Understanding the Underwater Light Field and Its Relevance to Seagrass Sustainability and Resource Management in Tampa Bay

Bay Area Scientific Information Symposium 5

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Tampa Bay Seagrass Management Strategy

• Light is a limiting factor for seagrass occurrence and depth distribution
  – Seagrass have among the highest light requirements than any other organism in the plant kingdom (Gallegos 1994)

• In Tampa Bay, a bay-wide minimum light target of 20.5% was established
  – Based on work in Lower Tampa Bay on the species *Thalassia testudinum* (Dixon and Leverone 1995)
Tampa Bay Seagrass Target Re-Evaluation

• The Estuary Program and its partners concluded:
  – Utilizing a single bay-wide target may not be appropriate
  – Better characterization of the light quantity in shallow seagrass areas is needed
  – Quality of light in shallow seagrass areas is not well understood
  – Major causes of light attenuation are not well quantified

• Need an operational framework that can be easily incorporated into existing monitoring networks and management strategies

• Ultimate goal is to transition optical oceanography from a largely academic field to an operational one
Photosynthetically Active Radiation

\[ PAR(z) \equiv \int_{400nm}^{700nm} \frac{\lambda}{hc} E_d(x, \lambda) d\lambda \]

- \( E_d(\lambda) = \) downwelling irradiance (\( \mu \text{mol m}^{-2} \text{s}^{-1} \)) defined as: the radiant flux per unit area of a surface

\[ E_d = \int L(\theta, \phi) \cos \theta d\omega \]

- Light for photosynthesis is in terms of quanta rather than energy because once a quantum has been absorbed by a plant cell, its contribution to photosynthesis is the same regardless of its wavelength-specific energy
- Usefulness of a given light field is not only a function of the total intensity of PAR but the spectral distribution of the light field across photosynthetically useable radiation (PUR) wavelengths
Photosynthetically Useable Radiation

A given photon must first be absorbed by a photosynthetic pigment, like chlorophyll, and this process is wavelength specific.

Sufficient quantities of PAR may give the impression that ample light is available but the contribution of photosynthetically useable radiation (PUR) to PAR may reveal a different story.

Absorption Spectrum for *Thalassia testudinum* (Zimmerman 2003)
Selected wavelength ranges of the color bands blue, green, and red and the pigments that are represented by each. Only the red algae, blue-green algae, and the cryptophytes contain billiproteins that allow them to harvest green light.

<table>
<thead>
<tr>
<th>Wavelength Range</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>400nm-490nm</td>
<td>490nm-600nm</td>
<td>640nm-690nm</td>
</tr>
<tr>
<td>Pigments</td>
<td>chlorophyll/carotenoid protein complex</td>
<td>billiproteins</td>
<td>chlorophylls</td>
</tr>
<tr>
<td>Found in Seagrass</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
Measuring Light

- **Secchi Disk** = the depth to which a black and white disk is no longer visible. If the bottom is visible with the eye, the Secchi Disk will not work. Dependent on the user’s eyesight.

- **Photosynthetically Active Radiation, PAR** (\( \mu \text{mol photons} / \text{m}^2/\text{s} \)) = the total amount of light at a given depth (quantity). Need at least 1.5m of water depth to be useful. Only measures quantity of light.

- **Downwelling Irradiance** \( Ed(\lambda) \): The radiant flux per unit area of a surface. Uses a portable spectrometer attached to a light collector via a fiber optic cable. Can be used in depths as shallow as 0.25m.
Attenuation Coefficient ($K_d$)

- Describes the rate at which light is lost through the water column
- Light loss is exponential with depth and follows the Beer-Lambert Law

$$K_d(z) = -\frac{1}{z} \ln \frac{E_d(z)}{E_d(0)}$$

- $E_d$ is in units of $\mu$mol photons $m^{-2} s^{-1}$
- A more accurate estimate of $K_d$ is to calculate the slope of the $\ln(E_d)$ with depth
Percent subsurface $E_d(\lambda)$

- The relative difference between the irradiance at the surface and the irradiance at the bottom
- Operationally the optical depth ($\zeta$) is used and is the attenuation coefficient times the total depth
- Total depth is the average depth at mean sea level

