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Understory plant diversity assessment of *Eucalyptus* plantations over three vegetation types in Yunnan, China

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Abstract Biodiversity in managed plantations has become an important issue for long-term sustainability of ecosystems. The environmental effects of plantations comprised of fast-growing introduced trees have been vigorously debated. On one hand, monocultures have been said to exhaust resources, resulting in decreased biodiversity. Conversely, it has been stated that monocultures may favor regeneration of undergrowth plants from surrounding forests, increasing biodiversity. In order to clarify the effects of planting *Eucalyptus* trees on species composition, diversity, and functional type of understory vegetation in Yunnan province, a field trial was implemented to compare *Eucalyptus* plantations (EPs) with two other local current vegetation types (secondary evergreen forests (SEs), and abandoned farmlands (AFs)). Each vegetation type was sampled in each of three elevational ranges (low = 1,000–1,400 meters above sea level (masl), medium = 1,400–1,800 masl, and high = 1,800–2,200 masl). Sample sites within each elevational range had similar environmental characteristics (slope, aspect, etc.). Thus, we sampled three vegetation types at each of three sites at each of three elevations for a total of 27 plots. We calculated relative abundance and importance value of species and diversity indexes to evaluate differences among local current vegetation types and elevational ranges, employing multivariate ordination analyses and other methods such as Analyses of Variance (ANOVA) and Indicator Species Analysis. We found that fast growing introduced *Eucalyptus* plantations led to reduced plant diversity in the study area, and that rare or

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threatened species were recorded almost exclusively in the SE plots, being essentially absent from the EP and AF plots. The understory plant diversity did not correlate with the altitude gradient significantly. *Eucalyptus* plantations (EPs) have a simpler community structure than that of either secondary evergreen forests (SEs; similar to natural state) or abandoned farmlands (AFs). No variable significantly explained variation of the understory shrub layer, but soil moisture-holding capacity and overstory coverage were significant in explaining variation of the understory herb layer, suggesting that the study of soil physical properties is necessary for better understanding of their importance in *Eucalyptus* plantations and other local current vegetation types.

Keywords Understory · *Eucalyptus* plantation · Secondary evergreen forests · Abandoned farmland · Plant diversity · Assessment

Introduction

Due to a large demand for wood products, *Eucalyptus* trees are widely planted in tropical and subtropical China (Boland et al. 1984). China, with more than 2.0 million ha of *Eucalyptus* plantations, has one of the largest areas of *Eucalyptus* plantations in the world (Wen 2008). Here, the area of *Eucalyptus* plantations in Yunnan province is large; e.g., at the end of 2008, *Eucalyptus* plantations (EPs) occupied 42,350 and 19,680 ha in Pu'er city and the Wenshan state of Yunnan province, respectively. *Eucalyptus* is not native to these regions. Given the ongoing global expansion of plantations, biodiversity enhancement has attracted worldwide attention (FAO 2005). Interestingly, understory vegetation of the plantations, which plays an important role in plant diversity, rarely has been examined properly. Understory plants make substantial contributions to overall species diversity in plantations because many species are restricted to this layer and others must pass through it during their seedling stages (Ramovs and Roberts 2003; Taverna et al. 2005).

It has been debated internationally whether the fast-growing *Eucalyptus* plantations cause local biodiversity to increase or decrease (e.g., IFS 1989; Tang et al. 2007). Some argue that such monocultures decrease local biodiversity; e.g., only eight bird species were recorded in *Eucalyptus* plantations in Brazil, which may be a result of intensive clearance of understory vegetation (Stuart et al. 2001). Also, soil fauna is impoverished in *Eucalyptus* plantations compared to mixed forests (Liao and Chen 1990). Bargali et al. (1993) reported that EPs have led to reduced biodiversity and soil degradation in subtropical areas of the central Himalayas. Likewise, Liu et al. (2000) found that biologically diverse natural evergreen broad-leaved forests in central Yunnan have more rapid leaf litter decomposition rates and nutrient cycling than that of fast-growing pine forests. Both natural forests and mixed stands had better hydrological function than monospecific tree plantations (Liu et al. 2003). Large amounts of nutrients were lost from fast-growing monoculture plantations through timber harvesting (Merino et al. 2003, 2005). Proença et al. (2010) reported that 28 plant species were observed in eucalypt plantation, while 52 and 33 were observed in oak forest and pine plantation, respectively. These authors also found that forest bird richness and diversity were higher in both oak and pine forests than in eucalypt forest. These results suggested that forest species patterns might be affected by forest management. To compare the understory vegetation and analyze its determinant factors, Duan et al. (2010) found that native species plantations shaded out more grasses and herbs than *Eucalyptus* plantations. They pointed out that soil nutrients and soil moisture had important effects on understory community diversity.

In contrast, some studies have found that fast-growing tree plantations, including those comprised solely of eucalypts, favor regeneration of undergrowth plants from surrounding forests, thus increasing biodiversity and fertility (Geldenhuys 1997; Harrington and Ewel 1997; Loumeto and Huttel 1997). Peng (2003) reported that artificial rehabilitation (e.g., planting some native species) could accelerate the restoration process on degraded land in China. Other studies in many countries have documented that plantation forests can provide habitat for a wide range of native species, including plants, animals, and fungi (Barbaro et al. 2005; Carnus et al. 2006). As more targeted surveys are undertaken, uncommon and threatened species are increasingly recorded in plantations. Brockerhoff et al. (2008) reported that there is abundant evidence that plantation forests can provide valuable habitat, even for some threatened species, and may contribute to the conservation of biodiversity by various mechanisms, such as habitat supplementation or complementation to forest species, connectivity, and buffering effects.

