Invasive Species Process Studies

—the foundation of ecosystem forecasting in the new world

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As noted by earlier speakers, we are living in a new Great Lakes world, one dominated by dreissenid mussels and other invasive species. We have not seen anything like it before. It is not possible to develop scenario or forecast models without process studies on these invaders to define their roles in the ecosystem.

Why We Do This

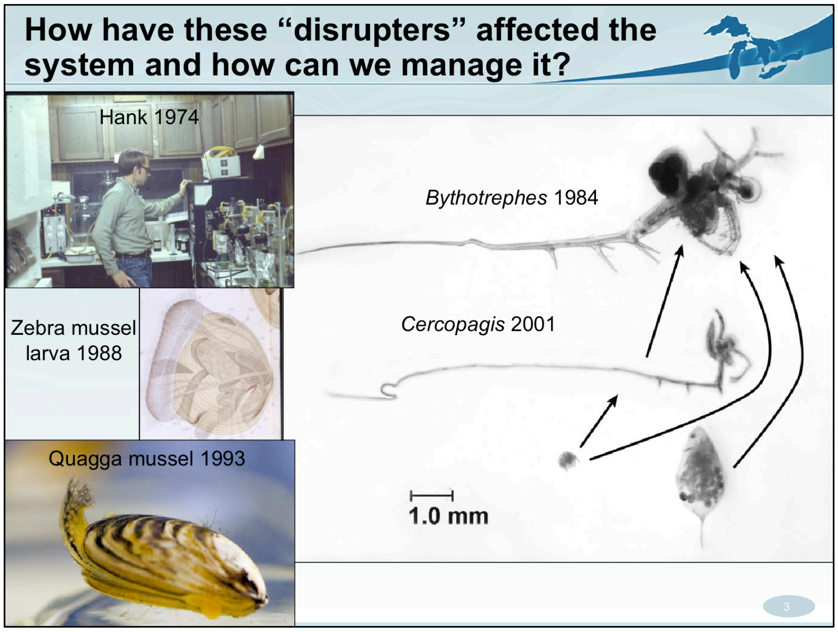
- Process research to understand the functioning of and changes in the Great Lakes ecosystem
- Work on most important and exciting *mandated* questions relevant to the Great Lakes
- Develop new paradigms, methods, and models as necessary

Process research: This provides the connection between observation of state variable and models.

Mandates: Congressional acts and presidential executive orders specify GLERL do research on ecosystem effects of invasive species. These mandates can be found in the appendix of the GLERL Science Strategy document.

- The Great Lakes citizens recognize this as a major problem, if not the most important issue in the Great Lakes.
- Invasive species are recognized as an important issue in recent NOAA strategy documents.

Paradigms, methods, models: Our understanding of the Great Lakes and other aquatic systems is incomplete. The invaders occupy new niches and have taken the system to states far from past equilibria, which reveal weaknesses in our understanding. New methods are typically required for such studies, and new models have to be developed.



The actors in the drama: I arrived at the opening of GLERL and was asked to start up the most exciting research program as possible on the ecology of the Great Lakes. I chose to work on developing models of food web interactions of zooplankton, particularly copepods, the most understudied group of zooplankton in freshwater, but the most important group in the Great Lakes and oceans. Our research on quantifying food web interactions and on feeding mechanisms prepared me and my team for doing research to understand effects of invasive species and for modeling their impacts. A major portion of our food-web research is devoted to understanding invasive species and their connection with the total ecosystem. Our team has worked on all major invertebrate food-web disrupters. The dates on the pictures show time of entry of the invader into the system. (My arrival did not excite as much interest as the other invaders.)

