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Understory plant diversity assessment of Szemao pine (*Pinus kesiya* var. *langbianensis*) plantations in Yunnan, China

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Abstract

UNDERSTORY PLANT DIVERSITY ASSESSMENT OF SZEMAO PINE (*PINUS KESIYA* VAR. *LANGBIANENSIS*) PLANTATIONS IN YUNNAN, CHINA.— Sustainability is a key objective for managers of both natural forests and plantations, and biodiversity assessments are important tools to improve conservation of endangered species. Szemao pine (*Pinus kesiya* var. *langbianensis*) is a native Chinese tree species used in plantations. This study evaluated differences in understory diversity among Szemao pine plantations (SP) and other local current vegetation types: secondary evergreen forests (SE) and abandoned farmlands (AF) in Yunnan Province. Sampling was performed at three elevation ranges, where species richness, species cover, and environmental variables in the herb and shrub layers were measured. We found that indexes for average richness and Shannon–Wiener diversity were higher in SE than in SP, which were in turn higher than in AF, while the index for evenness was higher in SP. These indexes increased with elevation in SP and AF, but were higher at low and medium elevations in SE. Inclusion of environmental factors highlighted elevation differences, with water content (at herb layer) and soil type (at shrub layer) being the most significant variables. In conclusion, plantations of Szemao pine negatively affect understory diversity in Yunnan, and furthermore, only a few rare or threatened species could be found in the plantations. Nature reserves and transplanting could protect threatened species if established before plantations.

Key words: abandoned farmlands; endangered species; herbs; plant diversity; secondary evergreen forests; shrubs.

Resumen

EVALUACIÓN DE LA DIVERSIDAD DE PLANTAS DE SOTOBOSQUE EN PLANTACIONES DE PINO SZEMAO (*PINUS KESIYA* VAR. *LANGBIANENSIS*) EN YUNNAN, CHINA.— La sostenibilidad es un objetivo clave para la gestión tanto de bosques naturales como de plantaciones, mientras que los estudios sobre biodiversidad constituyen herramientas muy útiles para mejorar la conservación de especies amenazadas. El pino Szemao (*Pinus kesiya* var. *langbianensis*) es un árbol nativo de China que se usa en plantaciones. Este estudio evalúa la diversidad del sotobosque en plantaciones de pino Szemao (SP) y otros tipos de vegetación local, como bosques secundarios perennifolios (SE) y tierras de cultivo abandonadas (AF), en la provincia de Yunnan, China. El muestreo se realizó en tres rangos altitudinales, y se evaluó riqueza y cobertura de hierbas y arbustos además de factores ambientales. En general, la riqueza promedio y la diversidad de Shannon-Wiener fueron mayores en SE que en SP, y a su vez que en AF, mientras que la equitatividad tendió a ser mayor en SP. Asimismo, dichos índices tendieron a aumentar con la altitud en SP y AF, aunque en SE fueron mayores a altitudes bajas y medias. La inclusión de factores ambientales resaltó las diferencias entre rangos altitudinales, siendo el contenido de agua (en el estrato herbáceo) y el tipo de suelo (en el estrato arbustivo) las variables más significativas. Las plantaciones de pino Szemao en Yunnan afectan al sotobosque, encontrándose pocas especies raras o amenazadas en su interior. Las reservas naturales y los transplantes podrían ser una alternativa para proteger a las especies amenazadas si se llevan a cabo anticipadamente a las plantaciones.

Palabras clave: arbustos; bosques secundarios perennifolios; diversidad de plantas; especies amenazadas; hierbas; tierras de cultivo abandonadas.

INTRODUCTION

Worldwide, forest plantations are promoted as a tool by which to increase forested areas and produce timber and pulpwood (Li, 2000). Such plantations are usually considered a viable long-term forestry development strategy to reduce or eliminate the need to exploit natural forests and could also achieve the goal of natural forest biodiversity protection and long-term ecosystem sustainability. However, while plantations can be managed in ways that enhance their biodiversity protection functions, they are not generally important as habitat for native biodiversity, and in practice, plantations often replace natural forests (Brockerhoff *et al*., 2008; Duan *et al*., 2010; Wang *et al*., 2011). At the same time, loss of biodiversity is occurring at an ever-increasing rate, resulting from land use conversion accompanied by both habitat destruction or alteration, and the introduction of invasive species (Gilliam, 2007).

In tropical and subtropical forests, deforestation is the main cause of forest decline. According to Brown (2000), about 7% of natural closed forest lost in tropical lands has been converted to plantations, while the remaining 93% of these losses are lands being converted to agriculture and other uses. Furthermore, 15% of plantations in tropical countries have been established on originally closed canopy natural forest (Brown, 2000). Tropical forests house many threatened forest hotspots defined by international associations around the world (Mittermeier *et al.*, 2005), such as the Indo-Burma Hotspot, where today only five percent of the original habitat remains. This hotspot includes the northern Indochina subtropical forests, which extend from Vietnam to Laos, Thailand, Myanmar and the province of Yunnan in China (Wikramanayake *et al.*, 2001).

Szemao pine [*Pinus kesiya* Royle ex Gordon var. *langbianensis* (A. Chev.) Silba], a geographic variant of *Pinus kesiya*, is distributed naturally in the humid and sub-humid area of the tropical and subtropical zone within Yunnan Province, and is concentrated in Pu'er and other prefectures or cities of this province (ECFRPS–CAS, 1978). Szemao pine is one of the native species of China selected for plantations, and has been sown by airplane since 1960s (Zha, 2003). The species produces good quality timber and is widely used in the construction, furniture and paper industries. Additionally, its high yield of quality resins, including rosin and turpentine, make Szemao pine the main timber and resin tapping tree in Yunnan Province (Wu, 1994). Even though they constitute one of the main timber plantations in the province, Szemao pine plantations have been the subject of few studies regarding the conservation value of their understory biodiversity. Chen *et al.* (2009) studied the undergrowth plant diversity of five types of Szemao pine plantations in Pu'er Prefecture. However, that study did not focus on the understory layer nor did it compare Szemao pine to other current local vegetation types. Likewise, it remains unknown if and how Szemao pine plantations will affect threatened species, and how environmental factors could influence their understory diversity.

Among other forest biodiversity components (e.g. trees, arthropods, birds, mammals; Gilliam, 2007), understory plants provide a crucial role in maintaining the structure and function of forest ecosystems, as they contribute to forest biodiversity, generate the initial competitive interactions with regeneration phases of dominant canopy species, determine energy flow and nutrient cycling, and respond complexly to disturbances of both natural and anthropogenic origin (Gilliam, 2007). In plantations, understory vegetation could act as a conservation refuge for many animal species and might play an important role in plant diversity and ecosystem functionality, but rarely has been examined properly (Geldenhuys, 1997; Harrington & Ewel, 1997). Although plant species richness in the herbaceous layer is typically greater than in any other forest stratum, discussions of threats to biodiversity often omit the herb layer (Gilliam, 2007). The occurrence of rare (often threatened or endangered) species in the herbaceous layer has practical relevance to the biodiversity of forest ecosystems. Spyreas & Matthews (2006) suggested that, because of their habitat and resource specificity, rare plants of the herbaceous layer have excellent potential for use as biodiversity indicators.

With the ongoing expansion of plantations, its putative biodiversity enhancement has attracted worldwide attention (FAO, 2006), and the environmental effects of plantations comprised of fast-growing native or exotic trees have been vigorously debated, especially with regard to plantations in subtropical regions (IFS, 1989; Tang *et al*., 2007; Duan *et al*., 2010; Wen *et al*., 2010). On one hand, monocultures have been said to exhaust resources, resulting in decreased biodiversity (e.g. Shiva *et al.*, 1982; Shiva & Bandyopadhyay, 1983; Poore & Fries, 1985; Abbasi & Vinithan, 1997; Tang *et al.*, 2007). Conversely, it has been stated that monocultures may favor regeneration of undergrowth plants from surrounding forests, increasing biodiversity (Geldenhuys, 1997; Harrington & Ewel, 1997; Loumeto & Huttel, 1997).