Reports on the effects of *Eucalyptus* plantation on floristic diversity and species composition of local current vegetation are rare. In this study, we selected three typical local current vegetation types, including secondary evergreen forests (similar to native forest), *Eucalyptus robusta* plantations, and abandoned farmlands. We then performed field surveys of understory species over an elevational gradient to assess: (1) the differences in understory vegetation among three vegetation types; and, (2) environmental factors that affect the composition and structure of understory vegetation. Our work contributes to a better understanding of how biodiversity in *Eucalyptus* plantations and other vegetation types might be enhanced.

Material and methods

Study area

Pu'er, a prefecture, is located in southwestern Yunnan province, China, adjacent to Myanmar in the southern section of Hengduan Mountains, and occupies 4,538,500 ha. Yunnan's landscape is mostly mountainous. Mean annual temperature is 18.9°C and annual precipitation was 1,502 mm in 2009. The area has a characteristic monsoon seasonality in which summers are wet and winters are dry. Vegetation in this area is dominated by monsoon evergreen broad-leaved forest; however, some tropical plant species are also found in the area between 0 and 700 meters above sea level (masl), and some moisture-loving broad-leaf plant species are found in more than above 1,400 masl. We conducted our study in the three southwestern counties of Pu'er: Lancang, Menglian, and Ximeng.

Pu'er is home to many well-known economically and ecologically important trees, plants, and animals. Hundreds of timber species have been recorded, such as ceylon ironwood (*Mesua ferrea*), purple teak (*Tectona grandis*), camphor (*Cinnamomum camphora*), *Toona ciliate*, and *Trigonobalanus doichangensis*, among many other rare species (Li et al. 2009). Over a hundred species of animals are expressly protected by state-level agency, including leopard (*Pantherauncia schreber*), slow lori (*Nycticebus coucang*), gibbon (*Hylobates leucogenys*), indian python (*Python molurus*), monocled cobra (*Naja kaouthia*), malayan pangolin (*Manis pentadactyla*), peacocks (*Pavo muticus*), and silver pheasant (*Lophura nycthemera*). More than 2,000 herbal components of Chinese medicine, including *Paris quadrifolia*, wild notoginseng (*Panax stipuleanatus*), and *Polygonum* *multiflorum* are native to the region. In addition, the region has many centuries old trees, including cypresses (*Platycladus orientalis*) and tea trees (*Melaleuca alternifolia*).

Sampling methods

In December 2008 and May 2009, we selected three ranges of elevation in Lancang, Menglian, and Ximeng counties of Pu'er: low (1,000–1,400 masl), medium (1,400–1,800 masl), and high (1,800–2,200 masl). Using satellite images, local relief maps, and ground truthing with global positioning, we identified three sites in each elevational range. Each site encompassed three major local current vegetation types (Fig. 1, Table 1). (1) Five to seven year old *Eucalyptus* (*Eucalyptus robusta*) plantations (EPs) that were established on lands where secondary evergreen forest was cut. EP undergo tillage and herbicide treatments; the *Eucalyptus* species are not native to the local forest communities. (2) Ten-year old secondary evergreen forests (SEs), which have become established on lands originally occupied by primeval forests. As a result of long-time logging, man-made destruction, grazing and fire, most adult trees have disappeared; only young trees and shrubs remain to represent the current secondary evergreen forests, which naturally regenerate after timber harvest. (3) Six-year-old abandoned farmlands (AF). Initially, local farmers cut a large area of forest and burn the cut vegetation for farm fertilizers. Following this, farmers plant corn, sugar cane or upland rice on the burned lands. After years of farming, the soil becomes barren and the production of agricultural crops becomes reduced, so the farmers abandon the land and search for another high-production land in the same way. During farming, the land is tilled and treated with herbicides. The distance between the sampling sites in the

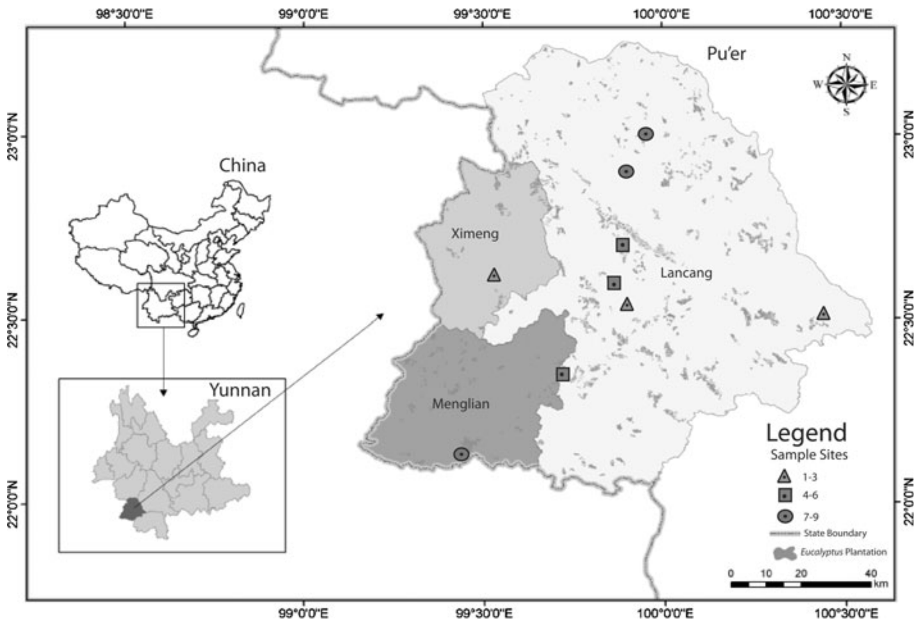

Fig. 1 Location of the nine sampling sites in Pu'er prefecture, Yunnan province, China, where three counties are illustrated: Ximeng, Menglian, and Lancang. See the legend on the *lower right* of the figure for further details