Use-inspired Fundamental Food-web Products/Accomplishments

- Developed modeling frameworks necessary to predict interactions among food web components
- Determined role of keystone indigenous and non-indigenous species on ecosystem function

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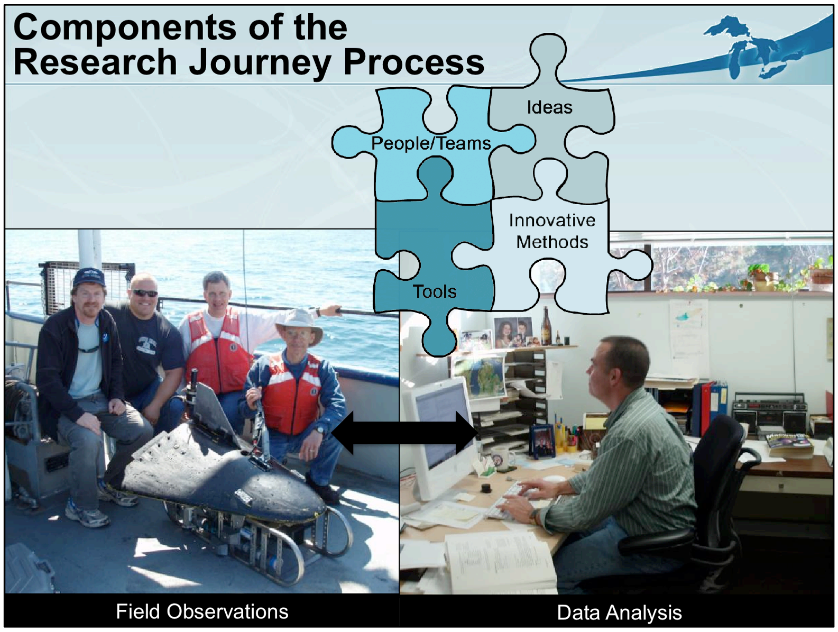
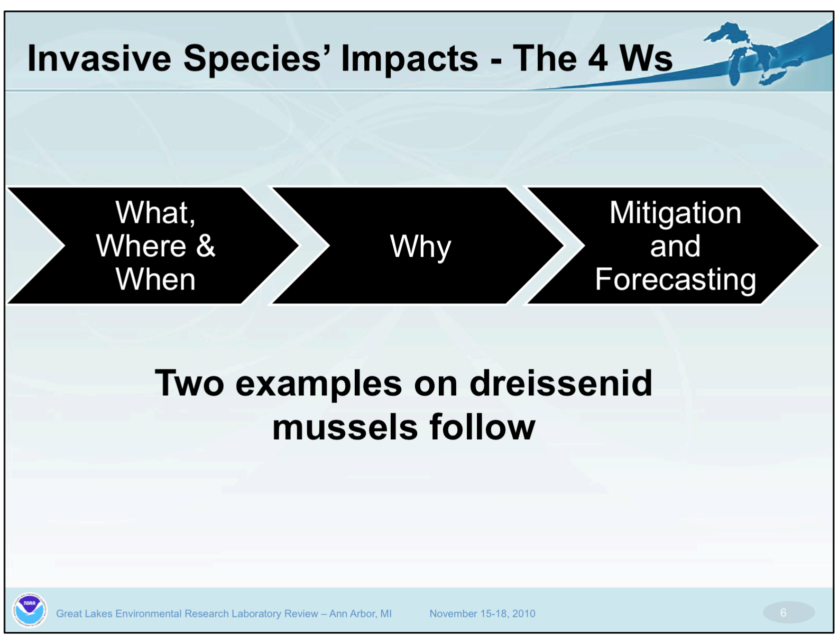
1. Developed quantitative frameworks: predict food selection, feeding of predators in mixtures of prey in nature.
2. Determined sensory modalities and developed physical model of processes that copepods used to detect and capture prey (necessary for framework development).
3. Developed in situ method: determining predation rate of predators in nature, applied to *Mysis* and *Bythotrephes*
4. Parameterized frameworks for a variety of indigenous and non-indigenous Great Lakes species.
5. First to develop methods for culturing *Dreissena* larvae in the lab using freshwater algae and establishing link between algal food quality (eutrophy) and larval survival.
6. Established link between *Dreissena* and return of HABs to the Great Lakes.
7. Developed multifaceted approach and new experimental designs to describe spatio-temporal coupling among food-web components.
8. Established link between loss of spring phytoplankton bloom and *Dreissena*.
9. Discovered likely cause of immediate loss of some cladoceran species after the invasion of *Bythotrephes*.



