Riverine Nutrient Inputs and Extent of Estuarine Eutrophication in the Southern California Bight

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June 20, 2013
Eutrophication is a Leading Cause of Impairment in U.S. Waterbodies

Increased Nutrient Loads

Eutrophication: Excessive Organic Matter Production

Low Dissolved Oxygen
Harmful Algal Bloom
Loss of Habitat

Beneficial Use Impairment
Data on Eutrophication in California Estuaries is Limited

2007 NOAA National Eutrophication Assessment
Key Questions:

• What is the extent and magnitude of eutrophication in southern California estuaries?

• What is the relationship between expression of eutrophication and nutrient inputs?

• What are the implications for nutrient management?
Study Design

- 27 Segments from 23 Estuaries; Randomly Selected
- Monitored from Nov 2008 - Oct 2009
- Targeted “index area” within each estuary--Conservative Answer
Conceptual Model of Development of Eutrophication

Minimally Disturbed

Increased Nutrient Loading

Affected by Eutrophication

Nutrient inputs

Light

Nutrient inputs

Shading

Changes in Water Chemistry (DO, pH)

Changes in Sediment Chemistry (Sulfide, Ammonia)

Seagrass

Benthic Diatoms

Macroalgae

Phytoplankton
Approach

Assess Extent and Magnitude Using Indicators of Eutrophication:
• Primary producers – biomass and cover, bimonthly
  – Macroalgae
  – Phytoplankton
• Dissolved Oxygen – continuous in bottom water

Relationship with Nutrient Inputs
• Estuarine ambient nutrients- bimonthly
• Riverine Nutrient Loading
  – Continuous flow
  – Dry weather concentrations- bimonthly
  – MS4 data or modeled (Sengupta et al. in prep)
Bight ‘08 Eutrophication Assessment: Filling in the Data Gap

**Key Questions:**

- What is the extent and magnitude of eutrophication in southern California estuaries?
- What is the relationship between expression of eutrophication and nutrient inputs?
- What are the implications for nutrient management?
How Do We Assess Eutrophication?
European Union – Water Framework Directive

- Thresholds for indicators related to biological response to eutrophication
  - Dissolved oxygen
  - Macroalgae
  - Phytoplankton

- Categorize estuaries based on ecological condition

Ecological Condition:
- Very High
- High
- Moderate
- Low
- Very Low

Considered Problem Area
# Macroalgae Assessment

<table>
<thead>
<tr>
<th>Biomass (g dw m(^{-2}))</th>
<th>Percent Cover</th>
<th>(\leq 5%)</th>
<th>&gt; 5%</th>
<th>&gt; 15%</th>
<th>&gt; 25%</th>
<th>&gt; 75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 415</td>
<td>Moderate</td>
<td>Low</td>
<td>V. Low</td>
<td>V. Low</td>
<td>V. Low</td>
<td></td>
</tr>
<tr>
<td>&gt; 140</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>V. Low</td>
<td>V. Low</td>
<td></td>
</tr>
<tr>
<td>&gt; 70</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>&gt; 15</td>
<td>V. High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>(\leq 15)</td>
<td>V. High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td></td>
</tr>
</tbody>
</table>

**Ecological Condition Interpreted from WFD Framework**

- **Very High**
- **High**
- **Moderate**
- **Low**
- **Very Low**

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*Images show various levels of macroalgae coverage and biomass.*
78% of segments had macroalgae indicative of degraded condition.

% of segments in each category based on mean biomass and cover of highest two periods.
Biomass AND Duration of Bloom Affect Benthic Infauna in Intertidal Flats

Lauri Green, Ph.D. Dissertation, UCLA Department of Biology (Spring 2010)
Macroalgal Bloom Duration is a Concern for the SCB Estuaries

Bloom Duration Interpreted from Consecutive Periods of Moderate or Worse Macroalgal Biomass/Cover

- 0 Periods: 11%
- Duration May Affect Benthic Infauna: 30%
- Bloom Duration Expected to Adversely Affect Benthic Infauna: 59%
**Phytoplankton Assessment**

