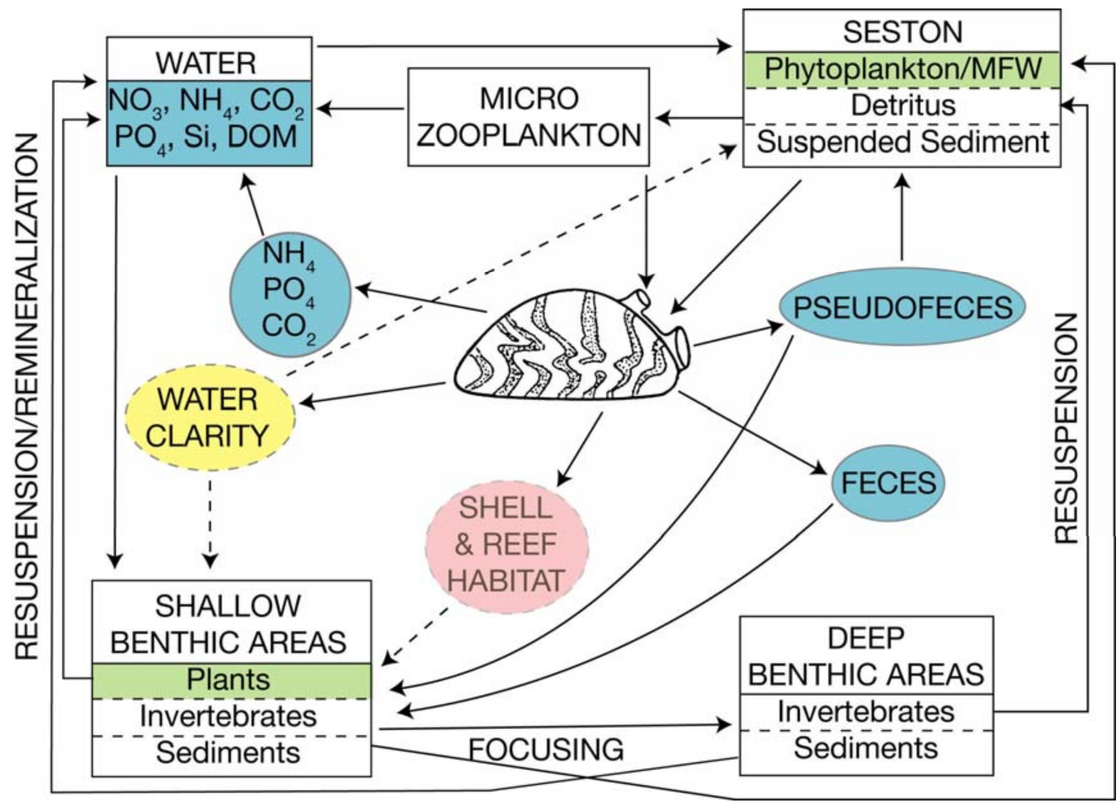
The mussel-HAB collaboration: biophysical and nutrient interactions lead to toxic *Microcystis* dominance

Hank Vanderploeg & GLERL, CILER, & Academic collaborators



The Dreissenid Mussel Wild-Card Questions

Worries:

- As mussels spread throughout the U.S. will *Microcystis* blooms follow?
- If we achieve the 40% reduction goal in P loading in Lake Erie will HABs go away as predicted (hoped) or will mussels mess it up?

Science Question:

Under what conditions will mussels promote *Microcystis* dominance?

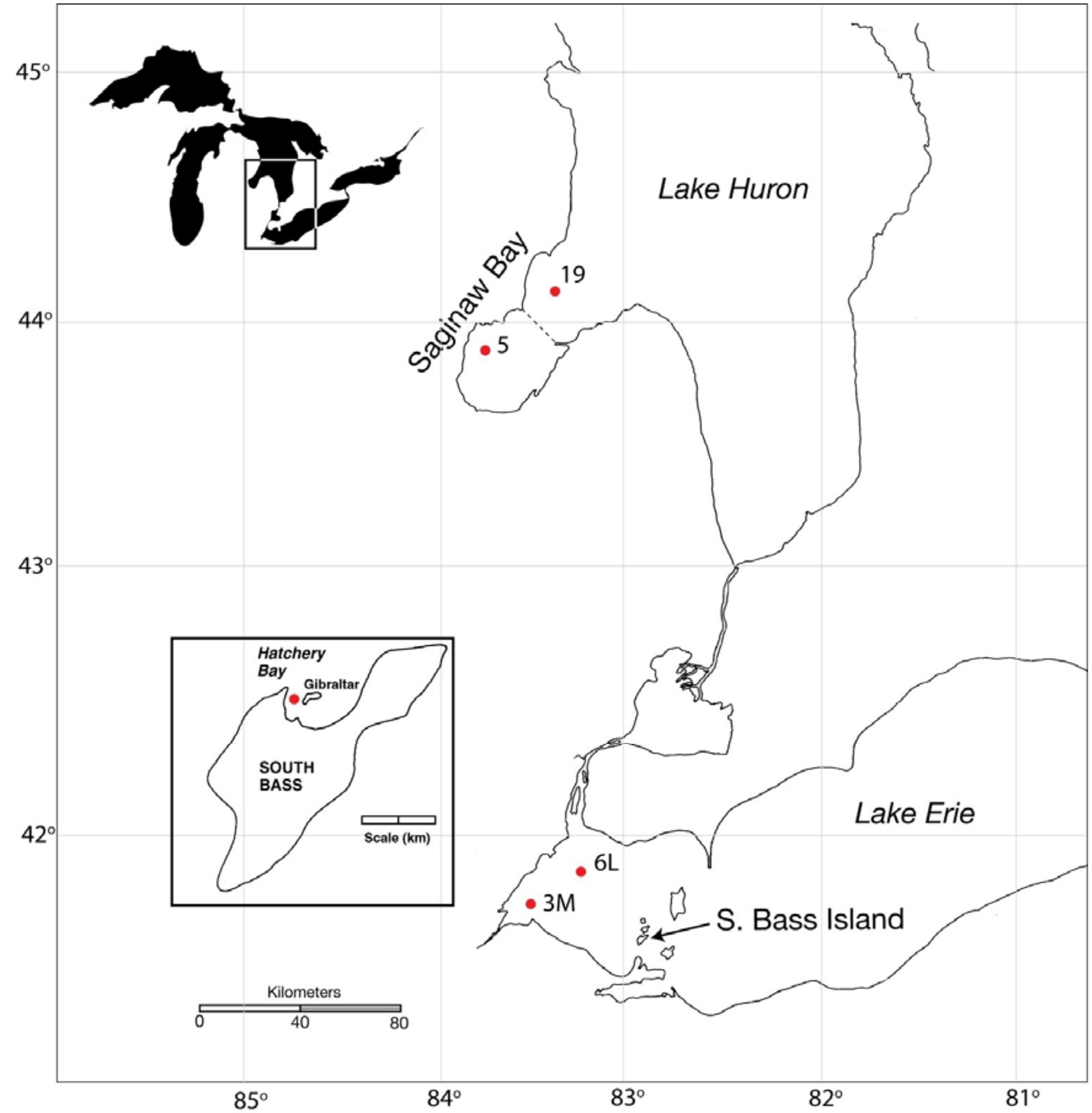
Experimental approaches to examine Processes

- Paired feeding and nutrient excretion experiments
- Enclosure studies
- Genetic characterization
- Behavior

First work focused on selective rejection mechanism In Saginaw Bay and Lake Erie

The study sites

Some of our shallow water study sites in the Great Lakes region



Measured changes in size-fractioned Chlorophyll: < 53µm and > 53 µm (*Microcystis* fraction)…

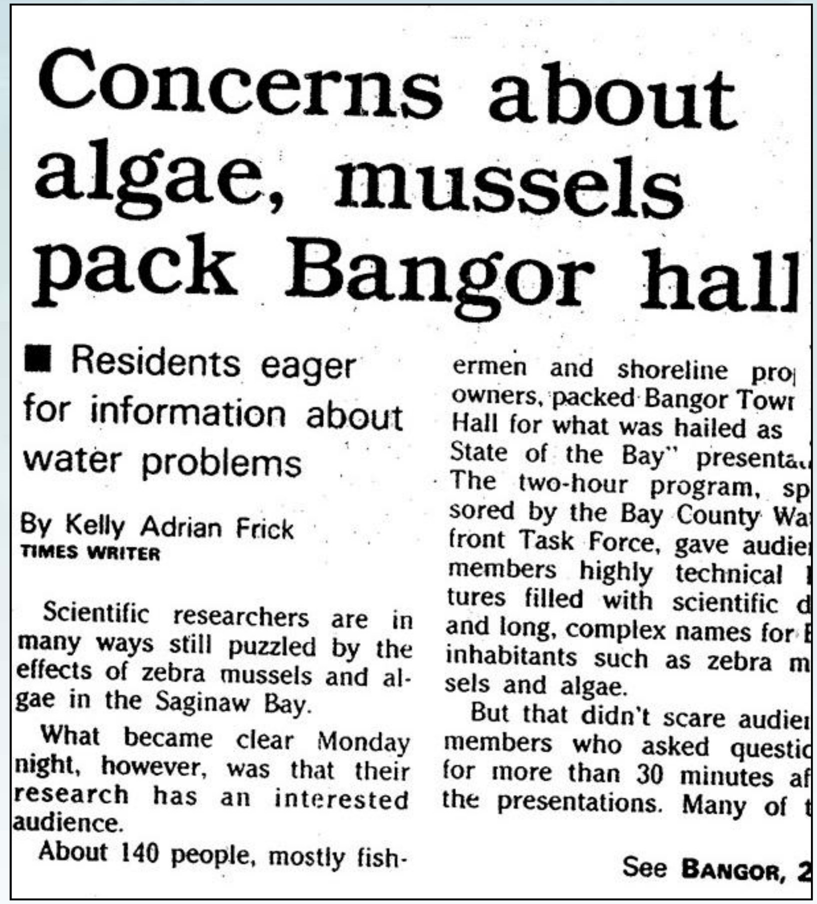
Feeding & Nutrient Experiments: Quagga Mussels in their Baskets

…Paired with videotapes of mussel behavior

… and we were ready for show time

Harmful Algal Blooms (HABs) return to Great Lakes

- *Microcystis* blooms were seen on Saginaw Bay: *Were mussels involved?*
- Water quality model said it shouldn't have happened
- I blamed mussels



Concerns about algae, mussels pack Bangor hall

■ Residents eager for information about water problems

By Kelly Adrian Frick
TIMES WRITER

Scientific researchers are in many ways still puzzled by the effects of zebra mussels and algae in the Saginaw Bay.

