PROCEEDINGS OF THE ADVANCED FIELDCOURSE IN ECOLOGY AND CONSERVATION – XTBG 2011

XISHUANGBANNA TROPICAL BOTANICAL GARDEN, YUNNAN, CHINA
22 Oct – 3 DEC 2011

EDITED BY
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Preface

The AFEC-X Field Biology Course is an annual, graduate-level field course in tropical forest biology run by the Program for Field Studies in Tropical Asia (PFS-TropAsia; www.pfs-tropasia.org), Xishuangbanna Tropical Botanical Garden, Chinese Academy of Science, in collaboration with institutional partners in the region. The course is held at Xishuangbanna Tropical Botanical Garden in Yunnan, China and at field sites in Xishunagbanna.

AFEC-X 2011 Field Biology Course was held from from 22 October to 3 December 2011, and was the third such course to be organised by PFS-TropAsia after launching the program in 2009. The aim of these courses is to provide high-level training in the biology and conservation of forests in tropical Asia. The courses are aimed at entry-level graduate students from the region, who are at the start of their thesis research or professional careers in forest biology. During the course topics in forest biology are taught by a wide range of experts in tropical forest science. There is also a strong emphasis on the development of independent research projects. Students are exposed to different ecosystem types through course excursions.

The AFEC-X 2011 Field Biology Course was attended by 25 students from 12 countries (China, Thailand, Laos, Philippines, Indonesia, India, Sri Lanka, Cambodia, Vietnam, Malaysia, USA and DPR Korea) and a total of 15 resource staff from a variety of national and international institutions gave lectures and practical instruction. Twenty participants received full fellowships, including travel awards, to attend the field course. The course was run by Dr. Lan Qie (PFS-TropAsia, XTBG) with the assistance of Liu Xiamo (XTBG). Due to their efforts the course proved to be a huge success. The following report illustrates the hard work of the organizers and the enthusiasm and commitment of the students.

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Acknowledgements

The AFEC-X China 2011 organizers wish to thank all resource staff listed at the end of this proceedings, who generously gave their time to teach the field course. A field course like this will not be possible without the commitment and support from these researchers, many of whom have become a regular fixture in the course schedule. We are especially grateful to Dr. Jeremy Miller and Dr Jacob Wickham, who devoted enormous amount of time into the course and played critical role in the success of this year's student projects. The AFEC-X China 2011 also saw a few new faces in a growing resource staff pool: Dr. Kathryn Bushley, Dr. Bosco Chan and Jay Wan. We hope they will join us again in future field courses. We thank Dr. Li Qingjun, the Deputy Director of Xishuangbanna Tropical Botanical Garden (XTBG) for opening the AFEC-X China 2011 and sitting in the judging panel at the closing symposium. We were also honored to have XTBG Director, Dr. Chen Jin for visiting the field course in Mengsong and giving valuable comments when the participants proposed their projects.

We give our sincere thanks to our Fieldcourse Assistant Liu Xiamo (Summer) who was a returning participant from AFEC-X China 2010 and gladly helped coordinating the logistics this year. The enthusiasm she injected into the AFEC-X China 2011 and the social activities she organized were invaluable, making it a much richer experience for all participants. We would like to thank Dr. Mareike Roeder, EN Paudel, and Gbadamassi Dossa, who provided helpful inputs for the field course projects while conducting their own research in Mengsong.

We would like to thank the supporting staff from the XTBG Personnel and Education Office: Mr. Chen Zhiyun and Ms. Liu Zhiqiu, from the Project Management Office: Mr. Yang Qing and Ms. Fang Chunyan, for their wonderful help to make sure the administration and logistics of this course went smoothly. We are very grateful for the kind help from the XTBG Student Union in taking care of the international participants upon their arrival.

We give out special thanks to the local Hani people at Mengsong, the Village Head Mr. He Yongneng, the Chief Forest Guard San Tu, Ah Tu, Ah Dong and Li Chunhai. Their great hospitality made all the international participants feel just at home. The wonderful and authentic Hani dinner we had at He's house was one of the most memorable experiences during the field course.

AFEC-X China 2010 was funded by XTBG, the Key Lab of Tropical Forest Ecology and the World Agroforestry Centre (ICRAF). The organizers acknowledge the support from the Xishuangbanna Nature Reserve management for giving permission to access field sites located in the reserve.

Thanks to all.

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Independent projects

Butterflies Biodiversity in the Tea Based Agro-forestry System in Mengsong, China

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ABSTRACT

Though it is generally accepted that agroforestry (AF) contributes to the conservation of fauna biodiversity, few studies have investigated butterfly diversity in AF systems. We studied butterfly diversity in a tea-based AF system in Mengsong village near Bulong Nature Reserve, Xishuangbanna, SW China. The study investigated the relationship between butterfly community composition and environmental factors in the tea-based AF system. We used general linear models and classification trees to test the effects of tea density, tea height and canopy openness on butterfly abundance and diversity. The results revealed that the tea based AF system maintained high butterfly biodiversity. In addition, butterfly biodiversity was positively associated with tea height and forest cover, and negatively associated with tea density. Further analysis revealed that dark coloured butterflies were more common in open conditions, and light coloured ones under the forest canopy.

Key words: agroforestry; biodiversity; butterfly; conservation; tea plantation; Xishuangbanna

AGROFORESTRY HAS EMERGED AS A PROMISING APPROACH for reducing the impact of deforestation on biodiversity while enhancing rural livelihoods. It has been practiced in almost all ecological regions. Both traditional and improved AF systems already exist such as the home gardens and taungya systems in the humid tropics and the use of strips of perennial vegetation, tiered parklands and plantations, and various silvipastoral systems in drier areas (Brader 1993). It has been suggested that AF systems can alleviate the resource use pressure on protected areas, enhancing habitats for some wild species and increase the connectivity of landscape components, thereby making conservation more effective (Bhagwat *et al.* 2008). Many authors have shown that traditional agroforestry practices contribute to the conservation of flora biodiversity through *in situ* conservation of tree species on farms, reduction of pressure on remnant forests, and the provision of suitable habitat for a number of plants and animal species on farmland (Assogbadjoa *et al.* 2011). Through conserving plant diversity and improving habitat quality, AF is likely to have potential impacts on fauna biodiversity as well, especially in comparison with other land-uses. Moguel and Toledo (1999) noted the high number of resident, migratory and endemic bird species in traditionally shaded coffee AF systems. Klein (2002) found that intensively managed coffee based AF systems were associated with changes in abiotic habitat parameters and positively corresponding changes in the bee and wasp communities. In addition, the research supported the idea that many non pest and beneficial insect species may even profit from agricultural land use. Similarly, Jhaab and Vandermeer (2010) found that coffee based AF systems have great positive effects on tropical bee communities.

The positive effect of AF systems on biodiversity conservation and enhancement of different fauna groups has been recognized, but there is still limited data on the diversity of butterflies in such systems. In addition, butterfly communities are a useful model group for investigating the impacts of AF system management methods on biodiversity. In forest and nearby areas, butterflies play an important role as pollinators (Jha & Vandermeer 2010). In tea-based AF system, butterflies, on the one hand, serve as potential pollinators for wild tea plants thus enhancing production of seedlings from seeds; while on the other hand, their larvae can be pests to tea leaves and reduce tea yield.

This study aimed to evaluate the abundance and diversity of butterfly communities in a tea-based AF system in Xishuangbanna, SW China. Tea-based AF comprises tea plantations under forest canopy, and in addition we aimed to understand the relationship between canopy structure and butterfly biodiversity. We predicted that butterflies would prefer areas with lower tea density.

METHODS

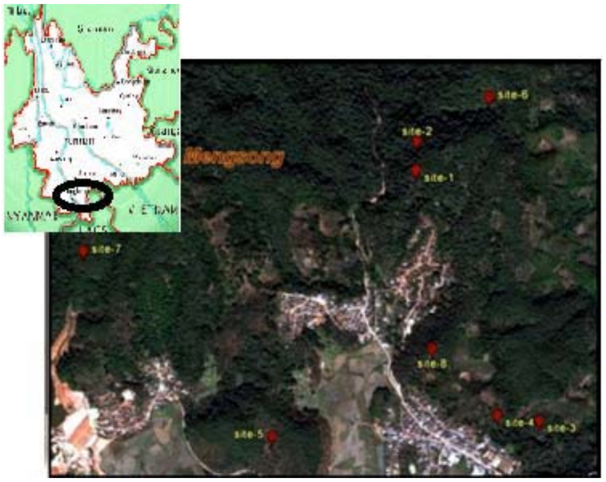

FIGURE 1. Study sites in Mengsong, marked in black within inserted map of Yunnan province, China

STUDY SITE.— The research was conducted in Mengsong village, Xishuangbanna, China on the border with Myanmar (Fig. 1). There are four main land-uses in the area: primary forest, secondary forest, AF systems with tea under canopy forest and terraced tea plantations. The research area is located between 100°29'25"-100°30'56"E and 21°30'36"-21°29'30"N, while the elevation ranges from 1566-1755m.

SAMPLING DESIGN.---We examined eight different tea based AF fields which varied in forest cover, tea density and tea height. In each site, one 50 x 50 m plot was selected for butterfly sampling, measuring tea density, tea height and forest cover. For each plot we maintained a minimum distance of 2 m from the forest edge. In addition, all plots were selected to contain a wild herb understory cover (i.e. no herbicide treatments had been applied).

BUTTERFLY SAMPLING.— The transect walk method was selected for sampling butterflies (Liu *et al.* 2011). One plot was sampled per day. Each of the two available recorders walked from opposite sides of the plot until they met each other. The observers caught any butterfly flying close to them. Captured species will be placed in plastic bags which were labeled with date, time, plot number and recorder. Each transect round took 15 minutes and

FOREST COVER, TEA DENSITY AND TEA HEIGHT.— Forest tree species were located both within and at the boundaries of the plots selected for the survey. Canopy photographing method was used for examining forest cover. In each survey site, five photographs were taken at four corners and the center of each 50x50m plot. The photographs were later used for analyzing forest cover by Gap Light Analysis (ALG) software. The mean Leaves Area Index (LAI) was calculated to represent forest cover in each plot.

Within each plot, one subplot (15 × 15m) was randomly selected for examining tea density and tea height. Tea density are measured by counting the number of tea trees with height above 40 cm and. Height of all tea trees included this way were measured the mean height was calculated.

STATISTIC ANALYSIS.— Species accumulation curves were generated using the EstimateS software to assess the sampling completeness (Stenchly 2011). We used linear models to investigate the relationship between butterfly diversity and predictor factors (tea density, tea height, forest cover). We employed canonical correspondence analysis (CCA) to examine the relationship between butterfly species composition and environmental factors. In addition, in order to understand linkages between butterfly functional colour groups with environmental factors, conditional inference trees were conducted in the package *party* in Program R (R Development Core Team 2011). This method evaluated the importance (conditional permutation-importance) and significance (p-value) of each variable.

RESULTS

BUTTERFLY BIODIVERSITY IN AF TEA BASED SYSTEM.— We collected a total of 117 butterfly individuals from 37 species, in 15 sub-families. The most common species were *Eurema hecabe, Pareronia anais*, *Neptis Magadha,*and *Cethosia bibles*, with abundance between 8 and 20 individuals.

Species accumulation curves and estimates based on all individuals collected during the survey are shown in Fig. 2. There were a high number of singletons. The total butterfly species in the system is estimated to reach 70 species, with a maximum between 140 and 180 species, if sampling would have been more thorough for 8 selected sites.

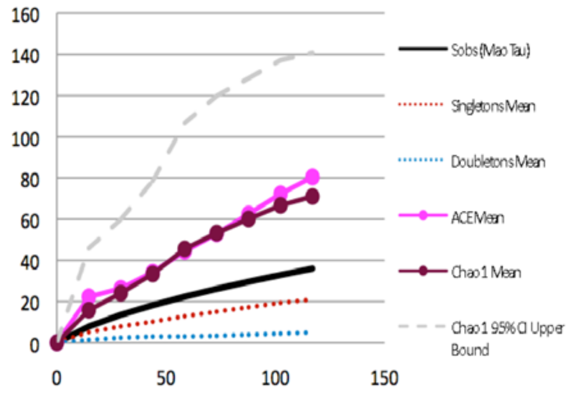

FIGURE 2. Species accumulation and estimation by EstimateS.

RELATIONSHIP BETWEEN BUTTERFLY BIODIVERSITY AND ENVIRONMENT FACTOR.— The general linear model analysis indicates that there exist no significant relationships between tea density, tea height and LAI with Fisher's alpha index. When considering the simplest model which does not take the relationship between tea density, tea height and LAI into account, their coefficient values with the Fisher's alpha index are -19.255, -2.379, 4.487; and p-values: 0.319, 0.528, 0.471, respectively. The overall p-value showing the relationship between butterfly biodiversity and overall environmental factors is 0.3926, for 4 DF. Further analysis indicates significantly negative relationship between tea height and tea density (coefficient = -3.796, p-value = 0.0121).

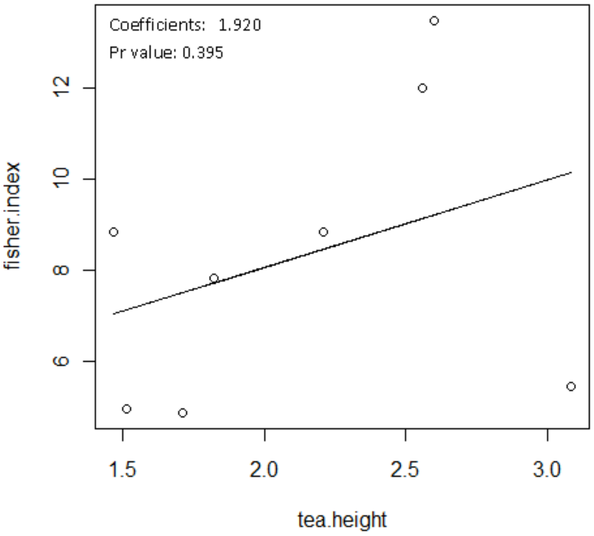

FIGURE 3. Relationship between Fisher's alpha index and tea height.

