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Tree size predicts vascular epiphytic richness of traditional cultivated tea plantations in Southwestern China

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ABSTRACT

Species–area relationship has been widely addressed on many plant communities, but very few have conducted on epiphytic communities. Epiphytic plants are plentiful on ancient tea trees (*Camelia sinensis* var. assamica) in the well-known Jingmai tea plantation area, Langcang region of Yunnan Province, SW China, and add to the plant community biodiversity. We investigated 343 tea trees with various ground diameter, canopy area, under branch height, and tree height. A total of 146 vascular epiphytic plants, belonging to 19 species in seven families were recorded from the trunk or branches of 93 (27.11%) investigated trees. We examined *in situ* abundance, richness, and diversity (Shannon–Weiner index) of the recorded vascular epiphytes, and their relationships to tree variables. Our results showed that the distribution (abundance, richness, and diversity) of epiphytic plants are significantly related to the canopy area ($p < 0.05$) and basal diameter ($p < 0.0001$) of tea trees, supporting their use as key factors and good predictor for the epiphyte's appearance in this type of agro-ecosystems. We also concluded that the species–area relationship is a useful epiphytic species community research tool.

1. Introduction

Species richness is positively influenced by many factors, such as habit size (Schuler, 2015), heterogeneity (Lundholm, 2009), and spatial scale (Palmer and White, 1994; Crawley and Harral, 2001; Engelhardt and Ritchie, 2002). Species–area relationship has been widely studied in different plant communities (Keeley, 2003; Fridley et al., 2005) for both micro- (e.g., eukaryotic soil microbes (Peay et al., 2007)) and macro-organisms (e.g., woody plant communities (Tsai et al., 2015)) as well as tussocks (Yu et al., 2008).

Spatial scale (e.g., straight plot size, slope, and intercept) should be considered when patterns of plant species richness is of concern (Palmer and White, 1994; Crawley and Harral, 2001; Engelhardt and Ritchie, 2002). Species–area relationship

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considers two main sampling schemes; namely, physically separated areas (e.g., islands or habitat patches) and adjacent or abutting areas of continuous habitat (e.g., independent, non-overlapping replicates) (Connor and McCoy, 2001). For testing epiphytic species–area relationship, the physically separated areas scheme is more suitable. Epiphytic species occupy three-dimensional space of their host trees, allowing more than one individual to be closely clustered spatially than a situation where populations occupying two dimensions (Rahbek, 2005). The research subject's communities in the most of the previous research grow on the ground and only occupied two-dimension spaces. This is the first time we study the species–area relationship of the epiphytic community which occupied three-dimension spaces and suggested this kind of community need consider horizontal and vertical distribution.

Epiphytes are plants that practically grow on the surface of trees but remain physiologically independent (Benzing, 2004), and they may contribute to more than half of plant species richness in tropical forests (Benzing et al., 1990; Wells, 1991). Epiphytes provide unique micro-climates and habitats for other species; thus their decline could negatively affect many animals and plants that rely upon them (Magrach et al., 2014) and are known to be the major contributors to vascular plant diversity, biomass (Laube and Zotz, 2003), and nutrient and water cycling (Gotsch et al., 2015). These plants play a key role in biodiversity and functionality of some important ecosystems (Gabriela et al., 2015) and they may even act as keystone species (Press and Phoenix, 2005).

While vascular epiphytes play an important role and represent a highly diverse element of tropical rain forests and subtropical regions (Gotsch et al., 2015), they also exist in different forestry systems (e.g., coffee agro-ecosystems (Goodall et al., 2015) and oaks at the westernmost part of Hungary (Király et al., 2013)). Yet, few studies have been conducted on epiphytes in subtropical regions (e.g., southwest China (Han et al., 2010; Einzmann et al., 2015)) and they have been ignored in forest biodiversity protection and management.

The ancient plantations of tea (*Camelia sinensis* var. *assamica*) represent a unique example of agro-ecosystems utilization and conservation (natural resources protection) (Qi et al., 2013). Here we explore the epiphytic species-tree size relationship and hypothesize that each host tree acts as a separate island (area) with tree size represented by basal diameter (Meinzer et al., 2005) (BD) or diameter at breast height (Zhao et al., 2015) (DBH), height (Niinemets and Reichstein, 2003), and canopy area (Schumann and Zaman, 2005). We investigated the effect of tree size on three-dimensional scale (spatial scale) of epiphyte richness, abundance, and diversity in tea communities, specifically we wanted to address the following: (1) how do epiphyte species richness, abundance, and diversity change with tea tree size? And, (2) does species–area relationship perform well on epiphytic communities?

