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Species Diversity in a Naturally Managed Rubber Plantation in Hainan Island, South China

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Abstract

Due to production activities, species richness in rubber plantations varies considerably. To answer the question of how many species could potentially survive rubber plantation, we established a dynamic plot with an area of 1 hm^2 in a rubber plantation in Danzhou, Hainan Island, south China. We surveyed and analyzed plant species diversity and spatial distribution patterns of dominant species in the plot. The results showed that (a) there are a total of 183 species belonging to 155 genera and 69 families in the 1 hm^2 plot of the plantation. This level of species richness is slightly lower than a typical tropical rainforest of the same size. (b) Subplots as small as 4,000 m^2 already contain at least 90% of species, genus, and family, respectively, which indicates that 1 hm^2 plot may be large enough for the dynamic monitoring of species diversity in rubber plantations, in our region at least. (c) All of the 20 dominant species have a clumping distribution at Scale 0 to 5 m, which is similar to the finding in tropical rain forests. In conclusion, many plant species grow back in rubber plantations that are minimally managed or called *naturally managed*. Such a management approach could be useful in maintaining species diversity in rubber plantations.

Keywords

Hainan Island, rubber plantation, species diversity, species richness, spatial distribution pattern

Introduction

Tropical forests are hyperdiverse but are being lost at the rate of approximately 1.2% per year in Asia (Whitmore, 1997). Deforestation and extracting products from forests affects local temperature, light, moisture, and litter conditions, resulting in changes of microhabitats and loss of forest biodiversity (Chaudhary, Burivalova, Koh, & Hellweg, 2016). Although the environmental consequences of converting rain forest into rubber plantation are uncertain, more than 1,000,000 ha of nontraditional rubber-growing land have been planted with rubber trees to satisfy market demand in tropical Southeast Asia (Mann, 2009; Ziegler, Fox, & Xu, 2009), which currently supplies over 90% of the world's natural rubber (Chen et al., 2016). The replacement of forest by rubber plantation was shown to have a strong negative impact on the diversity of various species groups (He & Martin, 2016). Compared with the tropical rain forest, the structure of rubber plantation is simple and its species diversity is low (Beukema, Danielsen, Vincent, Hardiwinoto, & Andel, 2007; Li, Aide, Ma, Liu, & Cao, 2007).

Hainan Island is the only major island in the Indo-Burma biodiversity hotspot, which ranks one of the top eight hotspots in the world (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Its flora and fauna possess a high level of diversity and endemism, with usual biogeographic characteristics in China (Zhai, Cannon, Slik, Zhang, & Dai, 2012). However, tropical rubber plantations are widely distributed in Hainan Island and account for about one fourth of the total vegetation of Hainan Island.

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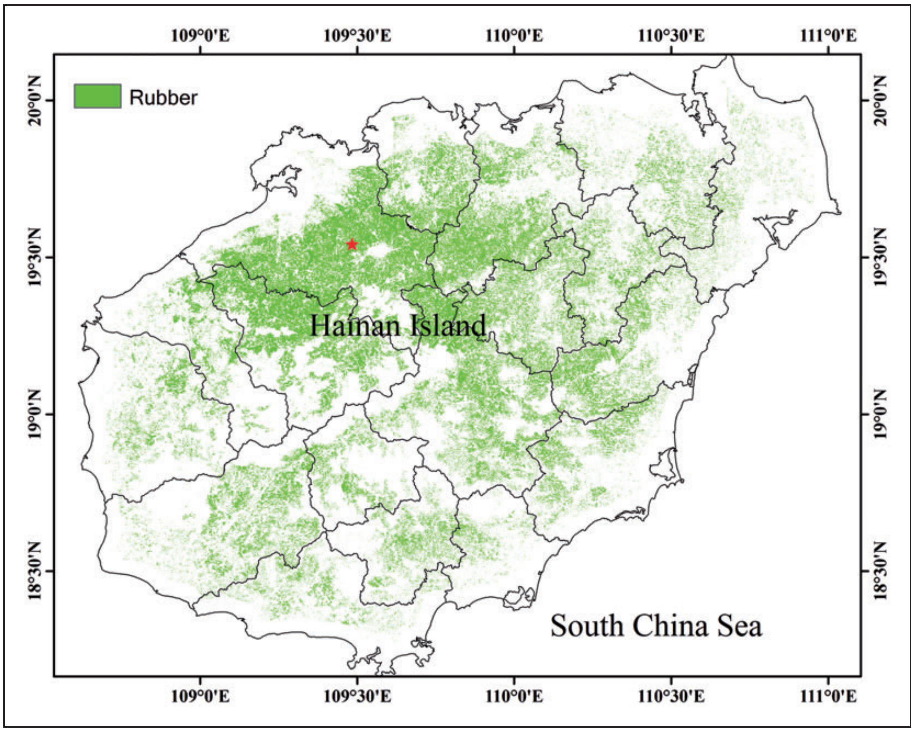

Figure 1. Distribution of the study rubber plantation in Hainan Island and the study site (marked with "☆").