Table 1 Location and general description of the nine sample sites in southwestern Yunnan province, China

Site	Prevalent plant community	Type of soil	Soil texture	Slope and aspect	Elevation (masl)	Longitude	Latitude
(1) Mengbin village, Menglang town, Lancang county (MB)	Secondary evergreen broad-leaved forest	Lateritic red	Light clay	15°—NW37°	1 068	99°53′55.2″	22°32′17.7″
(2) Baowo village, Dapingzhang town, Lancang county (BW)	Secondary evergreen broad-leaved forest	Lateritic red	Loam soil	27°—S	1 179	99°51′39.2″	22°35′57.0″
(3) Mengsuo town, Ximeng county (MS)	Secondary evergreen broad-leaved forest	Lateritic red	Loam soil	15°—W	1 212	99°31′34.6″	22°31′50.2″
(4) Xiangshuihe village, Nuozhadu town, Lancang county (XS)	Secondary evergreen broad-leaved forest	Lateritic red	Loam soil	30°—NW156°	1 505	100°26′42.7″	22°30′47.2″
(5) Nanweng village, Donghui town, Lancang county (NW)	Secondary evergreen broad-leaved forest	Red	Loam soil	13°—SE53°	1 588	99°43′07.3″	22°21′21.6″
(6) Panzhihua village, Zhutang town, Lancang county (PZ)	Secondary evergreen broad-leaved forest	Lateritic red	Middle loam soil	20°—NE37°	1 710	99°53′22.7″	22°42′35.1″
(7) Mengma village, Menglian county (MM)	Coniferous and broad-leaved mixed forest	Red	Middle loam soil	22°—N	1 847	99°26′07.0″	22°08′50.4″
(8) Fubang town, Lancang county (FB)	Coniferous and broad-leaved mixed forest	Red	Loam soil	6°—SW89°	1 995	99°53′46.7″	22°54′36.8″
(9) Donghe town, Lancang county (DH)	Coniferous and broad-leaved mixed forest	Yellow brown	Light clay	25°—W	2 070	99°57′08.1″	23°00′38.7″

three local current vegetation types is less than 1 km, and the sites had similar environmental characteristics (e.g., slope, aspects, etc.).

In each site, three "large" 20 × 20 m plots were established for each local current vegetation type (SE, EP, and AF). While the projected area is 20 × 20 m, the actual investigated area was 400 m^2/cos α, α is the angle of slope. Thus, we sampled three vegetation types at each of three sites at three different elevations for a total of 27 large plots. To minimize edge effects, all large plots were located at least 100 m away from the edge of each vegetation patch.

Floristic surveys for the overstory tree layer were carried out in large plots; trees were defined as woody species having a diameter at 1.30 m height (i.e., diameter at breast height, DBH) of more than 2 cm. In tree layer, species were identified and the number of individuals for each species was recorded considering clones as only one individual, and then the relative density per species was obtained. We used a frequency estimation method to estimate the overstory coverage (OCOV) for the entire large plot; that is, we estimated the percentage of the projected shadow area in five random "small" 5 × 5 m subplots within the tree layer, then combined the data.

Floristic surveys for the understory vegetation, differentiated as shrub layer, interlayer, and herbaceous layer, were carried out in five "small" 5 × 5 m subplots for shrub species and 1 × 1 m subplots for herb species in each large plot (one subplot in the center and the other four on each corner of each large plot); the combined data for the five small subplots were used to characterize each large plot. Shrubs were defined as woody species with a DBH less than 2 cm, while interlayer species were characterized as those living above herbs, but below the shrub layer (e.g., lianas). We also categorized and enumerated genera and families represented in each plot, and noted rare or threatened species. We used categorization of species following the Chinese National Forest Bureau (YNCC 2009), considering a species as "level II-protected" if it is in some need of protection, and "level I-protected" if it is in greatest need of protection. In the understory layers (shrub and herb), species were identified and number of individuals for each species was recorded in each subplot. These data were used to calculate relative abundance (density) for quantitative analysis. Again, clonal units were recorded as a single individual.

In the five small subplots of each vegetation type, five per subplot (for a total of 25) of soil were collected using a 5-cm-diameter soil corer inserted to a depth of 20 cm and combined into a composite sample of about 1 kg. These soil samples were air-dried and sieved for analysis of soil chemical characteristics, where pH, percentage of organic matter (OM), hydolyzable nitrogen in mg kg^{-1} (HN), available phosphorus in mg kg^{-1} (AP) and rapid available potassium in mg kg^{-1} (RAK) were measured (Standford and English 1949; Olsen et al. 1954; Institute of Soil Science, CAS 1978; MEWAM 1986). To measure the soil physical characteristics, nine intact soil cores were collected randomly in each subplot using ring knives after removing the litter and humus layer. Three of these samples were used to determine soil bulk density (SBD), soil moisture-holding capacity (WC), and soil thickness (THICK). Soil cores for soil bulk density were oven-dried at 105°C for 24 h. The OCOV was used to estimate light intensity for the understory plant species. Soil types (SOIL) for each site (Table 1) were used as a "dummy" variable (1 = latheritic red, 2 = red and 3 = yellow brown) to test the influence of soil type differences.

