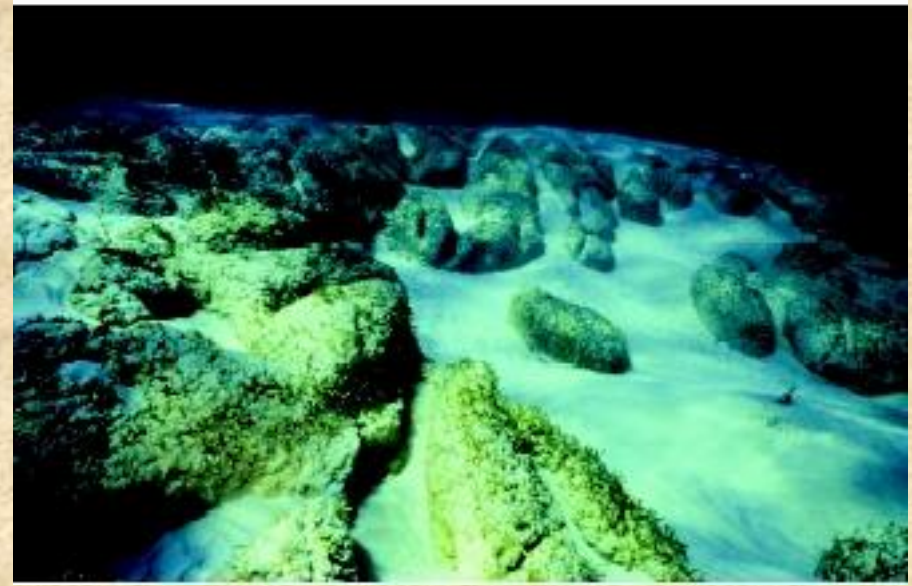
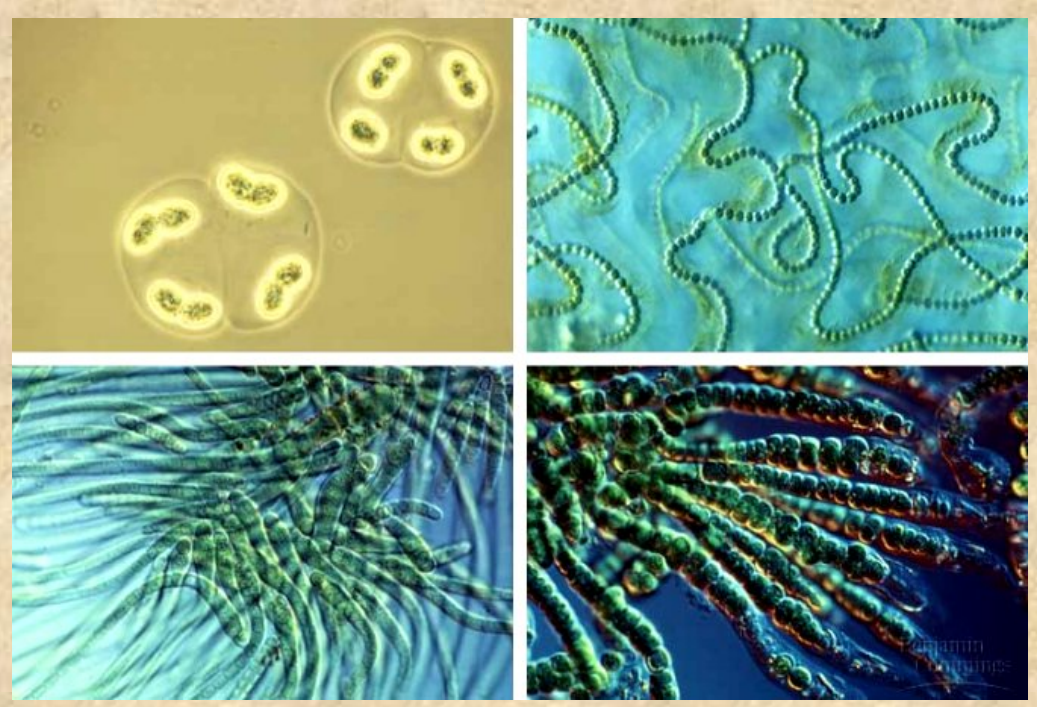
Factors Influencing Cyanobacteria Blooms in Farmington Bay, Great Salt Lake, Utah.

Brad Marden Leland Myers Theron Miller David Richards



The ability of cyanobacteria to perform oxygenic photosynthesis is thought to have converted the early reducing atmosphere into an oxidizing one, which dramatically changed the composition of life forms on Earth by stimulating biodiversity and leading to the near-extinction of oxygen-intolerant organisms.

Cyanobacteria are arguably the most successful group of microorganisms on earth. They are the most genetically diverse; they occupy a broad range of habitats across all latitudes, widespread in freshwater, marine and terrestrial ecosystems, and they are found in the most extreme niches such as hot springs, salt works, and hypersaline bays.



GSL Stromatolites

Cover about 10% of Lake bottom

Calcium/Magnesium Cyanobacteria Deposits

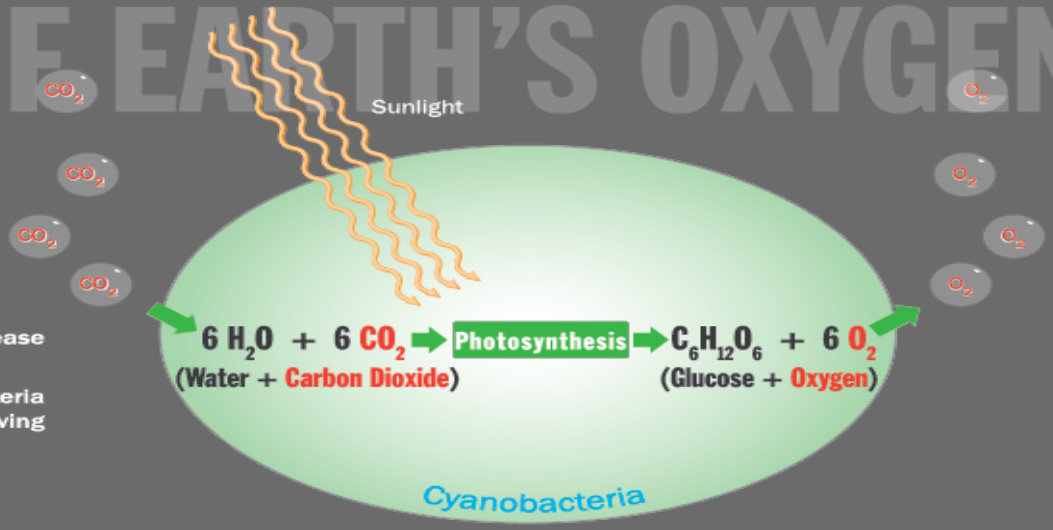
Primary substrate for Brine Fly Pupae life stage

1/4 OF EARTH'S OXYGEN

CYANOBACTERIA — WORLD'S SMALLEST OXYGEN PRODUCERS

Cyanobacteria take in carbon dioxide and release oxygen during photosynthesis.

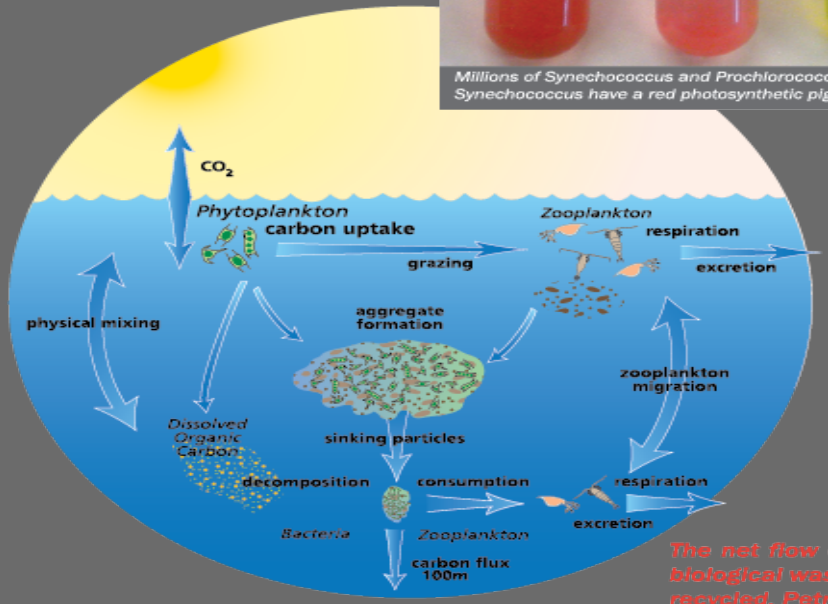
Evolving about 2.5 billion years ago, cyanobacteria were Earth's first photosynthesizers, the first living source of oxygen on earth.

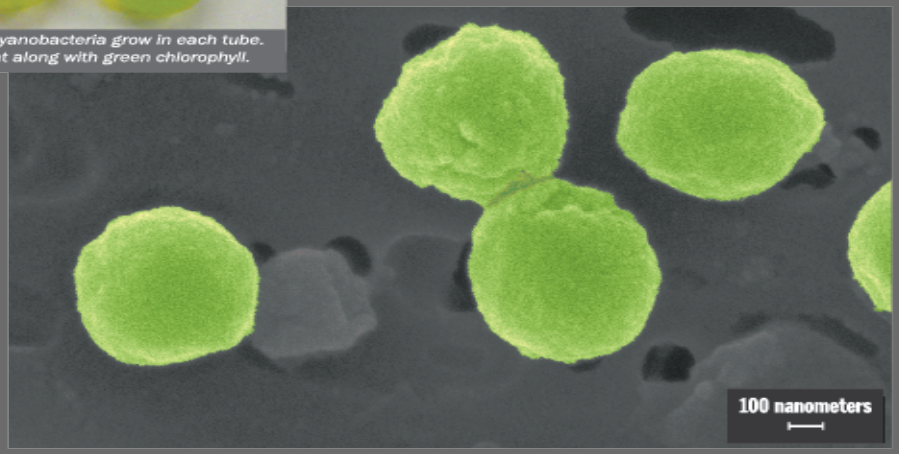


CYANOBACTERIA

Millions of Synechococcus and Prochlorococcus cyanobacteria grow in each tube. Synechococcus have a red photosynthetic pigment along with green chlorophyll.

> **"... the most important microbe you've never heard of."**
>
> **Joe Palca, National Public Radio**
> **August 2008, 20th anniversary of the discovery of Prochlorococcus**





False-color scanning electron micrograph of Prochlorococcus *bacteria*

The net flow of carbon is into the ocean, because of biological waste that falls to the ocean floor and is not recycled. Petroleum extraction reverses this process.


ADVISORY
Blue-green algal blooms have been observed in this area.
If a bloom IS present:
Do not swim
Do not drink the water
Do not allow pets in the water
If NO bloom is present, water may be used for regular recreational activities.
Sudbury & District Health Unit


Notice
An algae bloom has made this area potentially unsafe for water contact. Avoid direct contact with visible surface scum.

Hepatoxins (Microcystin/ Nodularian)

- Fitzgeorge et al. (1994) demonstrated that microcystin [and other hepatoxins] toxicity is cumulative: a single oral dose resulted in no increase in liver weight (which is a measure of liver damage), whereas the same dose applied daily over seven days caused an increase in liver weight of 84% and thus had the same effect as a single oral dose 16 times as large.

Anatoxins

Saxitoxins and anatoxin-a(s) are among the most neurotoxic substances known. However, evidence is accumulating that in lakes and rivers they do not occur as frequently as microcystins. This applies especially to anatoxin-a: to date, it has been found only in a small number of Anabaena blooms in North America. Furthermore, concentrations even of these highly toxic substances in scums will scarcely reach levels acutely neurotoxic to a human ingesting a mouthful. In contrast, neurotoxicity may be experienced by livestock that drink many litres of contaminated water and pets—especially dogs—that gather scum material in their fur and ingest it through grooming with the tongue.

What is too much Cyanotoxins ???

Development of Warning Levels

- In a 13-week gavage study in mice, conducted under good laboratory practice (GLP), pure microcystin-LR was administered orally to groups of 15 male and female mice at 0, 40, 200, or 1,000 µg/kg bw per day for 13 weeks
- 40 µg/kg – NOAEL
- 200 µg/kg – slight liver tissue changes in some male and female mice
- 1,000 µg/kg - all male and most female mice showed liver changes
- All other studies had higher NOAEL identified

Development of Warning Levels

$$\text{Guideline Value} = \frac{\text{(Tolerable Daily Intake) (Body Wt. – Kg) (Proportion H2O Contaminated)}}{\text{Liters of Water}}$$

- Assumed a typical individual weight of 60 Kg (132 lbs)
- Liters of water drunk daily – 2 Liters
- Proportion from Contaminated Water Source – 80%
- Safe Tolerable Daily Concentration – 0.04 µg/kg bw per day

$$\frac{\text{40 µg/kg bw per day}}{\text{uncertainty factor of 1,000}}$$

(10 for intra-species variability, 10 for inter-species variability and 10 for database limitations)

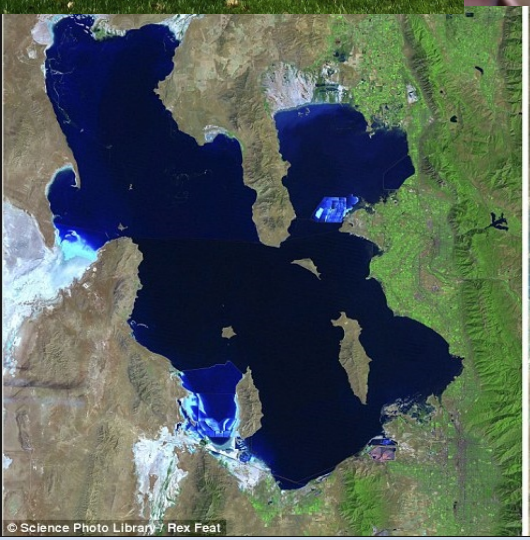
Drinking Water – 1.0 µg/L

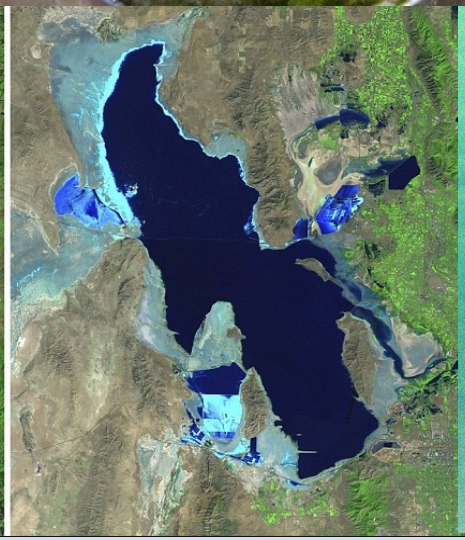
Recreation Water – 20 µg/L (assumes 200 ml Ingested)

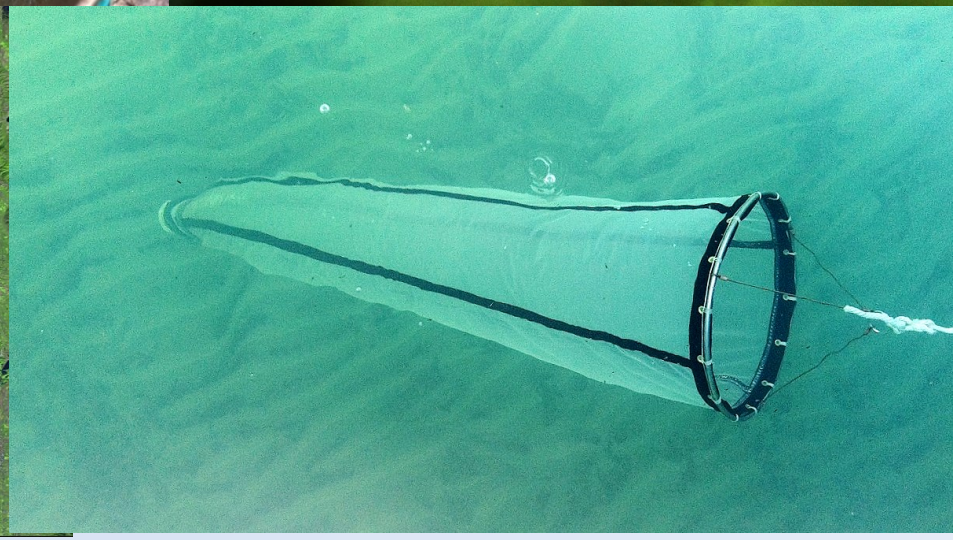
Toledo Experience

FBAY Research Program

Cooperation with GSLA







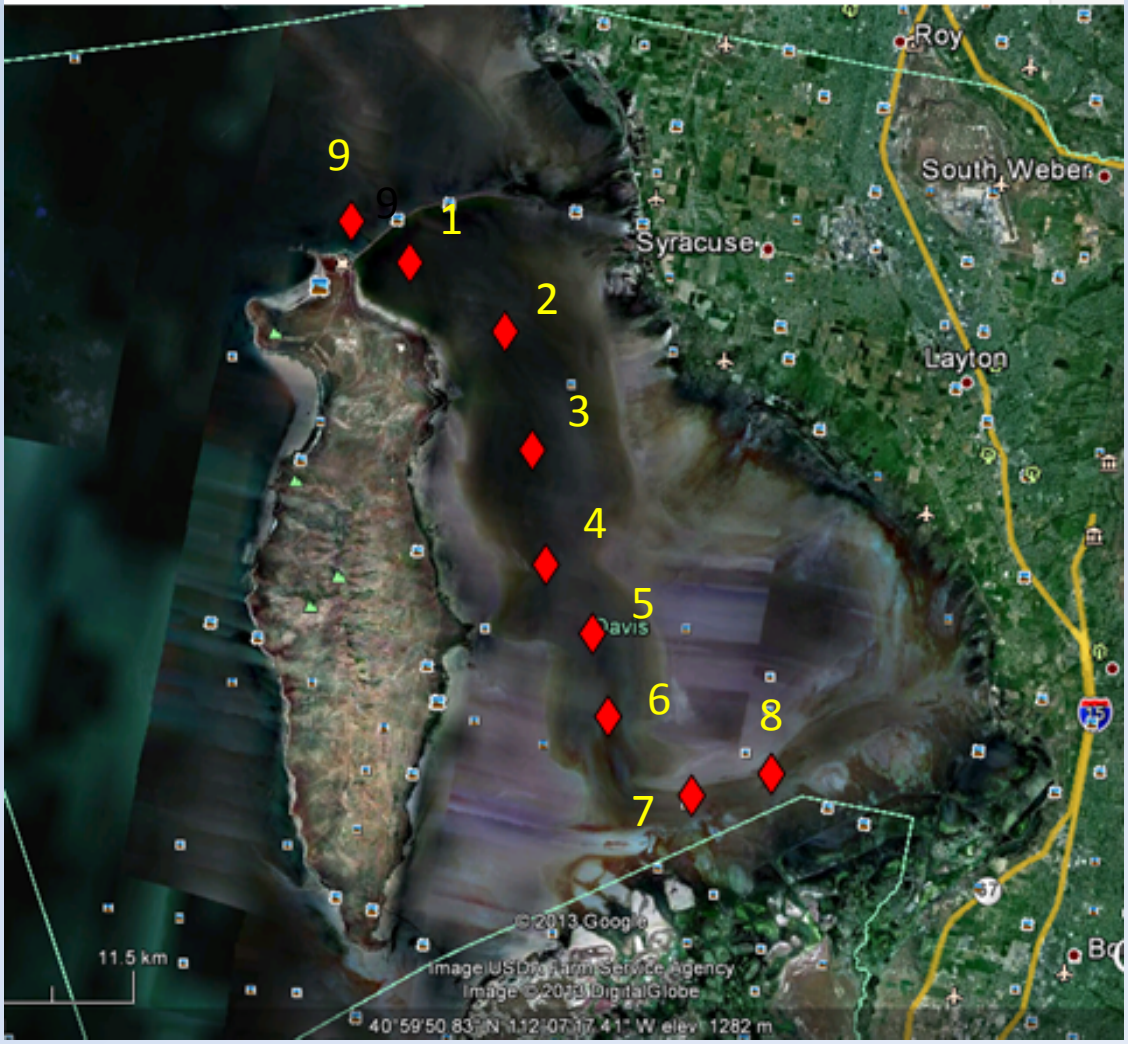
Project Goals of a Multi-year Investigation of Cyanobacteria Blooms in Farmington Bay