Rubber plantation has become a dominant vegetation type in this tropical region (Lan, Wang, Wu, & Xie, 2013).

Dependent on the production activities, species richness of rubber plantation varies a lot (Lan et al., 2013; Liu, Jang, & Dong, 2006; Wang, Ouyang, Zhang, Xu, & Xiao, 2012; Zhou, Yan, Zhang, Zhang, & Wei, 2012). This imposes difficulties for us to evaluate the potential of rubber plantation in supporting diversity. To understand the possible utility of rubber plantation in hosting species diversity, we established a 1 hm^2 dynamics plot in Danzhou, Hainan Island, in 2012, following the same field protocol of establishing the 50 hm^2 stem-mapping plot in Barro Colorado Island in Panama (Condit, 1995). We then maintained and managed this rubber plantation plot in a natural way, that is, prohibiting use of herbicides, avoiding clearing vegetation, and minimum use of compound fertilizers and pesticides, and so on. We call such management as "natural management." After 3 years of such management, many species have grown back to the rubber plantation. This study presents the results of the plant species diversity of the 1 hm^2 plot. We attempt to answer the following questions: (a) What is the level of species diversity and what are the distribution patterns of the dominant species in the rubber plantation compared with other tropical rain forests? (b) Can natural management be used to improve biodiversity in rubber plantations?

Methods

Study Site

Hainan Island (18°10′-20°10′N and 108°37′-111°03′E) is the largest tropical island in China, with an area of 33,920 km^2 (Lopez, Rousset, Shaw, Shaw, & Ronce, 2009), and the largest island in the Indo-Burma biodiversity hotspot (Francisco-Ortega et al., 2010). The island's tropical rainforests are located at the northern margin of tropical Asia (Zhu & Zhou, 2002) and are known for their high biodiversity. The Island has a tropical monsoon climate, with a rainy season from May to October and a dry season from November to April (Luo, 1985). Rubber plantation is distributed in almost every county in the island, especially in the middle west of Hanian (see Figure 1). The largest distribution area of rubber plantation is in Danzhou where our study area is located.

Data Collection

A 1 hm^2 (100 × 100 m) permanent plot was established in the rubber plantation in 2012 following the field protocol of the Centre for Tropical Forest Science (Condit, 1995, 1998). The elevation of the plot ranges from 79 to 105 m above sea level. The slope of the plot varies from 5° to 10°. The rubber plantation canopy density is more than 85%. The average diameter of rubber trees at breast height is 15.7 cm, and the average tree height is about 14 m. The age of the rubber plantation is about 12 years old, and has been tapped for 4 years. We managed the plantation as naturally as possible to avoid any major human interference (no vegetation clearance, no use of herbicide/pesticide, and no fertilization). Every rubber tree was mapped and tagged with a unique number. We recorded plant species names, number of individuals, and their locations in 5×5 m quadrat grid. Because most plant species are herbaceous species, it was difficult to count the number of stems. So we further divided the plot into 1×1 m quadrats and recorded the number of such quadrats where a given species appeared. We selected the 20 most dominant species to analyze their spatial distributions.

To evaluate the diversity of the plantation, we selected two small plots of 20×20 m nearby the 1 hm^2 dynamic plot for comparison. The two small plots shared similar condition with the dynamic plot, that is, they had similar rubber tree age, density, mean tree height, and so forth, but we applied treatments of green manuring and herbicides and understory clearance to the two small plots. The understory of the small plots was composed of plant species of Gramineae and Compositae.

