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The mid-altitude zone of the Qinling Mountains in China were once dominated by birch and pine-oak belts 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 species composition and community assemblages of secondary forests of the birch and pine-oak belts in the Huoditang forest region of the Qinling Mountains after identical natural recoveries. Both types of belts had richspeciescompositions and similar floristiccomponents but clearly different community structures. Tree diversity was significantly higher for the birch than the pine-oak belt. Niche and neutral processes simultaneously influenced the species distribution and community dynamics of the belts, and these forests were able to maintain stable development during natural recoveries. The conservation and management of these forests should receive more attention to protect biodiversity and the forest resources in the Qinling Mountains.

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Abstract: The mid-altitude zone of the Qinling Mountains in China were once dominated by birch and pine-oak belts 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 species composition and community assemblages of secondary forests of the birch and pine-oak belts in the Huoditang forest region of the Qinling Mountains after identical natural recoveries. Both types of belts had rich species compositions and similar floristic components but clearly different community structures. Tree diversity was significantly higher for the birch than the pine-oak belt. Niche and neutral

processes simultaneously influenced the species distribution and community dynamics of the belts, and these forests were able to maintain stable development during natural recoveries. The conservation and management of these forests should receive more attention to protect biodiversity and the forest resources in the Qinling Mountains.

Conserving biodiversity in forests has long been an important 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 primary forest in China were cut between the 1950s and 1980s. After a long period of recovery, secondary forests formed with varying patterns of natural succession (Kan et al. 2015), which now account for approximately 50% of the total forested area 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 ecosystemic 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; Zhao et al. 2014) and play important roles in the establishment and maintenance of ecosystems and their functions, such as the conservation of soil and water (Chai & Wang 2016; Lei et al. 1996b; Lei et al. 1996c).

Previous studies have determined that the deforestation led to variation in the landscape pattern of the secondary forests (Lei et al. 1996b; Lei et al. 1996c; Wang et al. 2015; Zhang et al. 2014), community dynamics (Chai & Wang 2016; Ma et al. 2014; Zhang et al. 2014), regeneration characteristics (Chai & Wang 2016; Yu et al. 2013), nutrient cycles (Liu et al. 2001), and soil properties (Cheng et al. 2013; Cheng et al. 2015; Ren et al. 2012) in the Qinling Mountains. 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. 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. The following questions were addressed. (1) How do species composition and community structure vary among different secondary forest types? (2) Do the patterns of tree

diversity in the secondary forests differ between the birch and pine-oak belts? (3) What are the underlying ecological mechanisms for the community assemblages of the secondary forests in the mid-altitude zone of the Qinling Mountains, China? We aimed to improve our understanding of the status of secondary forests and to contribute to the success of vegetation restoration and the 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; Zhao et al. 2014; Wang et al. 2015). 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. The Huoditang forest region at 850-2470 m is in the typical vertical vegetation 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 deforested during the 1960s and 1970s, and 95% of the area are 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 2016; 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, and data were collected from July to September in 2012-2014 using typical

91 sampling methods for surveying the floristic composition, diversity, and structure of the forests (Figure 3).
92 Five plots were randomly placed in each of the five forest types in each of the birch and pine-oak belts. The
93 total study area was 4.5 ha. The elevation, slope, aspect, and GPS location of each plot were determined. The
94 forest types met the following criteria: (1) stand age of approximately 50-60 years, representing the earliest and
95 largest secondary forests after the deforestations, (2) minimal disturbance after cutting, and (3) similar habitat
96 conditions among the forest types.

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

102 **Data analysis**

103 Importance values (IVs)

104 The importance value (IV) of a species is defined as the average of its relative density (RD), relative
105 frequency (RF), and relative dominance (Rd). The IVs of the tree species were calculated as (Arbainsyah et al.
106 2014; Curtis & Mclntosh 1951):

107 $$\text{Density } (D) = \frac{\text{Number of individuals of a species}}{\text{Area of all sample units}}$$

108 $$\text{Relative abundance } (RD) = \frac{\text{Number of individuals of a species}}{\text{Density for all species}} \times 100\%$$

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

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

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

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

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

Rarefaction and extrapolation curves with Hill numbers

Hill numbers, or the effective number of species, are a mathematically unified family of diversity indices (differing among themselves only by an exponent q) (Hill 1973), and are increasing used to characterize the taxonomic, phylogenetic, or functional diversity of an assemblage (Chao et al. 2010; Chao et al. 2014a; Chao et al. 2014b; Chiu et al. 2014; Ibanez et al. 2016). Integrated curves based on sampling theory that smoothly link rarefaction and extrapolation standardize samples on the basis of sample size or sample completeness and facilitate the comparison of biodiversity data. To characterize the species diversity of an assemblage, Chao et al. (2014b) applied a unified approach for both individual-based data and sample-based data to estimate rarefaction and extrapolation curves for the first three Hill numbers: species richness (q=0), the exponential of the Shannon entropy (Shannon diversity, q=1), and the inverse Simpson concentration (Simpson diversity, q=2). The proposed estimators are accurate for both rarefaction and short-range extrapolation.

We compared the patterns of species diversity using the rarefaction and extrapolation curves with Hill

127 numbers. Constructing rarefied and extrapolated curves produced patterns based on abundance and incidence
128 data, respectively. Species diversity (species richness, Shannon diversity, and Simpson diversity) was
129 estimated as the mean of 200 bootstrap replications with 95% confidence intervals.

