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ORIGINAL PAPER

Structure and diversity of remnant natural evergreen broad-leaved forests at three sites affected by urbanization in Chongqing metropolis, Southwest China

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Abstract Evergreen broad-leaved forests (EBLFs, lucidophyllous forests) are vegetation types characteristic of East Asia. The extent of EBLFs has decreased significantly due to long-term anthropogenic disturbance, and remnant EBLFs in urban area are rare and important landscape types contributing to biodiversity and sustainable development. This study focuses on remnant EBLFs on Mt. Gele (GL), Mt. Tieshanping (TSP), and Mt. Jinyun (JY), located from the inner city to outskirts of Chongqing metropolis, Southwest China. Species of Theaceae, Lauraceae, Symplocaceae, and other families, which are essential floristic components of primary EBLFs, were still the main components at the three sites. GL and JY showed higher biodiversity, with richer heliophytes and shade-tolerant species, respectively. *Castanopsis carlesii* var. *spinulosa* was the sole dominant species at all three sites in woody layer, with codomination by *Pinus massoniana* and *Cinnamomum camphora* at GL and by *Machilus pingii* and *Castanopsis fargesii* at JY; these evergreen broad-leaved trees all showed inverse-J or sporadic-shaped size distribution with large numbers of small stems, but the conifer tree *Pinus massoniana* showed unimodal distribution with small stems at GL. The height growth of tree species, especially *Castanopsis carlesii* var. *spinulosa*, was increasingly restricted from JY to TSP to GL. Sprouting is an important life history strategy at community and population level, and differences were exhibited from GL to TSP to JY. A rural–urban gradient from JY to TSP to GL was indicated in this study. Species composition, biodiversity, and stand structure of these remnant EBLFs showed obvious differences along this gradient, and conservation responses to address the effects of urbanization need to be carefully considered.

Keywords Landscape · Conservation · Heliophyte · Inherent component · Sprouting · Fragmentation

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Introduction

Urbanization is a global phenomenon. Cities are growing in number, size, and population throughout the world, particularly in developing countries (United Nations 2004;

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McKinney 2006). Climate, soils, hydrology, disturbance regime, and land management practices are all strongly affected by urbanization. In turn, changes in these environmental factors profoundly affect urban biodiversity (Sukopp 2004).

It is implicit to the process of urbanization that many natural areas are destroyed. Human actions such as removal of native vegetation, garden planting, and introduction of exotic weed species lead to homogenization of biota, and associated loss of biodiversity (McKinney 2002, 2006; Sukopp 2004).

Urbanization is a huge challenge to the conservation of biodiversity and has therefore become a hot topic of concern (McKinney 2002, 2006; Chocholoušková and Pyšek 2003; Sukopp 2004). The challenge of urbanization is made more complicated by the fact that it affects different kinds of landscapes, and their associated taxa, in different ways (Forman and Godron 1995; Alig et al. 2004; Hong et al. 2005; Song et al. 2005; McKinney 2006). For this reason, conservation responses to address the effects of urbanization need to be carefully considered.

Patches of remnant natural vegetation in urban areas are significant components of biodiversity and provide habitats for both vertebrate and invertebrate animals. In addition to these biological values, urban patches of native vegetation hold social value; they provide educational resources for display of natural communities that previously covered the landscape (Willison 1996), and in this way they represent a historical phase in the development of urban land uses (Maurer et al. 2000; Stenhouse 2004). Natural patches of vegetation also provide opportunities for monitoring environmental changes, and act as nuclei from which native plants and animals can recolonize urban environments (Stenhouse 2004; Murakami et al. 2005; Yang et al. 2007).

Chongqing Municipality has experienced intense urban development since 1997. Within this municipality there are many towns and cities, of which the largest is Chongqing metropolis (Yang et al. 2007), often described as the "mountain city" or "foggy capital." It lies across four parallel mountain folds and includes many small hills. These upland areas provide habitats for forest vegetation. Locally specific types of evergreen broad-leaved forests (EBLFs, lucidophyllous forests) are the characteristic climax vegetation, but these natural forests have been severely damaged by urban expansion, and only a few patches remain around the tops of the mountains (Yang et al. 2007). As the expansion process of the urban area of Chongqing metropolis occurred almost parallel to the process of breaking through the barriers of the mountains gradually from the 1920s, the remnant natural forest patches are excellent subjects for research on the ecological effects of urbanization because the mountains have experienced different urbanization impacts and thereby provide indicators of an urban–rural gradient from inner city to outskirts.

EBLFs, as warm and subtropical systems, are a key source of the world's biodiversity and sustainable development (Ovington 1983). Those dominated by the genera *Castanopsis*, *Lithocarpus*, and *Cyclobalanopsis* (Fagaceae), *Machilus* (Lauraceae), and *Schima* (Theaceae), accompanied by many additional families such as Magnoliaceae, Symplocaceae, and Hamamelidaceae influenced by East Asia monsoon wind, are vegetation types almost exclusively confined to East Asia, with those of subtropical China being the largest and particularly notable (Kawano et al. 1999; Song 2001; Tang et al. 2007). In China, EBLFs occur between 24–32°N and 99–123°E and formerly covered around 25% of the area of the country (Song 2001). The forests are extremely diverse, particularly in terms of tree and shrub species, ranging from over 100 vascular plant species/400 m^2 in the south to 30–45 species in the north of its distribution, with a large number of them being endemic to China or East Asia (Song 1988, 2001). However, most of the primary EBLFs have been reduced to remnant fragments over the historical period (Yang et al. 2007). Located in the center of subtropical China, Chongqing metropolis and its surrounding areas lie at the core of the regions in which EBLFs are distributed. Of further significance, the EBLFs dominated by *Castanopsis carlesii* var. *spinulosa* in Chongqing metropolis are a unique formation in the classification system of the EBLFs of China, being only distributed on Mt. Gele, Mt. Tieshanping, and Mt. Jinyun in Chongqing metropolis (Zhen 1985; Song 2004). Clear understanding of changes in these remnant EBLFs will provide valuable input for management purposes.

The research reported in this paper is focused on the remnant EBLFs mainly dominated by *Castanopsis carlesii* var. *spinulosa* in Chongqing metropolis. It is aimed at: (a) describing the differences in species composition and stand structure among the patches affected by urbanization, (b) analyzing the regeneration dynamics and survival possibilities of these patches, and (c) evaluating the relative significance of the patches, and providing strategies for their conservation.

