Determining light requirements of groundcover plants from subtropical natural forest using hemispherical photography

Yi Zhang, Yonglin Zhong, Mingfeng Xu and Zhiyao Su[1]

College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou 510642, China

E-mail: zysu@scau.edu.cn

Abstract. In order to determine light requirements of indigenous groundcover plants for potential use in urban landscaping, we conducted a plant census in Yinpingshan Nature Reserve, Dongguan, China, and measured canopy structure and understory light regimes using hemispherical photography. We found that canopy openness, transmitted direct solar radiation, and transmitted diffuse solar radiation exhibited highly significant spatial heterogeneity. Species composition and diversity of groundcover plants were highly dependent on canopy structure and understory light condition. Greater diversity and more stems of groundcover plants were associated with greater canopy openness and understory radiation in most cases. Highly significant differences in species composition were detected along canopy openness, transmitted direct solar radiation, and transmitted diffuse solar radiation gradients, respectively. We also detected indicator species for specific understory light regimes, which will provide useful information when applying such species in urban greening under various light environments.

1. Introduction

Groundcover plants play an essential role in plant diversity maintenance, energy flow, and nutrient cycling in forest ecosystems [1]. Understanding the mechanisms of species composition and diversity patterns of groundcover plants is beneficial to the delivery of forest ecosystem services and to selecting plants for urban greening. Groundcover plants respond sensitively to environmental changes [2]. Understory light regime is regarded as one of the most important environmental factors driving groundcover plant distributions [3, 4], as light is the primary element in plant photosynthesis and directly affect the growth and development of plants [5]. In addition, light indirectly affect plant distributions through changing soil properties, including soil temperature, humidity, and nutrients [6]. Thus, heterogeneity in understory light contributes to the forming of species composition and diversity patterns of groundcover plants [2]. However, effects of understory light on the species composition and diversity patterns of groundcover plants remain unclear.

Understory light regimes are affected by many factors, particularly canopy structure and the distribution of overstory plants [7]. Forest canopy intercepts and redistributes light resources in the understory. Greater canopy openness results in greater availability and intensity of understory light. Therefore, canopy structure indirectly affects groundcover plants through altering understory light regimes [8]. Thus, effects of canopy structure and understory light on the species composition and diversity patterns of groundcover plants require further studies.

In this study, we collected data on canopy structure of overstory plants, understory light regime, and analyzed species composition and diversity patterns of groundcover plants in Yinpingshan Nature Reserve in Dongguan city, China. We assessed the effect of canopy structure, understory light regime on species composition and diversity patterns of groundcover plants.

2. Methods

2.1. Study area

The research was conducted in Yinpingshan Nature Reserve (22°52'N~22°56'N, 114°10'E~114°15'E), Dongguan city, China. The study site is located in the central south of Guangdong province and lies within the south subtropical monsoon climatic zone. The reserve receives abundant precipitation and solar radiation. The mean annual temperature and mean annual precipitation range from 21 to 22°C and from 1500 to 2400 mm, respectively. The mean relative humidity is 79%. The vegetation is largely evergreen monsoon forests and evergreen broadleaved forests. The soil type is largely mountain red soil, latosolic red soil, and yellow soil. The parent rock is granites and sand shales [9].

2.2. Data collection

We established two 1-ha permanent forest plots in the reserve. Each plot was a square of 100 m × 100 m and was divided into 25 subplots (20 m × 20 m). Five 2 m × 2 m quadrats were established in each subplot. In each quadrat, we recorded all groundcover plants by species name, number of stems, and coverage.

In each quadrat, a hemispherical image was obtained using a Nikon CoolPix 4500 digital camera connected with a Nikkor FC-E8 fisheye lens. Hemispherical images were analyzed using the free software Gap Light Analyzer 2.0 [2].