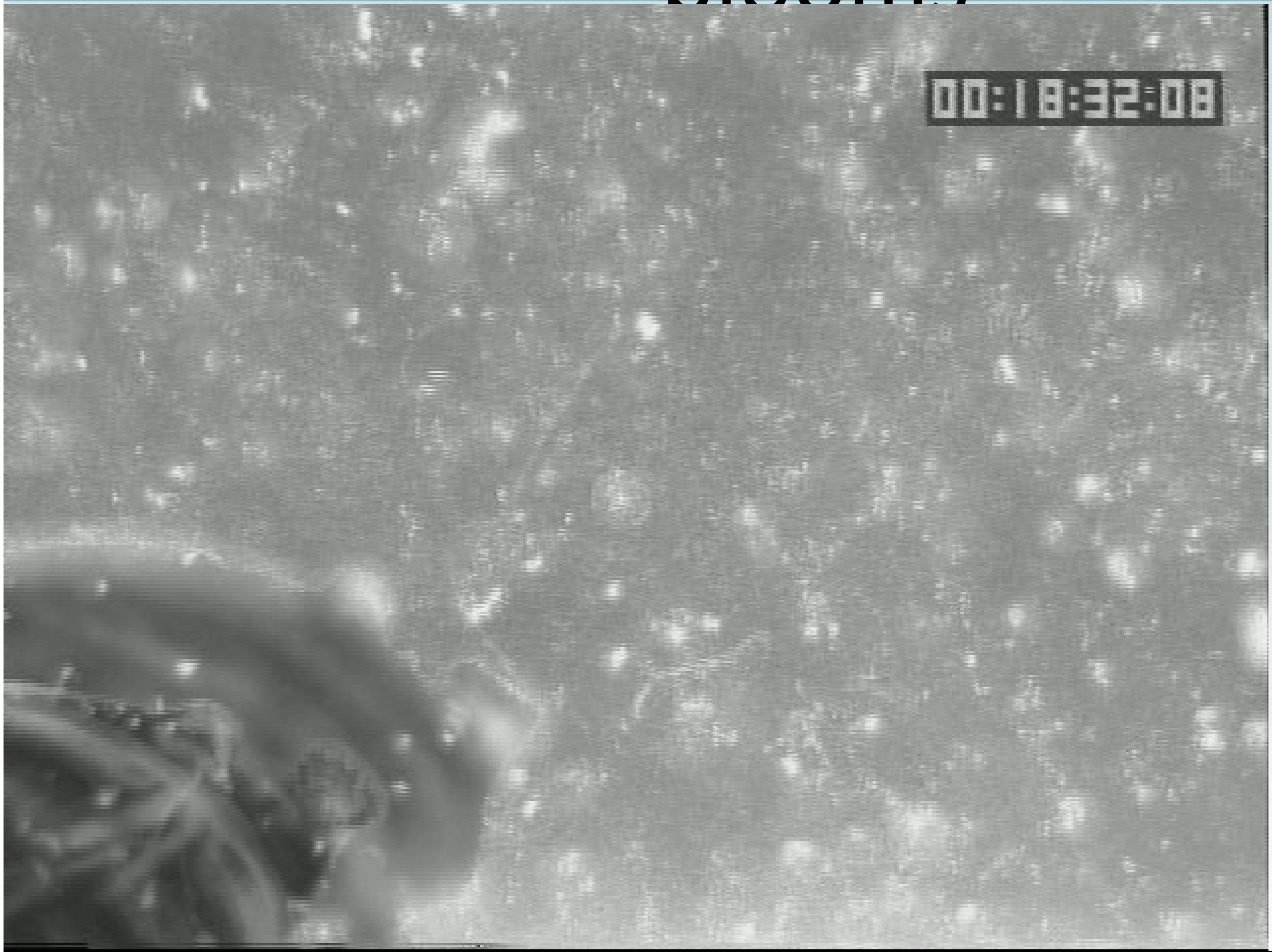
What became clear Monday night, however, was that their research has an interested audience.

About 140 people, mostly fishermen and shoreline pro owners, packed Bangor Towr Hall for what was hailed as State of the Bay" presenta The two-hour program, sp sored by the Bay County Wa front Task Force, gave audie members highly technical tures filled with scientific d and long, complex names for inhabitants such as zebra m sels and algae.

But that didn't scare audie members who asked questic for more than 30 minutes af the presentations. Many of t

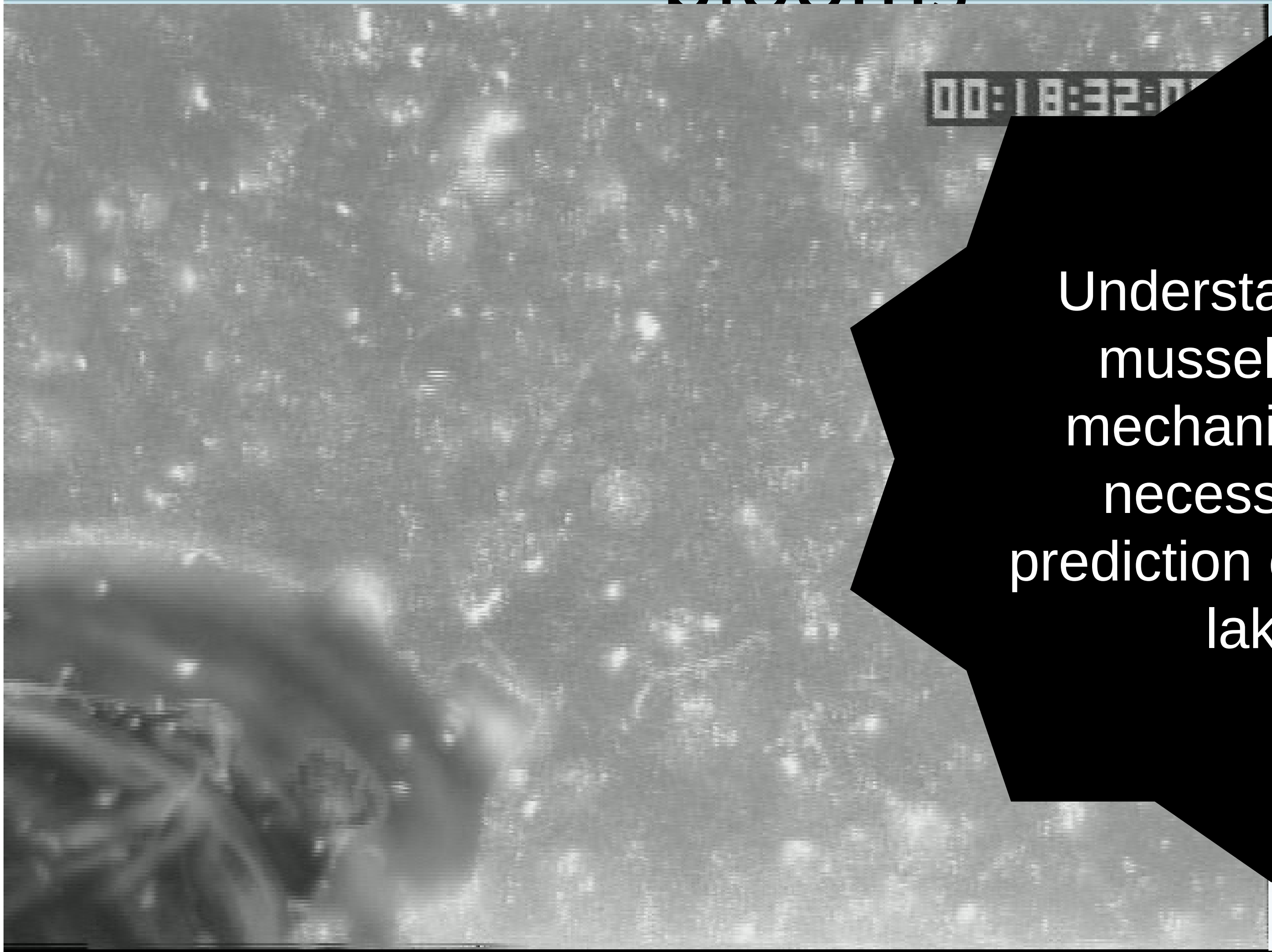
See BANGOR, 2

Mussels promote harmful algal blooms



The selective rejection paradigm: large toxic colonies are rejected while small algae are ingested

Mussels promote harmful algal blooms



Understanding of mussel/bloom mechanisms are necessary for prediction of HABs in lakes

The selective rejection paradigm: large toxic colonies are rejected while small algae are ingested

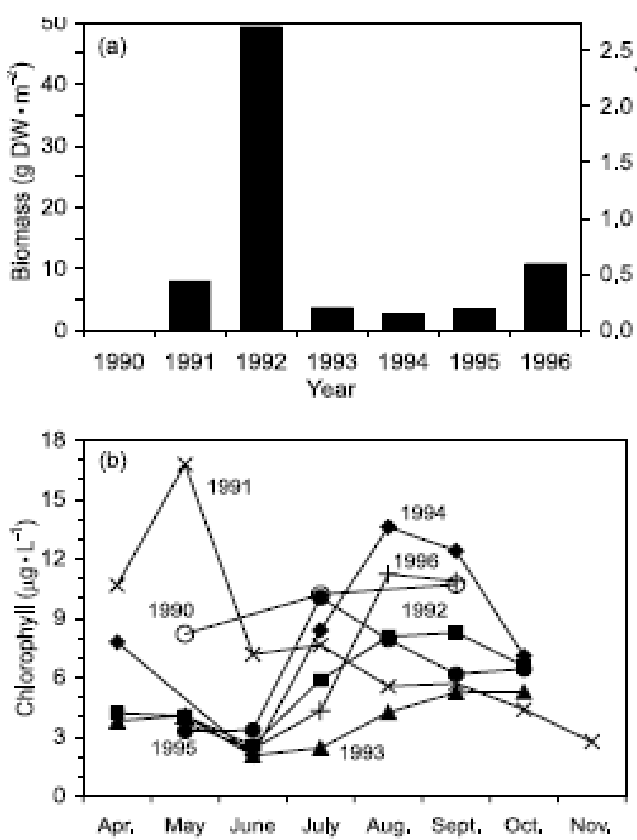
Original paradigm details*

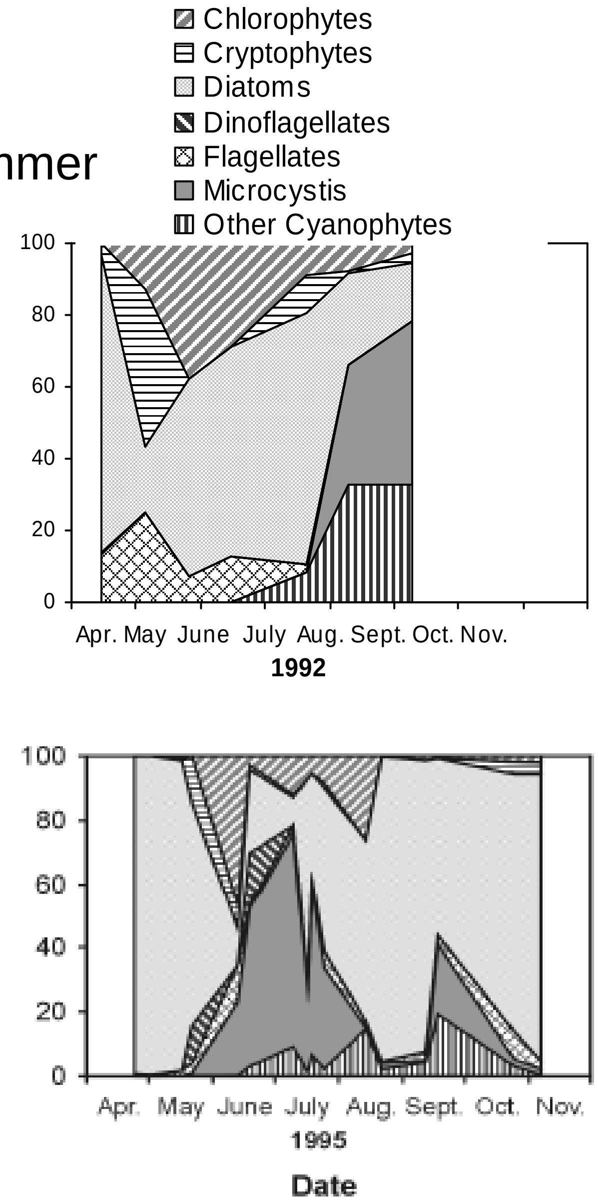
- Abundant dreissenids clear a significant fraction of the water column per day
- Large toxic (or unpalatable) *Microcystis* are easily sorted from smaller phytoplankton and rejected as pseudofeces
- Pseudofeces are loosely aggregated with *Microcystis* returned to water column
- Nutrients from "processed" algae returned to water column to "feed" *Microcystis*

*Vanderploeg H.A., Liebig J.R., Carmichael W.W., Agy M.A., Johengen T.H., Fahnenstiel G.L. & Nalepa T.F. (2001). *Canadian Journal of Fisheries and Aquatic Sciences,* **58,** 1208-1221.