Study sites

Chongqing metropolis, the urban center of Chongqing Municipality, had a population of 6.6 million people in 2006 within its 5473 km^2 area. Jialing River joins Yangtze River (Changjiang) in the center of the metropolis. The confluence of the two rivers lies just below the tail area of the reservoir created by the Three Gorges Dam.

While there are many treed areas in and around Chongqing metropolis, remnant patches of primary EBLFs remain only on Mt. Gele (GL, N29°34′, E106°25′), Mt. Tieshanping (TSP, N29°37′, E106°41′), and Mt. Jinyun (JY, N29°50′, E106°22′; Fig. 1). These three mountains are parts of the four unusual mountain folds that are characteristic of the physical geography of Chongqing. Temperatures and precipitation on these mountains are suitable for development of EBLFs. Summary climate data from the meteorological stations nearest to the study sites are listed in Table 1.

GL is a national forest park in the inner city (generally indicating the most developed six districts of Chongqing metropolis) that is widely used for recreation such as hiking and strolling. The altitude of the peak is 680.3 m a.s.l. It is only 3 km away from Shapingba, the second largest business district of the metropolis. The natural vegetation of GL has been significantly damaged by three intense sets of disturbances that have taken place since the 1930s: construction of the chief officers' villa during the Provisional Capital period from 1937 to 1946, selective cutting of large trees in the 1950s during a period of primary industrial development, and construction and use of a sports establishment from the late 1990s to the present. Consequently, there are only five small remnant patches of EBLFs scattered near the peak surrounding the old Yunding Temple, each with an area of about 400 m^2.

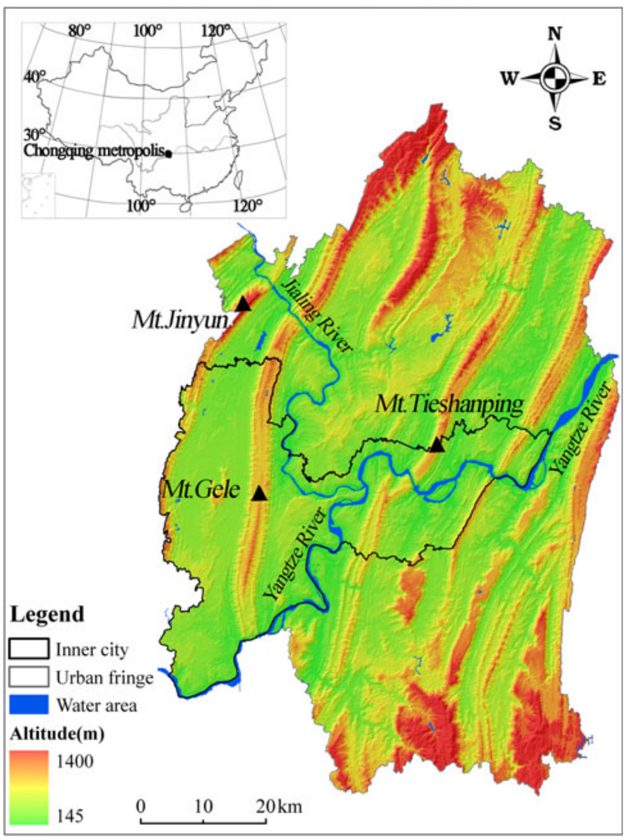


Fig. 1 The location of the study sites

TSP is a national forest park located at the boundary between the inner city and the urban fringe (generally indicating the three districts surrounding the inner city and now the newly developing area of Chongqing metropolis), lying 27 km from the urban core of the metropolis. The altitude of the peak is 583.3 m a.s.l. There is only one remnant patch of EBLF on TSP, having an area of about 3000 m^2 on the flat crest of the mountain. The patch may have been preserved for geomantic reasons (i.e., for spiritual reasons related to geography that are of special significance in China, usually transliterated as "feng shui") in view of the presence of a grand tomb within it. Up until 20 years ago, the residents of nearby villages and workers of a large factory at the foot of the mountain cut only small trees or the branches of large trees for use as fuel. Since then, cutting has diminished due to improved economic conditions. Farmland tourism has been flourishing since the 1990s, and many visitors from the inner city come to spend their weekends at the farmland hotels near the remnant EBLF patch; several large industrial parks have been operated at the foot of TSP. Therefore, some forested land has been replaced by constructions for residence and entertainment since the 1990s.

JY, located at the boundary between urban fringe and rural area, is a national nature reserve created in 2001 to protect the extensive subtropical forests on its slopes and peak. It is the highest of the three mountains, with altitude of the peak of 951.5 m a.s.l., and is 60 km from the urban

Table 1 Environmental characteristics of the study sites: Mt. Gele, Mt. Tieshanping, and Mt. Jinyun

Study site	Mt. Gele	Mt. Tieshanping	Mt. Jinyun
Mean altitude of the investigated plots (m)	550	650	800
Mean annual temperature (°C)^E	16.2	15.6	15.3
Monthly mean temperature for July (°C)^E	26.5	25.8	25.7
Monthly mean temperature for January (°C)^E	5.4	4.7	4.4
Warm index (°C month)^E	134.9	126.9	124.3
Cold index (°C month)^E	0	0.3	0.6
Mean annual precipitation (mm)^R	1079.4	1159.3	1105.4
Mean foggy days (/years)^R	57.2	40	16.4

Superscripts "E" and "R" indicated values estimated using a lapse rate of 0.6°C/100 m and real values based on observations at the nearest meteorological stations to the study sites: Shapingba, Yubei, and Beibei, respectively core of Chongqing metropolis. About 200 years ago a severe fire burned almost all the forest at JY. This severe disturbance took place when local wealthy people constructed fortresses to try to evade the persecutions of followers of the Bailian Religion. In the 1950s, many EBLFs on the mountain were converted to plantations of *Phyllostachys heterocycla* and *Cunninghamia lanceolata* for economic reasons. The remnant EBLFs remain on the upper slopes of the mountain and in steep valleys that are difficult to reach.

At GL, the remnant patches of natural EBLFs are surrounded by constructions for sports and recreation, and several types of artificial forests such as *Pinus mossoniana* forests, *Cinnamomum camphora* forests, *Firmiana simplex* forests, etc. At TSP, the patch is surrounded by artificial *Pinus mossoniana* forests and *Phyllostachys heterocycla* forests, roads for tourism, hotels for agritainment, and residential buildings. At JY, they are surrounded by artificial *Phyllostachys heterocycla* forests and *Cunninghamia lanceolata* forests.