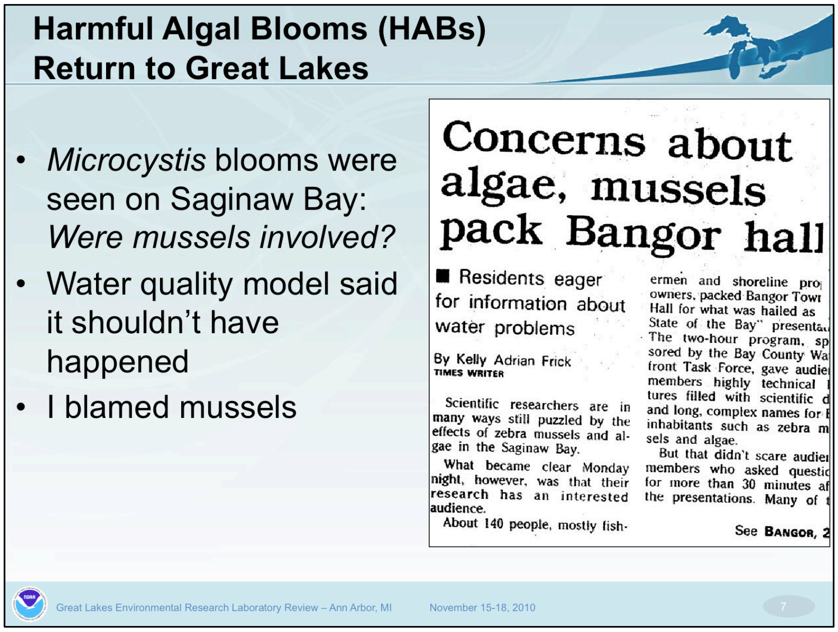
• The ideas come from observations in the field and experience in doing basic food web research.
• This sort of research is a team sport.
• To answer these fundamental questions requires innovative methods as well as standard cutting-edge tools.

Plankton Survey System (PSS) field and data analysis team. The PSS has a CTD, PAR sensor, fluorometer, and laser optical plankton counter. It is used with fishery acoustics to map out fine scale (spatial and temporal) distribution of physical variables, plankton, and fishes. The team puts the instrument package together, evaluates its function, and uses it on the Great Lakes. We then process the very large data stream that is collected.

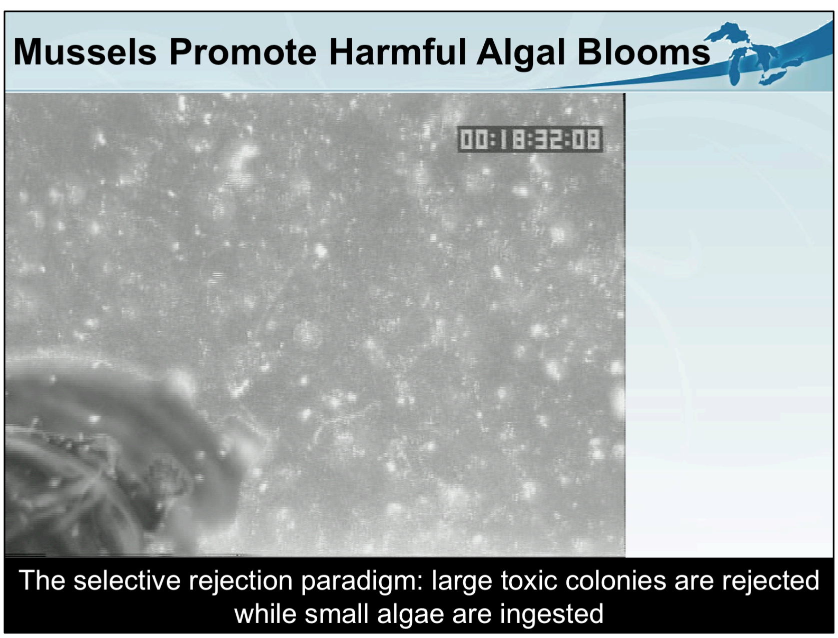


*Also see posters on *Bythotrephes* and whole ecosystem spatial interactions.