Thus, we conducted this study to compare understory diversity in Szemao pine plantations with two other current local vegetation types: secondary evergreen forests (SE, similar to native forests), and abandoned farmlands (AL) in order to assess: (1) the differences in understory vegetation among the three vegetation types; and (2) environmental factors that affect the composition and structure of understory vegetation. The study included both a special consideration of threatened species as well as an evaluation of the influence of environmental factors on understory diversity. Among environmental factors, special attention was given to altitudinal influence by evaluating current vegetation types at three different elevations. Our work contributes to a better understanding of how biodiversity in Szemao pine plantations and other vegetation types might be enhanced.

MATERIALS AND METHODS

Study area

Pu'er Prefecture is found beside Myanmar in the southern section of Hengduan Mountains in China, and is located in southwestern Yunnan Province. Pu'er has a mean annual temperature of 18.9ºC, and in 2009, the annual precipitation was 1502 mm (Li *et al.*, 2009). Monsoon seasonality (i.e. wet summers and dry winters) characterizes the region, with monsoon evergreen broad-leaved forest being the dominant vegetation type. Between 0 and 700 m, tropical plant species can be found; moisture-loving broad-leaf plant species are distributed above 1400 m. The fieldwork took place in the three southwestern counties of Pu'er: Lancang, Menglian, and Ximeng.

Pu'er is home to many economically and ecologically important trees, plants, and animals (Li *et al.*, 2009). Ceylon ironwood (*Mesua ferrea* L.), purple teak (*Tectona grandis* L. f.), camphor [*Cinnamomum camphora* (L.) T. Nees & C. H. Eberm.], *Toona ciliata* M. Roem. var. *pubescens* (Franch.) Hand.-Mazz. and *Trigonobalanus doichangensis* (A. Camus) Forman are among the hundreds of timber species have been recorded in Pu'er, among many other rare species. Trees of several hundred years old, including cypresses [*Platycladus orientalis* (L.) Franco] and tea trees (*Melaleuca alternifolia* Cheel), can be found in the region. Also native to Pu'er are over 2000 herbal components of Chinese medicine, including *Paris quadrifolia* L., wild notoginseng (*Panax stipuleanatus* Tsai & Feng), and *Polygonum multiflorum* Thunb. Over one hundred animal species are protected as well.

Sampling protocol

In Lancang, Menglian, and Ximeng counties, three ranges of elevation—low (1000–1400 m), medium (1400–1800 m), and high (1800–2200 m)—were selected between December 2008 and May 2009. We identified three sites at each elevation range that possessed similar environmental characteristics (e.g. slope, aspects, etc.) by the use of satellite images, local relief maps, and ground studies coupled with global positioning. All three major local current vegetation types were found at each site: Szemao pine plantations (SP), secondary evergreen forests (SE) and abandoned farmlands (AF). At each sampling site, there was less than 1 km between the three local current vegetation types.

Szemao pine plantations were more than ten years old and were established on lands where secondary evergreen forest had been harvested. The Szemao pine is native to the local forest communities and was seeded by airplanes from 1960 to 2000 (Zha, 2003). Over a ten-year period, secondary evergreen forests in China have become established on lands originally occupied by primary forests, from which most adult trees have disappeared because of long-time logging, anthropogenic destruction, grazing and fire. Thus, the secondary forests are comprised only of young trees and shrubs, which naturally regenerate after timber harvesting. The abandoned farmlands studied had been deserted for about six years. Prior to abandonment, farmers had cut a large area of forest, burning the cut vegetation and then had planted corn, sugar cane or upland rice. During farming, the land was tilled and treated with herbicides. After about three decades of farming, the soil became barren and the production of agricultural crops was severely curtailed, so the farmers abandoned the land in search of more productive land.

Three "large" 20 × 20 m plots were delineated for each local current vegetation type (SP, SE and AF) in each of the nine sites; the actual investigated area was 400 $m^2/\cos\alpha$, where α is the angle of slope. All large plots were located at least 100 m away from the edge of each vegetation patch to minimize edge effects. In summary, three vegetation types at each of three sites at three different elevations were sampled for a total of 27 large plots.

The understory vegetation was delineated into herbaceous and shrub layers. The floristic surveys were carried out in five 5 × 5 m subplots for shrub species and five 1 × 1 m subplots for herb species in each large plot: one subplot was in the center and the other four were on each corner of each large plot. To characterize each plot, the data for the five small subplots were combined.

Shrubs were defined as woody species with a diameter at breast height (DBH) of less than 2 cm; "breast height" was considered to be 1.30 m from the ground. Trees (woody species with a DBH of more than 2 cm) were avoided. At the time field work was being done in all plots, discrete interlayer species (i.e. species that live above the herb layer but below the shrub layer, e.g. lianas and ferns) were initially considered separately. However, since widely different local vegetation types were surveyed, these interlayer species were effectively absent in some vegetation types, while being very abundant in others (e.g. in SE). Therefore, we decided to consider lianas and tall ferns to be species in the shrub layer, whereas short ferns were considered species in the herb layer.

Plant richness was estimated by combining the counts of different species across all five subplots in each site. We also categorized and counted both genera and families observed in each plot, and kept track of rare or threatened species. We used definitions outlined by the Chinese National Forest Bureau (NRE, 2004; Zhou, 2010) to categorize the threatened species: a "level II-protected" species requires some protection, while a "level I-protected" species is in greatest need of protection. Species were identified and the number of individuals for each species was recorded in each subplot for the understory layers (shrub and herb); clonal units were considered to be a single individual. Collectively, these data were used to calculate relative abundance (density) for quantitative analysis.

The heights for shrub and herb layer canopy closure measurement were 1.2 m and 0.30 m, respectively. To estimate shading, we calculated the percentage of shaded area (dark patches), representing overstory canopy cover (OCOV) in four or five random 1 × 1 m small subplots. Each subplot was a 1 × 1 m plastic frame with nine uniform size cells. If shade covered more than 50% of the area of a cell, we counted the cell as a "shade cell". We then used the number of shade cells as the shadiness of each 1 × 1 m subplot, from which could derive a value of 0 to 9. To estimate the OCOV for the entire large 20 × 20 m plot, we used a frequency estimation method in which we estimated the percentage of the projected shadow area in five random "small" 5 × 5 m subplots within the tree layer (derived from the 1 × 1 m subplot), and then combined the data.

To test the influence of soil differences, the soil type was defined for each site, and considered as "dummy" variable (SOIL) for multivariate analysis (1 = Lateritic red, in five sites; 2 = Red, in two sites; and 3 = Yellow brown, in a single site). To determine soil chemistry, five samples of soil per subplot (total of 25 per plot) at the five small subplots of each vegetation type were obtained with a soil corer (diameter 5 cm) inserted to a depth of 20 cm. The five samples were combined into a composite sample (about 1 kg), each of which was then air-dried and sieved prior to chemical. Soil chemical characters measured were: pH, percentage of organic matter (OM), hydrolyzable nitrogen in mg kg^{-1} (HN), available phosphorus in mg kg^{-1} (AP) and rapid available potassium in mg kg^{-1} (RAK) (Standford & English, 1949; Olsen *et al.*, 1954; ISS–CAS, 1978; SCA, 1987). After removing the litter and humus layer, nine intact soil cores were collected randomly in each subplot using ring knives in order to measure the soil physical characteristics. Three of these samples were used to determine soil bulk density (SBD), soil moisture-holding capacity (WC), and soil thickness (THICK). For the measurement of soil bulk density, soil cores were oven-dried at 105ºC for 24 h.