2. Material

2.1. Study area

The present study was carried out in Jingmai Ancient Cultivated Tea Plantation located in Mangjing Village (22°08′36″–22°11′37″N, 99°59′37″–100°02′27″E) in the Langcang region of Yunnan Province, SW China. In this area, annual precipitation ranges from 1600 to 1800 mm and mean annual temperature ranges from 18 to 20 °C, it is foggy here all year round and the soil is very fertile with elevation between 1250 and 1586 m. Vegetation type is subtropical monsoon evergreen broadleaved forest (CCLLNACYP, 1996). The tea plantation is an assembly of unique biodiversity with naturally occurring tea trees measuring up to 50 cm in basal diameter along with commercially planted tea trees (Lu et al., 2011). Most tea trees in this plantation had been top-pruned when it is more than 4 m in high for ease of harvest. This area has a high biodiversity, and this ecosystem is resilient to diseases and insect pests (CL et al., 1997) with vegetation consisting of herbs (36.1%), trees (24.1%), shrubs (16.0 %), vines (15.6%), and epiphytes and parasites (8.2%) (Qi et al., 2013).

2.2. Sampling and data collection

Field work was conduct between February and April, 2013. A total of 46, 5 m ×5 m plots were established and surveyed. A total of 343 tea trees with basal diameter $\geq$ 2 cm were present (trees with basal diameter $<$ 2 cm were not considered), with a range of 5–12 tea trees in each plot. Plots differed in their slope aspects (east, south, west, and north) and covered an altitudinal gradient from 1250 to 1590 m. On each tree, using binoculars when necessary, we counted individuals ($\geq$2 cm in height) of each vascular epiphytic species as a measure of its abundance. We also measured the basal diameter (5 cm above the soil level), canopy area (south–north canopy × west–east canopy), tree height, and under branch height. Tree height was measured by tree probe (Nikon-550AS, Japan). Under branch height was measured from the first branch down to the soil level. We calculated species richness (total number of species) and abundance (i.e., total number of individuals) of vascular epiphytes on each tree.

2.3. Data analysis

For each tree, we calculated Shannon–Wiener diversity index (H') as:

$$H' = -\sum P_i \ln P_i \quad (i = 1, 2, 3, \ldots, S) \tag{1}$$

Table 1
Occurrence, frequency and abundance of the vascular epiphytic species in the tea plantation.

Species	Family	Occurrence (# of trees)	%	Total no. of individuals
Davallia ylindrica	Davalliaceae	26	8.05	48
Drynaria ropinqua	Drynariaceae	2	0.61	2
Pyrrosia lingua	Polypodiaceae	22	6.81	34
Peperomia tetraphylla	Piperaceae	7	2.16	11
Bulbophyllum ambrosia	Orchidaceae	3	0.93	3
Bulbophyllum nigrescens	Orchidaceae	14	4.33	27
Bulbophyllum brevispicatum	Orchidaceae	3	0.93	3
Bulbophyllum spp	Orchidaceae	1	0.31	1
Oberonia falconeri	Orchidaceae	1	0.31	1
Oberonia jenkinsiana	Orchidaceae	5	1.55	6
Coelogyne flaccida	Orchidaceae	1	0.31	3
Liparis elliptica	Orchidaceae	37	11.46	60
Ceratostylis himalaica	Orchidaceae	11	3.41	12
Ascocentrum mpullaceum	Orchidaceae	1	0.31	1
Ascocentrum himalaicum	Orchidaceae	2	0.62	2
Dendrobium hrysanthum	Orchidaceae	4	1.24	6
Dendrobium capillipes	Orchidaceae	1	0.31	1
Hoya lantsangensis	Asclepiadaceae	4	1.24	11
Lysionotus petelotii	Gesneriaceae	1	0.31	2

where, P_i is number of individuals for species i divided by total number of individuals across all species in the tree, and S is the number of species in the tree. Studied trees were classified into four size groups, each with comparable tree number, based on each of the four variables (basal diameter, canopy area, tree height, and under branch height). Trees were grouped into ≤ 5, 5–10, 10–20 and ≥ 20 cm in basal diameter, ≤ 0.8, 0.8–1.5, 1.5–3.5, and ≥ 3.5 m^2 in canopy area, ≤ 1.7, 1.7–2, 2–2.9, and ≥ 2.9 m in tree height, and ≤ 0.05, 0.05–0.2, 0.2–0.6, and ≥ 0.6 m under branch height. We used Kruskal–Wallis, a non-parametric test to explore whether tree size classes affected richness and abundance of vascular epiphytes. Analyzes were performed with SPSS version 19.0 (IBM).