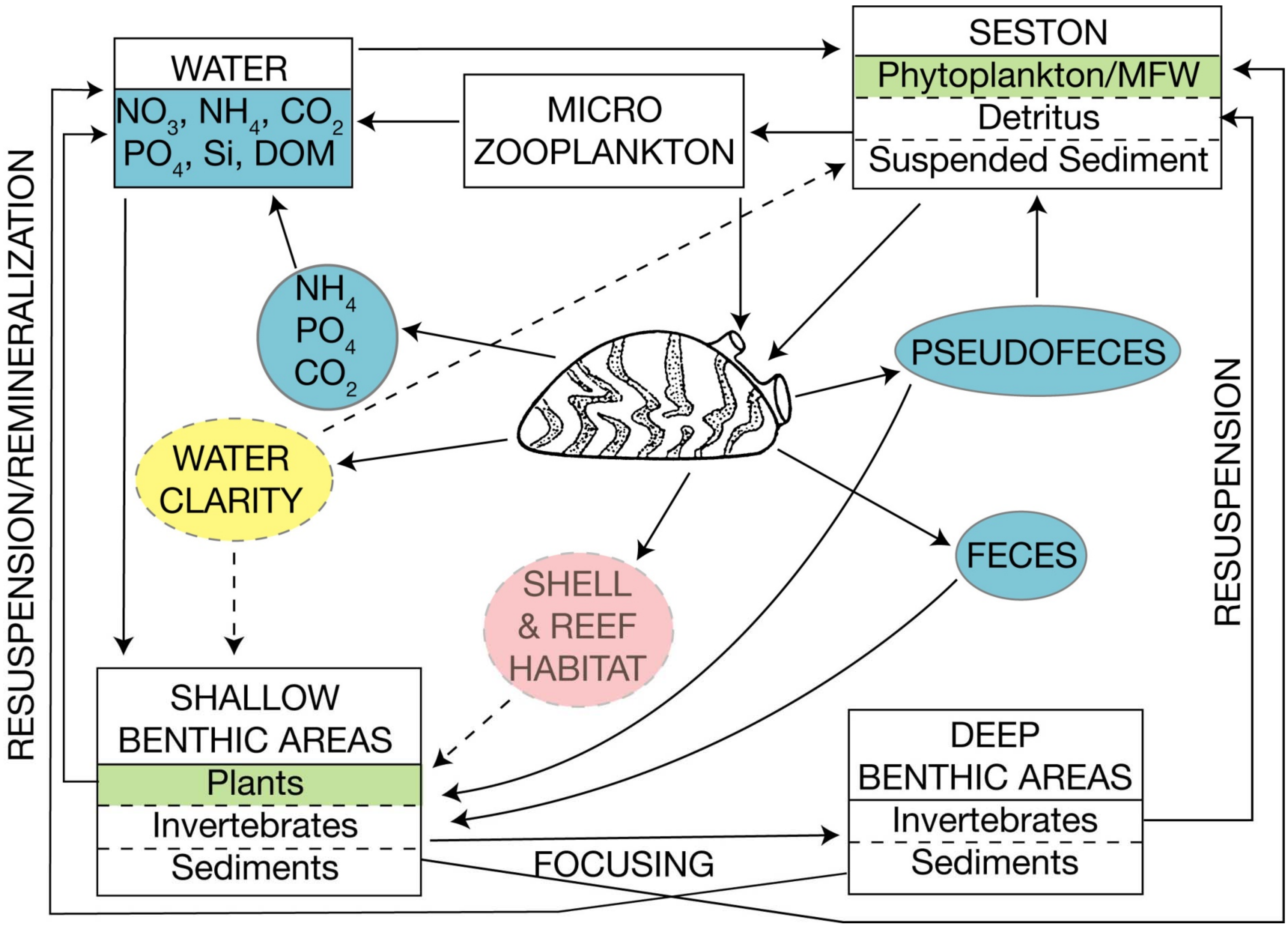
Saginaw Bay Story

- Mussels knock down chlorophyll in Spring
- Chlorophyll & *Microcystis* increase during summer





What zebra & quagga mussels do



Counter evidence

- Many laboratory strains of *Microcystis* are filtered at high rate
- No *Microcystis* increase was seen in mussel-invaded (hypereutrophic) lakes in the Netherlands
- Both cultures isolated from a Dutch lake and Microcystis in a Dutch lake were readily ingested.
- *Microcystis* (small colonies and single cells) were readily ingested by zebra mussels in the Hudson River

Forecasting Implication

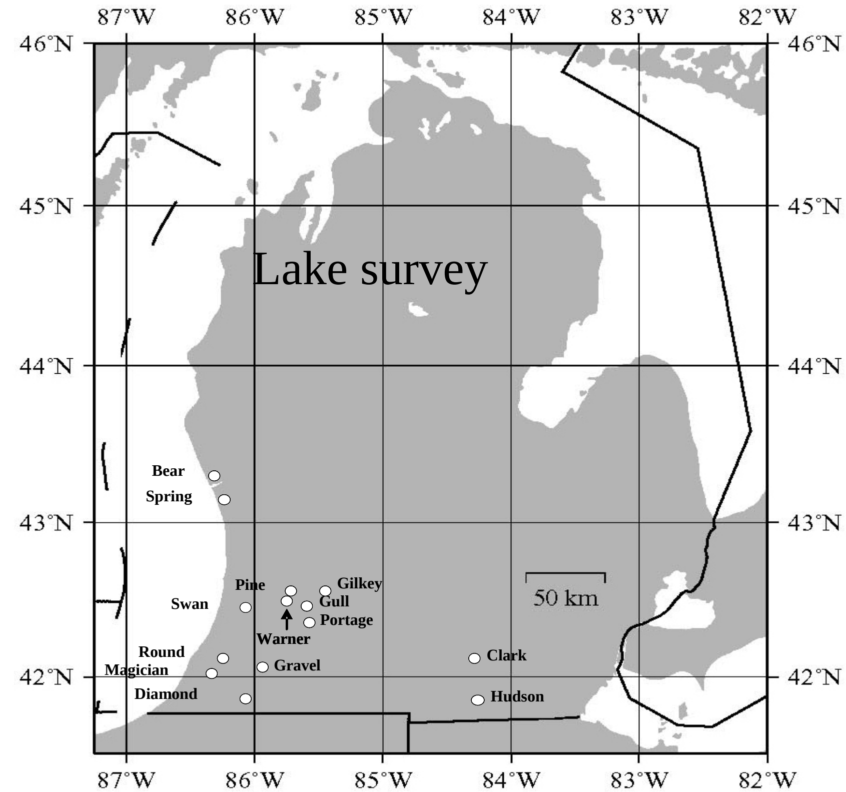
There is a nutrient/trophic gradient interaction

A few hypotheses:

- Grazing and nutrient excretion interaction—a nutrient stoichiometry story?
- Strains vary among lakes of different eutrophy?
- Grazing not important at high TP concentrations?

More evidence and puzzling results

Microcystis increased in low TP lakes (<25 µg L^{-1}), but not in high TP lakes (>25 µg L^{-1}) invaded by zebra mussels*



*Raikow D.F., Sarnelle O., Wilson A.E. & Hamilton S.K. (2004) *Limnology and Oceanography,* **49,** 482-487.

What we did

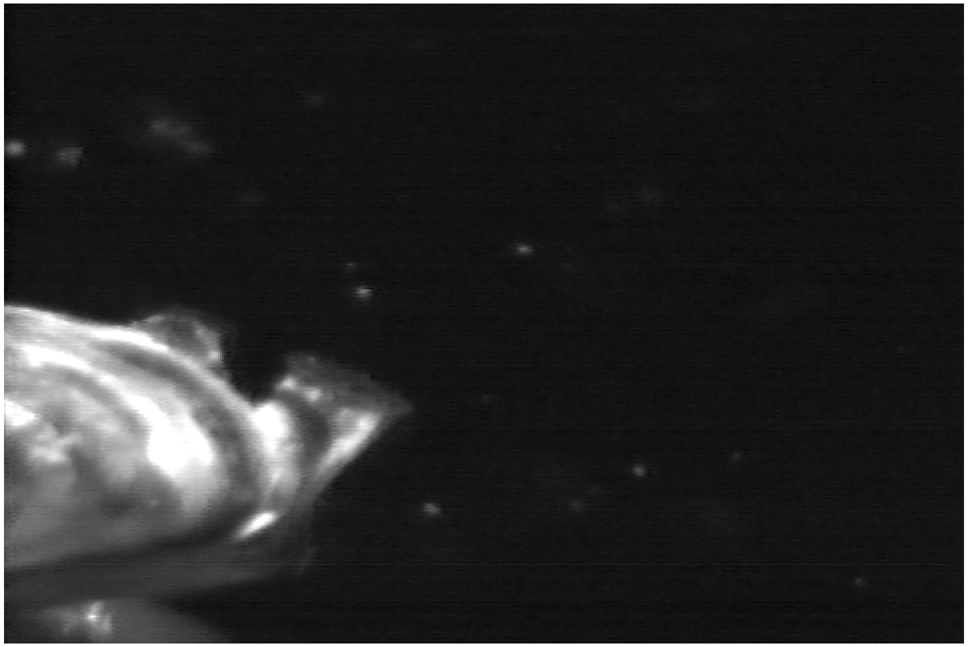
- We looked at the strain question—what factors induce rejection?
- We did more work with natural seston using different methods of observing changes in phytoplankton
- We looked at potential effect of nutrient excretion of mussels on promotion of Microcystis

Some results emphasizing:

- Importance of working with freshly isolated cultures or natural seston*
- There is more than one reason for rejection

*Cultures isolated by Alan Wilson (Wilson et al., 2005) used in paper Vanderploeg et al. (2014); videos in Vanderploeg & Strickler (2014)

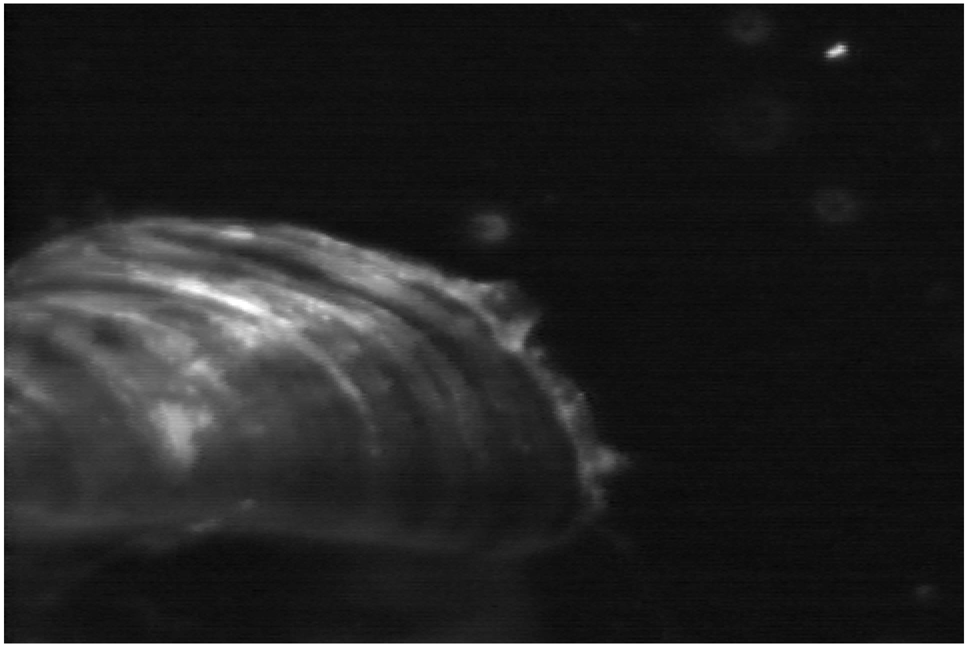
Bear Lake (mussels present) *Microcystis* strain — much feeding on smaller size fraction