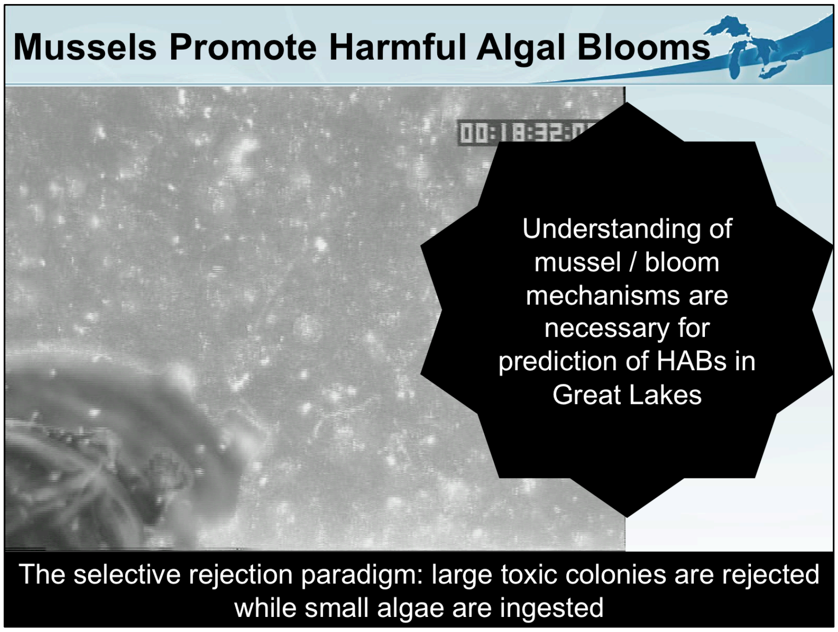
Why does this happen boils down to:
What are they doing?—Lab and in situ studies
Where are they and **when**?—Field studies
Which leads to: A forecast and mitigation strategy



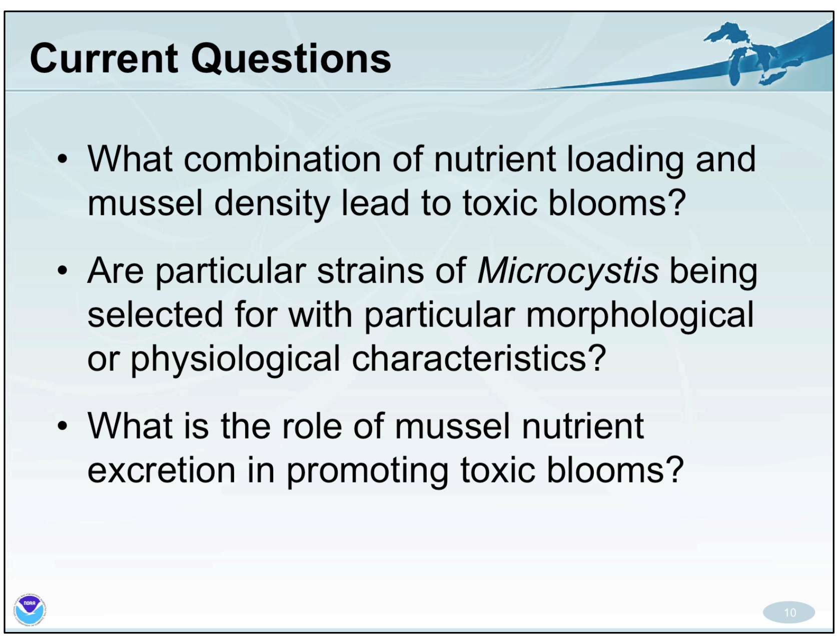
Bay City Times, Tuesday March 19, 1996
Large blooms of the toxic colonial cyanobacterium, *Microcystis,* were seen on Saginaw Bay. Phosphorus loads had decreased to levels where nuisance blooms of blue-green algae should not have occurred according to standard (without mussels) water quality models.