Quantitative analyses of data

To explore the relationships among current vegetation types and elevation ranges, non-metric multidimensional scaling (NMS) ordinations of herb and shrub layer data were conducted with PC-ORD software (McCune & Mefford, 1999); this process employed Bray-Curtis (Sørensen) distance. NMS ordinations for the understory data (herb and shrub layers) revealed different patterns in species composition for these layers, patterns that were independent of local current vegetation type, elevation range, or site (data not shown). Thus, the herb and shrub layers were analyzed separately in all cases.

For the characterization of understory diversity, three indices were chosen after Pielou (1969): (1) average plant richness (*S*), which measures the number of species recorded in each large plot; (2) the Shannon–Wiener diversity index (H'), where $H' = -\sum p_i \ln(p_i)$ and p_i represents the relative abundance of *i* species at each plot; and (3) the Pielou evenness index (*J*), where $J = H'/H'_{max}$, and $H'_{max} = \ln(S)$ (Pielou, 1969). The Shannon–Wiener diversity reduces the effect of rare species (Margalef, 1974; Pielou, 1975). The Pielou evenness index (*J*) compares diversity among communities. Species cover was used as a measure of relative abundance, although individual species counts were performed as well. Species exclusive to one layer and vegetation type (i.e. "exclusive species richness") was also recorded.

Two-way ANOVAs were used to analyze diversity indices for each understory layer (herb and shrub), with local current vegetation types (SP, SE and AF) and elevation ranges (low, medium and high) as principal factors (three replicates for each range and type). Complementary one-way ANOVAs comparing local vegetation types for each elevation and then comparing all elevations for each local vegetation type were also performed. The Tukey Multiple Range test ($P < 0.05$) was used to compare means in all of these analyses.

In addition, Canonical Correspondence Analysis (CCA) was conducted using CANOCO for Windows (McCune & Mefford, 1999), using ten environmental factors (OCOV, OM, HN, WC, SBD, THICK, RAK, AP, pH and SOIL) as explanatory variables. Owing to some incomplete environmental data, six AF plots were excluded from these analyses; similarly, species observed in three or fewer plots were not included in the analysis. Data were not transformed and downweighting of rare species was not applied. In the CCA analysis, the length of the environmental factor line represents the degree of correlation with vegetation, and the angle and direction of the line represents the relationship with the coordinated axis.

RESULTS

Community structure of local current vegetation types and elevation ranges: a comparison

With respect to the entire study, a total of 234 plant species belonging to 46 families and 97 genera was sampled. This total species richness was distributed homogeneously between the herb and shrub strata, with 102 species only observed in the herb layer, 98 species only found in the shrub layer and 34 species present in both layers.

Plant community composition differed in each local current vegetation type across all elevations, where canopy cover values were 89 ± 3% in SP, 76 ± 7% in SE and 34 ± 11% in AF. Understory richness was higher in SE than in SP, which in turn was higher than in AF (Table 1), with 50 species shared among the three vegetation types. Exclusive species richness in each vegetation types followed the general trend, as did total and exclusive species richness at the herb layer and total richness at the shrub layer (Table 1). Different vegetation types shared 27 species in the herb layer and 19 species in the shrub layer. However, exclusive species richness in the shrub layer was higher in SE than in AF, which was in turn higher than in SP (Table 1). Indeed, only five to 17 species were shared between herb and shrub layers in each different local vegetation types across all elevations. The dominant plants in the herb layer were *Carex baccans* Nees in SE, *Ageratina adenophora* (Spreng.) R. M. King & H. Rob. in SP, and *Neyraudia reynaudiana* (Kunth) Keng ex Hitchc. in AF. In the shrub layer, the dominant species were

Table 1. Total understory vascular plant species richness (exclusive species richness in parentheses) in the herb and shrub layers for each current vegetation type (SP: Szemao pine plantations; SE: secondary evergreen forests; AF: abandoned farmlands) and each elevation range (low, medium and high) in Yunnan Province, China.

Vegetation type	**SP**	**SE**	**AF**	**Total**
Herb layer	78 (21)	99 (44)	50 (7)	136 (102)
Shrub layer	66 (19)	83 (32)	62 (21)	132 (98)
Total	139 (31)	165 (58)	104 (21)	234
Elevation range	**Low**	**Medium**	**High**	**Total**
Herb layer	88 (35)	73 (16)	74 (18)	136 (102)
Shrub layer	79 (32)	64 (13)	80 (24)	132 (98)
Total	157 (54)	124 (20)	145 (33)	234

Eurya groffii Merr. and *Craibiodendron stellatum* W. W. Sm. in SE, *Debregeasia orientalis* C. J. Chen and *Ficus microcarpa* Blume in SP, and *Schima wallichii* (DC.) Choisy in AF (Appendix).

Plant community composition also differed in each elevation range, with the highest values found at low elevations compared to the high elevations, which both had higher plant community composition values than the medium elevations (Table 1); 65 species were shared among the three elevation ranges. Exclusive species richness in each elevation range followed the general trend, but in the herb and shrub layers, richness varied slightly from this general pattern. In the herb layer, higher total species richness as well as exclusive species richness was observed at the low elevations when compared to either the high or medium elevations (Table 1), with 32 species shared among all elevations. Conversely, in the shrub layer, higher total richness was observed at both the high and low elevations, with lower values seen at medium elevation (Table 1), and 24 species were shared across the three elevations. Higher exclusive species richness in the shrub layer was found at the low elevations when compared to the high elevations, which in turn had a higher exclusive richness than medium elevations. Only nine to 13 species were shared between herb and shrub layers on different elevation ranges when considering all vegetation types.

The plant community structure significantly varied among vegetation types for the herb and shrub layers, but did not differ greatly among elevation ranges (Table 2). In the herb layer, the two-way ANOVAs revealed significant differences among current vegetation types for average plant richness (S) and Shannon–Wiener diversity (H'), which were highest in SE and lowest in AF (Table 2). SP presented intermediate values (i.e. between the two extremes), and significant differences in the other vegetation types were not detected. In the shrub layer, only Pielou evenness (J) indices showed significant differences among the vegetation types, with SP having the higher value and the other vegetation types sharing lower values (Table 2). Since interactions among vegetation types and elevation ranges were not significant, differences for local vegetation types in the three diversity indices analyzed in this study are independent of elevation range (Table 2). However, the one-way ANOVAs also performed do highlight trends among vegetation types and elevations. In the comparison of vegetation types for each elevation (Table 3), significant differences were found only within the shrub layer. These differences were seen in evenness at low elevations and average richness at medium elevations. With respect to evenness at low elevation, the lowest values were observed in SE and the highest values in SP, with intermediate values seen in AF; for average richness at medium elevation, SE had significantly higher values than either SP or AF.

In the one-way ANOVAs comparing elevations for each vegetation type (Table 4), significant differences were found in the herb layer for average richness in SP and for evenness in SE. Both variables had the largest values at the high elevations and lowest values at the medium elevations. In the shrub layer, differences were found only with respect to evenness in SE, with values for evenness being lower at the low elevations compared to the medium or high elevations.

Table 2. Mean (± standard error) values and results of a two-way ANOVA analyzing average richness (*S*), Shannon–Wiener (*H*′) and Pielou evenness (*J*) indices of the shrub and herb layers in southwestern Yunnan Province, China, considering current vegetation type (SP: Szemao pine plantations; SE: secondary evergreen forests; AF: abandoned farmlands) and elevation range (low, medium and high) as main factors ($N = 27$). *F (P)*: *F* statistic and probability at $P < 0.05$. Values followed by different letters in each column are significantly different by Tukey Multiple Range test at $P < 0.05$.