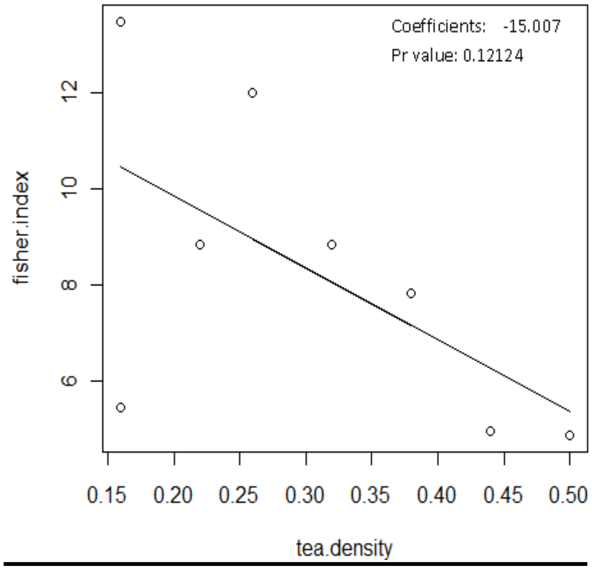

FIGURE 4. Relationship between Fisher's alpha index and tea density.

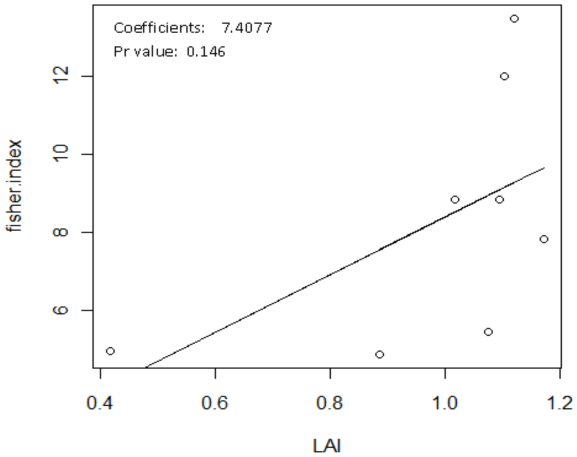

FIGURE 5. Relationship between Fisher's alpha index and forest cover (LAI value).

Figs. 3, 4 and 5 indicate the relationship between Fisher's alpha index and the three predictors: tea height, tea density and LAI value when considering three predictors separately. Tea height and LAI value have positive but non-significant relationship with diversity of butterfly communities, while tea density shows negative but non-significant interaction.

Fig. 6 indicates the relationship between butterfly species composition and the environment factors, including tea height, tea density and forest cover. Tea density appeared to be the most important factor affecting the biodiversity of butterfly species. Some species such as *Eurema hecabe*, *Pareronia* *anais* and *Neptis magadhan* shows preference in the system with higher tea density, while *Sumalia daraxa* and *Hebomoia glaucippe* are more abundant in the areas with higher forest cover. In addition, *Cepora nerissa, Mycalesis fraucisea Sanatana* indicate close linkages with tea height factor and more abundance the system with higher tea trees.

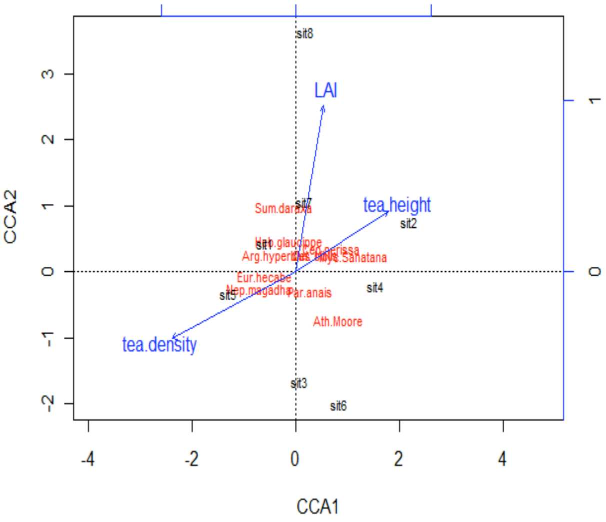

FIGURE 6. CCA analysis between environment factors and butterfly species collected (abundance>=3).

ENVIRONMENTAL FACTORS AND FUNCTIONAL BUTTERFLY GROUPS BY COLORS.— Fig. 7 shows the ratio of dark and bright butterfly species on the basis of their incidence in different survey sites by tea height. None of the detected patterns was significant, but there is a trend that in the areas with higher tea trees, there is higher ratio of dark butterfly species observed. Conversely, bright butterfly species are more abundant in the systems with lower tea height. Similarly, the relationship between forest cover and the ratio of dark/bright butterfly species are described in Dark species appeared to prefer to areas with lower forest cover (Fig. 8). In higher forest cover systems (LAI>1.076), it is quite equal number of dark and bright butterfly species observed.

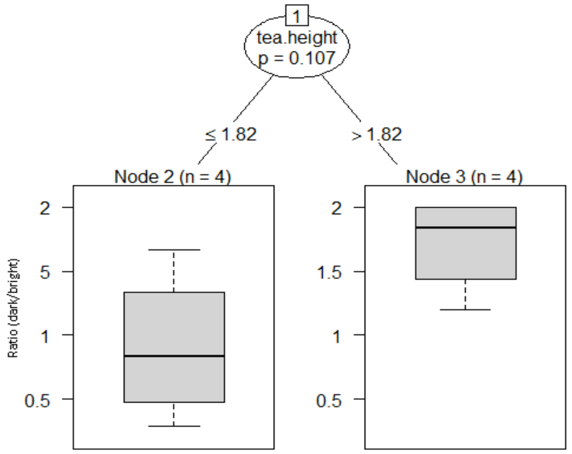

FIGURE 7. Classification tree of butterfly color-functionalgroups by tea height (based on species incidence).

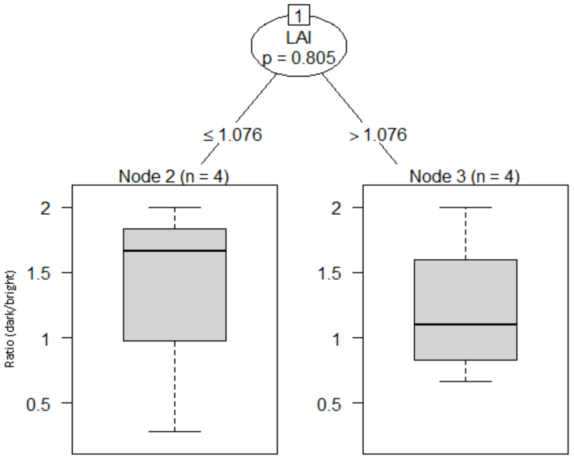

FIGURE 8. Classification tree of butterfly color-functional groups by LAI (based on species incidence).

DISCUSSION

More than half of the butterfly species we collected were in the rarest abundance classes, the singletons and doubletons. This can be considered as the results of lacking replications for the survey sites, where can be the preferred environment of some specific species. In addition, the total time to sample butterflies in each plot is only two hours and therefore the chance to meet duplicate species is also limited. With the high number of singletons, the total missing butterfly species in surveyed sites is estimated to be 40 species.

Even our data are not strong enough to reject the negative relationship between forest cover and butterfly biodiversity, but there is positive trend that in the area with higher canopy, there is higher butterfly biodiversity. This was explained by the relationship between light condition and distribution of butterflies from ground to forest canopy by Dumbrell and Jane (2005). As observed, the LAI values of most of most of our research sites range from 0.8-1.2. With a narrow ranges of forest cover surveyed, our data were not strong enough to conclude a significant positive linkage between forest cover and butterflies cover. In addition, it can also be assumed that the tea system represents a better habitat for butterfly caterpillars to develop when the forest cover is increasing within the surveyed forest cover range.

In addition, there is a potentially negative relationship between tea density and butterfly biodiversity. It is logical in considering previous researches on linking between understory cover and fauna biodiversity (Taki *et al.* 2010). It is generally the case that in systems with lower tea density, there are more areas left for understory herb to grow better, which in turn attract more butterfly species. The negative relationship between tea height and tea density explains why in the areas with higher tea trees, there were more butterflies.

Interestingly, the classification of butterfly colour groups by forest cover supports different distribution of dark and bright butterfly species in various tree covers. Our results indicate that there is higher ratio of bright butterflies over dark butterflies in the areas with better forest cover. In darker environment with higher forest cover, butterfly species may need to be more colourful to attract mates who look for certain colors and patterns (Join Enchanted Learning 2011). Functional classification suggests that dark and bright butterfly species may be attracted differently to different forest cover and storey.

Overall, although our study was limited by time and scale, there is potentially a relationship between butterfly biodiversity and the environment factors of the systems, including tea density, tea height and forest cover. Further analysis indicates different functional distribution of butterflies by colors under varied conditions.

ACKNOWLEDGEMENTS

We would like to appreciate all resource staff in AFEC-X 2011 who gave their valuable time to support this field course and made the course running smoothly and excitingly. Special thanks to Dr. Cao Kunfang, Dr. Chen Jin (XTBG Director), Dr. Doug Schaefer, Dr. Doug Yu, Dr. Fan Zexin, Dr. Ferry Slik, Dr. Jacob Wickham, Dr. Jeremy Miller, Dr. Qie Lan, Dr. Shi Lingling, Dr. Richard Corlett and Dr. Rhett Harrison for technical supports and encouragements. We wish to thank to the financial sponsors and the Xishuangbanna Tropical Botanical Garden. This field course could not be held without the support of XTBG. Thanks to all participants for sharing experiences.

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The Relative Abundance and Proportions of Web-building and Wandering Spider Functional Groups in Leaf Litter Are Determined by Prey Availability

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ABSTRACT

The litter layer in tropical forests supports high arthropod diversity. Spiders play an important role in shaping and controlling these communities as a main predator group. Within litter dwelling spiders, two contrasting hunting strategies can be recognized: free wandering and web-based hunters. Our objective was to determine if and how prey abundance affects the proportion of both spider groups in a community. We expect that wandering spiders will be more important in relative abundance than web-spiders under high prey abundance conditions because they can actively track prey. To test this we studied wandering and web building spider groups within the litter layer of the seasonal tropical forest at Bulong Nature Reserve in Xishuangbanna, China. Leaf litter was collected from seven plots including four plots in old growth forest and three in secondary forest. Winkler bags were used to separate arthropods from litter. Litter depth, canopy cover, slope and soil moisture were also measured within sampling units. GLMM (Generalized Linear Mixed Models) were used to assess effects of prey availability on spider functional group abundance. Our results showed that prey abundance was the main driver of spider abundance while environmental variables accounted for limited variation in spider community composition. Contrary to our expectations, the proportion of web building spiders relative to wandering spiders was higher when prey was abundant. Our results give evidence that web building spiders in tropical leaf litter communities may be more dependent on prey abundance than wandering spiders. The free hunting wandering strategy, on the other hand, can exploit both low and high prey abundance conditions.

***Key words**:* Bulong Nature Reserve, functional diversity, litter communities, spider guild

LEAF LITTER LAYERS WITHIN TROPICAL FORESTS support extensive levels of arthropod diversity and biomass. These arthropods play a crucial role in litter decomposition by breaking down larger litter fragments (such as leaves and woody debris) into smaller fragments, thus greatly increasing litter surface area available for microbial breakdown. The obligate predatory role of spiders in the litter layer makes them particularly important in shaping the litter arthropod communities (Wise 1993), but the litter arthropod community, and especially its abundance and biomass can also influence the assembly of spider communities (Castro and Wise 2010). Toft (1999) suggested that spiders select prey based on size and behavior, and several groups of spiders have been observed to use more than 10 arthropod orders as prey. Uetz and Hartsock (1987) found that with orb weavers smaller prey are likely to be ignored whereas prey close to spider body size are attacked. Boeve (1991) suggested that spiders can choose large prey items because they can kill prey with venom.

Two widely accepted functional spider groups with alternative hunting strategies are web spiders and wandering spiders. Wandering spiders often take smaller prey items in relation to body size than web spiders under laboratory conditions (Enders 1975).

Our objectives were to investigate the effect of prey abundance on spider functional group structure and absolute abundance within the leaf litter layer. We hypothesized that compared with web building spiders, the abundance of wandering spiders should be stronger correlated with prey abundance because of their mobility; hence their ability to migrate to areas with high prey numbers. So although we expect both functional groups to have higher diversity and abundances in plots with high arthropod prey densities, the relative abundance of wandering spiders as compared to web-based spiders should increase stronger with increasing prey abundance.

METHODS

STUDY SITE.— Our research took place within 7 previously established forest plots at Bulong Nature Reserve located at the southern tip of Yunnan province China, and within 10 km of the border with Myanmar. The reserve consists of a patchy landscape with both secondary and old growth forest interspersed with terraced tea and other open landscapes. Elevation of the reserve varies between 1500 and 1800m and is classified as primarily seasonal tropical rainforest with mean annual temperatures ranging between 15-21°C.

DATA COLLECTION.— In each of the previously established 7 1-ha plots we placed four 1x1 m sample quadrats, resulting in a total of 28 quadrats. On each side of a plot two quadrats were positioned 50 m apart and thus 100 m from the pair on the other side. Four plots were located within old growth forest and three within secondary forest. To sample each quadrat we first placed a 7cm high barrier constructed of bamboo surrounded by plastic wrapping around its perimeter to reduce arthropod escapes. At five pre-determined points within each quadrat, litter depth and soil temperature were measured with a metric ruler and soil thermometer, respectively, to obtain an understanding of their variation within quadrats. Additionally we estimated canopy, breast and knee cover using a hand held spherical densiometer. Any observed arthropods were captured if possible, during the sampling phase. Immediately after measuring we pushed all litter within the quadrat to the center with a wide plastic shovel. The collected litter was then placed into plastic Ziploc bags while collecting any escapees with an aspirator. Finally a soil sample of approximately 50 g was collected with a vial pressed into the soil surface to approximately 5 cm depth.

Collected litter was transferred to Winkler bags after sifting for one minute with a 1 cm mesh size soil sifter. Sifted litter was searched quickly for escaping insects in large plastic trays and then sifted again for one minute before pouring it into the inner net of a Winkler bag. While the sample gradually dries up inside the Winkler bag, invertebrates start moving out of the inner net and fall down in a cup filled with ethanol at the bottom of the Winkler bag. After 24 hours all bags were checked and searched for surviving arthropods. Then the content was remixed and placed back into the Winkler bag to facilitate further drying. At 48 hours bags were removed and we searched thoroughly for 5-10 minutes before discarding excess.