**Ecological Condition**
Interpreted from WFD Framework

<table>
<thead>
<tr>
<th>Annual Average of Sonde Chlorophyll a (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very High</strong></td>
</tr>
<tr>
<td>&lt; 5</td>
</tr>
<tr>
<td><strong>High</strong></td>
</tr>
<tr>
<td>5 - 7</td>
</tr>
<tr>
<td><strong>Moderate</strong></td>
</tr>
<tr>
<td>7 - 10</td>
</tr>
<tr>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>10 - 30</td>
</tr>
<tr>
<td><strong>Very Low</strong></td>
</tr>
<tr>
<td>≥ 30</td>
</tr>
</tbody>
</table>

![Graph showing chlorophyll a levels]

- **Very High**: 0 - 1
- **Annual Average**: 3 mg L⁻¹

- **Low**: 0 - 1
- **Annual Average**: 21 mg L⁻¹
39% of Segments had Phytoplankton Biomass Indicative of Degraded Condition

### Annual Average of Sonde Chlorophyll a (μg/L)

- **Very High**: < 5
- **High**: 5 - 7
- **Moderate**: 7 - 10
- **Low**: 10 - 30
- **Very Low**: ≥ 30
Magnitude and Duration of Phytoplankton Blooms Adversely Affect Benthic Primary Producers

Ruiz and Romero, *Marine Ecology Progress Series*, 2001
Bloom Duration is a Concern for the SCB Estuaries

Bloom Duration Interpreted from Daily Averages of Instantaneous 15 Minute Interval Chlorophyll Data

- Bloom Duration where shading affects benthic primary producers: 25%
- Bloom duration may affect benthic primary producers: 15%
- Bloom duration < 1 month
- Bloom duration < 2 weeks
- Bloom duration < 24 hours
### Dissolved Oxygen Assessment

#### Ecological Condition Interpreted from WFD Framework

<table>
<thead>
<tr>
<th>Ecological Condition</th>
<th>Dissolved Oxygen Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>$\geq 5.7$</td>
</tr>
<tr>
<td>High</td>
<td>4.0 - 5.7</td>
</tr>
<tr>
<td>Moderate</td>
<td>2.4 - 4.0</td>
</tr>
<tr>
<td>Low</td>
<td>1.6 - 2.4</td>
</tr>
<tr>
<td>Very Low</td>
<td>$&lt; 1.6$</td>
</tr>
</tbody>
</table>

10th percentile of hourly running average DO data (mg/L)

![Graph showing dissolved oxygen concentration](image)

- **Very Low**: DO $< 1.6$
- **Moderate**: 1.6 - 2.4
- **Low**: 2.4 - 4.0
- **High**: 4.0 - 5.7
- **Very High**: $\geq 5.7$

10th %tile
75% of Segments had DO Indicative of Degraded Condition

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
<th>mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>7%</td>
<td>≥ 5.7</td>
</tr>
<tr>
<td>High</td>
<td>40%</td>
<td>4.0 – 5.7</td>
</tr>
<tr>
<td>Moderate</td>
<td>29%</td>
<td>2.4 – 4.0</td>
</tr>
<tr>
<td>Low</td>
<td>18%</td>
<td>1.6 – 2.4</td>
</tr>
<tr>
<td>Very Low</td>
<td>7%</td>
<td>&lt; 1.6</td>
</tr>
</tbody>
</table>

5th percentile of hourly DO data (mg/L)
Magnitude and Duration of Hypoxia Adversely Affect Ecosystem Quality

Mean ± SE = 266.62 ± 22.08 h
N = 460

Median = 116.7 ± 27.67 h

~5 days

10 percentile = 6.8 h

Vaquer-Sunyer, Duarte PNAS 2008
Duration of Hypoxic Events (DO < 4 mg/L) is a Concern for SCB Estuaries

Hourly Averaged Data

Longest Single Event in All Estuaries
Eutrophication is Pervasive in Southern California Estuaries

<table>
<thead>
<tr>
<th>Indicator</th>
<th>% With Ecological Condition Less than High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any One</td>
<td>96%</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>78%</td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>39%</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>63%</td>
</tr>
<tr>
<td>Either Primary Producer &amp; DO</td>
<td>52%</td>
</tr>
</tbody>
</table>

Ecological Condition:
- Very High
- High
- Moderate
- Low
- Very Low
Uncertainties

• Did we adequately capture variability?
  – Temporal variability
  – Spatial variability

• What is the appropriate assessment framework for SCB estuaries?
  – What are the right indicators?
  – Relevance of European thresholds?
  – Little guidance on data management
  – Little guidance on frequency of sampling or how to incorporate event duration
## How Do SCB Estuaries Compare?