Main factors	Herb layer			Shrub layer		
	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)
A: Local current vegetation type						
SP	19.18 ± 1.59 ab	2.30 ± 0.10 ab	0.78 ± 0.03	13.67 ± 1.29	2.53 ± 0.09	0.98 ± 0.02 b
SE	22.33 ± 2.05 b	2.46 ± 0.11 b	0.80 ± 0.03	19.44 ± 2.61	2.52 ± 0.24	0.88 ± 0.03 a
AF	14.56 ± 1.68 a	2.01 ± 0.12 a	0.76 ± 0.02	19.44 ± 2.52	2.16 ± 0.24	0.87 ± 0.03 a
F (P)	5.79 (0.012)	4.04 (0.036)	0.53 (0.598)	2.41 (0.118)	1.36 (0.282)	5.97 (0.010)
B: Elevation range						
Low	19.56 ± 2.62	2.23 ± 0.14	0.77 ± 0.01	16.33 ± 2.67	2.37 ± 0.23	0.87 ± 0.03
Medium	17.56 ± 1.69	2.14 ± 0.11	0.76 ± 0.03	13.44 ± 2.28	2.28 ± 0.23	0.91 ± 0.04
High	19.56 ± 1.86	2.38 ± 0.11	0.81 ± 0.03	16.89 ± 2.13	2.56 ± 0.17	0.93 ± 0.02
F (P)	0.49 (0.620)	1.13 (0.344)	1.40 (0.273)	0.73 (0.497)	0.59 (0.562)	0.90 (0.424)
Interaction *F (P)* **A × B**	2.31 (0.098)	0.40 (0.805)	1.11 (0.384)	1.45 (0.258)	2.76 (0.060)	2.43 (0.085)

The NMS ordination for the herb layer indicated that the greatest similarity could be found between SP and AF plots, whereas the SE plots were quite different (Fig. 1). However, all local current vegetation types were interspersed in the shrub layer, and elevation ranges were not differentially grouped.

Table 3. Mean (± standard error) values and results of a one-way ANOVA analyzing average richness (*S*), Shannon–Wiener (*H*′) and Pielou evenness (*J*) indices of the shrub and herb layers in southwestern Yunnan Province, China, considering current vegetation type (SP: Szemao pine plantations; SE: secondary evergreen forests; AF: abandoned farmlands) as the main factor ($N = 9$). *F (P)*: *F* statistic and probability at $P < 0.05$. Values followed by different letters in each column are significantly different by Tukey Multiple Range test at $P < 0.05$.

Main factors	Herb layer			Shrub layer		
	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)
For low elevations						
SP	18.33 ± 4.06	2.20 ± 0.28	0.76 ± 0.02	13.33 ± 2.96	2.47 ± 0.23	0.95 ± 0.03 b
SE	26.67 ± 4.67	2.59 ± 0.22	0.79 ± 0.02	16.00 ± 8.14	1.93 ± 0.63	0.79 ± 0.04 a
AF	13.67 ± 0.88	1.90 ± 0.07	0.79 ± 0.01	19.67 ± 0.33	2.72 ± 0.08	0.92 ± 0.02 ab
F (P)	3.34 (0.106)	2.69 (0.147)	1.46 (0.304)	0.40 (0.685)	1.06 (0.404)	7.05 (0.027)
For medium elevations						
SP	16.00 ± 2.90	2.18 ± 0.26	0.79 ± 0.08	11.00 ± 2.64 a	2.37 ± 0.46	1.00 ± 0.08
SE	22.33 ± 2.40	2.24 ± 0.22	0.72 ± 0.05	21.33 ± 2.33 b	2.86 ± 0.13	0.94 ± 0.01
AF	14.33 ± 1.53	1.99 ± 0.14	0.76 ± 0.03	8.00 ± 1.00 a	1.62 ± 0.03	0.81 ± 0.04
F (P)	3.23 (0.112)	0.38 (0.700)	0.34 (0.723)	10.92 (0.010)	5.14 (0.050)	3.06 (0.122)
For high elevations						
SP	25.00 ± 2.85	2.50 ± 0.16	0.78 ± 0.01	16.67 ± 5.13	2.75 ± 0.39	0.99 ± 0.06
SE	18.00 ± 2.08	2.54 ± 0.07	0.88 ± 0.01	21.00 ± 1.15	2.79 ± 0.07	0.91 ± 0.02
AF	15.67 ± 2.31	2.11 ± 0.24	0.78 ± 0.08	13.00 ± 3.28	2.14 ± 0.22	0.89 ± 0.01
F (P)	3.98 (0.079)	1.94 (0.224)	1.65 (0.268)	1.25 (0.351)	1.91 (0.228)	2.03 (0.212)

Table 4. Mean (± standard error) values and results of a one-way ANOVA analyzing average richness (*S*), Shannon–Wiener (*H′*) and Pielou evenness (*J*) indices of the shrub and herb layers in southwestern Yunnan Province, China, considering elevation range (low, medium and high) as the main factor (*N* = 9). *F (P)*: *F* statistic and probability at *P* < 0.05. Values followed by different letters in each column are significantly different by Tukey Multiple Range test at *P* < 0.05.

Main factors	Herb layer			Shrub layer		
	Average richness (*S*)	Shannon–Wiener (*H′*)	Evenness (*J*)	Average richness (*S*)	Shannon–Wiener (*H′*)	Evenness (*J*)
For Szemao pine plantations (SP)						
Low	18.33 ± 1.59 ab	2.20 ± 0.10	0.76 ± 0.03	13.33 ± 1.29	2.47 ± 0.09	0.95 ± 0.02
Medium	16.00 ± 2.05 a	2.18 ± 0.11	0.79 ± 0.03	11.00 ± 2.61	2.38 ± 0.24	1.00 ± 0.03
High	25.00 ± 1.68 b	2.50 ± 0.12	0.78 ± 0.02	16.67 ± 2.52	2.75 ± 0.24	0.99 ± 0.03
F (P)	7.75 (0.022)	1.14 (0.382)	0.10 (0.903)	2.05 (0.210)	1.98 (0.218)	0.63 (0.567)
For secondary evergreen forests (SE)						
Low	26.67 ± 2.62	2.58 ± 0.14	0.79 ± 0.01 ab	16.00 ± 2.67	1.93 ± 0.23	0.79 ± 0.03 a
Medium	22.33 ± 1.69	2.24 ± 0.11	0.72 ± 0.03 a	21.33 ± 2.28	2.86 ± 0.23	0.94 ± 0.04 b
High	18.00 ± 1.86	2.54 ± 0.11	0.88 ± 0.03 b	21.00 ± 2.13	2.78 ± 0.17	0.92 ± 0.02 b
F (P)	1.77 (0.249)	1.02 (0.416)	6.37 (0.033)	0.37 (0.708)	1.90 (0.230)	9.50 (0.014)
For abandoned farmlands (AF)						
Low	13.67 ± 2.62	1.90 ± 0.14	0.75 ± 0.01	8.00 ± 2.67	1.62 ± 0.23	0.81 ± 0.03
Medium	14.33 ± 1.69	1.99 ± 0.11	0.76 ± 0.03	13.00 ± 2.28	2.14 ± 0.23	0.89 ± 0.04
High	15.67 ± 1.86	2.11 ± 0.11	0.78 ± 0.03	19.67 ± 2.13	2.72 ± 0.17	0.92 ± 0.02
F (P)	0.09 (0.911)	0.19 (0.835)	0.07 (0.930)	2.44 (0.168)	2.19 (0.193)	0.84 (0.475)

Relationships among environmental factors and understory vegetation

When CCA was performed (Fig. 2), ordinations highlighted differences among elevation ranges better than among local current vegetation types for both herb and shrub layers. In the herb layer, RAK, WC and pH were the most important variables, positively correlated with axes 1 and 2. Also, low elevation plots were associated with high OCOV values and low pH and RAK values, whereas medium and high elevation plots were interspersed and related to low OCOV, high pH and high RAK values. The only significant variable with respect to understory herb variation in the plot ordination was WC ($F = 1.6$, $P = 0.04$), and this variable as well as SBD, AP, PM and SOIL were associated with internal variation at each elevation. In this CCA, the significance of all canonical axes was 0.933 ($F = 1.026$, $P = 0.404$).

