		0.001	
Aralia elata			0.05	0.25	0.01	
Enkianthus deflexus			0.05		0.005	
Catalpa fargesii			0.04			
Davidia involucrata			0.02		0.22	
Deutzia glomeruliflora			0.02			0.05
Populus davidiana			0.02		0.25	1.30
Buddleja albiflora			0.01			
Buddleja macrostachya			0.01			0.04
Polygonum molle			0.01			
Viburnum foetidum var. *ceanothoides*			0.01			
Salix daliensis			0.004			

Range of altitude (m)	2000-2100	2615-2636	1829-2760	2398-2612	2356-2850	2583-2650
N. of plots	2	2	11	4	12	2
Total plot area (㎡)	800	800	4800	2400	5000	800
Species	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)
Ficus heteromorpha			0.004			
Philadelphus delavayi			0.001		0.06	0.36
Acer franchetii			0.001		0.03	
Populus yunnanensis				1.41	1.54	**11.59**
Pterocarya stenoptera				0.92	3.20	
Cyclobalanopsis augustinii				0.60	6.47	0.01
Ilex polyneura				0.47		
Fraxinus chinensis				0.04	0.005	
Hydrangea chinensis				0.03	0.08	
Rubus stans				0.004		
Zanthoxylum simulans				0.002	0.001	
Magnolia officinalis					0.43	
Lindera fruticosa var. fruticosa					0.42	
Tilia chinensis var. investita					0.22	0.11
Enkianthus chinensis					0.07	
Parthenocissus semicordata					0.03	
Magnolia rostrata					0.02	
Cardiocrinum giganteum var. *yunnanense*					0.02	
Hydrangea davidii					0.004	
Rubus lineatus					0.001	
Eleutherococcus nodiflorus						1.70
Fagus longipetiolata						0.23
Corylus yunnanensis						0.09
Meliosma cuneifolia						0.06
Cerasus yunnanensis						0.01
Polygala arillata						0.004
Evergreen broad-leaved						
Lithocarpus glaber	**17.70**			1.37	1.73	
Cyclobalanopsis argyrotricha	4.06		0.99			
Rhododendron irroratum	3.48		1.85			
Cyclobalanopsis multinervis	2.29					
Rhododendron delavayi	2.09		2.13		0.18	
Schima superba	1.37		0.55			
Castanopsis platyacantha	1.18		0.81		3.79	
Eurya japonica	0.22		0.05		0.02	
Rhododendron simsii	0.18		0.13			
Lithocarpus hancei	0.11		0.73			
Lyonia ovalifolia var. *lanceolata*	0.09	0.26				
Machilus salicina	0.07		0.07			
Viburnum cylindricum	0.01	1.55	0.04	0.22		0.07
Eurya semiserrata	0.01					
Mahonia imbricata	0.004				0.001	
Illicium simonsii		**11.27**	1.90	2.17	1.92	
Schima khasiana		**10.00**	0.14	**27.73**	0.70	
Lindera obtusiloba		**9.12**	0.62	0.52	3.30	1.21
Cyclobalanopsis glaucoides		7.05		3.01	0.26	1.07
Eurya nitida		3.25	0.01	0.04	0.03	
Vaccinium mandarinorum		0.97	0.31	5.31	0.001	
Schefflera octophylla		0.85	0.02	2.92	0.08	0.001
Picea brachytyla var. *complanata*		0.46				
Symplocos laurina		0.35				
Rhododendron araiophyllum		0.16	0.13	0.22	1.46	0.12
Pieris formosa		0.13	0.04	0.20	0.61	0.01
Ilex forrestii			1.04			
Rhododendron grande			0.78	0.04	0.78	1.33
Lyonia ovalifolia			0.63	0.26	0.24	0.004
Rhododendron annae			0.53			
Cinnamomum glanduliferum			0.37	0.08	2.68	0.04
Rhododendron neriiflorum			0.37		0.22	0.01
Ilex triflora			0.28			

Range of altitude (m)	2000-2100	2615-2636	1829-2760	2398-2612	2356-2850	2583-2650
N. of plots	2	2	11	4	12	2
Total plot area (㎡)	800	800	4800	2400	5000	800
Species	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)	RBA (%)
Acer kungshanense			0.26	0.38	0.30	0.11
Rhododendron decorum			0.26			
Myrica esculenta			0.24			
Lithocarpus kawakamii			0.11		0.04	
Ilex cornuta			0.03	0.20		
Elaeagnus bockii			0.02			
Lithocarpus variolosus			0.02	1.74	1.69	
Cotoneaster franchetii			0.01			
Pentapanax leschenaultii			0.01	0.27	0.03	
Ligustrum quihoui			0.004		0.17	3.79
Pyracantha fortuneana			0.002			
Photinia integrifolia				2.28	0.001	0.54
Schima argentea				0.93		
Manglietia hookeri				0.80		
Machilus longipedicellata				0.26	0.34	
Gaultheria forrestii				0.02		
Swida oblonga				0.01	0.01	1.62
Craibiodendron stellatum				0.01		
Vaccinium bracteatum var. *obovatum*				0.004	0.17	
Buxus myrica				0.002		
Dendrobenthamia capitata					0.85	
Viburnum chingii					0.39	0.07
Symplocos phyllocalyx					0.03	
Rhododendron sidereum					0.02	
Lindera supracostata					0.02	
Euonymus theifolius					0.01	
Ligustrum lucidum					0.01	0.04
Lyonia doyonensis					0.01	
Myrsine semiserrata					0.002	
Coniferous						
Pinus armandii	2.68		0.06		2.43	0.07
Tsuga dumosa		8.84	0.80	2.83	3.90	3.65