- **Collect a systematic record of the spatial and temporal changes in the biotic community and abiotic characteristics of Farmington Bay from March through November.**
- **Correlate changes in the algal population size and structure and with changes in abiotic factors such as nutrient concentrations, salinity, temperature, and water transparency .**
- **Correlate changes in the macroinvertebrate population composition and abundance, with changes in abiotic factors such as nutrient concentrations, salinity, and temperature, as well as with algal population size and structure, and cyanotoxin concentration.**
- **Identify the linkage between cyanobacteria blooms and cyanotoxin production in Farmington Bay.**
- **Correlate isotopic ^{15}N and ^{13}C levels in macroinvertebrates and algae with nutrient sources.**

Sampling Locations and Totals

FBAY Research Program

- **14 Transect Surveys**
- **February to November**
- **23 Single Point Collections**
- **January to December**



Program Schedule

14 Transects Surveys

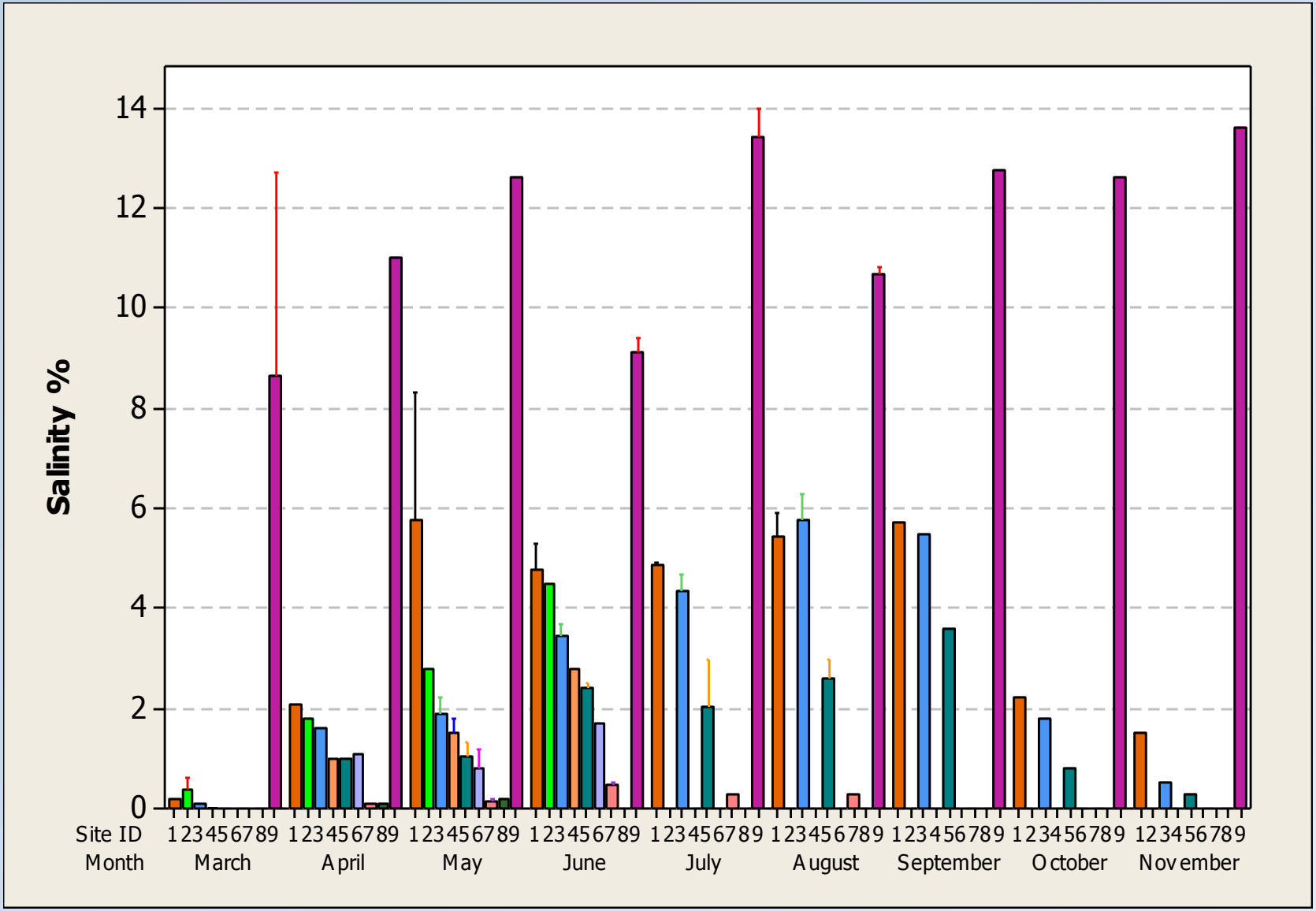
Proposed Date	Actual Date	Proposed Sites	Actual Sites Sampled
Friday, February 15, 2013	Friday, February 15, 2013	2	2
Thursday, March 07, 2013	Thursday, March 14, 2013	9	5
Thursday, April 04, 2013	missed	9	0
Thursday, April 18, 2013	Thursday, April 18, 2013	9	9
Thursday, May 02, 2013	missed	9	0
Thursday, May 16, 2013	Monday, May 13, 2013	9	9
Thursday, May 23, 2013	Thursday, May 30, 2013	9	8
Monday, June 03, 2013	Monday, June 10, 2013	9	8
Friday, June 14, 2013	missed	9	0
Monday, June 24, 2013	Tuesday, June 25, 2013	9	5
Monday, July 01, 2013	Thursday July 11, 2013	9	5
Thursday, July 18, 2013	Monday, July 22, 2013	9	5
Thursday, August 08, 2013	Tuesday, August 06, 2013	9	5
Thursday, August 22, 2013	Monday, August 26, 2013	9	4
Thursday, September 05, 2013	Thursday, September 19, 2013	9	4
Thursday, October 10, 2013	Thursday, October 17, 2013	9	4
Thursday, November 07, 2013	Thursday, November 14, 2013	9	4

METHODS

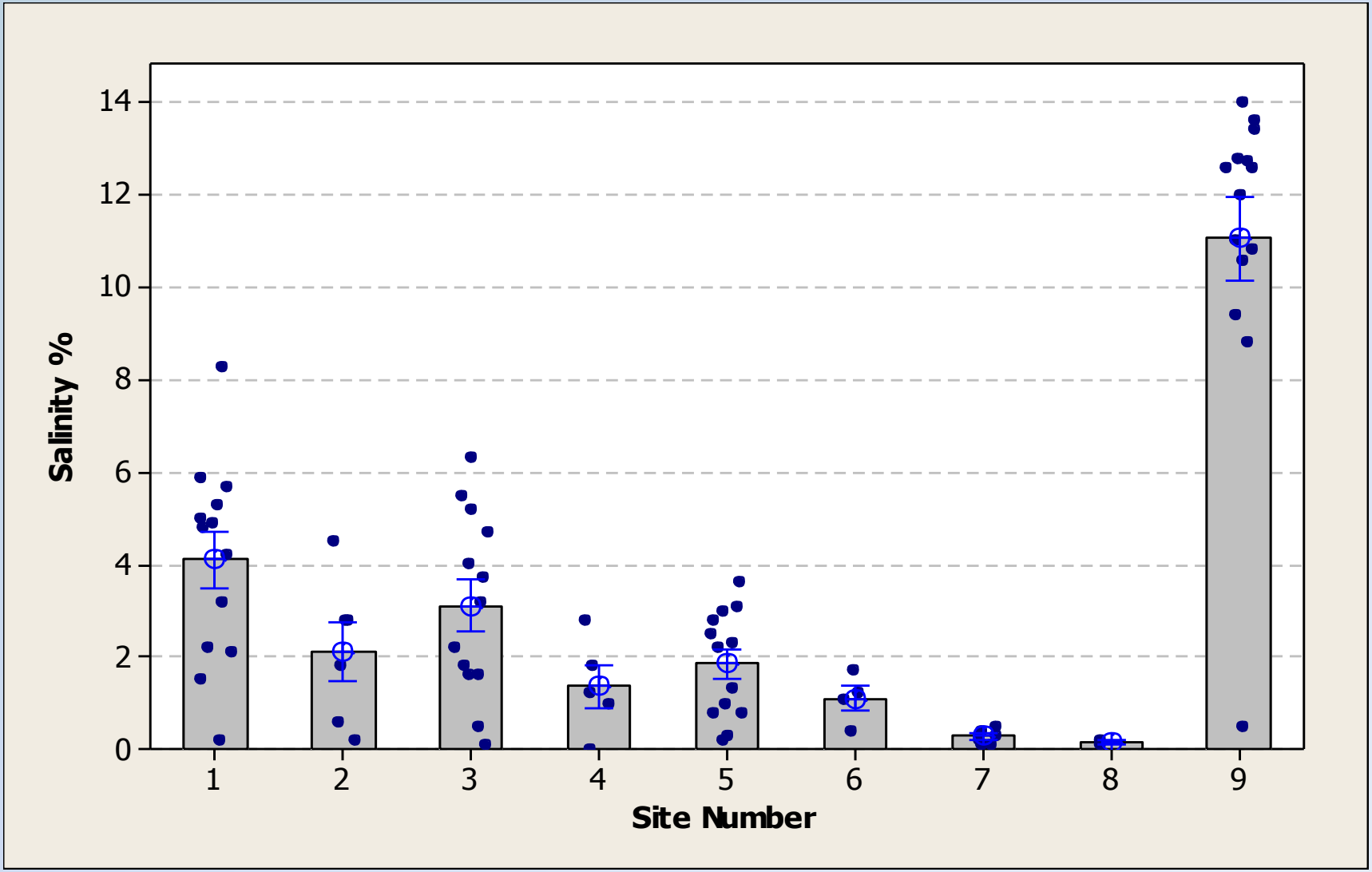
Water Sample Collection

- 500 ml PE bottles.
- 25 cm sample at each location
- Nutrients: no preservative, no headspace, kept in dark, cooler and shipped within 24 hours, analyzed by Aquatic Research Laboratory (ARL) in Seattle WA.
- Chlorophyll: preserved, dark, cooler and shipped within 24 hours to ARL.
- Algae samples: no preservative, no headspace, kept in dark, cooler and shipped within 24 hours, analyzed by Green Water Laboratory, Palatka, FL.