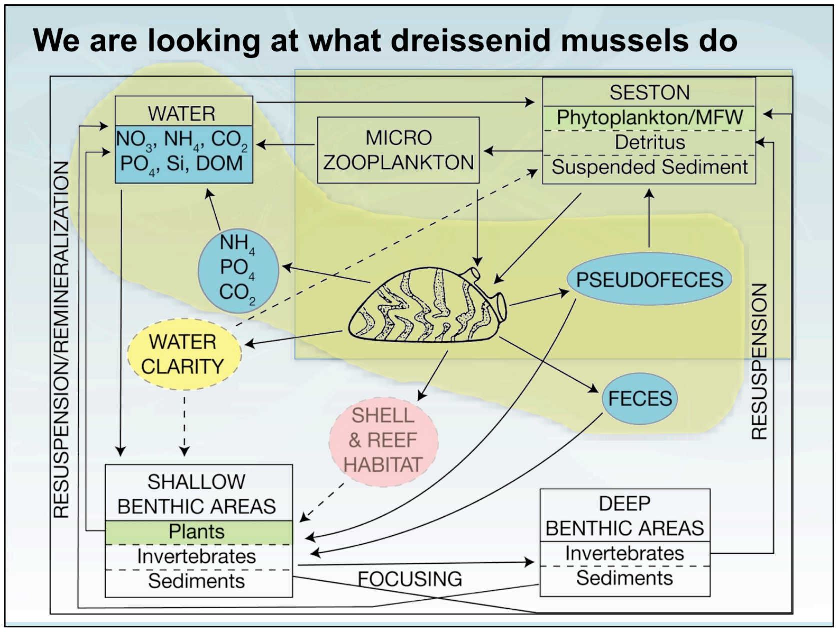
Mussels and Lake Erie *Microcystis* bloom of September 1995
Feeding experiment in beakers with natural seston from Saginaw Bay and Lake Erie plus direct observations such as these allowed Vanderploeg et al. (2001) to deduce that mussels were promoting blooms through selective rejection of *Microcystis* in pseudofeces. The *Microcystis* in the loosely consolidated pseudofeces is uninjured, readily re-suspended and available for growth.



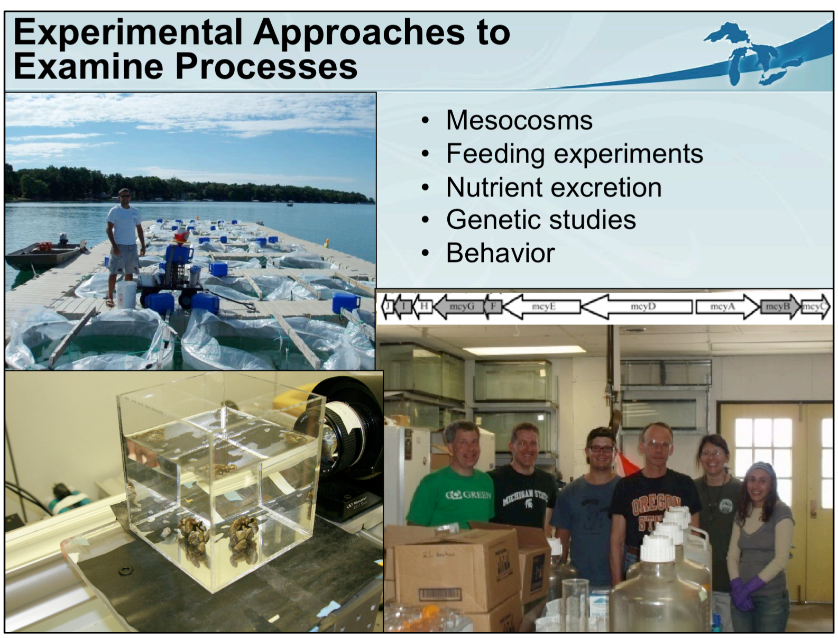
Mussels and Lake Erie *Microcystis* bloom of September 1995
These experiments also looked at a few laboratory strains of *Microcystis*. Only the strain isolated from Lake Erie elicited the response, although these other strains were toxic to zooplankton.



