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 vines, 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 foliage [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 m². 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 \( \geq 90 \), including *Sinobambusa tootsik var. Laeta*, *Adiantum flabellatum*, *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-m² 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 \( \geq 90 \) in the forest understory.

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>F</th>
<th>RA</th>
<th>RF</th>
<th>I.V.(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sinobambusa tootsik var. laeta</em></td>
<td>1215</td>
<td>88</td>
<td>8.39</td>
<td>4.03</td>
<td>6.21</td>
</tr>
<tr>
<td><em>Adiantum flabellatum</em></td>
<td>1068</td>
<td>153</td>
<td>7.37</td>
<td>7.00</td>
<td>7.19</td>
</tr>
<tr>
<td><em>Rourea microphylla</em></td>
<td>710</td>
<td>75</td>
<td>4.90</td>
<td>3.43</td>
<td>4.17</td>
</tr>
<tr>
<td><em>Evodia lepta</em></td>
<td>542</td>
<td>66</td>
<td>3.74</td>
<td>3.02</td>
<td>3.38</td>
</tr>
<tr>
<td><em>Rourea minor</em></td>
<td>528</td>
<td>104</td>
<td>3.64</td>
<td>4.76</td>
<td>4.20</td>
</tr>
<tr>
<td><em>Ardisia quinquegona</em></td>
<td>509</td>
<td>109</td>
<td>3.51</td>
<td>4.99</td>
<td>4.25</td>
</tr>
<tr>
<td><em>Scheffleria octophylla</em></td>
<td>463</td>
<td>53</td>
<td>3.20</td>
<td>2.43</td>
<td>2.81</td>
</tr>
<tr>
<td><em>Cryptocarya concinna</em></td>
<td>406</td>
<td>86</td>
<td>2.80</td>
<td>3.94</td>
<td>3.37</td>
</tr>
<tr>
<td><em>Tetraceria asiatica</em></td>
<td>405</td>
<td>49</td>
<td>2.80</td>
<td>2.24</td>
<td>2.52</td>
</tr>
<tr>
<td><em>Calamus rhobolodus</em></td>
<td>371</td>
<td>54</td>
<td>2.56</td>
<td>2.47</td>
<td>2.52</td>
</tr>
<tr>
<td><em>Lygodium flexuosum</em></td>
<td>367</td>
<td>57</td>
<td>2.53</td>
<td>2.61</td>
<td>2.57</td>
</tr>
<tr>
<td><em>Dalbergia hancei</em></td>
<td>367</td>
<td>37</td>
<td>2.53</td>
<td>1.69</td>
<td>2.11</td>
</tr>
<tr>
<td><em>Symplocos adenophylla</em></td>
<td>329</td>
<td>40</td>
<td>2.27</td>
<td>1.83</td>
<td>2.05</td>
</tr>
<tr>
<td><em>Massaenda pubescens</em></td>
<td>292</td>
<td>48</td>
<td>2.02</td>
<td>2.20</td>
<td>2.11</td>
</tr>
<tr>
<td><em>Gahnia tristis</em></td>
<td>292</td>
<td>44</td>
<td>2.02</td>
<td>2.01</td>
<td>2.01</td>
</tr>
<tr>
<td><em>Lophatherum gracile</em></td>
<td>266</td>
<td>43</td>
<td>1.84</td>
<td>1.97</td>
<td>1.90</td>
</tr>
<tr>
<td><em>Millettia dielsiana</em></td>
<td>262</td>
<td>41</td>
<td>1.81</td>
<td>1.88</td>
<td>1.84</td>
</tr>
<tr>
<td><em>Psychotria ribebr</em></td>
<td>240</td>
<td>59</td>
<td>1.66</td>
<td>2.70</td>
<td>2.18</td>
</tr>
</tbody>
</table>

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

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 2. Variation in species composition and diversity.

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

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,
Dieranopteris, Smilax china, Itea chinensis, Breyenia
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 hemispherial photography, a novel
photogrammetric approach. Studies have shown that
hemispherial 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.

<table>
<thead>
<tr>
<th>Species</th>
<th>Habit</th>
<th>Canopy Openness</th>
<th>Indicator value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapium discolor</td>
<td>Tree</td>
<td>3</td>
<td>46.3</td>
<td>0.0001</td>
</tr>
<tr>
<td>Dieranopteris dichotoma</td>
<td>Fern</td>
<td>3</td>
<td>27.6</td>
<td>0.0091</td>
</tr>
<tr>
<td>Meliosma thorelii</td>
<td>Tree</td>
<td>2</td>
<td>24.1</td>
<td>0.1036</td>
</tr>
<tr>
<td>Smilax china</td>
<td>Shrub</td>
<td>3</td>
<td>22.4</td>
<td>0.0004</td>
</tr>
<tr>
<td>Pithecellobium lucidum</td>
<td>Tree</td>
<td>1</td>
<td>22.2</td>
<td>0.2739</td>
</tr>
<tr>
<td>Itea chinensis</td>
<td>Tree</td>
<td>3</td>
<td>22.1</td>
<td>0.0302</td>
</tr>
<tr>
<td>Breyenia fruticosa</td>
<td>Shrub</td>
<td>3</td>
<td>20.9</td>
<td>0.0359</td>
</tr>
<tr>
<td>Lithocarpus longanoides</td>
<td>Tree</td>
<td>2</td>
<td>20.6</td>
<td>0.5019</td>
</tr>
<tr>
<td>Calophyllum membranaceum</td>
<td>Shrub</td>
<td>1</td>
<td>19.6</td>
<td>0.0561</td>
</tr>
<tr>
<td>Melastoma sanguineum</td>
<td>Shrub</td>
<td>3</td>
<td>19.2</td>
<td>0.0565</td>
</tr>
<tr>
<td>Embelia laeta</td>
<td>Shrub</td>
<td>2</td>
<td>18.5</td>
<td>0.1427</td>
</tr>
</tbody>
</table>
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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References