130 Cluster and correspondence analyses

131 The similarities in the species compositions and distributional patterns were explored using clustering
132 and correspondence analyses. The objective of a clustering analysis is to identify subgroups within a group.
133 Clustering analysis generally refers to the methods that attempt to categorize the data into subgroups such that
134 the observations within the same group are more similar compared to the observations in different groups
135 (Legendre & Legendre 2012). Correspondence analysis is a powerful method for the multivariate exploration
136 of large-scale data (Greenacre 1984), which are commonly used by ecologists to analyze data on the incidence
137 or abundance of species in samples (Cakir et al. 2006; Hill 1974), and provides a robust statistical tool for
138 understanding species distribution relative to environmental factors (Beebe et al. 2000; ter Braak 1985). We
139 used cluster analysis with group averages based on the species-abundance data of the forest stands,
140 categorizing the ten forest stands into two major groups, and then applied the correspondence analysis to
141 exploit the same information as used in the cluster analysis to strengthen the validity of the cluster analysis.

142 Species abundance distribution (SAD)

143 The following six SAD models were considered: broken-stick, niche-preemption, log-normal, Zipf,
144 Zipf-Mandelbrot, and neutral-theory models (Table 2, for the details of these models, see the introduction in

145 the supplementary materials). The Kolmogorov-Smirnov (K-S) test was applied for comparing the discrepancy
146 of the fitted and observed SAD patterns; this test is recommended for testing the agreement to models of
147 abundance distribution (Hill & Harmer, 1998; Basset et al., 1998) because it is more powerful than the chi-
148 square test. The Akaike Information Criterion (*AIC*) method was also used to compare the models and identify
149 the best model by using log-likelihoods (log *L*) of the fitted models as the input (Filho et al., 2002). *AIC* is
150 calculated by:

151 $$AIC=-2\log L+2k$$

152 where *k* is the parameter number in the fitted model.

153 Statistical analyses

154 R version 3.1.3 (R Core Team 2015) was used for all statistical analyses. Cluster analysis,
155 correspondence analysis, and SAD were conducted using the vegan (Oksanenet al. 2008) and untb (Robin
156 2009) packages. Rarefaction and extrapolation curves were compiled using the iNEXT package (Chao et al.
157 2014b). The figures were drawn and the data were manipulated using the ggplot2 (Hadley 2015) and reshape2
158 (Hadley 2014) packages, respectively.

159 # Results

160 **Tree species composition**

161 A total of 50 tree species belonging to 30 genera in 16 families were identified among 5686 individual
162 trees (DBH$\geqslant$5 cm) in the 50 plots (totaling 4.5 hm^2) from the 10 typical secondary forest stands in the two
163 forest belts in the mid-altitude zone of the Qinling Mountains. The attributes of the stands are summarized in

Table 3. 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) (Table S1 and 3).

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%), and *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, Aceraceae, 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 4).

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 5).

Similarity among tree community structures

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 4). Correspondence analysis ordination supported the findings of the cluster analysis, indicating similarities and differences among the ten forest stands.

Comparison of tree species diversity in the two forest belts based on abundance data

We constructed individual-based and coverage-based rarefaction and extrapolation curves for Hill numbers q=0, 1, and 2 to compare the diversities of the birch and pine-oak forest belts (Figure 5). The reference sample size (number of individual trees) for the birch belt was 2934, and observed species richness (q=0), Shannon diversity (q=1), and Simpson diversity (q=2) for this reference sample size were 43, 23, and 17.72, respectively. The reference sample size for the pine-oak belt was 2752, and the observed species richness, Shannon diversity, and Simpson diversity were 41, 7.51, and 4.63, respectively.

We extrapolated the reference sample size to 5504 (double the smaller reference sample size), and the base coverage (the lowest coverage for the doubled reference sample sizes or the maximum coverage for reference samples, whichever was larger) was closer to 1.0. Both individual-based and coverage-based rarefaction and extrapolation curves indicated that the birch belt was more diverse than the pine-oak belt, although the confidence intervals for species richness overlapped.

Comparison of tree species diversity in the two forest belts based on incidence data

We next constructed the sample-based and coverage-based rarefaction and extrapolation curves for Hill

numbers q=0, 1, 2 to compare the diversities of the birch and pine-oak forest belts (Figure 6). Both belts had the same sample size (25) and species richness (25). The Shannon diversities were 24.82 and 23.53 and the Simpson diversities were 24.65 and 22.24 for the birch and pine-oak forest belts, respectively. We extrapolated the reference sample size to 50 (double the smaller reference sample size) and the base coverage to 1.0, indicating that sampling was nearly complete for these two belts. Both the sample-based and coverage-based rarefaction curves indicated little overlap between the Shannon and Simpson diversities for the birch and pine-oak belts, implying that the birch belt was more diverse than the pine-oak belt. The confidence intervals for species richness, however, overlapped considerably between the birch and pine-oak belts.

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 7. The expected and observed SADs of the birch belt differed significantly (indicated by a K-S test). The niche-preemption, neutral-theory, broken-stick, and log-normal models simulated SAD of the birch belt well, but the observed SAD departed from the outputs of the Zipf-Mandelbrot and Zipf models; the Zipf-Mandelbrot model especially failed to fit the SAD patterns. Among the models, the niche-preemption had lowest AIC value, indicating that this model best represented the SAD pattern of the birch belt. The neutral-theory, Zipf-Mandelbrot, log-normal, and Zipf models simulated SAD well for the pine-oak belt, and the neutral-theory model were best for the SAD patterns.

Discussion

Tree species composition and community structure

The birch and pine-oak belts had rich species compositions and similar floristic components, but the tree community structures clearly differed. 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, 4, and 5), 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, and these two forest belts share most species of trees and have similar floristic components. Both the cluster and correspondence analyses, however, demonstrated 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, small-scale topographic variation, and soil conditions (Lei et al. 1996a, 96b; Ren et al. 2012; Wu et al. 2012; Zhao et al. 2003) among forest stands can affect the distribution of forest stands in the mid-altitude zone of the Qinling Mountains.