- What combination of nutrient loading and mussel density are likely to lead to toxic blooms in lakes?
- Are particular strains (intra-specific variation!) of *Microcystis* being selected for with particular morphological or physiological (secondary compound or toxins) characteristics?
- What is the role of mussel nutrient excretion in promoting toxic blooms?



The diagram shows the way in which dreissenid mussels affect the environment. Not only do they affect the environment by consuming algae and affecting the nutrient cycling but, they also affect the physical environment (ecosystem engineering) by increasing water clarity (removing particles) and changing the benthic substrate through creation of shell and reef habitat. We are doing process studies on the selective feeding process and nutrient excretion as indicated by the shaded areas on the figure.



• Mesocosms—experimental manipulation of mussel density and P concentration allowed us to simultaneously examine the role of mussel filtering and nutrient excretion across a trophic gradient (ECOHAB project in cooperation with Michigan State University investigators—Orlando Sarnelle and Steve Hamilton). Pictured upper left is the floating dock on Gull Lake with the 2-m diameter × 11-m deep mesocosms in which mussels and nutrients were manipulated.
• Feeding and nutrient experiments are done with natural seston from the Great Lakes, cultured algae, and mesocosms. In contrast to most studies, nutrient excretion is done simultaneously with the feeding experiments to quantify the factors (e.g., seston quality as food, seston nutrient ratios, mussel feeding rate) affecting nutrient excretion (N and P). N and P ratios are thought to affect probability of *Microcystis* and other cyanobacteria dominance.
• Genetic studies allow us to determine what strains are selected for and whether the mussels stimulate toxic gene expression—See poster by Juli Dyble Bressie. The genus *Microcystis* consists of a single species that has diverse morphology and very diverse variants of the toxin gene and secondary compounds. Our initial study demonstrated that mussels rejected only certain strains of *Microcystis* and the rejection was not necessarily related to quantity of their toxin, microcystin. Genetic tools are the only way to examine the strain selection issue in natural systems, where there may exist simultaneously more than one strain.
• Behavior—direct observations of mussels are necessary to link changes observed in beaker experiments with mechanisms. If *Microcystis* was not eaten, was this because it was never captured or was it rejected after capture?

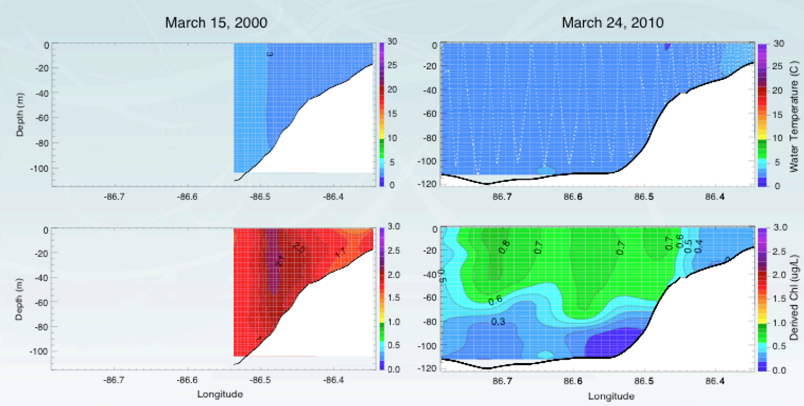
Are mussels responsible for disappearance of spring phytoplankton bloom?

- Everyone blames the mussels for everything, but there is no proof
- Others argue that a decrease in P loading over time explains the change
- Everyone knows its too cold for anything important to happen in winter and spring, including mussel filtering.

