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A comparison of tree community assemblage and diversity of secondary forests between the birch and pine-oak belts in the mid-altitude zone of the Qinling Mountains, China

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Deforestation is a major driver of forest loss and fragmentation, threatening forest biodiversity worldwide. The conservation and restoration of secondary vegetation is thus an important developmental goal. Birch and pine-oak belts have been the two main types of vegetation in the mid-altitude zone of the Qinling Mountains in China but are now mainly covered by secondary growth following large-scale deforestation. Assessing the recovery and sustainability of these forests is essential for their management and restoration. We investigated and compared the tree community assemblages and diversity patterns of secondary forests between birch and pine-oak belts in the Huoditang forest region of the Qinling Mountains after identical natural recoveries. Both the birch and pine-oak belts had richspeciescompositions and similar floristiccomponents but clearly different tree community structures. Niche and neutral processes simultaneously influenced the distribution of species and the community dynamics of the belts. Tree diversity was significantly higher for the birch than the pine-oak belt. Monitoring biodiversity is essential for the recovery and development of forest resources in the Qinling Mountains to safeguard biodiversity, especially tree diversity.

A comparison of tree community assemblage and diversity of secondary forests between the birch and pine-oak belts in the mid-altitude zone of the Qinling Mountains, China

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Abstract: Deforestation is a major driver of forest loss and fragmentation, threatening forest biodiversity worldwide. The conservation and restoration of secondary vegetation is thus an important developmental goal. Birch and pine-oak belts have been the two main types of vegetation in the mid-altitude zone of the Qinling Mountains in China but are now mainly covered by secondary growth following large-scale deforestation. Assessing the recovery and sustainability of these forests is essential for their management and restoration. We investigated and compared the tree community assemblages and diversity patterns of secondary forests between birch and pine-oak belts in the Huoditang forest region of the Qinling Mountains after identical natural recoveries. Both the birch and pine-oak belts had rich species compositions and similar floristic components but clearly different tree community structures. Niche and neutral processes simultaneously influenced the distribution of species and the community dynamics of the belts. Tree diversity was significantly higher for the birch than the pine-oak belt. Monitoring biodiversity is essential for the recovery and development of forest resources in the Qinling Mountains to safeguard biodiversity, especially tree diversity.

Subjects: Ecology, Biodiversity, Conservation Biology, Plant Science

Key words: biodiversity conservation, restoration effect, floristic composition, coexistence mechanism

Conserving biodiversity in forests has been a significant global concern (Brockerhoff et al. 2008; Ratcliffe et al. 2015), because forest ecosystems provide services essential to human well-being and refuges for terrestrial plants and animals (Schuldt & Scherer-Lorenzen 2014; Sharma et al. 2010). Rapid changes in forest landscapes due to urbanization, agriculture, road construction, and especially deforestation have caused forest loss and fragmentation, threatening forest biodiversity worldwide (Elliott & Swank 1994; Imai et al. 2014;

Jung et al. 2014).Urgent intervention for conserving biodiversity and forest remnants is thus necessary (Jactel & Brockerhoff 2007; Nyafwono et al. 2014; Oishi & Doei 2015).

Large areas of original forest in China were cut between the 1950s and 1980s. After years of protection, secondary forests formed with varying patterns of natural succession (Kan et al. 2015), which now account for approximately 50% of the total forests in China (Chen et al. 1994 ; Yan et al. 2013; Yang et al. 2013). Forest restoration has been increasingly addressed by the Chinese government and ecologists, because deforestation has caused serious environmental problems and the loss of ecological services (Huang et al. 2006; Zhang et al. 2010b).

The Qinling Mountains are speciose and a key region of biodiversity of global importance. The forests in the mountains unfortunately suffered from large-scale deforestation in the 1960s and 1970s.Young secondary forests now cover large areas and increasingly define the prospects of long-term conservation of ecosystem~~ic~~ services and biodiversity (Cheng et al. 2015; Wang et al. 2015). The mid-altitude zone covers a large area, with complicated geomorphology and various climatic and soil conditions, and is characterized by the richest species diversity in the Qinling Mountains. Birch (*Betula*) and pine-oak (*Pinus*-*Quercus*) belts are the two main types of vegetation in the zone (Figure 1) (Liu et al. 2001) and play important roles in the establishment and maintenance of ecosystems and their functions, such as the conservation of soil and water (Chai & Wang 2015; Lei et al. 1996b; Lei et al. 1996c).

Previous studies of the vegetation~~al~~ community assemblage and diversity of belts of birch and pine-oak in the Qinling Mountains found that: (1) both types of belts had high species richness and diversity (Lei et al. 1996b; Lei et al. 1996c; Wang et al. 2015; Zhang et al. 2014), (2) the developmental stage influenced the community assemblage and diversity pattern (Chai & Wang 2015; Ma et al. 2014; Zhang et al. 2014); and (3) environmental factors influenced the community assemblage, diversity pattern, and especially micro-habitats and soil conditions (Lei et al. 1996b; Ren et al. 2012; Wu et al. 2012; Zhao et al. 2003). These studies, however, did not compare the characteristics of the birch and pine-oak belts, especially the secondary vegetation that established at the same time and region after clear-cutting. ~~This information is essential for assessing the sustainability of forests and the role they play in the conservation of biodiversity and the management of the forest ecosystems.~~

We investigated and compared the tree community assemblages and diversity patterns of secondary forests in the birch and pine-oak belts in the Huoditang forest region of the Qinling Mountains after identical natural recoveries. We aimed to improve our understanding of the status of secondary forests and to contribute to the success of vegetation~~al~~ restoration and conservation of biodiversity.

Materials and methods

Study site

The Qinling Mountains are in the transitional region between the subtropical and warm temperate zones of central China and are generally considered as the physical geographical dividing line between southern and northern China. The mountains are valuable reservoirs of biodiversity and play a key role in the maintenance of other natural resources, such as soils, air, and water. The vegetation of, and environmental change in, the mountains have long been of academic interest due to the unique geographical location (Dang et al. 2010; Huang et al. 2006; Wang et al. 2015; Zhang et al. 2013). The vegetation displays a vertical zonation. The zones in Figure 2 represent a general model for Taibai Mountain, the highest peak in the Qinling Mountains, with a summit altitude of 3767 m a.s.l.. The zones extend laterally and vary locally (Fang & Gao 1963; Zhao et al. 2014).

The birch belt at 2200-2700 m contains *Betula albosinensis* Burk., *B. utilis* D. Don, *B. luminifera* H. Winkl., and *B. platyphylla* Suk. Pine-oak mixed forests and mosaic pure forests of *Pinus tabuliformis* Carr., *P. armandii* Franch., and *Quercus aliena* var. *acutiserrata* Maxim. are distributed at 800-2300 m and constitute the pine-oak belt (Liu et al. 2001). These two forest belts are the most common types in the mid-altitude zone (1300-2600 m) of the Qinling Mountains.

We conducted a field survey at the Qinling National Forest Ecosystem Research Station in the Huoditang forest region in Ningshan County (Figure 3A). The Huoditang forest region at 850-2470 m in the typical vertical vegetation~~al~~ zone on the south slopes of the Qinling Mountains, and the research station is in the mid-altitude zone between 1400 and 2400 m. The birch belt is distributed at higher elevations of the mid-altitude zone (1800-2400m), and the pine-oak belt is widely distributed at lower elevations (1300-2000 m) (Wang et al. 2015).

Most areas of the Huoditang forest region were last cut during the 1960s and 1970s~~, which undoubtedly contributed to the regeneration of diverse natural secondary forests~~, and 95% of the area is ~~consequently~~ now covered by secondary growth (Cheng et al. 2013; Lei et al. 1996a). The forest region has rich plant resources and complex forest types, and the area of secondary forest is large and centrally distributed. The Huoditang forest was thus favorable for studying the secondary forests in the Qinling Mountains (Chai & Wang 2015; Cheng et al. 2013; Lei et al. 1996a; Wang et al. 2015).