In the shrub layer, CCA analysis indicated that SOIL and WC were the most important variables, both positively correlated with axis 1 (Fig. 2). The main variables correlated with axis 2 were SDB (positively correlated), and OCOV and THICK (negatively correlated). Only SOIL significantly explained the variation in the understory shrub layer ($F = 1.66$, $P = 0.05$). In this CCA, the significance of all canonical axes was 1.621 ($F = 1.336$, $P = 0.064$).

Native, rare and/or threatened species encountered

In the SE plots at all elevation ranges (except in one site), Chinese national level I- and level II-protected species were encountered. On the other hand, rare species could not be detected in the SP and AF plots, aside from a single documentation of *Cibotium barometz* (L.) J. Sm., a level II-protected species, in AF at one site of low elevation range. *Vanda coerulea* Griff. ex Lindl. (level II-protected in Yunnan Province), *Dendrobium officinale* Kimura & Migo (level II-protected), *Paramichelia baillonii* (Pierre) Hu (level II-protected), *Cyathea chinensis* Copel. (level II-protected), *Dendrobium chrysotoxum* Lindl. and *D. devonianum* Paxton (both level II-protected) were some of the native rare or threatened species seen in the SE.

DISCUSSION

Community structure of local current vegetation types

In our work, we compared the understory plant

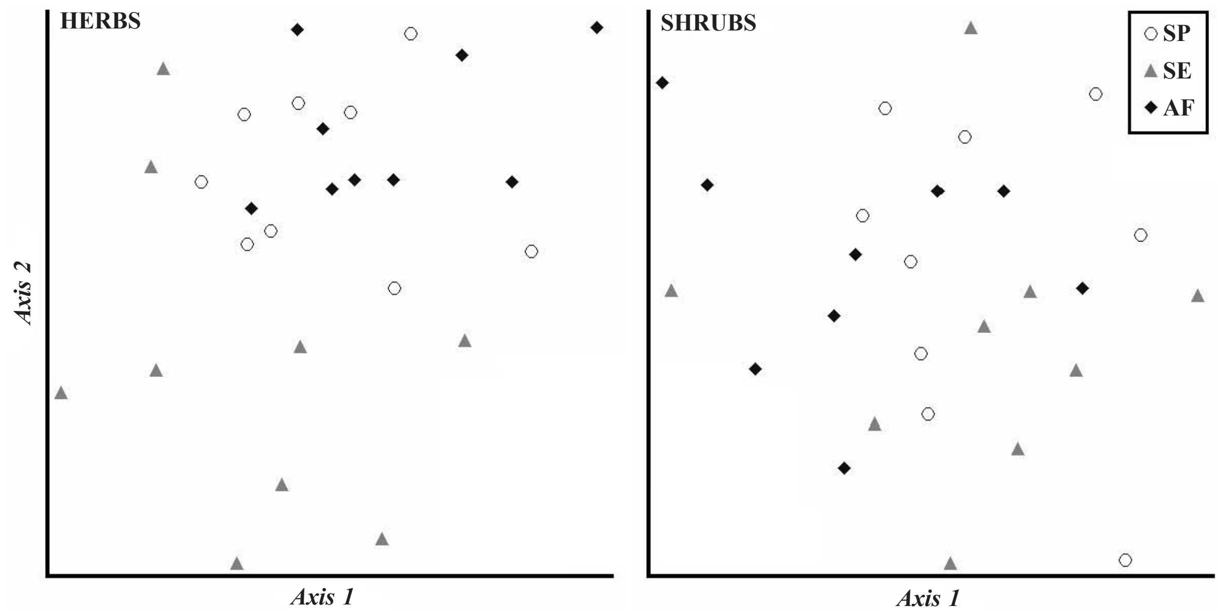

Figure 1. Non-metric multidimensional scaling (NMD) for shrub and herb layer plots in Szemao pine plantations (SP), secondary evergreen forests (SE) and abandoned farmlands (AF) over all three elevation ranges in Yunnan Province, China.

composition among the current local vegetation types usually found in this area, which could be associated with different stages of succession in these evergreen broad-leaved forests (Tang *et al.*, 2010). Despite the low number of replicates used in this study, the vegetation diversity we observed (234 species)

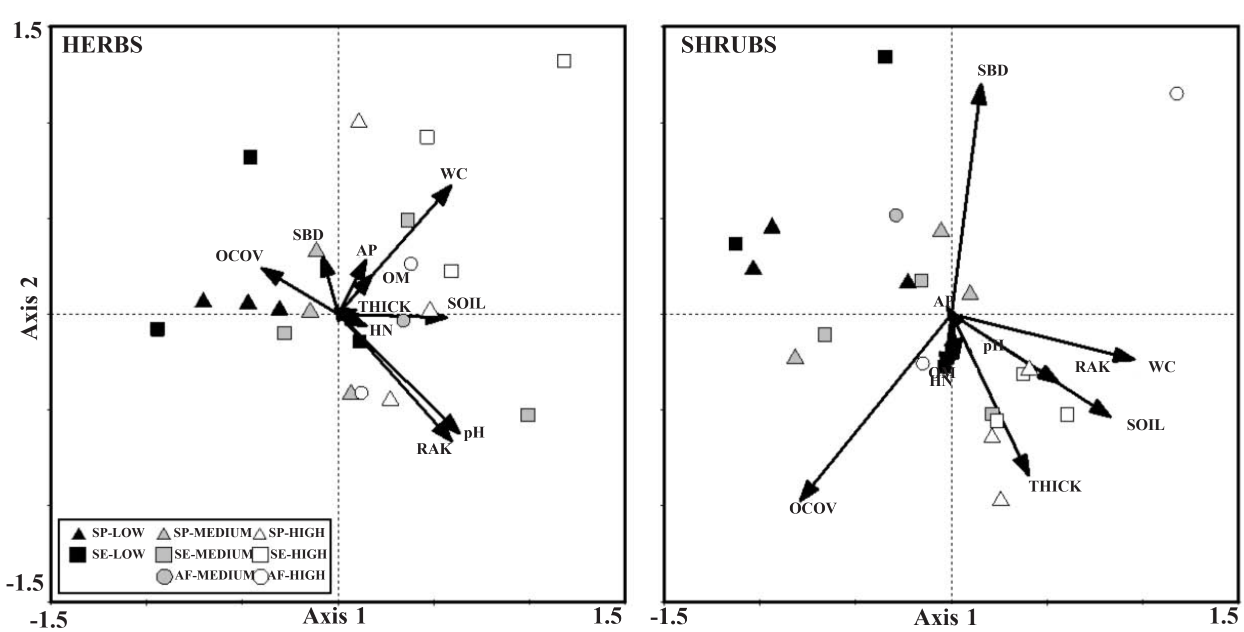

Figure 2. Canonical Correspondence Analysis (CCA) for understory vegetation (shrub and herb layers) and 10 environmental variables (OCOV: overstory coverage; OM: organic matter; HN: hydrolyzable nitrogen; WC: water content; SBD: soil bulk density; THICK: thickness of the soil; RAK: rapid available potassium; AP: available phosphorus; pH: soil acidity; SOIL: soil types). Plots were classified by current vegetation type (SP: Szemao pine plantations; SE: secondary evergreen forests; AF: abandoned farmlands) and elevation ranges (low, medium and high).

is comparable to the 222 species observed by Tang *et al.* (2010) in their studies of several vegetation types in other counties of Yunnan Province. We found differences among forest types and between layers of vegetation (shrub and herb), as was also observed by Tang *et al.* (2010) and Zhang *et al.* (2010). In our study, plant community structure of Szemao pine plantations differed from secondary evergreen forests and abandoned farmlands, and SP negatively affected the understory plant diversity that originally characterized Yunnan Province. As the biodiversity of Yunnan is high, and because very few rare or threatened species were observed in SP plots (even though they were regularly observed in the SE plots), conversion of SE to SP might be considered to be the cause behind the loss of rare or threatened species. Other authors have also observed depletion of richness in pine plantations compared to local broad-leaf forests in other regions of the world. For example, Proença *et al.* (2010) reported that 52 and 33 plant species were observed in oak forest and pine plantation, respectively.