In the lab we removed 5g from each soil sample and measured the mass. After 30 minutes drying in a soil oven at 100°C we measured once more. The difference in soil mass gave an approximate measure of moisture percentage in the soil samples.

Arthropod samples were sorted by order under a stereo-microscope All captured arthropods above 1mm in size were measured and identified as spider predator, spider prey, or NA for unknown interactions. We excluded adult coleopterans, millipedes and centipedes from prey because of their strong anti-predation defenses. Additionally, prey were classified into size groups. Moreover, all spiders were measured, identified to functional guild, and morphological species Voucher specimens for each morphological species were separated and curated in 95% ethyl alcohol for future reference.

DATA ANALYSIS.— All statistical analyses were performed with R (R Development Core Team 2011). CCA (Canonical Correspondence Analysis) was used to determine the importance of environmental factors on spider guild makeup. Multiple regression with GLMM were used to test our main hypothesis. Mantel Tests were performed on size matrices of prey and both spider guilds to determine correlations in spider and prey sizes.

RESULTS

Within the 28 1x1m quadrats we collected 4625 arthropods of which 482 were spiders. The collected spiders consisted of 66 morphological species.

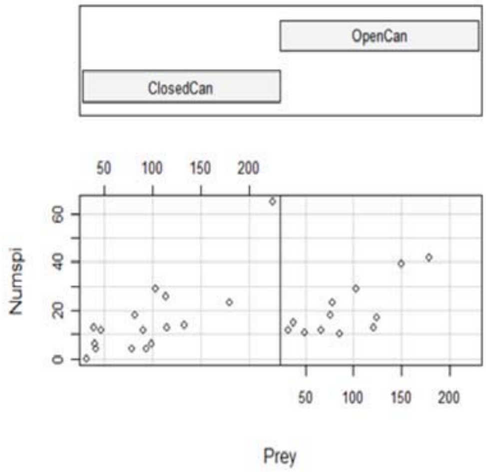
The trends between the total number of spiders and prey abundance did not differ between habitat types of old growth and secondary forest (Fig.1). The CCA (Fig. 2) showed no significant correlation between the environmental factors and spider species composition (Sig=0.343, Permutations=999). Both wandering and web spider abundances were positively correlated with prey abundance, while habitat was not a significant term (Fig. 2). The most parsimonious predictor for both wandering and web spider abundance was prey availability (Table 1).

Overall size distributions of both wandering (r= 0.3005, Sig=.027) and web (r= 0.6215, Sig=.001) spiders correlated with prey sizes (Table 2). However, web spider size distributions correlated more closely with that of their prey. Although both wandering and web building spiders increased in numbers with increasing prey availability, the relative proportion of web builders increased more than that of wanders when prey availability increased (Fig. 3). Figure 4 shows that the proportion of wandering to web building spider species does not change with increasing prey availability.

TABLE 1. *The model selection parameters for spider guild interactions including 6 models of 3 comparisons each, give evidence for prey as the most parsimonious predictor for spider guild.*

Model	Intercept	Std Error	Df	Pr (>|z|)	AIC$_c$
WanderSpiders.Prey	1.462223	.199958	27	2.62e-13 ***	69.904*
Prey	0.007398	0.001495		4.95 7.50e-07 ***	
WanderSpiders.Litter	2.73701	0.24310	27	2e-16 ***	88.134
Litter	-0.17834	0.06861		0.00934 **	
WanderSpider.Moisture	2.0314	0.4267	27	1.93e-06 ***	94.734
Moisture	0.2120	0.5255		0.687	
WebSpiders.Prey	0.46994	0.26882	27	0.0804	86.614*
Prey	0.01299	0.00164		2.3e-15 ***	
WebSpiders.Litter	2.01692	0.37709	27	8.86e-08 ***	157.653
Litter	-0.07494	0.07451		0.315	
WebSpiders.Moisture	-0.2816	0.6737	27	0.675946	145.4
Moisture	2.6843	0.7722		0.000508 ***	

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



FIGIURE 1. Co-plot of total spider abundance against total prey items within closed canopy (old growth) and open canopy (secondary) forest within litter layer sub-plots of Bulong Nature Researve.

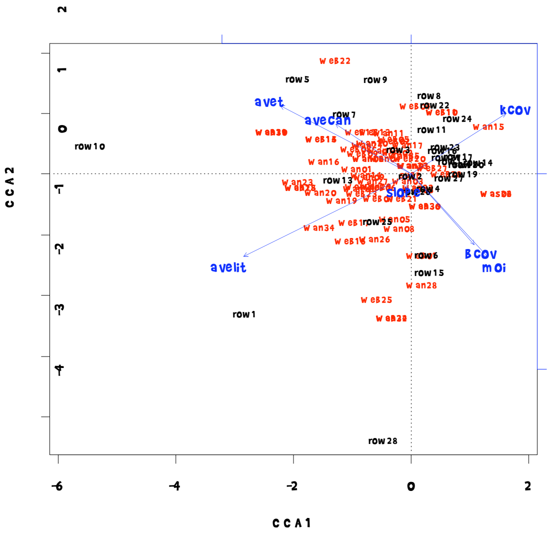


FIGURE 2. CCA analysis of environmental factors of average litter depth (avelit), percent moisture (moi), breast cover (bcov), average temperature (avet), canopy cover (avecan) and knee cover (kov) on 66 species found within the litter layer quadrats of Bulong Nature Reserve.

TABLE 2. *Distance matrices analysis of prey size distributions to spider distributions within spider guilds of the litter layer from quadrats of Bu-long Nature Reserve.*

	Available/Web	**Available/Wander**	**PreyDist/Web**	**Wan**
Mantel statistic r	0.5541	0.2227	0.6215	0.3005
Significance	0.003**	0.079	0.001**	0.027*

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

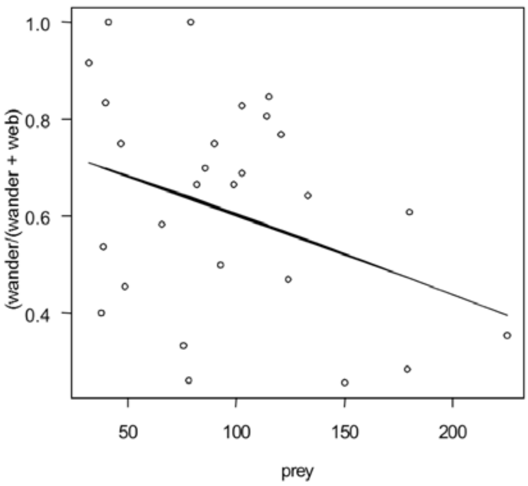


FIGURE 3. Proportion of wandering spiders to web spiders as prey items increase within 1×1m leaf litter sub-plots at Bu-Long Nature Reserve, Mengsong China.

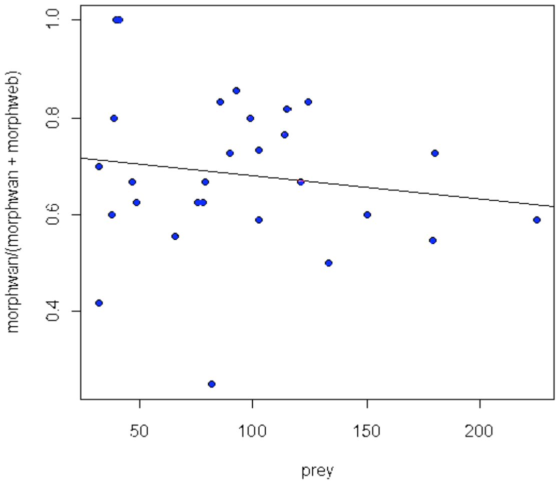


FIGURE 4. Proportion of wandering species to web species as prey items increase with 1×1m leaf litter sub-plots at Bu-Long Nature Reserve, Mengsong China.

DISCUSSION

A number of studies (Horváth *et al.* 2005; Stevenson & Dindle 1982) have argued that environmental parameters such as litter depth, characteristics and moisture are the most important factors in determining abundance of spiders within the leaf litter. Most of these studies were conducted in the temperate where such parameters can vary widely within the same forest and from season to season. Our models showed that environmental factors were not as important as prey abundance in determining spider communities of the litter layer in the tropics (Table 1). In the tropical rainforests there is less variation of temperature and humidity than in temperate forests. We suspect that for soil temperature there was not enough variation to test for importance, however there were strong gradients in canopy cover, and soil moisture.

Body size is important in determining what arthropods are available to spiders as prey. We initially expected wandering spider body sizes to correlate more evenly with prey body sizes because they lack the advantage of webs. In contrast our results showed that web builder body size distributions mirrored available prey body size distributions more closely with higher r values and significance than wanderers (Table 2). Previously we mentioned that spiders on webs attack prey close to their body size (Uetz & Hartsock,1987). Our results give further support for this pattern in the litter layer.

We also expected wanderers to increase in relative abundance with more abundant prey. In fact, contrary to our assumption the success of the web building strategy appears to be closely linked to prey densities. The proportion of web-building spiders to wandering spiders was in general lower. We found when prey densities were high, the ratio of web-building spiders to wanderers rose (Fig. 3). The findings may be a factor of site selection strategy. Furthermore web spiders are tied to their ambush site and therefore gain little reward from setting nets in areas with prey outside of their available size range.

In terms of species richness, the ratio between web building spiders and wandering spiders did not change with prey abundance (Fig. 4). We attribute this to the ability of one particular species, of the family Therididae to capitalize on high levels of prey abundance within the litter layer. Further study using long term manipulations of prey availability may yield insight into the driving factors of the surprising functional response in web building spiders.

Sources of Error:

Toft (1999) suggested that coleopterans like staphilinid beetles can make up a substantial portion of prey for some groups of spiders. We excluded the entire order on the basis that armor makes the group less appealing than highly attractive. holometabolous immature insects (HII) and other easy prey. Further studies would include specific families of known spider prey. In addition we did not account for the presence of spider predators with our models and it stands to reason that guild group success must have a relationship with their predators as well as prey. Further research should classify prey items to morphological species to determine whether diversity of prey has a similar relationship to spider functional group proportions.

Additionally we garner support for deeper interactions between spider prey and guild makeup in the tropics than that of environmental factors. This study suggests that prey have a strong influence on the success of functional strategy and the abundance of spiders within the leaf litter, however further analyses should be made on broader spatial scales.

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Vertical Abundance and Composition Distribution of Long Horned Beetles in Montane Tropical Forest of Mengsong, China

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ABSTRACT

This study examined the effect of vertical stratification of the long horned beetles (LHB, Cerambycidae), and other associated arthropods in the rain forest in Bulong Nature Reserve, Xishuangbanna, China. Pheromone intercept traps were employed to attract LHB at three heights (1 m, 5 m, and canopy (~18m)) on 18 trees. We collected a total of 59 individuals of LHB belonging to 18 morpho-species. The diversity of LHB in canopy height was higher than the understorey. However, some species showed height preference to either the canopy or the understorey. Four species of the LHB were significantly attracted to pheromone 3 hydroxy-2 hexanone. The NMDS analysis found that axis one roughly corresponded to pheromone type and axis two to canopy height. Predator beetles collected belong to four families: Cleridae, Carabidae, Cicindelidae, Staphylinidae. The abundance of predators in pheromone 2-undecyloxy-1-ethanol was significantly higher than that in the other baits. Predator beetles also showed significant association with pheromone type and canopy height, with more being captured in the canopy. Bark beetles (Scolytidae) were effectively captured by pheromone and one species show preference to canopy height. We conclude that bark beetles and Cleridae are both using LHB pheromones as kairomones to locate hosts and prey.

Key words: arboreal arthropods, Bulong Nature Reserve, Coleoptera, species richness

THE LONG HORNED BEETLES (LHB) belonging to order Coleoptera and family Cerambycidae are an entirely phytophagous group of insects; composed of species that feed on a range of woody and herbaceous plant species (Linsley 1959). Contact pheromones play an important role in mating system (Lacey *et al.* 2008) and therefore signalling molecules are critical in the life history of cerambycidae (Allison *et al.* 2004). Adult Cerambycids can be attracted to plant volatiles (from inflorescences as well as from trunk and leaf volatiles of larval hosts), the pheromones of bark beetles and their own sex pheromones. Chemical cues also regulate oviposition through stimulation at available hosts and through deterrence at occupied hosts (Borden *et al.* 2004).

Most species of LHB feed on dead and decaying woody host materials (Yanega 1996) and thus playing an important ecological role in breakdown of dead wood (Harmon *et al.* 1986), while a few species are recognised as important pests due to their wood boring tendencies (Beal *et al.* 1952, Donley & Acciavatti 1980, Galford 1916, Solomon 1980).

The chemical ecology of the cerambycide is little known as compared to heir geographical distribution and taxonomy. The scarcity of information can be attributed to their low economic importance, nocturnal habit and rarity of many taxa (Hanks 1999). Although the ecology of long horned beetles is not well known, they represent an ideal group of insects for ecological studies, with established taxonomy, wide geographical distribution and conspicuous adults

Sampling cerambycids in forest canopies is rare although they are known to display preferences for specific regions of trees (Krinsky & Godwin 1996, Vance *et al.* 2003). Krinsky and Godwin, (1996) sampled cerambycids by canopy fogging, but no comparative study between the community structure of canopy and understorey was carried out. The advantage of sampling at multiple levels (heights) rather than sampling at one height is that they provide a more representative sample of the community and a comparison between understorey and canopy community (Vance *et al.* 2003). Also it tends to avoid the usually understorey based vertical bias in inter site comparisons (Su & Woods

2001). By comparing the composition of ecological guilds between the canopy and the understorey, information also can be obtained on the vertical stratification of ecological processes in the forest. (Vance *et al.* 2003).

We studied the abundance and species richness of the long horned beetle at different canopy heights using pheromone lures and intercept traps. In addition we investigated the abundance and diversity of the bark beetles and predator species captured in the same traps.