Data analyses

We calculated relative abundance (density expressed as individuals/ha), frequency, dominance, and importance value of each tree species across all large plots of the same local current vegetation type (SE, EP, or AF) over all elevational ranges. As the tree layer was monospecific in EP sites and devoid of tree species in AF, and as the interlayer data in all cases did not have enough species to enable valid statistical inferences, further data analyses and index calculations were conducted primarily on shrub and herb layer data.

For characterization of diversity, three indices were chosen according to Pielou (1969): (1) Plant richness (*S*), represented by number of species recorded in each large plot; (2) Shannon–Wiener diversity index $H' = -\sum p_i \ln p_i$, where p_i is relative abundance of *i* species at each plot; and (3) Pielou Evenness index $J = H'/H'_{\max}$, where $H'_{\max} = \ln(S)$. The Shannon–Wiener diversity index (H') was used as a synthetic measure of community structure, as it reduces the effect of rare species (Margalef 1974; Pielou 1975). The Pielou Evenness index (*J*) was selected to quantify community similarity. We count the individuals to measure the relative abundance,

In each layer (again, only the shrub and herb), richness, Shannon–Wiener diversity, and evenness were analyzed by two-way ANOVA, with local current vegetation types (SE, EP, and AF) and elevational ranges (low, medium and high) as principal factors, and with three replicates for each range and type. Mean comparisons were done by Tukey Multiple Range test ($P < 0.05$).

The ordination software PC-ORD (McCune and Mefford 1999) was used to conduct non-metric multidimensional scaling (NMS) ordinations of our shrub and herb layer data to examine the relationships among our vegetation types and elevation ranges. Bray-Curtis (Sørensen) distance measure was used. Then, permutational multivariate ANOVA (PERMANOVA, Anderson 2001, 2005) and permutational test of multivariate dispersion (PERMDISP, Anderson 2004) were conducted to test effects for local current vegetation type, elevational range, and their interaction on shrub and herb composition data. These PERMANOVA and PERMDISP analyses were conducted on relative abundance data (i.e. we used the number of each species as the measure of relative abundance) using Bray-Curtis distances and 9,999 unrestricted random permutations of the raw data. Local current vegetation type and elevational range were considered fixed effects. Also, Canonical Correspondence Analyses (CCA) were conducted using CANOCO for Windows (McCune and Mefford 1999), excluding species observed in three or fewer plots. Also, six AF plots were excluded (BW, MB, MM, MS, NW and PZ sites) from these analyses, because incomplete environmental data were available. Square root transformation of data was used, without "downweighting" rare species.

Indicator Species Analysis (Dufrêne and Legendre 1997) was used to examine whether any of the common species had significant indicator values (IndVals) for any one of the three local current vegetation types. A random reallocation procedure with 1,000 permutations was used to test for the significance of IndVals. We used a subjective benchmark value for IndVal of >0.7 (i.e., 70% when expressed as a percentage) as a defining characteristic indicator for the habitats in question (McGeogh et al. 2002; Nakamura et al. 2007). Indicator Species Analyses were conducted by using the *t* "duleg" function of the "labdsv" package of R language (Roberts 2007; R Development Core Team 2009).

Results

Comparison of community structure among local current vegetation types

A total of 97 families, 189 genera and 357 species were sampled, with 103 tree species found in the tree layer, 85 species in the shrub layer, 6 species in the interlayer, and 163 species in the herb layer. The plant community structure varied among vegetation types. Community structure of EPs was simpler than that of SEs, because only tall *Eucalyptus* trees were found in the tree layer of EPs, with fewer interlayer species. In addition, the EP herb layer was mainly dominated by *Eupatorium odoratum* and *E. adenophorum*, whose coverage reached up to 70% in EPs, and only some shrub species such as *Maesa japonica* were occasionally found in the herb layer. Compared with EPs, more shrub species (e.g. *Eurya groffi*) and interlayer species (e.g. *Smilax china*) were found in SEs. The tree layers are usually divided into upper and lower levels in SEs, taller growing species (e.g. *Lithocarpus fenestratus*) were usually found in their upper levels while lower levels were usually dominated by shorter growing species (e.g. *Craibiodendron stellatum* and *Viburnum cylindricum*). The number of species in the herb layer was less than in other layers (tree and shrub) in SEs. There is an absence of tree layers in AFs, although some lower shrub (e.g. *Schima wallichii*) in shrub layer and herb species (e.g. *Neyraudia reynaudiana*) in herb layer were found there.

Across all elevations and layers, predominant species in SE plots mainly belonged to four families (Ericaceae, Fagaceae, Lauraceae and Theaceae): key species were *Lithocarpus fenestratus* (Fagaceae), *Craibiodendron stellatum* (Ericaceae), and *Eurya groffi* (Theaceae). However, in EP and SP plots, *Eupatorium adenophorum* and/or *E. odoratum* (Asteraceae) dominated species composition at all elevations, occupying as much as 80% cover. In AF plots, species composition was highly variable amongst different plots, although *Neyraudia reynaudiana* was a common element in the herb layer.