$$\%E_d(\lambda) = \left[ \frac{e^{(\zeta+1)}}{e} \right] \times 100$$

$$\zeta = (-K_d(\lambda) \times z)$$
- Sites were chosen based on a priori knowledge of the spectral characteristics and seagrass distribution
  - **Egmont Key**
    - Chosen for its proximity to the Gulf of Mexico and relative distance from major freshwater sources.
  - **Coffeepot Bayou**
    - Considered a chlorophyll-dominated area containing mostly urban run-off from the adjacent watershed. The shoreline is almost completely sea-wall.
  - **Kitchen and Wolf Branch**
    - Both areas considered CDOM rich. Mostly a mangrove dominated shoreline with some salt marsh vegetation. Downstream of major freshwater inflows (Alafia River and Bullfrog Creek).
  - Information from City of Tampa Bay Study Group’s seagrass transects were used to site fixed stations for in-water measurements
<table>
<thead>
<tr>
<th>Location</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
<th>PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOLF BRANCH</td>
<td>17.1</td>
<td>47.2</td>
<td>45.8</td>
<td>40.9</td>
</tr>
<tr>
<td>KITCHEN</td>
<td>17.7</td>
<td>46.4</td>
<td>45.0</td>
<td>39.8</td>
</tr>
<tr>
<td>COFFEEPOT BAYOU</td>
<td>14.2</td>
<td>32.8</td>
<td>26.6</td>
<td>30.1</td>
</tr>
<tr>
<td>AVERAGE @ Seagrass Deep Edge</td>
<td>18.1</td>
<td>41.7</td>
<td>35.6</td>
<td>35.7</td>
</tr>
<tr>
<td>EGMONT KEY</td>
<td>23.3</td>
<td>40.2</td>
<td>25.1</td>
<td>32.1</td>
</tr>
</tbody>
</table>

- Based on these numbers light environment may be blue-light limited
Mapping Percent subsurface irradiance using a GIS-model approach

- Apply a simple model to map the percent subsurface irradiance over seagrass management areas
- $K_d(\lambda)$ derived from in-water measurements
- Total depth is derived from high resolution LIDAR bathymetry using NASA EAARL system
- Depths are in meters ± 0.2cm relative to mean sea level
Coffeepot Bayou
Kitchen
Total measured depth, percent subsurface blue light, and percent subsurface PAR relative to surface conditions along the mapped seagrass deep edge. These data were extracted using a sub-routine in ARCGIS in which percent subsurface irradiance was collected for each pixel that fell along the seagrass deep edge.

<table>
<thead>
<tr>
<th>Location</th>
<th>% Blue Light</th>
<th>% Green Light</th>
<th>% Red Light</th>
<th>%PAR</th>
<th>MSL Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffeepot Bayou</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± standard deviation</td>
<td>13.6 ± 3.5</td>
<td>48.5 ± 5.1</td>
<td>30.7 ± 7.3</td>
<td>31.7 ± 6.7</td>
<td>1.21 ± 0.30</td>
</tr>
<tr>
<td>Median</td>
<td>13.8</td>
<td>48.9</td>
<td>31.5</td>
<td>32.7</td>
<td>1.14</td>
</tr>
<tr>
<td>Max</td>
<td>24.1</td>
<td>87.15</td>
<td>43.6</td>
<td>43.6</td>
<td>2.05</td>
</tr>
<tr>
<td>Min</td>
<td>4.5</td>
<td>26.26</td>
<td>13.6</td>
<td>15.5</td>
<td>0.82</td>
</tr>
<tr>
<td>Kitchen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± standard deviation</td>
<td>17.3 ± 2.7</td>
<td>44.5 ± 3.2</td>
<td>40.7 ± 2.72</td>
<td>38.7 ± 3.25</td>
<td>0.87 ± 0.08</td>
</tr>
<tr>
<td>Median</td>
<td>17.4</td>
<td>44.8</td>
<td>40.3</td>
<td>38.9</td>
<td>0.86</td>
</tr>
<tr>
<td>Max</td>
<td>29.6</td>
<td>57.15</td>
<td>51.8</td>
<td>51.8</td>
<td>1.09</td>
</tr>
<tr>
<td>Min</td>
<td>11.0</td>
<td>36.26</td>
<td>35.0</td>
<td>30.3</td>
<td>0.60</td>
</tr>
<tr>
<td>Wolf Branch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± standard deviation</td>
<td>18.1 ± 4.9</td>
<td>45.1 ± 5.6</td>
<td>40.7 ± 5.7</td>
<td>38.9 ± 5.8</td>
<td>0.97 ± 0.15</td>
</tr>
<tr>
<td>Median</td>
<td>18.0</td>
<td>45.4</td>
<td>40.9</td>
<td>39.1</td>
<td>0.95</td>
</tr>
<tr>
<td>Max</td>
<td>27.8</td>
<td>55.0</td>
<td>50.9</td>
<td>49.2</td>
<td>1.29</td>
</tr>
<tr>
<td>Min</td>
<td>18.0</td>
<td>34.4</td>
<td>29.8</td>
<td>28.1</td>
<td>0.72</td>
</tr>
</tbody>
</table>