Research methods

Field surveys

Field surveys were carried out in 2007. Five plots, each of 400 m^2, were set up and divided into four 100 m^2 (10 m × 10 m) meshes for each site. The mean elevations of the plots at GL, TSP, and JY are 650, 550, and 800 m a.s.l., respectively. An inventory was carried out of all individual trees taller than 1.5 m (woody layer). Species name, vital status (living or dead), diameter at breast height (DBH in cm, including all stump sprouts), and tree height (H, in m) were recorded. Meanwhile, the maximal natural height (cm) and the ground cover (%) for each vascular plant species less than 1.5 m in height (herb layer) were measured.

Data analysis

All species were categorized into eight lifeforms based on the lifeform system of *Vegetation in China* (Wu 1980), namely evergreen conifers (EC), evergreen broad-leaved trees (EBT), evergreen broad-leaved subtrees and shrubs (EBSS), deciduous broad-leaved trees (DBT), deciduous broad-leaved subtrees and shrubs (DBSS), lianas (L), perennial herbs (PH), and annual herbs (AH). Additionally, two groups (unique species and common species) were distinguished according to their distribution. Species recorded at just one site were defined as unique species and those at more than one site were defined as common species.

The presence–absence data for woody layer and herb layer of each plot were combined and classified by two-way analysis using TWINSPAN by means of the PCORD program (McCune and Mefford 1999).

Dominant species were identified by dominance analysis (Ohsawa 1984) using the following equation:

$$d = 1/N\left\{\sum_{i\in T}(x_i - x)^2 + \sum_{j\in U}x_j^2\right\},$$

where x_i is the relative dominance of the top species (T), x is the ideal percentage share of dominant species, determined by the number of dominant species, and x_j is the percentage share of the remaining species (U). N is the total number of species. In a community dominated by a single species, the ideal percentage share of the dominant species is 100%. If there are two dominant species, their ideal percentage share is 50%, and if there are three dominants, their ideal percentage share is 33.3%, and so on. The number of dominant species in the actual community is given as that which shows the least deviation (d) in the above equation. In this way the dominant species of each plot were identified, and then the dominant species of each site were found by combining the data of the five plots.

The relative dominance of the species of woody layer was expressed as the relative basal area (RBA, %) obtained by calculating the relative proportion of each woody species' basal area (BA) from DBH data of all the individual trees of each species. The relative dominance of herb layer was estimated by measuring the relative volume equivalent value (RVEV, %), which is the relative proportion of the volume equivalent value of each species, obtained by multiplying the maximal plant height and coverage (%) in each plot.

Two indices of species diversity, H' and J' (Pielou 1969), were calculated as follows for each plot:

$$H' = -\sum_{i=1}^{s} P_i \log_2 P_i,$$

$$J' = H'/\log_2 S,$$

where P_i is the relative quantity of species i, and S is the total number of species. RBA was used as the relative quantity of each species for woody layer, while RVEV was used for herb layer.

For the scaling of tree dimensions, the following expanded allometry equation was used to describe the relationship between DBH (D, cm) and tree height (H, m) and to obtain H* (m) as an estimate of potential tree height:

$$1/H = 1/(A \times D^h) + 1/H^*,$$

where A is a constant for the particular stands of trees and h is an allometric constant (Ogawa 1969). The equation was applied both to all the individuals as a whole in each plot and to the characteristic species *Castanopsis carlesii* var. *spinulosa* at each site.

Results

Species composition

In the 15 plots on the three sites, a total of 141 vascular plant species from 64 families were recorded. In order of number of species per family, they were mainly Theaceae (12 spp.) and Lauraceae (8 spp.), followed by Symplocaceae, Myrsinaceae, Gramineae, Liliaceae, Rosaceae, Fagaceae, Aquifoliaceae, and others represented by fewer species. Theaceae, Lauraceae, and Myrsinaceae were among the most numerous families at all three sites (Table 2).

The total number of species was 93, 58, and 76 for GL, TSP, and JY, respectively. However, the numbers of unique species were 39, 16, and 25 for the three sites, and the corresponding numbers of common species were 54, 42, and 51.

The lifeform composition of the species at the three sites is shown in Fig. 2. The relative number of evergreen woody species (EBT and EBSS) at GL was the smallest among the three sites. By contrast, the relative number of deciduous woody species (DBT and DBSS) decreased from GL to JY, the trend of DBSS being more obvious. The relative number of PH at GL was the largest among the three sites, and AH only appeared at GL. Most unique species of GL were deciduous trees and herbs (PH and AH), while the unique species of TSP and JY were evergreen trees (EBT and EBSS). Nine out of 39 unique species at GL were escaped horticultural ornamentals, namely *Cinnamomum camphora*, *Magnolia officinalis*, *Sophora japonica*, *Firmiana plantanifolia*, *Ligustrum lucidum*, *Citrus sinensis*, *Euphorbia pulcherrima*, *Parthenocissus tricuspidata*, and *Iris japonica*; by contrast, none of the unique species at TSP and JY were escapes.

Table 2 Constituent species of those plant families that contained more than 4 species in the remnant evergreen broad-leaved forests, as a whole and by site

Family	Whole	GL	TSP	JY
Theaceae	12/1	6/1	8/1	6/2
Lauraceae	8/2	5/2	4/2	7/1
Myrsinaceae	6/3	4/4	4/2	4/3
Symplocaceae	6/3	2/14	4/2	3/4
Gramineae	6/3	5/2	4/2	1/16
Liliaceae	5/6	4/4	1/13	2/7
Rosaceae	5/6	4/4	1/13	3/4
Fagaceae	4/8	3/7	2/6	2/7
Aquifoliaceae	4/8	1/22	2/6	3/4

Numbers indicate the number of plant species and their rank as a whole and at each site

GL Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

TWINSPAN clearly distinguished three forest types A, B, and C at the division level two (Fig. 3), coinciding with the three sites, GL, TSP, and JY. JY was the most different of the three sites, while GL and TSP were closer in species composition.

In the 15 plots at the three sites, a total of 10 species dominated woody layer and 39 species dominated herb layer in at least one plot. The number of dominant species of herb layer was always larger than that of woody layer at the same site. Among the three sites, the number of dominant species of woody layer at JY was significantly higher than at the other two sites according to Tukey's post hoc honestly significant difference (HSD) test for one-way analysis of variance (ANOVA) ($P < 0.05$). The numbers of species of herb layer displayed an increasing trend from GL to JY, although the trend was not statistically significant (Fig. 4).