The total species number in the three local current vegetation types was greatest in SE (270 species, the same as below), lower in EP (135 species), and lowest in AF (105 species). In the tree layer, differences among local current vegetation types were obvious, as there was a variety of species (52 families and 106 genera) in SE, but no tree species in AF, and only *Eucalyptus robusta* in EPs. Species number of shrub and interlayer followed a similar trend. Excluding species found in the tree layer, understory species composition was still greatest in SE plots (165 non-tree species). In the shrub layer, the most families and genera were found in SE (41 families, 89 genera in the shrub layer and 6 families, 7 genera in the interlayer), followed by EP (26 families, 48 genera in the shrub layer); the fewest families and genera were found in AF (21 families, 43 genera in the shrub layer). Species number in the herb layer followed a different trend than that observed in the shrub and interlayer, as the most families and genera (53 and 67, respectively) in the herb layer were found in EP, followed by AF (48 and 59, respectively), with the fewest families and genera (7 and 13, respectively) found in SE.

Plant species diversity indices for different local current vegetation types

Non-metric multidimensional scaling (NMS) for the whole shrub and herb layer data highlighted the different patterns observed in species composition for these layers independently of local current vegetation type, elevational range, or site. For this reason, the following analyses were done separately for these layers.

Statistical comparisons of average plant richness (S), Shannon–Wiener diversity (H') and Pielou Evenness (J) indices showed significant differences among local vegetations types in the herb layer (Table 2). The average richness and Shannon–Wiener diversity indices (23 species and 2.46, respectively) for the herb layer in the SE plots were higher than those in the AF plots (15 species and 2.01, respectively). Those indices for the herb layer of the EP plots presented intermediate values (20 species and 2.07) that were not significantly different from those in either the SE or AF plots. Likewise, the evenness index for the herb layer of the SE plots was significantly higher (2.46) than that of the EP plots (0.70), but neither value differed significantly from the index for the AF plots (0.76), which was of intermediate value. Neither elevational range nor variable interaction presented significant differences in the herb layer for any of the three diversity indices (Table 2). Contrary to the results found for the herb layer, there were no significant differences among local current vegetation type, elevational range, or interactions in the shrub layer for any of the three diversity indices (Table 2).

In the NMS ordination for the shrub layer, all local current vegetation types can be seen to be interspersed (Fig. 2), and the centroid position did not indicate significant differences amongst local current vegetation type ($F = 1.03$, $P = 0.40$), elevational range ($F = 1.05$, $P = 0.35$), or interaction ($F = 1.07$, $P = 0.26$). However, dispersion was significantly different in local current vegetation type ($F = 7.03$, $P \leq 0.01$), with dispersion for AF being smaller than either SE or EP dispersion. Dispersion for elevational ranges ($F = 0.69$, $P = 0.52$) was not significantly different, although interaction exists ($F = 9.07$, $P \leq 0.01$). In herb and shrub layer ordination, differences among elevational ranges were not large enough to warrant separation into groups.

The NMS ordination for the herb layer indicated that there was a lot of homogeneity shared between EP and AF, whereas the SE plots were quite different (Fig. 2). In particular, significant differences were detected by PERMANOVA for centroid position in local current vegetation type ($F = 2.10$, $P \leq 0.01$), but not for elevational range ($F = 1.06$, $P = 0.38$) or interaction ($F = 1.13$, $P = 0.26$). In this case, SE plots had a significantly different centroid position than EP and AF. Complementary analysis by PERMDISP showed significant differences for dispersion of local current vegetation type

Table 2 Mean values of two-way ANOVA analyzing average richness (*S*), Shannon–Wiener (*H*′) and Pielou Evenness (*J*) indices of shrub and herb layer in southwestern Yunnan province, China, considering local current vegetation type (secondary evergreen forest, SE; *Eucalyptus* plantation, EP; abandoned farmland, AF) and elevational range (low, medium and high) as main factors

Main factors	Herb layer			Shrub layer		
	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)	Average richness (*S*)	Shannon–Wiener (*H*′)	Evenness (*J*)
A = Local vegetation type						
SE	22.56 b	2.46 b	0.80 b	19.78	2.54	0.88
EP	20.11 ab	2.07 ab	0.70 a	15.00	2.40	0.94
AF	15.00 a	2.01 a	0.76 ab	13.56	2.16	0.87
F(P)[a]	*4.69 (0.023)*	*4.32 (0.029)*	*4.07 (0.035)*	*1.54 (0.242)*	*0.89 (0.427)*	*2.43 (0.117)*
B = Elevational range						
Low	18.22	2.04	0.77	15.00	2.33	0.87
Medium	19.67	2.24	0.72	15.67	2.38	0.90
High	19.78	2.26	0.77	17.67	2.39	0.92
F(P)	*0.24 (0.791)*	*1.15 (0.338)*	*1.58 (0.233)*	*0.28 (0.760)*	*0.03 (0.973)*	*1.11 (0.351)*
Interaction F(P)						
A × B	*1.70 (0.193)*	*0.48 (0.748)*	*2.14 (0.117)*	*1.25 (0.326)*	*2.76 (0.060)*	*2.75 (0.060)*