Tree diversity patterns

Tree diversity was significantly higher in the birch than the pine-oak belt. The confidence intervals for

236 species richness (q=0) overlapped considerably between the birch and pine-oak belts, but the rarefaction
237 curves for Hill numbers (q=1, 2) indicated that tree diversity was significantly higher in the birch than the
238 pine-oak belt; inferences for diversities of $q \geq 1$ are reliable (Chao et al. 2014b). Tree diversity was
239 significantly higher in the birch than the pine-oak belt, likely for two main reasons. (1) The distributional range
240 suited the birch belt better. Lei et al. (1996a) reported that the birch belt was distributed toward the upper limit
241 of the mid-altitude zone (1800-2400m) in the study area, and the pine-oak belt was distributed at lower
242 elevations (1200-2000 m); species richness and diversity, however, were highest between 1800 and 2200 m,
243 because the elevation zone is an ecotone of birch and pine-oak belts. Diversity may also have been higher in
244 the birch than the pine-oak belt because the elevation zone (1800-2200 m) was within the main distributed
245 zone of birch belts. Other studies have supported this proposal that species diversity in the Qinling Mountains
246 is higher between 1800 and 2200 than in other elevation zones (Kang & Zhu 2007; Tang et al. 2004; Xin et al.
247 2011). (2) These two belts were the most common forest types, but the dominant species differed between the
248 belts as the forests developed. The dominant species *B. albo sinensis* was not very conspicuous in the birch
249 belt, and pure stands were rare (Lei et al. 1996b). In contrast, *P. tabuliformis*, *P. armandii*, and *Q. aliena* var.
250 *acutiserrata* predominated in the pine-oak belt (Liu et al. 2001). These dominances were reflected by the IV
251 index (Table S1). IV was highest for *B. albo sinensis* in the birch belt (10.63%) but only slightly higher than
252 for the other dominant tree species. The IVs of the predominant species *Q. aliena* var. *acutiserrata*
253 (IV=26.15%), *P. tabuliformis* (IV=20.05%), and *P. armandii* (IV=22.50%) in the pine-oak belt indicated

254 evident advantages.

255 **Mechanism of coexistence of tree communities**

256 Niche and neutral processes are simultaneously influencing the distribution of species and the
257 community dynamics of the birch and pine-oak belts. The neutral-theory model was suited to the data for
258 species abundance for both belts, which identified randomness as the main ecological process determining the
259 distributional pattern of species abundance in these two forest belts. These forests can thus maintain a dynamic
260 balance during growth and development and are amenable to stable development, supporting the findings by
261 Lei et al. (1996a, b, and c). The log-normal model had good predictive power for the SAD patterns of both
262 belts, which further confirmed that statistical models based on statistical theory (e.g. the log-normal model) are
263 superior to resource-apportioning models based on ecological theory (e.g. the broken-stick and niche-
264 preemption models) (McGill et al., 2007).

265 The niche-preemption model and broken-stick model were also suitable for simulating SAD patterns for
266 the birch belt, which showed that niche theory was important in the community assemblages of the birch belt.
267 Lei et al. (1996b) reported that the dominant species *B. albo sinensis* regenerated poorly in the Qinling
268 Mountains and that the continuity of *B. albo sinens* populations was maintained by gap regeneration. These
269 findings are consistent with the regeneration-niche hypothesis (Grubb 1977) and suggest that both the neutral
270 and niche theories have played important roles in understanding the mechanisms of species coexistence in the
271 birch belt.

The combination of the Zipf/Zipf-Mandelbrot (niche-based model) and neutral-theory models suggested that the pine-oak belt contains progressive successional communities and can maintain stable community development during succession, consistent with the findings by Chai & Wang (2016) and Lei et al. (1996a). We concluded that the successional characteristics of pine-oak forests accords with the ecological interpretations of the Zipf/Zipf-Mandelbrot model that climax species need more time and resources 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 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

290 at Changbaishan in northeastern China also indicated that niche and neutral processes were simultaneously
291 regulating species coexistence.

292 **Conclusion and recommendations**

293 The conservation and management should receive more attention to protect biodiversity and the forest
294 resources in the Qinling Mountains. Understanding forest species composition, diversity patterns, and
295 community assemblages are very important for managing ecosystems for their environmental and conservation
296 value (Jung et al. 2014; Kacholi et al. 2015; Ragavan et al. 2015). Protecting biodiversity and forest resources
297 in the Qinling Mountains has become a focus of attention (Lei et al. 1996a; Wang et al. 2015; Zhao et al. 2014).
298 Although the forests with rich species compositions, and many forest fragments remain at risk (Cheng et al.
299 2015; Wang et al. 2015), so their conservation must be given priority to avoid the loss of species, especially
300 endemic and nearly endemic species. In addition, the forests have been harvested since the 1950s, and much of
301 the area is now covered by secondary growth that has low productivity and poor community stability and with
302 varying patterns of natural succession (Chai & Wang 2016; Cheng et al. 2015; Li et al. 2004). Enhancing the
303 multi-functionality of forests is a goal of modern and sustainable forest management, which tries to balance a
304 multitude of economic, ecological, and societal demands. Increasing the tree diversity of forests is particularly
305 promising (Schuldt & Scherer-Lorenzen 2014). We suggest that scientific management of the forests
306 should be increased to improve forest quality and productivity and consequently to realize the sustainable use
307 of the forest resources.