Field sampling

We divided the birch and pine-oak belts into five forest types (Table 1) based on a previous study (Lei et al. 1996a) and a reconnaissance survey. These forest types are the most common in the mid-altitude zone of the Huoditang forest region. A total of 50 permanent plots (30 × 30 m) were established, 25 plots for each of the birch and pine-oak belts, using typical sampling methods for surveying the floristic composition, diversity, and structure of the forests. Five plots were randomly placed in each of the five forest types in each of the birch and pine-oak belts. The total study area was 4.5 h~~m^2~~. The elevation, slope, aspect, and GPS location of each plot were determined. The forest types met the following criteria: (1) stand age of approximately 50-60 a representing the earliest and largest secondary forests after the deforestations, (2) minimal disturbance after cutting, and (3) similar habitat conditions among the forest types.

All trees with a diameter at breast height (DBH, at 1.3 m) ≥5 cm were marked, and their locations were determined using a total station (TOPCON-GTS-602AF). Canopy closure, stem height (height of the first major branch), tree height, DBH, crown width, and health status were surveyed for the trees in each plot following the Forestry Standards "Observation Methodology for Long-term Forest Ecosystem Research" of People's Republic of China (LY/T 1952-2011).

Data analysis

Importance values (IVs)

The Importance value (IV) of species is defined as average of its relative density (RD), relative frequency (RF), and relative dominance (Rd), and IVs of tree species were calculated using the following equations (Arbainsyah et al. 2014):

$$\text{Density } (D) = \frac{\text{Number of individuals of a species}}{\text{Area of all sample units}}$$

$$\text{Relative abundance } (RD) = \frac{\text{Number of individuals of a species}}{\text{Density for all species}} \times 100\%$$

$$\text{Frequency } (F) = \frac{\text{Number of quadrats containing a certain specis}}{\text{Total number of quadrats}}$$

$$\text{Relative Frequency } (RF) = \frac{\text{Frequency of a certain species}}{\text{Total number of species}} \times 100\%$$

$$\text{Dominance } (d) = \frac{\text{Basal area of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Dominance } (Rd) = \frac{\text{Dominance of one specis}}{\text{Domiance of all species}} \times 100\%$$

$$IV= (RD+RF+Rd)/3$$

Species accumulation curves (SACs)

SACs are used to compare the diversity properties of community data sets. The classic "random" method finds the mean SAC and its standard deviation by randomly permutating the data (Gotelli & Colwell, 2001). We obtained a SAC for the tree species by computing the cumulative number of species encountered as the number of plots sampled increased (or total area). The plots were randomly laid, and this procedure was repeated 100 times for obtaining the mean SAC and its standard deviation.

Species abundance distribution (SAD)

The following six SAD models were considered: broken-stick, niche-preemption, log-normal, Zipf, Zipf-Mandelbrot, and neutral-theory models (Table 2, the details of these models see the introduction of common species abundance distribution models in the supplementary materials). The Kolmogorov-Smirnov (K-S) test was applied for comparing the discrepancy of the fitted and observed SAD patterns; this test is recommended for testing the agreement to models of abundance distribution (Hill & Harmer, 1998; Basset et al., 1998) because it is more powerful than the chi-square test. The Akaike Information Criterion (*AIC*) and Bayesian Information Criterion (*BIC*) methods were also used to compare the models and identify the best model by using log-likelihoods (log *L*) of the fitted models as the input (Filho et al., 2002). *AIC* and *BIC* are calculated by:

$$AIC=-2\log L+2k$$

$$BIC=-2\log L+ k \log (n)$$

where *k* is the parameter number in the fitted model and *n* is the sample size.

Diversity indices

We used six common diversity indices, including distance-independent (Table 3, Codes 1-4) and distance-dependent (Table 3, Codes 5 and 6) indices (Hui et al. 2011).

Mingling (*M*) describes the spatial segregation of different species in a multispecies forest and is defined as the proportion of the four nearest neighbors that are different species from a reference tree *i*:

$$M_i = \frac{1}{4}\sum_{j=1}^{n} v_{ij}, \quad v_{ij} = \begin{cases} 1, if\ neighbor\ j\ is\ not\ the\ same\ species\ as\ reference\ tree\ i \\ otherwise\ 0 \end{cases}$$

Accordingly, the mean mingling is:

$$\overline{M} = \frac{1}{N_{sp}}\sum_{i=1}^{N_{sp}} M_i = \frac{1}{4N_{sp}}\sum_{i=1}^{N_{sp}}\sum_{j=1}^{4} v_{ij}$$

where N_{sp} is the number of trees of species sp in the community.

The status of spatial diversity (MS_i) of a tree species is determined by the relative species richness within structural unit *i* and the degree of mingling of the reference tree and can be expressed as:

$$MS_i = \frac{s_i}{5} \cdot M_i$$

Where S_i is the number of tree species in the neighborhood of reference tree *i*, including tree *i*.

The species average spatial status (MS_{sp}) is defined as:

$$MS_{sp} = \frac{1}{5N_{sp}}\sum_{i=1}^{N_{sp}} M_i \cdot S_i$$

The tree species spatial diversity (TSS) of a tree population is the sum of the average spatial diversity states of the various tree species:

$$TSS = MS_{sp1} + MS_{sp2} + \cdots + MS_{spn}$$

$$= \sum_{sp=1}^{n} \left[\frac{1}{5N_{sp}} \sum_{i=1}^{N_{sp}} (M_i \cdot S_i) \right]$$

where n is the number of tree species. The maximum value that *TSS* can assume is equal to the number of species in the community, provided each species is exactly represented by one tree, in which case all MS_{spi} are equal to 1 and *TSS* equals the maximum tree species richness. Species richness is minimum when a community contains only one species and *TSS* is zero (Hui et al. 2011).

We eliminated edge effects and improved the accuracy of the calculations of the distance-dependent diversity indices (Table 3, Codes 5 and 6) by establishing a 5-m buffer zone around the plots. Only trees in the reduced window (20×20 m) were used as reference trees in the statistical analysis, and the individual trees in the buffer zone were only considered to be the nearest neighbors of the trees in the reduced window. This edge correction could individually evaluate each tree to determine whether all *n* nearest neighbors were truly located within the plot.

R version 3.1.3(R Core Team 2015) was used for all statistical analyses. The distance-independent diversity indices (Table 3, Codes 1-4), SAC, SAD, and CA were conducted using the vegan (Oksanenet al. 2008) and untb (Robin 2009) packages. The figures were drawn and the data were manipulated using the ggplot2 (Hadley 2015) and reshape2 (Hadley 2014) packages, respectively.

Results

Tree species composition

A total of 50 tree species belonging to 30 genera in 16 families were identified among 5686 individual trees (DBH⩾5 cm) in the 50 plots (totaling 4.5 hm^2) from the 10 typical secondary forest stands in the two forest belts in the mid-altitude zone of the Qinling Mountains. The attributes of the stands are summarized in Table 4. The 25 plots of the birch belt contained 2934 individual trees in 43 species (27 genera, 16 families).

The 25 plots of the pine-oak belt contained 2752 individual trees in 41 species (28 genera, 14 families) (Tables S1 and 4).