Even though Szemao pine is a native species in Yunnan Province, SP are human-managed plantations tending to a monospecific overstory stratum in which the natural dynamic is modified for economic benefits. In plantations, Szemao pine trees had a comparative advantage over native or endemic species in our study areas, impeding the ability of native or endemic species to live in their understory (NRE, 2004; Liu *et al*., 2010). A well-developed Szemao pine tree layer in plantations resulted in less sunshine reaching the forest floor, as was evidenced by canopy cover values, which could contribute to the low average richness values obtained in the herb and shrub layer of SP compared to SE. Particularly with respect to shrubs, low diversity is usually attributed to low resource availability (Huston, 1994), because few shrub species are able to tolerate the competition with trees and herbs. Notably, the shrub layer in the SP possessed the highest evenness value in all three elevation ranges (Table 3), which can be explained by the presence of only a few species in this shrub layer, of which none was totally dominant. However, in the herb layer, the evenness index was lower in SP than in SE at the low and high elevations, which points to a lower level of diversity at these altitudes, while it was highest at the medium elevations. The lower evenness value in the herb layer compared to the shrub layer is explained by the presence of a greater number of dominant species with more significant roles. Furthermore, the absence of native rare and threatened species in the SP plots strongly indicate that Szemao pine plantations deplete the original diversity of native understory plants in Yunnan Province.

Secondary evergreen forests were the most biologically complex at the understory stratum in almost all cases, as they had the most layers, families, genera (data not shown), and species. Also, secondary evergreen forests possessed the highest values for average richness and Shannon–Wiener diversity in the herb layer at low and medium elevations, and in the shrub layer at medium and high elevations. These SE forests also had the highest evenness value in the herb layer at the low and high elevation. SE plots represent a state closer to the natural state (Wang *et al.*, 2011), because natural dynamics drive community diversity (Tang *et al.*, 2010), and also because many rare or threatened species can be found in SE. Conditions in SE are also more conducive to complex functional processes, as was observed by Liu *et al.* (2000), who found that biologically diverse natural evergreen broad-leaved forests in central Yunnan have more rapid leaf litter decomposition rates and nutrient cycling when compared with relatively less diverse fast-growing pine forests. Likewise, natural evergreen forests have better hydrological function than monospecific tree plantations (Liu *et al.*, 2003). On the other hand, secondary plant communities may act as reservoirs for recolonization and as corridors linking the remaining primary forest fragments (Tang *et al.*, 2010).

In contrast to secondary evergreen forests, understory traits in abandoned farmlands showed that they have been drastically disturbed by agricultural activities. Consequently, AF present the lowest average richness and Shannon–Wiener for all elevations in the herb layer, the lowest average richness, Shannon–Wiener and evenness indices for medium and high elevations in the shrub layer, and the greatest average richness and Shannon–Wiener diversity for low elevations in the shrub layer (Table 3). Despite the high level of disturbance, this vegetation type commonly contains rare or threatened species in their understory. In the absence of human management, we believe these areas could recover their natural dynamics, fertility, processes and diversity. Species richness and diversity significantly increase with increased time since abandonment (Zhang

& Dong 2010), so AF could potentially reach an improved biodiversity conservation value after a sufficiently long period of time.

Environmental factors affecting community structure at different elevation ranges

Our two-way ANOVA results of diversity index analyses did not show significant differences in understory diversity measures along the elevation ranges, and the one-way ANOVAs did not show great differences among elevations for each vegetation type, perhaps due to the low number of replicates. This lack of significant differences can also be explained by the shared species (half of the total SP understory richness) among the three elevation ranges. This similarity possibly exists because the difference between the maximum and the minimum elevation in this study, 1002 m, was not large enough to elicit a response in understory composition. Nonetheless, trends in understory characteristics are observed (Table 4), showing a slightly poorer composition at the medium compared to the high or low elevations in both herb and shrub layers in Szemao pine plantations, an increase in diversity with elevation in both herb and shrub layers of abandoned farmlands, and more complex patterns of diversity in secondary evergreen forests. In the SE, there was greater richness at low elevations in the herb layer and at the medium elevations in the shrub layer. More studies are necessary in order to understand the interactions between understory plant diversity and elevation.

Inclusion of other environmental factors in the comparison among local current vegetation types through the CCA analyses, such as canopy cover and soil variables, enabled understanding of the differences among the clearly grouped elevation ranges. In both the herb and shrub layers, the medium elevation range presented intermediate values for the most important correlated variables, such as rapid available potassium, water content, pH and overstory cover for the herb layer; and soil types, water content, overstory cover, soil bulk density, and thickness of the soil for shrub layer. These ordination results emphasized that soil properties are significant factors controlling the distribution of understory vegetation. Liu *et al.* (2010) similarly identified a relationship between height of Szemao pine and aspect, thickness of soil, and available phosphorous (Liu *et al.*, 2010). Positive correlations for overstory characteristics and soil properties have also been observed in other systems (Deckers *et al.*, 2004; Jiang *et al.*, 2007; Zhang & Dong, 2010). These results should be more deeply explored using a greater number of replicates.

Suggestions for diversity protection

As was suggested by Brockerhoff *et al.* (2008), we propose that the role of plantations in biodiversity conservation can be enhanced if plantations are managed as a whole with the surrounding landscape. We also suggest efforts be placed into conserving species within the plantations themselves. Therefore, in order to improve the biodiversity of Szemao pine plantations, retention of some native plant species before Szemao pine trees are planted as well as during the nursery stage, instead of clearing mountains before planting and/or mowing at the nursery stage, could be recommended as a mechanism by which to protect biodiversity. Other authors observed that a higher biodiversity and a high timber production results when Szemao pines are planted with some native species (Chen *et al.*, 2009).

Similarly, nature reserves should be initiated and protected species transplanting programs implemented before Szemao pine plantations are established in order to protect the threatened species. For example, a large number of *Vanda coerulea* (level II-protected in Yunnan Province; Zhou, 2010) were found in the dark and humid secondary evergreen forests at Baowo Village (Dapingzhang Town, Lancang County) during field work. In addition, isolated adult *Alsophila costularis* Baker (level-II protected; NRE, 2004) were occasionally found living at the edge of a forest or on the roadside. We suggest the establishment of nature reserves, as well as the transplantation of suitable rare species into local natural reserves or botanical gardens, with similar climate conditions to those found in the field, to protect local endangered species threatened by Szemao pine plantations.

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REFERENCES

Abbasi, S. A. & Vinithan, S. 1997. Ecological impacts of *Eucalyptus* – myths and realities. *Indian Forester* 123: 710-739.

Brockerhoff, E. G., Jactel, H., Parrotta, J. A., Quine, C. P. & Sayer, J. 2008. Plantation forests and biodiversity: oxymoron or opportunity? *Biodivers. & Conservation* 17: 925-951.

Brown, C. 2000. *The global outlook for future wood supply from forest plantations* (Global Forest Products Outlook Study Working Paper Series, GFPOS/WP/03). Forestry Policy and Planning Division [FAO (Food and Agriculture Organization of the United Nations)], Rome.

