Patterns of Understory Plant Diversity in Response to Transmitted Solar Radiation in a Subtropical Forest

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Abstract. In order to reveal how transmitted solar radiation affects understory plant diversity patterns, we carried out plant census in a subtropical forest in south China. We determined canopy structure and understory gap light regimes using hemispherical photography. The results showed that a total of 206 species and 14489 individuals occur in the understory vegetation of the 2-ha sampling plots. Canopy openness was found to be a good predictor for transmitted direct radiation, diffuse radiation, and total radiation. Indicator species analysis detected a number of indicators to varying canopy openness. Six of these indicator species with significant indicator values are tree seedlings, shrubs, or vine, which are shade-intolerant, or frequently occur in habitats with the greatest canopy openness. Our results demonstrated that understory plant species composition and diversity are affected by transmitted gap light and different species may have varying response to the radiation gradient, which will have implications for using plants from the natural environment in landscaping.

1 Introduction

Understory plants play a key role in species diversity maintenance, soil and water conservation, and forest community succession. Understory plant species composition and diversity change in response to varying forest canopy structure [1,2]. These changes are mainly dependent on the light passing through the canopy of the forest. Plant species adapted to different environmental conditions can exhibit quantitative indication in abundance and distribution frequency. Shrubs, herbs, vines, ferns, and the tree seedlings in the understory can serve as effective indicators of various environmental gradients [3-5], such as solar radiation, soil moisture availability, and topography. Therefore, by studying understory plant diversity patterns and the distribution of transmitted gap light under varied canopy openness, we can determine light requirements of understory plants and detect indicator plant species in response to solar radiation or canopy openness gradient.

Understory gap light regimes are dependent on the forest canopy structure. Canopy structure can be reflected by the canopy openness, which means that when one look upward from under the forest, the percentage of the sky sphere not obstructed by the tree foliages [6, 7, 9]. Canopy adjust understory light by blocking the transmission of solar radiation or by increasing canopy openness to permit greater light transmission. Thus canopy structure has a great impact on the understory light. Understory light transmitted through the canopy involves direct radiation and diffuse radiation. Direct radiation is the light directly passing through the canopy to the understory, while diffuse radiation refers to the light reflected from any orientation within the understory [8,9]. In this study, we collected inventory data from plant census and determined canopy structure and understory gap light using hemispherical photography, a short-range remote sensing technology currently widely use in fields of agriculture, forestry, and ecological monitoring [10, 11]. We aim to reveal the relations of understory plant diversity patterns to canopy structure and understory transmitted radiation, as well as to detect indicator species of various canopy openness or light regimes, which will have significant implications for applying plants from the natural environment in landscaping.

2 Methods

2.1 Study site

This study was conducted at Deqing Sanchading Nature Reserve (23°24′~23°28′N, 111°59′~112°03′E), western Guangdong Province of south China. The study area is hilly and mountainous, with the highest point at 700 m a.s.l and the lowest at 120 m a.s.l. The zonal soil types are mainly red soil, with some dark brown and brown soils. The study area has a typical southern subtropical monsoon climate, with an average annual temperature and precipitation of 21.5°C and 1502.4 mm, respectively [12]. The dominant families of this area are Gramineae, Adiantaceae, Connaraceae, Rutaceae, Myrsinaceae, Araliaceae, and Lauraceae.

2.2 Data collection

In order to study the patterns of understory plant diversity in response to solar radiation, a 2-ha plot was set up within the forest vegetation of Sanchading Nature Reserve. The plot was further divided into 200 subplots, each 100 m^2. Dominant canopy trees and all the understory plants were censused and recorded, together with habit designation for each plant, such as tree seedling, shrub, forb, graminoid, vine, and fern. In the center of each subplot, a hemispherical photograph was taken using a Nikon CoolPix 4500 digital camera adapted with a Nikkor FC-E8 Fisheye converter. The Camera was placed at 1.65 m from the ground on a tripod, levelling and looking upward to the sky.