Spatial Pattern Analysis

We used the pair-correlation function (Stoyan & Stoyan, 1994; Wiegand & Moloney, 2004) as summary statistic to quantify the spatial structure of the univariate patterns for the 20 dominant species. The pair correlation function $g(r)$ for univariate patterns of a species can be defined based on a neighborhood density $O_{11}(r) = \lambda_1 \ g_{11}(r)$ which is the mean density of trees of the species within rings of radius r and width dr centered in the focal trees of the species (Wiegand & Moloney, 2004). Here, λ_1 is the intensity (number of trees in a unit plot area). The pair correlation function is defined as the ratio of the observed mean density of trees in the rings to the expected mean density of trees in the rings. The pair correlation function is especially suitable for exploratory analysis because it isolates specific distance classes (Law et al., 2009; Perry, Miller, & Enright, 2006). The univariate pair correlation function $g(r)$ can be used to test if the distribution of a species is random, aggregated, or regular; and at what distances (r) these patterns occur. Under the null model of complete spatial randomness, where the points are independently and randomly distributed over the entire plot, the pair correlation function yields $g(r) = 1$, for aggregation $g(r) > 1$, and for regularity $g(r) < 1$ (Wiegand & Moloney, 2004). We used a Monte-Carlo approach to test for significant departures from the null models. Each of the 199 simulations of a point process underlying the null model generates a summary statistic; and simulation envelopes with $\alpha \approx .05$ were calculated from the fifth highest and lowest values of the 199 simulations (Stoyan & Stoyan, 1994). Significant departure from the null model occurred at distance r if the test statistic was outside the simulation envelopes. This approach allowed us to assess scale effects and to determine the type of significant effect. Thus, the univariate analysis indicated aggregation, if the observed $g(r)$ was above the simulation envelopes and regularity, if it was below.

Results

Species Diversity

There are 441 rubber trees and a total of 183 plant species belonging to 155 genera and 69 families in the 1 hm^2 plot. Of these species, there are 46 tree species, 45 shrub species, 22 lianas species, and 70 herbaceous species (including annual and perennial). There are five dominant families (with more than 10 species), that is, Rubiaceae, Euphorbiaceae, Gramineae, Asteraceae, and Moraceae. The largest family is Rubiaceae, which has 15 species, accounting for 8.2% of the total species. Appendix shows the 20 most dominant species in the plot.

We plotted the species–area curve of the plot (see Figure 2). In Area 0 to 4,000 m^2, number of species

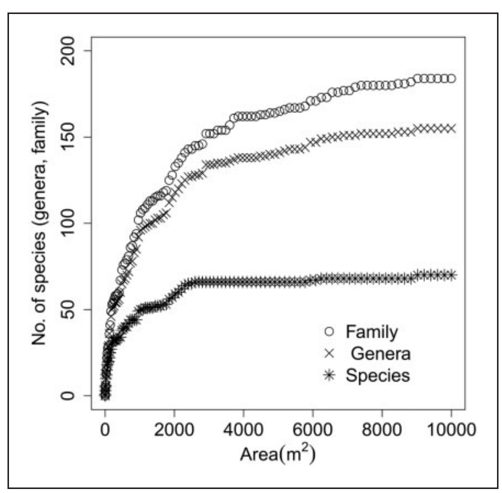

Figure 2. Species (genus, family)-area relationship of the study rubber plantation.

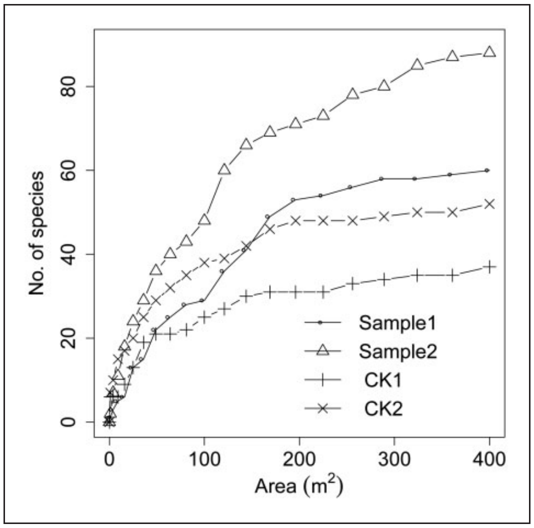

Figure 3. Species-area relationships of the rubber plantation managed in close to natural way and the intensively managed plots. Subplot 1 and 2 indicate two subplot (400 m^2) of from the 1 hm^2 naturally managed rubber plantation. Small Plot 1 and 2 indicate two small plots (400 m^2) of the intensively managed plantation plots.