METHODS

STUDY SITE.—The study was conducted in rain forests of Mengsong, which is located in Bulong Nature Reserve, Yunnan Province, China (Fig. 1). The study site has a typical monsoon climate with three distinct seasons distributed throughout the year as follows: 1. A humid hot rainy season that runs from May to October; 2. A foggy cool-dry season from November to February; 3. A hot-dry season from March to April. Mean annual temperature ranges from 15.1°C to 21.7°C, and precipitation between 1200 and 2500 mm. Rainfall during the wet season between May and October accounts for over 80 percent of total annual precipitation. With an undulating topography and its location on the edge of the tropics, a great variety of ecological communities are found here (Wang and Lu. 1987). It is considered as a priority biodiversity conservation area (100º24'48"-100º40'25" E; 21º56'54" -22º16'56" N; 1640 m a.s.l.).

STUDY DESIGN AND INSECT SAMPLING PROCEDURE.—We selected 18 trees in old growth forest in three transects, each with six trees (Fig. 2). Pheromone intercept traps were hung at three different heights in the trees: viz. 1 m, 5 m and the canopy (18.2m±1.1m). The minimum distance between the trees with traps was 15 m. A total of 54 traps were employed with six different pheromone treatments.

LHB were sampled from November 9th to November 23rd, 2011. We used pheromone traps as they are sensitive and can attract insects present at very low density in the forests. Collecting containers at the bottom of the traps were filled with soap water to ensure that the beetles that fall in could not escape.

According to previous study (Wickham unpublished), we chose the compounds, which captured the most species in the same area, 3-hydroxy-2-hexanone (50 mg/lure), 2R*,3R*-octanediol (50 mg/lure), 2R*,3S*-octanediol (50 mg/lure), and 2-undecyloxy-1-ethanol (25 mg/lure). Compounds were formulated in ethanol and lures were prepared by adding 1 ml ethanol solution to small polyethylene ziplock bags and sealing the zipper. All the traps were operated continuously for the study period. To control for spatial effects, we rotated the traps one tree position (keeping the same height) after 5 days and made the final collection after a further five days hence we made two temporal replicates. Specimens were collected, sorted to morpho-species, and preserved in 99.9% alcohol.

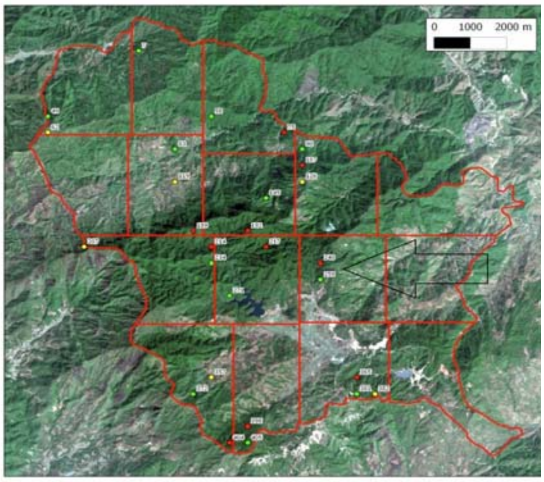

FIGURE 1. Mengsong study area, with the arrow indicating is our study site.

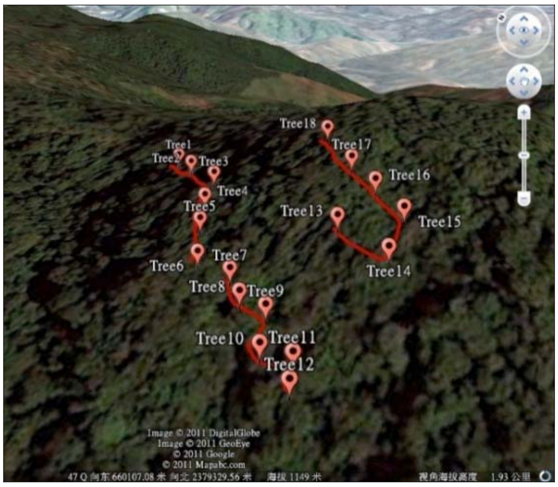

FIGURE 2. The location of the trees with traps in Bulong Nature Reserve, Mengsong, China.

DATA ANALYSIS.—Differences between treatments in numbers of beetles captured per trap were tested separately for the two most abundant species. We used a nonparametric test to compare the abundance of each species of LHB, predator beetle and bark beetle in different treatments and at different tree heights, as the number of zeros precluded using linear models. Generalised Linear Model (GLM) was also conducted to compare the abundance of the predator beetle species and the bark beetles.

All analyses were conducted in R 2.13.2 (R Development Core Team 2011). Estimation of species richness was performed using Estimate S 8. 20. Fisher's alpha Index was used for diversity of LHB at three different trap heights (1m, 5m, canopy). The Chao-Jaccard Index was used to compare the species richness and the shared species both for height.

Nonmetric Multi-Dimensional Scaling (NMDS) was employed to explore the dissimilarities among species, based on treatments and heights in order to support and explain the nonparametric rank tests in ordination.

RESULTS

LONG HORNED BEETLE ABUNDANCE AND DIVERSITY.—We collected a total of 59 individuals of LHB belonging to 18 morpho-species (Table 1). 3 hydroxy-2 hexanone proved to be the most effective lure than other treatments. The abundances of 4 species were significantly associated with 3 hydroxy-2 hexanone ($p < 0.001$). Abundance of one species is significantly higher in 2R, 3R octanediol lure ($p < 0.05$).

The diversity of LHB in the canopy was higher than in the understorey (1m and 5m; Table 2) with more species and abundance.

The LHB community in the canopy shared the fewest species with that of the lower understorey (1m in height); the canopy LHB diversity was also significantly different between canopy and lower understorey (Critical value = 0.53; Fig. 3). Only one species showed a significant preference for the canopy ($p < 0.05$).

For NMDS analysis, the result showed that 5 species were clearly in one cluster for 3 hydroxy-2 hexanone as suggested by Nonparametric Rank test. Other species show a correlation with trap height which means LHB species abundance is different in trap heights but more data needed to get more detail. (Fig. 4).

PREDATORS AND BARK BEETLES.—We collected a total of 90 individuals of predator beetles belonging to 4 families (Cleridae, Carabidae, Cicindelidae, Staphylinidae) and 13 morpho-species. According to the generalis-ed linear model, the abundance of predators in 2-undecyloxy-1-ethanol is significantly higher than the other treatments ($p < 0.05$). Also the abundance of predators in canopy height is significantly higher than in the understorey ($p < 0.01$). Nonparametric Rank test shows that one species of Cleridae significantly attracted to pheromone 2-undecyloxy-1-ethanol ($p < 0.01$) and canopy height ($p < 0.05$).

We also collected a total of 213 individuals of bark beetles belonging to 4 morpho-species in the family Scolytidae. As Fig. 5 shows, the abundance of bark beetles in 3 hydroxy-2 hexanone (code C, $p < 0.01$), 2R*, 3S*-octanediol (code E, $p < 0.01$), 2-undecyloxy-1-ethanol (code H, $p < 0.05$) are significantly higher than the other treatments. And the abundance of bark beetle in 5m and canopy heights are higher than in 1m height ($p < 0.05$). Nonparametric Rank test shows one bark beetle species show preference to 3 hydroxy-2 hexanone ($p < 0.01$) and other two species have a higher abundance in pheromone 2R*,3S*-octanediol trap, one of the four bark beetle species show a significantly higher preference to the canopy height ($p < 0.01$).

TABLE 1. *Species richness and abundance of LHB in different treatments.*

Treatment	Code	Species richness	Species Abundance
hydroxy-2 hexanone	C	10	37***
2R*,3R*-octanediol	D	5	6*
2R*,3S*-octanediol	E	3	4
2-undecyloxy-1ethanol	H	6	8**
Ethanol	EB	3	3
Blank	B	1	1

p<0.05, ** p<0.01, ***p<0.001

TABLE 2. *LHB species abundance and diversity at different trap heights.*

Height	Species richness	Species Abundance	Fisher' alpha
1m	5	10	3.98
5m	10	22	7.08
canopy	12	27*	8.28*

p<0.05, ** p<0.01, ***p<0.001

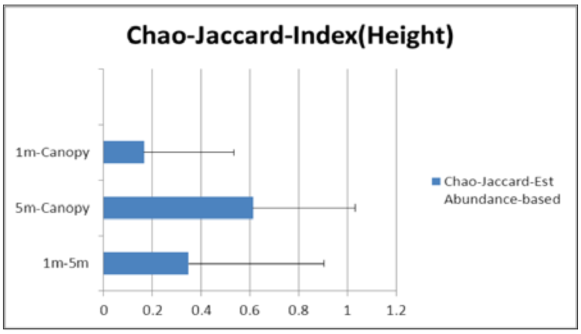

FIGURE 3. Chao-Jaccard similarity Index for different trap heights.

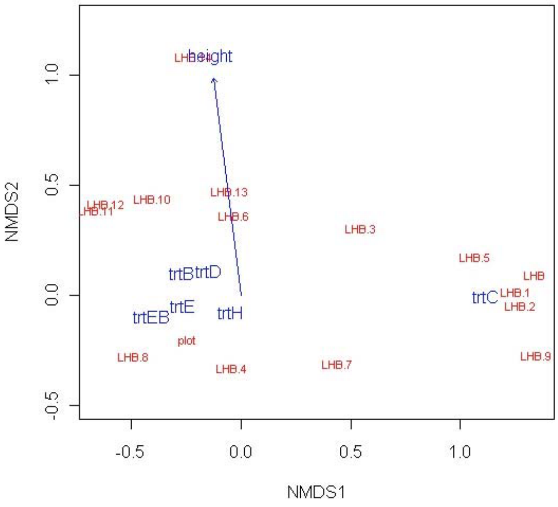

FIGURE 4. NMDS of morpho-species and treatment and height.

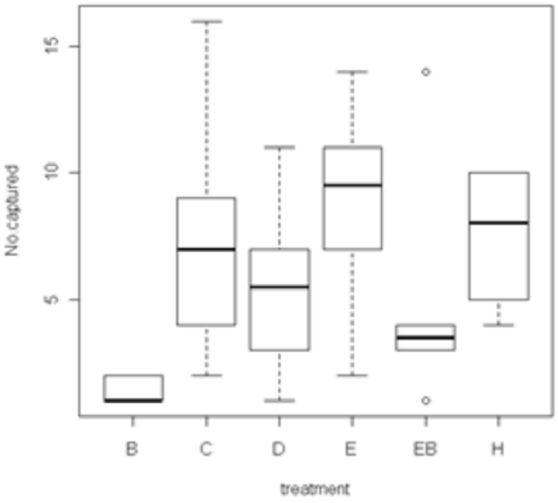

FIGURE 5. Abundance of bark beetles in 6 pheromone treatments.

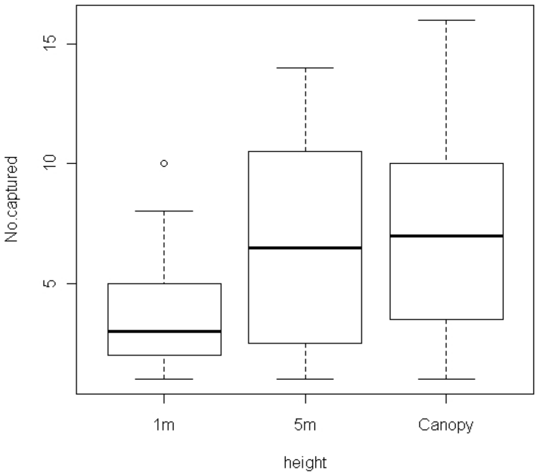

FIGURE 6. Abundance of bark beetles at three trap heights.

DISCUSSION

During our study we collected 18 species of LHB in 10 days (1.8 species/day), while a similar study in the same area during summer 2010 (at 1 m height only) collected 62 species of LHB in a period of 28 days (2.2 species/day) (Wickham unpublished) The lower species richness and diversity can be attributed to the short study period and likely also the cool dry season; as the insects may be less active during this period of the year. Out of the 18 species we caught, only five were captured in 2010, indicating that different species may be active in different seasons then the community of the LHB in the old forest in different season is different, also different in height. It is better to consider all the season and all the heights to do the biology and ecology study about LHB.

3 hydroxy-2 hexanone proved to the most effective lure, and significantly attracted four species which belonging to cerambycine of LHB, which can be used for other study to capture LHB as a reference. Our results support that multiple cerambycine species will be attracted to compounds of diol/hydroxyketone pheromone motif, and the attraction of multiple species from different cerambycine tribes to this compound at a single field site supports the hypothesis that the hydroxyketone pheromone structural motif is highly conserved within this subfamily (Hanks *et al.* 2007).

By placing the pheromone interception traps both in the canopy and in the understorey, we increased our representation of the cerambycid community. Out of 18 species, only three were captured both at 1m and canopy, and four at both 5m and canopy. Although cerambycids are considered to be strong active flyers, Bense (1995) argued that some species live their entire adult lives in the tops of host trees, where all their feeding and oviposition requirements are met. Our data support this idea for at least six species, which were captured only at canopy height but more sample size needed.

The result of the NMDS analysis indicates that some of the morphospecies showed height preference, which proved our hypothesis of the long horned beetles have a height preferen-ce to the pheromone traps. Our data was limited both by time period and sample size, hence detailed study is required to support these findings. Some study have found certain cerambycid species display preferences for specific regions of trees (e.g., roots versus canopy) to which maturation, mating, or oviposition may be restricted (Krinsky & Godwin 1996; Vance *et al.* 2003), so it is very important to know the life history of the long horned beetles and their predators' life history. By combining the life history study, we can truly know whether the LHB have height preference or not and why they show the height preference.

Ninety individuals of predator beetles belonging to 4 families (Cleridae, Carabidae, Cicindeli-dae, Staphylinidae) and 13 morphospecies were captured in our trap which proved pher-omone trap can also attract predator beetles especially Cleridae. One species of Cleridae show significant difference to lure 2-undecyloxy-1-ethanol and canopy height ($p < 0.01$), which is similar to some species of LHB. This supporting our result that Cleridae have interactions with some LHB and share some similar host or have prey relationship.

Out of 108 traps, four species of bark beetles (Scolytidae) were captured in 105 traps, as Fig. 7 shows, four species were both found in 1m and canopy height, each of them has a height preference, with more number captured respectively.