Enthusiastic captures and forceful rejections

Fraction	Initial chl (µg/L)	Microcystin / chl	F_A (mL/cm^2/h)
>53µm	1.56	0.202	-7.26
<53µm	2.42		64.91
Total	3.97		29.23

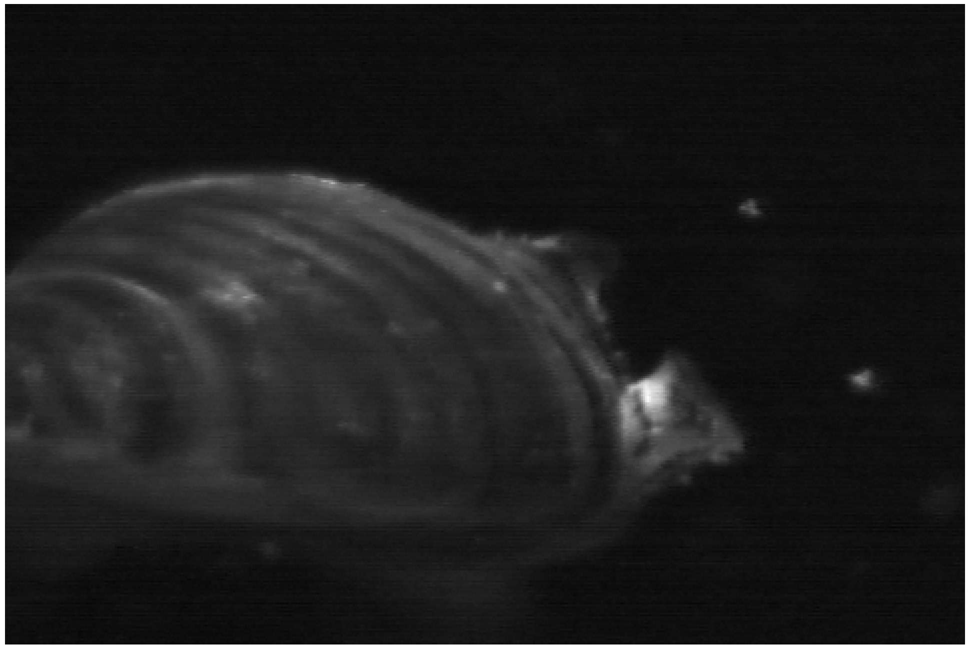
Gilkey Lake strain — no feeding on any size category



Note symptoms of distress: siphon not fully open & weak expulsion response

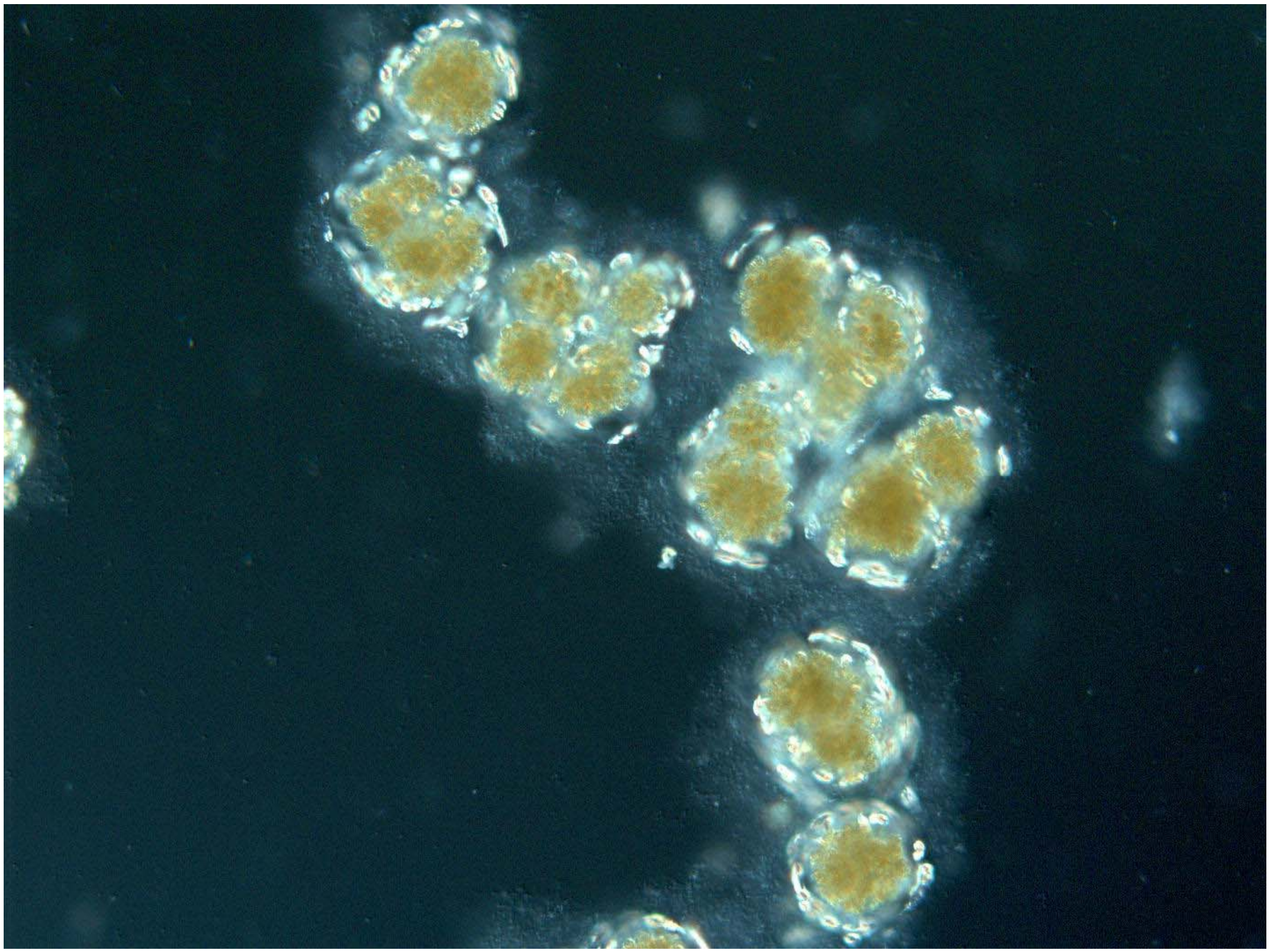
Fraction	Initial chl (µg/L)	Microcystin / chl	F_A (mL/cm^2/h)
>53µm	1.96	0.099	-10.53
<53µm	0.84		-1.90
Total	2.79		-8.20

Gilkey Lake strain plus *Cryptomonas*

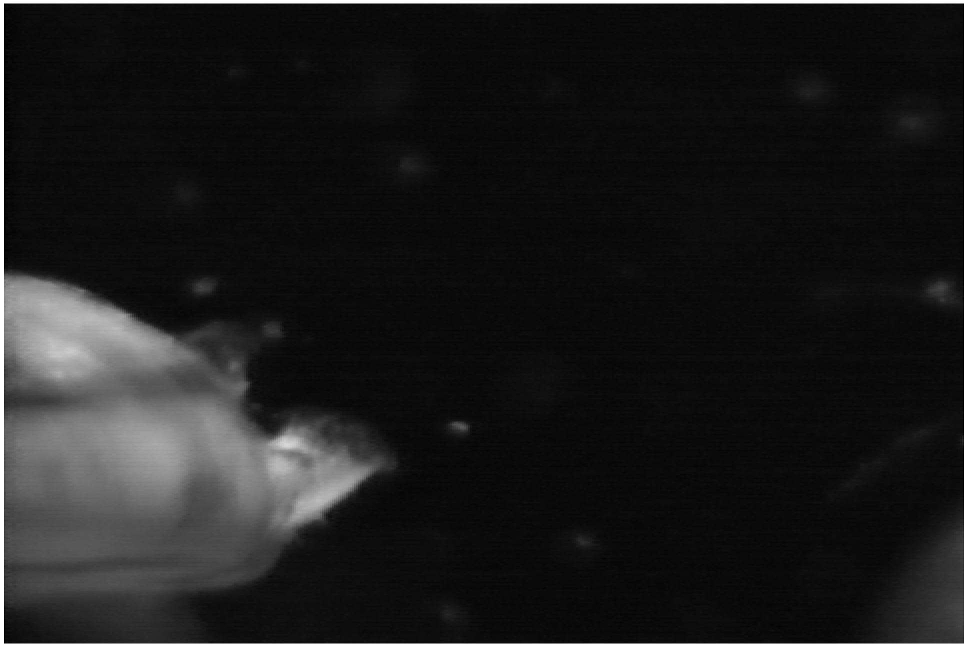


Note rejection of individual colony
as it enters siphon

Hudson Lake BD strain—note halo indicating heavy investment of mucilage



Hudson (no mussels present) BD strain — non toxic, little ingested



Enthusiastic captures and forceful rejections

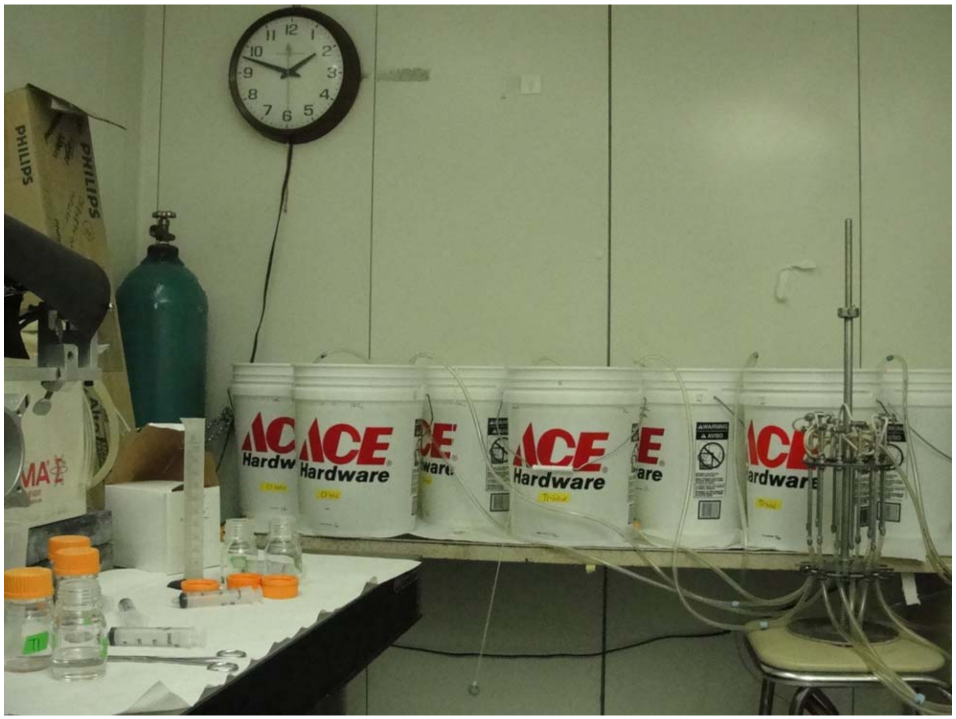
Fraction	Initial chl (µg/L)	Microcystin / chl	F_A (mL/cm^2/h)
>53µm	3.72	0.003	4.01
<53µm	0.01		-238.41
Total	3.73		1.61

*Follow-up later: Colonies broken up into small colonies by sonification—nothing ingested.