Four species, *Q. aliena* var. *acutiserrata*, *P. armandii*, *Toxicodendron vernicifluum* (Stokes) F. A. Barkl., and *Carpinus turczaninowii* Hance had the broadest distributions, irrespective of forest type. The dominant species in the birch belt were *B. albo sinensis* (IV=10.63%), *P. armandii* (10.19%), *Acer davidii* Franch. (8.76%), *T. vernicifluum* (8.25%). The dominant species in the pine-oak belt were *Q. aliena* var. *acutiserrata* (26.15%), *P. tabuliformis* (22.50%), *P. armandii* (20.05%), and *T. vernicifluum* (10.27%) (Table S1).

The seven most common families were Pinaceae, Fagaceae, Aceracea, Betulaceae, Anacardiaceae, Rosaceae, and Lauraceae. These families accounted for 91.44% of all trees recorded and were among the ten most important families in both the birch and pine-oak belts. Aceraceae, Pinaceae, and Betulaceae were the dominant families with the highest values of overall relative importance (ORI) in the birch belt. Pinaceae, Fagaceae, and Anacardiaceae were the dominant families in the pine-oak belt (Table 5).

Acer, *Betula*, *Pinus*, *Toxicodendron*, *Tsuga*, *Quercus*, and *Carpinus* were among the most common and important genera in both forest belts. *Acer*, *Betula*, and *Pinus* were the dominant genera with the highest ORIs in the birch belt. *Pinus*, *Quercus*, and *Toxicodendron* were the dominant genera in the pine-oak belt (Table 6).

Species accumulation curves

The species accumulation curve for the birch belt rapidly approached an asymptote and the cumulative number of species in the pine-oak belt tended to increase as the number of sample plots increased. The species accumulation curves indicated that species richness was higher in the birch than the pine-oak belt (Figure 4).

Distribution of species abundance

The observed SADs of the tree communities of the birch and pine-oak belts, together with the distributions fitted by the six classical models (broken-stick, niche-preemption, log-normal, Zipf, Zipf-Mandelbrot, and neutral-theory), are shown in Figure 3. ~~The effects of the simulations were tested by Akaike's Information Criterion, the Bayesian Information Criterion, and Kolmogorov-Smirnov tests (Table 7).~~

The niche-preemption, neutral-theory, broken-stick, and log-normal models simulated SAD of the birch belt well. The observed SAD departed from the outputs of the Zipf-Mandelbrot and Zipf models (Figure 5, Table 7). The niche-preemption and neutral-theory models were much superior to the other models and should be suitable for simulating SAD patterns for birch belts. The Zipf-Mandelbrot, neutral-theory, log-normal, and Zipf models simulated SAD well, and the Zipf-Mandelbrot and neutral-theory models were better suited to the SAD patterns of the pine-oak belt.

Species diversity patterns

Species richness, Shannon-Wiener, Simpson, McIntosh, mean mingling, and TSS diversity indices were significantly higher in the birch than the pine-oak belt (Figure 6). The trends of all diversity indices were mostly consistent, with higher indices in the birch than the pine-oak belt. The indices differed significantly among the forest stands in the pine-oak but not the birch belt and were significantly lower in oak forests (QA) than pine-oak mixed forests (PAQA, PTQA) and pine forests (PA, PT).

Discussion

Tree species composition

The birch and pine-oak belts had rich species compositions and similar floristic components. The mid-altitude zone in the Qinling Mountains is rich in forest resources and species diversity that provide an important gene pool (Lei et al. 1996a; Wang et al. 2015). Birch and pine-oak belts are the two main forest types in the zone (Liu et al. 2001; Zhao et al. 2014), with rich species compositions (Lei et al. 1996b; Lei et al.

1996c; Wang et al. 2015; Zhang et al. 2014), in agreement with our findings. The numbers of species, genera, and families are very similar between the belts (Tables S1, 5, and 6), perhaps due to the similarity of their habitats. The range of the mid-altitude zone (1300-2600 m) is relatively small, especially in our study forests distributed between 1400 and 2400 m, so altitude would have little effect on species distribution and composition. These two forest belts share most species of trees and have similar floristic components.

Mechanism of coexistence of tree communities

Niche and neutral processes are simultaneously influencing the distribution of species and the community dynamics of the birch and pine-oak belts. The neutral-theory model was suited to the data for species abundance for both belts, which identified randomness as the main ecological process determining the distributional pattern of species abundance in these two forest belts. These forests can thus maintain a dynamic balance during growth and development and are amenable to stable and sustainable development, supporting the findings by Lei et al. (1996a, b, and c).

The niche-preemption model was also suitable for simulating SAD patterns for the birch belt, which showed that niche theory was important in the community assemblages of the birch belt. Lei et al. (1996b) reported that the constructive species *B. albo sinensis* was unstable in our study area, and regeneration was poor. The continuity of *B. albo sinens* populations was maintained by gap regeneration, supporting the regeneration-niche hypothesis (Grubb 1977). The above analysis suggests that both neutral and niche theories have played important roles in understanding the mechanisms of species coexistence in the birch belt.

The combination of the Zipf-Mandelbrot (niche-based model) and neutral-theory models suggested that the pine-oak belt contains progressive successional communities and can maintain community stability and sustainable development during succession, consistent with the findings by Chai & Wang (2015) and Lei et al.

(1996a). We concluded that the successional characteristics of pine-oak forests accords with the ecological interpretations of the Zipf-Mandelbrot model that climax species need more time and costs to replace the pioneer species during succession but ultimately survive for a long time. Species of pines are common pioneer species and are often later succeeded by climax species of oaks (Gracia et al., 2002; Yu et al., 2013; Broncano et al., 1998), and pine-oak mixed forests are usually an initial successional stage after a disturbance in pine forests where pines mainly dominate the forest canopy and oaks predominate in the understory (Gracia et al. 2002; Yu et al. 2013). Our results support this successional series, and our previous observations and studies also suggest that pine-oak mixed forests become oak forests within a few decades in the Qinling Mountains (Kang et al., 2011; Xu, 1990; Yu et al., 2013).

Many studies have warned against drawing ~~relevant~~ conclusions based on the ability of exclusive models to fit SAD patterns (Chen 2014), because the data may be equally well fitted by more than one model, which may provide substantially different interpretations. Our results at least suggest a possibility that niche and neutral processes are simultaneously influencing the distribution of species and the community dynamics of the birch and pine-oak belts. Both the findings by Legendre et al. (2009) for a subtropical evergreen broadleaved forest at the Gutianshan National Nature Reserve in eastern China and by Zhang et al. (2010a) for a temperate forest at Changbaishan in northeastern China also indicated that niche and neutral processes were simultaneously regulating species coexistence.

Tree diversity patterns

Tree diversity was significantly higher in the birch than the pine-oak belt, for ~~a number of~~ reasons. (1) The distributional range suited the birch belt better. (Lei et al. 1996a) reported that the birch belt was distributed toward the upper limit of the mid-altitude zone (1800-2400m), but the pine-oak belt was distributed at lower elevations (1200-2000 m). Species richness and diversity in the study area were highest between 1800 and 2200 m. (2) These two belts were the most common forest types, but the dominance of constructive species differed between the belts as the forests developed. The constructive species *B. albo sinensis* was not dominant in the birch belt; *B. albo sinensis* consocition community hardly ever existed, and was always mixed with other tree species (Lei et al. 1996b). In contrast, the constructive species *P. tabuliformis*, *P.armandii*, and *Q.aliena* var. *acutiserrata* predominated in the pine-oak belt (Liu et al. 2001). These dominances were reflected by the importance-value index (Table S1). IV was highest for *B. albo sinensis* in the birch belt (10.63%) but only slightly higher than for the other dominant tree species. The IVs of the constructive species *Q. aliena* var. *acutiserrata* (IV=26.15%), *P. tabuliformis* (IV=20.05%), and *P. armandii* (IV=22.50%) in the pine-oak belt indicated evident advantages. (3) The species accumulation curves (Figure 4) suggested that our sample size reasonably represented the expected number of species for the birch belt, but our sampling was less extensive for the pine-oak belt. The species diversity of the birch belt was nevertheless significantly higher than that of the pine-oak belt under the same sampling conditions.

milarity among the forest stands

The tree community structures clearly differed between the birch and pine-oak belts. Cluster analysis with group averages based on the species composition and abundance of forest stands divided the ten forest stands into two major groups, corresponding to the birch and pine-oak belts (Figure 7)~~, indicating commonness and differences among the ten forest stands.~~ Both the cluster and CA analyses were thus sufficient to demonstrate a clear difference between the belts. Previous studies have shown that climate change (Zhao et al. 2014), the influence of species interaction on the pattern of floristic composition, and small-scale topographic variation, especially elevation (Lei et al. 1996a), among forest stands can affect the distribution of forest stands in the mid-altitude zone of the Qinling Mountains.