Host colonization in the Cerambycidae is somewhat analogous to that in bark beetles (Scolytidae), i.e. phases of dispersal, selection, concentration, and establishment (Wood 1982). Putative primary attractants (kairomones) have been identified for many ceramby-cids including bark beetle pheromones. Larvae of cerambycids feed and develop in the phloem and xylem of healthy, stressed or recently dead trees and often overlap spatially and temporally with other members of this guild, particularly bark beetles (Allisonn *et al.* 2004). They have classified the sub-cortical interactions between bark and longhorned beetles as competitive and commensal. It is interesting to consider the interactions between long horned beetles, and predators in the ecology of this system.

All the bark beetles and predator beetles were captured in four types of pheromone lures and they are attracted to pheromone tarp significantly ($p < 0.01$). So we support that bark beetles and Cleridae are both using LHB pheromones as kairomones to locate hosts and prey, respectively. Detail studies on the life history of predators and LHB is required to know interactions between them. It is a good way to analyse the chemicaly mediated communication between LHB and predators.

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Ontogenic and Environmentally Induced Variation in the Mechanical Properties of a Rain Forest Canopy Tree

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ABSTRACT

Due to the force of gravity, every living being need to be strong enough to support itself. For a tree trunk to sustain the increasing weight of the tree, there are two ways to achieve the same safety factor, one is to become wider and the other is to increase its material strength. Here we show that the hard-wood species invest more carbon in this trunk construction, but it gets a bigger potential growing margin. This may help us to understand why its maximum height is bigger than that of the soft wood species. We also discuss its implications in community succession.

> It is so arranged, that the trees do not grow into the heavens
> ----- *Dichtung und Wahrheit*

Key words: biomechanics, Bulong Nature Reserve, safety factor, succession, tree growth, Xishuangbanna

WHEN WE CONSIDER THE GROWING ENVIRONMENT FOR PLANTS, we always think of limiting factors such as light, water and soil nutrients. However, all living beings in this world cannot violate the laws of physics and chemistry (Niklas 1992). Gravity is one of the most common physical factors, which has great impact on evolution and performance of every life in this planet (Niklas 1998), but it was usually ignored. In order to withstand gravity, every living being must be strong enough to support itself (McMahon 1973, Niklas 1993).

The Euler-Greenhill function (McMahon 1973) from the material science pointed out that a trunk can achieve the same buckling height and then the same buckling safety factor by getting wider (bigger dbh/h) or getting stronger (higher E/Wd).

$$Hc = 0.792(\frac{E}{\rho})^{1/3} D^{2/3}$$

$$BSF = Hc / h = 0.792(\frac{E}{\rho})^{1/3} \frac{D^{2/3}}{h}$$

A point to note is that the outer part of the trunk account disproportional more for the stiffness of the trunk (Larjavaara and Muller-Landau 2010).

Pioneering trees are always heliophytes which grow fast with low wood density and low construction cost but short saturation height, while the climax trees always shade plant which need to invest more carbon on its trunk but have higher saturation height (Muller-Landau 2004).

Here we sampled one pioneering and one climax trees, by measuring its construction cost and the mechanical character of the trunk and the canopy area it get, we want to see whether the pioneering and climax trees have different strategies to support themselves and we discuss its implication for community succession. We hypothesized that, the pioneering species in open area employed the structure method to support itself (wider trunks), while the climax species living in inner areas employed the material strategy to support itself (stronger trunks). Although the climax trees may have a higher construction cost, they may in turn achieve a greater growing margin, which is of competitive benefit for them in the closed canopy forest where light is limiting.

METHOD

STUDY SITE.—The study was conducted in Bulong Nature Reserve, Xishuangbanna, Yunnan province, China. The annual rainfall is between 1600 mm and 1800 mm, the average annual temperature is around 18 ºC. The study was conducted from November 7th to 23th, 2011.

SAMPLING DESIGN.—*Litsea pungens* is a common pioneering species in the research area with no individuals higher than 18 m, while *Castanopsis mekongensis* is a common climax species with maximum height more than 35 m which can be found both in the inner forest and open area.

Trunk cost and mechanical characteristics

For each individual, we measured its height and height of the first branch, width of the crown in four directions. For individuals with more than 10 cm dbh, we sampled tree cores from the up slope and down slope sides of the trunk at 1m and 1.3 m from the ground respectively. All tree cores were submerged in water for 24 h and their toughness measured using a set of simple equipment (Fig. 1). Density specific strength is always proportional to density-specific stiffness (Niklas 1993). As saturation with water makes the wood weak, this method measures the minimum strength of the samples (Kollmann *et al.* 1975). Subsequently all these tree cores were oven dried at 100 ºC for 24 h and the dry weight was recorded. We calculated the volume of the cores based on the diameter (0.5 mm) and the length, and the wood density by dry weight/volume. Because the outer part of the trunk accounted disproportional more for the stiffness of the trunk (Niklas 1992, Larjavaara and Muller-Landau 2010), the outmost 5 cm of the tree core was used to for these measurements.

DATA ANALYSIS.—We used linear models to test the height-dbh, height-mass per unit length, and height-canopy area relationships, and whether the relationships differ between the two species. All data analyses were conducted using R (R Development Core Team 2011).

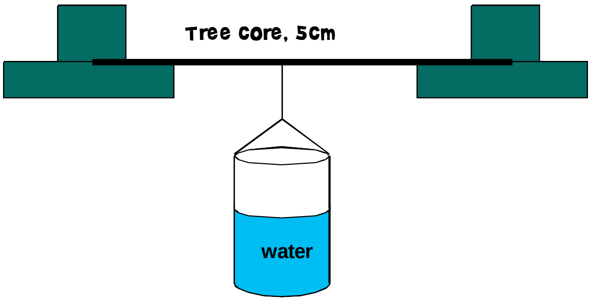

FIGURE 1. Experimental setup used to measure the strength of the tree core. Water was added into the at 50 ml increments until the tree core was broken. The weight of water at that point was recorded as the strength of the tree core.

RESULT

We measured 49 individuals of *C. mekongensis* and 27 individuals of *L. pungens* of different sizes, with their height dbh, dgh and the height of the first branch. Among these 14 *C. mekongensis* individuals and 16 *L. pungens* individuals were sampled for tree cores (two samples each, from both up and down slope sides of the trunk). The wood density readings of *C. mekongensis* were 0.41 ± 0.02 g/cm^3 (up slope) and 0.45 ± 0.01 g/cm^3 (down slope); the density-specific strength of *C. mekongensis* were 10.02 ± 1.63 Ncm^3/g (up slope) and 10.59 ± 1.51 Ncm^3/g (down slope). And the wood density of *L. pungens* were 0.66 ± 0.02 g/cm^3 (up slope) and 0.71 ± 0.01 g/cm^3 (down slope); and density-specific strength of *L. pungens* were 13.55 ± 1.57 Ncm^3/g (up slope) and 15.41 ± 1.34 Ncm^3/g (down slope). Although *C. mekongensis* had a higher wood density than that of *L. pungens* (0.69 ± 0.01 and 0.43 ± 0.01 g/cm^3 respectively, $P < 0.01$), it had a higher density-specific strength (14.48 ± 1.03 and 10.30 ± 1.09 Ncm^3/g respectively, $P < 0.01$).

In *C. mekongensis*, dbh increased more rapidly with h than in *L. pungens*, as seen in the different slopes of the two regression lines (Fig. 2, $P < 0.001$). The young individuals of *L. pungens* (shorter than 6 m) generally had higher dbh than those of *C. mekongensis* for the same heights. In oder individuals, however, *C. mekongensis* had greater dbh than *L. pungens* for the same heights.
For both species, the lg(mpl) is significantly positively correlated with lg(h), but the slope was significantly different steeper in *C. mekongensis*. For the range of height we sampled, *L. pungens* appeared to invest less mass in its trunk than *C. mekongensis*.

Canopy area was positively correlated with h for both of these two species, however the slope was different between the two species (Fig. 4). For younger individuals *L. pungens* always have bigger canopy than *C. mekongensis* (Fig. 4).

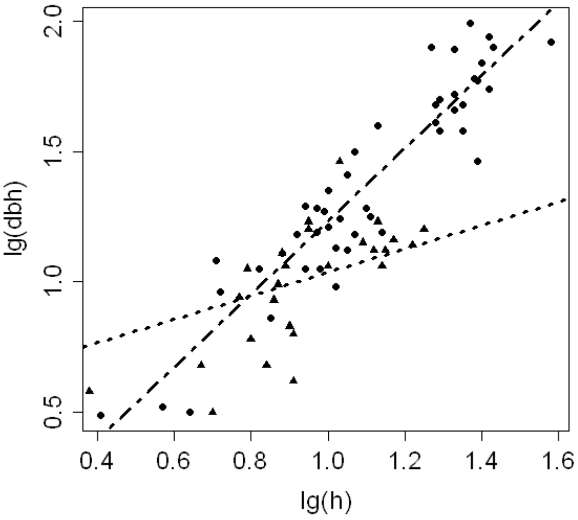

FIGURE 2. The relationship between log(h) and log(dbh), (circle and dot-dash line for *C. mekongensis*; triangle and dotted line for *L. pungens*).

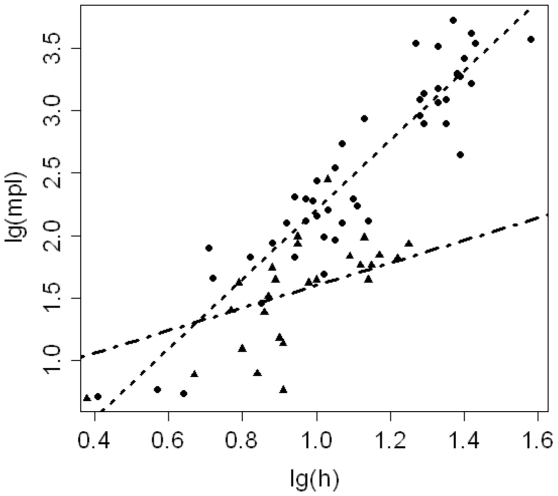

FIGURE 3. The relationship between log(h) and log(mpl), (circle and dash line for *C. mekongensis*; triangle and dot-dash line for *L. pungens*).

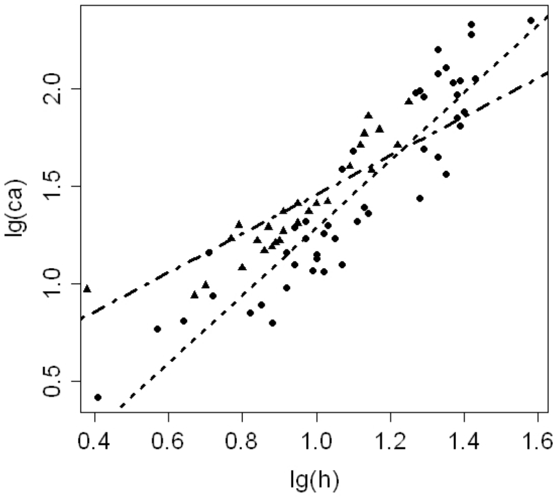

FIGURE 4. The relationship between log(g) and log(canopy area), (circle and dot-dash line for *C.mekongensis*; triangle and dotted line for *L.pungens*).

DISCUSSION

Although the young individuals of *L. pungens* have higher dbh/h, hence a bigger trunk volume (Fig. 2), but due to the lower wood density, they invest less mass per unit stem length than individuals of *C. mekongensis* (Fig. 3), and for a given height, the younger *L. pungens* always have bigger canopy area (Fig. 4). Both are strategies for *L. pungens* to grow fast to capture more light. This finding is consistent with reports of the tradeoff between rapid growth and increased risks of damage and mortality (King *et al.* 2006).

In terms of community succession, we can see from the result that the adult individuals of *C. mekongensis* have both bigger e/p and dbh/h. Therefore in general *C. mekongensis* has a bigger critical height (Hc) than *L. pungens* which gives it a bigger safety factor (a bigger grow margin). When approaching the saturation height of *L. pungens*, some external forces such as strong wind and the weight of woody lianas may cause *L. pungens* individuals to fall. In contrast, *C. mekongensis* individuals are more likely to grow in size and become the dominant species in late succession. Because *L. pungens* is a light-demanding plant, it tends not to survive well in the closed forest, therefore remains a pioneer species.

ACKNOWLEDGEMENTS

It would not have been possible without the kind support, advice and help of many individuals and organizations. We would like to acknowledge and gratitude to the following persons who have made the completion of this project possible: Our XTBG director, Dr. Chen Jin, our lecturers; Dr. Rhett D. Harrison, Dr. Qie Lan, Dr. Jeremy Miller, Dr. Jacob D. Wickham, Dr. Chuck Canon, Dr. Douglas Schaefer, and Dr. Ferry Slik. Our thanks and appreciations also go to all the staff in XTBG in developing the project and people who have willingly helped us out with their abilities. Thanks to all our friends for sharing experiences, knowledge and happiness throughout the course.

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Colonial Web Building Behavior of *Nephila clavata* L.Koch (Nephilidae) in a Forest Tea Plantation: When to Join the Crowd

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ABSTRACT

Animals may associate with companions for gaining protection, finding and monopolizing food, finding mates or rearing young. Here we studied the colony forming spider *Nephila clavata* in a forest tea plantation at Mengsong, Xishuangbanna, China, to determine if colony size was driven by prey capture efficiency - parasite infestation trade off. Web area, web height, spider body length, captured prey items and the numbers of kleptoparasitic and commensal spiders were compared among webs of solitary *Nephila* and those living in colonies of different sizes. Web area declined with the number of webs in the colony, after controlling for spider body size. However, there was no change in the capture frequency, nor estimated captured prey biomass per spider. Consequently, prey-capture efficiency increased with the number of webs in a colony. The increasing web height limited number of prey items, cumulative prey and prey capture efficiency. Number of kleptoparasitic spiders was highly variable and showed no pattern with number of webs in a colony while number of commensal spiders was highest for two web colonies and decreased rapidly with increasing colony size. The results suggest that when living in colonies, *N. clavata* use less energy than solitary individuals in building and maintaining their webs but have higher prey capture efficiency.

