

Toxic Algae in Lakes in the Chambers-Clover Creek Watershed

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Jean Jacoby
Seattle University
Seattle, WA

Toxins produced by blue-green algae (“cyanobacteria”) are of increasing concern to lake managers, health officials, the public, and others who rely on freshwater systems for a variety of uses. Adverse health effects on humans as result of exposure to these toxins through drinking water or recreational contact have been increasingly documented.

In this presentation, I am going to give an overview of the toxic algae issues in the C-C watershed.

Overview

- Introduction to Algal Toxins
- Background on Toxic Blooms in the Watershed
- In-depth Studies
 - American Lake
 - Steilacoom Lake
- Recent Monitoring Results
- Assessing Health Risks in Recreational Lakes
- Conclusions

I'll begin by giving a brief introduction to the major groups and effects of algal toxins in lakes. Then, I'll give some background information on toxic incidences in the C-C watershed, focusing on a couple of more in-depth with which I have been involved. I present some of the monitoring results from Ecology new algae control program this past summer and fall. I'll end by trying to put some context on all these data from a human health perspective.

Introduction to Algal Toxins

- Harmful algal blooms in coastal marine systems primarily caused by dinoflagellates
- Cyanobacteria (“blue-green algae”) produce toxins in fresh waters.



In freshwater systems, cyanobacteria are the primary producers of toxins whereas harmful or toxic blooms of algae in marine systems are primarily caused by dinoflagellates such as the ones that cause “red tides”.

Cyanobacteria are also called “blue-green algae” but are more accurately classified as photosynthetic bacteria.

Toxic Cyanobacteria

- About 50 species of toxin-producing cyanobacteria
- Common bloom-forming genera include *Microcystis*, *Anabaena*, *Planktothrix*, *Aphanizomenon*, and others
- Cyanotoxins classified into four broad groups:
 - Hepatotoxins – affect the liver
 - Neurotoxins – affect the nervous system
 - Dermatotoxins – skin and respiratory irritants
 - Endotoxins – gastrointestinal irritants

There are many species of toxin-producing cyanobacteria but several of these most commonly form blooms. Annie, Fannie and Mike are amongst the most notorious bloom formers. Animal deaths and adverse effects on human health have most often been caused by toxins produced by toxigenic strains of these genera during bloom situations.

Cyanotoxins have been classified into groups based on the organs or systems that they affect.

Cyanotoxin Groups and Sources

Toxin	No. Variants	Genera
Hepatotoxins		
Microcystins	80+	Microcystis, Anabaena, Nostoc, Anabaenopsis, Planktothrix, Oscillatoria, Hapalosiphon
Nodularins	9	Nodularia, Theonella
Cylindrospermopsin	3	Cylindrospermopsis, Anabaena, Aphanizomenon, Raphidiopsis
Neurotoxins		
Anatoxin-a	5	Anabaena, Oscillatoria, Phormidium, Aphanizomenon
Anatoxin-a(s)	1	Anabaena
Saxitoxins	20	Aphanizomenon, Anabaena, Lyngbya, Cylindrospermopsis, Planktothrix
Dermatotoxins		
Lyngbyatoxins-a	1	Lyngbya, Schizothrix, Oscillatoria
Aphlysiatoxins	2	Lyngbya, Schizothrix, Oscillatoria

Source: Codd et al. 2005. Chapter 1. in *Harmful Cyanobacteria*. Huisman, J., H. Matthijs, & P. Visser (eds). Aquatic Ecology Series Volume 3. Springer, The Netherlands.

Within these major groups (note that I omitted the endotoxins in this table), several toxins have been identified. Note that many of the toxins have multiple structural variants. Additional variants and new toxins are continually being identified. This table will likely be outdated soon.

Within the hepatotoxins, I have highlighted the microcystins as they are the most commonly measured cyanotoxin worldwide. Also note that most cyanotoxins are produced by multiple genera.