Maintenance and monitoringof tree diversity

Monitoring biodiversity is essential for the recovery and development of forest resources in the Qinling Mountains to safeguard biodiversity, and tree diversity should be an especially crucial aspect of the monitoring. The Qinling Mountains have high biodiversity, support a large variety of plants and wildlife, and play a key role in the maintenance of other natural resources, such as soil, air, and water (Wang et al. 2015; Yu et al. 2014; Zhao et al. 2014). The forests, however, have been harvested since the 1950s, and much of the area is now covered by secondary growth that has low productivity and poor community stability (Chai & Wang 2015; Li et al. 2004). Protecting biodiversity and forest resources in the mountains has become a focus of attention (Lei et al. 1996a; Wang et al. 2015; Zhao et al. 2014). Enhancing the multi-functionality of forests is a goal of modern and sustainable forest management, which tries to balance a multitude of economic, ecological, and societal demands. Increasing the tree diversity of forests is particularly promising (Schuldt & Scherer-Lorenzen 2014). Tree diversity can reduce the severity and extent of insect damage to host trees by providing associational resistance (Castagneyrol et al. 2014; Conner et al. 2014; Schuldt & Scherer-Lorenzen 2014), and can serve as a robust indicator of forest degradation, because the diversity of trees often correlates with that of other taxa, and patterns in remotely sensed data of forest canopies often correlate with floristic patterns, implying a potential tool of the large-scale monitoring of trees (Imai et al. 2014). We thus conclude that the maintenance and monitoring of tree diversity should be included in the efforts to conserve forest resources in the Qinling Mountains.

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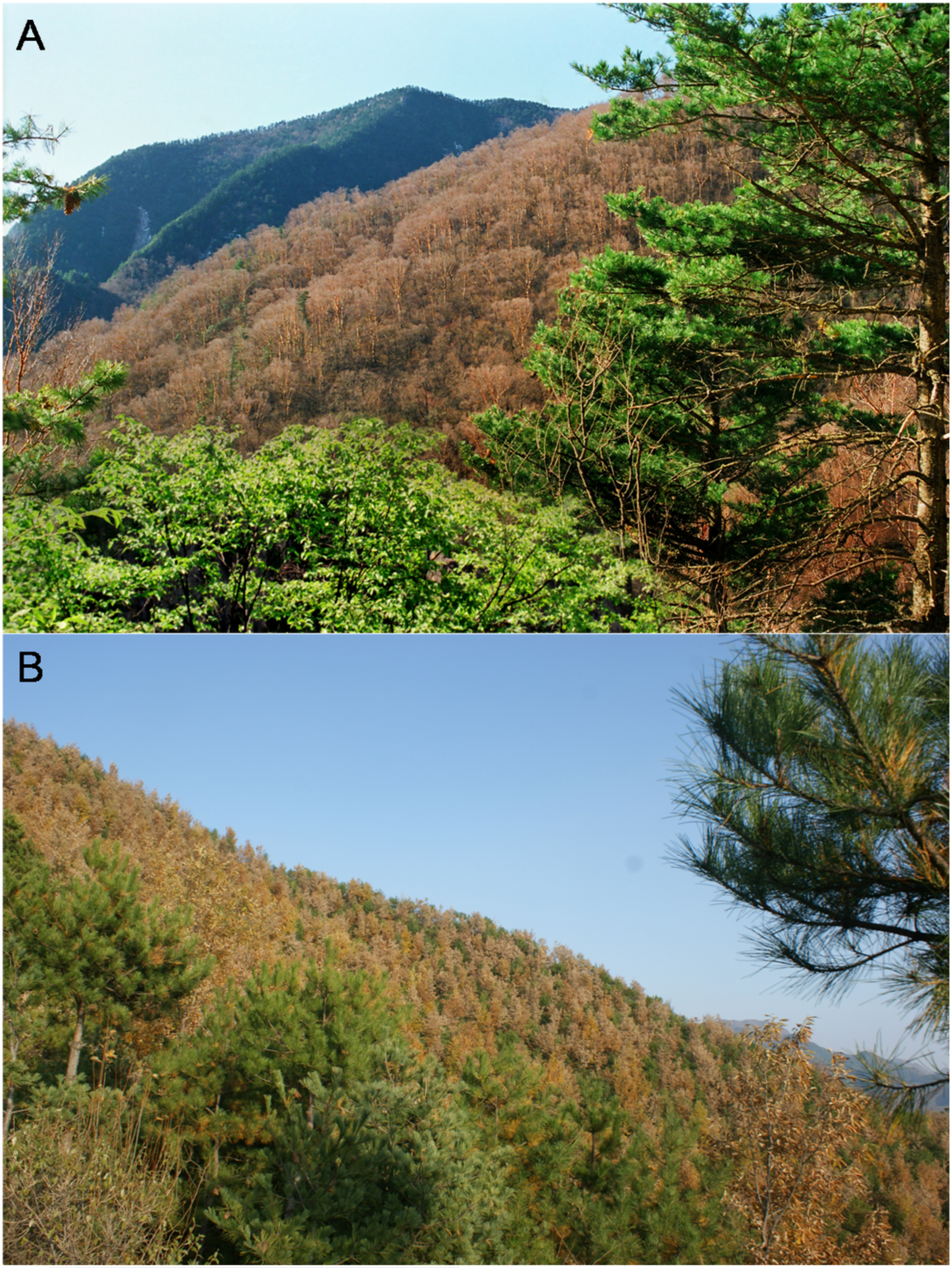
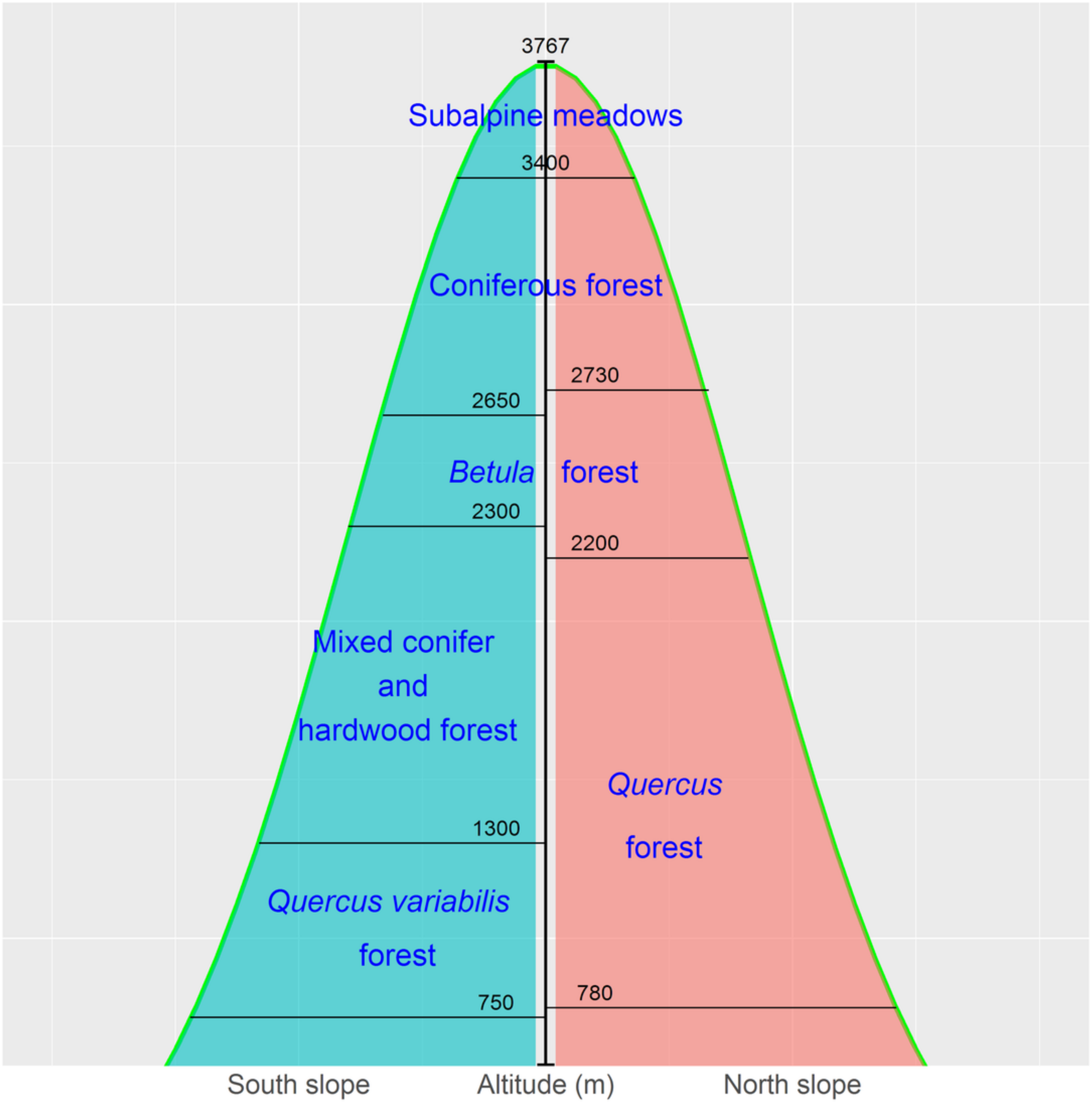
1