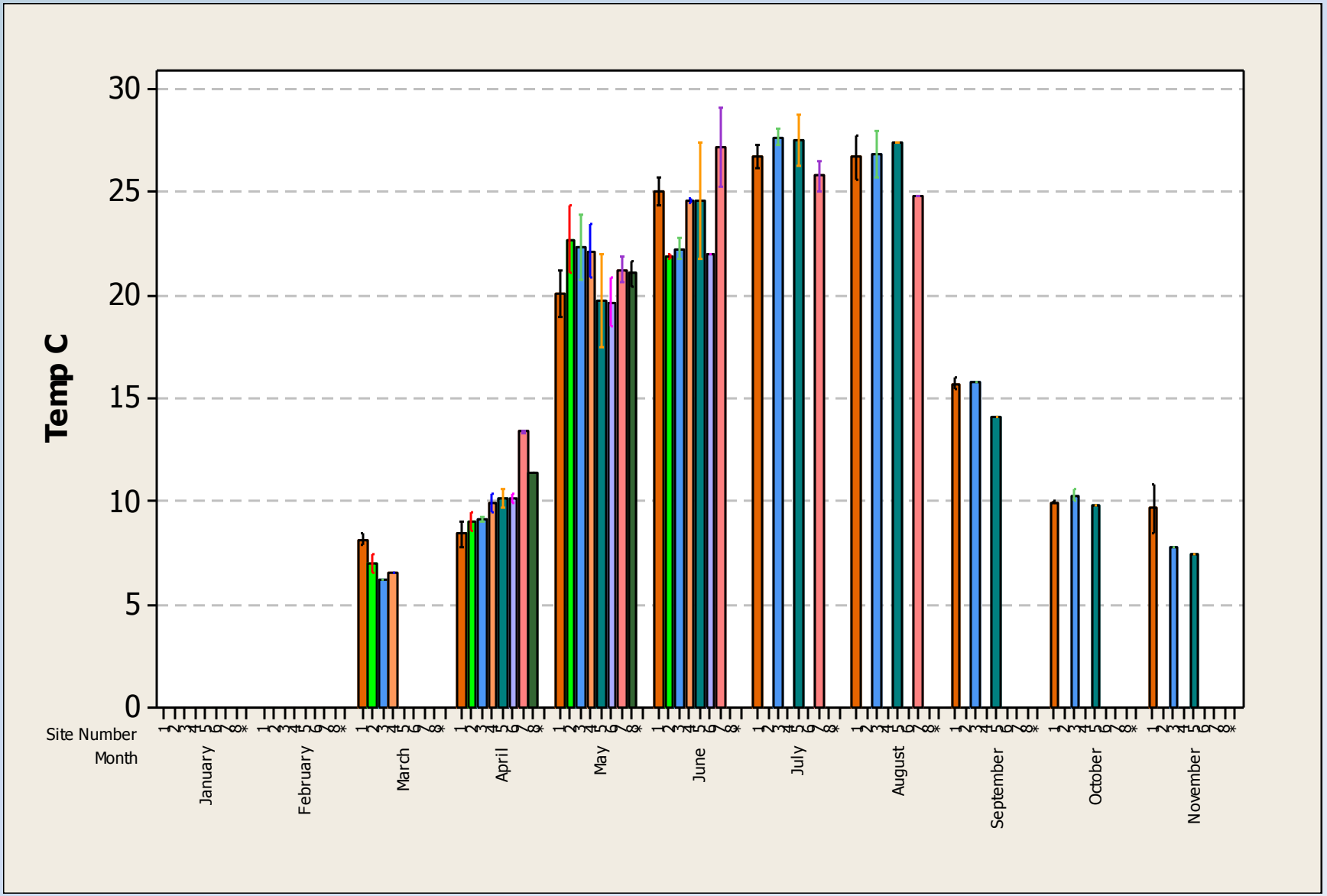
Temporal Variability of Salinity



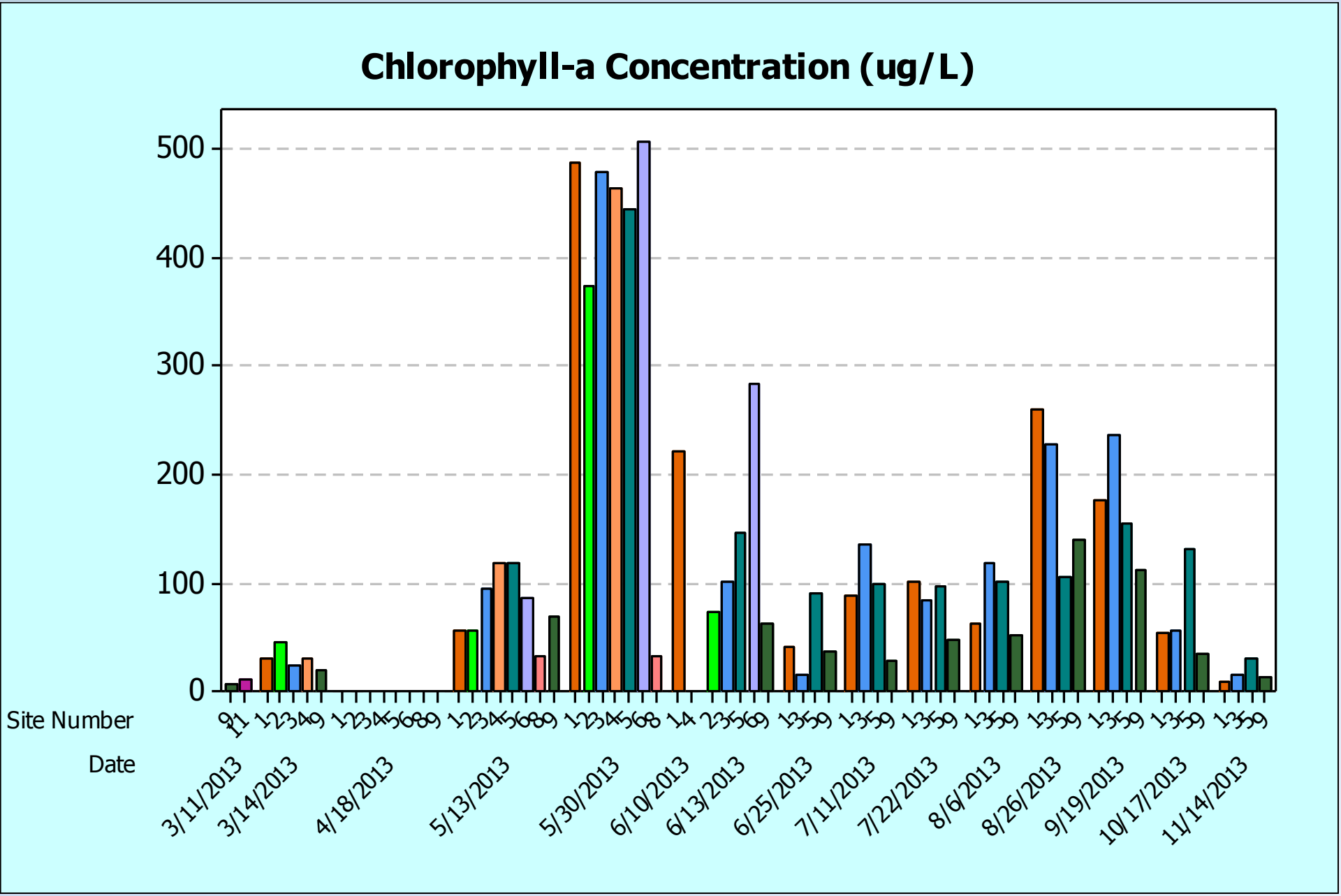
Spatial Variation of Salinity



Temporal Variability of Water Temperature



CHLOROPHYLL-A CONCENTRATION



Nutrients

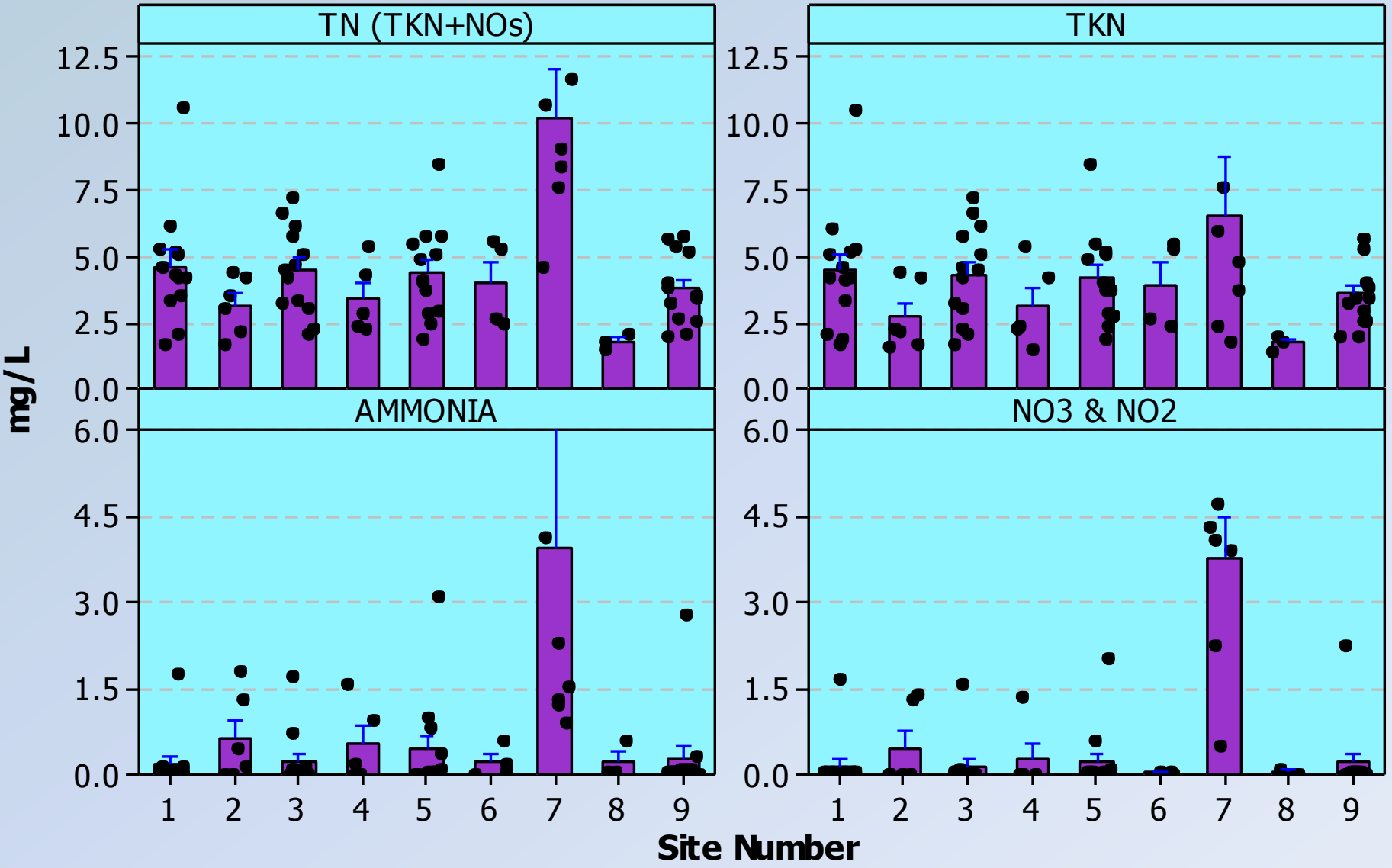
Nutrient Sample Collection and Analysis

- Ammonia (reporting limit .01 mg/l)
- Nitrate and Nitrite
- Total Phosphorous
- Ortho-Phosphate
- TKN
- Lab: Aquatic research (Seattle)

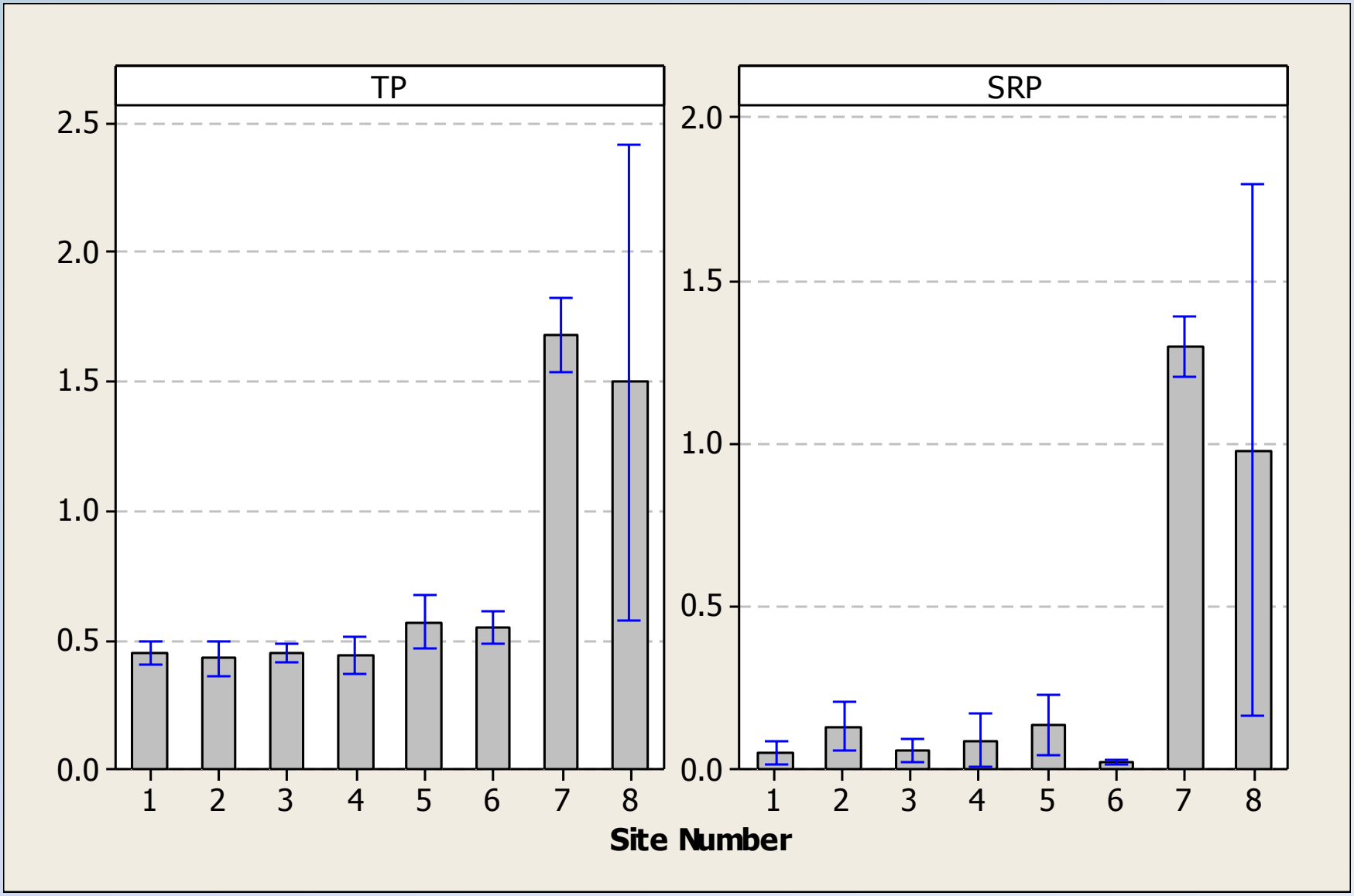
Purpose

- Evaluate the potential influence that nutrients exert on the algal composition of Farmington Bay.

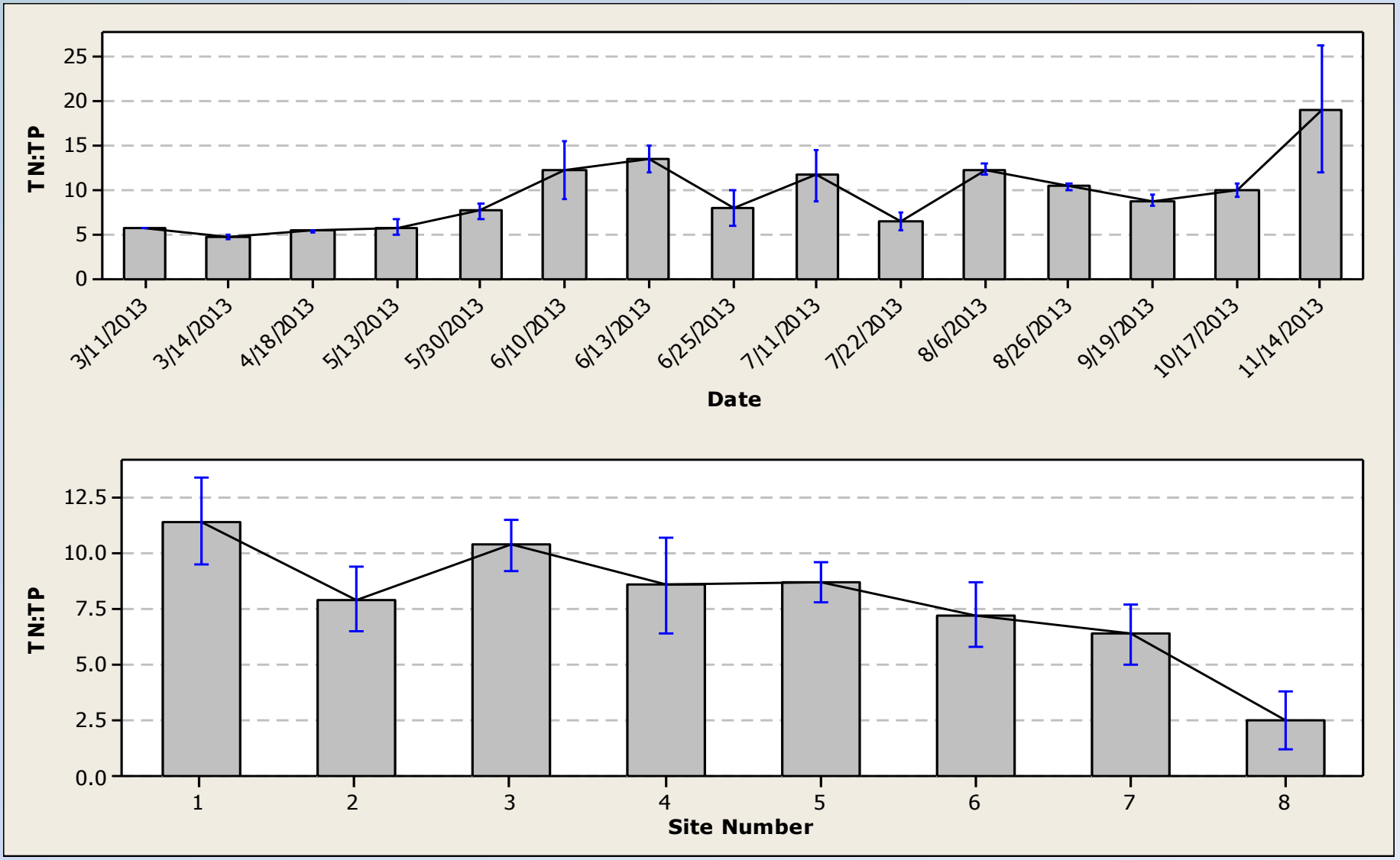
Spatial Variation of Nitrogen Species



Spatial Variation of Phosphorus



Spatial & Temporal N:P Ratio



Cyanobacteria and Cyanotoxin Analytical Laboratory

GreenWater laboratories

AQUATIC ANALYSIS, RESEARCH, & CONSULTING

Cyano LAB

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Protecting Our Most Precious Resource Through:

- Algal Identification
- Algal Toxin Analysis
- Algal Toxin Standards
- Water Quality Monitoring

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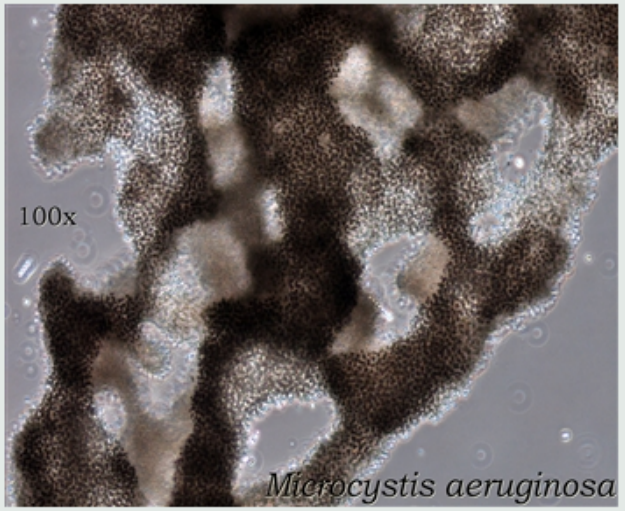


Preliminary Results

Primary Algal Groups

- Blue-green algae: Cyanobacteria
- Green algae: Chlorophyta
- Diatoms: Bacillariophyta
- Cryptomonads: Cryptophyta
- Dinoflagellates: Pyrrhophyta

Preliminary Results

Diatoms (Bacillariophyta)

Fig. 4 *Nitzschia* sp. 400X (scale bar = 10µm)

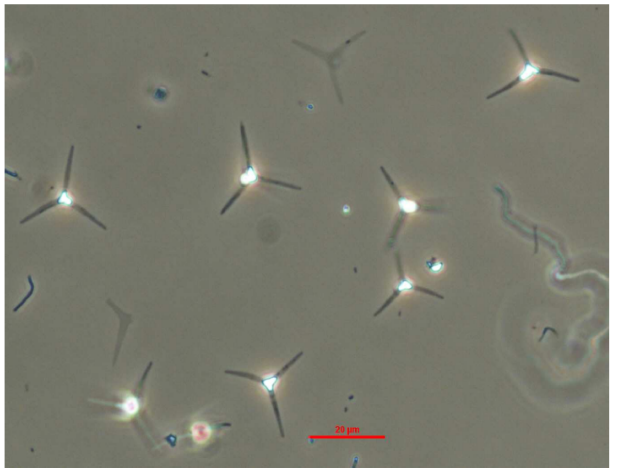


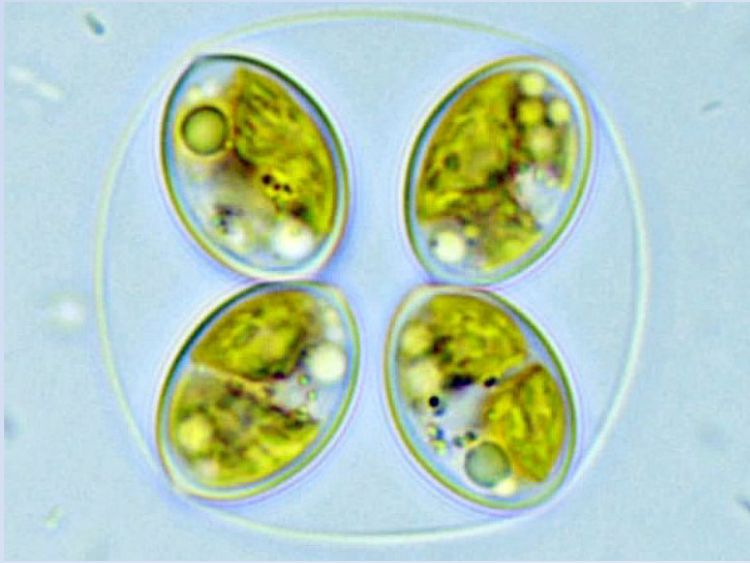
Fig. 1 *Phaedactylum tricornutum* 400X (scale bar = 20µm)

Chaetocerous

Preliminary Results

Green Algae: Chlorophyta

Fig. 3 chlorophyte unicells 400X (scale bar = 10µm)



Oocystis

Preliminary Results

Primary Cyanobacteria Found in Farmington Bay

- *Nodularia spumigena*
- *Pseudanabena catenata*
- *Pseudanabena sp.*
- *Phormidium sp.*
- Planktothrix sp.
- Spirulina sp.