Chen, H.-W., Feng, X., Liu, Y.-G., Meng, M., Li, J., Tang, S.-Y. & Zhou, Y. 2009. 5种思茅松人工幼林生长及林下植物动态的研究 [Growth performance and undergrowth diversity of five types of *Pinus kesiya* var. *langbianensis* young plantations]. *J. West China For. Sci.* 38: 24-27 [in Chinese].

Deckers, B., Hermy, M. & Muys, B. 2004. Factors affecting plant species composition of hedgerows: relative importance and hierarchy. *Acta Oecol.* 26: 23-37.

Duan, W., Ren, H., Fu, S., Wang, J., Zhang, J., Yang, L. & Huang, C. 2010. Community comparison and determinant analysis of understory vegetation in six plantations in South China. *Restorat. Ecol.* 18: 206-214.

ECFRPS–CAS (Editorial Committee of Flora Reipublicae Popularis Sinicae of Chinese Academy of Sciences) 1978. [*Flora Reipublicae Popularis Sinicae* 7]. Science Press, Beijing [In Chinese].

FAO (Food and Agriculture Organization of the United Nations) 2006. *Global forest resources assessment 2005 – Progress towards sustainable forest management* (FAO Forestry Paper, 147). FAO, Rome.

Geldenhuys, C. J. 1997. Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa. *Forest. Ecol. Managem.* 99: 101-115.

Gilliam, F. S. 2007. The ecological significance of the herbaceous layer in temperate forest ecosystems. *BioScience* 57: 845-858.

Harrington, R. A. & Ewel, J. J. 1997. Invasibility of tree plantations by native and non-indigenous plant species in Hawaii. *Forest. Ecol. Managem.* 99: 153-162.

Huston, M. A. 1994. *Biological diversity – The coexistence of species on changing landscapes.* Cambridge University Press, New York.

IFS (International Foundation for Science) 1989. *Trees for development in Sub-Saharan Africa. Proceedings of a regional seminar held by the International Foundation for Science (IFS). ICRAF House, Nairobi, Kenya, February 20-25, 1989*. IFS, Stockholm.

ISS–CAS (Institute of Soil Science, Chinese Academy of Sciences) 1978. [*Soil physical and chemical analysis*]. Shanghai Science & Technology Press of China, Shanghai [in Chinese].

Jiang, Y., Kang, M., Zhu, Y. & Xu, G. 2007. Plant biodiversity patterns on Helan Mountain, China. *Acta Oecol.* 32: 125-133.

Li, Q., Chen, Y., Wang, S., Zheng, Y., Zhu, Y. & Wang, S. 2009. 普洱市亚热带季风常绿阔叶林区蚂蚁多样性 [Diversity of ants in subtropical evergreen broadleaved forest in Pu'er City, Yunnan]. *Biodivers. Sci.* 17: 233-239 [in Chinese].

Li, W.-C. 2000. 世界森林资源保护及中国林业发展对策分析 [Analysis on world's forest resources protection and China's forestry development policies]. *Resources Sci.* 22: 71-76 [in Chinese].

Liu, S. R., Sun, P. S. & Wen, Y. G. 2003. Comparative analysis of hydrological functions of major forest ecosystems in China. *Acta Phytoecol. Sin.* 27: 116-122.

Liu, W.-Y., Liu, L.-H., Jing, G.-F. & He, A.-J. 2000. 云南松林与常绿阔叶林中枯落叶分解研究 [Decomposition of leaf litter in *Pinus yunnanensis* forest and evergreen broad-leaved forest in central Yunnan]. *Acta Bot. Yunnan*. 22: 298-306 [in Chinese].

Liu, X., Su, J. & Shi, L. 2010. 思茅松人工林生长与立地条件的关系研究 [Relation between growth increments of *Pinus kesiya* var. *langbianensis* and site conditions]. *Chin. Agric. Sci. Bull.* 26: 142-145 [In Chinese].

Loumeto, J. J. & Huttel, C. 1997. Understory vegetation in fast-growing tree plantations on savanna soils in Congo. *Forest. Ecol. Managem.* 99: 65-81.

Margalef, R. 1974. *Ecología*. Omega, Barcelona.

McCune, B. & Mefford, M. J. 1999. *PC-ORD. Multivariate analysis of ecological data, version 4.0*. MjM Software Design, Gleneden Beach.

Mittermeier, R. A., Robles Gil, P., Hoffman, M. *et al*. 2005. *Hotspots revisited: Earth's biologically richest and most endangered terrestrial ecoregions*. CEMEX, Mexico City.

NRE (Natural Reserve of China) 2004. 国家重点保护野生植物名录（第一批） [Database of national key protected wild plant species (first batch)]. Retrieved July 19, 2010, from http://www.nre.cn/htm/04/bhqsj/2004-07-10-12808.htm [in Chinese].

Olsen, S. R., Cole, C. V., Watanabe, F. S. & Dean, L. A. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (US Department of Agriculture Circular, 939). US Government. Printing Office, Washington.

Pielou, E. C. 1969. *An introduction to mathematical ecology*. Wiley, New York.

Pielou, E. C. 1975. *Mathematical ecology*. Wiley, New York.

Poore, M. E. D. & Fries, C. 1985. *The ecological effects of* Eucalyptus (FAO Forestry Paper, 59). FAO (Food and Agriculture Organization of the United Nations), Rome.

Proença, V. M., Pereira, H. M., Guilherme, J. & Vicente, L. 2010. Plant and bird diversity in natural forests and in native and exotic plantations in NW Portugal. *Acta Oecol.* 36: 219-226.

SCA (Standing Committee of Analysts) 1987. *Methods for the determination of metals in soils, sediments and sewage sludge and plants by hydrochloric-nitric acid digestion, with a note on the determination of the insoluble metal contents 1986.* Her Majesty's Stationary Office, London.

Shiva, V. & Bandyopadhyay, J. 1983. *Eucalyptus* – a disastrous tree for India. *Ecologist* 13: 184-187.

Shiva, V., Sharatchandra, H. C. & Bandyopadhyay, J. 1982. Social forestry – no solution within the market. *Ecologist* 12: 158-168.

Spyreas, G. & Matthews, J. W. 2006. Floristic conservation value, nested understory floras, and the development of second-growth forest. *Ecol. Applic.* 16: 1351-1366.

Standford, S. & English, L. 1949. Use of flame photometer in rapid soil tests for K and Ca. *Agron. J.* 41: 446-447.

Tang, C. Q., Hou, X., Gao, K., Xia, T., Duan, C. & Fu, D. 2007. Man-made versus natural forests in mid-Yunnan, Southwestern China: plant diversity and initial data on water and soil conservation. *Mountain Res. Developm*. 27: 242-249.

Tang, C. Q., Li, Y.-H. & Zhang, Z.-Y. 2010. Species diversity patterns in natural secondary plant communities and man-made forests in a subtropical mountainous karst area, Yunnan, SW China. *Mountain Res. Developm*. 30: 244-251.

Wang, H.-F., Lencinas, M. V. , Ross Friedman C., Wang, X.-K. & Qiu J.-X. 2011. Understory plant diversity assessment of *Eucalyptus* plantations over three vegetation types in Yunnan, China. *New Forests* 42: 101-116.

Wen, Y., Ye, D., Chen, F., Liu, S. & Liang, H. 2010. The changes of understory plant diversity in continuous cropping system of *Eucalyptus plantations*, South China. *J. Forest Res.* 15: 252-258.

Wikramanayake, E. D., Dinerstein, E., Loucks, C. *et al*. 2001. *Terrestrial ecoregions of the Indo-Pacific: A conservation assessment*. Island Press, Washington.