At site level, 5 species dominated woody layer and 19 species dominated herb layer at at least one site (Table 3). The number of dominant species of woody layer of GL, TSP, and JY was 3, 1, and 3, respectively. *Castanopsis carlesii* var. *spinulosa* was the sole species that dominated at all three sites, while the other dominants were different, being *Pinus massoniana* and *Cinnamomum camphora* at GL and *Machilus pingii* and *Castanopsis fargesii* at JY. Compared with woody layer, the numbers of dominant species of herb layer of GL, TSP, and JY were far larger, being 7, 9, and 9, respectively. TSP and JY were dominated by quite similar lifeforms, but notably, dwarf bamboo *Pseudosasa victorialis* and the planted nonindigenous species *Schima superba* dominated on TSP, while GL revealed a lack of evergreen broad-leaved trees.

Biodiversity characteristics

Species richness, Shannon–Wiener index, and Pielou index were used to compare the remnant EBLFs at GL, TSP, and JY, and the differences were tested by Tukey's post hoc HSD tests for one-way ANOVA. For woody layer, TSP had the lowest species richness, Shannon–Wiener index, and Pielou index among the three sites. Species richness and Shannon–Wiener index of TSP were significantly lower than those at GL and JY ($P < 0.05$). Between GL and JY, the former had the higher species richness, but its Shannon–Wiener index and Pielou index were significantly lower than those of the latter. For herb layer, the species richness of TSP was significantly lower than those of the other two sites ($P < 0.05$), while Shannon–Wiener and

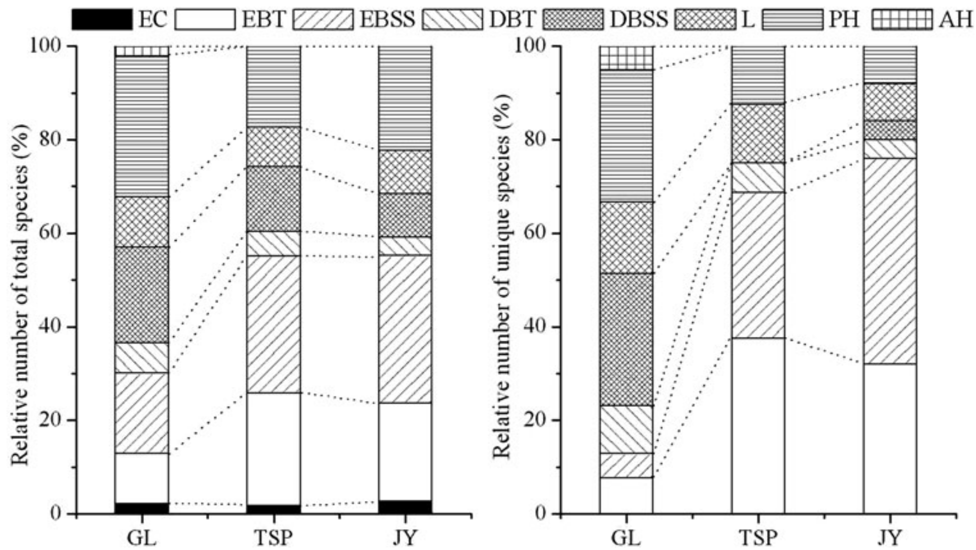


Fig. 2 Lifeform composition of the species at the three sites. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun, *EC* evergreen conifers, *EBT* evergreen broad-leaved trees, *EBSS* evergreen broad-leaved subtrees and shrubs, *DBT* deciduous broad-leaved trees, *DBSS* deciduous broad-leaved subtrees and shrubs, *L* lianas, *PH* perennial herbs, *AH* annual herbs

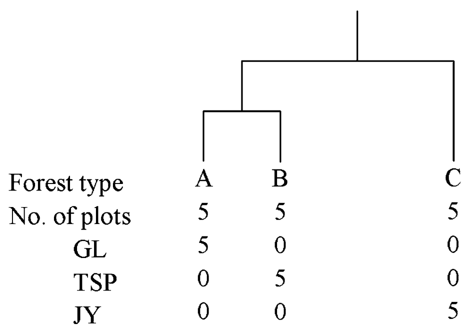


Fig. 3 TWINSPAN classification of forest types for the 15 plots. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

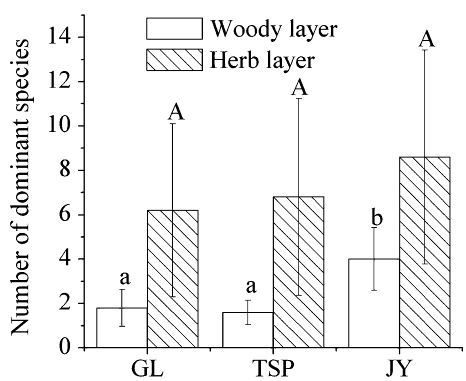


Fig. 4 Numbers of dominant species in the plots at the three sites. Means ± SE ($n = 5$) that have the *same letter* are not significantly different using Tukey's post hoc HSD tests ($P < 0.05$). *a* and *b* for woody layer and *A* for herb layer. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

Pielou indices were almost the same among the three sites (Fig. 5).

The dominance–diversity curves for all the plots at the three sites clearly indicated some differences in the allotments of relative dominance among the various species (Fig. 6). For woody layer, the TSP plots exhibited steep geometric curves because there are relatively few species, and most have a relatively low level of dominance. However, the other two sites (GL and JY) have dominance–diversity curves that approach the typical log-normal type. JY had somewhat more species with larger relative dominance, and so the curves decay with respect to dominance less quickly initially than those for GL and TSP. For herb layer, all the dominance–diversity curves tended towards log-normal form and showed fairly similar allotments of relative dominance.

Stand structure

As seen in Fig. 7, several parameters of stand structure were compared and the differences were tested by Tukey's post hoc HSD tests for one-way ANOVA. Stem density at GL was found to be significantly larger than at the other two sites ($P < 0.05$), with the differences in sprouting stems contributing much to the differences among the three sites. Estimates of basal areas (BA) revealed no significant differences among the three sites, although JY appeared to have the largest trees as shown by significantly greater maximum DBH. With respect to stratum structures, the maximal height and potential height increased significantly ($P < 0.05$) from GL to TSP to JY.