Birch (A) and pine-oak (B) belts in the mid-altitude zone of the Qinling Mountains, China.


A
B

2

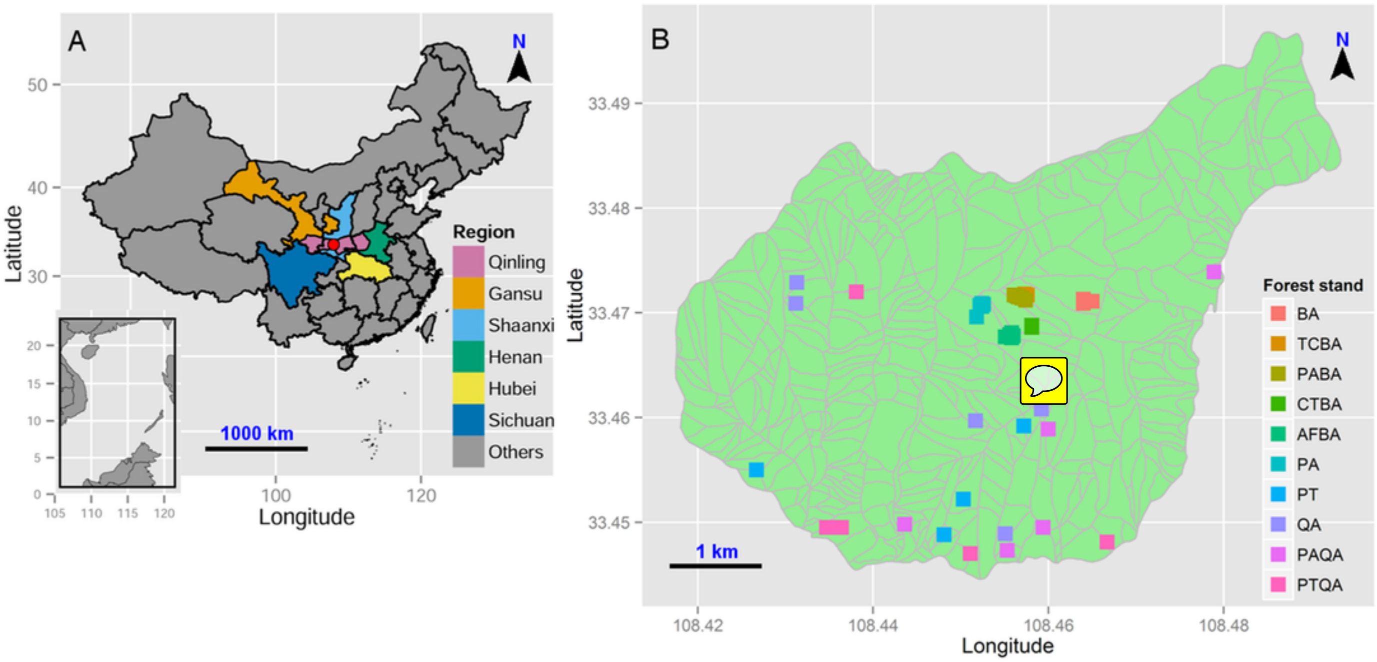
The vertical zones of vegetation in the Qinling Mountains, China (Zhao et al, 2014



3

Distribution of sample plots

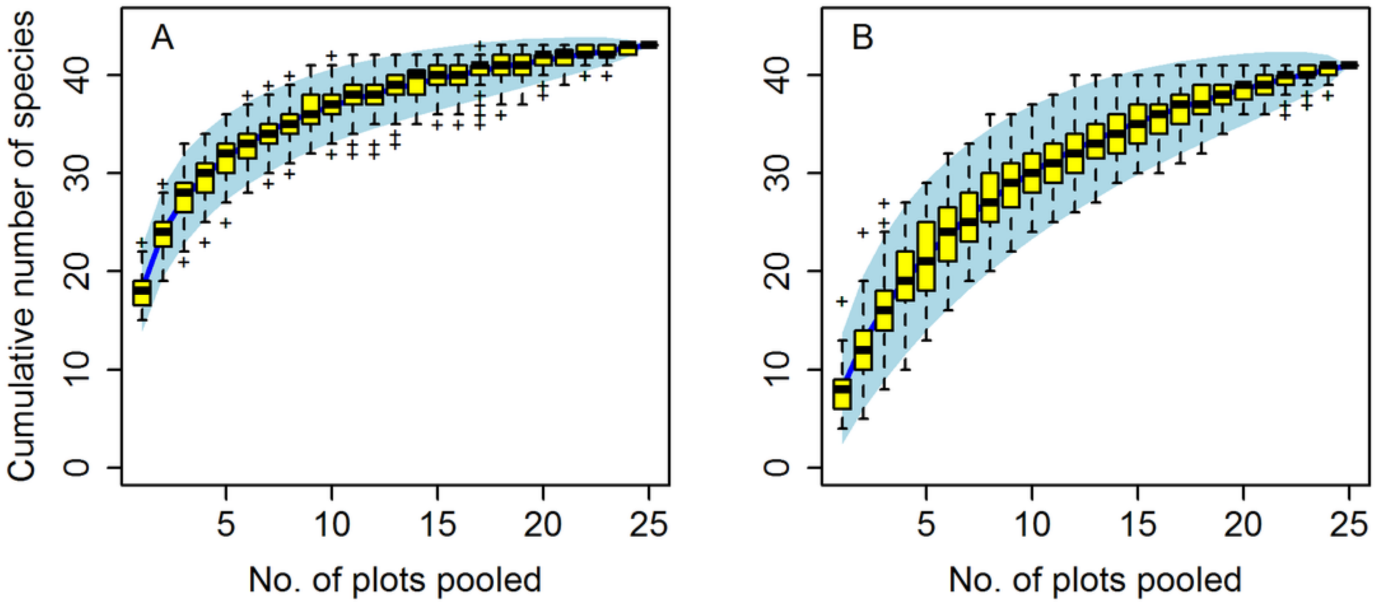
A, the location of the Qinling Mountains in China, and the red point represent Huoditang forest region. B, the distribution of the 50 sample plots in10 forest stands of the birch and pine-oak belts in the mid-altitude zone of the Huoditang forest region.



