ENVIRONMENTAL FACTORS DRIVING CYANOBACTERIA BLOOM DEVELOPMENT AND TOXIN PRODUCTION IN CALIFORNIA

Alexander E. Parker, Allison Johnson, Jamie Lee, Adam Pimenta, Cecile Mioni

CyanoHAB Workshop
Oakland, CA – November 28, 2012
1. Quantify primary (C) production in cyanobacteria dominated communities.

**H1: Cyanobacteria have low growth rates (low PP).**

2. Determine N uptake rates and percent contribution of N substrates (ammonium, nitrate, urea) to growth.

**H2: Cyanobacteria will use reduced N (NH₄, urea) over NO₃.**
1. Evaluate temperature influences on cyanobacterial growth
   
   **H1: Cyanobacteria favored at higher temperature.**

2. Investigate DIN and PO$_4$ influence on cyanobacterial growth
   
   **H2: Nutrient-replete conditions in the SFE result in no nutrient effect on growth.**
**Microcystis aeruginosa (MIC)**

- Colonial species (cells ~2μm), forms surface scums.
- Cosmopolitan in temperate and tropical freshwater systems.
- Produce secondary metabolite hepatotoxin microcystin (70+ variants).

- Studied for >50 years, although only recently observed in along west coast of North America (Moisander et al. 2009).
- First observed in the SFE Delta in 1999 (Lehman et al. 2005, 2008) and present most years since.
- Some indication of microcystin toxins in estuarine foodweb (Lehman et al. 2008).
CYANOBACTERIA IN THE SFE DELTA

Aphanizomenon flos-aquae (APHA)

- Colonial, forming “tufts”.
- May contain heterocysts, capable of N₂ fixation.
- Generally found in cooler temperature conditions than MIC.
- Capable of producing toxic secondary metabolites, anatoxin.
- Although present in the SFE Delta, first abundant blooms in 2011 (this study and others).
SAMPLING LOCATIONS

The San Francisco Estuary Delta: Large Rivers (ANT, RIO), Small Rivers (MOK, OLD) and Flooded Islands (FRK, MIL)
## STATION CONDITIONS

<table>
<thead>
<tr>
<th>Station</th>
<th>Temp. C</th>
<th>Secchi (m)</th>
<th>$\text{NO}_3+\text{NO}_2$ (μmol L$^{-1}$)</th>
<th>$\text{NH}_4$ (μmol L$^{-1}$)</th>
<th>Urea-N (μmol L$^{-1}$)</th>
<th>$\text{PO}_4$ (μmol L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIO</td>
<td>21.2</td>
<td>1.5</td>
<td>10.22</td>
<td>12.6</td>
<td>0.44</td>
<td>1.02</td>
</tr>
<tr>
<td>ANT</td>
<td>21.3</td>
<td>0.9</td>
<td>12.12</td>
<td>1.05</td>
<td>0.32</td>
<td>1.05</td>
</tr>
<tr>
<td>Small River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOK</td>
<td>21.6</td>
<td>1.9</td>
<td>9.36</td>
<td>3.61</td>
<td>0.64</td>
<td>0.43</td>
</tr>
<tr>
<td>OLD</td>
<td>22.8</td>
<td>3.5</td>
<td>4.59</td>
<td>1.34</td>
<td>0.14</td>
<td>1.66</td>
</tr>
<tr>
<td>Flooded Island</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIL</td>
<td>23.1</td>
<td>2.3</td>
<td>21.64</td>
<td>0.32</td>
<td>0.56</td>
<td>1.70</td>
</tr>
<tr>
<td>FRK</td>
<td>21.6</td>
<td>&gt;2</td>
<td>10.40</td>
<td>1.15</td>
<td>0.78</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Representative conditions (MIC11-5, September 8, 2011)


$^{13}\text{C}^{15}\text{N}$ incubations performed at three light intensities (50%, 25% and 5%) of surface irradiance. 24-hr incubations.

Resulting in 216 discrete measurements of carbon and nitrogen uptake.

MIC found at 25% of sites. APHA found at 64% of sites in 2011.

Water collection (in some cases cyanobacteria concentrated) for use in experimental manipulations.
PRODUCTION: CARBON UPTAKE

**RIO VISTA**

- **Chl-a (µg L⁻¹)**
  - Y-axis: 0, 2.5, 5, 7.5, 10, 12.5, 15
  - Data points for each date

- **Cells ml⁻¹ x 10⁰⁰⁰**
  - Y-axis: 0, 1, 2, 3
  - Data points for each date

- **PP (mg C m⁻² d⁻¹)**
  - Y-axis: 0, 200, 400, 600, 800, 1000
  - Data points for each date

**ANTIOCH**

- **Chl-a (µg L⁻¹)**
  - Y-axis: 0, 0.0, 50.0, 100.0, 150.0, 200.0
  - Data points for each date

- **PP (mg C m⁻² d⁻¹)**
  - Y-axis: 0, 100.0, 150.0, 200.0
  - Data points for each date

**Legend:**
- **GFF**
- **>75**
- **Microcystis**
- **Apha**

**Dates:**
- 7/19
- 8/1
- 8/8
- 8/30
- 9/8
- 9/19

**Cyanobacteria:**
- **Lower**
- **Higher**
PRODUCTION: CARBON UPTAKE

MOKELUMNE RIVER

Chl-a (µg L⁻¹)

Old River

Microcystis

Apha

Lower Cyanobacteria

Higher Cyanobacteria

PP (mg C m⁻² d⁻¹)

PBM MOK 0m

PBM

MOK 0m

7/19 8/1 8/8 8/30 9/8 9/19

7/19 8/1 8/8 8/30 9/8 9/19

0 1 2 3 4 5 6 7 8 9 10

Cells ml⁻¹ x 10000
PRODUCTION: CARBON UPTAKE

MILDRED ISLAND

FRANK'S TRACT

Chl-a (µg L⁻¹)

Cells ml⁻¹ x 10,000

Lower Cyanobacteria

Higher Cyanobacteria
How do these rates compare to other measurements in the SFE?