[a] $F(P) = F$ statistic and probability at $P = 0.05$. Values followed by different letters in each column are significantly different with Tukey multiple range test at $P < 0.05$

The italics refer to the main factors of the two-way ANOVA, interactions are expressed as A × B

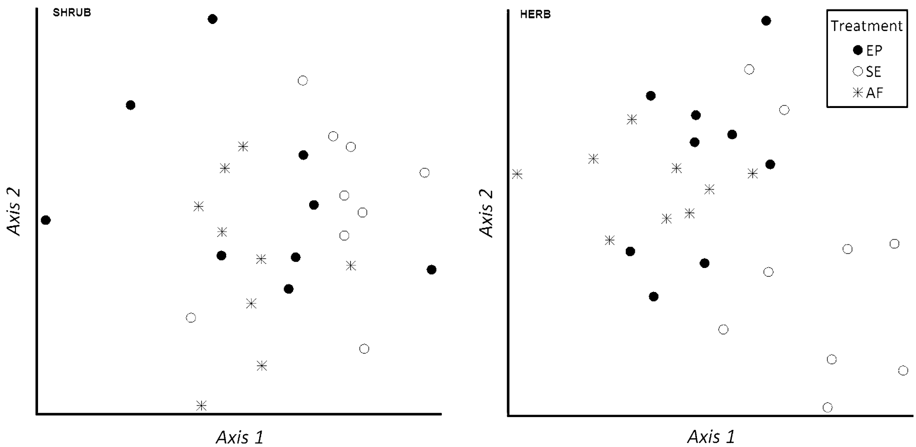

Fig. 2 Non-metric multidimensional scaling (*NMD*) for shrub and herb layer plots in secondary evergreen forest (*SE*), *Eucalyptus* plantation (*EP*) plots and abandoned farmland (*AF*) plots over all elevations in southwestern Yunnan province, China

($F = 8.39$, $P \leq 0.01$), elevational ranges ($F = 8.78$, $P \leq 0.01$), and interaction ($F = 3.26$, $P = 0.03$), with dispersion in the AF and EP plots being greater than that of the SE plots.

Relationships among environmental factors and understory vegetation

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 (Fig. 3). In the shrub layer, this analysis indicates that THICK > OCOV were the most important negatively correlated variables with Axis 1, meanwhile WC > AP > RAK were the main variables negatively correlated with Axis 2. However, local current vegetation types were not well differentiated, so no one variable significantly explained variation in the understory shrub layer ($F < 1.41$, $P > 0.07$ for all ten variables). In this CCA, significance of all canonical axes was 1.315 ($F = 1.127$, $P = 0.296$). In the herb layer, OM > RAK > AP > WC were the most important positively correlated variables with Axis 1, while OCOV > HN were the main variables positively correlated with Axis 2. This ordination showed a good differentiation among local current vegetation type plots, with WC and OCOV being significantly explaining variation of the understory herb layer ($F = 1.74$, $P = 0.01$ and $F = 1.54$, $P = 0.04$, respectively). AF plots were located where OCOV, HN and OM had the lowest values. EP plots occupied an intermediate position among AF and SE plots, which were associated with highest values of OCOV, OM, RAK, HN and pH. The variables SDB, THICK, AP, and WC were associated with EP and SE internal variation. In this CCA, the significance of all canonical axes was 0.984 ($F = 1.263$, $P = 0.110$). Significant correlation was not detected between soil type and plot distribution in any CCA performed.

Indicator species of different vegetation types

Regarding the shrub species, only the IndVals for *Helicia shweliensis, Craspedolobium schochii,* and *Embelia laeta* were higher than 0.5, and thus *H. shweliensis* was the apparent

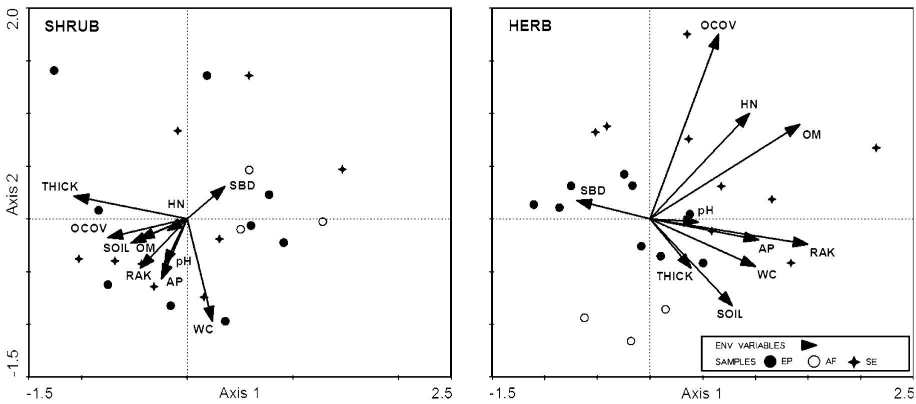

Fig. 3 Canonical correspondence analysis (*CCA*) for understory vegetation (shrub and herb layer) and nine environmental variables. *OCOV* overstory coverage, *OM* organic matter, *HN* hydrolyzable nitrogen, *WC* water content, *SBD* soil bulk density, *THICK* thickness of the soil, *RAK* rapid available potassium, *AP* available phosphorus, pH. *EP Eucalyptus* plantation; *SE* secondary forest, *AF* abandoned farmland

indicator for SE. These species were only observed in secondary forest. Regarding the herb species, only the IndVals of seven species (see Table 3) were higher than 0.5; *Carex baccans* and *Vernonia esculenta* were the indicator species of the herb layer in SE, while *Pteris cretica var. nervossa* was the indicator species in the herb layer of EP. There was no indicator species described for AF.