Toxicity as LD₅₀ (Lethal doses based on weight for 50% of the population)

■ Algal Toxins

- Anatoxin-a: 0.2 mg/kg
- Anatoxin-a(s): 0.02 mg/kg
- Saxitoxins: 0.008 mg/kg
- Nodularin: 0.05-0.3 mg/kg
- Microcystins: 0.05-0.3 mg/kg
- Cylindrospermopsin: 2 mg/kg

■ Pesticides

- DDT: 113 mg/kg
- Atrazine: 246 mg/kg
- Carabryl: 3000 mg/kg
- Parathion: 2-20 mg/kg
- Paraxon: 2 mg/kg

If you compare the toxicity of the algal toxins to some common pesticides, many of which are banned to their hazard, you can see that nature can “pack a punch”. For example, the lethal doses for anatoxin a is only 0.2 mg/kg, which is an order of magnitude lower than the neurotoxic pesticide Parathion.

The common MCs are also very toxic relative to these pesticides.

Adverse Health Effects Observed

- Recreational activities: swimming, sailboarding, boating, angling.
- Diverse symptoms: Skin rashes, nausea, vomiting, gastroenteritis, sore throat, eye and ear irritation, fevers, blistered mouth, etc.



Diverse health effects from exposure to cyanobacteria have been observed. No single symptom or disease can be attributed to cyanotoxins and other causes (e.g., swimmers itch) can cause similar reactions making diagnosis difficult. Reporting of illnesses is also believed to be low because cyanotoxicity is still an emerging health issue.

Different recreational activities are associated with varying levels of risks, and children and immuno-compromised individuals are more susceptible.

Background on Toxic Blooms in Watershed

- 1989-2006: toxic blooms documented in American, Clear, Spanaway, Steilacoom, Wapato, and Waughop Lakes
 - Summarized in Jacoby, J. and J. Kann (2007) *The occurrence & response to toxic cyanobacteria in the PNW. Lake & Reservoir Management* 23:123-143
- Microcystins – most common cyanotoxin
- Anatoxins in American and Clear lakes

Let's now focus on toxic blooms in the C-C watershed. Toxic blooms have been observed in about a half dozen lakes here. Ray Hanowell with TPCHD will be speaking later today, has collected most of these bloom data and kindly provided it to me as part of a survey that I conducted recently. The results of this survey, which encompassed the entire PNW, was published this last summer in L&RM.

Consistent with what we found throughout the PNW, microcystins were the most commonly detected cyanotoxin. However, anatoxins were also measured in American and Clear lakes. In A.L., the presence of anatoxins was associated with animal deaths.

Occurrence in Chambers-Clover Creek Watershed Relative to PNW

(Jacoby & Kann 2007)

- Most monitoring in OR and WA
- Microcystins most frequently detected
 - <0.5 - 2,000 $\mu\text{g}/\text{L}$
 - 30 mg/L in scum sample (Klamath Lake, OR)
 - 20 WA, 13 OR, 10 BC, & 1 ID lakes
- Anatoxins in several PNW lakes
 - Often associated with animal deaths
- Saxitoxin measured at 4 $\mu\text{g}/\text{L}$ in one WA lake



In fact, the toxic blooms observed in C-C watershed comprised 6 of the 25 lakes in WA where toxic blooms have been measured.

May 2006 toxic *Anabaena* bloom in Anderson Lake (Jefferson Co., WA); 20 $\mu\text{g}/\text{L}$ anatoxin-a; dog deaths

Saxitoxin was also measured at 4 $\mu\text{g}/\text{L}$ in Ketchum Lake, WA in Oct. 2006 (anatoxin and MC previously measured during other years in this lake).

American Lake

- First toxic bloom documented west of Cascades in winter 1989-1990
 - 11 animal poisonings
 - *Anabaena flos-aquae* dominant - anatoxin(a)
- Toxic blooms in winters 1992, 1993, and 1996 (R. Hanowell - TPCHD)
- Wintertime toxic blooms in a mesotrophic lake - very unusual!

Now let's focus further on one of the two more in-depth studies in the C-C watershed.

American Lake was the first lake on the west side of the mountains where toxic algae were documented. In winter 1989-1990, anatoxins were measured along with *Anabaena* and were presumably the cause of 11 animal poisonings including the deaths of 5 cats. Toxic blooms reoccurred....

Very unusual to have wintertime cyano blooms in a lake that is considered only moderately productive.