Preliminary Results

Filamentous Cyanobacteria

Fig. 3 *Nodularia spumigena* 400X (scale bar = 20µm)

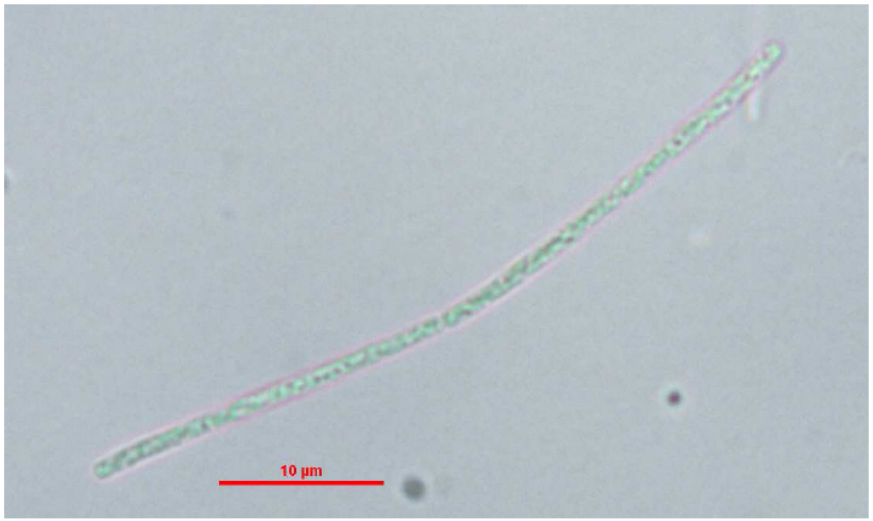


Fig. 1 cyanophyte filament 1000X (scale bar = 10µm)

Fig. 5 *Planktothrix* cf. *suspensa* 400X (scale bar = 10µm)

Preliminary Results

Cyanobacteria: Pseudanabaena

Fig. 2 *Pseudanabaena catenata* 400X (scale bar = 10µm)

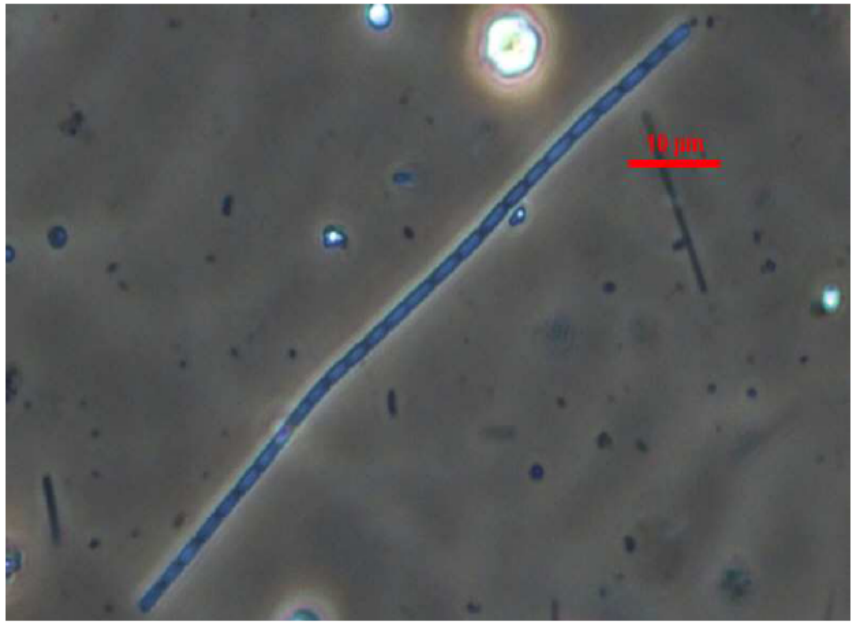
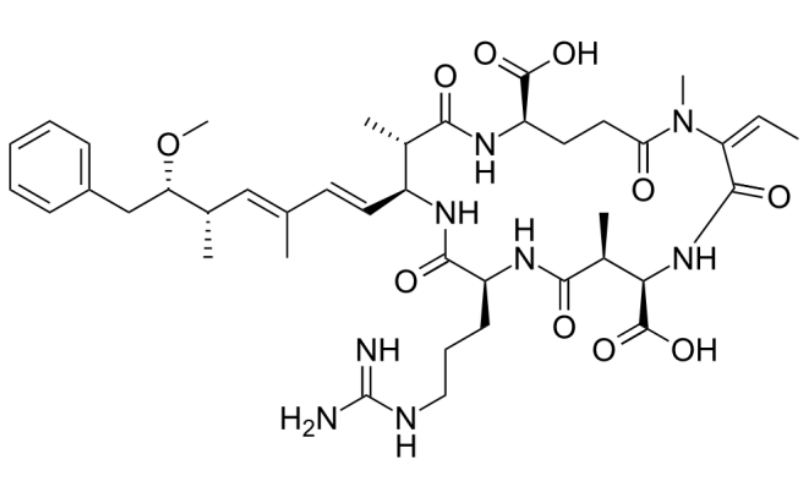
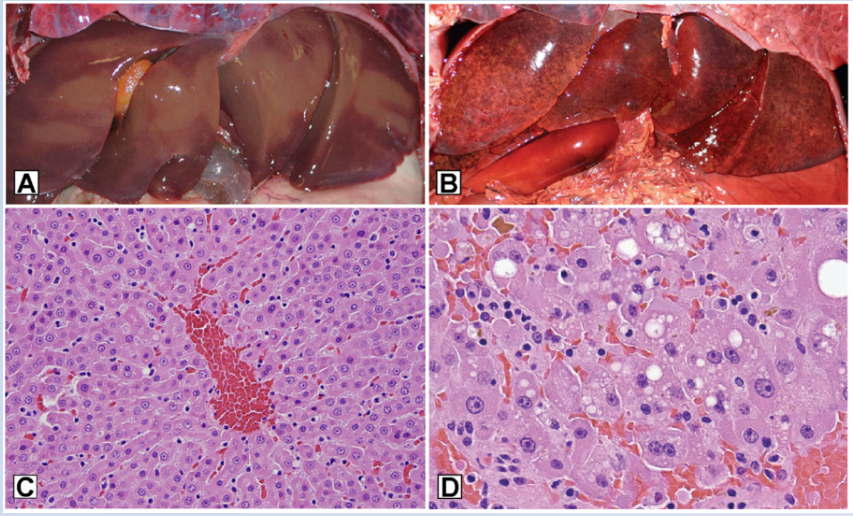


Fig. 4 *Pseudanabaena* sp. 400X (scale bar = 10µm)

Cyanotoxins of Concern

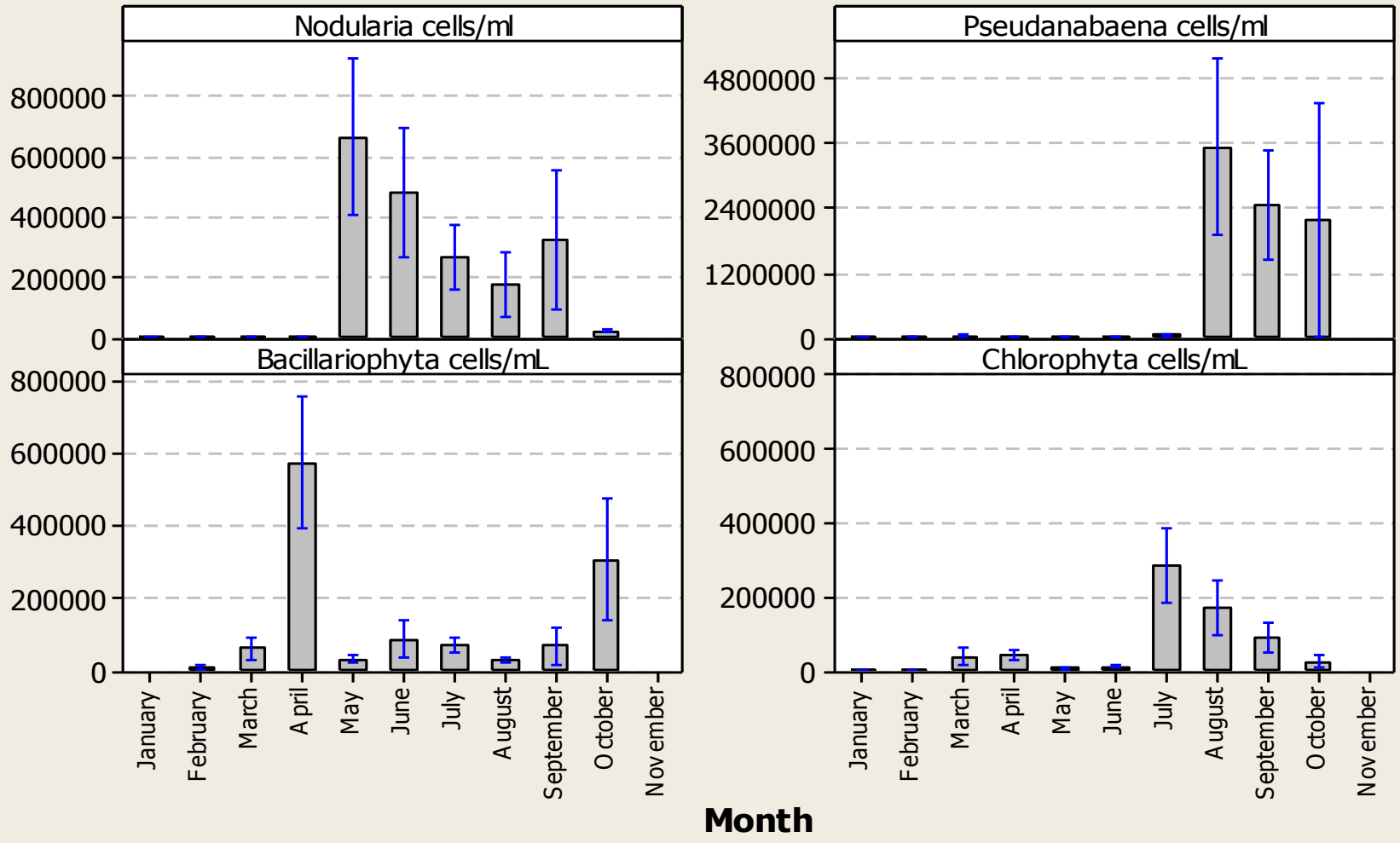


Nodularin



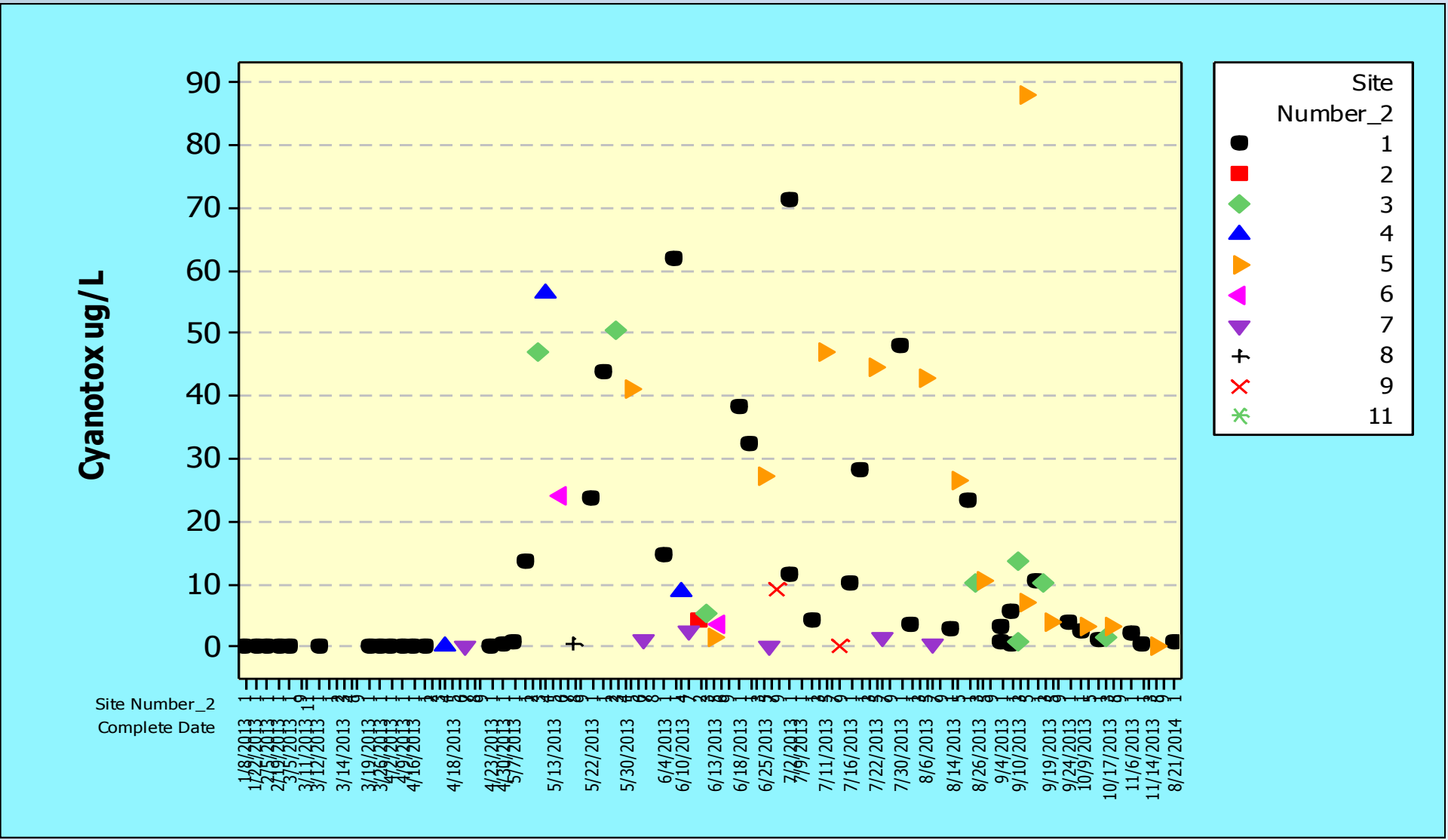
Nodularins are produced by *Nodularia spumigena*
Toxic effect via severe liver damage (potent hepatotoxin)