Native, rare or threatened species in different vegetation types

Level I- and level II-protected species were found in the SE plots at all elevational ranges in every site except Site 4. Conversely, rare species are essentially excluded from EP and AF types, aside from a sighting of *Cibotium barometz* in AF at Site 1 (lowest elevational range), a level II-protected species. Some of the native rare or threatened species of SE

Table 3 Indicator values (IndVal index) of different species in the herb layer as habitat indicators for secondary evergreen forest (SE) and *Eucalyptus* plantation (EP) in southwestern Yunnan province, China

Local vegetation type	Species	IndVal index	P[a]
SE	*Helicia shweliensis*	0.7778	0.001
	Craspedolobium schochii	0.5995	0.005
	Embelia laeta	0.5111	0.043
	Carex baccans	0.7833	0.001
	Vernonia esculenta	0.7356	0.001
	Dryopteris chinensis	0.5714	0.006
	Smilax glabra	0.5556	0.004
EP	*Pteris cretica var. nervossa*	0.8611	0.001
	Setaria viridis	0.5556	0.004
	Carex spp.	0.5556	0.006

Only the species with values >0.5 are presented in the table and that only the species with values >0.5 were considered as characteristic

[a] Probabilities (*P*) are based 1,000 permutations

were *Dendrobium officinale* (level II-protected; Site 1), *Paramichelia baillonii* (level II-protected; Sites 2 and 5), *Vanda cristata* (level I-protected; Site 3), *Cyathea chinensis* (level II-protected; Site 7), *D. chrysotoxum* and *D. devonianum* (both level II-protected; Site 8).

Discussion

As reported by Zhang et al. (2010), we also found that the plant composition and importance values (IndVal index) showed distinct differences between vegetation layer (i.e., shrub and herb layer) and forest types (i.e., SE, EP and AF). *Craibiodendron stellatum* was the dominant tree with an IndVal index of 0.168 in Secondary evergreen forests (SEs). However, *Eucalyptus* was the dominant tree in EPs and there was no dominant tree in abandoned farmlands (AFs). In the shrub layer, *Eurya groffii* and *Craibiodendron stellatum* were the dominant shrubs with IndVal index of 0.068 and 0.061, respectively in SEs, while *Maesa japonica* (IndVal index = 0.014) and *Glochidion lanceolarium* (IndVal index = 0.009) were the dominant shrubs in EPs, and *Schima wallichii* (IndVal index = 0.052) was the dominant shrub in AFs. In the herb layer, *Carex baccans* was the dominant herb (IndVal index = 0.066) in SEs, while *Eupatorium adenophorum* was the dominant herb (IndVal index = 0.246) in EPs and *Neyraudia reynaudiana* was the dominant herb (IndVal index = 0.241) in AFs. SEs were the most biologically complex, as they had most layers, families, genera, and species, the highest values for richness and Shannon–Wiener diversity in the herb and shrub layers, and the highest evenness value in the herb layer (Table 2). SE plots represent a state closer to the natural state, while EPs are human-managed plantations, and AFs have been disturbed drastically by agricultural activities. With regard to forest structure, AF plots were the least complex, although shrub and herb layer evenness was lowest in EP. The prevalence of *Eupatorium adenophorum* in the EP plots largely accounted for the low evenness value and lack of diversity in the plantations.

In biological systems, the number of families, genera, and species typically decreases with an increase in elevation (Whittaker 1977); however, our ANOVA results did not show significant differences in understory diversity measures along the elevational gradient. While elevational changes are known to have an effect on climate, which in turn affect vegetation, we could not detect such changes in our study. The difference between the maximum and the minimum elevation was 1,002 m, and so was perhaps not large enough to elicit a response. Furthermore, our sampling area (projected area 400 m^2) was relatively small; perhaps elevational changes manifest over a larger area. We do not believe that slope/aspect had a major role in affecting the plant community, likely because the anthropogenic influences drove the analyses, particularly in the EP and AF plots.

Nonetheless, there seemed to be a trend in which EP plots were more diverse than the AF plots (although not as diverse as SE plots) at higher elevations (Oosting 1942). This could be due to an altitudinal limit of distribution for *Eupatotorium adenophorum*, or less human activity in plantations at higher elevation, and consequently fewer invasions by *E. adenophorum*, since our results indicate that there is less *E. adenophorum* at the higher elevations. More studies are necessary in order to understand interactions between understory plant diversity and elevation.

Notably, the shrub layer in the EP plots had a higher evenness value than the other local current vegetation types. Lowest evenness in EPs can be explained by the presence of only two species in the shrub layer and none was dominant, so this reflects regularity in the abundance of the species. However, in the herb layer and the interlayer, the evenness index was lowest in the EP plots, which points to a low level of diversity. Furthermore, the absence of native rare and threatened species in the EP plots indicates that *Eucalyptus* plantations deplete the original richness of native understory plants. This depletion likely occurs for two reasons: firstly, initial site preparation techniques are not conducive to the survival of native species. *Eucalyptus* trees are planted after the mountains were cleared; i.e., nearly all native plant species are cut and burned after the plantation site is established. Moreover, other plant species are extirpated artificially during the *Eucalyptus* tree nursery stage. These practices made the biodiversity in EP plots decrease sharply in the beginning. Secondly, as an exotic species, *Eucalyptus* trees have a comparative advantage over endemic or native species in their ability to absorb water and mineral nutrients, which results in the near absence of these species from EPs (Zhao et al. 2007).