2.3. Statistical analysis

We used Kruskal-Wallis test to determine the differences in canopy openness, transmitted direct solar radiation, and transmitted diffuse solar radiation among plots. Canopy openness, transmitted direct solar radiation, and transmitted diffuse solar radiation were classified into three classes, respectively. We used Multi-response Permutation Procedures (MRPP) to test for the differences in species composition along a canopy openness gradient and each understory light gradient. We also detected indicator species in communities along a canopy openness gradient and each understory light gradient, using Indicator Species Analysis (ISA). Kruskal-Wallis test was performed using Statistica 8.0, while MRPP and ISA analyses were carried out using PC-ORD 6.0.

3. Results

3.1. Understory light regimes

Canopy openness varied strongly among plots, indicating highly significant spatial heterogeneity ($P < 0.0001$). Canopy openness of plot 26 to plot 50 was greater than those of plot 1 to plot 25 (Figure 1). Both transmitted direct solar radiation ($P < 0.0001$; Figure 2) and transmitted diffuse solar radiation ($P < 0.0001$; Figure 3) showed highly significant spatial heterogeneity and differed consistently with canopy openness.

3.2. Species composition and diversity

Number of stems, number of species, and Shannon-Wiener index of groundcover plants strongly fluctuated among plots. Plots with greater canopy openness and understory light intensity had more stems and species of groundcover plants in most cases (Figures 4-5). However, Shannon-Wiener index did not vary with canopy openness and understory light (Figure 6).

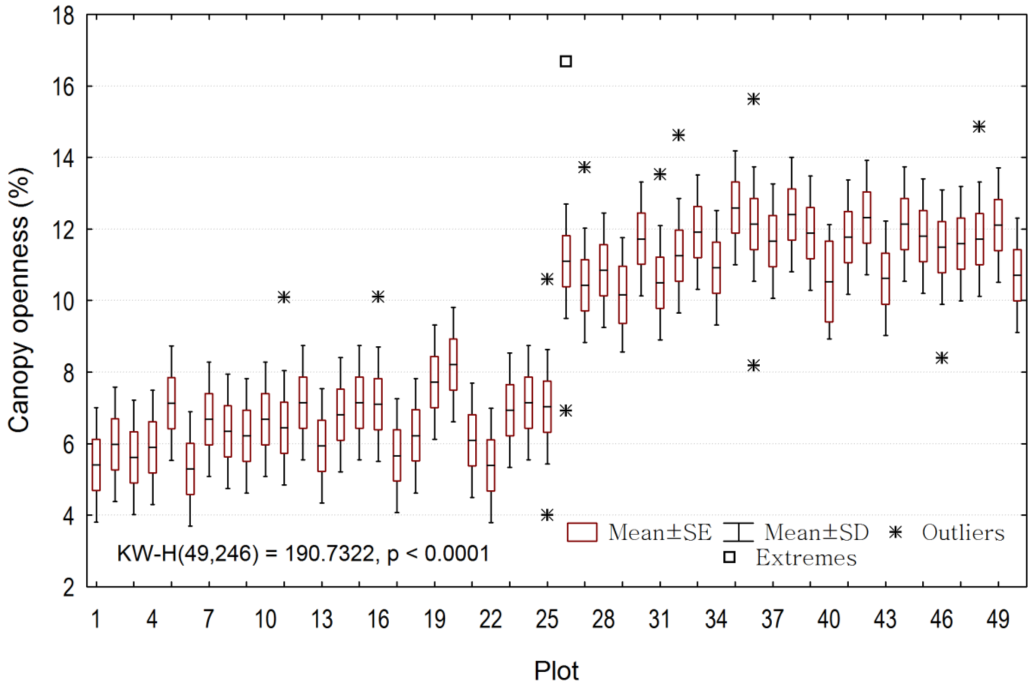

Figure 1. Spatial variations in canopy openness across plots.