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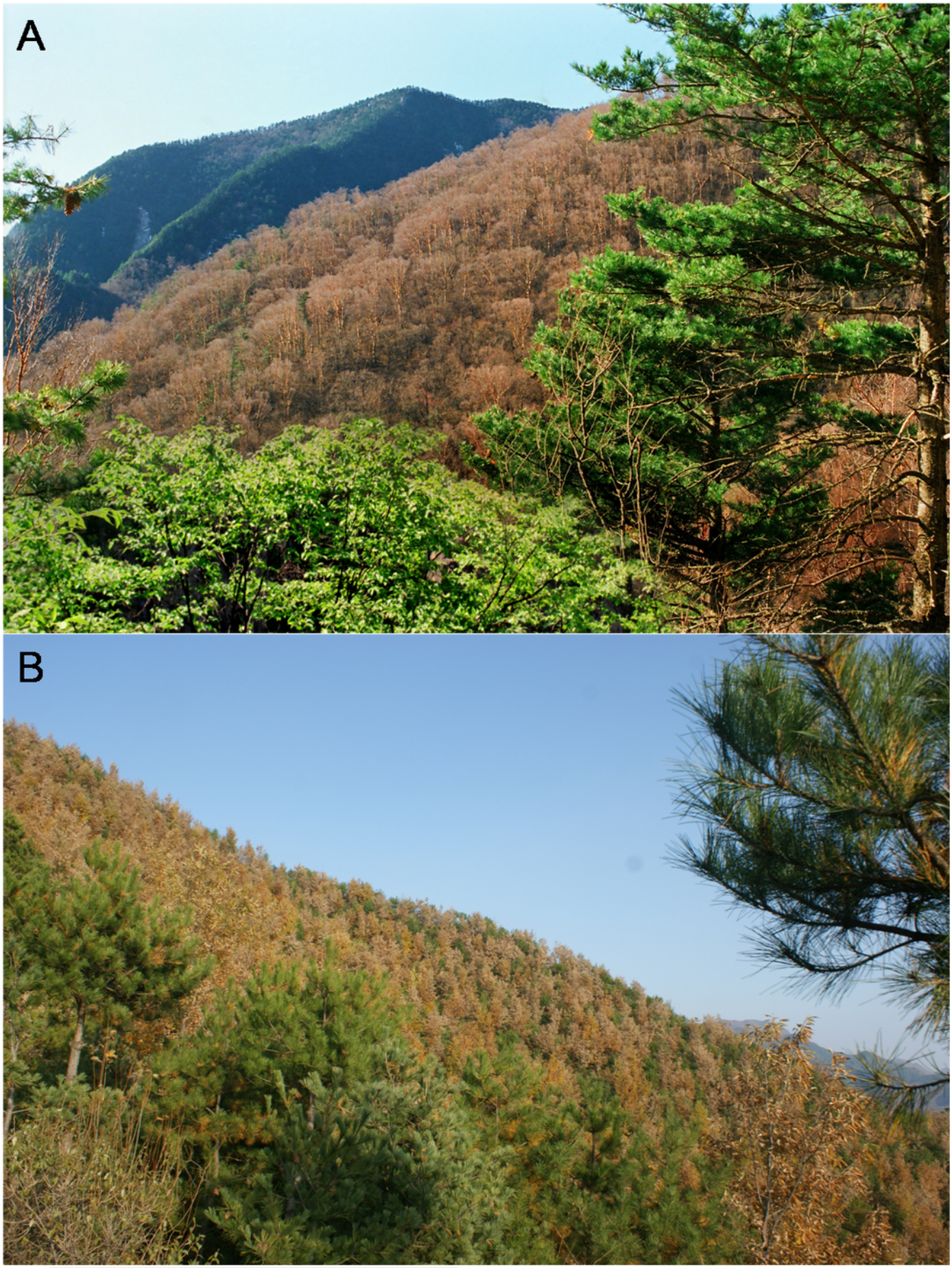
1

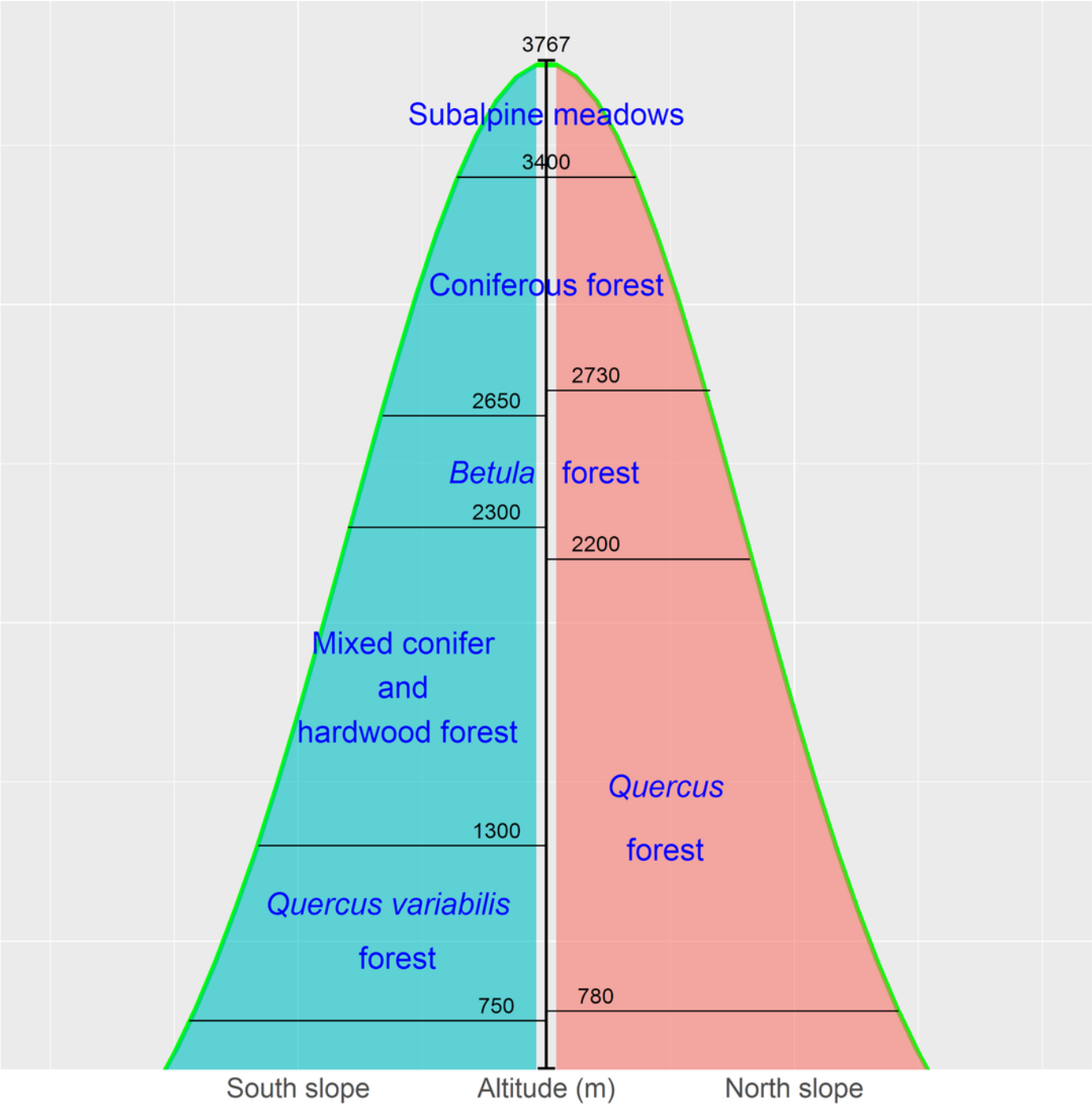
Birch (A) and pine-oak (B) belts in the mid-altitude zone of the Qinling Mountains, China.