Anabaena vs TP concentrations

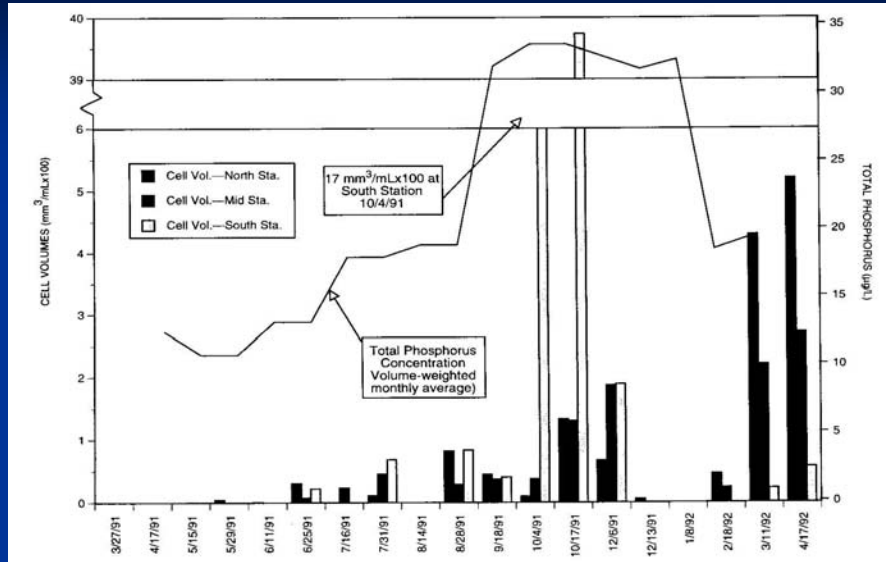


Figure 2. *Anabaena flos-aquae* cell volumes ($\text{mm}^3/\text{mL} \times 100$) and volume-weighted mean total phosphorus concentrations ($\mu\text{g}/\text{l}$) in American Lake.

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This figure shows how the abundance of *Anabaena* (cell volumes in the bars) builds as TP (line) increases in the lake from fall through winter. For much of the year, the lake has rather low TP but then it increases abruptly in the fall.

American Lake Summary of 1991-1992 Study

- Toxic blooms associated with increased P (30-35 $\mu\text{g/L}$) following winter turnover
- P released from anoxic sediment and groundwater inputs fueled winter blooms as lake mixed Nov-Feb.
- Insufficient iron to completely remove P from water column during lake mixing.

(Jacoby et al. 1994. *Journal of Freshwat. Ecol.* 9: 241-251)

I don't have time to present more details from this study, but would like to summarize our findings.

The high TP following lake turnover in fall indicates that the P released from anoxic sediment during stratification was not removed by iron, which typically happens. The iron content of AL is relatively low (68 $\mu\text{g/L}$ annual mean) indicating that there was insufficient Fe to totally remove P from the water column during lake mixing.

Nutrient-rich GW inputs during the wet season may have also fueled the toxic blooms.

Steilacoom Lake

■ Characteristics

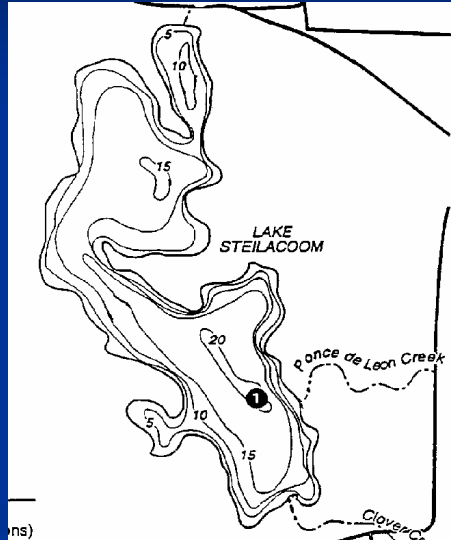
Surf. Area: 129 ha

Volume: $4.3 \times 10^6 \text{ m}^3$

Mean Depth: 3.4 m

Max Depth: 6.1 m

Flushing Rate: 10 /yr.