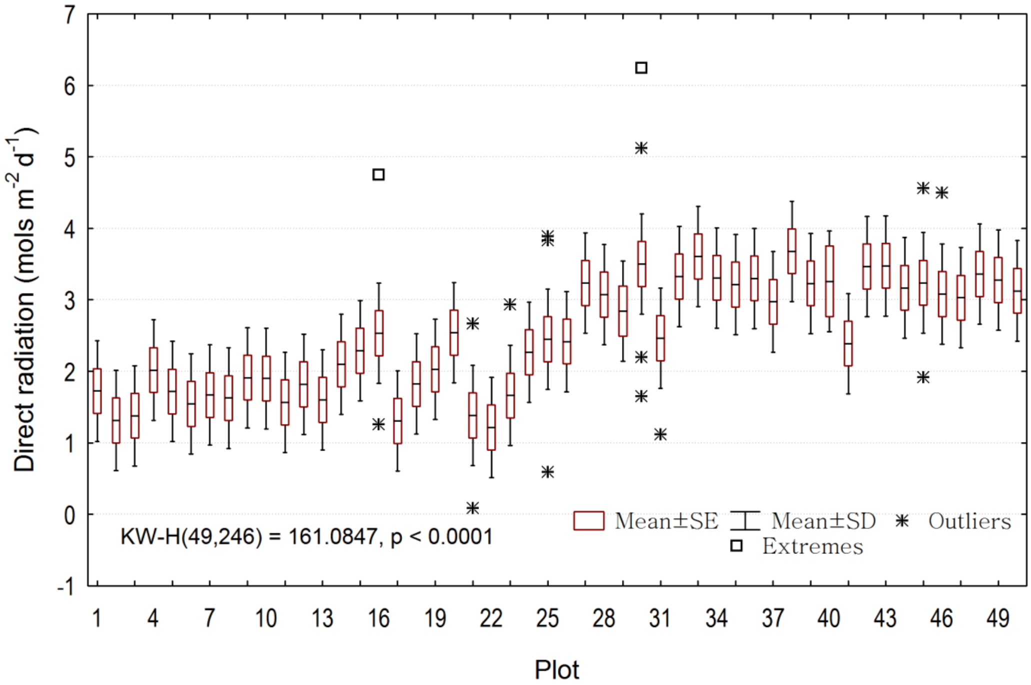

Figure 2. Spatial variations in transmitted direct radiation across plots.

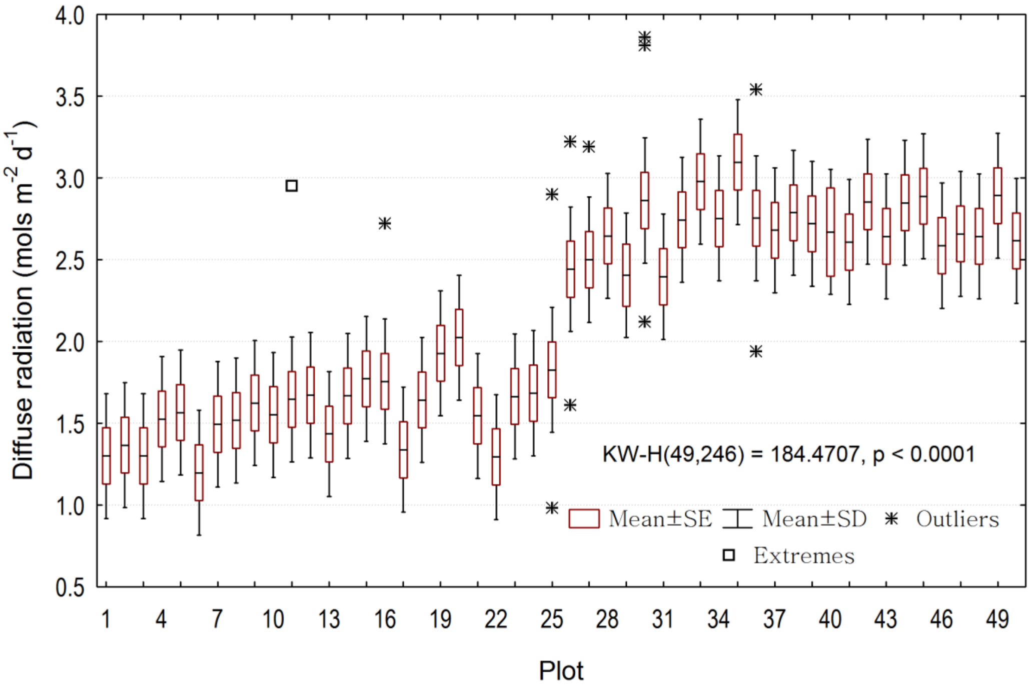

Figure 3. Spatial variations in transmitted diffuse radiation across plots.