Photos taken on October, 2012.


A
B

2

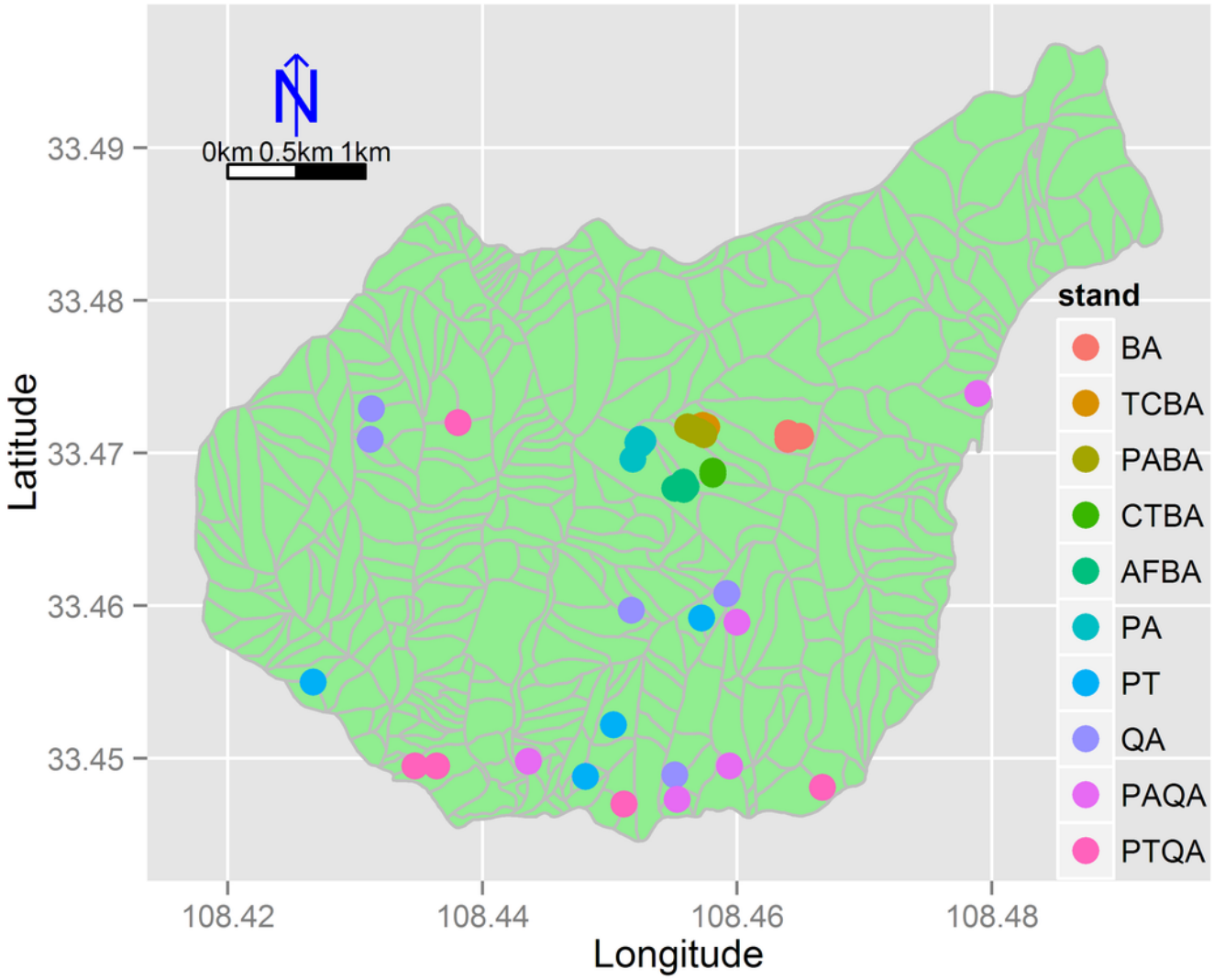
The vertical zones of vegetation in the Qinling Mountains, China (Zhao et al, 2014)



3

The distribution of the 50 sample plots in 10 forest stands of the birch and pine-oak belts in the mid-altitude zone of the Huoditang forest region.