The table below compares the overall rank of various segments in terms of Macroalgal, Phytoplankton, and Dissolved Oxygen conditions.

<table>
<thead>
<tr>
<th>Overall Rank</th>
<th>Segment</th>
<th>Macroalgal</th>
<th>Phytoplankton</th>
<th>Dissolved Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Batiquitos Lagoon</td>
<td>7</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Seal Beach</td>
<td>5</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Los Penasquitos Lagoon</td>
<td>6</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Bolsa Chica</td>
<td>15</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Mugu Lagoon</td>
<td>18</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>San Diego Bay</td>
<td>10</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>Santa Ana R. Wetlands-Diked</td>
<td>14</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Seal Beach-Diked</td>
<td>9</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>San Elijo Lagoon</td>
<td>8</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>San Mateo Lagoon</td>
<td>24</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Topanga Lagoon</td>
<td>2</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>Tijuana River Estuary</td>
<td>11</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>13</td>
<td>San Diego Bay-Diked</td>
<td>22</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>Agua Hedionda Lagoon</td>
<td>3</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>15</td>
<td>Ballona Lagoon-Diked</td>
<td>19</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>16</td>
<td>Santa Margarita Estuary</td>
<td>20</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>San Juan Creek</td>
<td>4</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>Zuma Lagoon</td>
<td>17</td>
<td>14</td>
<td>18</td>
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<tr>
<td>19</td>
<td>Bolsa Chica-Diked</td>
<td>21</td>
<td>4</td>
<td>15</td>
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<tr>
<td>20</td>
<td>Ballona Wetlands</td>
<td>13</td>
<td>6</td>
<td>26</td>
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<tr>
<td>21</td>
<td>Mission Bay</td>
<td>12</td>
<td>9</td>
<td>27</td>
</tr>
<tr>
<td>22</td>
<td>Goleta Slough</td>
<td>23</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>23</td>
<td>Mugu Lagoon-Diked</td>
<td>26</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>24</td>
<td>San Diego River</td>
<td>16</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>25</td>
<td>UCSB Campus Lagoon</td>
<td>25</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>26</td>
<td>Santa Clara River</td>
<td>1</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>27</td>
<td>Devereux Lagoon</td>
<td>27</td>
<td>16</td>
<td>25</td>
</tr>
</tbody>
</table>
Bight ‘08 Eutrophication Assessment: Filling in the Data Gap

Key Questions:

• What is the extent and magnitude of eutrophication in southern California estuaries?

• What is the relationship between expression of eutrophication and nutrient inputs?

• What are the implications for nutrient management?
Nutrient Loads to SCB Estuaries are Variable

![Absolute Load Graph]

- DL
- UCL
- GS
- SCR
- MLM
- MLF
- ZC
- TC
- SBM
- SBF
- BCM
- BCF
- SAR
- SJC
- SMC
- SME
- AHL
- BQL
- SEL
- LPL
- MB
- SDR
- SDF
- SDM
- TJE

Annual TN Load (kg)
Estuary Size Affects Its Ability to Assimilate Nutrient Loads

Topanga Canyon Lagoon 3.68 km²

Mission Bay 8,795 km²
If Loads Are Area-Normalized, Loading “Hot Spots” Change

Absolute Load

Area Normalized Load
Riverine Nutrient Loads are Correlated with Estuarine Concentrations

\[ R^2 = 0.2910 \]
\[ p = 0.0037 \]
For Algae, Response Related to Nutrient Inputs; Reflecting Disturbance Gradient

Estuarine Nutrient Concentrations

Riverine Nutrient Loads

Annual Average Total Nitrogen (uM)

Annual TN Load-Volume and Residence Time Normalized (g m⁻³)
For Dissolved Oxygen, No Relationship with Nutrient Inputs

**Estuarine Nutrient Concentrations**

**Riverine Nutrient Loads**

- $R^2 = 0.000003$
- $p = 0.9931$
- $R^2 = 0.045$
- $p = 0.2898$
Why the Poor Correlation?