4

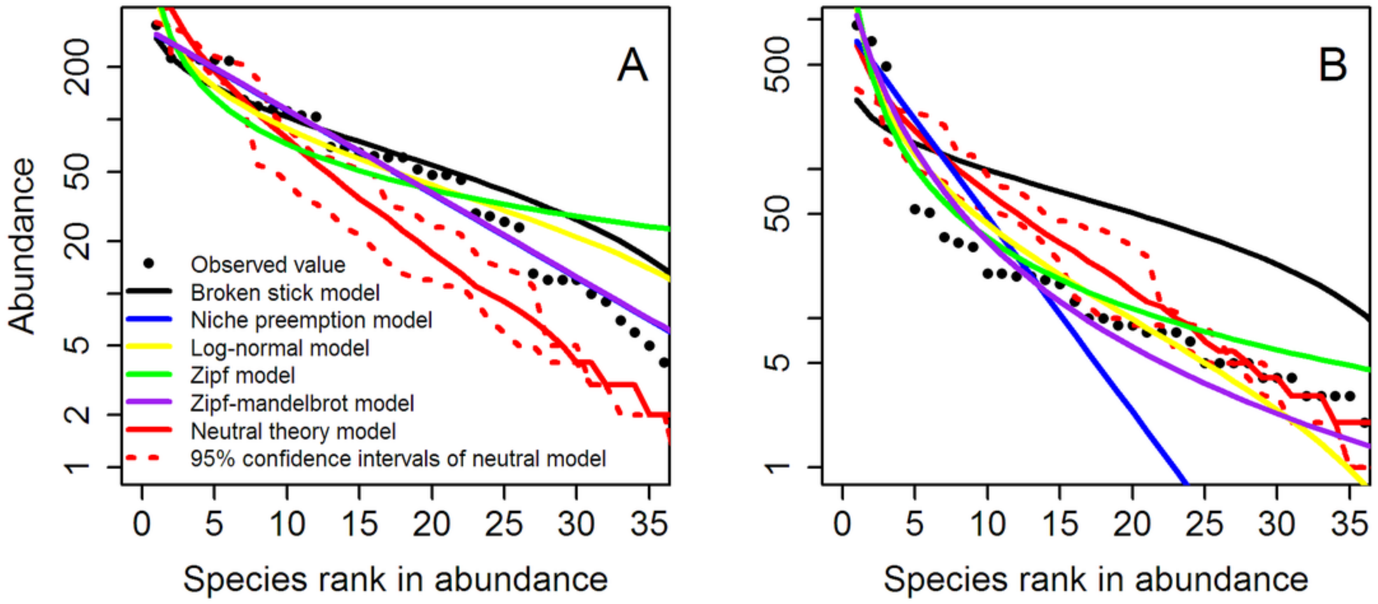
Species accumulation curvesof the typical secondary forests for the birch (A) and pine-oak (B)belts in the mid-altitude zone of the Qinling Mountains, China.

The dark blue line is the average species accumulation curve, the shaded light blue areas represent the distributional interval of the standard deviations from 100 random permutations of the data, and the box plots represent the distribution of the species accumulation curve from 100 random permutations of the data.



5

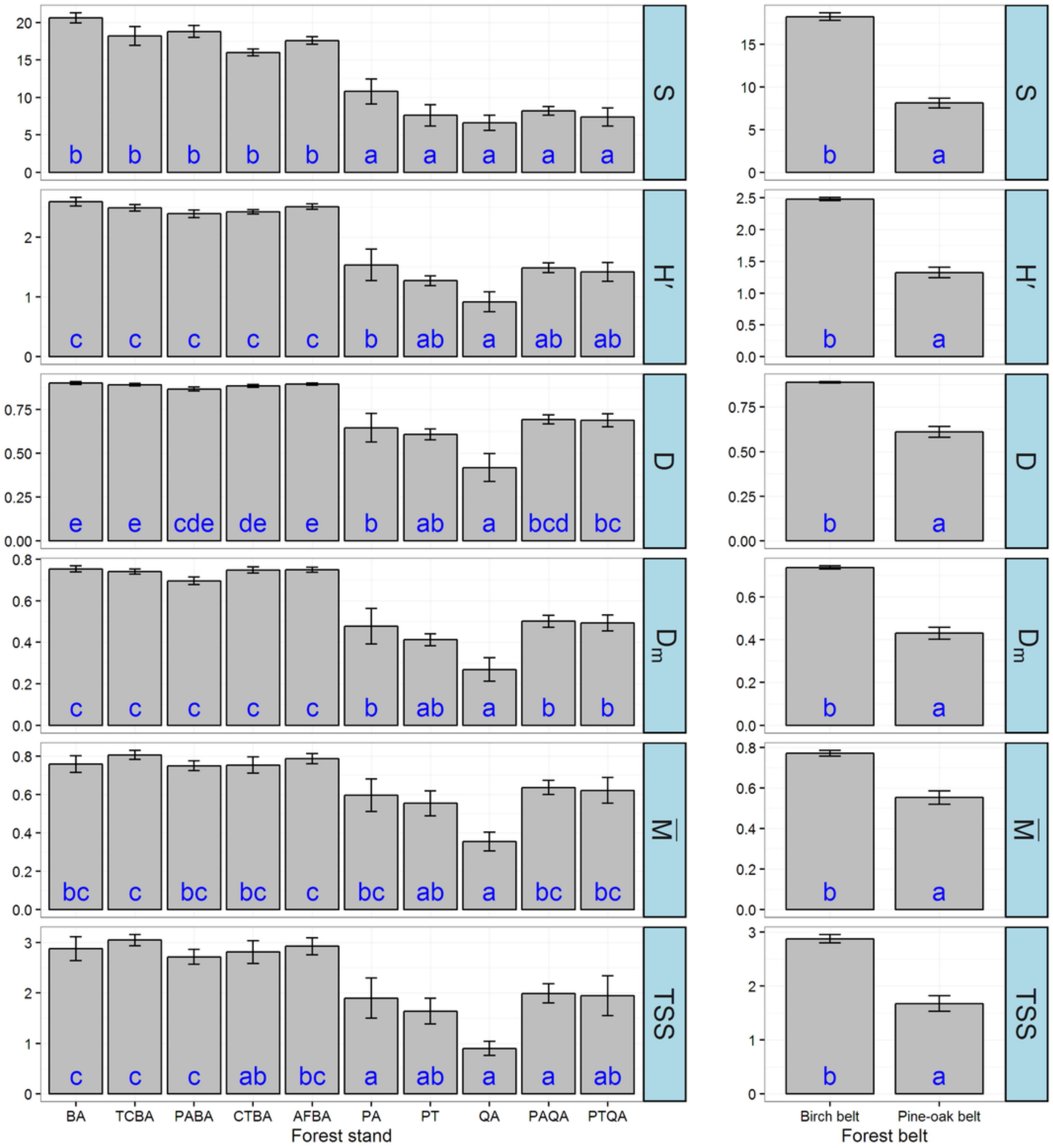
Species-abundance distribution and model fittings of the typical secondary forests for the birch (A) and pine-oak (B) belts in the mid-altitude zoneof the Qinling Mountains, China



6

Diversity indices of the typical secondary forests for the 10 forest stands (left) and twoforest belts(right) in the mid-altitude zone of the Qinling Mountains, China

S, species richness; H′, shannon-wiener index; D, simpson index; D_m , mcIntosh index; M is the mean mingling index; TSS, tree species spatial diversity.