All the hemispherical images were processed and analyzed using Gap Light Analyzer 2.0 image processing software [13]. Latitude and longitude were entered when setting the site parameters as required. Canopy Openness, Transmitted Direct Solar Radiation, Transmitted Diffuse Solar Radiation, and Transmitted Total Solar Radiation were obtained from the image analysis.

2.3 Statistical analysis

Diversity indexes computation and indicator species analysis were performed using PC-ORD 6.0, while correlation analysis was carried out using Statistica 6.0.

3 Results and analysis

3.1. Species composition and diversity

A total of 206 species and 14489 individuals occurred in the understory vegetation of the 2-ha sampling plots. Forty-one of these species had an abundance ⩾ 90, including *Sinobambusa tootsik var. Laeta*, *Adiantum flabellulatum*, *Rourea microphylla*, *Evodia lepta*, *Rourea minor*, and *Ardisia quinquegona*. The maximum abundance reached 1215 individuals, while the average frequency per species ranged from 10 to 153 subplots, and the relative abundance from 0.620 to 8.390. The maximum frequency was 7.00 and the minimum was 0.46, while the Importance Value had the maximum of 7.19, with the minimum of 0.59 (Table 1).

In each 100-m^2 subplot, the number of individuals ranged from 25 to 266, with a mean value of 72 and the coefficient of variation (CV) 41.91. The number of species ranged from 8 to 34, with a mean value of 21 and CV 22.71. The Pielou's evenness ranged from 0.54 to 0.97, with a mean value of 0.85 and CV 10.13. Shannon-Wiener diversity index ranged from 1.19 to 3.32, with a mean value of 2.57 and CV 14.91. Simpson's diversity index ranged from 0.58 to 0.96, with a mean value of 0.88 and CV 6.91 (Table 2). Diversity metrics were also calculated for the entire community, as listed in Table 2.

Table 1. Dominant species with an abundance ⩾ 90 in the forest understory.

Species	N	F	RA	RF	I.V.(%)
Sinobambusa tootsik var. *laeta*	1215	88	8.39	4.03	6.21
Adiantum flabellulatum	1068	153	7.37	7.00	7.19
Rourea microphylla	710	75	4.90	3.43	4.17
Evodia lepta	542	66	3.74	3.02	3.38
Rourea minor	528	104	3.64	4.76	4.20
Ardisia quinquegona	509	109	3.51	4.99	4.25
Schefflera octophylla	463	53	3.20	2.43	2.81
Cryptocarya concinna	406	86	2.80	3.94	3.37
Tetracera asiatica	405	49	2.80	2.24	2.52
Calamus rhabdocladus	371	54	2.56	2.47	2.52
Lygodium flexuosum	367	57	2.53	2.61	2.57
Dalbergia hancei	367	37	2.53	1.69	2.11
Symplocos adenophylla	329	40	2.27	1.83	2.05
Mussaenda pubescens	292	48	2.02	2.20	2.11
Gahnia tristis	292	44	2.02	2.01	2.01
Lophatherum gracile	266	43	1.84	1.97	1.90
Millettia dielsiana	262	41	1.81	1.88	1.84
Psychotria rubra	240	59	1.66	2.70	2.18
Blechnum orientale	209	36	1.44	1.65	1.55
Smilax glabra	208	27	1.44	1.24	1.34
Pithecellobium lucidum	194	37	1.34	1.69	1.52
Lithocarpus longanoides	177	38	1.22	1.74	1.48
Meliosma thorelii	162	24	1.12	1.10	1.11
Machilus chinensis	155	30	1.07	1.37	1.22
Calophyllum membranaceum	152	21	1.05	0.96	1.01
Dicranopteris dichotoma	149	19	1.03	0.87	0.95
Thysanolaena maxima	142	32	0.98	1.46	1.22
Embelia laeta	141	11	0.97	0.50	0.74
Syzygium rehderianum	114	25	0.79	1.14	0.97
Sinosideroxylon wightianum	113	10	0.78	0.46	0.62
Sapium discolor	106	16	0.73	0.73	0.73
Lithocarpus corneus	105	17	0.72	0.78	0.75
Diospyros eriantha	104	18	0.72	0.82	0.77
Sarcandra glabra	103	23	0.71	1.05	0.88
Glochidion eriocarpum	103	14	0.71	0.64	0.68
Canarium pimela	99	14	0.68	0.64	0.66
Lithocarpus glaber	98	19	0.68	0.87	0.77
Smilax hypoglauca	97	17	0.67	0.78	0.72
Lithocarpus uvariifolius	91	12	0.63	0.55	0.59
Woodwardia japonica	90	16	0.62	0.73	0.68
Melastoma sanguineum	90	15	0.62	0.69	0.65