***Key words**:* colonial web, commensalisms, kleptoparasites, *Nephila clavata*, prey capture efficiency, sex ratio

SPIDERS CAN SHOW COMPLEX SOCIAL BEHAVIOR, varying from a completely solitary lifestyle to sharing overlapping home ranges (including web colonies) to corporative parental care. Social groups can be permanent or seasonal. By being social, a spider may obtain various benefits: it may save silk production by reduced per capita investment in colonial webs, increase its opportunities to catch larger prey and finding a mate, and reduce the risk of predation. On the other hand, there are some disadvantages of living socially. When a colony captures more prey, it creates a more attractive environment for kleptoparasites and other parasites and predators.

Nephila spp. are well known for their large yellow aerial webs. Generally, most of *Nephila* spiders live in solitary webs though social behaviors has been reported. However, in Mengsong, Xishuangbanna, China we found a large population of *Nephila clavata* in forest tea plantations of which some were solitary and some lived in colonies. This provided an opportunity to try and understand why spiders chose to live solitary or in colonies of different sizes. More specifically, our aim was to determine if colony size was driven by prey capture efficiency - parasite infestation trade off.

METHOD

STUDY SITE.—Project was conducted in Bulong Nature Reserve, Mengsong, Xishuangbanna, Yunnan, China, with annual rainfall of 1374 mm and average temperature of 18 – 21℃. The study site was a tea plantation area at the edge of closed canopy montane rain forest with total area of approximately 1000 m^2. Vegetation within the tea plantations consisted mainly of low tea shrubs and sparsely distributed trees.

PREY CAPTURE EFFICIENCY EXPERIMENT.—This project was conducted on adult females of *Nephila clavata* only. Colony size was determined by the number of adult *N. clavata* females found in a web or colony of webs.

All solitary and colonial webs of *N. clavata* with heights below 3 m in study area were first counted for total number of adult female *N. clavata*, then marked and mapped. Solitary and colonial webs were chosen randomly from the mapped webs. Each study web and the adult female *N. clavata* on the web were assigned unique ID numbers. Web area (length x width), web height from ground and spider size (combined length of head and abdomen) were measured with measured tape and ruler. Male *N. clavata* and other spider species on the web were counted, and captured prey remains were collected and kept in vials. Accumulated prey was determined by measuring the thorax width of all prey items using a microscope with calibrated ocular micrometer.

DATA ANALYSIS.—A T-test was used to compare web area and prey numbers in solitary versus colonial webs. The differences in number of prey, web size, size of prey/area (as prey capture efficiency) against colony size were tested with ANOVA. Moreover, ANOVA was also used to test if abundance of commensal/kleptoparasitic spiders in webs has a relationship with colony size. A Wilcoxon test was used to compare two groups, colonial and solitary webs in three categories: number of males, number of commensal spiders and number of kleptoparasitic spiders in webs. A generalized linear model with quasi-poisson error distribution was used to test the correlation between the number of prey items in webs and web size. The relationship between web height from ground with the number of prey and prey size were also considered in the linear model.

All tests were done in R software (R Development Core Team 2011).

RESULT

PREY CAPTURE EFFICIENCY.—Twenty-three solitary webs and 64 colonies consisting of between two to eight webs of *N. clavata* were chosen randomly from a total of 137 solitary webs and 118 colonies in the studied area.

Colonial webs were significantly smaller than solitary ones (t = - 0.8657, df = 28.179, $p = 0.03$). Adult female body length was positively correlated with web area ($p < 0.05$) and cumulated prey ($p = 0.001$). There was no significant difference in captured prey items or prey size versus colony size, whereas web size tended to decrease with increasing number of spiders in the colony (Fig.1).

Number and size of captured prey items and prey capture efficiency significantly declined against height of webs (Fig. 2).

Since web area was significantly correlated with colony size and spider size, the relationship between the number of prey items on webs and web area has to be tested with inclusion of these interactions. We used a generalized linear model with a quasipoisson error structure for this test. The result showed that captured prey items was not related to web size ($p = 0.2$).

Although colony size did not have a significant effect on total number of prey items and size (Fig. 1a & b), an increase in colony size led to an increase in prey capture efficiency (Fig. 3).

MALES, KLEPTOPARASITIC AND COMMENSAL SPIDERS.—Commensal spiders had a clear preference for small *N. clavata* colonies, but were absent in the solitary webs sampled. In contrast, the number of kleptoparasites was highly variable and showed no pattern of variation with increasing colony size (Fig. 4). In addition, the ratio of male and female *N. clavata* in colonies was approximately equal to that in solitary webs (0.51 and 0.52 respectively).

Number of males, kleptoparasitic and commensal spiders in webs were compared between 2 groups: colonial webs and solitary webs. The results showed all insignificant differences (p-value are 0.72, 0.53 and 0.4, respectively).

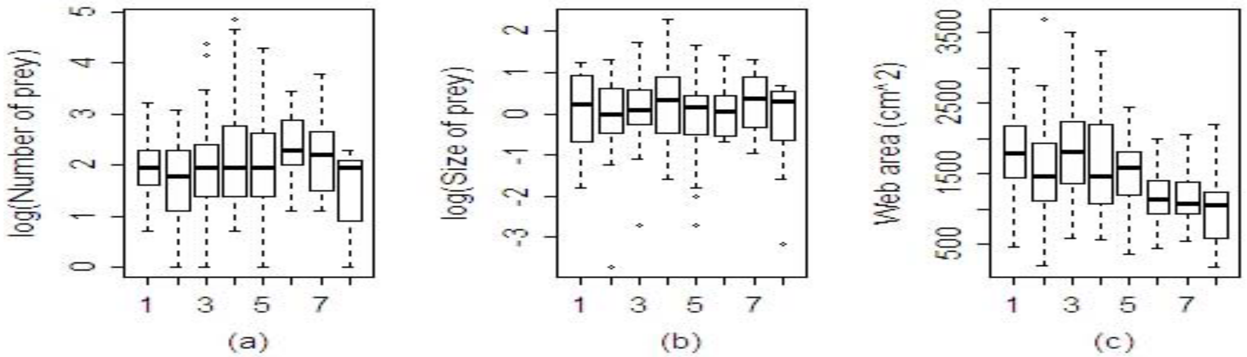

FIGURE 1. The relationship between colony size and (a) number of prey ($p = 0.3028$), (b) size of prey ($p = 0.8992$) and (c) web area ($p = 0.001$).

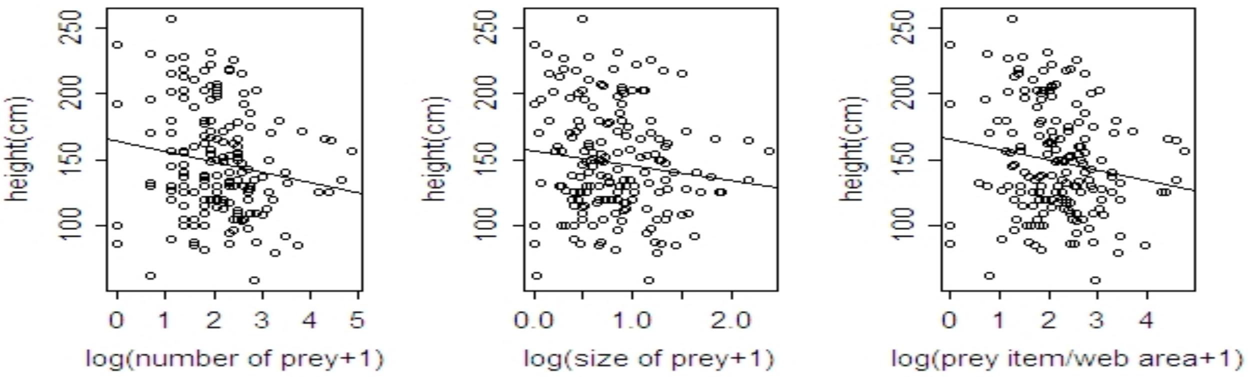

FIGURE 2. Significant correlation between height against number of prey (intercept = 164.7, slope = -7.93, p = 0.02), size of prey (intercept = 157.3, slope = -11.43, p = 0.08) and prey capture efficiency (intercept = 164.9, slope = -7.76, p = 0.02).

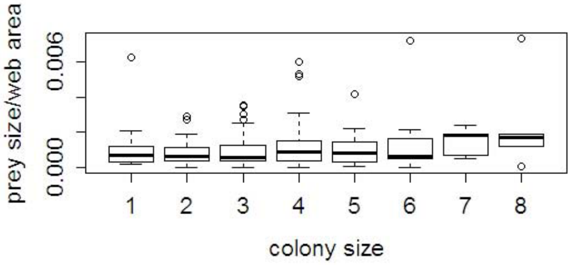

FIGURE 3. Prey capture efficiency is represented by ratio of cumulative prey and web area. The plot shows significant effect of colony size on prey capture efficiency (p = 0.03).

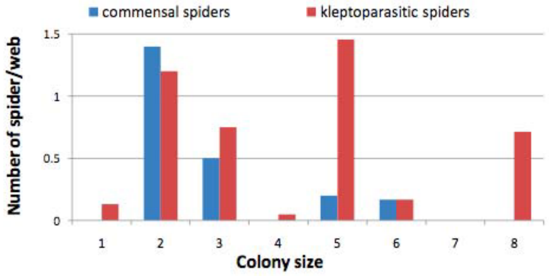

FIGURE 4. Kleptoparasitic and commensal spiders in *Nephila clavata* webs. Commensal spiders attach their own web to the *Nephila* web, while kleptoparasites live in the *Nephila* webs.

DISCUSSION

Although our study did not suggest that big webs may capture more prey items, we still recognized that bigger spiders owned not only higher cumulative prey but also bigger webs. It seems that web area still plays a role in spider life, possibly to increase prey capture efficiency (Cynthia et al. 2006). Our results proved that solitary spiders had to build bigger webs to get equal prey items to colonial ones.

The benefits of living in colonies may be manyfold: more food, saving energy, better protection and mating opportunities. Similarly to our result, Fincke (1981) reported that prey capture efficiency was significantly greater for the bigger colonies. However, prey consumption per spider may vary between juvenile and adult spiders. Observation on *Philoponella semiplumosa* by Spiller (1992) showed that ratio was positively correlated with colony size in juvenile webs but curvilinear in adult webs (highest in intermediate colonies). The negative correlation between web area and colony size indicated spiders living in bigger colonies invested less in building and maintaining their webs. Although colonial webs were smaller in area, members of colonies still had equal prey items and cumulative prey to solitary one, which means higher prey capture efficiency. Additionally, Hodge and Uetz (1992) found solitary spiders suffered greater relative predation than those in single species groups or those in association. We did not however, find any difference between colonial and solitary webs in mating opportunities, with approximately equal sex ratio in both colonial and solitary webs.

On the other hand, some disadvantages of being a member in a colony were discovered in previous researches. As large webs will supply not only living place but also food for relative small kleptoparasites (Eberhard et al. 1993), colonial webs of *N. clavata* provided suitable habitat for both web and non-web spiders. With host webs of similar sizes, more kleptoparasitic individuals were found in the colonial webs than in the solitary ones. The number of kleptoparasites in the colonial webs was correlated with host web size and body size (Koh and Li 2002, Rypstra and Binford 1995, Tso and Severinghaus 2000). Since kleptoparasitic spiders steal captured prey from host webs, they may reduce the weight gain and fitness of the host spiders, or possibly force the hosts to relocate the webs more frequently or remove large quantity of silk from the host web (Koh and Li 2002). However, the relationship between hosts and symbiont species is complicated. It depends on the kleptoparasitic species as well as the host. Observation by Tso and Severinghaus (2000) and Henaut et al. (2005) indicated that kleptoparasitic spiders merely consumed small prey ignored by the hosts and there was a clear partitioning of prey items between hosts and kleptobiotic spiders. Additionally, symbiont species may even become prey for the host (Eberhard et al. 1993). Nonetheless, our results did not find any correlation between number of either kleptoparasitic spiders or commensal spiders and colony size of *N. clavata*. Consequently, the disadvantage of living in colonies was not clear based on this research.

Web height was found to be a factor which limited number of prey items, cumulative prey in webs and also prey capture efficiency of *N. clavata* in Mengsong, a similar result to that of Cynthia et al. (2006). We found no insignificant relationship between height and colony size, although this is possible (Foelix 2011). Our observation was limited for webs below 3 m from ground, and future studies should look into the importance of vertical location of webs in prey capture efficiency.

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Biological Control in Terrace and Forest Tea Plantation in Mengsong, Yunnan Province, China

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ABSTRACT

We investigated the effects of habitat complexity factors in providing biological control in terrace and forest tea plantations in Mengsong, Xishuangbanna, SW China. We used linear mixed effects models to analyze the variation in leaf damage level, abundance and species richness of pest and predator arthropods, and predictor variables including tea density, tree number, basal area, percentage understory coverage and distance to nearest forest. We found that there was no significant difference in forest and terrace tea plantations in the leaf damage, number of individuals and species of pest and predator arthropods. We found relationships between habitat complexity factors and the abundance and diversity of predator arthropods in both tea plantations. However, CCA results showed that there was no significant pattern in the composition of arthropod communities, although tea density and basal area contributed most to the distribution of species.

Key words: agroforestry, biological control, ecosystem service, forest tea, herbivory, terrace tea

CHINA IS WELL KNOWN FOR ITS GREEN TEA PRODUCTION. The ancient tea growing areas of Mengsong village in Yunnan Province, China are nearly 4,000 mu or 666,67 acre in size and produce approximately 120 tons of high quality tea per year. The tea in Mengsong is grown as a perennial monoculture crop over large contiguous areas and as well in parts of the nearby forest of Bulong Nature Reserve. Farmers in Mengsong practices organic farming, which is thus pesticide free although they spray herbicides under the tea bushes once a year. Such cropping conditions provide a comparatively stable microhabitat, continuous supply of food and suitable sites of reproduction for various phytophagus pest insects almost throughout the year, which could impact tea production (Radhakrishnan & Muraleedharan 2009). Under such conditions the potential importance of insect natural enemies (predators and parasitoids) as control agents is apparent.