Temporal Variability of Algae/BG Algae



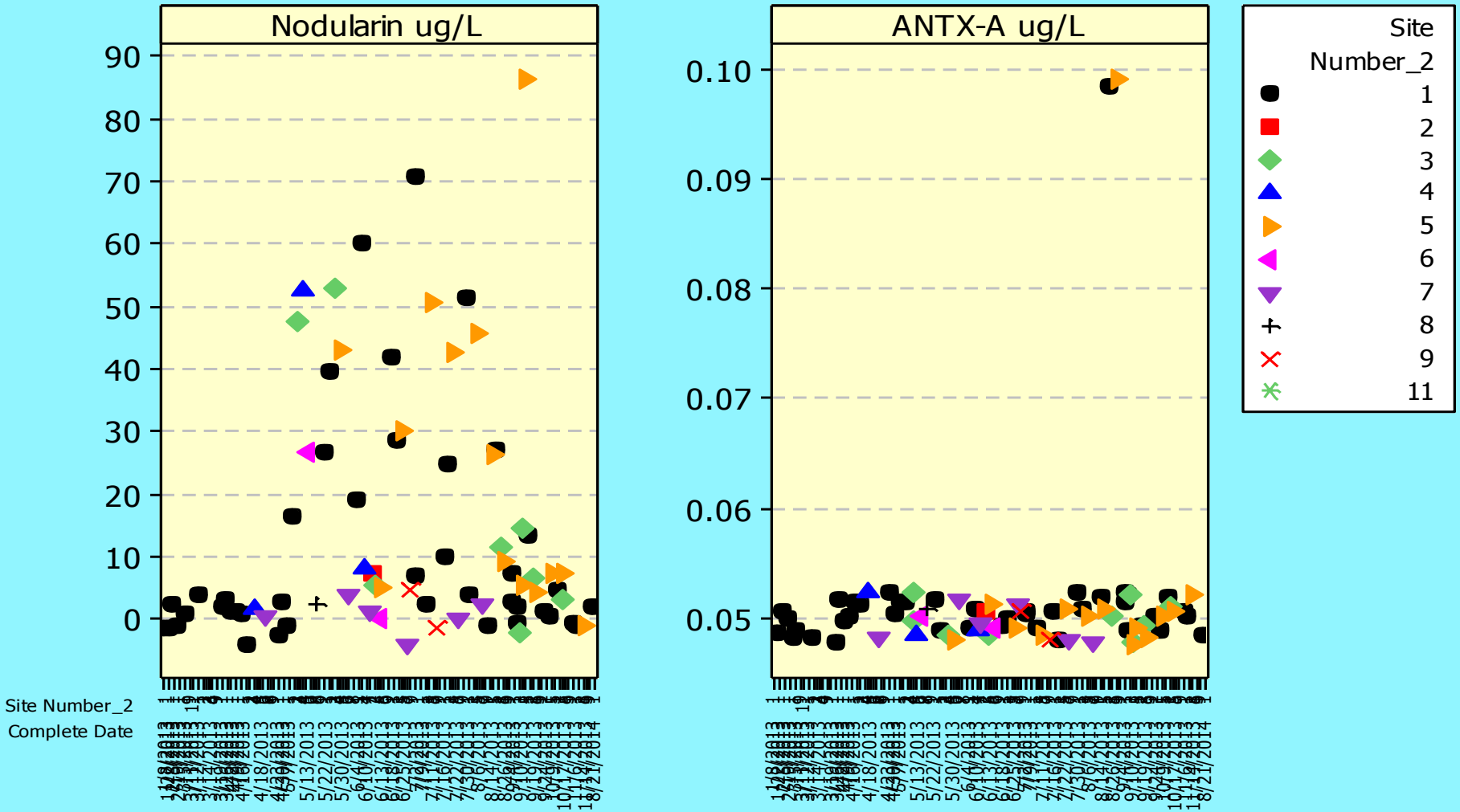
Preliminary Results

Total Cyanotoxin Concentration

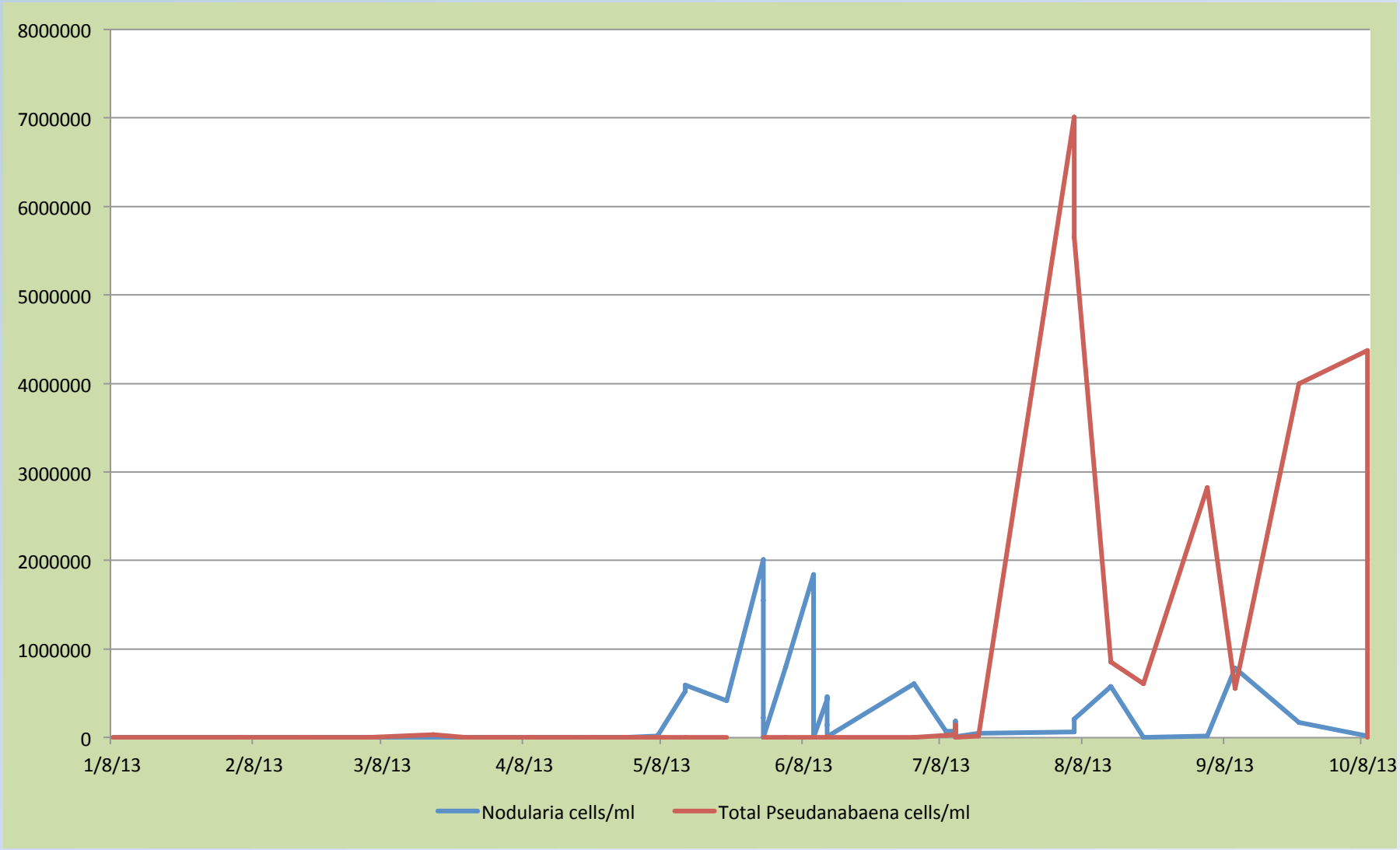


Preliminary Results

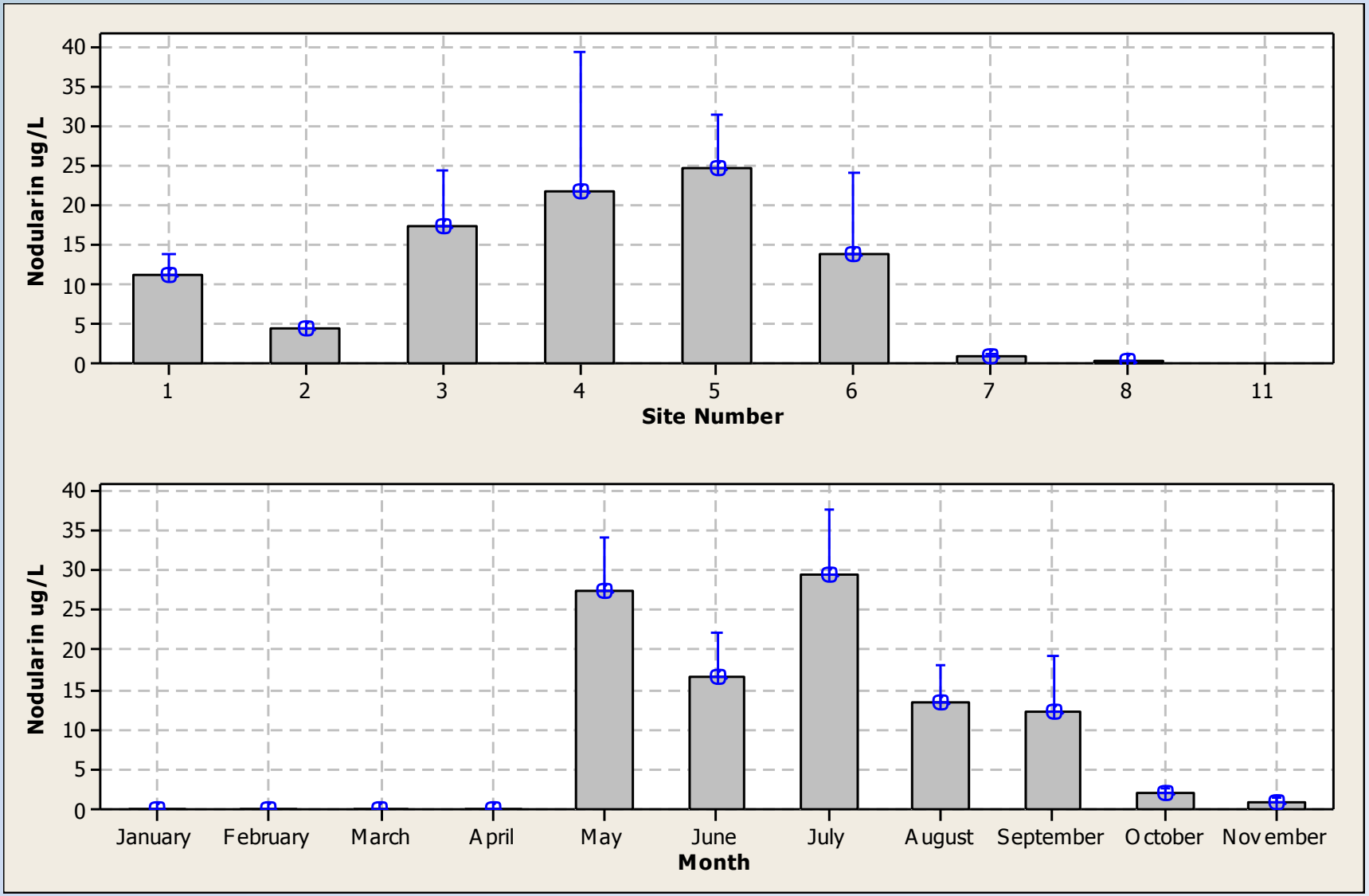
Cyanotoxins: Nodularin and Anatoxin-a



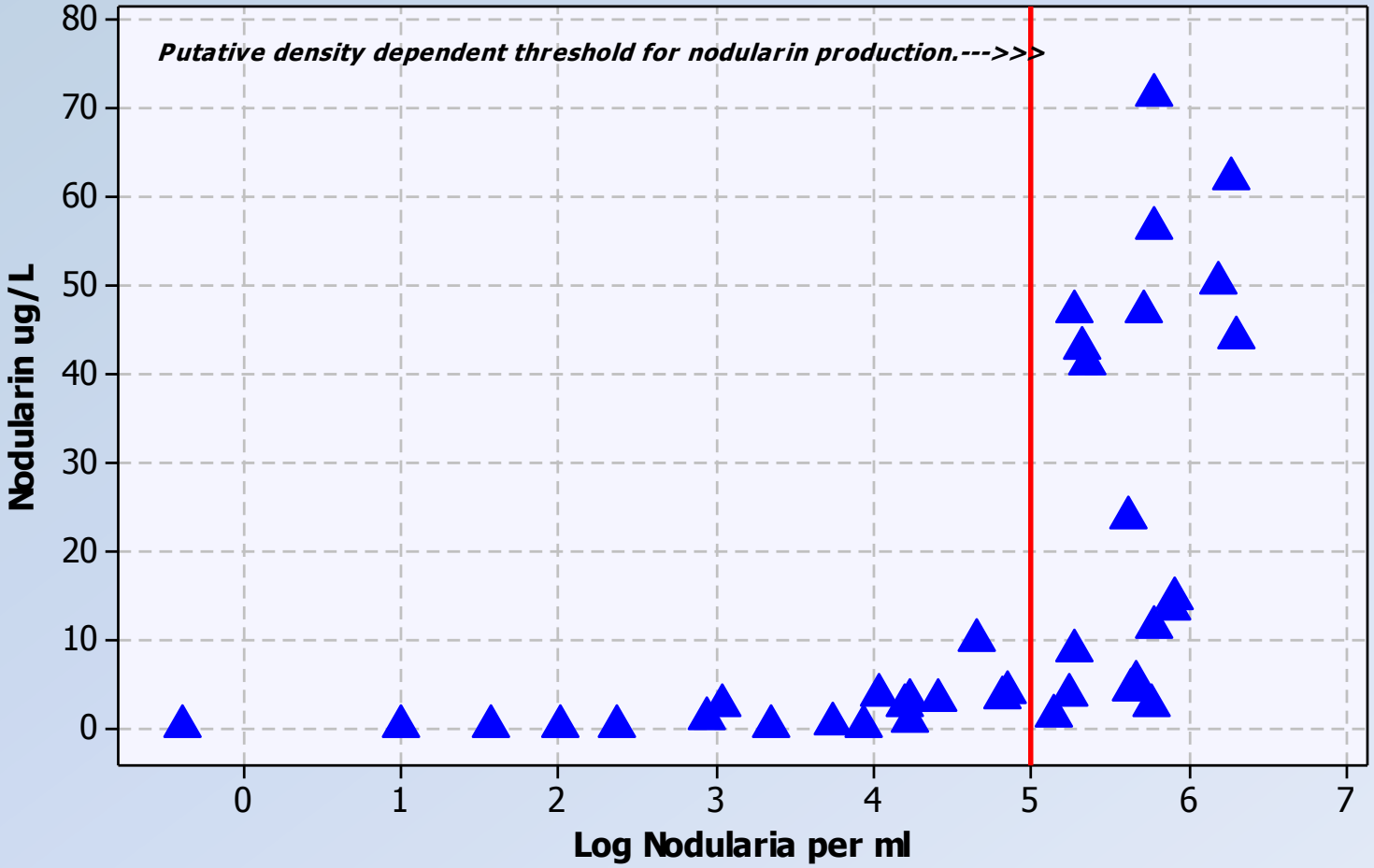
Nodularia and Pseudanabaena Timing



Spatial & Temporal Variation - Nodularin

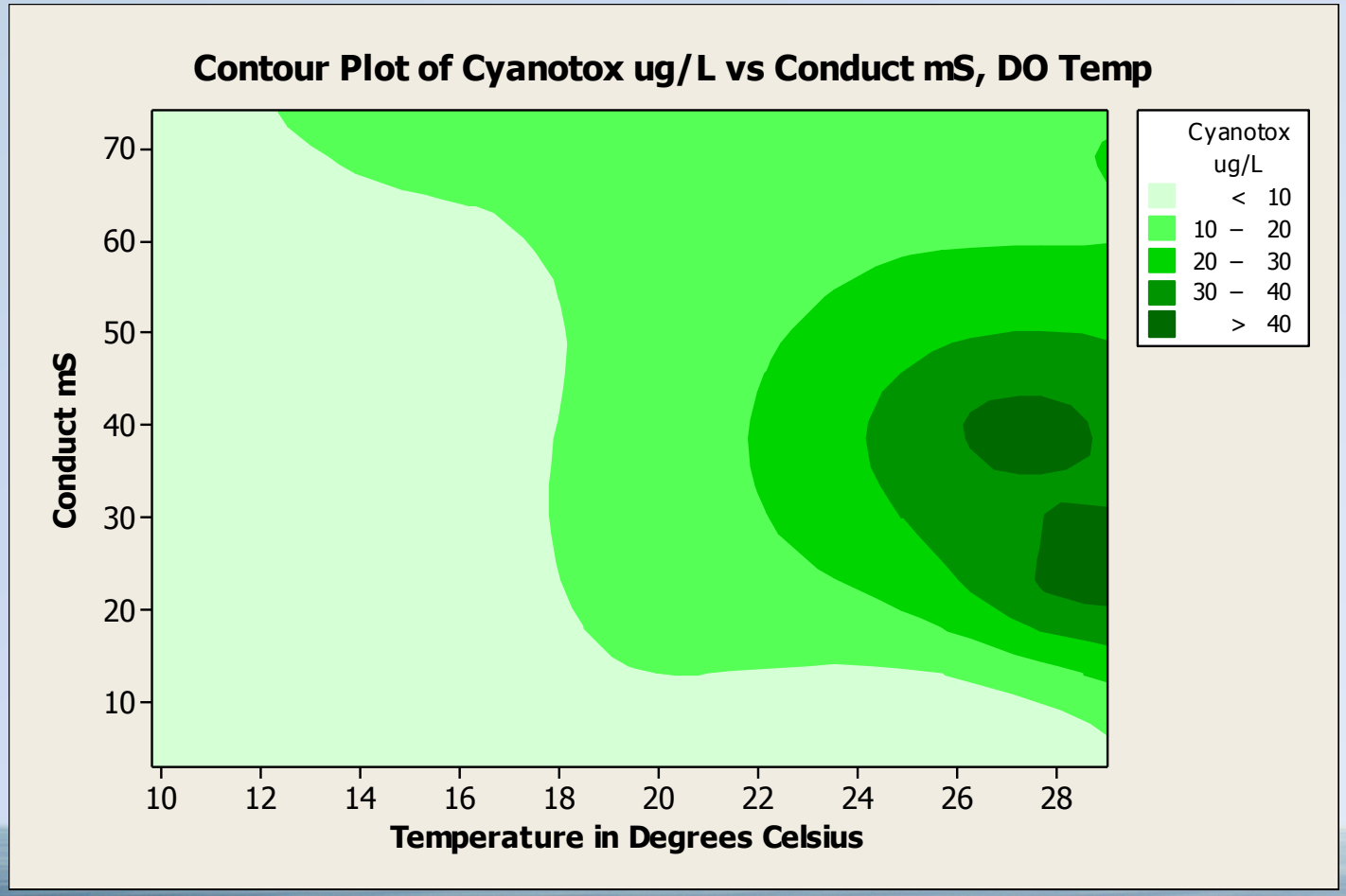


Nodularia does not uniformly produce the toxin. Rather toxin production appears to be a function of a particular density threshold.