I was involved in another in-depth study of toxic algae in Steilacoom Lake. Supported by a Centennial CWF grant to the Dept of Health and Dr. Mike Crayton at PLU, we conducted extensive monitoring of SL during two summers.

Steilacoom Lake Study 1994-1995

- Environmental conditions compared during two summers: 1994 (toxic *Microcystis* bloom) and 1995 (no bloom).
- Toxic bloom in 1994 was associated with:
 - higher P
 - lower water clarity
 - higher water temperature and stability
 - lower N:P ratios
 - lower zooplankton abundance.

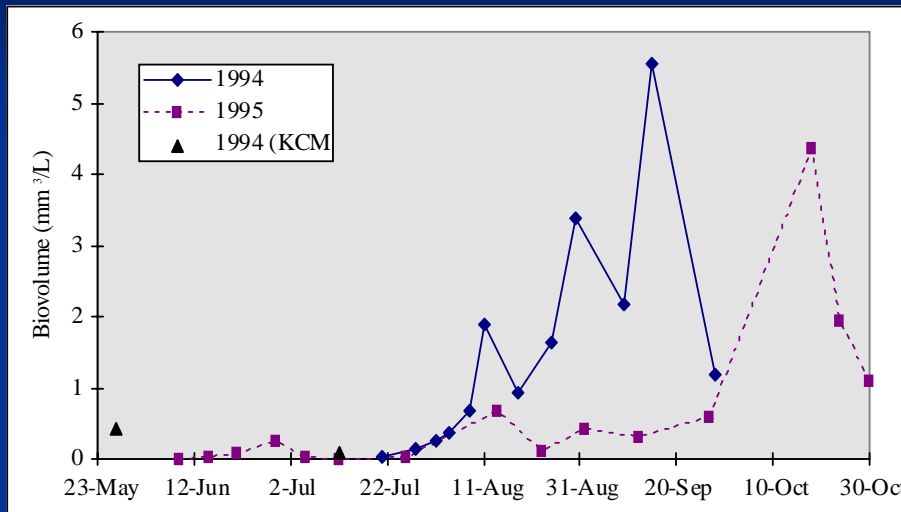
(Jacoby et al., 2000, Can. J. Fish. Aquat. Sci. 57)

Results of this study reported previously and published.

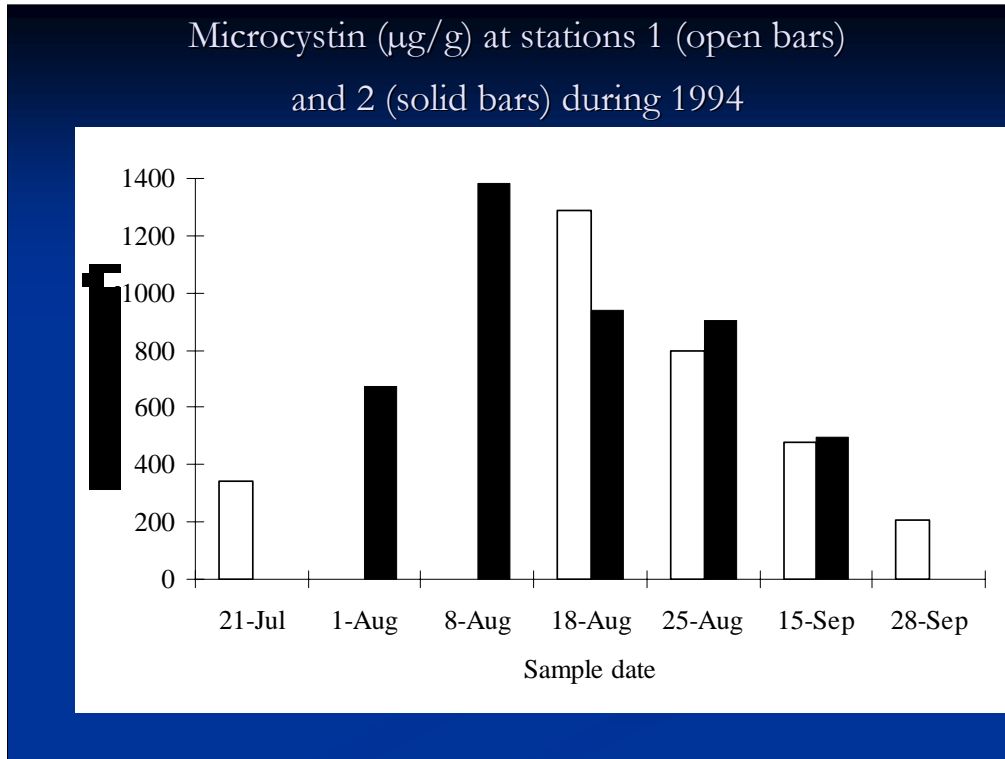
We were so lucky to have had a natural experiment (i.e., one year with a prolonged toxic bloom and one without...)

