St. Lucie Estuary: Analysis of Annual Cycles and Integrated Water Column Productivity

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Overview

- Description of St. Lucie Estuary
- Purpose of Project
- Overview of 2000-2001 SLE Productivity Study
- Data Analysis Tasks, Methods, and Results
- Management Implications and Follow-Up Actions
St. Lucie Facts

- Surface area: ~11 mi²
- Drainage area: ~827 mi²
- Historic drainage area ~160mi²
- Freshwater system until 1892
- Depth
  - Littoral margins: 3-7 ft
  - Channel: 10-17 ft
  - Mean tidal flux: ~0.9 ft
- Hydraulically connected to Lake Okeechobee & Everglades (1924), St. Lucie County ag. Lands (1950s) by canals
High DOC, tannin-stained (CDOM) freshwater inputs
Highly developed shoreline
Evidence of Impairment

- High sedimentation rates; “ooze”/”muck”
- Eutrophic, algal-dominated system; blooms
- Loss of seagrass & oysters
- Benthic macroinvertebrate indices
- Health of the fish community

Source: Chamberlain and Hayward, 1996; IRL SWIM Plan, 2002 Update; Graves and Strom, 1992; Sime, 2005;
2000-2001 SLE Productivity Study

- **Purposes**
  - Improve understanding of nutrient sources, cycling, and fluxes
  - Support PRGs and TMDLs

- **Partners**
  - SFWMD
  - Harbor Branch Oceanographic Institute
  - Malcolm Pirnie, Inc.
Water Quality Monitoring

- 4 locations, 8 stations
- Monthly sampling (Jan 2000 – March 2001)
- Weekly sampling for 8-week periods
  - Aug-Oct 2000
  - Jan-Feb 2001
- Constituents by depth
  - Field parameters
  - Light attenuation
  - Nutrients
  - Chlorophyll-a
  - Primary Productivity
    - In-situ incubation
    - Variable depths
    - D.O. by Winkler method
SLEP Data Analysis Tasks

1. Identify Spatial and Seasonal Trends in Water Quality
   Interpret trends with regard to major drivers of water quality and phytoplankton growth

2. Primary Productivity Modeling
   Predict depth-integrated primary productivity as a function of water quality and light-related variables

3. Benthic Nutrient Flux Analysis

4. Estuarine Nutrient Budget
Task 1: Spatial and Seasonal Gradients in Water Quality

- **Sub-Tasks**
  - Hypothesis
  - Correlations between key variables
  - Seasonal differences
  - Spatial differences
    - Between regions of the estuary
    - Between shallow v. deep

- **Methods**
  - Graphical
  - Statistical
    - Principal Components Analysis
    - Correlation coefficients
    - Non-parametric hypothesis testing
Bloom Events

- Occur in summer around seasonal max temperature
- Follow large freshwater inputs
- Show evidence of contribution to low bottom D.O.

![Graph showing Bloom Events with data points for Chl-a, Salinity, and Bottom D.O.]

South Florida Water Management District
Nutrient Limitation

P-limited

N/P Ratio

Mixed or co-limited

N-limited

11.4

17.7

Median

90th percentile

10th percentile

90th percentile

Median

10th percentile
Correlations Between Key Variables
Principal Components Analysis

Factor Loadings, Factor 1 vs. Factor 2
Rotation: Unrotated
Extraction: Principal components

DO
OPO4
pH
Photic Depth
salinity
Temp
TKN
TP

DO-Temp

15-20% of Variance
Salinity-Nutrients-Clarity

50-60% of Variance
Correlations Between Key Variables

Spearman’s \( \rho \) Correlations

- **Salinity as “master” variable**
  - **Direct correlations**
    - Light availability
    - Normalized primary productivity
    - pH
  - **Inverse correlations**
    - Nutrients (except ammonia)
    - Chlorophyll-a
    - Temperature
    - Net & Gross primary productivity

*In short, as salinity increases water clarity increases and nutrients, algal biomass, and productivity decrease.*
Correlations Between Key Variables
Spearman’s $\rho$ Correlations