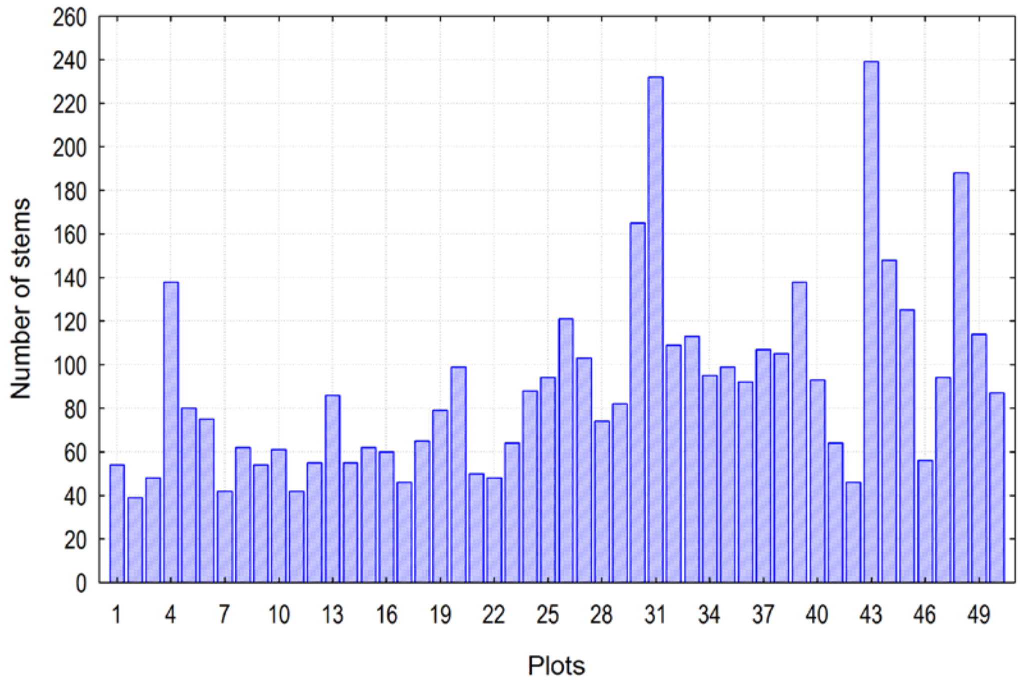

Figure 4. Number of species recorded in plots.