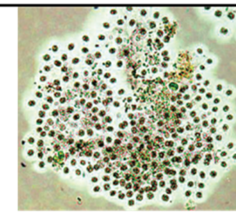
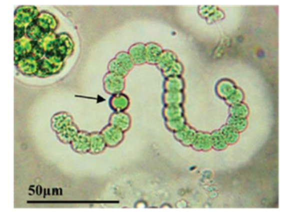
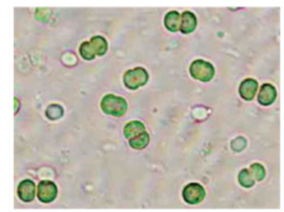
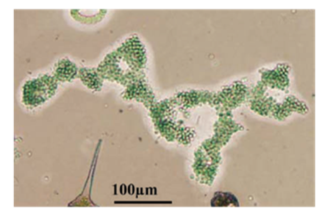
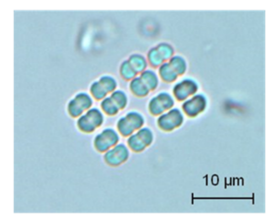
Conclusions-cultures

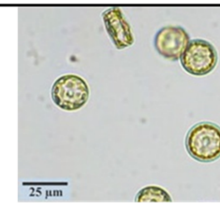
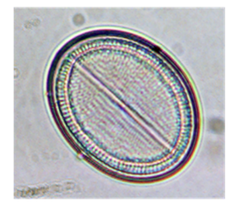
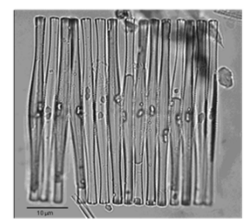
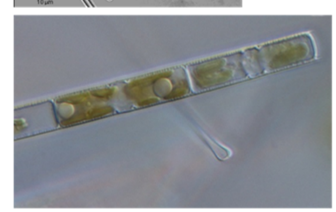
- Colony size (and mucilage) is a sufficient condition for rejection.
- *Microcystis* from invaded and not invaded lakes elicited rejection response.
- There is a toxicity response (not necessarily microcystin) in mussels that makes the rejection response more sensitive
- There does not appear to be a clear connection between microcystin concentration and probability of rejection—both for irritating and non-irritating cultures

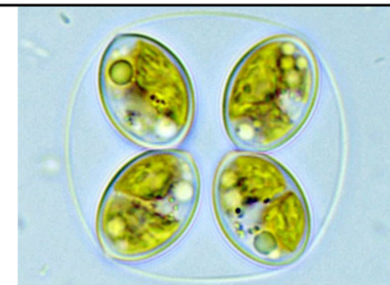
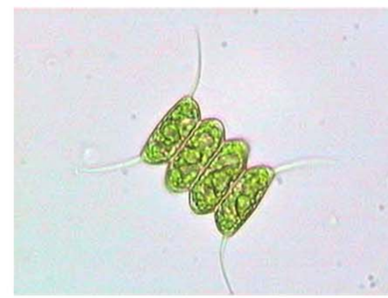
What about other algae?
Preferences & Impacts from detailed phytoplankton counting*

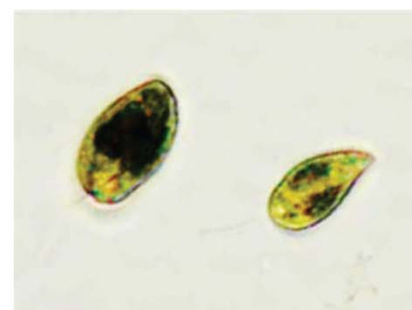


*Tang et al. (2014)—1 year counting results of 5 feeding experiments May-December with Saginaw Bay water

Blue greens	Colony or cell size (µm)		Grazing pref.	Environ. change	
	Range	Mean			
Aphanocapsa sp.	14-187	65	-	↑	
Anabaena sp.	30-174	95	++		
Chroococcus sp.	8-163	57	-		
Microcystis sp.	20-460	120	--	↑	
Merismopedia glauca	6-77	43	+		

Diatoms	Colony or cell size (µm) Range	Mean	Grazing pref.	Environ. change	
Cyclotella sp.	4-15	7	-	↑	
Cyclotella comta	15-48	32			
Cocconeis placentula	16-30	24	+		
Fragilaria crotonensis	4-1000	200	++	↓	
Aulacoseira italica	24-1380	348	+		

Greens	Colony or cell size (µm)		Grazing pref.	Environ. change	
	Range	Mean			
Oocystis sp.	8-90	28	**-**		
Scenedesmus sp.	4.3-82	15	**+-**		

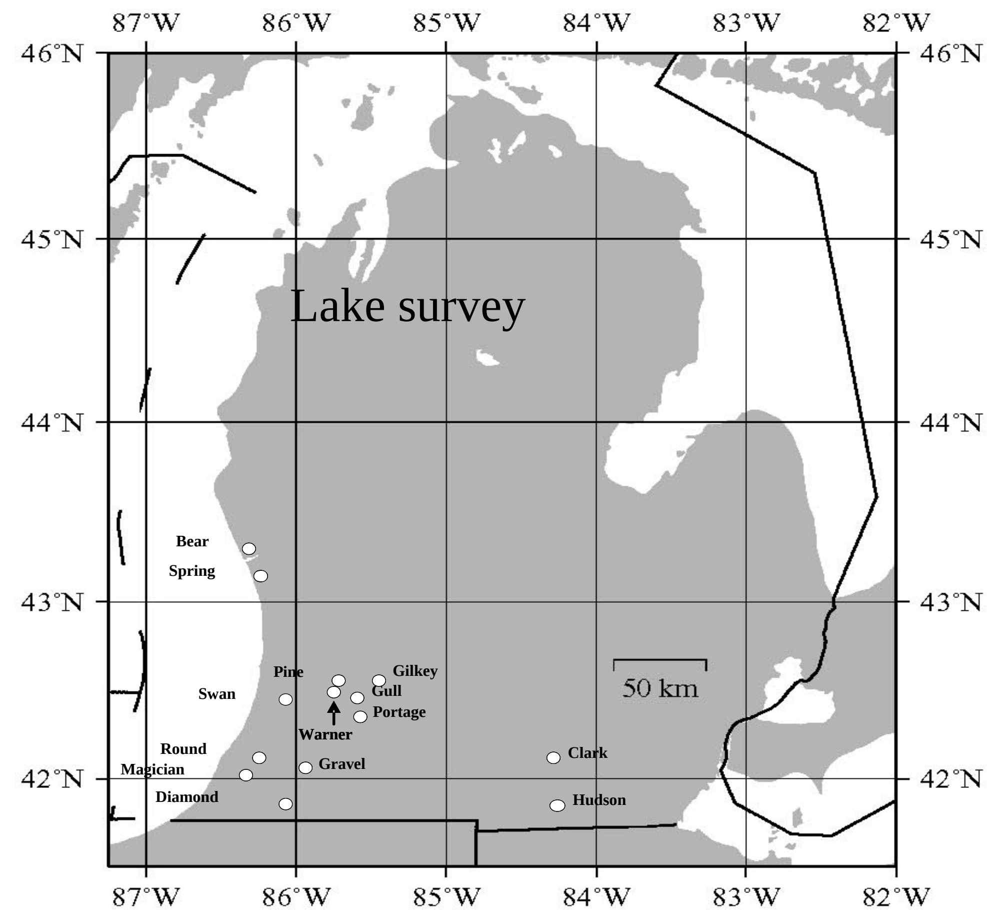
Flagellates	Colony or cell size (μm)		Grazing pref.	Environ. change	
	Range	Mean			
Dinobryon divergens	40-174	96	+	↓	
Peridinium sp.	15-25	20	+	↓	
Rhodomonas minuta	6.1-9.2	7.9	+		

Conclusions

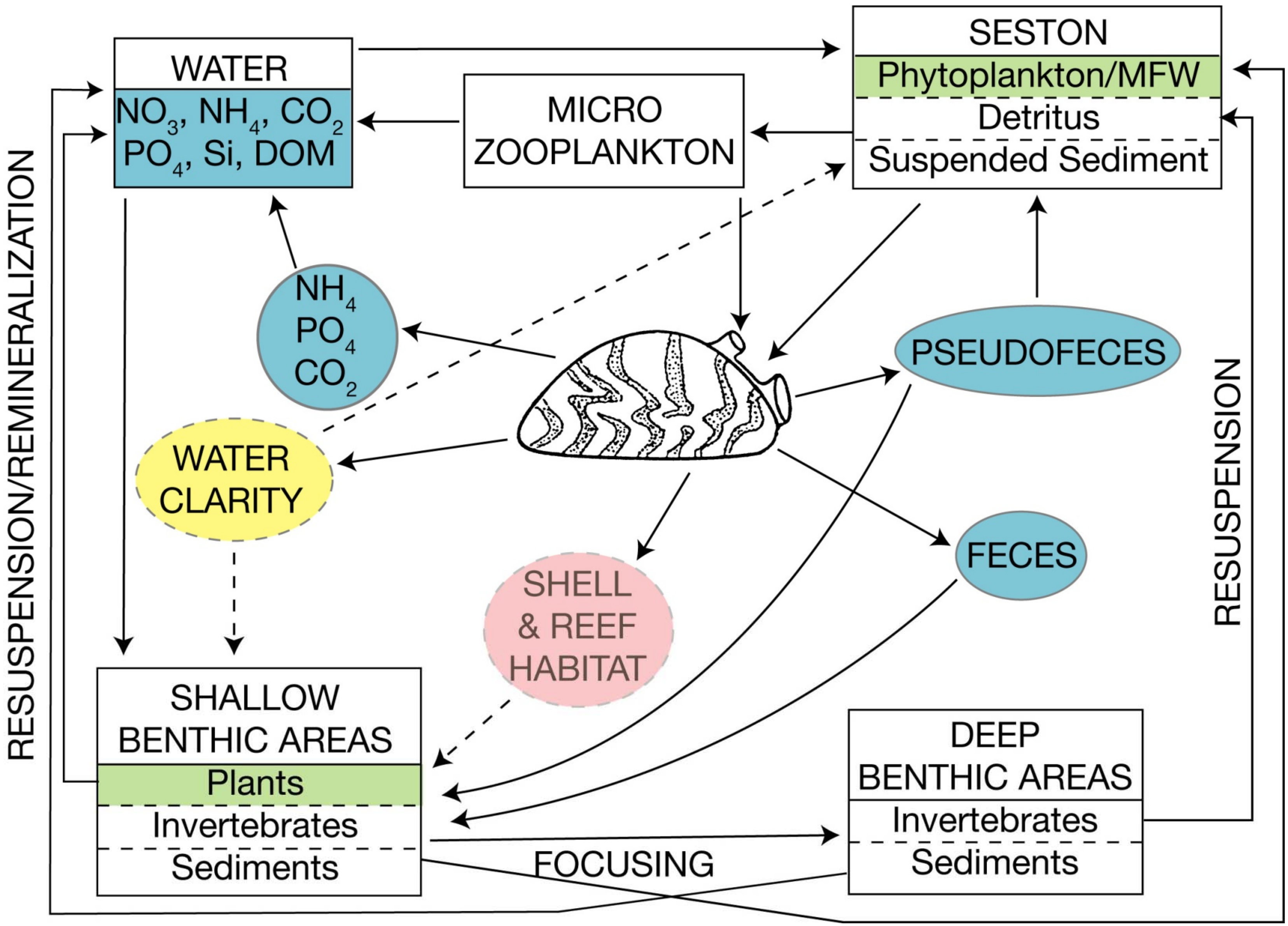
- Although Lake Erie is a high TP Lake mussels will not ingest Microcystis there
- If mussels are abundant enough relative to algal growth rate they will likely contribute to *Microcystis* dominance
- Imagine if they ate *Microcystis*—it would disappear fast because it grows slowly

Gull Lake Story—Investigate why

Microcystis increased in low TP lakes (<25 μg L^{-1}), but not in high TP lakes (>25 μg L^{-1}) invaded by zebra mussels (Raikow et al. 2004)