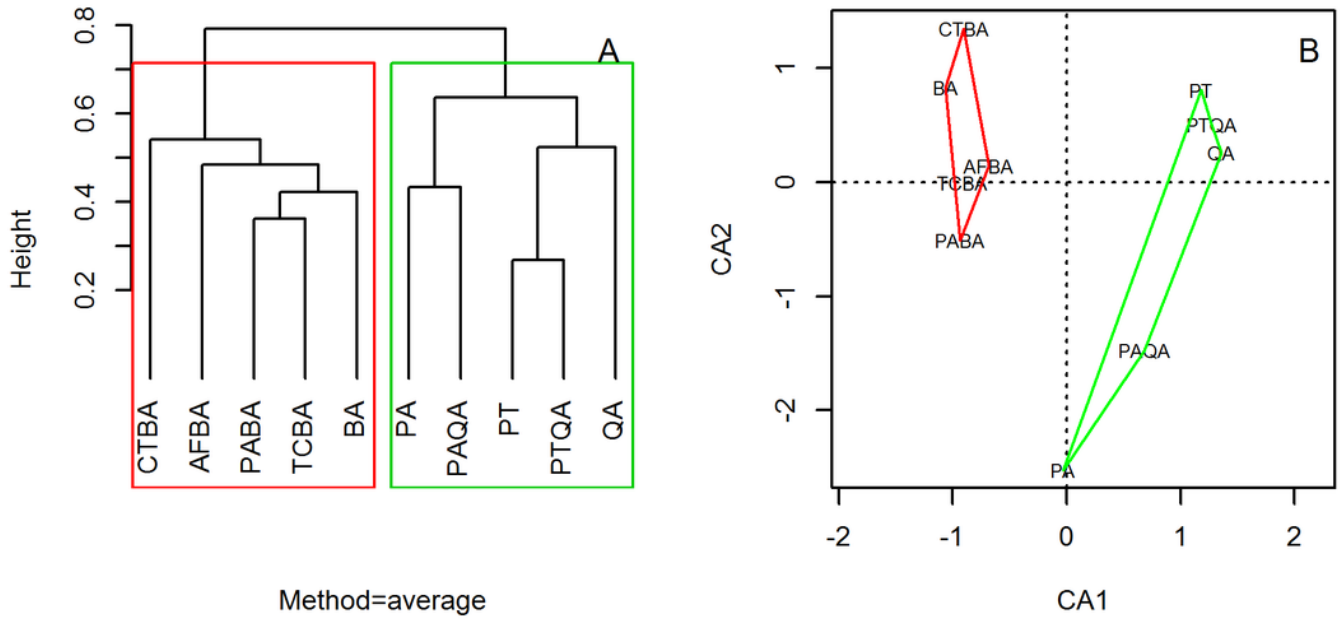
The polygons are the distribution of sub-compartment. See Table 1 for the stand codes.



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.

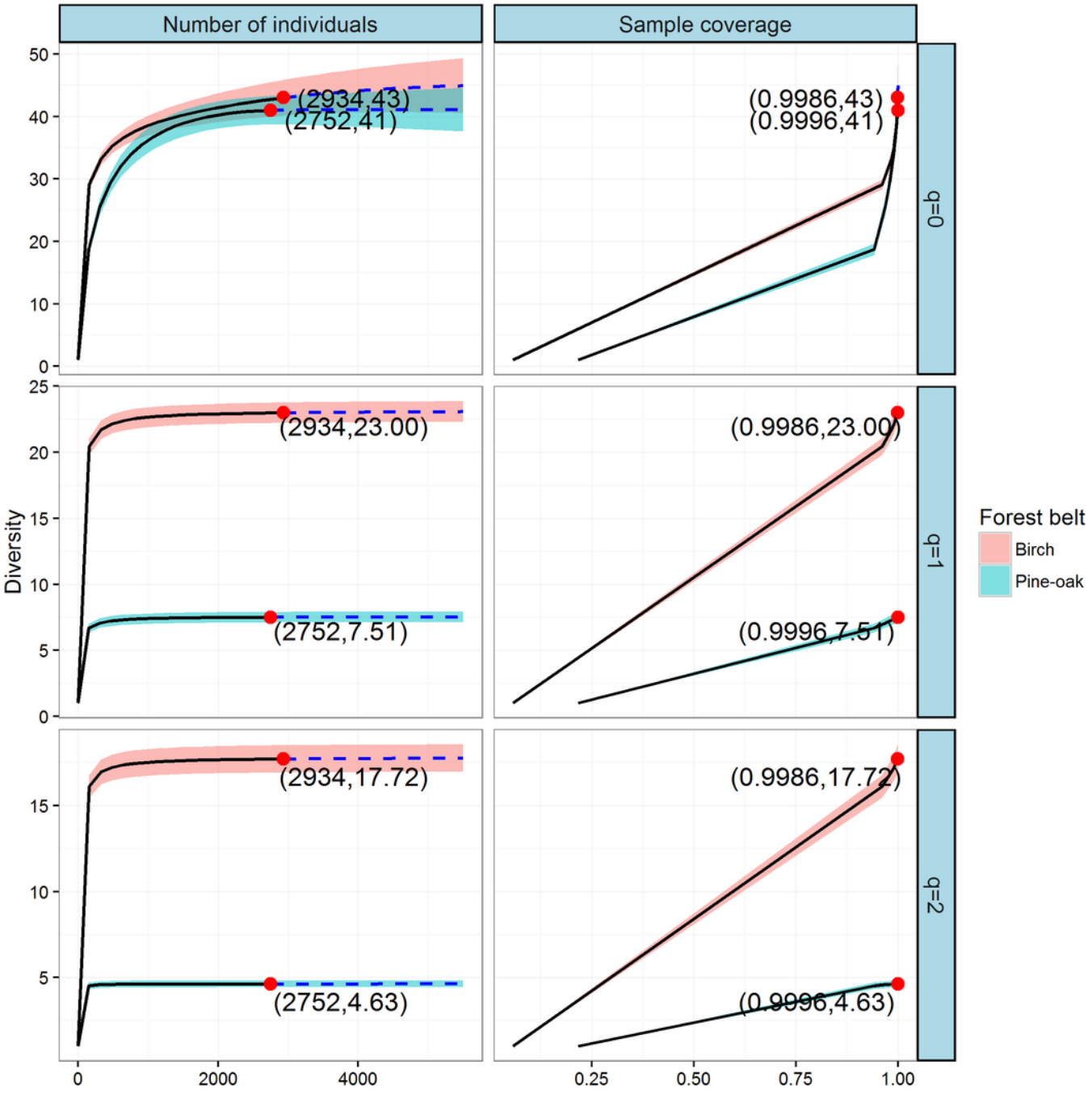
Red polygon is birch belt and green polygon is pine-oak belt. See Table 1 for the stand codes.



