Canopy structure, light attenuation, and Gross Primary Production Chapin et al pages 115-121

Our last series of classes we focused on leaf-level gas and energy exchange. In this class we will move up to a larger scale and consider whole canopy exchange. Canopy gas exchange is dominated by the patterns of leaf gas exchange and can be largely understood based on what we have already learned. Let's start by interpreting the following plots that were collected at the marsh during the summer.
While an understanding of leaf gas exchange can help explain how canopy gas exchange varies over a day, we need more information if we are to predict the absolute rate of gas exchange by a canopy or if we are to explain why different canopies have different rates of gas exchange.

**What additional things do you think we will need to consider to understand canopy exchange?**

PAR: The wavelengths of sunlight that can be used for photosynthesis is referred to as the Photosynthetically Active Radiation, or PAR.

fAPAR: The fraction of PAR that is absorbed by the canopy is called fAPAR (sometimes also fIPAR for Intercepted). A low fAPAR means most of the incident sunlight (PAR) is absorbed by the soil or reflected back. Hence, not much of the PAR is absorbed by leaves and the rate of canopy photosynthesis is low.

What determines fAPAR? The fraction of light absorbed by a real canopy is mostly determined by two things - the LAI and the tip angle of the leaves.
\[
\frac{I_L}{I_0} = e^{-k \text{LAI}}
\]

\[IL/IO\] is the fraction of light that passes through a layer of leaves with thickness LAI.

\[f_{\text{PAR}} = 100 - 100 \left( \frac{I_L}{I_0} \right)\]

For \(k = 0.6\)

<table>
<thead>
<tr>
<th>LAI</th>
<th>f_{\text{PAR}} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>6</td>
</tr>
<tr>
<td>0.5</td>
<td>26</td>
</tr>
<tr>
<td>1.0</td>
<td>45</td>
</tr>
<tr>
<td>2.0</td>
<td>70</td>
</tr>
<tr>
<td>4.0</td>
<td>91</td>
</tr>
<tr>
<td>8.0</td>
<td>99</td>
</tr>
</tbody>
</table>

Desert

Tundra

Marsh, Forest

How would you expect light varies as a function of depth in a forest canopy?
How is a canopy designed?

Plants organize the photosynthetic capacity of their leaves through the canopy to adjust to the patterns of light.

Rules governing the light curve of an individual leaf:
(1) Net photosynthesis = Gross photosynthesis – Dark respiration
(2) The Quantum yield is the same for all C₃ plants
(3) Increasing levels of leaf metabolic activity (rubisco concentration) extend the amount of light that plants can use.
(4) The rate of photosynthesis at light saturation and the rate of dark respiration are closely linked – both are a function of the quantity of enzymes in the leaf.
This creates a series of light curves with increasing biochemical capacity.

So a low activity leaf is not necessarily inferior. It all depends on light level – at low light, low capacity leaves are better, at high light, high capacity leaves are better.
Why is canopy structure important?

Assume that respiration continues at night and that it is dark for 12 hours of the day. Also, assume that plants only keep leaves that gain carbon over a 24-hour period. Assume a $k$ of 0.6

For a canopy of only high capacity leaves:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Capacity</th>
<th>Sunlight</th>
<th>Day gain</th>
<th>Night loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>55%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>16%</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

For a canopy of high, medium and low capacity leaves:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Capacity</th>
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<th>Day gain</th>
<th>Night loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>100%</td>
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<td></td>
<td></td>
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<tr>
<td>2</td>
<td>M</td>
<td>55%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L</td>
<td>16%</td>
<td></td>
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</tbody>
</table>

Which canopy will be able to maintain a higher LAI and fAPAR, and realize a greater 24-hour CO$_2$ uptake?
We can now combine what we learned about leaf gas exchange with what we learned about the importance of LAI to construct a conceptual model of how canopy gas exchange at the marsh should vary over the year. Diagram the mechanistic interactions between these things:

LAI
Fraction of light reflected
Fraction of light absorbed by soil and dead plants
fAPAR
Sunlight
Net radiation
Photosynthesis
Evaporation
Sensible heat flux
How does gas exchange vary over a year? These data were collected at the marsh.
How would you expect the following midday fluxes to change over the year?
Midday (bright light) $\text{CO}_2$ uptake at the marsh

Interpreting real data:
Once you’ve understood the graph’s axes and what is being compared to what, the keys is to distinguish between:

(1)  Bad points, aka fliers

(2)  Sampling variability

(3)  True variability