3. Results

A total of 19 vascular epiphytic species from seven families were recorded (Table 1), representing 13 species from the Orchidaceae family and the remaining six species, each representing a single family (Table 1). The three most frequent species were *Liparis elliptica* (11.5%), *Davallia ylindrica* (8.1%) and *Pyrrosia lingua* (6.8%) (Table 1).

Basal diameter and canopy area were found to be significant determinants of species richness and abundance and Shannon–Weiner index of epiphytic communities; all three indices were positively correlated with both tree basal diameter ($\chi^2 = 20.250$, $p = 0.0$; $\chi^2 = 20.465$, $p = 0.0$; $\chi^2 = 17.224$, $p = 0.001$) (Fig. 1A–C) and canopy area ($\chi^2 = 8.985$, $p = 0.029$; $\chi^2 = 9.085$, $p = 0.028$; $\chi^2 = 12.198$, $p = 0.007$) (Fig. 1D–F). However, tree height and under branch height produced varying results with the three indices (species richness and abundance, and Shannon–Weiner index). Tree height was not important to species' distribution ($p > 0.05$). Under branch height was significantly correlated with richness ($\chi^2 = 8.192$, $p = 0.042$), not significant with abundance ($\chi^2 = 9.380$, $p = 0.25$) and Shannon–Weiner index ($\chi^2 = 4.992$, $p = 0.172$) (Fig. 2).

4. Discussion

4.1. Suitability of species–area relationship for epiphytic community

Four physical traits (basal diameter, canopy area, tree height, and under branch height) of tea trees were used to test the species–area relationship, with the hypothesis that larger trees, providing larger surface areas for accommodating greater number of epiphytic species. Our data supports the hypothesis that more epiphytic species are found on larger host trees, more specifically, the most species-rich epiphytic community occurred at the highest classes of tree height (although not significantly correlated), bigger basal diameter and canopy area ($p = 0.001$), and the lowest class of under branch height (statistically not significant). Therefore, tea tree basal diameter and canopy area are good predictors for epiphytic plant species richness on ancient cultivated tea plantations. Species–area relationship can hold true at horizontal distribution (basal diameter and canopy area) of epiphytic species. Epiphytic species–area relationship held true at canopy areas from 0.1 to 90 m^2 when the basal diameter is range from 2 to 29 cm^2. In our study, the most species-rich occurred when basal diameter is more than 20 cm and canopy area more than 3.5 m^2.