5

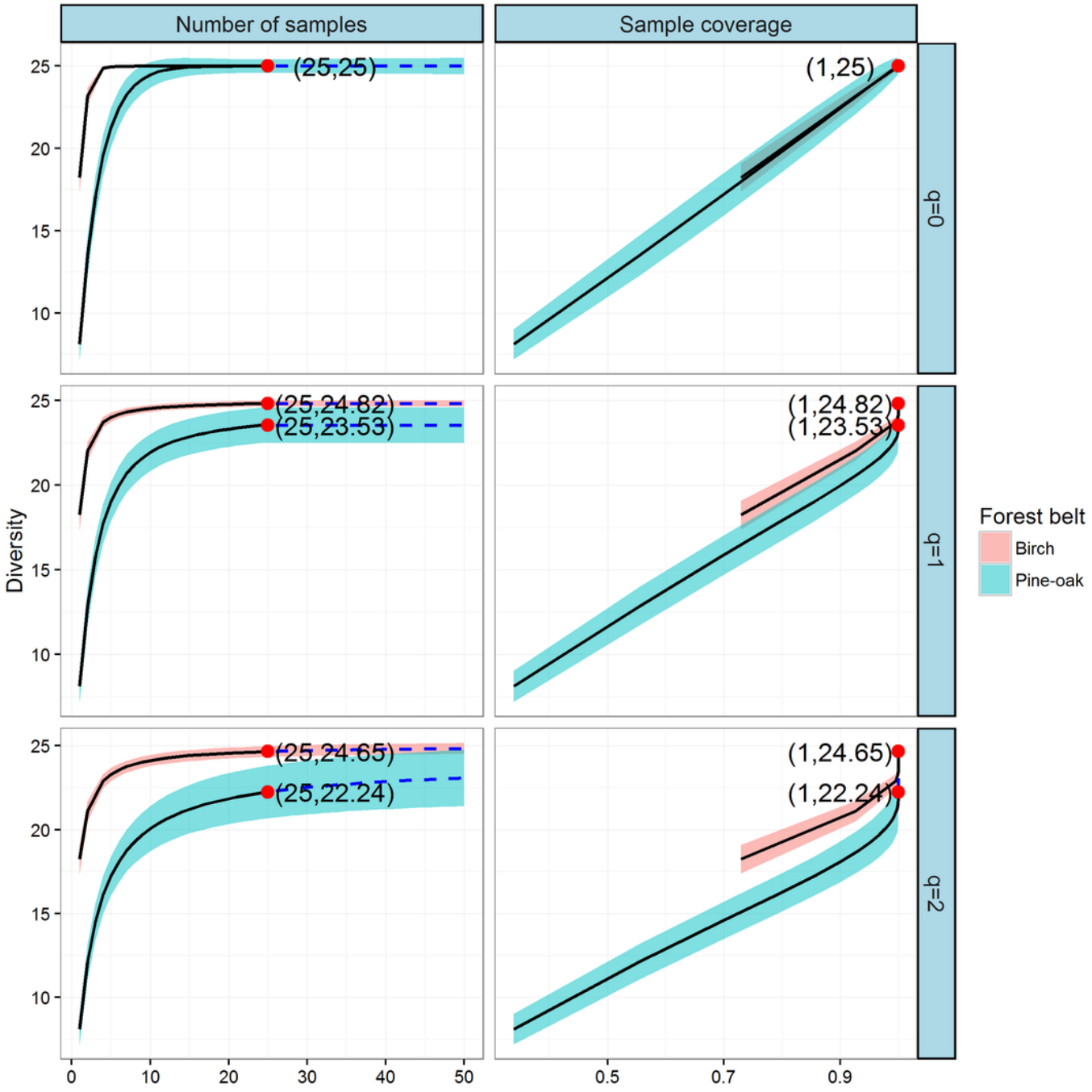
Individual-based and coverage-based rarefaction and extrapolation curves based on the Hill numbers (q=0, 1, 2) for the birch and pine-oak belts.

The 95% confidence intervals (shaded regions) were obtained by a bootstrap method based on 200 replications. Reference samples are denoted by solid dots, the numbers in the parentheses are the sample size and the observed Hill number for each reference sample.


Number of individuals
Sample coverage
q=0
q=1
q=2
Diversity
(2934,43)
(2752,41)
(0.9986,43)
(0.9996,41)
(2934,23.00)
(2752,7.51)
(0.9986,23.00)
(0.9996,7.51)
(2934,17.72)
(2752,4.63)
(0.9986,17.72)
(0.9996,4.63)
Forest belt
Birch
Pine-oak

sample-based and coverage-based rarefaction and extrapolation curves based on the Hill numbers (q=0, 1, 2) for the birch and pine-oak belts.

The 95% confidence intervals (shaded regions) were obtained by a bootstrap method based on 200 replications. Reference samples are denoted by solid dots, the numbers in the parentheses are the sample size and the observed Hill number for each reference sample.


