What Controls Microcystis Bloom & Toxicity in the San Francisco Estuary?
(Summer/Fall 2008 & 2009)

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Outline

• Background
  ✓ CyanoHABs Formation and Distribution
  ✓ Routes of exposure
  ✓ Health effects
  ✓ Microcystis/Microcystins

• CyanoHABs in the San Francisco Estuary (2009)
  ✓ Study Area – San Francisco estuary
  ✓ Results

• Future strategies and Prospective work
Background – CyanoHABs, Cyanotoxins
3.5 billion years ago….

**Cyanobacteria (blue-green algae):**
- Oldest oxygenic phototrophs (>3.5 billion yo)
- Instrumental in the evolution of life (oxygen)
- Origin of Plants (chloroplast/endosymbiosis)
- Important in the Nitrogen Cycle ($N_2$ fixation)
...the bad and the ugly

• 1000 years ago – Earliest report of cyanobacteria poisoning (soldiers) in Southern China
  General Zhu Ge-Ling

• 1878 – “Poisonous Australian Lake”
  (sheep poisoning, Lake Alexandrina)
  George Francis. *Nature*. May 2, 1878

• Similar early documented mass algae poisonings in the US in 1883, 1887, 1925.
### Harmful Cyanobacteria Blooms aka CyanoHABs

<table>
<thead>
<tr>
<th><strong>Produce dense blooms</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Affect water quality</strong> – dissolved oxygen sags, taste &amp; odor problems in drinking water, toxins</td>
</tr>
<tr>
<td><strong>Produce potent toxins</strong> – illness or death</td>
</tr>
<tr>
<td><strong>Alter water diversion &amp; treatment operation</strong> – clogging of filters in water treatment plants, fish screens or channels</td>
</tr>
<tr>
<td><strong>Alter the entire ecosystem</strong> – reduce growth of other algae, impact food quality/availability, fisheries decline.</td>
</tr>
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</table>

Courtesy: NOAA
CyanoHABs – Formation

**Drivers:**
- **Land use** – Urban, agricultural & industrial expansion
- **Nutrient loading** (N, P)
- **Water use & hydrologic changes** – reduced water flow & mixing
- **Climate** (temperature increase)
  - Blooms become more common, more intense and of longer duration.

*Courtesy: IPCC*
Harmful Algae Bloom in the US

(from U.S. National Office for Harmful Algal Blooms).
Reports of acute cyanotoxin poisonings of animals and/or humans

From Graham et al. 2009
Countries Exhibiting one or more documented CyanoHAB Events

(adapted from W. Carmichael)
Cyanotoxins – Routes of Exposure

**Human**
- Recreational
- Aerosols
- Drinking water
- Food
- Medical (dialysis)

**Animals**
- Aerosols
- Drinking water
- Food

**Plants**
- Irrigation

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**WARNING**
Harmful bacteria is present in this water. Contact may cause serious harm to humans and animals.

**Human intoxication by microcystins during renal dialysis treatment in Caruaru—Brazil (Feb. 1996)**

**W. Carmichael**
Cyanotoxins – Health Effects

Dermatologic effects
- Lyngbyatoxins (“swimmer itch”)

Neurotoxic
- Anatoxins
- Paralytic shellfish poisoning toxins (saxitoxins)

Hepatotoxic
- Microcystins
- Cylindrospermopsins
Microcystis

Microcystis

- Small planktonic cells (3 - 5 µM)
- Unicellular, Colonial
- Embedded in gelatinous matrix
- Buoyant (gas vesicle)
- Fresh and brackish water
- Warm, stable, nutrient enriched

Microcystins

(http://oehha.ca.gov/ecotox/documents/Microcystin031209.pdf)

- Most numerous of the cyanotoxins
- Over 80 variants
- Extremely stable (half life = 10 weeks)
- Hepatotoxins: inhibit protein phosphatases
- Carcinogenic: Liver, colon (Grosse et al. 2006)
The Snake Scale

Comparison of Algal Toxins with some of the most venomous snakes in the world

**LD-50 (mg kg⁻¹)**

- Saxitoxins: 0.009
- Microcystin-LR: 0.02
- Domoic Acid: 0.159
- 1.155
- 5.1
- 10.9

Coastal Taipan
Field’s horned viper
Mojave green rattlesnake
Cantil viper
Cottonmouth/Water mocassin
Southern copperhead

Note: this comparison based on route of exposure (intraperitoneal). LD-50 can differ among different exposure routes.

Microcystis – Adverse Impacts

- Death & cancer in human and wildlife (http://oehha.ca.gov/ecotox/documents/Microcystin031209.pdf)
- Hypoxia/anoxia (Carmichael, 1995)
- Bad taste and odor (Carmichael, 1995)
- Reduced zooplankton & fish feeding
  success (Rohrlack et al., 2005; Malbrouck & Kestemont, 2006)
- Fish food quality (Ger et al. 09)
- Total carbon production – shift from large to small zooplankton species (Smith & Gilbert, 1995)
- Marine species (Melissa Miller, pers. com)
- Kill crops
  (Allen.Milligan@science.oregonstate.edu)
Brazil is the only country to have CynoHABs mandatory regulations. Other countries have guidelines (WHO guideline for drinking water = 1µg/L).

(Graham et al. 2009)
Is 1µg/L enough?