The DBH size-class distribution pattern of all stems at TSP was quite different from that at the other two sites (Fig. 8). As the size class increased, the number of stems decreased gradually at GL and JY, while stems from 5 to 25 cm were relatively rare at TSP. Similarly, TSP was abnormal in having an excess of 25–30 cm stems relative to the neighboring size classes. In addition, the three sites showed obvious differences in the number of saplings (DBH < 5 cm), with the larger number at GL and smaller

Table 3 Frequency of species that dominated at at least one site

Dominant species	GL $n = 5$	TSP $n = 5$	JY $n = 5$	Total $n = 15$
Woody layer				
Conifer trees				
Pinus massoniana	2/5[b]	1/3	2/2	5/10
Evergreen broad-leaved trees				
Cinnamomum camphora	2/5[b]	–/–	–/–	2/5
Castanopsis carlesii var. *spinulosa*	5/5[b]	5/5[b]	4/5[b]	14/15
Machilus pingii	–/1	–/–	5/5[b]	5/6
Castanopsis fargesii	–/–	–/–	5/5[b]	5/5
Herb layer				
Evergreen broad-leaved trees				
Castanopsis carlesii var. *spinulosa*	–/5	4/5[b]	4/5[b]	8/15
Schima superba[a]	–/–	4/5[b]	–/–	4/5
Castanopsis fargesii	–/–	–/–	3/5[b]	3/5
Evergreen broad-leaved subtrees and shrubs				
Stranvaesia tomentosa	3/5[b]	–/–	2/4	5/9
Camellia rosthorniana	1/5[b]	–/–	–/2	1/7
Maesa japonica	2/4[b]	–/5	4/5[b]	6/14
Ardisia brevicaulis	2/3[b]	–/–	4/5[b]	6/8
Pseudosasa victorialis	1/1	5/5[b]	–/–	6/6
Symplocos botryantha	–/–	2/4[b]	–/–	2/4
Antidesma japonica	–/–	2/4[b]	–/–	2/4
Lianas				
Smilax china	–/5	3/5[b]	3/5[b]	6/15
Heterosmilax chinensis	–/–	2/5[b]	–/–	2/5
Perennial herbs				
Iris japonica	3/5[b]	–/–	–/–	3/5
Dryopteris erythrosora	3/5[b]	–/5	3/4[b]	6/14
Woodwardia japonica	5/5[b]	–/3	2/5[b]	7/13
Lophatherum gracile	1/5	2/5[b]	1/4	4/14
Dicranopteris pedata	2/5	2/4[b]	–/1	4/10
Arachniodes chinensis	2/4	–/–	3/4[b]	5/8
Diplopterygium glaucum	–/4	–/–	2/3[b]	2/7

The numbers indicate the numbers of plots in which each species was dominant and the numbers of plots in which each species occurred (i.e., frequency of dominance/frequency of occurrence)

GL Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

[a] Planted species

[b] Dominant at the site

at TSP and JY. Sproutings were concentrated in small size classes at the three sites, the number decreasing from GL to TSP to JY. Larger trees, with DBH >45 cm, were more prevalent at JY, and the only trees with DBH in the 55–60 cm size class were found there.

As the most dominant species and main component of the canopy at the three sites, *Castanopsis carlesii* var. *spinulosa* controlled the structure of the communities. As seen in Fig. 9, the height of individuals having the same DBH increased from GL to TSP to JY, most notably with respect to larger individuals. At GL, growth in height relative to DBH appears to have been suppressed in trees with larger DBH. The trees at JY showed less scatter with respect to height in relation to DBH, suggesting that the environment is more uniform and less stressful than at the other two sites.

Among the main species of evergreen broad-leaved trees, *Castanopsis carlesii* var. *spinulosa*, *Cinnamomum camphora*, *Machilus pingii*, *Elaeocarpus sylvestris*, and *C. fargesii* all showed inverse-J or sporadic-shaped distribution with large numbers of small stems as indicated by DBH (Fig. 10), reflecting regeneration by means of seedlings and sproutings. Although the DBH distribution of the conifer *Pinus massoniana* at GL and TSP was unimodal, there was evidence of regeneration in the form of small stems at GL. Sprouting stems of *Castanopsis carlesii* var. *spinulosa* decreased in number and proportion from GL to TSP to JY (Fig. 10).

Discussion

Floristic composition characteristics and biodiversity

Different intensities of disturbance and processes of fragmentation have led to differences in species composition and diversity of the remnant EBLF patches at the three sites examined. Nevertheless, these plant communities have retained the essential floristic composition that is characteristic of EBLFs of mid-subtropical China, having species of Theaceae, Lauraceae, Symplocaceae, and other characteristic families as their main components (Song 2004; Yang et al. 2007). The species composition at JY most closely resembled that of an unmodified primary EBLF, while the species composition at GL was least similar. This is probably because fragmentation of the remnant patches at GL has led to local extinctions as well as colonization by invading species, such as horticultural ornamentals, leading to higher occurrence of unique species (Grashof-Bokdam 1997; Ishida et al. 1998; Kitazawa and Ohsawa 2002), some of which were even dominant species, such as *Cinnamomum camphora* and *Iris japonica*, the commonest landscaping tree and ground cover plant in inner city of Chongqing metropolis (Table 3). As shown in Fig. 2, most of the unique species at JY and TSP are evergreen trees, while those at GL are deciduous trees and herbs, suggesting a trend of decreasing richness of shade-tolerant species and increasing richness of heliophytes. As forest fragmentation has progressively increased, it appears that the area of the patches has gradually decreased, interior forest