Notes: N = abundance or number of individuals; F = Frequency or plot occurrence; RA = relative abundance; RF = relative frequency; I.V. = importance value

Table 2. Variation in species composition and diversity.

Attribute	N	S	E	H'	D
Community-wide	14489	206	0.78	4.13	0.97
Across plots					
Mean	72	21	0.85	2.57	0.88
SD	30.36	4.73	0.09	0.38	0.06
Max	266	34	0.97	3.32	0.96
Min	25	8	0.54	1.19	0.58
CV(%)	41.91	22.71	10.13	14.91	6.91

Notes: 1) N = number of individuals; S = Number of species; E = Pielou's evenness; H' = Shannon-Wiener diversity index; D = Simpson's diversity index. 2) the mean values of individual number and species number have been rounded.

3.2 Canopy structure and gap light

Correlation analysis showed that canopy openness significantly and positively correlated with transmitted direct radiation (Figure 1), diffuse radiation (Figure 2), and total radiation (Figure 3), thus being a good predictor for understory gap light regimes.

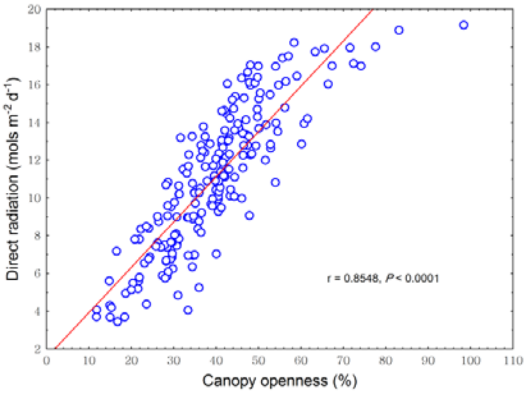

Figure 1. Relation of canopy openness to transmitted direct radiation.

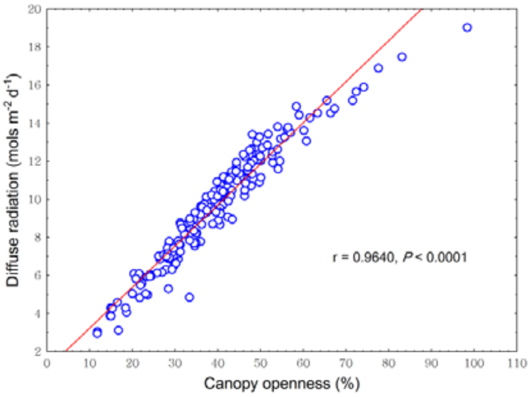

Figure 2. Relation of canopy openness to transmitted diffuse radiation.

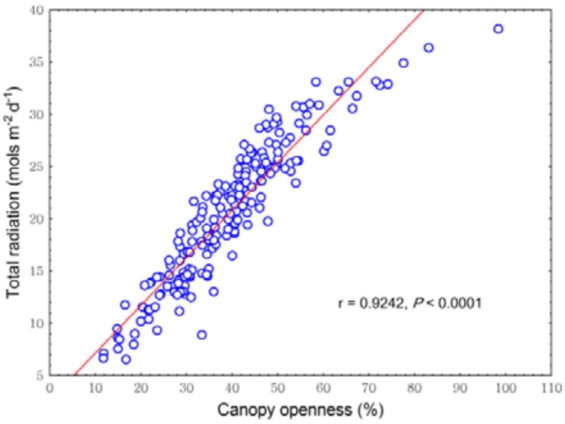

Figure 3. Relation of canopy openness to transmitted total radiation.