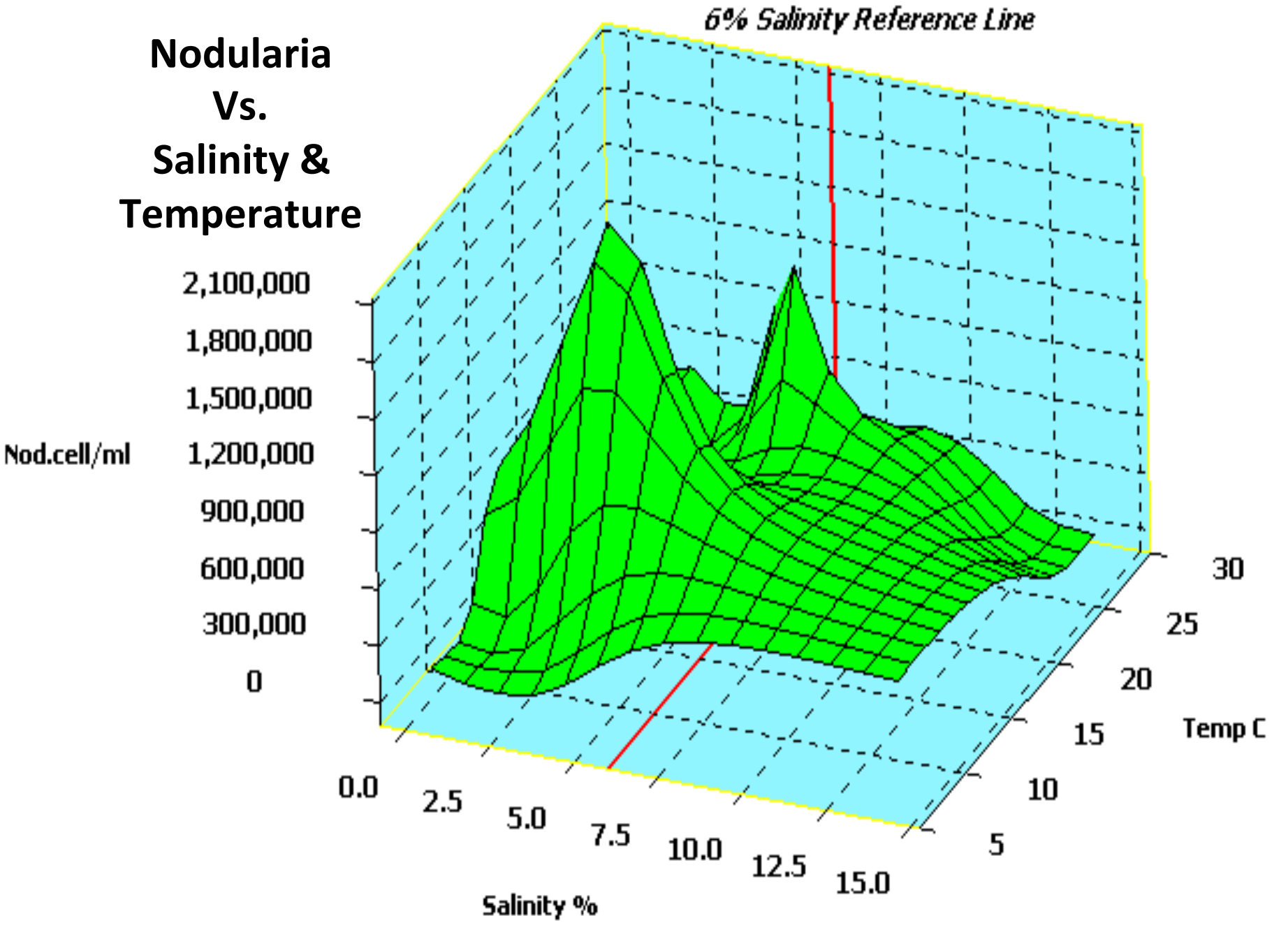


Preliminary Results

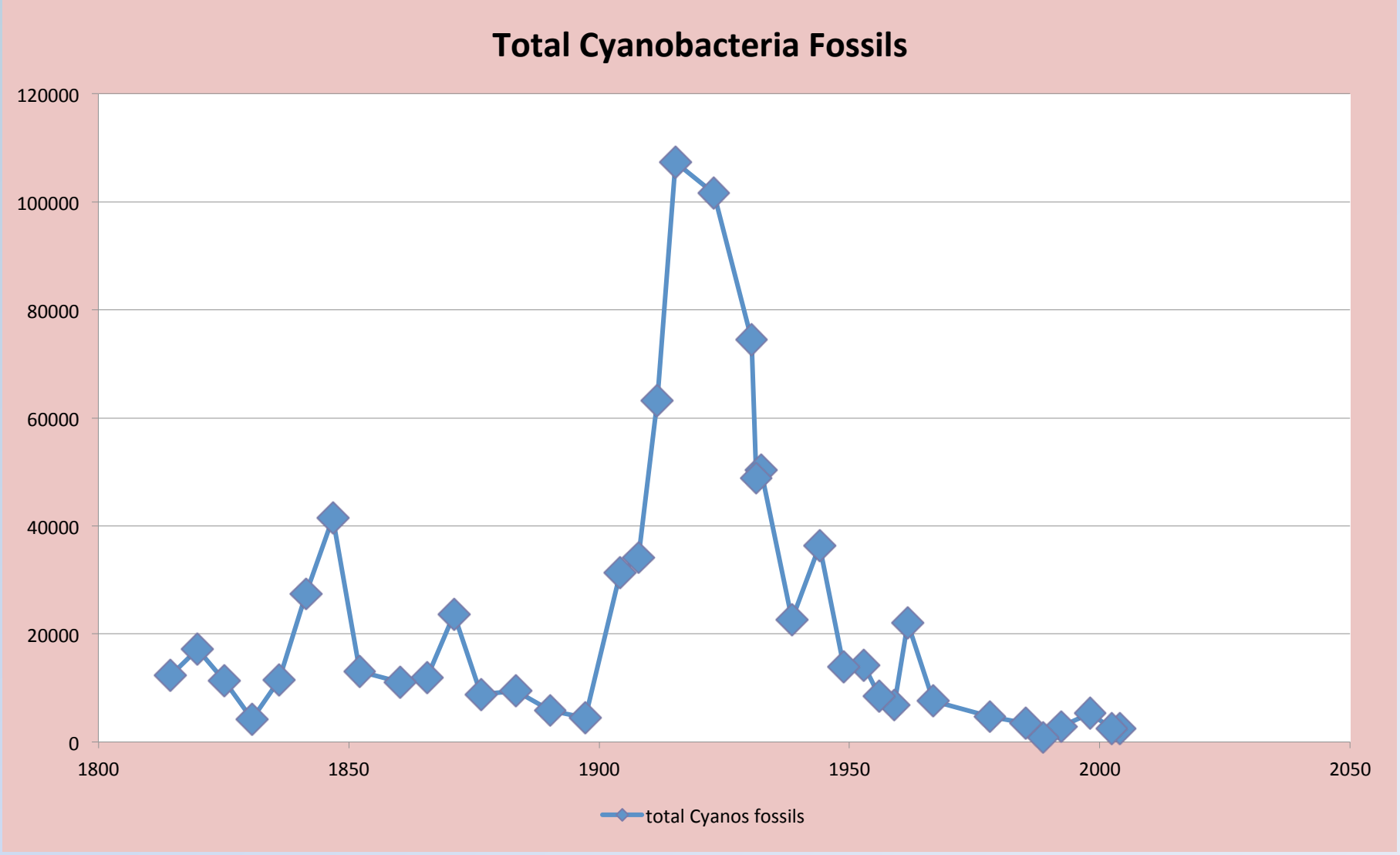
Comparison of Abiotic Factors and Cyanotoxin Concentration



Nodularia Vs. Salinity & Temperature

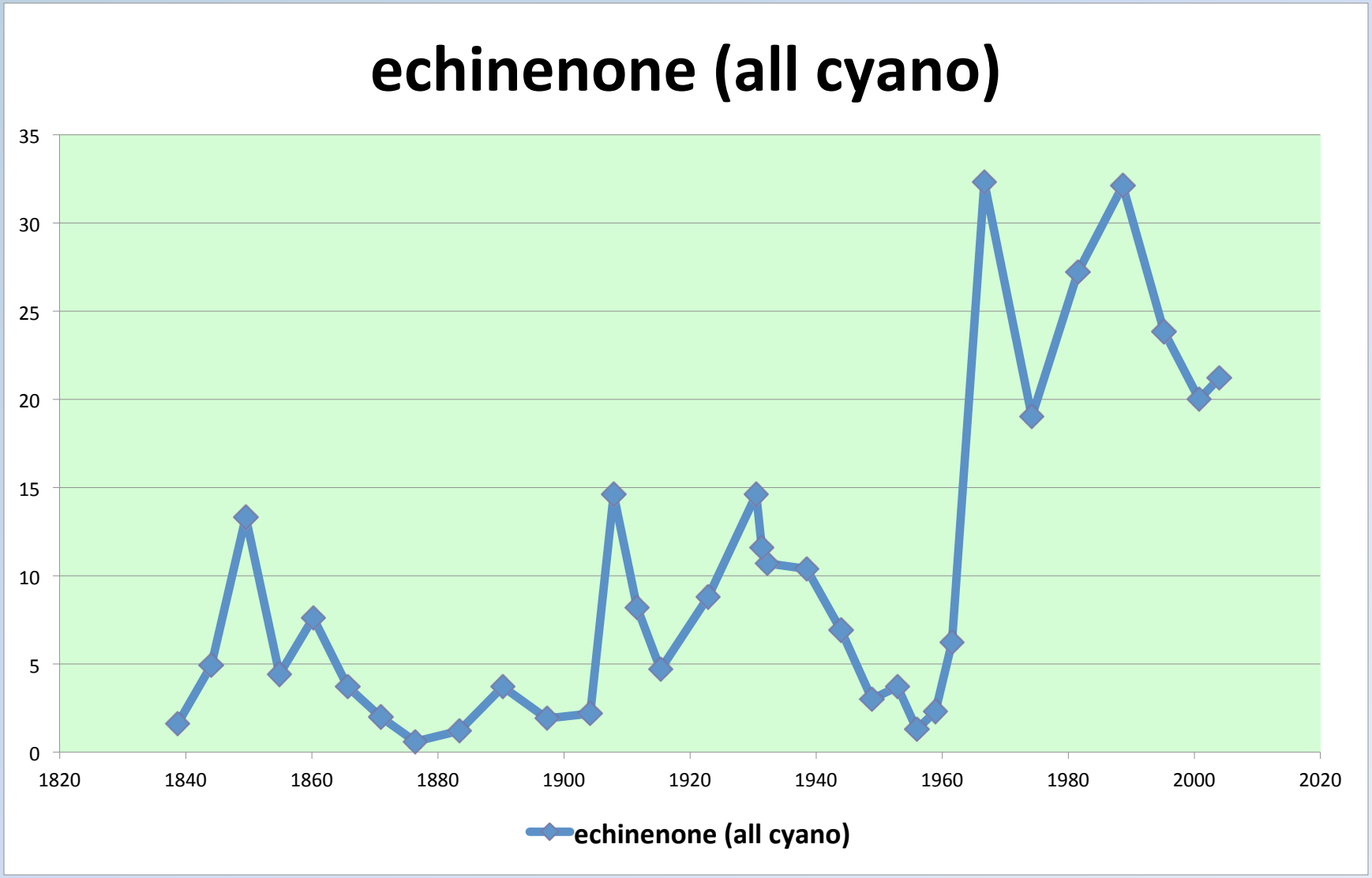


Historic Cyanobacteria Fossil Presence



Source: DWQ Paleo Study

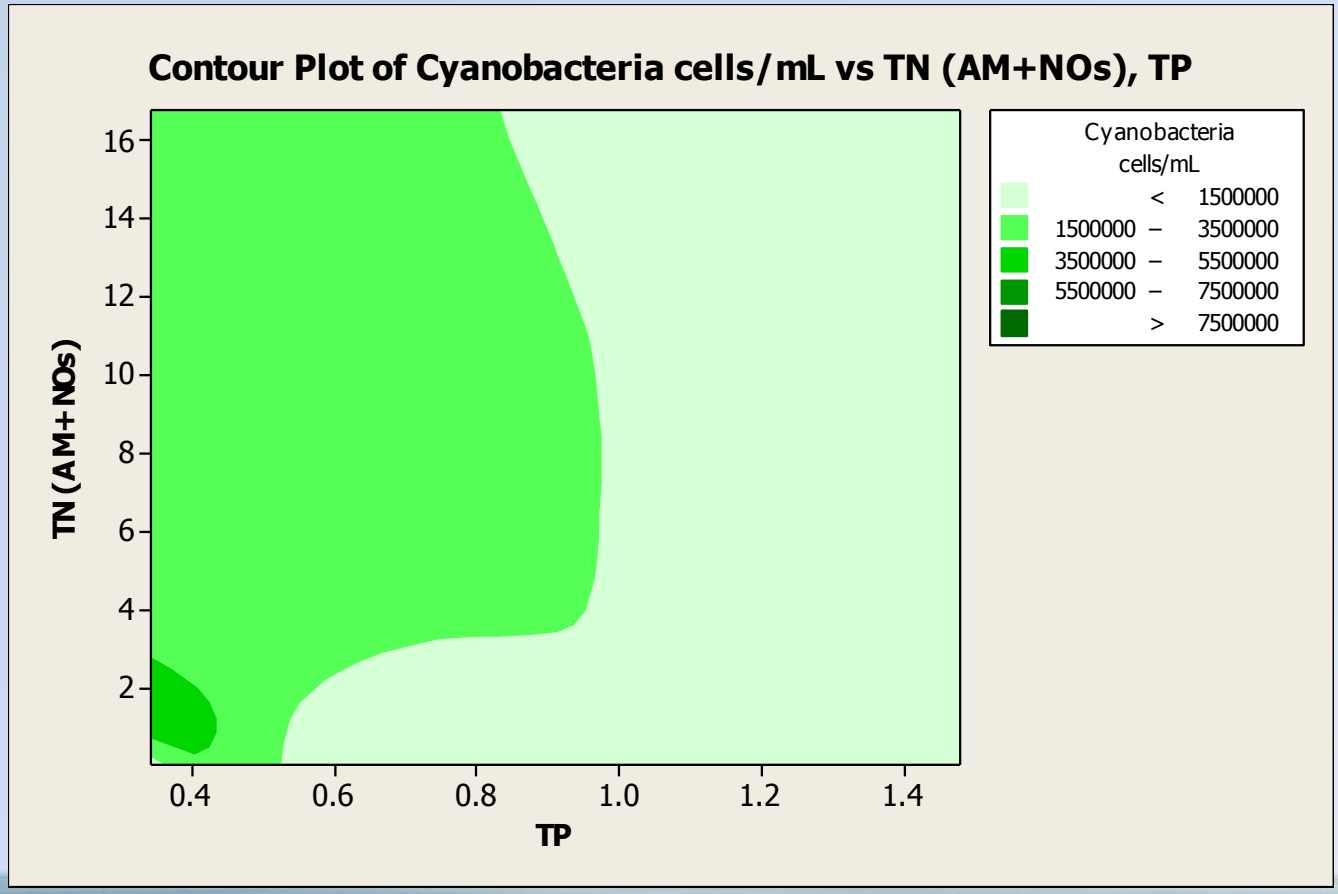
Historic Cyanobacteria Pigment Presence



Preliminary Results

Algal Composition

Comparison of Nutrient Dynamics and Cyanobacteria Abundance



Results

Zooplankton

Species Diversity and Population Structure

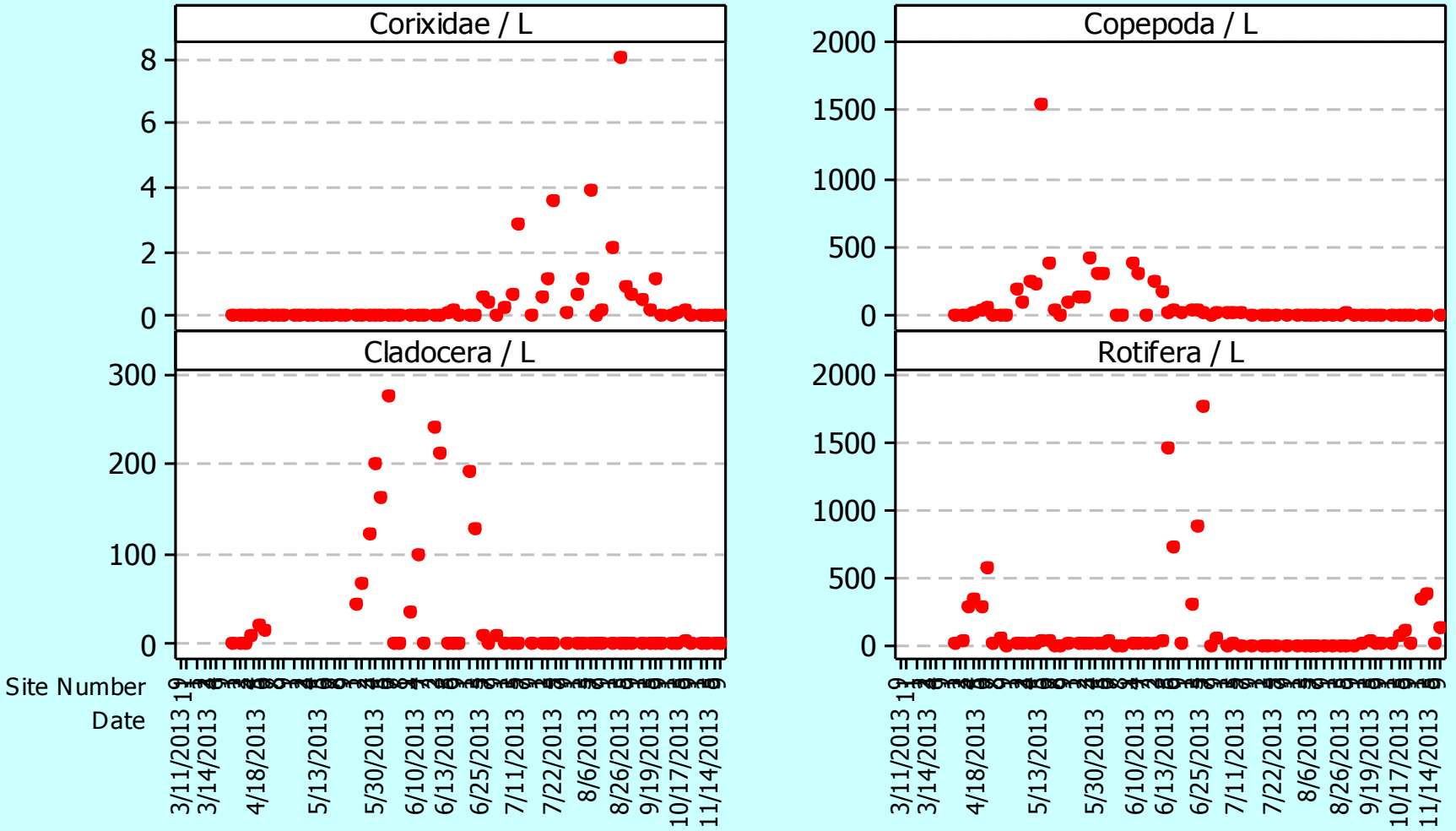
7 Major Taxonomic Groups
11 Families or Orders
20+ species
77 samples enumerated
Documented very interesting spatial distribution patterns
Collected additional samples for isotopic evaluation
Tracked population dynamics