S
H´
D
D$_m$
$\overline{M}$
TSS
Forest stand
BA
TCBA
PABA
CTBA
AFBA
PA
PT
QA
PAQA
PTQA
S: b b b b b a a a a a
H´: c c c c c b ab a ab ab
D: e e cde de e b ab a bcd bc
D$_m$: c c c c c b ab a b b
$\overline{M}$: bc c bc bc c bc ab a bc bc
TSS: c c c ab bc a ab a a ab
Forest belt
Birch belt
Pine-oak belt
S: b a
H´: b a
D: b a
D$_m$: b a
$\overline{M}$: b a
TSS: b a
0
5
10
15
20
0.0
0.5
1.0
1.5
2.0
2.5
0.00
0.25
0.50
0.75
0.2
0.4
0.6
0.8
1
2
3

7

Dedrogram from the cluster analysis (left) and CA ordination diagram (right) of the 10 typical secondary forestsin thebirch and pine-oak beltsin the mid-altitude zone he Qinling Mountains,China.

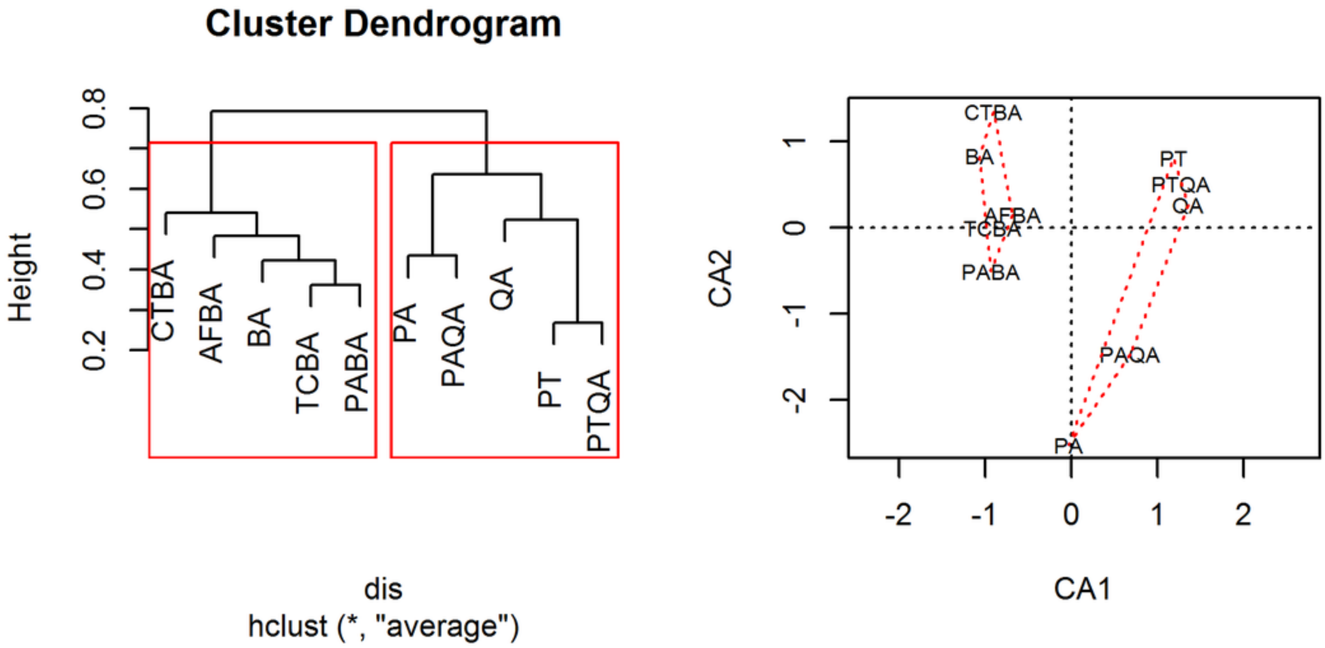


Table 1(on next page)

Main forest types of the birch and pine-oak belts in the mid-altitude zone of the Huoditang forest region of the Qinling Mountains, China

Forest belt	Forest stand	Code
Birch	*Betula albosinensis*	BA
	Tsuga chinensis + *Betula albosinensis*	TCBA
	Pinus armandii+ *Betula albosinensis*	PABA
	Carpinus turczaninowii+ *Betula albosinensis*	CTBA
	Abies fargesii+ *Betula albosinensis*	AFBA
Pine-oak	*Pinus armandii*	PA
	Pinus tabuliformis	PT
	Quercus aliena var. *acutiserrata*	QA
	Pinus armandii+ *Quercus aliena* var. *acutiserrata*	PAQA
	Pinus tabuliformis + *Quercus aliena* var. *acutiserrata*	PTQA

Table 2(on next page)

Six main models for the distribution of species abundance

Model	Equation	Code	Reference
Broken-stick	$\hat{a}_r = \frac{N}{S}\sum_{k=r}^{S}\frac{1}{k}$	(1)	MacArthur (1957)
Niche-preemption	$\hat{a}_r = N\alpha(1-a)^{r-1}$	(2)	Motomura (1932)
Log-normal	$\hat{a}_r = \exp\left[\log(u) + \log(\sigma)\Phi\right]$	(3)	Preston (1948)
Zipf	$\hat{a}_r = N\hat{p}_1 r^{\gamma}$	(4)	Frontier (1987)
Zipf-Mandelbrot	$\hat{a}_r = Nc(r+\beta)^{\gamma}$	(5)	
Neutral-theory	$\phi_n = \theta\frac{J!}{n!(J-n)!}\frac{\Gamma(\gamma)}{\Gamma(J+\gamma)}\int_0^{\gamma}\frac{\Gamma(n+y)}{\Gamma(1+y)}\frac{\Gamma(J-n+\gamma-y)}{\Gamma(\gamma-y)}\exp(-y\theta/\gamma)dy$	(6)	Hubbell (2001)

Notes: $\hat{a}_r$,expected abundance of species of rank *r*; *S*, number of species; *N*, number of individuals;Φ,a standard normal function; $\hat{p}_1$, estimated proportion of the most abundant species; α,σ,γ,β, and *c*, estimated parameters in each model. For the neutral-theory model, $\Gamma(z) = \int_0^{\infty} t^{z-1}e^{-t}dt$, which is equal to (z-1)!, for integer z, $\gamma = \frac{m(J-1)}{1-m}$, θ is a fundamental diversity number, and *m* is the migration rate.