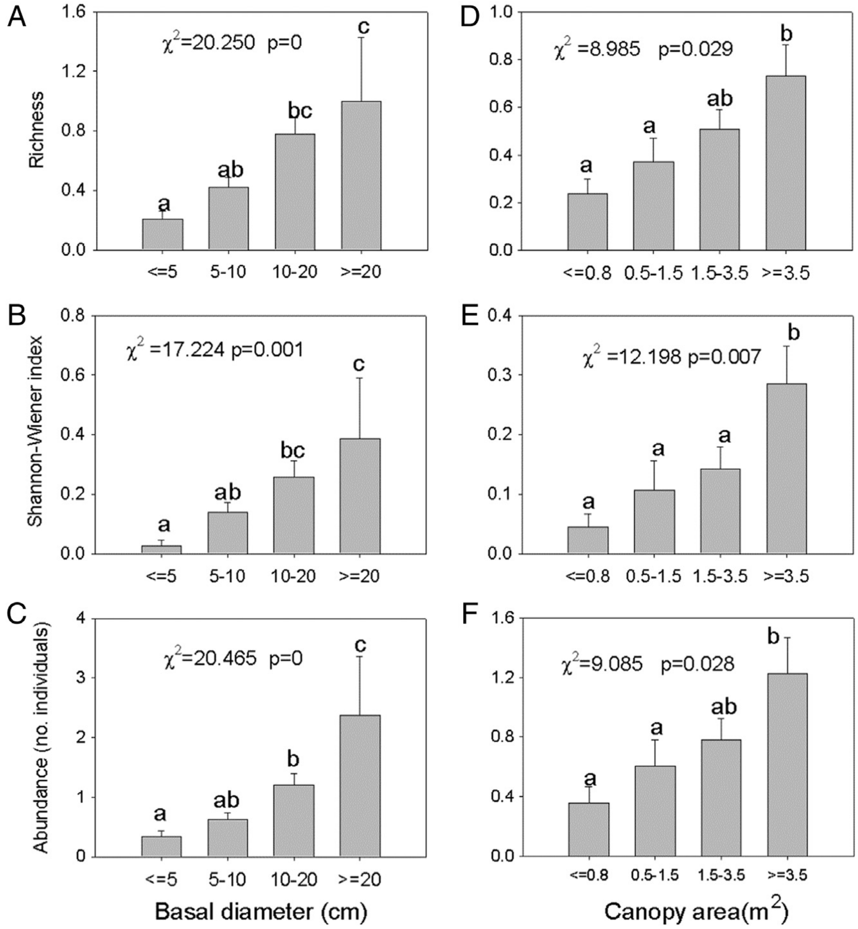

Fig. 1. Richness, abundance, and Shannon–wiener index of the vascular epiphytes on the tea trees of different size groups based on basal diameter (A–C) and canopy area (D–F) in the tea plantation.

4.2. *Species richness as affected by canopy area and basal diameter*

Different size of canopies provide different microclimatic conditions (Schuler, 2015), moreover, the configuration of canopy determines the availability of space for epiphytic growth, and the dispersal modes of these epiphytes affect their establishment on hosts (Nieder et al., 2000). In the present study, richness, abundance, and Shannon–Weiner index of epiphytic communities were highly significant with canopy area of tea trees, results concurring with the findings of Yeaton and Gladstone (1982) that reported positive relationship between the number (abundance) and category (richness) of epiphyte species on calabash trees with trees' canopy area. Other hosts species also support our result, such as coffee (Hylander and Nemomissa, 2008). While, basal diameter have the same regular pattern as shown by the canopy area. Our results suggest that the bigger the basal diameter of tea tree, the more likely higher abundance and diversity of epiphytes to occur. Koster (Köster et al., 2011) reported that basal diameter of host trees could be used as a core predictor for understanding the distribution of epiphytes in secondary forest. Similarly, positive relationship between epiphyte diversity and basal diameter of the host tree was reported by Zotz and Vollrath (2003) and Woods et al. (2015). However, it is suggested that this observed relationship may be due to longer time available for colonization (the length of time that the host trees have been around to serve as targets for the propagules of the epiphytes) with tree growth (Janzen and Liesner, 1980), but not due to an increase of habitat diversity (Yeaton and Gladstone, 1982; Cook et al., 2002). Large and old host trees generally have more epiphyte species than smaller trees, because the colonization probability (time and space available) are higher and the diversity of microhabitats are also higher (Hietz and Hietz-Seifert, 1995; Nieder et al., 2001; Flores-Palacios and García-Franco, 2004). Basal diameter is much more directly correlated with tree age, causing the high explanatory power of tree size parameters in this habitat type. As *V. koschnyi* trees increased in size, vascular epiphyte diversity and abundance also increased (Zotz and Vollrath, 2003). Our results can be interpreted as evidence for the predominant role of tree age for epiphytic growth (Flores-Palacios and García-Franco, 2004).