ZOOPLANKTON TAXA

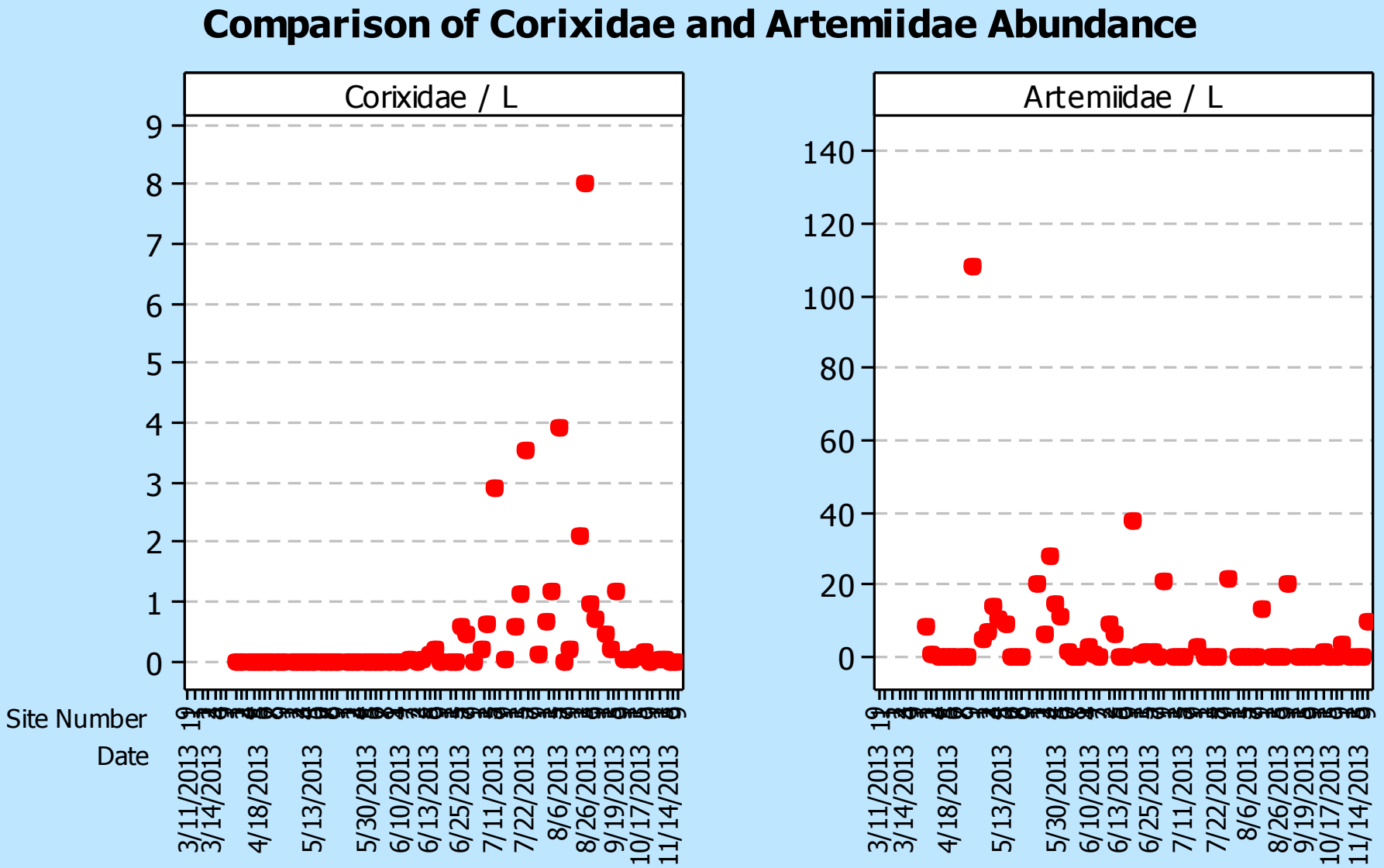
	April-November 2013	Species List: GSL Invertebrates from plankton net samples
Major Group (Crustacea)	Family or Order	Species
Cladocera	Daphniidae	*Daphnia dentifera* (Sars)
Cladocera	Daphniidae	*Daphnia pulex* Leydig
Cladocera	Daphniidae	*Simocephalus vetulus* (O.F.M.)
Cladocera	Daphniidae	*Ceriodaphniaquadrangula* (O.F.M.)
Cladocera	Moinidae	*Moina macrocarpa* Straus
Cladocera	Chydoridae	*Pleuroxusstriatus*Schoedler
Cladocera	Chydoridae	*Pleuroxus* sp.
Cladocera	Chydoridae	*Chydorus sphaericus* (O.F.M.)
Cladocera	Chydoridae	*Alona* sp.
Copepoda	Cyclopidae	*Eucyclops agilis* (Koch)
Copepoda	Diaptomidae	*Leptodiaptomus connexus* Light
Copepoda	Harpacticoida	*Cletocamptus* sp.
Branchiopoda	Artemiidae	*Artemia franciscana* Kellogg
Ostracoda		(undetermined)
Phylum Rotifera	Brachionidae	*Brachionusplicatilis*O.F.M.
Phylum Rotifera	Brachionidae	*Notholcaacuminata* Ehrenberg
Insecta: Diptera	Chironomidae	various
Insecta: Diptera	Ephydridae	(undetermined)
Insecta: Hemiptera	Corixidae	*Trichocorixaverticalis*(Fieber)
Insecta: Hemiptera	Corixidae	*Coriselladecolor*(Uhler)
Annelida: Oligochaeta	Naididae	(undetermined)

Comparison of Corixidae, Cladocera, Copepoda, and Rotifera Abundance

Temporal Pattern of Corixidae and Prey Abundance



Comparison of Corixidae and Artemiidae Abundance

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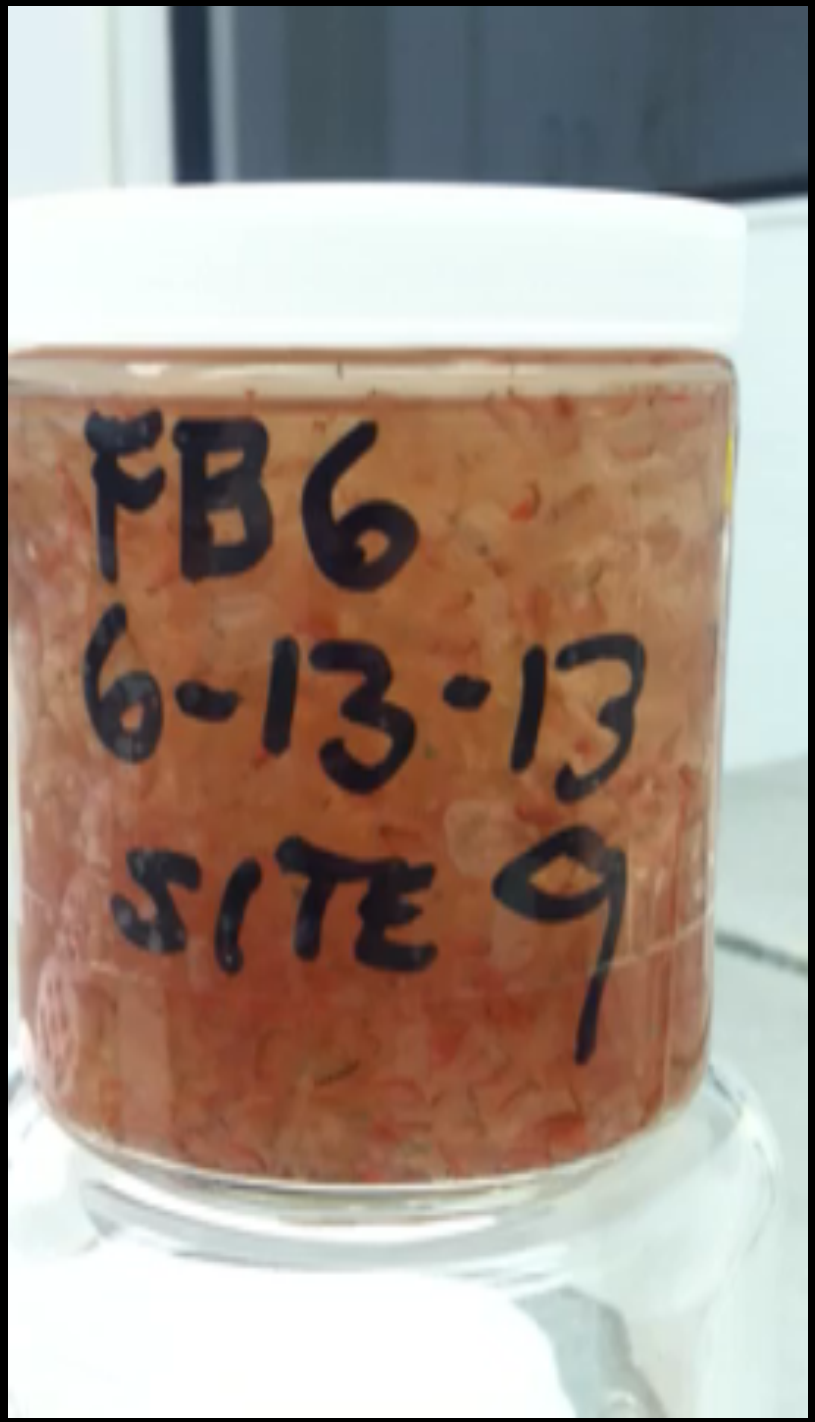
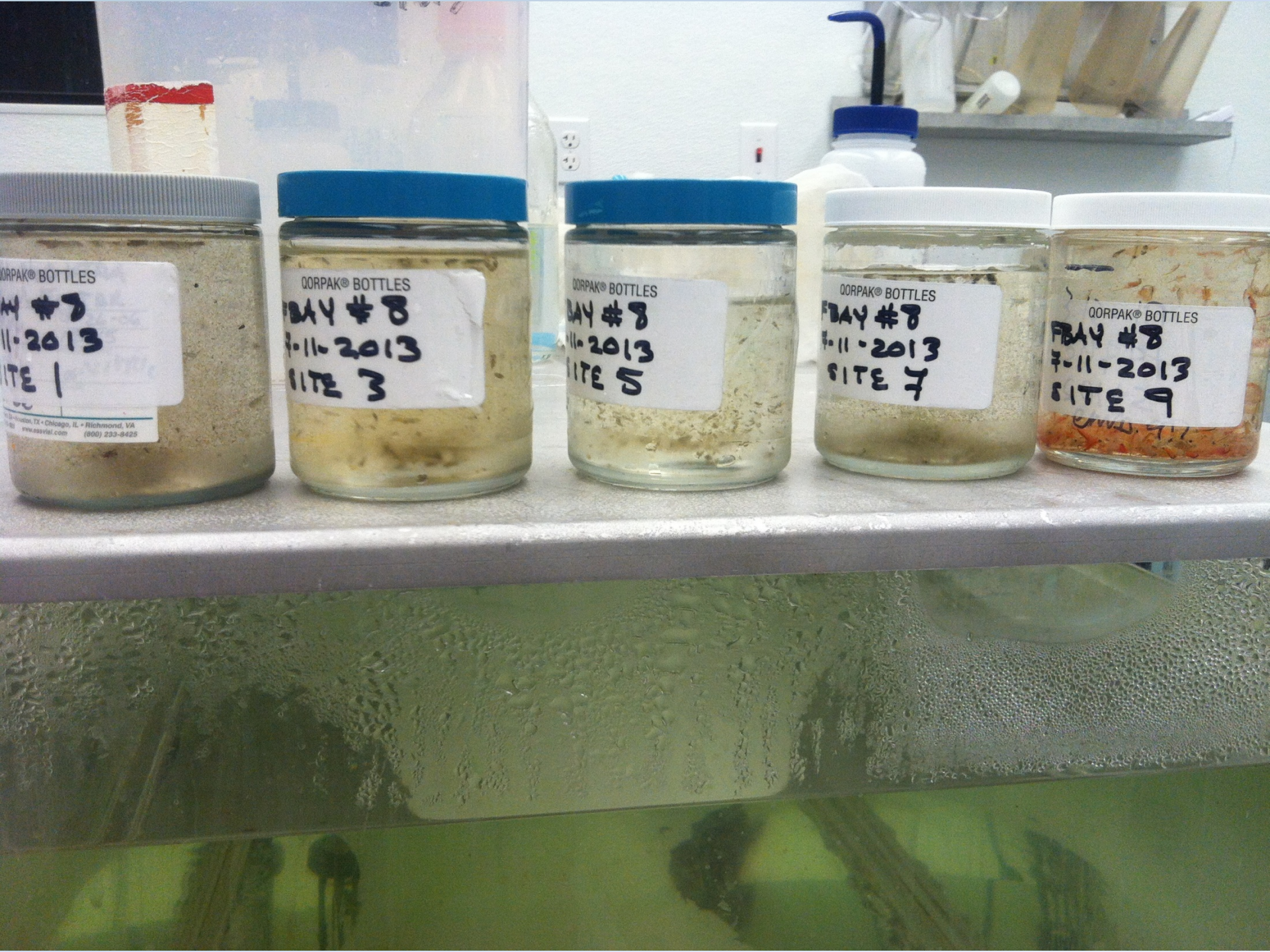
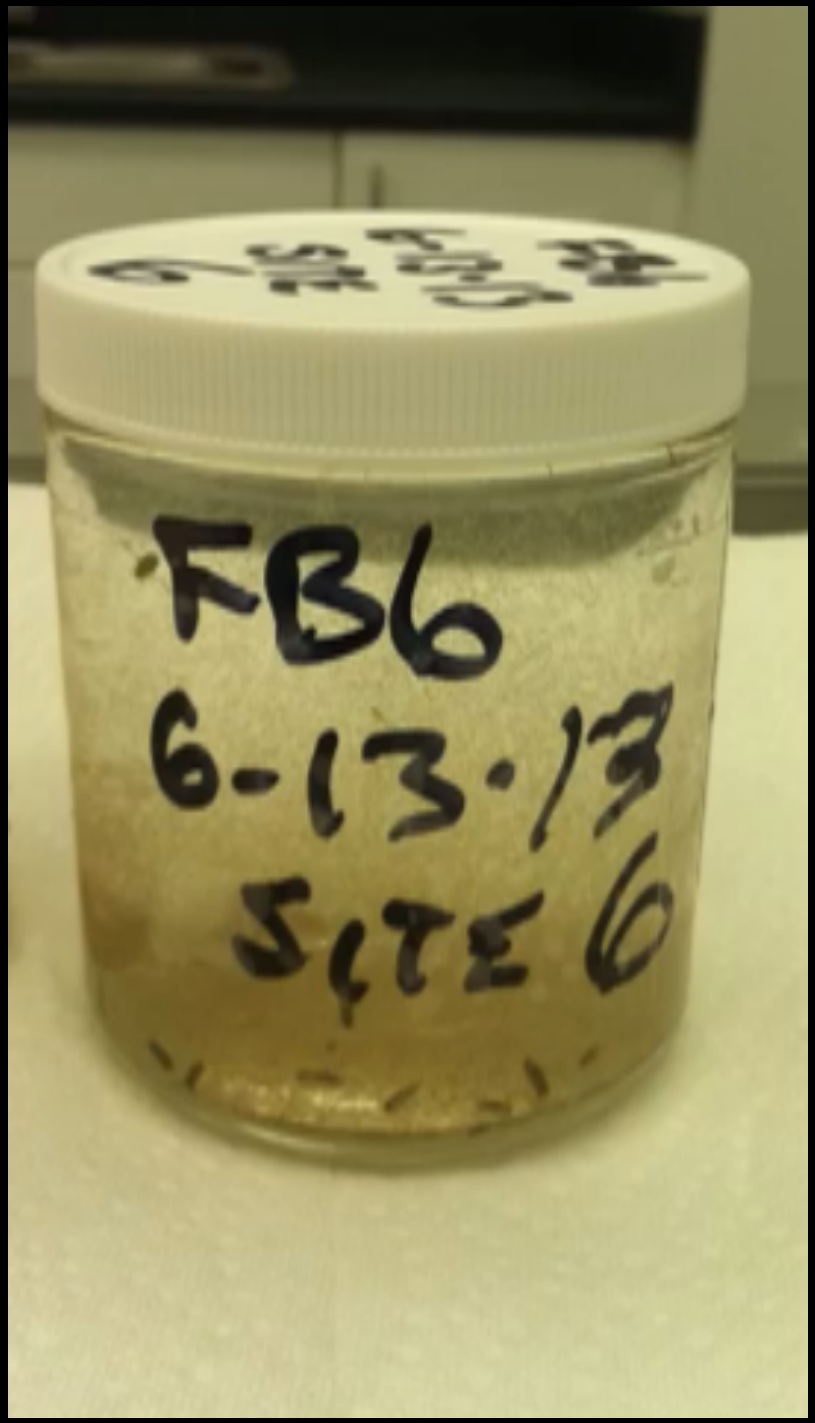
FBAY 7
6-25-13
SITE C