Table 3(on next page)

Six main distance-independent and –dependent diversity indices

Distance	Diversity index	Equation	Code	Reference
Independent	Species richness	S= total number of species	1	
	Shannon-Wiener	$H = -\sum_{i=1}^{s} p_i \ln(p_i)$	2	(Shannon & Weaver 1949)
	Simpson	$D = 1 - \sum_{i=1}^{s} p_i^2$	3	(Simpson 1949)
	McIntosh	$Dm = N - \left(\sum_{i=1}^{s} N_i^2\right)^{1/2} / (N - N^{1/2})$	4	(McIntosh 1967)
Dependent	Mean mingling	$\overline{W} = \frac{1}{N_{sp}} \sum_{i=1}^{N_{sp}} M_i$	5	(Gadow & Hui 2002)
	Tree species spatial diversity	$TSS = \sum_{sp=1}^{n} \left[\frac{1}{5N_{sp}} \sum_{i=1}^{N_{sp}} (M_i \cdot S_i) \right]$	6	(Hui et al. 2011)

Notes: N, total number of individuals in the population; N_i, number of individuals of species i; p_i, proportion of individuals of species i in the community; N_{sp}, number of trees of species sp in the community.

Table 4(on next page)

Summary of the stand attributes of the typical secondary forests in the mid-altitude zone of the Qinling Mountains, China. See Table 1 for the stand codes

Item		Forest stand										Forest belt	
		BA	TCBA	PABA	CTBA	AFBA	PA	PT	QA	PAQA	PTQA	Birch	Pine-oak
Sample number		5	5	5	5	5	5	5	5	5	5	25	25
Forest area (m^2)		4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	22500	22500
Stand age (a)		50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60	50-60
Family number		13	12	13	11	10	13	10	10	10	8	16	14
Genera number		22	19	20	17	16	18	16	13	17	14	27	28
Species number		32	27	32	25	25	24	22	17	22	17	43	41
Diameter at breast height (cm)	min	13.04	13.32	14.06	16.70	13.90	17.87	14.06	16.27	14.94	14.77	13.04	14.06
	max	16.94	17.18	16.12	19.06	17.24	21.44	19.42	22.23	20.08	21.04	19.06	22.23
	mean	14.77	14.43	15.24	18.00	15.26	19.27	16.37	18.68	16.81	17.36	15.54	17.70
Tree height (m)	min	8.46	10.89	9.75	10.08	12.14	17.25	10.39	10.39	10.18	12.87	8.46	10.18
	max	10.44	11.81	14.82	11.01	16.56	20.21	19.17	19.04	16.11	19.48	16.56	20.21
	mean	9.54	11.18	12.09	10.51	14.91	19.13	13.66	13.59	13.57	16.22	11.65	15.23
Crown width (m)	min	0.60	0.70	0.70	0.55	0.00	0.70	0.50	0.50	1.30	1.65	0.00	0.50
	max	11.35	11.40	15.05	8.65	10.15	11.75	9.50	9.60	10.05	16.85	15.05	16.85
	mean	3.98	3.96	4.44	3.91	4.44	4.20	3.30	4.18	4.90	5.51	4.17	4.36
Basal area (m^2 hm^{-2})	min	29.44	24.50	30.20	21.54	26.34	24.48	32.82	31.82	21.13	22.91	21.54	21.13
	max	37.31	33.25	45.44	30.70	32.40	37.05	46.78	64.16	38.09	43.87	45.44	64.15
	mean	31.99	27.28	34.80	26.27	30.02	30.98	40.36	43.41	30.44	36.10	30.07	36.26
Stand density (trees hm^{-2})	min	1122	967	1400	800	944	767	1156	1167	822	1067	800	767
	max	1867	1478	2100	878	1411	1189	1789	1789	1456	1356	2100	1789
	mean	1511	1345	1593	835	1235	929	1493	1385	1073	1236	1304	1223

Table 5(on next page)

Ten most important tree families, in descending order of overall relative importance (ORI), for the birch and pine-oak belts in the mid-altitude zone of the Qinling Mountains, China

Rank	Birch belt	R.Ab	R.Fr	ORI	Pine-oak belt	R.Ab	R.Fr	ORI
1	Aceraceae	23.59	11.31	34.9	Pinaceae	46.84	17.24	64.08
2	Pinaceae	19.39	11.31	30.7	Fagaceae	33.68	15.17	48.85
3	Betulaceae	15.78	11.31	27.09	Anacardiaceae	6.8	13.79	20.59
4	Rosaceae	12.07	11.31	23.38	Betulaceae	3.85	11.72	15.57
5	Anacardiaceae	7.74	10.41	18.15	Lauraceae	2.18	8.97	11.15
6	Fagaceae	7.53	10.41	17.94	Cornaceae	1.89	7.59	9.48
7	Salicaceae	6.95	5.88	12.83	Juglandaceae	1.53	5.52	7.05
8	Lauraceae	1.87	7.24	9.11	Aceraceae	1.13	5.52	6.65
9	Araliaceae	2.22	5.88	8.1	Tiliaceae	0.69	3.45	4.14
10	Bignoniaceae	1.64	4.98	6.62	Rosaceae	0.65	3.45	4.1
	$\sum 1-10$	98.78	90.04	188.82	$\sum 1-10$	99.24	92.42	191.66
	$\sum 11-16$	1.22	9.95	11.17	$\sum 11-14$	0.76	7.59	8.35

1 Notes: R.Ab, relative abundance; R.Fr, relative frequency.

Table 6(on next page)

Ten most important tree genera, in descending order importance (ORI), for the birch and pine-oak belts in the mid-altitude zone of the Qinling Mountains, China

Rank	Birch belt	R.Ab	R.Fr	ORI	Pine-oak belt	R.Ab	R.Fr	ORI
1	*Acer*	23.59	7.55	31.14	*Pinus*	44.33	14.12	58.45
2	*Betula*	10.02	7.55	17.57	*Quercus*	33.68	12.43	46.11
3	*Pinus*	8.52	7.55	16.07	*Toxicodendron*	6.58	11.3	17.88
4	*Sorbus*	8.45	7.55	16	*Carpinus*	2.58	7.34	9.92
5	*Toxicodendron*	7.74	6.95	14.69	*Lindera*	1.85	6.21	8.06
6	*Tsuga*	7.6	6.95	14.55	*Juglans*	1.27	4.52	5.79
7	*Quercus*	7.53	6.95	14.48	*Acer*	1.13	4.52	5.65
8	*Carpinus*	3.99	6.34	10.33	*Tsuga*	1.09	3.95	5.04
9	*Cerasus*	3.61	5.74	9.35	*Betula*	0.76	3.95	4.71
10	*Populus*	5.42	2.72	8.14	*Larix*	1.16	2.82	3.98
	$\sum 1-10$	86.47	65.85	152.32	$\sum 1-10$	94.43	71.16	165.59
	$\sum 11-27$	13.53	34.12	47.65	$\sum 11-28$	5.56	28.77	34.33

1 Notes: R.Ab, relative abundance; R.Fr, relative frequency.

Table 7(on next page)

Goodness of fit of the six models for the typical secondary forests for the birch and pine-oak belts in the mid-altitude zoneof theQinling Mountains, China

Testing	Birch belt			Pine-oak belt		
	AIC	BIC	K-S	AIC	BIC	K-S
Broken-stick	501.31	501.31	0.23	3673.52	3673.52	0.54***
Preemption	310.98	312.74	0.16	1216.36	1218.07	0.46***
Log-normal	522.74	526.26	0.21	770.25	773.67	0.20
Zipf	994.30	997.82	0.40**	779.51	782.93	0.24
Zipf-Mandelbrot	314.76	320.05	1.00***	488.08	493.22	0.15
Neutral model	421.62	425015	0.20	416.27	419.69	0.25
θ		19.121			0.012	
m		7.497			0.392	

Notes: θ and m are parameters of the neutral-theory model; ***, P<0.001; **, P<0.01; *, P<0.05; AIC, Akaike's Information Criterion; BIC, Bayesian Information Criterion; K-S, statistic of the Kolmogorov-Smirnov test.