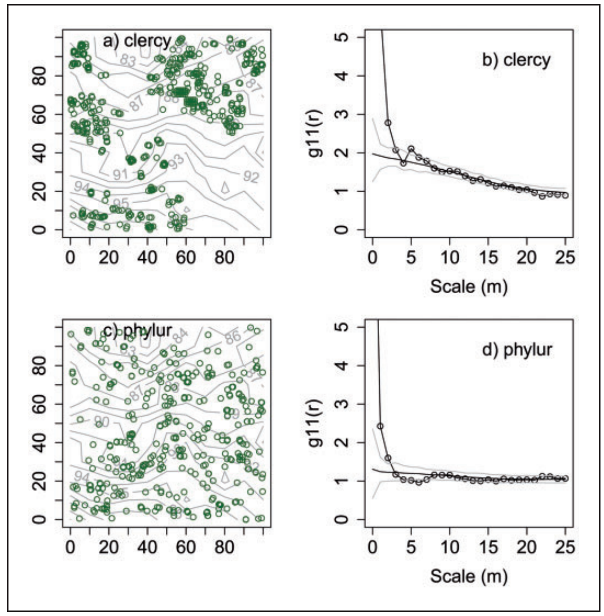

Figure 4. Distribution of two dominant species (*Clerodendrum cyrtophyllum* and *Phyllanthus urinaria*) and their *g*-functions. The univariate pair-correlation functions of the data are dependent on scale *r* (open circle) and the simulation envelopes (solid grey lines). Monte Carlo confidence was constructed at approximately 95% confidence level (199 simulations). See Appendix for species codes.

increases quickly with area, but the accumulation slows down when the area is greater than 4,000 m^2. There are 165 species at area of 4,000 m^2, which accounts for about 90% of total species. We also plotted the genera–area curve and family–area curve of the plot. The curves account for about 90% genera and 90% families at areas of 3,000 m^2 and 2,000 m^2 for genera–area and family–area, respectively. To compare the species diversity with the two small nearby 20×20 m plots (they were subject to intensive management), the species–area curves of both types were plotted in Figure 3. Species richness of the naturally managed plot is clearly higher than the more intensively managed plots.

Spatial Distribution Patterns of Dominant Species

We plotted distribution maps of the 20 dominant species (see Appendix) in our plot. The results of the *g*-function showed that all of 20 dominant species are clumped in distribution. As examples, Figure 4 shows the spatial distribution and the *g*-functions at 0 to 25 m of two dominant species: *Clerodendrum cyrtophyllum* and *Phyllanthus urinaria*. Distribution of *C. cyrtophyllum* clearly appears aggregation by visual inspection and is confirmed by the *g*-function but the distribution of *P. urinaria* is not so obvious. The *g*-function for *P. urinaria* indicates a clump distribution at scale of 0 to 2 m.

Table 1. Summary of Spatial Distribution Patterns of Dominant Species of Rubber Plantation in the Plot.

Distribution pattern	Scale (m)				
	0–5	6–10	11–15	16–20	21–25
Clumped	20 (100)	1 (5)	0 (0)	0 (0)	0 (0)
Random	0 (0)	19 (95)	17 (85)	13 (65)	12 (60)
Evenness	0 (0)	0 (0)	3 (15)	7 (35)	8 (40)

Note. The numbers within the parentheses show the percentage of species falls into that category.

To understand the effects of scale on the distribution of the dominant species, we counted the number of the 20 species which fall into random, clumping, and regular distributions at scales of 0 to 5, 6 to 10, 11 to 15, 16 to 20, and 21 to 25 m. The results in Table 1 show that the degree of aggregation deceases with increasing scale. At Scale 0 to 5 m, all of the 20 dominant species are clumped, at Scale 6 to 10 m, only one species shows clumping distribution, the rest are randomly distributed.

Table 2. Comparison of Species Richness Between Our Rubber Plantation and Other Tropical Rain Forests in South China.

Forest types	Elevation	Precipitation (mm)	Area (hm^2)	No. of species
Rubber plantation	70-100	1815	1.0	183
Tropical rainforest in Hainan	70-80	2000	0.9	155
Tropical rain forest in Xishuangbanna	709-869	1493	1.0	240

Note. In the rubber plantation, we investigated all plant in 1 hm^2 plot. In the tropical rainforest in Hainan, trees with height $\geqq$1.5 m and herbaceous were included. In the tropical rainforest in Xishuangbanna, all plants were included.

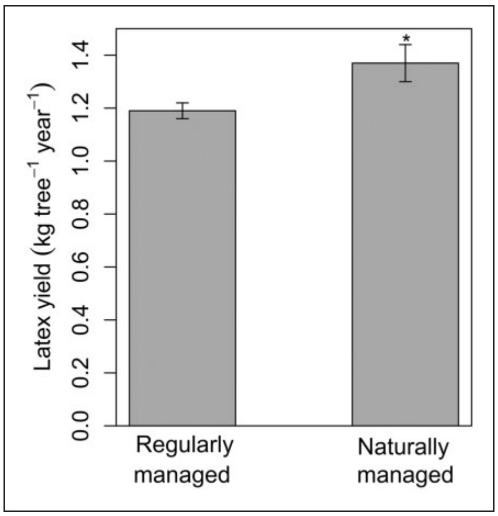

Figure 5. Comparison in latex yields between the naturally managed and regularly managed rubber plantations from the study site.
*significant differences at $p < 0.05$.