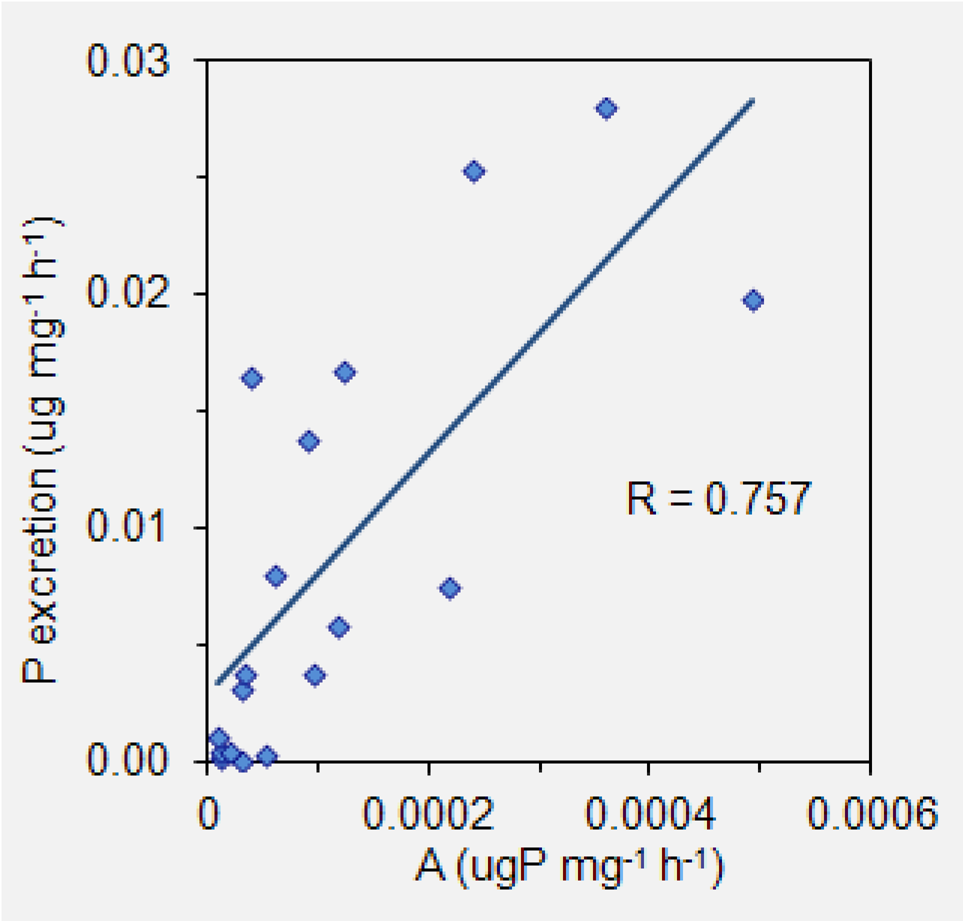


What zebra & quagga mussels do

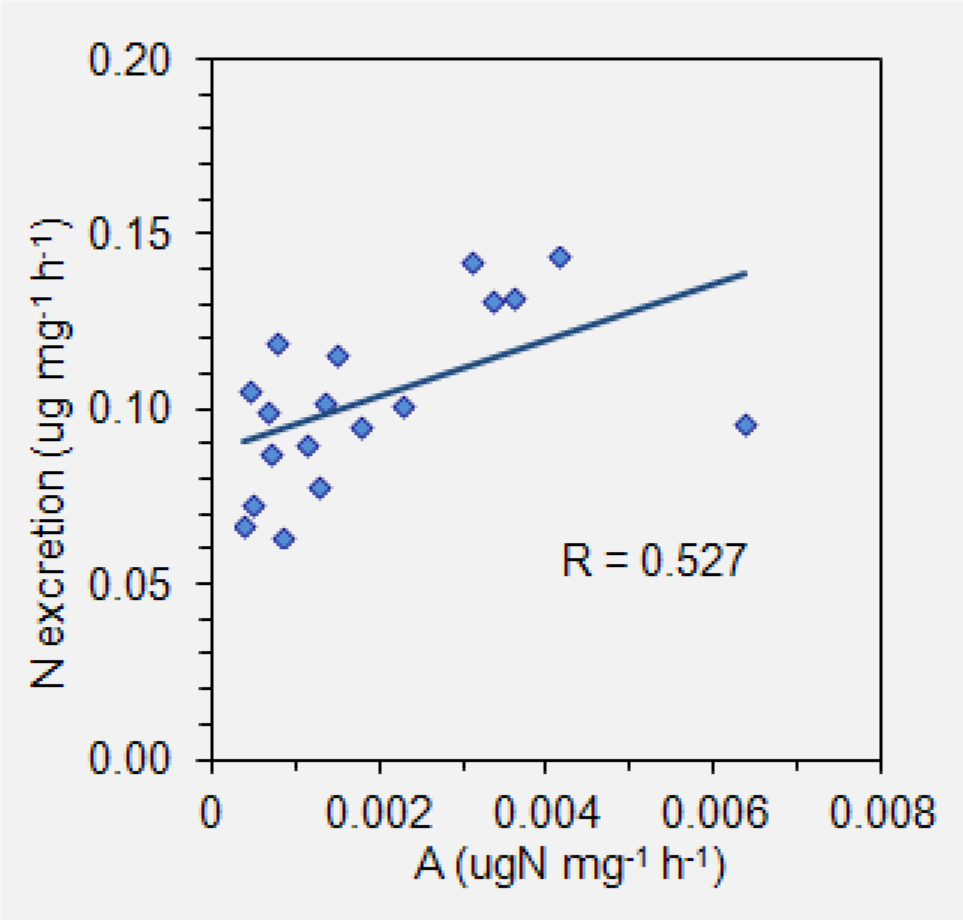


Study “sites” on Gull Lake—Enclosures with different nutrient and mussel concentrations

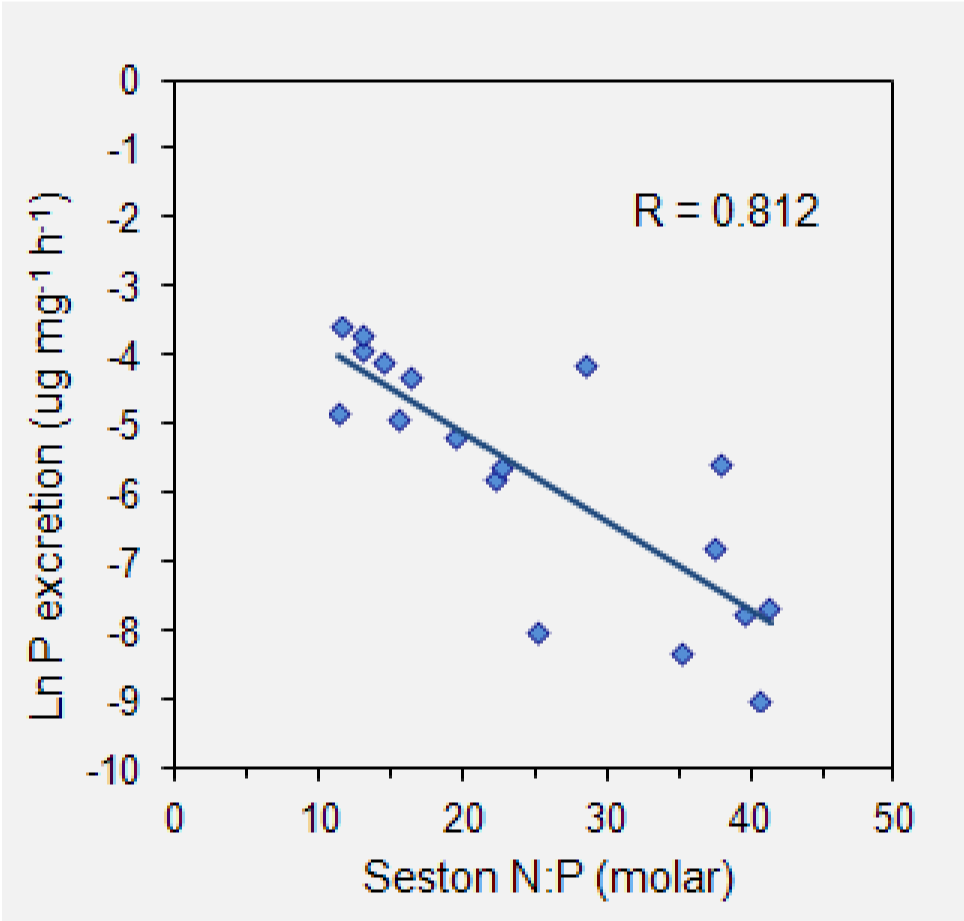
P excretion increased rapidly with (potential) P ingestion and no excretion when no ingestion



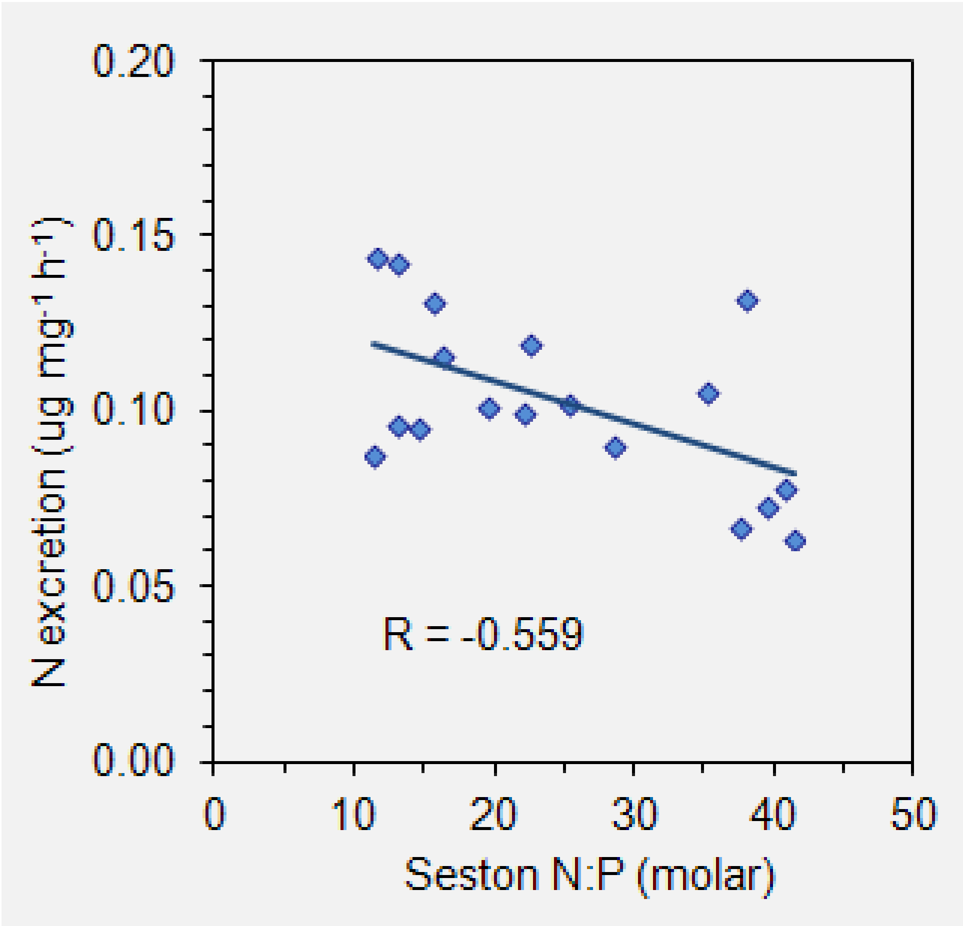
NH_4 excretion increased modestly with (potential) N ingestion and note high intercept