Wu, Z. 1994. 思茅松研究现状的探讨 [A review of the research status of *Pinus kesiya* var. *langbianensis* in southwestern China]. *Sci. Silvae Sin.* 30: 151-157 [In Chinese].

Zha, G.-S. 2003. 云南省飞播造林回顾与展望 [Review and prospect of aircraft seed in Yunnan Province]. *J. Mt. Agric. Biol.* 22: 151-154 [In Chinese].

Zhang, C., Xie, G., Fan, S. & Zhen, L. 2010. Variation in vegetation structure and soil properties, and the relation between understory plants and environmental variables under different *Phyllostachys pubescens* forests in southeastern China. *Environm. Managem.* 45: 779-792.

Zhang, J.-T. & Dong, Y. 2010. Factors affecting species diversity of plant communities and the restoration process in the loess area of China. *Ecol. Eng.* 36: 345-350.

Zhou, B. 2010. 云南省第一批省级重点保护野生植物名录修订 [Revising the Yunnan Key Protected Wild Plants List]. *Acta Bot. Yunnan.* 32: 221-226 [in Chinese].

Appendix. Tree, shrub and herb layer species for secondary evergreen forests, Szemao pine plantations, and abandoned farmlands over all elevations in southwestern Yunnan Province, China.

Secondary evergreen forests (SE)[a]	**Szemao pine plantations (SP)**	**Abandoned farmlands (AF)**
Tree layer		
Craibiodendron stellatum (Pierre) W. W. Sm.	*Pinus kesiya* Royle ex Gordon var. *langbianensis*	
Viburnum cylindricum Buch.-Ham. ex D. Don	(A. Chev.) Silba	
Castanopsis argyrophylla King ex Hook. f.		
Lindera thomsonii C. K. Allen		
Castanopsis hystrix Hook. f. & Thomson ex A. DC.		
Helicia shweliensis W. W. Sm.		
Adinandra millettii (Hook. & Arn.) Benth. & Hook.		
f. ex Hance		
Lithocarpus fenestratus (Roxb.) Rehder		
Castanopsis calathiformis (Skan) Rehder & E. H. Wilson		
Myrica esculenta Buch.-Ham.& D. Don		
Vaccinium bracteatum Thunb.		
Aporosa dioica (Roxb.) Müll. Arg.		
Decaspermum fruticosum J. R. Forst. & G. Forst.		
Pyrus betulifolia Bunge		
Rhus chinensis Mill.		
Antidesma bunius (L.) Spreng		
Diospyros strigosa Hemsl.		
Lithocarpus hancei (Benth.) Rehder		
Alnus nepalensis D. Don		
Ternstroemia gymnanthera (Wight & Arn.) Sprague		
Wendlandia uvariifolia Hance		
Syzygium szemaoense Merr. & L. M. Perry		
Phyllanthus emblica L.		
Photinia serrulata Lindl.		
Engelhardtia spicata Lechen ex Blume		
Shrub layer		
Eurya groffii Merr.	*Maesa japonica* (Thunb.) Moritzi & Zoll.	*Schima wallichii* (DC.) Korth.
Craibiodendron stellatum (Pierre) W. W. Sm.	*Glochidion lanceolarium* (Roxb.) Voigt	*Betula alnoides* Buch.-Ham. ex D. Don
Castanopsis argyrophylla King ex Hook. f.		*Adinandra millettii* (Hook. & Arn.) Benth. & Hook.
Lindera thomsonii C. K. Allen		f. ex Hance
Castanopsis hystrix Hook. f. & Thomson ex A. DC.		*Cinnamomum tamala* (Buch.-Ham.) T. Nees & Nees
Aporosa dioica (Roxb.) Müll. Arg.		*Pittosporum tobira* (Thunb.) W. T. Aiton
Viburnum cylindricum Buch.-Ham. ex D. Don		*Litsea pungens* Hemsl.
Antidesma bunius (L.) Spreng.		*Albizia julibrissin* Durazz.
Rhus chinensis Mill.		*Maesa japonica* (Thunb.) Moritzi & Zoll.
Turpinia montana (Blume) Kurz		*Toxicodendron succedaneum* (L.) Kuntze
		Decaspermum fruticosum J. R. Forst & G. Forst.

Secondary evergreen forests (SE)[a]	Szemao pine plantations (SP)	Abandoned farmlands (AF)
Engelhardtia spicata Lechen ex Blume		*Wendlandia uvariifolia* Hance
Litsea pungens Hemsl.		*Pygeum topengii* Merr.
Sladenia celastrifolia Kurz		*Macaranga denticulata* (Blume) Müll. Arg.
Vaccinium bracteatum Thunb.		*Ficus tinctoria* G. Forst.
Anneslea fragrans Wall.		*Rhus chinensis* Mill.
Castanopsis calathiformis (Skan) Rehder & E. H. Wilson		*Ficus tinctoria* subsp. *gibbosa* (Blume) Corner
Melastoma affine D. Don		*Litsea lancifolia* (Roxb. & Nees) Benth. & Hook f. & Fern.-Vill.
Myrica esculenta Buch.-Ham. ex D. Don		*Schefflera octophylla* (Lour.) Harms
Jasminum L. spp.		
Cayratia japonica (Thunb.) Gagnep.		
Helicia shweliensis W. W. Sm.		
Diospyros strigosa Hemsl.		
Ternstroemia gymnanthera Sprague		
Rubiaceae Juss. spp.		
Herb layer		
Carex baccans Nees	*Eupatorium adenophorum* Spreng.	*Neyraudia reynaudiana* (Kunth) Keng ex Hitchc.
Callipteris esculenta (Retz.) J. Sm. ex T. Moore	*Cyrtomium fortunei* J. Sm.	*Carex baccans* Nees
& Houlston var. *pubescens* (Link) Ching	*Arthraxon hispidus* (Thunb.) Makino	*Melastoma malabathricum* L.
Polygonatum sibiricum Redouté	Apiaceae Lindl. spp.	*Eupatorium odoratum* L.
Vernonia esculenta Hemsl.	*Artemisia carvifoli*a Buch.-Ham. ex Roxb.	*Mussaenda pubescens* W. T. Aiton
Eupatorium adenophorum Spreng.	*Fragaria* L. spp.	*Erigeron acris* L.
Microstegium ciliatum (Trin.) A. Camus	*Stellaria media* (L.) Cirillo	*Stephania tetrandra* S. Moore
Imperata cylindrica (L.) P. Beauv.	*Amorphophallus variabilis* Blume	*Urena lobata* L.
Cleidion brevipetiolatum Pax & K. Hoffm.	*Cleidion brevipetiolatum* Pax & K. Hoffm.	*Ageratum conyzoides* L.
Poa pratensis L.	*Microstegium ciliatum* (Trin.) A. Camus	*Eupatorium adenophorum* Spreng.
Artemisia japonica Thunb.	*Rostellularia procumbens* (L.) Nees	*Tadehagi triquetrum* (L.) H. Ohashi
Gonostegia hirta (Blume) Miq.	*Sida szechuensis* Matsuda	
Elsholtzia ciliata (Thunb.) Hyl.	*Epipremnum aureum* (Linden & André) G. S. Bunting	
	Lobelia clavata E. Wimm.	
	Polygonatum sibiricum Redouté	
	Docynia delavayi (Franch.) C. K. Schneid.	
	Melastoma malabathricum L.	
	Carex baccans Nees	
	Gonostegia hirta (Blume) Miq.	
	Plantago asiatica L.	
	Ainsliaea DC. spp.	
	Dichrocephala auriculata (Thunb.) Druce	
	Leonurus artemisia (Lour.) S. Y. Hu	
	Turpinia pomifera (Roxb.) DC.	
	Fagopyrum leptopodum (Diels) Hedberg	

[a] Only the top 25 species with the highest importance value are shown.