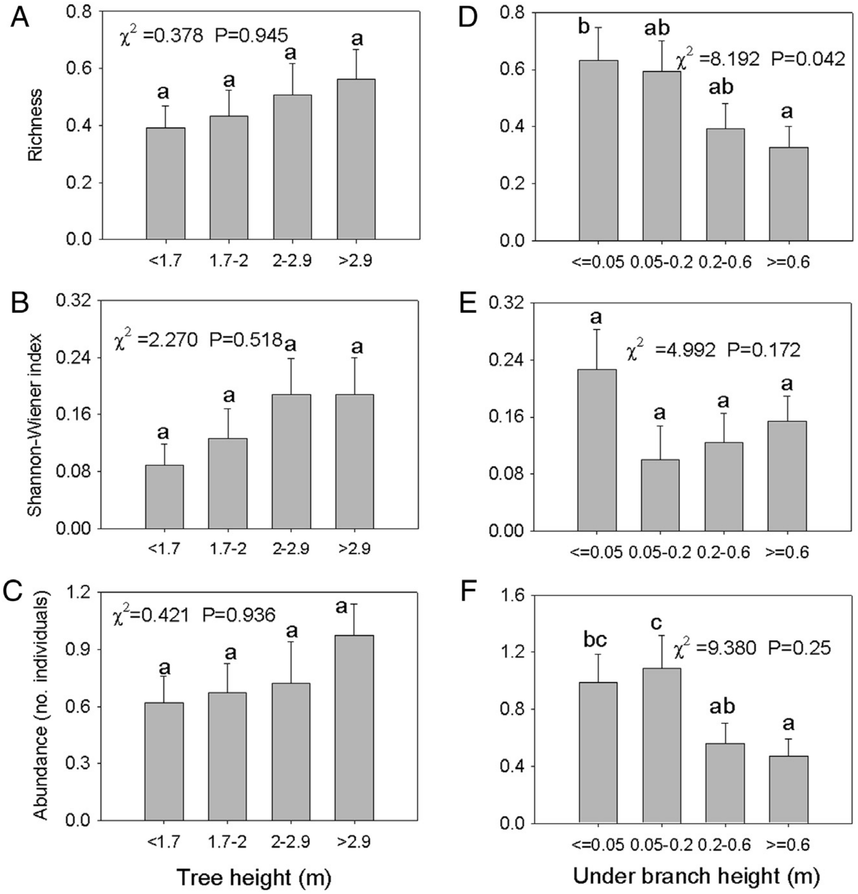

Fig. 2. Richness, abundance, and Shannon-winner index of the vascular epiphytes on the tea trees of different size groups based on tree height (A–C) and under branch height (D–F) in the tea plantation.

4.3. *Species richness as affected by tree height and under branch height*

Species richness of epiphytic increases with tree height in various forest ecosystems (Sillett et al., 2000; Williams and Sillett, 2007). Even though the highest class of species richness was found in the tallest trees, their relationship was found to be not-significant. This could be due to the effects of physiological adaptation and requirements on the vertical distribution of epiphytes (Nieder et al., 2000) and the limited range of tree height analyzed. Very few studies have paid attention to under branch height. Few reports found that the distribution of epiphytic species was only weakly or not related to under branch height (Woods et al., 2015; Zhao et al., 2015). Similarly, most species found in our study area attached to the branches of tea trees, and not the trunks. However, under branch height is not related to abundance and diversity, but correlated with richness ($p = 0.042$). The same species compete for the advantage space is likely to explain this issue, that is, most species in the research site are clustered type (such as, *P. lingua, Peperomia tetraphylla, Bulbophyllum ambrosia, Bulbophyllum nigrescens, Bulbophyllum brevispicatum, Oberonia falconeri, Oberonia jenkinsiana, Coelogyne flaccida, Coelogyne flaccida, L. elliptica, Ceratostylis himalaica, Dendrobium hrysanthum, Dendrobium capillipes*), these kind of plants often produced lots of clone individuals and cluster together.

5. Conclusion

Tea tree basal diameter and canopy area are good predictors for epiphytic plant species richness. Species–area relationship also holds true for epiphytic plants which occupied three-dimensional space when the canopy area range from 0.1 to 90 m^2 and the basal diameter range from 2 to 29 cm^2. To our knowledge, this is the first study on the relationship between *C. sinensis* size as host tree in SW China Jingmai ancient tea plantation and each vascular epiphytes lived in their canopies. Epiphytic species-canopy area relationship and epiphytic species-basal diameter relationship could be reasonable tool to predict the forestalling loss of species. The results from the present study provide insights into the distribution of epiphytic communities in the ancient tea plantation for better management of the ecological balance between epiphytic species and tea trees. However, there are evidence that differing host tree species may lead to significant differences in epiphyte appearance (Nieder et al., 2000), despite only examining one tree species (tea tree), our findings are likely applicable to other tree species attached by epiphytic species. Further research is needed to test the species–area relationship on other hosts, in addition, other agroforestry eco-economic systems.

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