P excretion decreased rapidly with seston N:P ratio



NH_4 excretion decreased slowly with seston N:P ratio



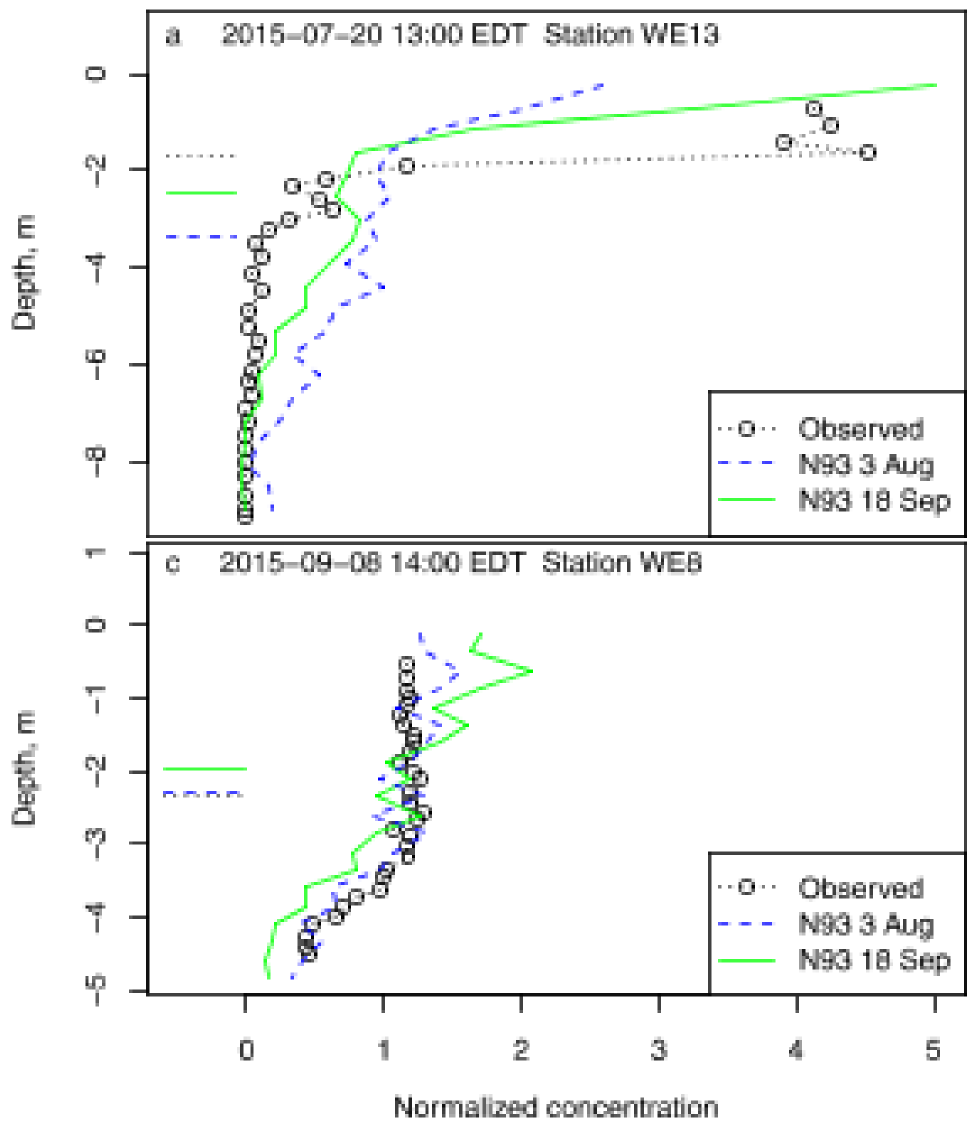
Implications

- P excretion will be low in low nutrient situations or when feeding rate is low
- In oligotrophic conditions mussels will further limit P availability
- In summer P excretion could be shut down—leading to high N:P ratio which actually favors Microcystis relative to N fixers
- In eutrophic situations were mussels are feeding they will decrease N:P ratio

Some things to consider

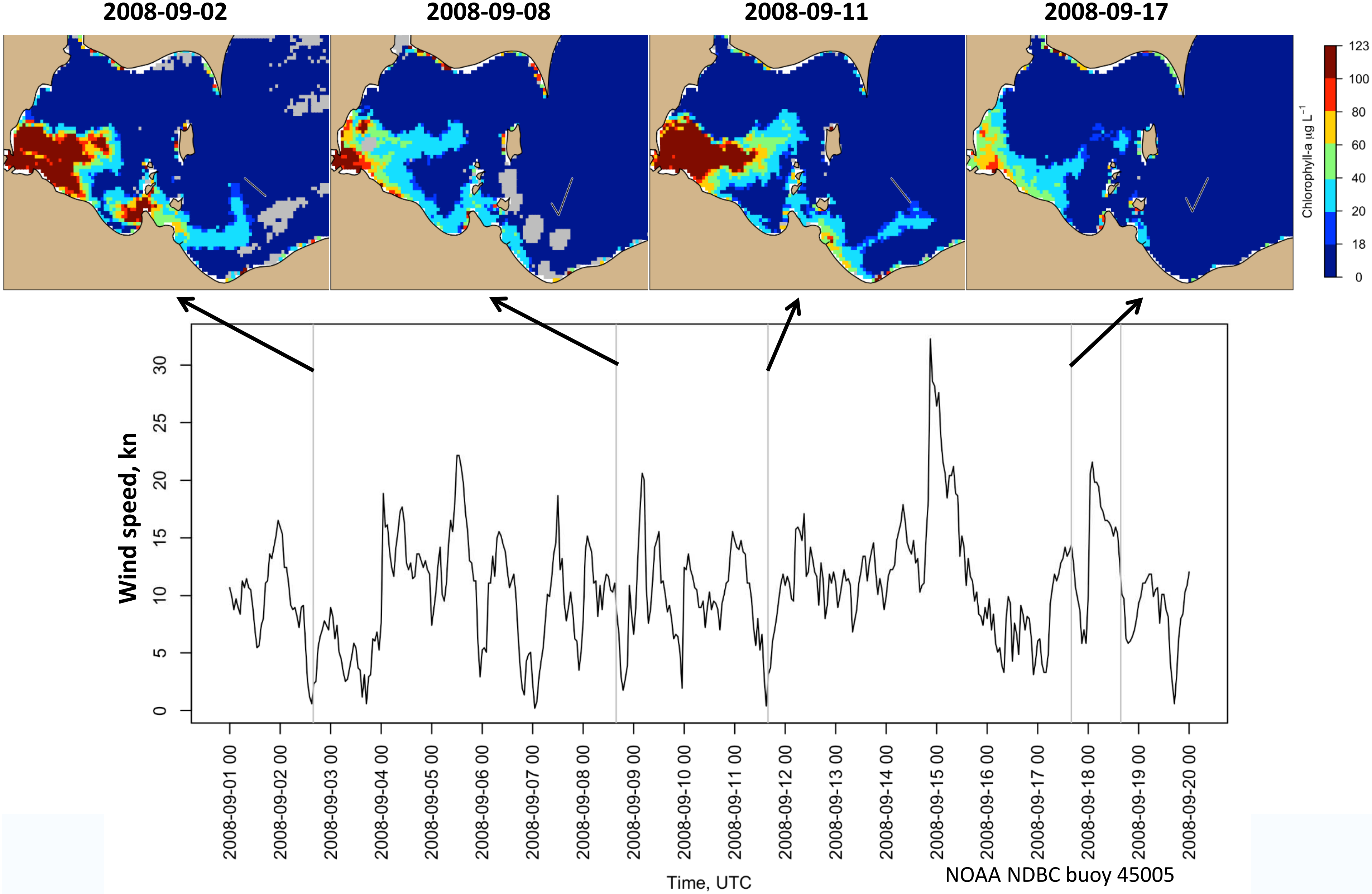
- When there are a lot of mussels under conditions of oligotrophic to moderately eutrophic conditions— increased toxic *Microcystis* dominance is possible (TP = 8 to ~ 50)—mussel feeding must exceed algal growth
- Temperature is important—HABs like hot conditions, mussels don't like temperatures > 28°C

Do mussels have contact with Microcystis and other algae during summer?