Discussion

Species Diversity

It is widely believed that artificial forests are subjected to production activities and always have lower species richness than natural forests (Chaudhary et al., 2016). However, our results show that after close to natural management, species richness of our rubber plantation is not so much lower than that of other tropical forests in south China as compared with two studies in Hainan Island and Xishuangbanna. The first one is in a tropical rainforest in Xishuangbanna (Chen & Zhu, 2009; Lan et al., 2008), in which the authors found 240 species in 1 hm^2 plot (Table 2). In the second study, there were 155 species in 132 genera and 64 families in a 0.9 hm^2 tropical rain forest in Wenchang, Hainan (Yang et al., 2005). Our further data indicate that rubber production of close to natural management at production level of 1.37/kg/tree is slightly higher that of conventional management (1.19/kg/tree; Figure 5). In other words, if we manage rubber plantation in a close to natural way, its production will not reduce as we may expect.

Species Distribution Pattern

Aggregated spatial distributions are commonly observed in naturally regenerating forests (Bunyavejchewin et al., 2003; Condit et al., 2000; He, Legendre, & LaFrankie 1997; Lan et al., 2009, 2012; Plotkin, Chave, & Ashton, 2002; Plotkin et al., 2000). Our results show that all of the 20 dominant species have clumping distributions at Scale 0 to 5 m (Table 1). Aggregated distribution patterns of dominant species in the rubber plantation confirmed that our results are consistent with the results of other tropical forests. However, previous research showed that trees in a tropical seasonal rain forest in Xishuangbanna have clump distribution at Scale 0 to 30 m (Lan et al., 2009, 2012). This difference may arise from that most of the species in this study are herbaceous species. It should be noted that most species in the rubber plantation recolonized after the natural management in 2012 and the effect of human interference has not yet disappeared.

Implications for Conservation

Preserving forest biodiversity while minimizing negative effects on economic interests is a big challenge in forest management. Our results revealed that plant species of rubber plantations can be restored reasonably quickly after if they are naturally managed. In addition, rubber production of close to natural management is slightly higher that of conventional management. In conclusion, close to natural management could be an effective way to improve plant diversity and rubber production in rubber plantations in Hainan Island.

Appendix Dominant Plant Species in the 1 ha Plot of Rubber Plantation in Hainan Island.

Rank	Species name	Code	Family	Life type	No. of individuals (or Frequency) FREQUENCYY)
1	*Broussonetia papyrifera*	*broupa*	Moraceae	Tree	599
2	*Clerodendrum cyrtophyllum*	clercy	Verbenaceae	Tree	506
3	*Wrightia pubescens*	wrigpu	Apocynaceae	Tree	485
4	*Combretum alfredii*	combal	Combretaceae	Tree	424
5	*Piper sarmentosum*	pipesa	Pipraceae	Shrub	683
6	*Pueraria montana*	puermo	Leguminosae	Liana	626
7	*Malaisia scandens*	malasc	Moraceae	Liana	505
8	*Polygonum chinense*	polych	Polygonaceae	Perennial herb	1951
9	*Praxelis clematidea*	praxcl	Asteraceae	Perennial herb	784
10	*Cyclosorus parasiticus*	cyclpa	Thelypteridaceae	Perennial herb	599
11	*Eupatorium odoratum*	eupaod	Asteraceae	Perennial herb	572
12	*Lepistemon binectariferum*	lepibi	Convolvulaceae	Perennial herb	464
13	*Microstegium vagans*	micrva	Poaceae	Perennial herb	417
14	*Pteris ensiformis*	pteren	Pteridaceae	Perennial herb	405
15	*Panicum brevifolium*	panibr	Gramineae	Annual herb	1264
16	*Cyrtococcum patens* var. *latifolium*	cyrtpa	Gramineae	Annual herb	4253
17	*Borreria latifolia*	borrla	Rubiaceae	Annual herb	1073
18	*Commelina diffusa*	commdi	Commelinaceae	Annual herb	794
19	*Oxalis corniculata*	oxalco	Oxalidaceae	Annual herb	510
20	*Phyllanthus urinaria*	phylur	Euphorbiaceae	Annual herb	380

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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