To summarize, we found... All these factors are known to increase cyano biomass.

Cyanobacterial Abundance

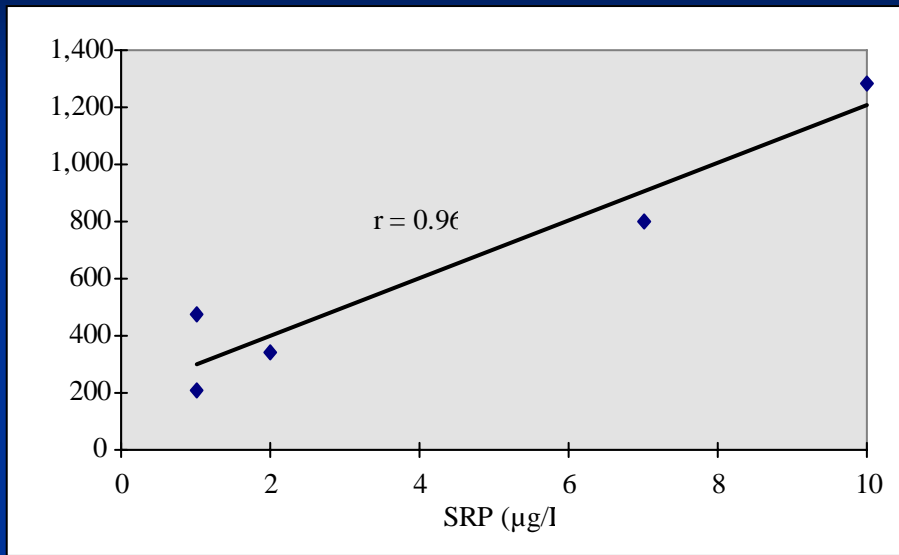


Here we can see how different cyano abundance was between the two years. In 1994, we had lots of cyano and toxicity in the summer, whereas in 1995 the cyano didn't come on until mid Oct. and were not associated with toxicity.



Fairly high MC throughout summer of 1994. MCs measured using HPLC in μg per g bloom material. Microcystis was the dominant phyto in the lake throughout this summer.

Microcystin ($\mu\text{g/L}$) vs. SRP ($\mu\text{g/L}$)



We also found a significant positive relationship between MC concentration and SRP, the form of P that is available for algal uptake, indicating that toxin prod may be limited by P

Recent Monitoring for Cyanotoxins in Watershed Lakes

- WA State Department of Ecology new Algae Control Program (\$250,000/yr)
 - Monitoring of blooms
 - Education and WA DOH website
 - Development of state-wide guidelines and database
- <http://www.ecy.wa.gov/programs/wq/plants/algae/index.html>.

WA State Dept of Ecology is developing an algae management program that will include technical and financial assistance to help manage algae problems in WA lakes. The program will give priority to cyanobacteria because of their increasing frequency of occurrence and the potential to produce potent toxins that affect human health and cause animal poisonings. Focus on lab testing, free mail-in service of bloom samples, development of a database and statewide guidelines.

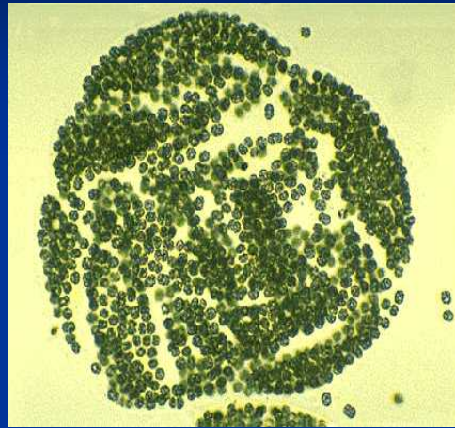
The state of OR is further along in its lake advisory and public notification process for toxic blooms. They have developed draft statewide guidelines for issuing and lifting advisories in recreational waters when toxigenic cyanobacteria are detected.