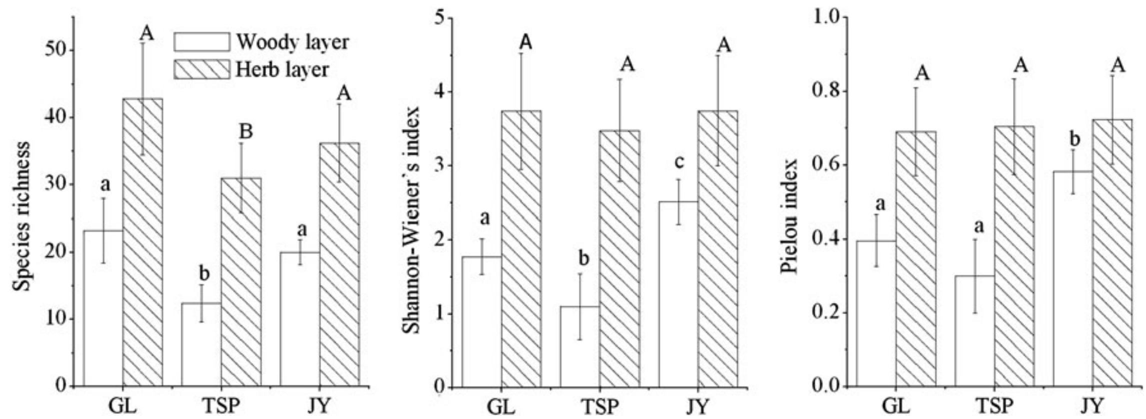
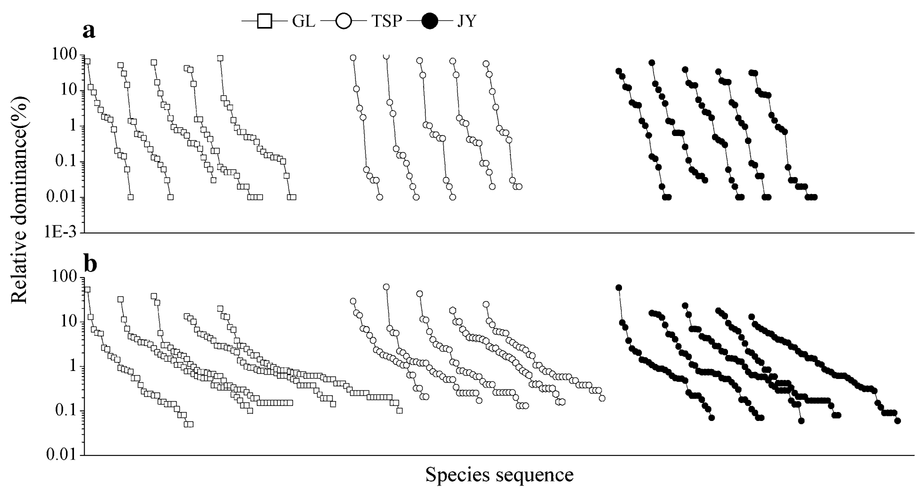


Fig. 5 Biodiversity indices of the three sites. Means ± SE ($n = 5$) that have the *same letter* are not significantly different using Tukey's post hoc HSD tests ($P < 0.05$). *a*, *b* and *c* for woody layer; *A* and *B* for herb layer. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

Fig. 6 Dominance–diversity curves for each site. **a** Woody layer. **b** Herb layer. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun



environments have been lost, and the smallest patches have become wholly forest edges (Murcia 1995).

Forest edges are dynamic environments. These boundaries play significant ecological roles as transition zones between different habitats (Murcia 1995; Fry and Sarlöv-Herlin 1997; Fujihara et al. 2005) and are easily invaded by light-demanding species such as deciduous trees and annual herbs (Fujihara et al. 2002; McKinney 2006; Hedblom and Söderström 2008). In addition to boundary effects themselves, the biodiversity of fragmented forests is also affected by the characters of the surrounding ecosystems. Urban habitats are a mosaic of land uses with varying extents of disturbance in time and space, leading to diversity of habitats and biotic communities (Sukopp 2004; McKinney 2006). Such habitats are seed sources for those deciduous trees and ruderals that rely on disturbance to sustain their populations (Luken 1997). In this study, numerous deciduous trees and ruderals such as *Sophora albescens*, *Quercus acutissima*, *Vernonia bockiana*, *Rubus corchorifolius*, *Blumea aromatica*, *Pteris multifida*, *P. vittata*, *Polygonum perfoliatum*, *P. muricatum*, *Arthraxon hispidus*, *Achyranthes bidentata*, and *Aster ageratoides* were found only at GL. Many studies have found that the number or proportion of escapes from cultivation tends to increase along the rural–urban gradient (McKinney 2002; Sukopp 2004), as was found at GL in this study in the inner city, where only 9 escaped horticultural ornamentals common in urban greening occurred. We conclude therefore that the series JY to TSP to GL reflects the rural–urban gradient from outskirts to inner city via urban fringe.

Among the three sites, GL and JY represent the extremities of disturbances, with TSP intermediate. However, the plant diversity was umbilicate, which does not support the intermediate disturbance hypothesis that suggests the number of species to be highest at intermediate levels of disturbance and lowest under conditions of both high and low disturbance (Connell 1979). GL has many heliophytes, while JY supports more inherent components of natural vegetation. On the contrary, inherent components of natural vegetation and heliophytes are both less at TSP. In fact, the intermediate disturbance hypothesis may be less valid in urban areas. In other words, only natives

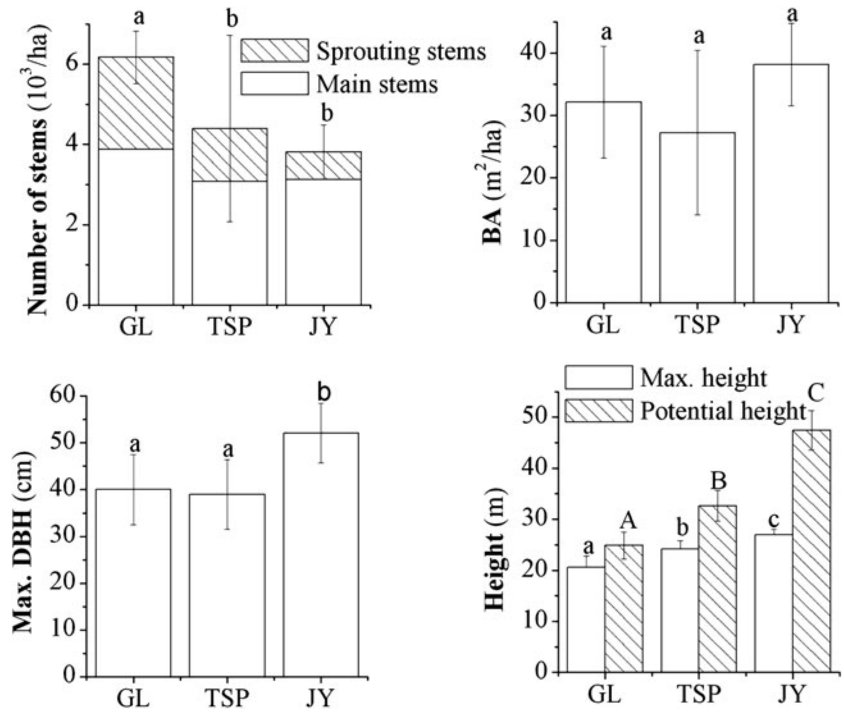


Fig. 7 Stand characteristics for each site. Means ± SE ($n = 5$) that have the same letter are not significantly different using Tukey's post hoc HSD tests ($P < 0.05$). *A*, *B*, and *C* only for potential height. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