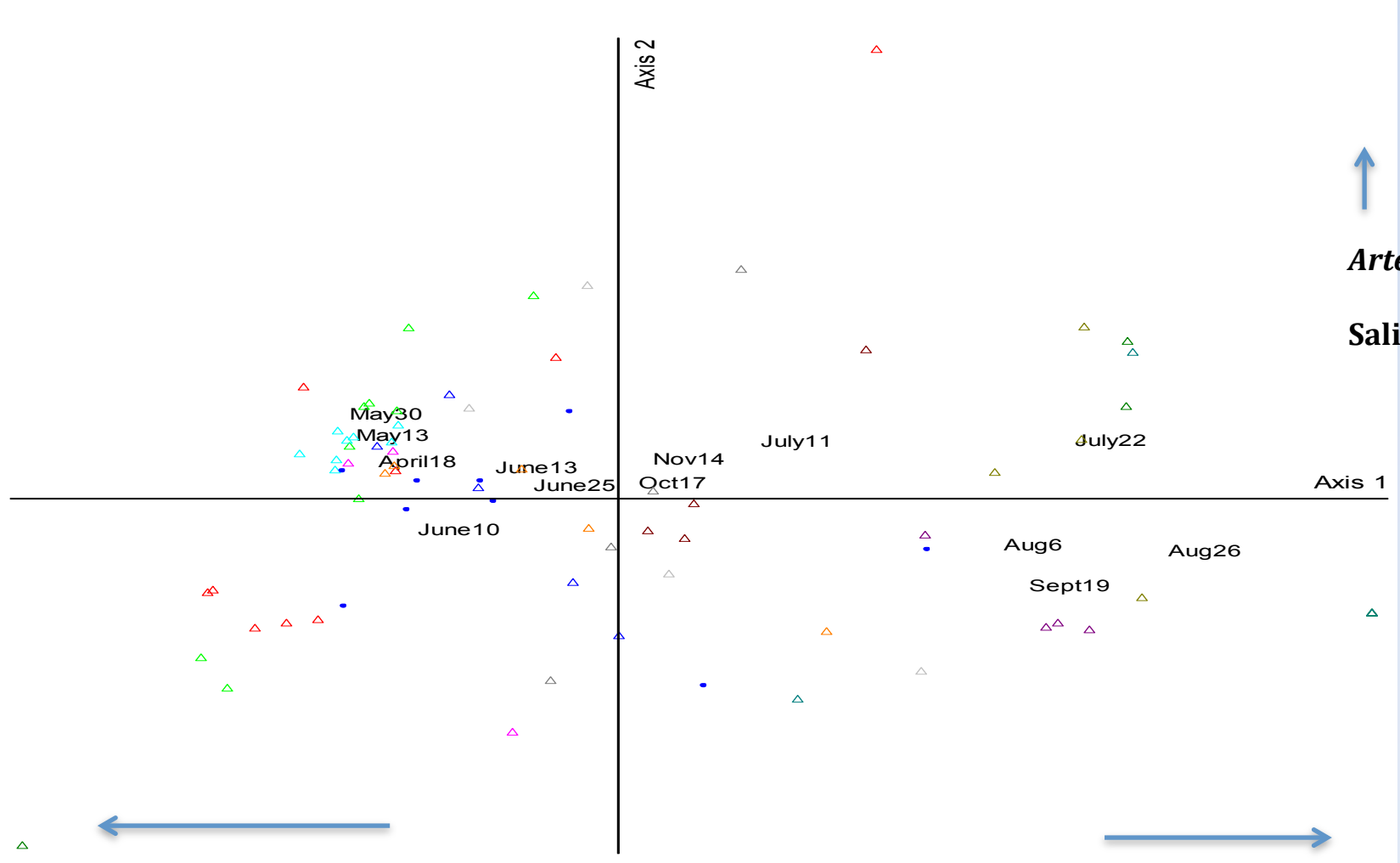

FB6
6-13-13
SITE 9


QORPAK® BOTTLES
#3
11-2013
ITE 1
QORPAK® BOTTLES
BAY #8
7-11-2013
SITE 3
QORPAK® BOTTLES
BAY #8
7-11-2013
SITE 5
QORPAK® BOTTLES
BAY #8
7-11-2013
SITE 7
QORPAK® BOTTLES
BAY #8
7-11-2013
SITE 9

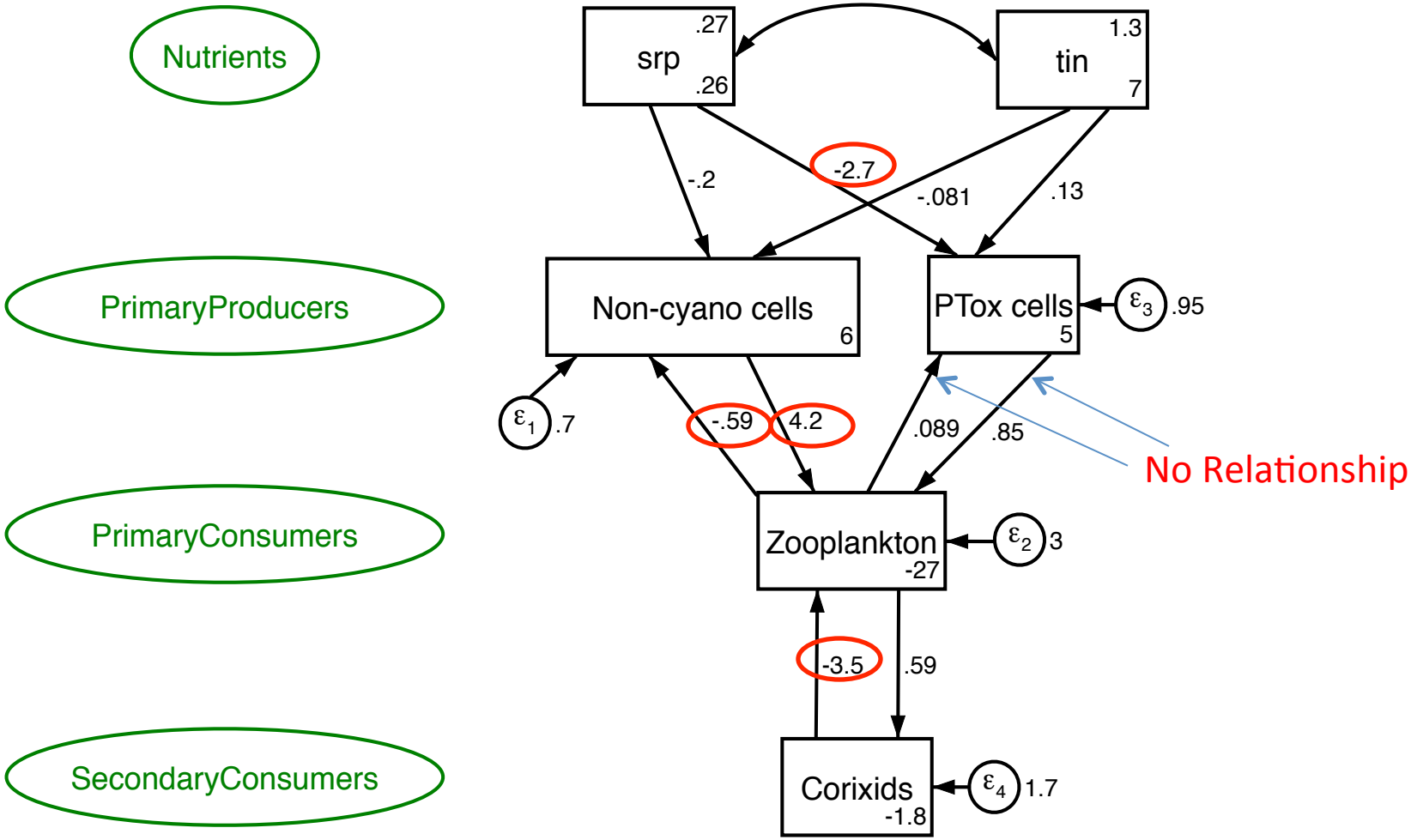

JULY CORIXID FEEDING FRENZY


FB6
6-13-13
SITE 6

Non-Metric Multidimensional Scaling Ordination



Structured Equation Model illustrating food web relationships in Farmington Bay. Numbers circled in red are significant at P< 0.05.



Toxicity Testing

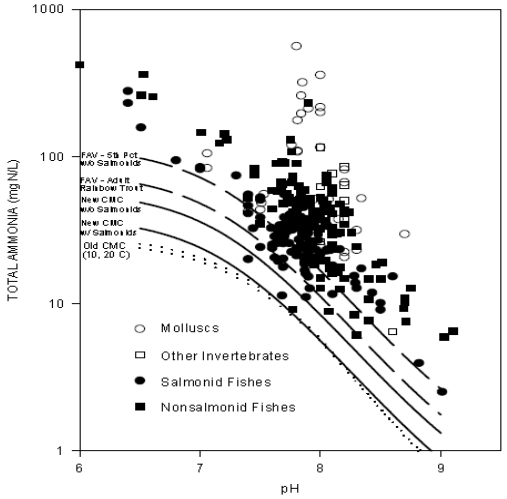
- Dried cysts with known hatching quality are acquired
- Cysts are then suspended in a hatching solution consisting of FBAY water or solution with known concentration of cyanotoxin.
- The suspension is used for 24- to 48-hour hatching using a micro-method—96-well hatching plates in incubator/ agitator.
- Recordings of shell content, early breaking, emergent hatching, and nauplii are all recorded.
- Hatching percentage and nauplii survival are recorded.

Exploratory Projects

- **Corixid predation Rates**
- **Stable isotopes in algae and zooplankton**
- **Water quality impacts on hatching and survival of Artemia nauplii**

Initial Artemia Toxicity Testing: Microplate Bioassay Method

METHOD	SOLUTION	Nauplii	umbrella/cysts	% nauplii	Average
cone	hatch sol	315	37	89.5%	89.6%
cone	hatch sol	316	36	89.8%	
cone	fbay #4	314	40	88.7%	90.6%
cone	fbay #4	317	26	92.4%	
microplate	hatch sol	252	51	83.2%	83.5%
microplate	hatch sol	259	50	83.8%	
microplate	fbay #4	254	76	77.0%	82.5%
microplate	fbay #4	264	36	88.0%	



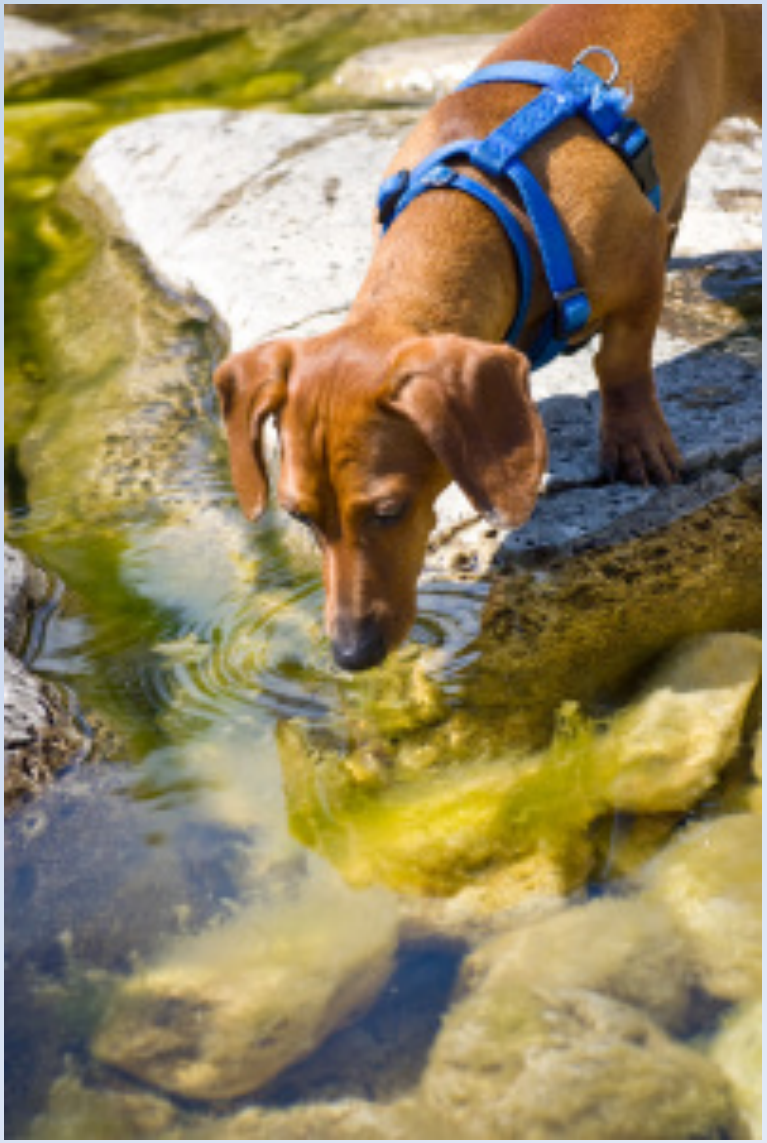
And then there was Utah Lake

October 5 & 6, 2014 – Two Dead Dogs

Canary in the Mine

=


I
EAT THE
TRASH.



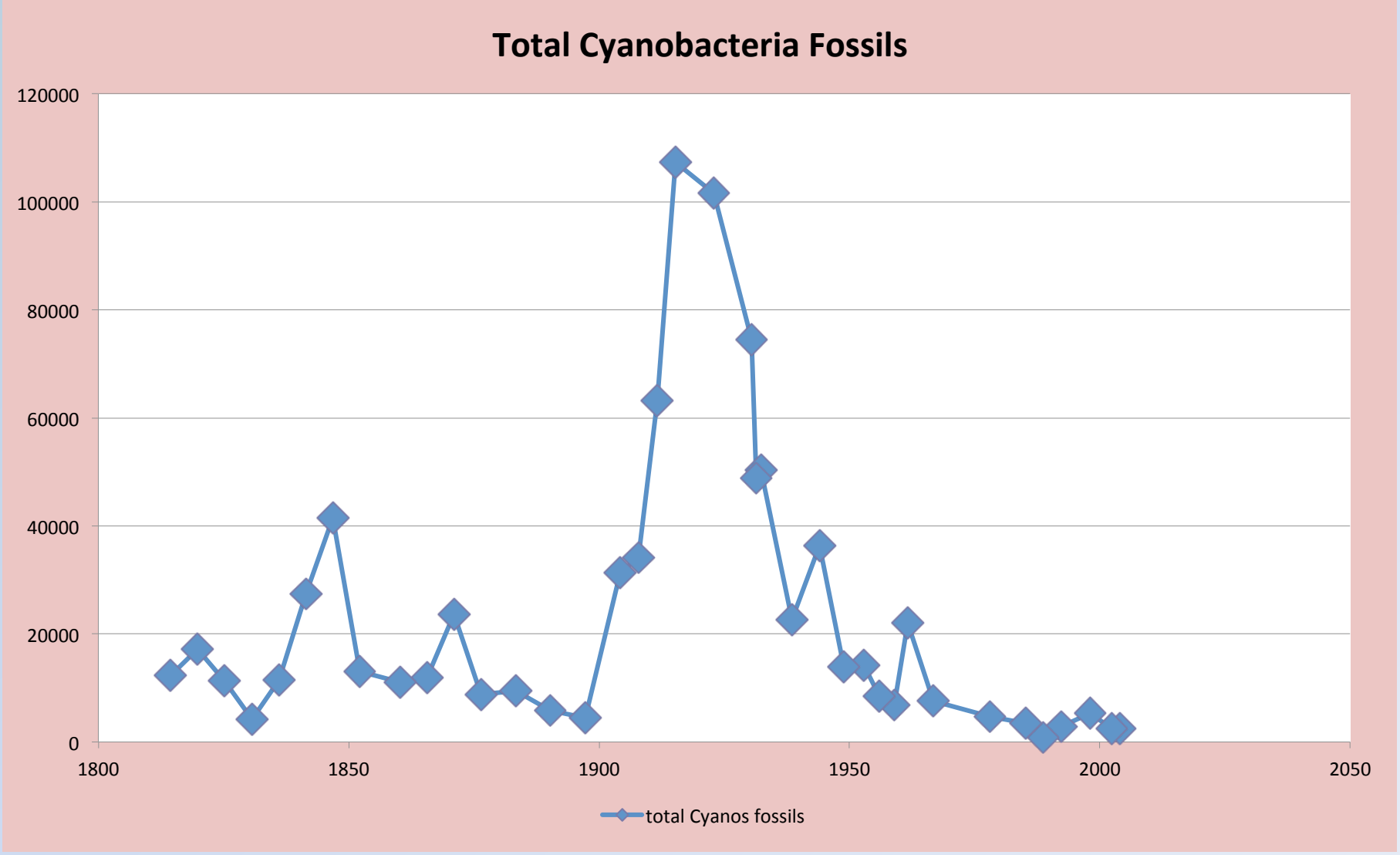
Measured Toxin Concentrations

Microcystin:	Max 11 ug/L (WHO 20 ug/L
Anatoxin	Max 0.2 ug/L (lowest Limit 1 ug/L

UTAH DWQ

The preliminary necropsy report for the dog that died shortly after drinking the water on October 5, 2014, from Utah Lake has been finalized. A specific cause of death was not identified. The Utah Veterinary Diagnostic Laboratory concluded that cyanobacteria toxins were an unlikely cause of death because no cyanobacteria or cyanotoxins were detected in the stomach contents or liver of the animal.

Historic Cyanobacteria Fossil Presence



Source: DWQ Paleo Study

Anatoxin Detection Problems

There are problems with anatoxin-a detection methods including an inability to determine whether it is anatoxin-a or another neurotoxin that causes the resulting deaths.

So, what do we do?

ALGAE BLOOM ADVISORY

Algae blooms have been spotted in this water body.

- Don't swim, wade or fish near blooms or surface scum.
- Don't drink the water.
- Keep children and animals away from any blooms or surface scum.
- Rinse with clean water if exposed.

For more information please visit our website at www.nyc.gov/parks.

City of New York Parks & Recreation

Maintain a Neutral and Objective Perspective

Questions?