Recent Microcystin Data

- Steilacoom Lake
 - 43 $\mu\text{g/L}$ on 9/12/07
 - 221 $\mu\text{g/L}$ on 9/27/07

- Spanaway Lake
 - 9.34 $\mu\text{g/L}$ on 9/12/07
 - 83.7 $\mu\text{g/L}$ on 9/27/07

- Wapato
 - 5.94 $\mu\text{g/L}$ on 9/12/07
 - 4,810 $\mu\text{g/L}$ on 9/27/07



I recently received some data from Ecology on MC measured in three lakes in C-C as part of this new program. As you can see, several of the lakes in C-C continue to be hot spots for cyanotoxicity. Some of these MC concentrations are quite high. I'd like to call your attention to the measurement of 4,810 $\mu\text{g/L}$ MC in Wapato Lake just last week.

Health Risks from Cyanotoxins due to Recreational Exposures

- WHO provisional drinking water guideline = 1 $\mu\text{g}/\text{L}$ MC-LR
- Guidance values for recreational exposures?
 - 6 $\mu\text{g}/\text{L}$ MC used in VT
 - 8 $\mu\text{g}/\text{L}$ MC used in OR

Last, how do we interpret the MC data in terms of assessing recreational quality and health effects?

WHO has developed a provisional DW guideline of 1 $\mu\text{g}/\text{L}$ MC-LR for drinking water. Many countries have used this GV as a basis for their own standards (Canada, Germany, Australia). The US has not yet established DW guidelines for any cyanotoxins but has included “cyanobacteria and their toxins” on the Contaminant Candidate List” and is in the process of conducting a toxicological review for three cyanotoxins: MC (LR, YR, RR and LA), cylindrospermopsin, and anatoxin-a.

But how do we assess risks from cyanotoxins due to recreational exposures?

10 $\mu\text{g}/\text{L}$ now used for rec closure in Australia (moderate health effect level).

WHO Guidelines For Safe Practice in Recreational Waters

(Chorus, I and J. Bartram. 1999. Toxic Cyanobacteria in Water. Published on behalf of WHO, E&FN Spon, London)

Guidance Level	Recommended Actions
I. Cyanobacterial scum in bathing area	<ul style="list-style-type: none">- Close beach- Prohibit contact- Conduct public health investigation
II. 100,000 cells/mL or 50 µg/L chl- <i>a</i>	<ul style="list-style-type: none">- Watch for scums- Restrict bathing- Post advisory signs
III. 20,000 cells/mL or 10 µg/L chl- <i>a</i>	<ul style="list-style-type: none">- Post advisory signs

WHO has established guidelines for safe practice in recreational waters based on cell counts or chl-*a* levels. Because it is not possible to measure all cyanotoxins in waters, cyano densities may be a more comprehensive basis for setting GVs. However, the downside of this approach is not all cyano blooms are equally toxic.

WHO Risk Categories for Adverse Health Effects in Recreational Waters

Microcystin	Risk Level*
< 10 µg/L	Low
10 - 20 µg/L	Moderate
20 - 2,000 µg/L	High
>2,000 µg/L	Very high

*Probability of adverse health effects (Based on WHO guidelines for safe practice in recreational waters. From: Chorus and Bartram, 1999).

WHO also used MC concentrations as orientation to determine levels for restricting recreational activity.

Conclusions

- Cyanotoxins are of increasing concern in lakes in the Clover-Chambers Creek Watershed
- Microcystins are the most commonly measured cyanotoxin but anatoxins have also been found in some lakes.
- Several lakes appear to be “repeat offenders” and pose potential risks to animals and humans
- Assessment of health risks during recreation is difficult
- state and national guidelines are needed.

On toxic algae...

- “anthropogenically amplified, but basically a natural phenomenon...”

Ingrid Chorus, 1993