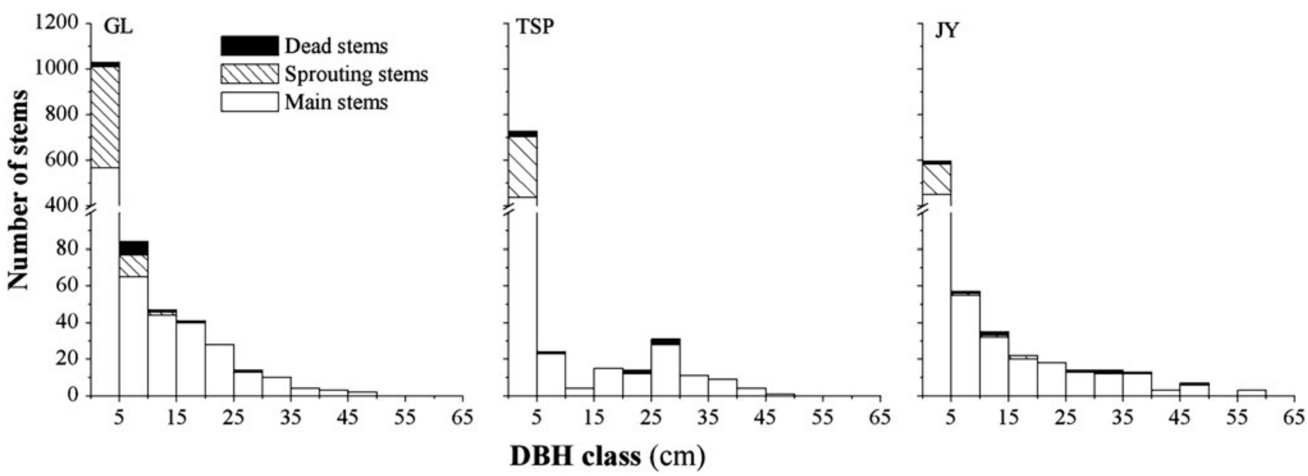


Fig. 8 DBH class frequency distribution of all stems at the three sites. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

support the general theory (Sukopp 2004). So, dividing the species reveals two contrary trends: the highest numbers of inherent components of natural vegetation are found in vegetation with little influence, whereas maximal species diversity of heliophytes exists in vegetation obviously more strongly influenced by humans.

Stand structure and regeneration dynamics

Regarding the structural characteristics of the stands (stem density, BA, maximal DBH, and height), only height varied remarkably (Fig. 7). The decreasing height from JY to GL indicates that growth of trees is progressively restricted from urban outskirts to inner city. The same restriction holds for the characteristic species *Castanopsis carlesii* var. *spinulosa* (Fig. 9). Among the possible causes for this pattern is the local climate and atmospheric quality. As shown in Table 1, there were 57.2, 40, and 16.4 foggy days near GL, TSP, and JY, respectively. For the year 2005, the Chongqing Center of Environmental Monitoring and the Chongqing Bureau of Environmental Protection reported similar gradients of air pollution (SO_2 was 0.084, 0.049, and 0.047 mg/m^3; NO_2 was 0.047, 0.031, and 0.030 mg/m^3 near GL, TSP, and JY, respectively), and the situation was more serious in the 1980s and 1990s (Zhao et al. 2002). It has been reported in many studies that acid rain has caused decline of forests in Europe, North America, and South China (Tomlinson 1983; Feng 2000; Zhao et al. 2002). Acid rain and acid fog, particularly the latter, directly affect the forest canopy, causing canopy die-back and loss of height (Hileman 1983; Bredemeier 1988; Zhao et al. 2002). The data for height in relation to DBH for *Castanopsis carlesii* var. *spinulosa* indicate that this signature species is also affected. Notably, the difference of height becomes remarkable from DBH of 20 cm and the corresponding height of nearly 12 m, implying that the individuals just enter the subcanopy (Fig. 9). Forest fragmentation also opens the forest to wind disturbance, thereby adding to the damage (Laurance et al. 2002). Further investigations and experiments are therefore required in order for the loss of tree height and its potential impacts on seed production to be fully understood and suitable forest management measures put in place.

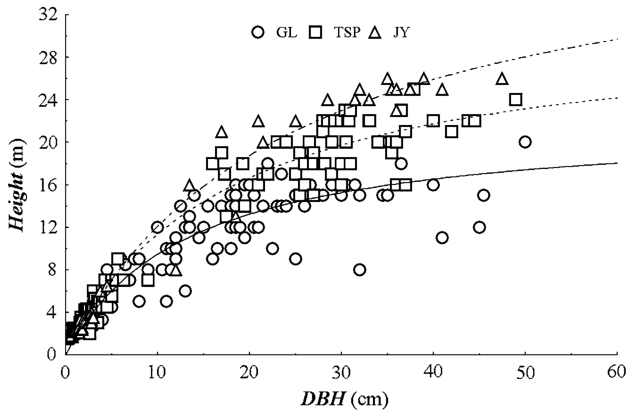
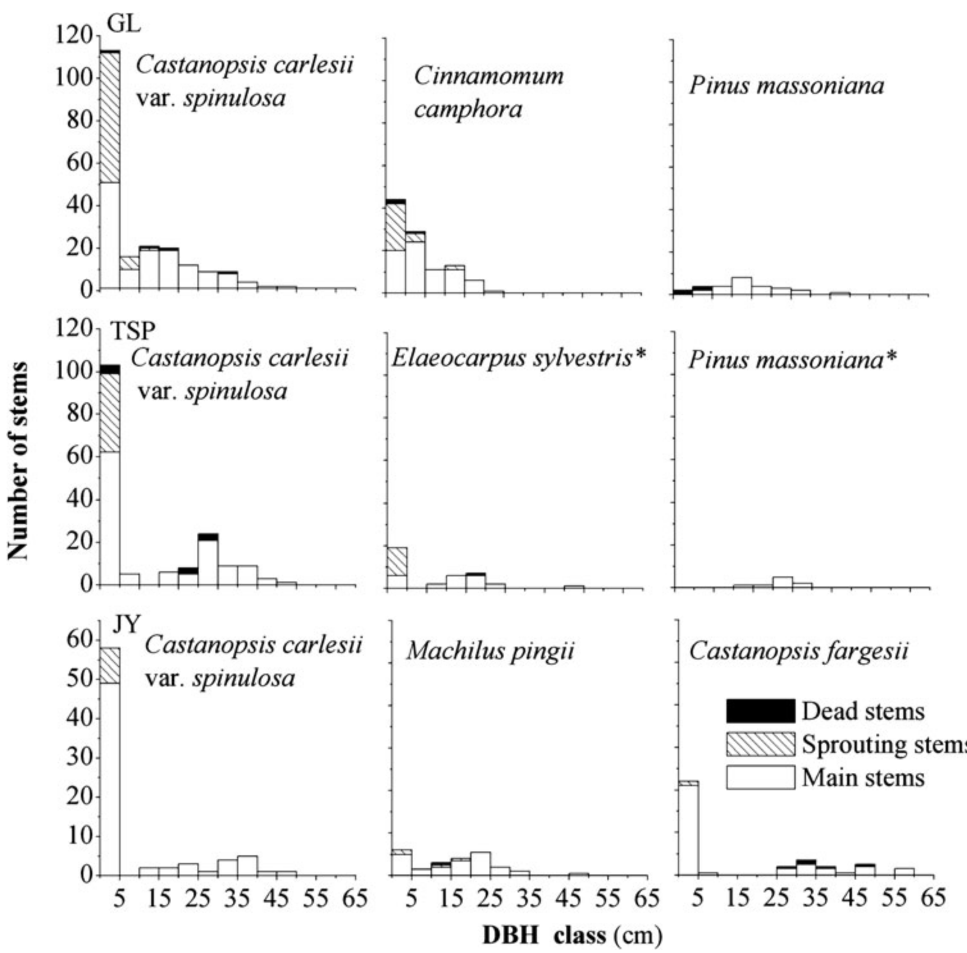