**Chronic Human Health Effects from drinking water: Liver and colorectal cancers**

– “Microcystins from tap water could be a risk factor for liver and colorectal cancer: A risk intensified by global change” (Martínez Hernández et al., 2009)

– 0.61 µg/L in areas of high incidence of liver cancer in China (Yu, 1994)
Microcystis in the San Francisco Estuary
SF Estuary: territory of outsize importance

SF Estuary/Delta
- Water diverted for agricultural, industrial & domestic uses
- Recreational area (fishing, water contact sports)
- Habitat of vulnerable species (Delta Smelt, Striped Bass, Threadfin Shad, Chinook Salmon)

Goals:
- Establishing a baseline
- Identifying HAB drivers

Strategy:
- Monthly monitoring @ 21 stn
- Variables: toxins, HA cells abundance, DOC, nutrients, ...
Microcystis in the Delta

- 1980’s: Increase in cyanobacteria biomass, decline of diatoms (Lehman & Smith, 1991)
- 1999: First Microcystis bloom (Lehman, 2000)
- Coincided with Pelagic Organism Decline (Delta Smelt, Striped Bass, Threadfin Shad, Chinook Salmon, Copepods)
- Coincided with environmental changes:
  - Increased water transparency
  - Increased temperature
  - Increased salinity (specific conductance)
  - Increased residence time

www.water.ca.gov/ssr/microcystis.cfm
Microcystis blooms: Environmental drivers

June 2009

(Mioni et al. in prep)
July 2009

Microcystins (μg/L)

0.0 0.5 1.0 1.5 2.0 2.5
MC-RR  MC-LR

D19 D28A D26

MC range: (cells mL⁻¹)
N/A <2×10⁴ <10⁵ ≥10⁵

(Mioni et al. in prep)
August 2009

(Mioni et al. in prep)

D12 D19 D28A D16 D26

Microcystins (µg/L)

MC range:
(cells mL⁻¹)

(Mioni et al. in prep)
September 2009
Temperature
(all stations)

(Mioni et al., in prep.)
Temperature
(only toxic stations)

(Mioni et al., in prep.)
MC-variants vs Temperature

Different strains/variants? Different requirements?

(Mioni et al., in prep.)
The lower the NOx:P ratio, the greater the toxicity?

(Mioni et al., in prep.)
Microbial Associations?

- Single Microcystis cells vs. Colonies
- Associated filamentous cyanobacterium

(Mioni et al., in prep.)
DIURNAL VARIATIONS
MC variations with time

Antioch Bridge - 08/13/2009

(Mioni et al., in prep.)
Why these diurnal variations?

<table>
<thead>
<tr>
<th>Time</th>
<th>NH$_4^+$ (µM)</th>
<th>NO$_3^-$ (µM)</th>
<th>PO$_4^{3-}$ (µM)</th>
<th>N/P</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:53</td>
<td>0.48</td>
<td>12.58</td>
<td>2.25</td>
<td>5.81</td>
</tr>
<tr>
<td>16:45</td>
<td>0.23</td>
<td>15.23</td>
<td>1.87</td>
<td>8.25</td>
</tr>
</tbody>
</table>

- Different water mass signatures
- Different microbial community?
- Horizontal transport?
Why these diurnal variations?

(Moni et al., in prep.)
They were at D28A in Aug. 09 too!

(Mioni et al., in prep.)
Role of biological drivers in Microcystin toxin production?

(Pearl & Pinckney, 1996)
Methionine: important source of methyl groups for microcystins and cyanotoxins

The methyl groups on C-2, C-6 and C-8 of the ADDA portion of microcystin derive from methionine.

(Moore, Chen et al. 1991)
Cobalt and Vitamin B12
Drivers of Community Structure and Function?

Vitamin B12 (Cobalamin/Cyanocobalamin)

Methionine Biosynthesis

(source: wikipedia)
Role of biological drivers in Microcystin toxin production?

(Pearl & Pinckney, 1996)
Conclusions

• Microcystins levels > 1µg/L at most stations during bloom.
• *Microcystis* abundance: high risk to very high risk levels.

<table>
<thead>
<tr>
<th>Date</th>
<th>Microcystis (cell/mL)</th>
<th>Microcystis (µg/L)</th>
<th>Method</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008/9</td>
<td>0 – 1.4x10⁷</td>
<td>0 – 6.46</td>
<td>LCMSMS</td>
<td>This study</td>
</tr>
<tr>
<td>2007</td>
<td>7.7x10⁴ – 9.9x10⁷</td>
<td>0.007 – 10.81</td>
<td>PPIA</td>
<td>Baxa et al. 2010</td>
</tr>
<tr>
<td>2005</td>
<td>0 – 32 x 10⁹</td>
<td>0 – 60 (ng/L)</td>
<td>PPIA</td>
<td>Lehman et al. 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HPLC</td>
<td></td>
</tr>
</tbody>
</table>

• Total microcystins concentrations correlate with surface water temperature. Different variants? Different needs?
Problems to solve

• Integrate strong short-time scale variations.
  – Vertical transport
  – Horizontal transport
  – Microbial consortia

• Identify associated filamentous cyanobacteria.

• Determine the Function of these cyanobacterial consortia.
Future work

We can do it!

Clear Lake, CA

The Delta, CA
New Strategies

• Integrating temporal variations:
  ✓ SPATT = Solid Phase Adsorption Toxins Tracking
    (Raphael Kudela, UCSC)

• Microbial community in a snapshot:
  ✓ PhyloCHIP : DNA barcoding microchip
    (Gary Andersen, LBNL).
  ✓ Distinguish 50,000 microbial species simultaneously
    (353 cyanobacteria, 184 algae).
  ✓ Microbial interaction (association, allelopathy)
Thank you!