- Chlorophyll a
  - Direct correlations
    - Temperature
    - Orthophosphorus
    - TKN
    - Daily surface irradiance
    - Primary productivity
  - Inverse correlations
    - Nitrate + Nitrite, Ammonia
    - Salinity

Low correlation between primary productivity and light availability.
Task 1: Spatial Trends in Water Quality

South Fork vs. HR1
South Fork > NO₃
HR1 > Light Penetration
HR1 > Net and Gross Primary Productivity

Decrease in Net and Gross Primary Productivity
Increasing Chlorophyll a
Increasing Normalized Primary Productivity
Increasing Light Penetration
Decreasing Nutrients

Lowest Light Penetration

Higher pH
Greater Normalized Primary Productivity
Task 1: Spatial Trends in Water Quality Variability with Depth

- Mild vertical salinity gradients
- DO, temperature lower with depth
- Chl-a, productivity lower with depth
- Shallow stations more turbid
## Task 1: Seasonal (Wet/Dry) Trends

<table>
<thead>
<tr>
<th>Higher in Wet Season</th>
<th>Higher in Dry Season</th>
<th>No Seasonal Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-(a)</td>
<td>Respiration</td>
<td>Average (k_d)</td>
</tr>
<tr>
<td>Gross Primary Productivity</td>
<td>Dissolved Oxygen</td>
<td>Benthic Chlorophyll-(a)</td>
</tr>
<tr>
<td>Net Primary Productivity</td>
<td>pH</td>
<td>DNO(_x)</td>
</tr>
<tr>
<td>(\text{OPO}_4)</td>
<td>Salinity</td>
<td>(\text{NH}_4)</td>
</tr>
<tr>
<td>Salinity Stratification</td>
<td></td>
<td>Normalized Primary</td>
</tr>
<tr>
<td>Surface Irradiance</td>
<td></td>
<td>Productivity</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td>\textbf{Photic Depth}</td>
</tr>
<tr>
<td>TKN</td>
<td></td>
<td>\textbf{Secchi}</td>
</tr>
<tr>
<td>TP</td>
<td></td>
<td>Vertical Salinity Gradient</td>
</tr>
</tbody>
</table>

*Note:* The table above lists the variables that are higher in the wet season, in the dry season, or show no seasonal difference.
Task 2: Primary Productivity Modeling

- Key environmental variable.
- Resource-intensive measurements.
- Often estimated as function of temperature (e.g., Eppley Curve).
- More successful models use:
  - Light availability
  - Algal biomass

From Brush and others (2002)
Basic regression model

\[ G_p = b_0 + b_1 (BZ_p I_o) \]

- B: Chorophyll-a
- Zp: Photic depth
- I_0: Surface irradiance

Does this model work for the St. Lucie Estuary?