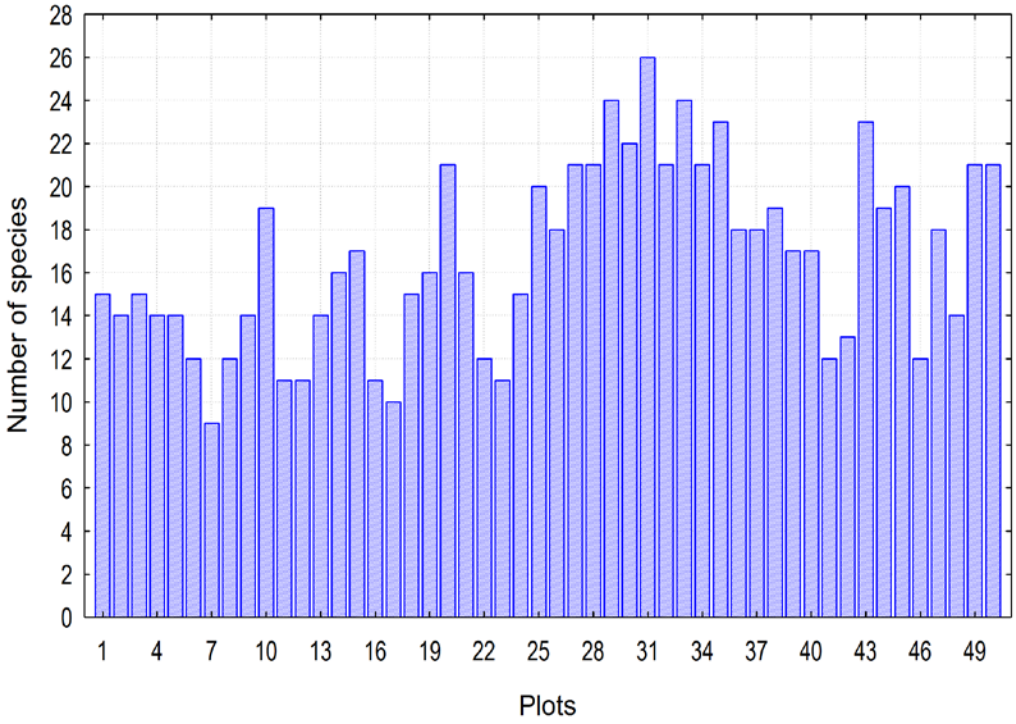

Figure 5. Number of stems recorded in plots.

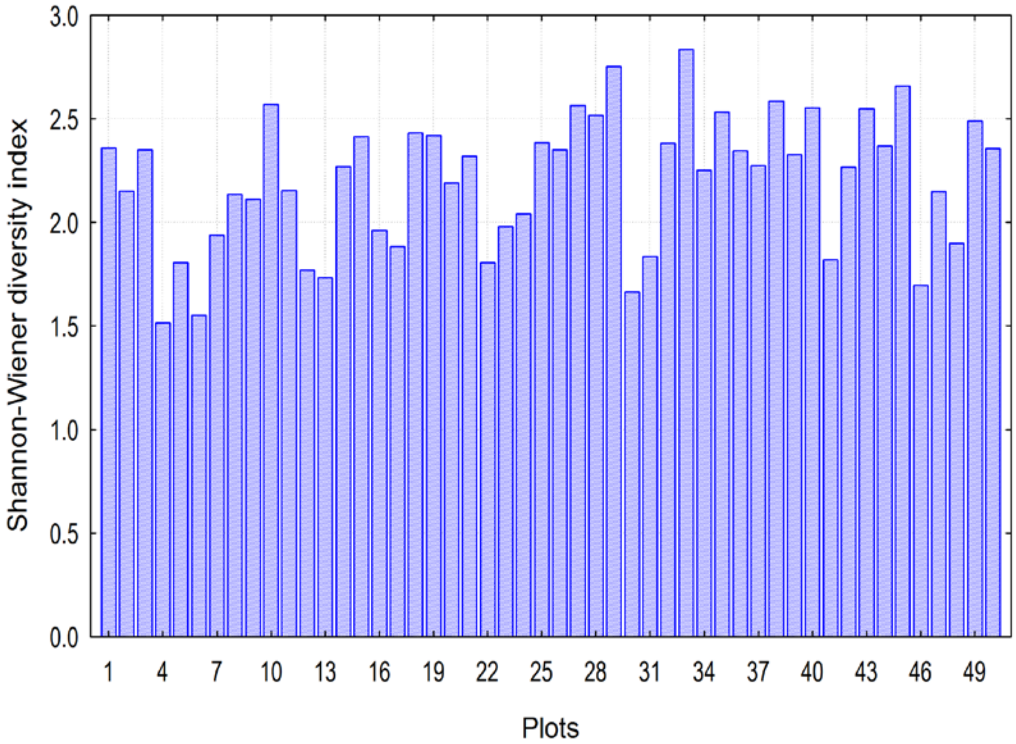

Figure 6. Shannon-Wiener diversity index for the sampling plots.

The species composition of groundcover plants was highly dependent on understory light regime, showing highly significant differences ($P < 10^{7}$) along the canopy openness, the transmitted direct solar radiation, and the transmitted diffuse solar radiation gradients, as assessed by multi-response permutation procedures (MRPP), respectively (Table 1).

Table 1. Multi-response permutation procedures used to test for the significance of variation in species composition across gap light-related gradients.