**AVERAGE from in-water measurements**  
18.1  41.7  35.6  35.7

**AVERAGE from GIS model**  
16.3  46.0  37.4  36.4
Summary

- Annual average percent subsurface PAR was around 36% suggesting that there is ample light at the deep edge using the current 20.5% minimum light target.
- Annual average percent subsurface blue light was around 17%.
- Need to better characterize the spatial and temporal variability in the light attenuation coefficient ($K_d$).
- If seagrass are in fact blue light limited, it may be more appropriate (in theory) to establish a minimum blue light target.
- Next step is to determine the root causes of blue light loss.
Competing for Light

As a photon of light propagates down through the water column, it can be absorbed by the following:

- Water (molecular absorption)
- Detritus (suspended organic matter)
- Colored Dissolved Organic Matter (CDOM)
- Phytoplankton absorption (chlorophyll)
Relative contribution and magnitude

\[ a_t(\lambda) = a_w(\lambda) + a_g(\lambda) + a_\phi(\lambda) + a_d(\lambda) \]

- The relative contribution of a given component is the percent of the total absorption attributed to that component.
- The magnitude is the absolute value of a given component.
- The relative contribution of a specific component can be high but the overall magnitude of the component may be low or vice versa.
  - For example: 80% of the total absorption may be from CDOM at 440nm but the magnitude \( a_g(440) \) may only be 0.16 m\(^{-1}\).
TBEP Nitrogen Management Strategy Paradigm

Empirical modeling approach defining relationships between TN loads and chlorophyll a concentrations and between chlorophyll a concentrations and light attenuation (Janicki and Wade, 1996)

- Data from stations outside seagrass management areas
- Assumes chlorophyll is the major attenuator of light
- Only considers quantity not spectral light quality
Colored Dissolved Organic Matter

Detritus

Chlorophyll

Light Attenuation

Seagrass Growth & reproduction, Depth Limit Coverage

Seagrass Light Requirement (20.5% in Tampa Bay)

- CDOM may be the major light attenuator in shallow seagrass areas
- High CDOM may create a poor quality blue-light limited environment
- Contribution from detrital material may be significant through re-suspension
Annual percent contribution to total absorption by phytoplankton, CDOM, and detritus

<table>
<thead>
<tr>
<th>Location</th>
<th>(\sigma_\phi(440))</th>
<th>(\sigma_g(440))</th>
<th>(\sigma_d(440))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolf Branch</td>
<td>20.2</td>
<td>58.9</td>
<td>20.9</td>
</tr>
<tr>
<td>Kitchen</td>
<td>18.7</td>
<td>58.3</td>
<td>23.0</td>
</tr>
<tr>
<td>Coffeepot Bayou</td>
<td>22.2</td>
<td>62.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Egmont Key</td>
<td>20.8</td>
<td>63.8</td>
<td>15.3</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>20.5</td>
<td>60.8</td>
<td>18.7</td>
</tr>
</tbody>
</table>

Annual average of the magnitude of the absorption coefficients

<table>
<thead>
<tr>
<th>Location</th>
<th>Chl (a) ((\mu)g L(^{-1}))</th>
<th>(\sigma_\phi(440)) (m(^{-1}))</th>
<th>(\sigma_g(440)) (m(^{-1}))</th>
<th>(\sigma_d(440)) (m(^{-1}))</th>
<th>(\sigma_t(440)) (m(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolf Branch</td>
<td>7.40</td>
<td>0.2233</td>
<td>0.6509</td>
<td>0.2315</td>
<td>1.1057</td>
</tr>
<tr>
<td>Kitchen</td>
<td>9.73</td>
<td>0.2655</td>
<td>0.8268</td>
<td>0.3269</td>
<td>1.4192</td>
</tr>
<tr>
<td>Coffeepot Bayou</td>
<td>5.45</td>
<td>0.1736</td>
<td>0.4893</td>
<td>0.1207</td>
<td>0.7836</td>
</tr>
<tr>
<td>Egmont Key</td>
<td>3.09</td>
<td>0.1052</td>
<td>0.2013</td>
<td>0.0774</td>
<td>0.3839</td>
</tr>
</tbody>
</table>
CDOM may dominate the absorption of light in these shallow seagrass areas, there may not be much we can do about it.
Conclusions

• The current minimum light target of 20.5% PAR is likely too low for Tampa Bay seagrass areas.
• Minimum light target for PAR between 30% - 40% may be more appropriate.
• Blue light is likely the limiting the distribution of seagrass into deeper waters and the average percent subsurface blue light was around 17%.
• Absorption increased with distance from the mouth of Tampa Bay with the maxima occurring in areas with well developed mangrove shorelines.
• Even though magnitudes were different, relative contributions were similar.
• CDOM accounted for most of the total absorption (60%).
• Detritus absorption accounted for 19% of the total and is likely a function of re-suspension of organic material in shallow waters.
• Phytoplankton chlorophyll only accounted for 21% of the total absorption but may be the only component that can be successfully managed.