Fig. 9 Scaling of tree height and DBH for the dominant species *Castanopsis carlesii* var. *spinulosa* at the three sites. The curves were drawn by using the expanded allometric equation of Ogawa (1969). *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun

Sprouting is a common response among broad-leaved trees to disturbance, and disturbance frequency and severity are important determinants of the relative frequency of sprouting at community level (Bellingham et al. 1994; Bond and Midgley 2001). As shown in Fig. 7, GL had the largest number of sproutings and appears to be the most disturbed of the three sites. Sprouting is an important survival strategy (Bellingham 2000) and is common for most *Castanopsis* species (Manabe et al. 2000; Miura and Yamamoto 2003; Nanami et al. 2004; Yang et al. 2005a, b). This is especially true for *Castanopsis carlesii* var.

Fig. 10 DBH class distribution for the main species of each site. *Asterisk* indicates species that were nondominant but still had RBA of about 10% at TSP. *GL* Mt. Gele, *TSP* Mt. Tieshanping, *JY* Mt. Jinyun



spinulosa, as shown by the many previously large trees of this species at GL which have lost their canopies and have responded by sprouting from their stumps (Figs. 9, 10). Once the main stem dies, the individual can survive for a while by means of this sprouting behavior and the population can be maintained.

Implications for conservation

As a typical subtropical mountainous region, the location of Chongqing metropolis would have been covered by EBLFs before human settlement began, but most of the natural forests have now been converted to other seminatural or artificial landscape types (Yang et al. 2007). The remnant EBLFs are therefore rare indicators and representatives of this regional natural feature, being relicts of historical and botanical heritage (Maurer et al. 2000).

Patches of remnant natural vegetation themselves are the core areas of biodiversity in the urban environment; meanwhile, they play important roles in the maintenance of regional biodiversity. Functionally, the populations of the species in remnant communities are seed sources for restoration of degraded vegetation at local scale.

There are three means by which this can occur. Seeds from remnant EBLFs can naturally facilitate the restoration process of degraded vegetation near them (Ito et al. 2003; Yang et al. 2007). As was also demonstrated by our research conducted at TSP, the natural restoration processes of artificial *Pinus massoniana* forests more than 250 m away from the remnant *Castanopsis carlesii* var. *spinulosa* forest were restricted due to the absence of seed sources of the inherent components of the EBLF (Yang and Li 2009). Most evergreen trees have lower dispersal capacity (Fujihara et al., 2002; Yang et al. 2006), which suggests that it is hard for evergreen broad-leaved forests to restore themselves spontaneously once they are destroyed. Secondarily, seeds of the remnant EBLFs can be collected for artificial restoration of seminatural or artificial plant communities lacking seed sources of the inherent components of zonal vegetation. It is preferable to obtain seeds from local sources given the higher probability that these will be genetically adapted to local conditions (Yang et al. 2005a, b). Finally, remnant EBLFs are sound model for rebuilding of local vegetation following “close-to-nature” or “back-to-nature” approaches (Gamborg and Larsen 2003; Miyawaki 2004). The essence of those approaches is to restore natural vegetation of combined native species in accordance with the potential abilities of the habitat, and to try to restore the whole ecosystem specific to a region (Miyawaki 1992). Many cases of application of these approaches have been conducted worldwide, such as in Japan, China, South-East Asia, Europe, Australia, and South America (Da et al. 2004; Miyawaki 2004).

As remnant EBLFs are so rare, constituting an important landscape type contributing to biodiversity and sustainable development in urban areas, suitable forest management measures should be taken. As the crowns of many large trees of *Castanopsis carlesii* var. *spinulosa* have been damaged at GL (Fig. 9), sustainable efforts should be taken to improve the environmental qualities in the inner city, especially atmosphere quality. Also, as the size of the patches is small (about 400 m^2 each), connectivity should be improved at GL, considering artificial forests among the patches as corridors or stepping stones for species movement (Forman and Godron 1995; Wu 2000). For the patch at TSP, it is urgent to control the extension of dwarf bamboo *Pseudosasa victorialis*, the most dominant species of the herb layer (Table 3), as many studies have demonstrated that dense bamboo in the understory of tropical, subtropic, and temperate forests prevents canopy tree regeneration (Takahashi 1997; Widmer 1998; Tang et al. 2007). Meanwhile, it is necessary to remove the nonindigenous tree species *Schima superba*, which we firstly identified as being able to complete its life history on Mt. Gele in 2008 (personal observation), representing a potential risk for the patch. For the patches at JY, the natural conditions should be maintained and the number of tourists should be controlled for more than 340000 persons visiting the EBLFs on Mt. Jinyun according to the tentative accounts of the Management Bureau of the Mt. Jinyun National Natural Reserve in 2005.

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