A greater canopy openness will permit more light transmitted from the canopy to the understory. Judging by the correlation coefficient, the perfect correlation was found between canopy openness and transmitted diffuse radiation.

3.3 Indicator species to gap gradient

A total of seventeen species with an indicator value > 15 were potential indicator species of canopy structure (Table 3). Six of these potential indicator species with significant indicator value, *i.e.*, *Sapium discolor*, *Dicranopteris*, *Smilax china*, *Itea chinensis*, *Breynia fruticosa*, and *Cyclea racemosa*, were exclusively related to the Class 3 canopy openness, indicating that they are shade-intolerant or sun plants.

4 Discussion

A significant positive correlation existed between canopy openness and understory light, indicating that understory gap light regimes varied with canopy openness. The perfect correlation was found between canopy openness and transmitted diffuse radiation, indicating that direct radiation is largely obstructed by the canopy. The difference in the shapes and sizes, and the uneven distribution of canopy gaps all affect the interception of solar radiation. Our study focuses on the relationship between solar radiation and understory vegetation, and we determine canopy structure and transmitted gap light, including direct radiation, diffuse radiation, and total radiation, using hemispherical photography, a novel photogrammetric approach. Studies have shown that hemispherical photography is a fast and accurate method for determining the canopy structure and understory gap light indicators, and applicably explaining the growth and distribution patterns of understory vegetation [14]. Indicator species analysis, on the other hand, is a sensitive approach for investigating species-habitat relationship, which will find increasingly wide application in many fields such as agriculture, biodiversity conservation, forest resource management, and ecological monitoring. Using a combination of these methods, we completed our investigation and the relations of understory plant diversity patterns in response to canopy structure and solar radiation were revealed.

Table 3. Indicator species with an indicator value ≥ 15 in relation to different canopy openness.

Species	Habit	Canopy Openness	Indicator value	*P*
Sapium discolor	Tree Seedling	3	46.3	0.0001
Dicranopteris dichotoma	Fern	3	27.6	0.0091
Meliosma thorelii	Tree Seedling	2	24.1	0.1036
Smilax china	Shrub	3	22.4	0.0004
Pithecellobium lucidum	Tree Seedling	1	22.2	0.2739
Itea chinensis	Tree Seedling	3	22.1	0.0302
Breynia fruticosa	Shrub	3	20.9	0.0359
Lithocarpus longanoides	Tree Seedling	2	20.6	0.5019
Calophyllum membranaceum	Shrub	1	19.6	0.0561
Melastoma sanguineum	Shrub	3	19.2	0.0565
Embelia laeta	Shrub	2	18.5	0.1427

Machilus chinensis	Tree Seedling	2	18.1	0.3594
Glochidion eriocarpum	Shrub	3	17.9	0.0809
Cyclea racemosa	Vine	3	17.7	0.0129
Lindera chunii	Tree Seedling	1	17.1	0.0652
Thysanolaena maxima	Graminoid	3	16.9	0.2845
Sarcandra glabra	Forb	2	15.6	0.1208

Note: Canopy openness (CO) gradient: 1: CO ≤30%; 2: 30% < CO ≤ 60%; 3: CO > 60%.

Our results demonstrated that understory plant species composition and diversity are affected by transmitted gap light. Different species may have various responses to the radiation gradient, including transmitted direct radiation and diffuse radiation. Indicator species analysis revealed that six of these indicator species with significant indicator values are shade-intolerant, or frequently occur in the subplots with the greatest canopy openness.

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