Grouping variable	Observed delta	Expected delta	*T*	*A*	*p*
Canopy openness	0.69	0.79	-13.75	0.13	$< 10^{-7}$
Direct radiation	0.67	0.79	-17.03	0.16	$< 10^{-7}$
Diffuse radiation	0.67	0.79	-16.63	0.15	$< 10^{-7}$

3.3. Indicator species of light gradient
Indicator species analysis revealed the preference of plant species for habitats [10]. Seven indicators were detected in the habitats with low canopy openness, transmitted direct solar radiation, or transmitted diffuse solar radiation. However, only two species, i.e., *Millettia dielsiana* and *Smilax china*, were the shared indicators (Table 2-4). Five indicators were found in the habitats with medium openness, transmitted direct solar radiation, or transmitted diffuse solar radiation, of which *Dalbergia hancei* and *Gnetum parvifolium* were the shared indicators (Table 2-4). Eleven indicators were found in the habitats with high canopy openness, transmitted direct solar radiation, or transmitted diffuse solar radiation, and only *Rhododendron simsii* was the shared indicator (Table 2-4).

Table 2. Groundcover plants as indicators of canopy openness gradient.

Canopy openness	Species	Indicator value	IV from randomization		*P*
			Mean	S.D.	
Low	*Camellia oleifera*	23.5	8.8	4.22	0.028
Low	*Castanopsis fissa*	29.3	15.4	5.57	0.029
Low	*Cunninghamia lanceolata*	36.6	13.9	5.63	0.004
Low	*Millettia dielsiana*	47.1	13	5.43	0.000
Low	*Smilax china*	48.3	18.5	5.74	0.001
Medium	*Dalbergia hancei*	25	8.8	4.4	0.010
Medium	*Gnetum parvifolium*	25.8	12	5.19	0.020
High	*Alyxia sinensis*	34	12.8	5.58	0.004
High	*Elaeagnus loureirii*	23.5	8.9	4.36	0.032
High	*Rhododendron simsii*	39	15.9	5.92	0.004

4. Conclusions
Highly significant spatial heterogeneity existed in canopy openness, transmitted direct solar radiation, and transmitted diffuse solar radiation. The number of stems and number of species also varied spatially and showed similar trends with canopy structure and understory light regimes.

Plants can be used as indicators for identifying special habitats. *Millettia dielsiana* and *Smilax china* were indicative of low light and low canopy openness environment; *Dalbergia hancei* and *Gnetum parvifolium* were indicative of medium light and medium canopy openness environment; and *Rhododendron simsii* was indicative of high light and high canopy openness environment. Thus, we regarded *Millettia dielsiana* and *Smilax china* as shade-tolerant plants and *Rhododendron simsii* as light-demanding plant. These indicators were dominant species in their specific habitats and had useful information for plant application in urban greening and landscaping in various light environments.

Table 3. Groundcover plants as indicators of direct radiation gradient.

Direct radiation	Species	Indicator value	IV from randomization		*P*
			Mean	S.D.	
Low	*Camellia oleifera*	23.5	8.9	4.52	0.014
Low	*Castanopsis fissa*	27.5	15.5	5.66	0.041
Low	*Cunninghamia lanceolata*	35.7	14	5.54	0.005
Low	*Evodia lepta*	35.2	21.7	6.43	0.038
Low	*Liquidambar formosana*	17.6	7.7	4.2	0.048
Low	*Millettia dielsiana*	33.6	13.1	5.46	0.004
Low	*Smilax china*	41	18.6	5.79	0.005
Medium	*Dalbergia hancei*	30.8	8.8	4.43	0.004
Medium	*Gnetum parvifolium*	42.9	12.1	5.21	0.001
Medium	*Litsea cubeba*	25.8	10.9	4.96	0.016
Medium	*Viburnum fordiae*	27.1	15.3	5.46	0.040
High	*Cayratia japonica*	43.2	18.3	6.78	0.003
High	*Clematis uncinata*	25	10.1	4.91	0.021
High	*Elaeagnus loureirii*	20	8.9	4.61	0.040
High	*Pandanus austrosinensis*	25.2	11.7	5.07	0.023
High	*Rhododendron simsii*	45.4	15.9	5.93	0.001
High	*Rhodoleia championii*	22.2	11.2	5.14	0.050
High	*Tetrastigma hemsleyanum*	46.6	16.4	5.69	0.000
High	*Tricalysia dubia*	25.6	11.9	5.11	0.020

Table 4. Groundcover plants as indicators of diffuse radiation gradient.