Naturally occurring bio-control agents are generally preferred to the introduction of exotic predators and parasitoids for better efficacy and to avoid ecological problems. Several studies have suggested that predator and parasitoid tend to more abundant in agroecosystems with increased habitat complexity (Risch & Caroll 1982; Gardiner *et al.* 2009). Thus habitat complexity can enhance bio-control efficacy (Harvey & Eubanks 2004). The aim of the present study was to characterize the differences in the leaf damage, pest populations and natural-enemy populations under two contrasting tea management regimes: monoculture terrace tea and forest tea. Planted under the canopy of diverse native tree species, forest tea is considered to have more complex habitat than terrace tea. We postulated that the forest tea, although less productive, would provide a better environment for harboring natural enemies and therefore would evidence lower pest populations and lower leaf damage than terrace tea.

METHODS

STUDY AREA.—The study was conducted at the terrace and forest tea plantation (Fig. 1) in Mengsong. Da Mengsong Tea Mountain is located in Mengsong Village, 31 km from Menglong Town of Jinghong City. Mengsong is an important border village on the border between Xishuangbanna and Myanmar inhabited by Dai, Hani, and Bulang ethnic minority groups. The Mengsong village area lies at elevations between 1,500 and 1,800 meters. Hills are scattered over its area, and its forest cover is nearly 70%. The mean annual temperature is 17°C. The soil is fertile and the climate is mild with a moderate rainfall.

In the study area, five terrace tea plantation and four forest tea plantation patches were selected (Fig. 2). Forest and terrace sites were selected relatively close to each other for a reasonable experimental comparison, with a minimum distance of 200 m.

FIGURE 1. Terrace and forest tea plantation in the study area.

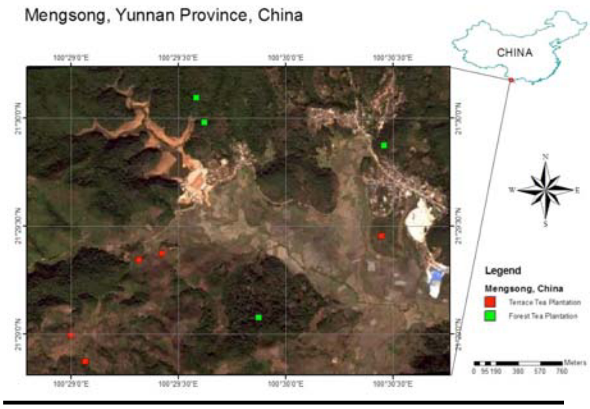

FIGURE 2. Study area in Mengsong, Yunnan Province, China (source: GoogleEarth 2011).

INSECT COLLECTION.—In each site, two transects of 50 m were set up. Each transect line was placed from North to South and apart with a minimum distance of 50 m. The 50 m transect line were marked at every 10 m to indicate quadrant points (Fig. 3). Each quadrant point is divided into four quadrates. The distance to the nearest tea bush in each quadrate was measured to estimate tea tree density. These bushes were then surveyed for leaf damage and arthropods. Observation and hand-sorting methods were used. Aspirators were used for capturing smaller insects on tea leaves. The number of spider webs was recorded. We also used one malaise trap per transect to collect flying insects over a period of 24 hours.

HABITAT COMPLEXITY MEASUREMENT.—Five habitat complexity factors (tea density, the basal area and number of other trees, ground coverage and distance to nearest forest) were measured at each transect. Tea density was measured using point-centered quarter method. DBH and number of trees within 5 m either side of the transect line were measured and counted. Three 1 m × 1 m quadrates were placed to estimate the ground coverage in the tea patch. Plants specimens were collected for identification.

LEAF DAMAGE MEASUREMENT.—From each tea tree, a single middle branch of the tree with a minimum number of five leaves was picked for leaf damage analysis. The five terminal leaves were scanned (Canon_CanoScan_LiDE_70_12) and the area was calculated using ImageJ software. Paper cut-outs of the entire leaves were made to obtain the original leaf area.

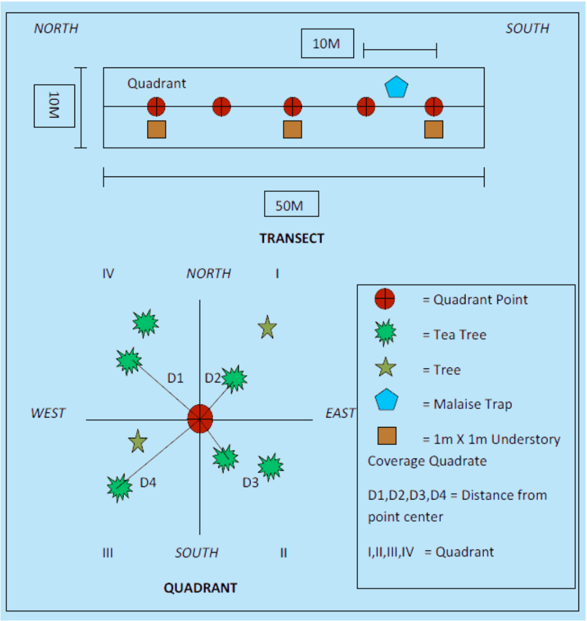

FIGURE 3. Transect and plot layout for insect collection and habitat complexity measurement.

DATA ANALYSES.—Program R 2.13.2 (R Development Core Team 2010) was used for data analyses. We used linear mixed effects models to compare the percentage of leaf damage, pest abundance and predator abundance between habitats (terrace tea and forest tea), as well to test the relationship between pest and predator abundance and diversity and habitat complexity (including tea tree density, number of other tree, basal area, understory cover and distance to nearest forest). We also used canonical correspondence analysis to explain the differences in species composition between patches of terrace tea and forest tea by differences in habitat complexity factors. Malaise trap result was analyzed separately. Shared species in different habitats was estimated using Jaccard-Chao abundance-based estimator performed by EstimateS 8.2.0.

TABLE 1. *Abundance, species richness and shared species of arthropod pest and predator collected from Malaise trap and hand collection in terrace and forest tea.*

Malaise Trap

Habitat	Abundance		Species richness		Shared species		Chao-Jaccard	
	Parasitoid	Pest	Parasitoid	Pest	Parasitoid	Pest	Parasitoid	Pest
Forest	6	9	6	7	5	2	0.833	0.726
Terrace	66	24	37	7				

Hand-collection

Habitat	Abundance		Species richness		Shared species		Chao-Jaccard	
	Predator	Pest	Predator	Pest	Predator	Pest	Predator	Pest
Forest	534	557	70	86	31	37	0.844	0.977
Terrace	785	661	96	97				

RESULTS

For all samples combined, we collected 349 and 57 arthropod species from hand collection and malaise traps, respectively. Of these, 183 and 14 were categorized as pest and 166 and 43 were natural enemy, respectively. In total, terrace tea plantation bushes had higher species richness and number of individuals (237 species, 1536 individuals) compared to forest tea plantation (169 species, 1106 individuals). For the malaise traps, the total number of individuals found in terrace tea plantation was 90, six times the number in the forest tea plantation (15 individuals). Based on Chao-Jacccard estimation of shared species, 5 species or 83% of parasitoid and 2 species or 73% of pest species collected from malaise trap were found in both tea plantation types (Table 1). Shared species of pest and predator from the hand collection were also high, 31 species or 84.4% of predator and 37 species or 97.7% of pest. For the following analysis, we excluded the malaise trap data due to the under-sampling of the forest habitat.

We used log-transformation for pest and predator abundance data. Pest abundance on the tea bushes was not significantly different between the terrace and forest tea (Fig. 4; p = 0.62). We also found that there was no significant difference in predator abundance between the two tea management types (Fig. 5; p = 0.95).

For the leaf damage data, we used arcsine square-root transformation. Leaf damage percentage was also not significantly different between tea management regimes, although there was a trend towards lower damage in the terrace tea (Fig. 6, p = 0.076).

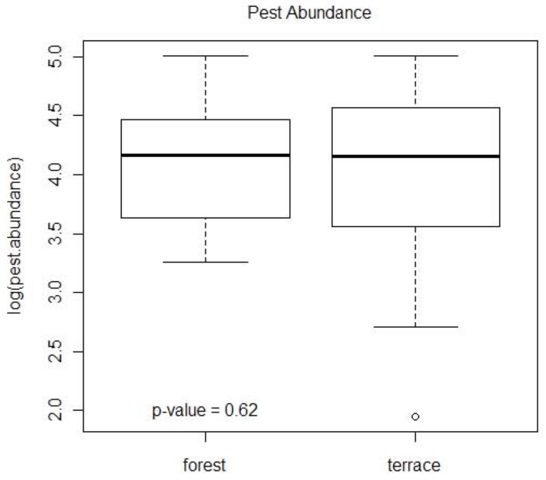

FIGURE. 4 Nested model showing abundance of pest was not significantly different between forest tea plantation and terrace tea plantation.

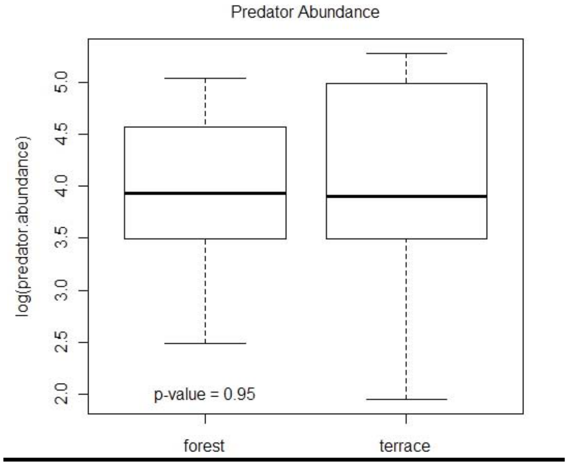

FIGURE 5. Nested model showing abundance of predator was not significantly different between forest tea plantation and terrace tea plantation.

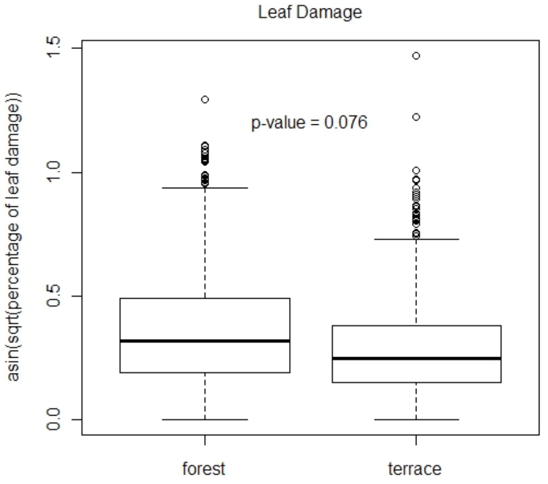

FIGURE 6. Nested model showing leaf damage percentage was not significantly different between forest tea plantation and terrace tea plantation.

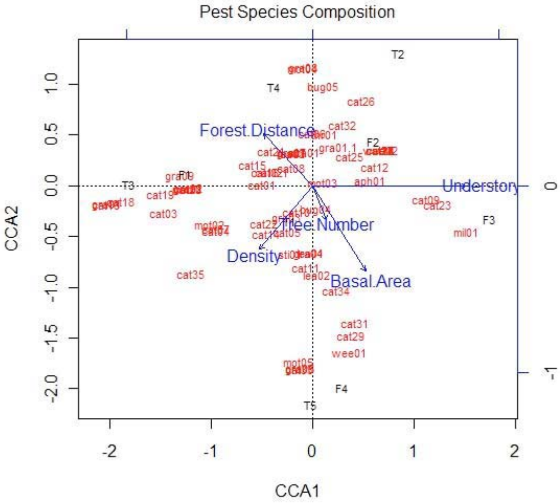

FIGURE 7. Results of canonical correspondence analysis (CCA) of arthropod pest abundance made at the study area.

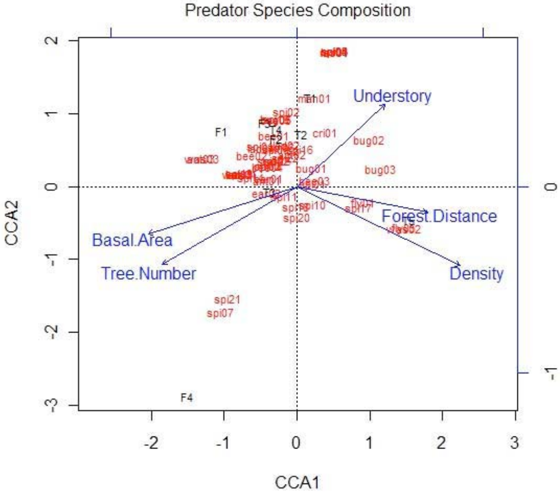

FIGURE 8. Results of canonical correspondence analysis (CCA) of arthropod predator abundace made at the study area.

To measure whether habitat complexity potentially provide better biological control, we tested the effects of tea density, number and basal area of trees, ground coverage and distance to nearest forest on arthropod predator species richness and abundance. However, we found that there was no significant relationship between habitat complexity variables and predator abundance or predator species richness ($p > 0.05$, linear mixed effects model).

We used canonical correspondence analysis (CCA) to explain the differences in pest and predator composition between patches of terrace and forest tea plantation by differences in habitat complexity factors and to examine the relationship between those factors with species composition. Based on the analysis for pest community, 29.5% of variance in pest composition was explained by CCA axis 1 and 27.4% by CCA axis 2. For predator community, we found that CCA axis 1 explained 35.7% of the variance in species composition, while CCA axis 2 explained 26.8%.
Species composition of arthropod pest in both tea plantations was mainly influenced by understory coverage, with CCA score 0.825 (Fig. 7). For predator community, we found that all habitat factors contributed to the distribution of predator in forest and terrace tea plantation (CCA score > 0.5) (Fig. 8). Based on the significance value calculated from a 99 permutations under reduced model, we found that there was a significant pattern in predator species composition between tea patches (sig. = 0.6), while for pest species composition there was no significant pattern (sig. = 0.43).

DISCUSSION

Our study investigated the ecosystem service provided by forest cover for tea production in terms of biological control of pest species. We found that pest abundance and richness were not significantly different among tea management regimes. One possible explanation for this is terrace tea plantations are actively managed. Alternatively, the comparatively stable microclimate, continuous supply of food and suitable sites for reproduction could enhance the number of phytophagus pest insects in forest tea plantation.