Number of samples
Sample coverage
q=0
q=1
q=2
Diversity
(25,25)
(1,25)
(25,24.82)
(25,23.53)
(1,24.82)
(1,23.53)
(25,24.65)
(25,22.24)
(1,24.65)
(1,22.24)
Forest belt
Birch
Pine-oak

7

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

Zipf-Mandelbrot model failed to fit the data of birch belt. AIC, Akaike's Information Criterion; K-S, statistic of the Kolmogorov-Smirnov test. ***, $P<0.001$; **, $P<0.01$; *, $P<0.05$.

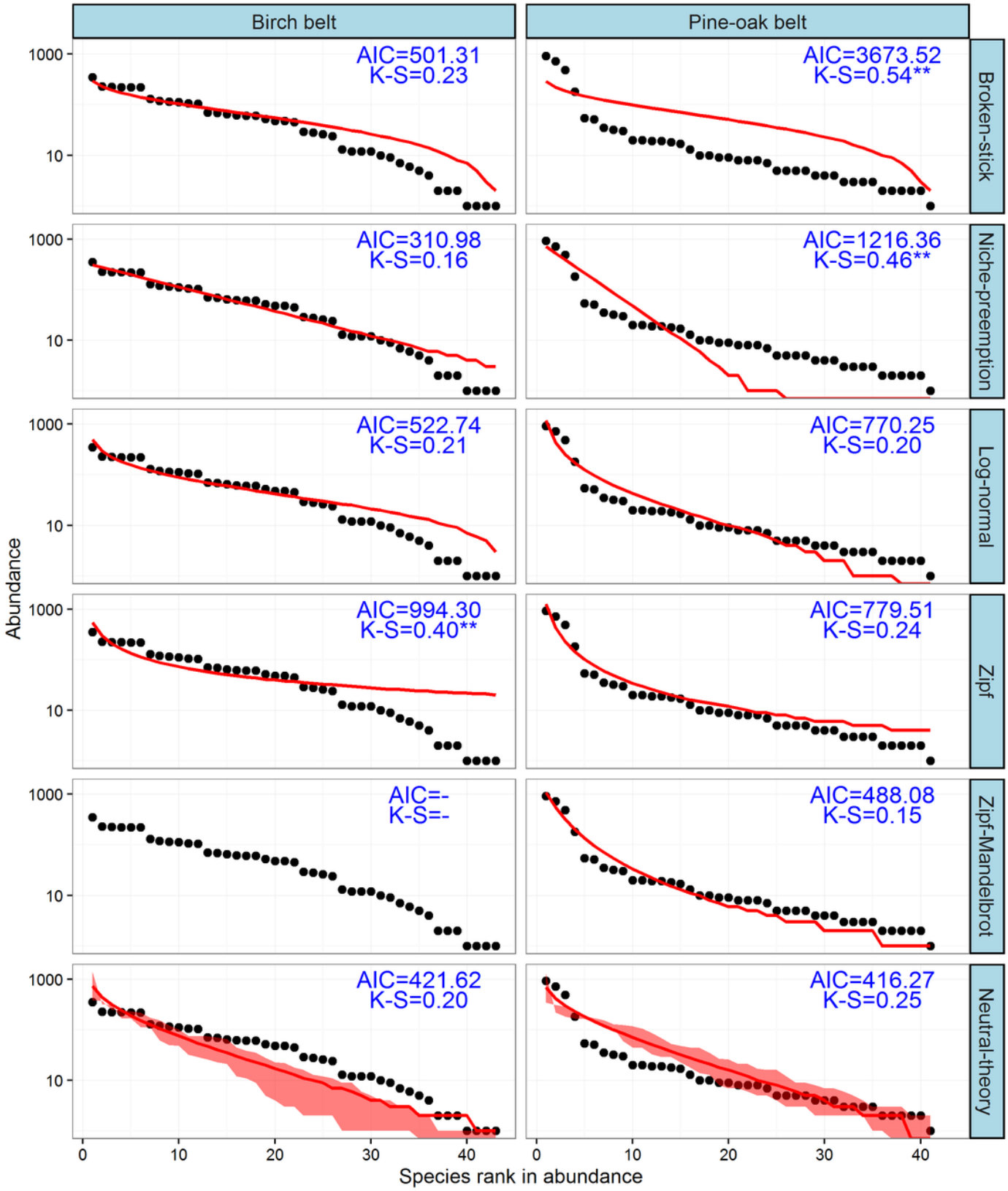

Birch belt
Pine-oak belt
Broken-stick
Niche-preemption
Log-normal
Zipf
Zipf-Mandelbrot
Neutral-theory
AIC=501.31
K-S=0.23
AIC=3673.52
K-S=0.54**
AIC=310.98
K-S=0.16
AIC=1216.36
K-S=0.46**
AIC=522.74
K-S=0.21
AIC=770.25
K-S=0.20
AIC=994.30
K-S=0.40**
AIC=779.51
K-S=0.24
AIC=-
K-S=-
AIC=488.08
K-S=0.15
AIC=421.62
K-S=0.20
AIC=416.27
K-S=0.25
Abundance
1000
10
0
10
20
30
40
Species rank in abundance

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

1

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	$\phi_n = \theta\frac{J!}{n!(J-n)!}\frac{\Gamma(\gamma)}{\Gamma(J+\gamma)}\int_0^{\gamma}\frac{\Gamma(n+y)\Gamma(J-n+\gamma-y)}{\Gamma(1+y)\quad\Gamma(\gamma-y)}\exp(-y\theta/\gamma)dy$	(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, $\Gamma(z) = \int_0^{\infty} t^{z-1}e^{-t}\mathrm{d}t$, 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)

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	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
breast	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
height (cm)	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	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
height (m)	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	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
width (m)	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	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
(m^2 ha^{-1})	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	min	1122	967	1400	800	944	767	1156	1167	822	1067	800	767
density	max	1867	1478	2100	878	1411	1189	1789	1789	1456	1356	2100	1789
(trees ha^{-1})	mean	1511	1345	1593	835	1235	929	1493	1385	1073	1236	1304	1223

1

Table 4(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

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

Table 5(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.