Diffuse radiation	Species	Indicator Value	IV from randomization		*P*
			Mean	S.D.	
Low	*Evodia lepta*	38	21.8	6.61	0.026
Low	*Millettia dielsiana*	61.5	13.2	5.57	0.000
Low	*Smilax china*	31.9	18.7	5.9	0.035
Medium	*Dalbergia hancei*	25	8.9	4.46	0.010
Medium	*Gnetum parvifolium*	33.4	12.2	5.42	0.006
Medium	*Pithecellobium lucidum*	34.6	14.5	5.45	0.005
Medium	*Viburnum fordiae Hance*	48.2	15.4	5.53	0.000
High	*Cayratia japonica*	46.2	18.4	6.86	0.002
High	*Clematis uncinata*	23.8	10.1	4.88	0.022
High	*Pandanus austrosinensis*	33.3	11.7	5.05	0.003
High	*Rhododendron simsii*	43.9	16	6.07	0.002
High	*Rhodoleia championii*	21.5	11.2	5.18	0.048
High	*Schefflera octophylla*	32.3	15.6	5.74	0.017
High	*Smilax hypoglauca*	23.8	10	4.81	0.023
High	*Tricalysia dubia*	24.9	11.9	5.24	0.030

Acknowledgments
This research is supported by the Science and Technology Planned Programs of Guangdong Province (Grant No. 2013B020305008) and a grant from Dongguan Forestry Administration of Guangdong (DCD-2013-115).

References:

[1] Bartels S F and Chen H Y H 2010 Is understory plant species diversity driven by resource quantity or resource heterogeneity? *Ecology* **91** 1931-38

[2] Ou Y, Su Z, Ke X and Li Z 2012 Vascular ground flora in relation to topography, canopy structure and gap light regimes in a subtropical broadleaved forest (south china) *Pol. J. Ecol.* **60** 463-478

[3] Ou Z, Cao J, Shen W, Tan Y, He Q and Peng Y 2015 Understory flora in relation to canopy structure, soil nutrients, and gap light regime: A case study in southern china *Pol. J. Environ. Stud.* **24** 2559-68

[4] Marialigeti S, Tinya F, Bidlo A and Odor P 2016 Environmental drivers of the composition and diversity of the herb layer in mixed temperate forests in Hungary *Plant Ecol.* **217** 549-563

[5] Selzer L J and Busso C A 2016 Pigments and photosynthesis of understory grasses: Light irradiance and soil moisture effects *Russ. J. Plant Physl.* **63** 224-234

[6] Abdallah F, Michalet R, Maalouf J, Ouled-Dhaou S, Touzard B, Noumi Z and Chaieb M 2016 Disentangling canopy and soil effects of a savanna tree species on its understorey *J. Veg. Sci.* **27** 771-779

[7] Abella S R and Springer J D 2015 Effects of tree cutting and fire on understory vegetation in mixed conifer forests *Forest Ecol. Manag.* **335** 281-299

[8] Cook J E 2015 Structural effects on understory attributes in second-growth forests of northern Wisconsin, USA *Forest Ecol. Manag.* **347** 188-199

[9] Cui J, Zeng H, Wang Y, Zhang Y, Hu Y and Su Z 2015 Canopy structure and radiation attenuation effects of broad-leaved forest in yinpingshan national nature reserve *Journal of Northwest Forestry University* **30** 45-49

[10] Su Z, Ke X and Zhang S 2012 Vascular plants as indicators of organic carbon gradient in subtropical forested soils *Pol. J. Environ. Stud.* **21** 1393-98