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

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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 | \( P \) |
|-----------------|---------------------|-----------------|-----------------------|--------|
| 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 Mean | S.D. | P       |
|------------------|------------------------|-----------------|---------------------------|------|---------|
| 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 loureitii    | 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 Mean | S.D. | P       |
|-------------------|-----------------------------|-----------------|---------------------------|------|---------|
| 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 hypoglaucac          | 23.8            | 10                        | 4.81 | 0.023   |
| High              | Tricalysia dubia            | 24.9            | 11.9                      | 5.24 | 0.030   |

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