- Ambient Concentrations Are “Left-Overs”
  - Not a true representation of exposure
- Most of TN is DON and PN
  - Macroalgae are leaky
Critical Periods are Decoupled: Wet Weather Dominates Nutrient Loads...
...But Critical Period For Indicators is Typically Dry Season
Macroalgal Biomass and Dissolved Oxygen are Significantly Correlated to Sediment Nutrients

R² = 0.200
p = 0.0221

R² = 0.28
p = 0.005
Wet Season Particulate Deposition is a Source of Dry Season Nutrient Loads

- **Dissolved N & P**
- **Particulate N & P**
- **Particulate Deposition**
- **Tidal Exchange**

**Wet Season**

**Dissolved N & P**

- **Tides**
- **Algae Biomass N & P Storage**
- **Dissolved N & P**

**Dry Season**

- **Organic Matter Remineralization**
Relative Contribution of Sediment Nutrients Varies By Estuary

Contribution of Sediment Nutrients Increases as Sediment % Fines and Organic Matter Increase

1 McLaughlin et al. 2008
2 Berelson et al., unpublished data

RED McLaughlin et al. 2008
BLUE Bight 08 Eutrophication Assessment
Estuarine Class is Important:
Some Estuaries are More Susceptible to Eutrophication

- **Fluvial**
  - Higher water velocity
  - Sandy sediments
  - Low sediment OC & benthic flux, low algal biomass

- **Lagoonal**
  - Lower water velocities
  - Fine grained sediments
  - High sediment OC & benthic flux, high algal biomass
Best Model Fit Accounts for Nutrient Loads, Sediment %OC, and Residence Time

Observed LOG [Dry Season Macroalgae Biomass (g dw m⁻²)]

Predicted LOG [Dry Season Macroalgae Biomass (g dw m⁻²)]

<table>
<thead>
<tr>
<th>Y</th>
<th>X</th>
<th>R²</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroalgae Biomass</td>
<td>Diurnal Z</td>
<td>0.3820</td>
<td>0.0008</td>
</tr>
<tr>
<td></td>
<td>Annual % OC</td>
<td>0.1893</td>
<td>0.0263</td>
</tr>
<tr>
<td></td>
<td>Annual TN Load</td>
<td>0.0536</td>
<td>0.1197</td>
</tr>
<tr>
<td></td>
<td><strong>Whole Model</strong></td>
<td><strong>0.5800</strong></td>
<td><strong>0.0002</strong></td>
</tr>
</tbody>
</table>
Example: Closed Inlet During Critical Period For Macroalgae
Nutrient-Response Relationship is Governed by Site-Specific Factors

• Across estuaries, nutrient loads and ambient nutrient concentrations are equally correlated with response
  — More reflective of disturbance gradient than true measure of exposure

• Across estuaries, estuary class drives large component of variability in nutrient-response relationships
Bight ‘08 Eutrophication Assessment: Filling in the Data Gap

**Key Questions:**

- What is the extent and magnitude of eutrophication in southern California estuaries?

- What is the relationship between expression of eutrophication and nutrient inputs?

- What are the implications for nutrient management?
Managing Eutrophication: Need Site-Specific Nutrient Targets

• We assess indicators of eutrophication, but we manage nutrients

• We need models to make the connection between nutrient input and biological response
Challenges

• How do you make the assessment?
  – What indicators do you use?
  – How do you integrate the data?

• What should the target look like?
  – Ambient concentrations (e.g., Basin Plan Objectives)
  – Nutrient loads (e.g., TMDL)
  – Sediment nutrients

• How should site specific factors be incorporated?
  – Geomorphology: depth, volume
  – Hydrology: residence time
Next Step... Simple 1-D Box Models

- Account for residence time
- Build in simple empirical relationships between sediment %OC and benthic flux

Increasing Precision, Accuracy, Utility for Scenario Analysis

HELPFUL BUT NOT PRECISE Models
Simple Box Models
Calibrated Numerical Models

Increasing Data Requirements, Cost
Conclusions from Bight ‘08 Study

• Eutrophication is pervasive in SCB estuaries

• Across estuaries, nutrient loads and ambient nutrient concentrations are equally correlated with response
  — More reflective of disturbance gradient than true measure of exposure

• Across estuaries, estuary class drives large component of variability in nutrient-response relationships

• Nutrient-response models must account for site-specific factors, e.g.
  — Residence time
  — Benthic nutrient fluxes
Questions?

Bight 08 Estuaries Eutrophication Assessment report is available:


For more information:
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karenm@sccwrp.org