Better model available?
Net Primary Productivity

\[ R^2 = 0.54 \]
Gross Primary Productivity

$R^2 = 0.58$
Log Transformation Improves Regression Properties…

\[ R^2 = 0.53 \]
<table>
<thead>
<tr>
<th>Source</th>
<th>Study area</th>
<th>b</th>
<th>m</th>
<th>R²</th>
<th>Source</th>
<th>Study area</th>
<th>b</th>
<th>m</th>
<th>R²</th>
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<tbody>
<tr>
<td>This study</td>
<td>St. Lucie Estuary</td>
<td></td>
<td></td>
<td></td>
<td>Harding et al. (1986)</td>
<td>Delaware Bay</td>
<td>131</td>
<td>0.39</td>
<td>0.76</td>
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<tr>
<td>All Data: Net PP</td>
<td></td>
<td>164</td>
<td>0.55</td>
<td>0.55</td>
<td>Pennock &amp; Sharp (1986)</td>
<td>Delaware Bay</td>
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<tr>
<td>All Data: Gross PP</td>
<td></td>
<td>227</td>
<td>0.79</td>
<td>0.58</td>
<td>Non-summer</td>
<td></td>
<td>100</td>
<td>0.07</td>
<td>0.68</td>
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<tr>
<td>Shallow: Net PP</td>
<td></td>
<td>202</td>
<td>0.45</td>
<td>0.60</td>
<td>Summer</td>
<td></td>
<td>300</td>
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<td>Shallow: Gross PP</td>
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<td>249</td>
<td>0.52</td>
<td>0.64</td>
<td>Cole &amp; Cloern (1987)</td>
<td>San Francisco Bay; Puget Sound; New York Bight</td>
<td>150</td>
<td>0.73</td>
<td>0.82</td>
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<tr>
<td>Deep: Net PP</td>
<td></td>
<td>133</td>
<td>0.63</td>
<td>0.56</td>
<td>Cole (1987)</td>
<td>South San Francisco Bay</td>
<td>94</td>
<td>0.88</td>
<td>0.88</td>
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<tr>
<td>Deep: Gross PP</td>
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<td>230</td>
<td>0.99</td>
<td>0.65</td>
<td>Cloern (1987)</td>
<td>North San Francisco Bay</td>
<td>63</td>
<td>0.67</td>
<td>0.72</td>
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<tr>
<td>Cole &amp; Cloern (1984)</td>
<td>San Francisco Bay</td>
<td>58</td>
<td>0.82</td>
<td>0.82</td>
<td>Keller (1988a)</td>
<td>MERL</td>
<td>199</td>
<td>0.59</td>
<td>0.86</td>
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<tr>
<td>Cole et al. (1986)</td>
<td>San Francisco Bay</td>
<td></td>
<td></td>
<td></td>
<td>Keller (1988b)</td>
<td>Narragansett Bay; MERL</td>
<td>220</td>
<td>0.70</td>
<td>0.82</td>
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<tr>
<td>Unfractionated</td>
<td></td>
<td>57</td>
<td>0.81</td>
<td>0.81</td>
<td>Cole (1989)</td>
<td>Tomales Bay</td>
<td>125</td>
<td>0.75</td>
<td>0.90</td>
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<tr>
<td>Netplankton</td>
<td></td>
<td>34</td>
<td>0.73</td>
<td>0.73</td>
<td>Cloern (1991)</td>
<td>San Francisco Bay</td>
<td>0</td>
<td>1.1</td>
<td>0.93</td>
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<tr>
<td>Nanoplankton</td>
<td></td>
<td>28</td>
<td>0.73</td>
<td>0.75</td>
<td>Mallin et al. (1991)</td>
<td>Neuse River estuary</td>
<td>Not reported</td>
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<td>Ultraplankton</td>
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<td>25</td>
<td>0.76</td>
<td>0.55</td>
<td>Kelly &amp; Doering (1997)</td>
<td>Mass. Bay; Boston Harb.</td>
<td>286</td>
<td>0.79</td>
<td>0.66</td>
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<td>Harding et al. (1986)</td>
<td>Chesapeake Bay</td>
<td>176</td>
<td>0.74</td>
<td>0.69</td>
<td>Kromkamp et al. (1995)</td>
<td>Westerschelde estuary</td>
<td>32-317</td>
<td>0.22-0.72</td>
<td>0.32-0.83</td>
</tr>
</tbody>
</table>
Task 2: Primary Productivity Regressions

Findings

- Use of multiple linear regression
  - Showed that most explanatory power came from chlorophyll-a, not light availability.
- Slopes, intercepts within ranges reported in literature
- Addition of nutrient terms (marginally significant)
  - TP coefficient positive
  - TKN, NH4, PO4 coefficients negative

**Recommendation:** Use simple linear regression with $BZ_{pI_o}$. 
Findings, Management Implications and Follow-Up Actions

- Productivity can be modeled as a function of algal biomass and light availability.

3. Benthic Nutrient Flux Analysis
4. Estuarine Nutrient Budget

Understand where the nutrients are going and what effects the CERP and TMDLs will have.