According to our results, EPs negatively affect understory plant diversity. While Peng and Fang (1995) and Peng (2003) suggest fast-growing plantations in tropical and subtropical regions of China can be generally regarded as a pioneer stage of evergreen broad-leaved climax forests that accelerate the process of succession and improve the development of species diversity, we do not agree entirely with this viewpoint, at least with respect to the first five to seven years following establishment of an EP. The studies of Peng and Fang (1995) and Peng (2003) examined *Eucalyptus* pioneer communities that ranged from 1 to 28 years of age, while the EPs examined in our study were only seven years old at the most; nonetheless, if the succession process were truly "accelerated", we would expect to see some improvements in diversity by seven years, and this was not the case in our study. In fact, our present study strongly indicated that diversity is compromised in *Eucalyptus* plantations in the subtropical region of Yunnan. The actual species diversity in the planted *Eucalyptus* regions is particularly low, and the regenerative quality of the understory is also low. However, we echo the comments of Brockerhoff et al. (2008): the role of plantations in biodiversity conservation can be enhanced if plantations are managed in a manner in which they can contribute to biodiversity conservation across the whole landscape, rather than within the plantations themselves.

The relationship between plants and environmental factors was assessed with CCA ordinations. The ordination analyses emphasized that soil properties (i.e., soil type, organic matter, water content, soil bulk density, thickness of the soil, rapid available potassium, available phosphorus) are significant factors controlling the distribution of vegetation. Others have reported similar findings (Deckers et al. 2004; Jiang et al. 2007; Zhang and Dong 2010). Factors that are critical in affecting vegetation density and diversity are not totally consistent across regions or locales. Some studies indicate that light intensity is one of the most important factors influencing understory vegetation (Parrotta 1995; Yirdaw and Luukkanen 2004; Duan et al. 2010). However, the degree of different environmental factors affecting biological diversity of different vegetation types is not the same in our study. In the shrub layer, THICK was the most important positively correlated variable, meanwhile WC was the most negatively correlated one. In the herb layer, OM was the most important positively correlated variable, meanwhile OCOV was the main variable positively correlated with Axis 2. WC and OCOV were significantly important to explaining variation of the understory herb layer, which indicated that knowledge of soil physical properties is necessary for better understand their importance in *Eucalyptus* plantations and other local current vegetation types. *Eucalyptus* leaves were narrow and long, like willow leaves, but most native species were broad-leaved species, such as *Eurya groffii* Merr. Thus, eucalypt overstory was not equivalent to the native overstory in terms of shade density; therefore, although the shade density was the same, the effects were might quite different. While eucalypt canopies may admit more or less light than the native canopy, using cover as a surrogate for light can only provide a very rough approximation, especially where large differences in species composition and structure are involved.

We firmly believe that the most important driver affecting the biodiversity of the understory in five to seven year old *Eucalyptus* plantations is the manner in which the site is prepared. In addition, we observed that *Eucalyptus* 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 the understory of *Eucalyptus* plantations.

Conservation science can help to inform political decision-making regarding land-use strategies by providing clear answers to questions regarding the biodiversity of different habitats. Given the high biodiversity in Yunnan province, and the fact that we found many rare or threatened species in SE plots but not in EP plots, we conclude that clearing SE for EP could result in the loss of rare or threatened species. Inquiry into determining whether plantation forests are detrimental or beneficial for conservation is not trivial, because each case is context-specific and depends on multiple factors (Brockerhoff et al. 2001; Carnus et al. 2006). Brockerhoff et al. (2001) suggested that attention be given to the protection of rare or threatened species when cultivating plantation forestry. In order to gain the maximum economical benefit from the large area of EP in Yunnan province, improper management practices by the *Eucalyptus* plantation workers (such as clearing mountains before planting, mowing at the nursery stage) greatly decrease the number of understory native species and endanger species. Therefore, in order to improve the biodiversity of *Eucalyptus* plantations, it could be better to retain some plant species before the *Eucalyptus* trees are planted as well as in the nursery stages.

Secondly, some nature reserves or protected species transplanting programs should be implemented before *Eucalyptus* plantations are established in order to protect the threatened species. In our field investigation, a large number of *Vanda cristata* (level I-protected, YNCC, 2009) were found in the dark and humid forests of SEs at Baowo village, Dapingzhang town, Lancang county (see Site 3, Table 1 for specific location); we suggest establishment of a nature reserve to protect local *Vanda cristata*. In addition, isolated adult *Alsophila costularis* (level-II protected, YNCC 2009) were occasionally found living at the edge of a forest or on the roadside. We suggest moving several representative *A. costularis* into a local natural reserve or botanical garden with the same or similar climate conditions.

Lastly, we feel that *Eucalyptus* trees should not be planted contiguously in a large-scale area in Yunnan province. As an exotic species, *Eucalyptus* trees out-compete endemic or native species, and this resulted in the decreased biodiversity observed in our study. In order to retain ecological corridors or habitats for native plant or animal species, a contiguous large-scale cultivation of eucalyptus planting in Yunnan should be expressly prohibited.

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