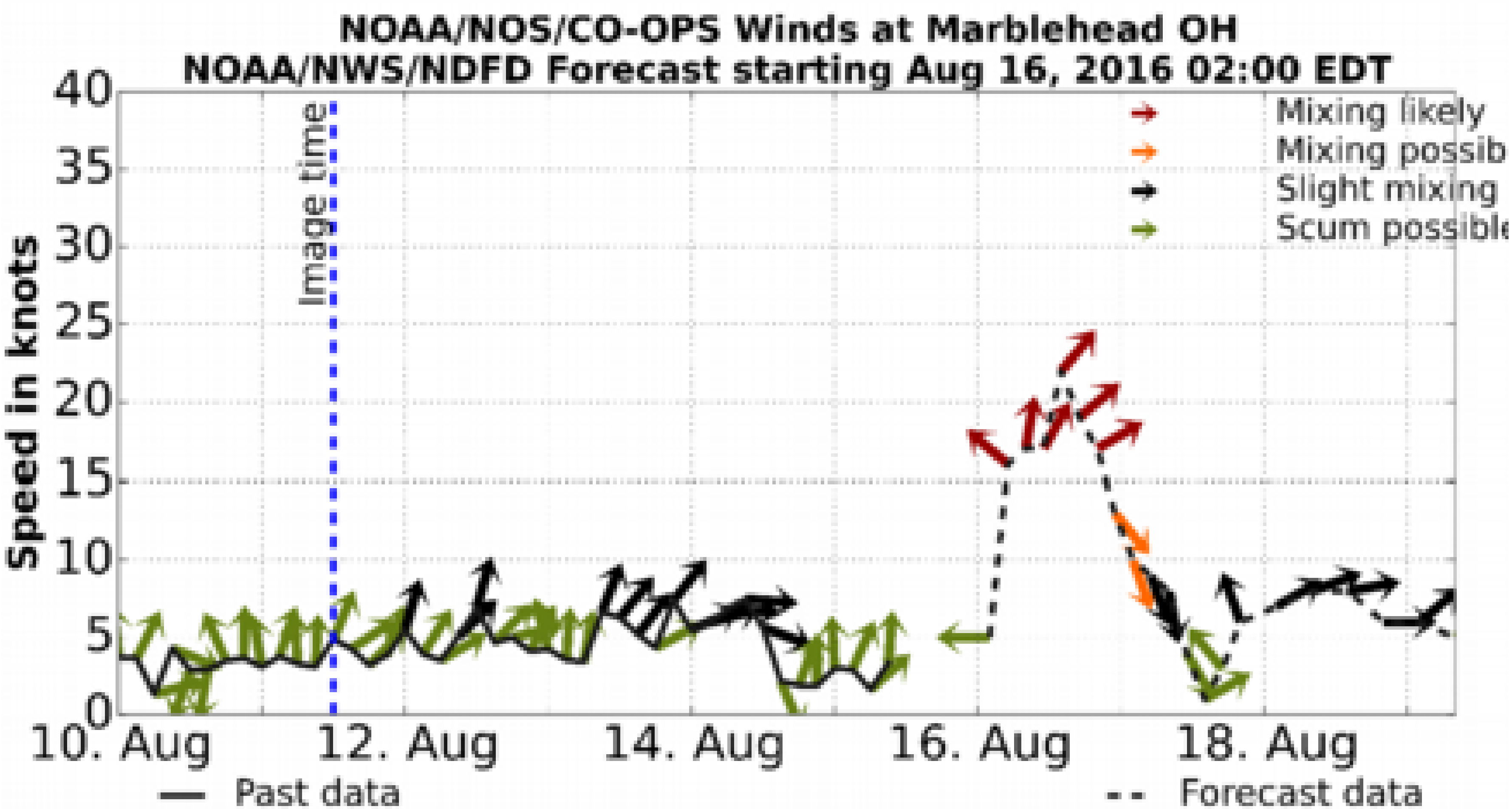


MERIS satellite surface chlorophyll

Wynne et al. 2010. Limnol. Oceanogr. 55(5), 2025-36



NOAA NDBC buoy 45005



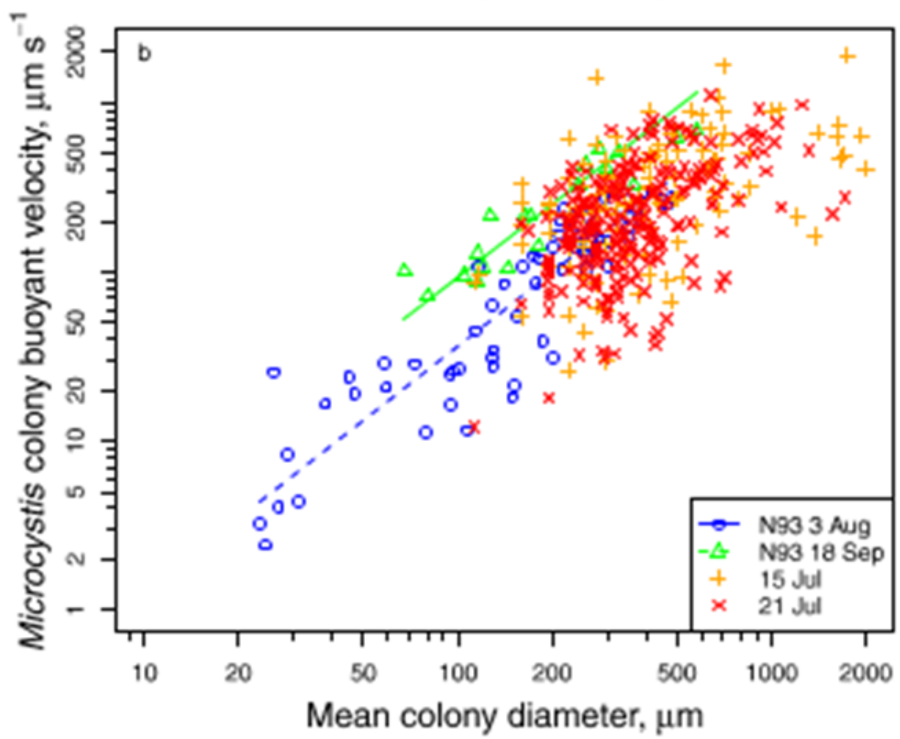
Wind speed and direction from Marblehead, OH. Blooms mix through the water column at wind speeds greater than 15 knots (or 7.7 m/s).

Factors affecting buoyancy

Factors:

- Strain—gas vacuole density
- Colony size
- Physiological health—nutrient concentration
- Time of day—carbohydrate production

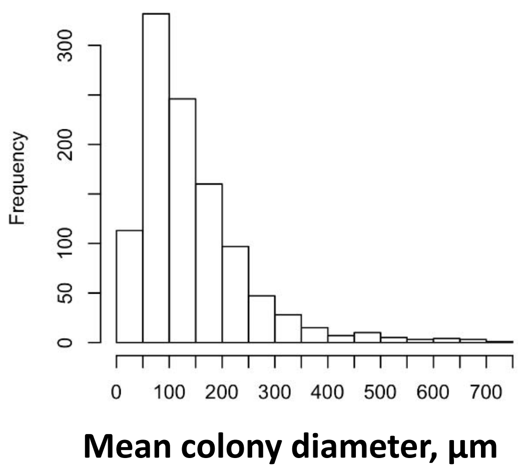
Buoyancy vs. size:



Rowe M.D., Anderson E.J., Wynne T.T., Stumpf R.P., Fanslow D.L., Kijanka K., Vanderploeg H.A., Strickler J.R. & Davis T.W. (2016) *Journal of Geophysical Research-Oceans,* **121,** 5296-5314.

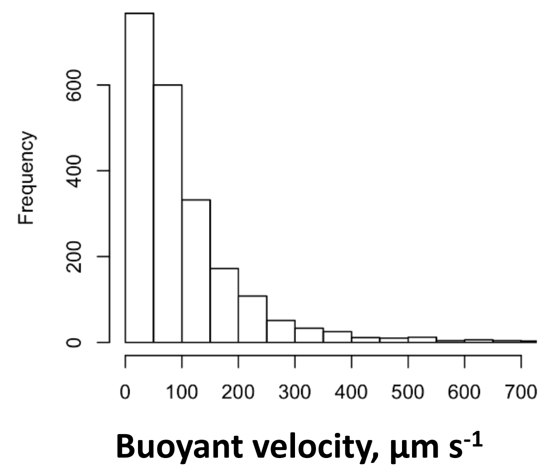
Estimation of the *Microcystis* colony buoyant velocity

Microcystis colony size distribution measured by FlowCam,
Lake Erie, August 4, 2014

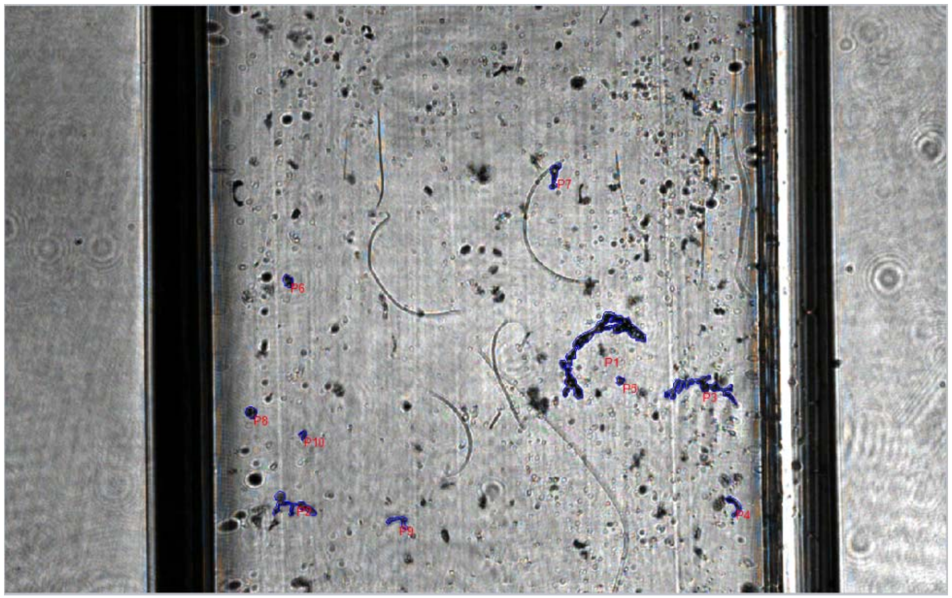


Empirical relationship between colony diameter and buoyant velocity

Nakamura, N. et al. 1993. Water Res., 27(6): 979-983.



Measurement of buoyant velocity using *Microcystis* from Lake Erie using video analysis



View of cuvette with *Microcystis* colonies (that float) and *Aulacoseiria* (that sink) August 16, 2016

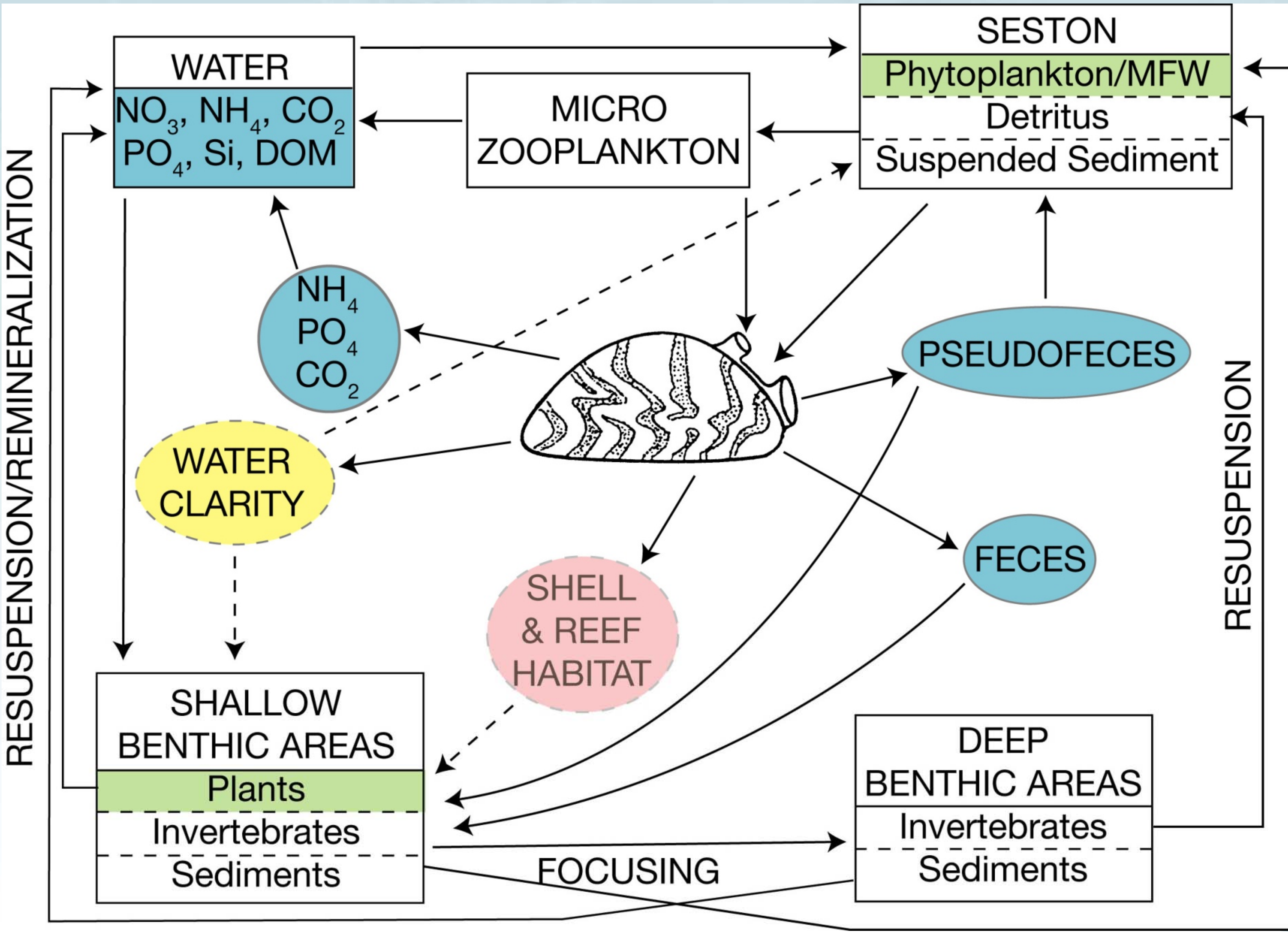
<u>Preliminary results:</u>

- Colonies from Lake Erie are very buoyant
- Colonies buoyant in early morning
- Colonies exposed to (high) surface irradiation sink during afternoon
- Colonies exposed to moderate light (12% surface) remain buoyant

Possible Implications

- Under calm conditions healthy *Microcystis* will float up during late evening and early morning hours and not be available to mussels on bottom, but big diatoms will be there for mussels
- During afternoon big colonies at surface may sink
- Under windy conditions all phytoplankton will be available to mussels.
- Regardless of conditions mussels are promoting Microcystis

Questions



WATER
NO_3, NH_4, CO_2
PO_4, Si, DOM
MICRO
ZOOPLANKTON
SESTON
Phytoplankton/MFW
Detritus
Suspended Sediment
NH_4
PO_4
CO_2
WATER
CLARITY
PSEUDOFECES
FECES
SHELL
& REEF
HABITAT
SHALLOW
BENTHIC AREAS
Plants
Invertebrates
Sediments
DEEP
BENTHIC AREAS
Invertebrates
Sediments
FOCUSING
RESUSPENSION/REMINERALIZATION
RESUSPENSION