Comparison with Low Salinity Zone (Suisun Bay) July – August 2007 (Kimmerer et al. 2012; Parker et al. 2012)

<table>
<thead>
<tr>
<th></th>
<th>LSZ (‘06/’07)</th>
<th>2011 All stations</th>
<th>2011 cyano stations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-α (µg L⁻¹)</td>
<td>2.1 – 2.3</td>
<td>3.7</td>
<td>9.4</td>
</tr>
<tr>
<td>Zp (m)</td>
<td>1.6 – 1.8</td>
<td>4.4</td>
<td>5.3</td>
</tr>
<tr>
<td>PP (mg C m⁻² d⁻¹)</td>
<td>107 – 171</td>
<td>604</td>
<td>660</td>
</tr>
<tr>
<td>$P_B^M$ (mg C (mg chl-α)⁻¹ d⁻¹)</td>
<td>62.8 – 68.1</td>
<td>91.3</td>
<td>29.7</td>
</tr>
</tbody>
</table>

*ANT, FRK, OLD for 9 and 19 September 2011
PRODUCTION: NITROGEN UPTAKE

Small Rivers

MOK

MIL

FRK

Large Rivers

RIO

ANT

% N Uptake

0%

25%

50%

75%

100%

OLD

Nitrogen Uptake:

- NO$_3$ 3-fold higher
- NO$_3$ 20-fold higher NH$_4$
- NO$_3$ equal to NH$_4$

(0.34 µM)
INVESTIGATING TEMPERATURE (2011)

50% PAR

18° C

23° C
## INVESTIGATING NUTRIENTS (2012)

<table>
<thead>
<tr>
<th></th>
<th>CONT</th>
<th>+NH₄</th>
<th>+NO₃</th>
<th>+UREA</th>
<th>+PO₄</th>
<th>+NH₄/PO₄</th>
<th>+NO₃/PO₄</th>
<th>+UREA/PO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N, μM</strong></td>
<td>5</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>4</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>P, μM</strong></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td><strong>N:P</strong></td>
<td>2.5:1</td>
<td>15:1</td>
<td>15:1</td>
<td>15:1</td>
<td>0.8:1</td>
<td>4.4:1</td>
<td>3.8:1</td>
<td>3.8:1</td>
</tr>
</tbody>
</table>

(50% PAR X or 10% PAR)
INVESTIGATING NUTRIENTS (2012)

Chlorophyll-a, µg L⁻¹

- Control: ~250% control
- +NH4: ~150% control
- +NO3: ~200% control
- +Urea: ~150% control
- +PO4: ~200% control
- +NH4/PO4: ~150% control
- +NO3/PO4: ~150% control
- +Urea/PO4: ~150% control
Kinetic Curves from field and culture
J. Lee (MS Student)

0.01 0.02 0.03 0.04 0.05 0.06 0.07
V, h⁻¹

0 10 20 30 40 50 60
Nitrogen concentration, µM

Nitrogen concentration, µM

Ks > 4 µM

Salinity Tolerance
A. Johnson (MS Student)

SUMMARY

Development of a mechanistic understanding of cyanobacterial bloom dynamics (and associated toxin production) will inform monitoring programs.
SUMMARY

1. Primary production and biomass rates relatively high, associated with clear water.
2. Lower assimilation numbers associated with cyanobacteria.
3. \( \text{NH}_4 \) used over \( \text{NO}_3 \), and urea.
4. Temperature regulation of cyanobacteria abundance and speciation.
5. Nutrient effects in some locations, differences in N form; no response to \( \text{PO}_4 \).
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Captain and Crew, RV Questuary

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## NITROGEN UPTAKE

<table>
<thead>
<tr>
<th>Station</th>
<th>Areal C : N Uptake (mol:mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLD 0m</td>
<td>8.5</td>
</tr>
<tr>
<td>MOK 0m</td>
<td>6.5</td>
</tr>
<tr>
<td>MIL 0m</td>
<td>6.3</td>
</tr>
<tr>
<td>FRK 0m</td>
<td>10.0</td>
</tr>
<tr>
<td>RIO 0m</td>
<td>11.7</td>
</tr>
<tr>
<td>ANT 0m</td>
<td>9.3</td>
</tr>
<tr>
<td><strong>mean</strong></td>
<td><strong>8.7</strong></td>
</tr>
</tbody>
</table>

*Microcystis (culture)  
Tsukada et al., 2006*  
5.2

*Redfield Ratio*  
6.6

Daily N demand of $5 \pm 1 \mu\text{mol L}^{-1} \text{d}^{-1}$ – suggests N limitation unlikely except OLD.
INVESTIGATING TEMPERATURE (2011)

23° C
18° C
50% PAR
50% PAR