The same result occured on the predator abundance and richness. There was no significant difference between the tea management regimes. Our initial expectation was that the forest tea plantation would provide high predator abundance and richness. However, since the experiment was only specifically focused on the tea trees and not on any other larger trees, the true predator abundance and richness in the forest tea plantation was not be able to be shown.

In line with number of pests and predators, there were no significant different in the percentage leaf damage between terrace and forest tea. Leaf damage in both tea plantations was mainly caused by chewing pest such as Lepidopteran larvae. A slightly higher damage level on the forest tea leaves was seen which may correspond to the higher abundance and diversity of Lepidopteran larvae found in forest tea.

In an agricultural ecosystem, Wackers *et al.* (2007) and Zehnder *et al.* (2007) suggested that habitat complexity increases both population size and impact of predators and parasitoids that regulate herbivorous arthropod pests by providing shelter, nectar, pollen and alternative host or prey to the natural enemies. In this study we found that habitat complexity variables such as tea density, number and basal area of trees, understory coverage and distance to nearest forest had no significant effect on predator abundance and richness. Other factors such as plant diversity, microclimate, tree canopy cover and breeding season can be affecting the natural enemy population in the tea plantation sites (Root 1973; Koech & Whitbread 2000).

We found that understory coverage seemed to be significant factors affecting the composition of pest species (Fig. 7). It might be that understory vegetation also provides suitable habitat for pests. Norris & Kogan (2005) stated that understory vegetation such as weeds are a major component of tea ecosystem and serve as alternative hosts for pests. Weeds also provide means for pest species in tea ecosystem to move from one part of the tea plant to another or to migrate from the tea plant to another host (Hazarika *et al.* 2009).

Predator species composition in terrace and forest tea were regulated by all habitat complexity variables, especially basal area and tea density (Fig. 8). Trees might provide refugia for many generalist predators such as spiders which were found in high number in both tea plantations. Landis *et al.* (2000) stated that denser tea plantation and larger trees may improve availability of alternative foods such as nectar, pollen and honeydew, and provide habitat and shelter or a moderated microclimate in which predator arthropods may seek refuge from factors such as environmental extremes.

Based on the permutation test, it is possible that the species composition pattern in our study sites was random. Nevertheless, more precise measurement and more environmental variable are needed in future research to better explain which and how habitat complexity variables affect the abundance and distribution of arthropod species in terrace and forest tea plantation.

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Different Canopy Types Induce Soil Macrofauna Variation in Bulong Nature Research, Yunnan, China

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ABSTRACT

Soil fauna comprises a large portion of the total diversity of living organisms described to date and they play important roles in below-ground soil ecosytem functioning. We sampled soil macrofauna communities across a disturbance gradient in Bulong Nature Research, Mengsong, Yunnan, China, to study the variation of soil macrofauna abundance and diversity at different soil depths with disturbance and correlated this with environmental factors, including soil moisture content, infiltration rate and tree basal area. Soil macrofauna abundance varied across the disturbance gradient, with open-canopy forest having the highest macrofauna abundance. Macrofauna abundance declined with soil depth. Our results showed that, after correcting for basal area, soil water content and soil water infiltration rate, canopy type had a significant effect on macrofauna abundance, with the highest abundance in open canopy forest. We also found that, except for plots in open land, macrofauna abundance decreased with soil depth.

Key words: Bulong Nature Reserve, canopy cover, soil macrofauna, species richness

SEVERAL ECOSYSTEM SERVICES (e.g. nutrient cycling) are provided by the soil – and that is made possible by the complex communities residing there (Lavelle *et al.* 2006; Schaefer *et al.* 2009). The soil fauna is estimated to consist of about 23% of the total identified living organisms currently described (Decaens *et al.* 2006; Sylvain & Wall, 2011). The soil fauna, as “ecosystem engineers”, affect both the below- and above-ground environment.

Studies have provided evidence of the close links between plant communities and the soil macrofauna by means of herbivory, decomposition, and the symbiotic relationship between these communities (Hooper *et al.* 2000; Laossi *et al.* 2008; Salamon *et al.* 2011). However, this association can be altered by disturbance, including removal of vegetation and heavy soil tillage (Laossi *et al.* 2008; Wu, 2002) which affects abundance and distribution of soil fauna due to degradation of available resources that they use. Differences in canopy cover might therefore have a dramatic effect on soil macrofauna because of the possible effect on soil moisture, temperature and resource availability.

The objective of our study was to understand the variation of soil macrofauna distribution and abundance in three different canopy types, and relate the possible differences to tree basal area, soil moisture content and soil water infiltration rate.

METHODS

STUDY AREA.—The study was carried out from November 11-22, 2011, in Bulong Nature Reserve (24º44’22.42” N, 98º14’01.49” E, 1600-1800 m a.s.l.) located in Mensong, Southern Yunnan, China (Fig. 1). The region has a typical monsoon climate with three distinct seasons distributed throughout the year, with a humid hot rainy season from May until October, a foggy cool-dry season from November to February and a hot-dry season between March and April. The mean annual temperature ranges between 15.1 ºC and 21.7 ºC, and precipitation between 1200 and 2500 mm. The mountain consists of lateritic red soils derived from sandstone substrates with pH values of 4.5-5.5 (Cao *et al.* 2006). The forest vegetation type is classified as tropical montane rainforest (Zhu 2006).

SOIL MACROFAUNA SAMPLING.—Soil macrofauna were sampled in pre-established permanent research plots which were classified into close canopy (CC), open canopy (OC) and open land (OL). We selected three plots for each canopy type, resulting in a total of nine sampling sites. In each site, we randomly selected three out of nine subplots using random numbers, and used card-draws to select for two sampling directions from the four cardinal directions. In each selected direction, sampling was undertaken 10 m away from the center of each subplot. The soil was sampled (25 cm^2 × 30 cm depth) using a spade and sorted by hand on a plastic sheet by layer: 0-10 cm, 10-20 cm and 20-30 cm. Specimens were identified to order and morpho-species.

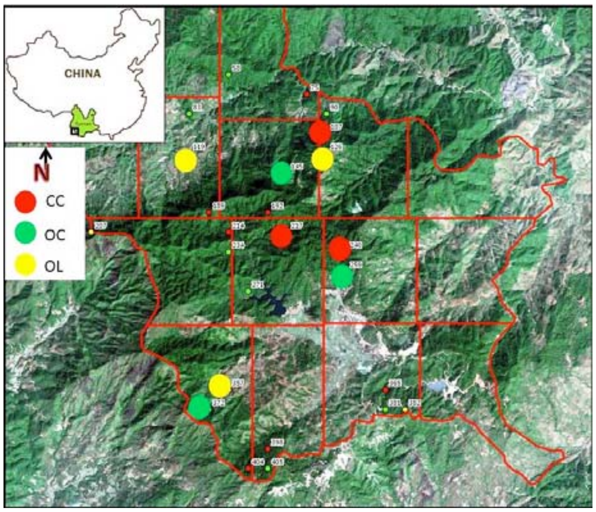

FIGURE 1. Map showing the location of the sampling points in Mengsong, Yunnan, China. Plots were classified into close canopy (CC), open canopy (OC) and open land (OL).

INFILTRATION RATE.—Soil macrofauna action in the soil layers affects soil aggregation that may hasten soil infiltration rate. We used a 5 cm metal cylinder of 10 cm height to determine soil infiltration rate. The metal cylinder was buried to 5 cm depth in the soil and water poured to a height of 2 cm from the surface soil. We recorded how long the water took to infiltrate the soil using a timer.

SOIL MOISTRURE CALCULATION.—Soil moisture was calculated by collecting approximately 10 g of soil from each depth layer in each sampling site. Wet and dry (dried at 105 ºC for 48 h) weights of the soil sample were measured using an electric balance. Water content was calculated as the difference between the wet and dry soil weight.

DATA ANALYSIS.—Due to the high diversity of taxa we selected only the top 7 most abundant groups of soil macrofauna, namely Isoptera, adult Hymenoptera, adult Coleoptera, Lumbriculida, Chilopoda, Diploda and holometabolous insect larvae. We used generalized linear models (GLM) to assess the effect of canopy type on macrofauna abundance, using basal area, soil moisture content and soil water infiltration rate as covariates. Canonical Correspondence Analysis (CCA) was used in determining the relationship of soil macrofauna composition with environmental factors. All analyses were performed using the statistics package R 2.13.2 (R Development Core Team 2010).

RESULTS

SOIL PHYSICAL CHARACTERISTICS AND TREE BASAL AREA.—Soil moisture, infiltration rate and tree basal area varied significantly among canopy types (Table 1). Mean soil moisture and infiltration rate were highest in close canopy plots while mean basal area was higher but also highly variable in the open canopy plots.

TABLE 1. *Soil physical characteristics and tree basal area of three canopy types in Mengsong.*

	Close canopy	**Open canopy**	**Open land**	***p***
Soil moisture (%)	55.50 (4.23)	58.19 (3.89)	47.47 (5.15)	<0.05
Infiltration rate (cm/s)	1.03 (0.29)	0.68 (0.11)	0.45 (0.16)	<0.01
Basal area (cm^2)	123.48 (20.78)	367.38 (172.64)	15.12 (0.34)	<0.001

Standard errors are given in parentheses. df=1

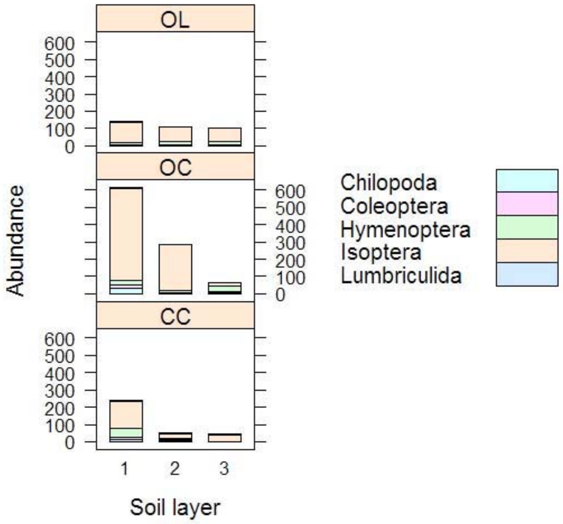

FIGURE 2. Abundance and distribution of soil macrofauna between 0 and 30 cm depth, under three canopy types.

TABLE 2. ANOVA table showing the frequency of termites and earthworms based on a present-absent tally.

	Termite	No Termite	*p*
Earthworm	12	3	ns
No Earthworm	9	3	ns

ns - not significant

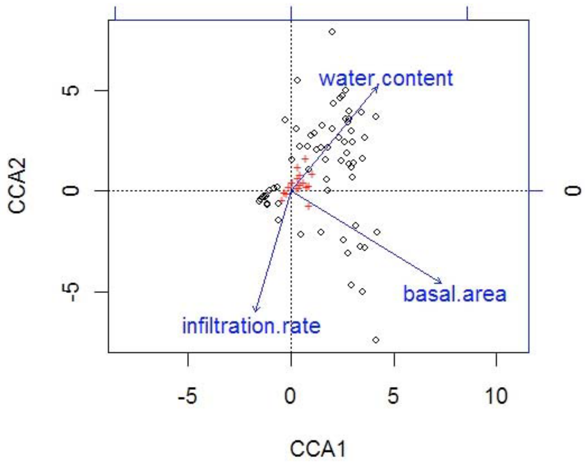

FIGURE 3. CCA based on macrofauna abundance and three environmental factors.

SPEICES COMPOSITION AND ABUNDANCE.—We identified 22 morphospecies belonging to 10 arthropod Classes with a total of 1921 individuals. Termites (1307) and ants (186) were the most abundant among the groups, followed by centipedes (72) and millipedes (64). Homo-metabolous larvae came second as the most abundant type of soil macrofauna, but could not be idendified to morpho-species.

Open canopy forest had the highest abundance of macrofauna (Fig. 2). Macrofauna abundance generally decreased with soil depth, except in open land plots. The generalized linear model ANOVA test showed that the soil macrofauna, apart from Diplopoda and Larvae, had a significant ($p < 0.001$) response to canopy type at different soil depths.

We also tested for correlation between termites and earthworms. This correlation was not significant (Table 2).

CANONICAL CORRESPONDENCE ANALYSIS.—The results of the CCA analysis found a clustering of species at the center of the graph, indicating poor separation of communities (Fig. 3). CCA axis 1 and 2 explained only 9% of the observed variance. Only basal area showed a significant influence ($p < 0.05$) on species composition. The CCA also shows that soil moisture and infiltration rate influence the soil macrofauna independently of basal area (Fig. 3).

DISCUSSION

There was a significant difference in macrofauna composition and abundance in different canopy plots. However, we also found that open-canopy and open-land plots had higher species richness than close-canopy plots. This was contrary to what we were expecting (Hofer *et al.* 2001). The dominance of termites, coleopterans, earthworms and ants was also observed in previous studies (Mathieu *et al.* 2005) tagging them as the most important and largest component of soil macrofaunal community. However, tropical forest conversion to other land uses had also been associated to significant decreases in soil macrofauna composition, abundance and diversity (Lavelle & Pashanasi 1989; Leon *et al.* 2003; Zou & Gonzalez 1997).

Given the significant differences in soil moisture content, infiltration rate and tree basal area in different canopy plots, these environmental factors did not influence the abundance of all the soil macrofauna. Again, maybe due to small number of sampling plots as affected by the time we carried the experiment compared to previously related research (Eggleton *et al.* 2009; Gongalsky *et al.* 2008; Laganiere *et al.* 2009; Zimmermann *et al.* 2010) wherein time was an important factor in determining the effects of environmental factors to soil macrofauna abundance.

Our study shows that soil macrofauna abundance varies significantly with soil depth and canopy cover. Our result shows that although there is a significant difference between environmental factors and the canopy plots, species abundance was still not influenced by these environmental factors.

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We would like to acknowledge the sponsor and organizer, the Xishuangbanna Tropical Botanical Garden (XTBG) for hosting this AFEC-X 2011. Special thanks to Dr. Rhett D. Harrison, Dr. Jacob D. Wickham, Dr. Jeremy Miller, Dr. Qie Lan, and Ms. Liu Xiamo for mentoring, advising, and facilitating both in class and fieldwork. Thanks to all our friends in the course with sharing knowledge, culture and happiness.

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