Paradigm destruction/construction. These are the issues we had to deal with:

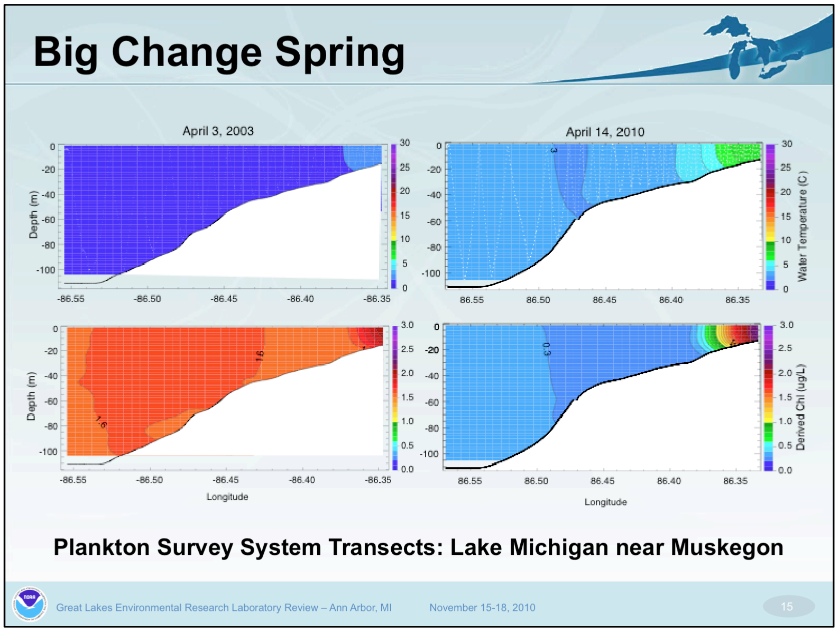
- Everyone blames the mussels for everything, but there is no proof
- Others argue that a decrease in P loading over time explains the change
- Everyone knows its too cold for anything important to happen in winter and spring, including mussel filtering.

Big Change Winter

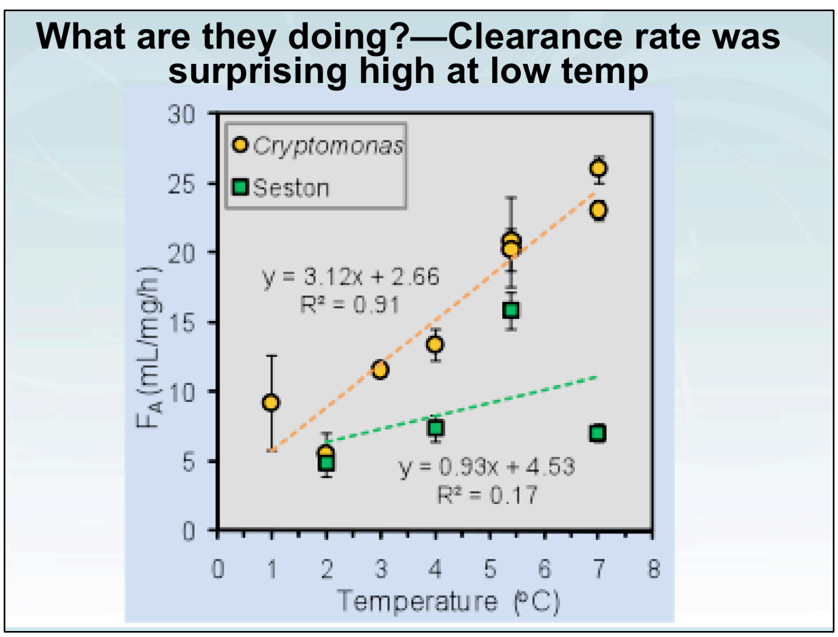


Plankton Survey System Transects: Lake Michigan near Muskegon

A slice through the water column from nearshore to offshore near Muskegon Michigan as observed by the PSS. The 15-km transect on the left was made during the EEGLE (Episodic Events Great Lakes Experiment) in March 2000. The 35-km transect on the right in the same area was made in March of this year. We extended the observations out to a greater distance to see if we could identify the mussel impacted region. The sinusoidal trace shows the path of the PSS. Chlorophyll concentration was very much higher in 2000, which was about 4-5 years before the major mussel population expansion into deep water. The March 2010 transect shows a very interesting feature. Although isothermal in both 2000 and 2010, chlorophyll is much higher in surface waters than in bottom waters during 2010. The weather in 2010 was uncharacteristically calm, allowing decoupling of surface from bottom waters. This may have allowed algal growth in surface waters and mussel cropping of algae in deep waters.



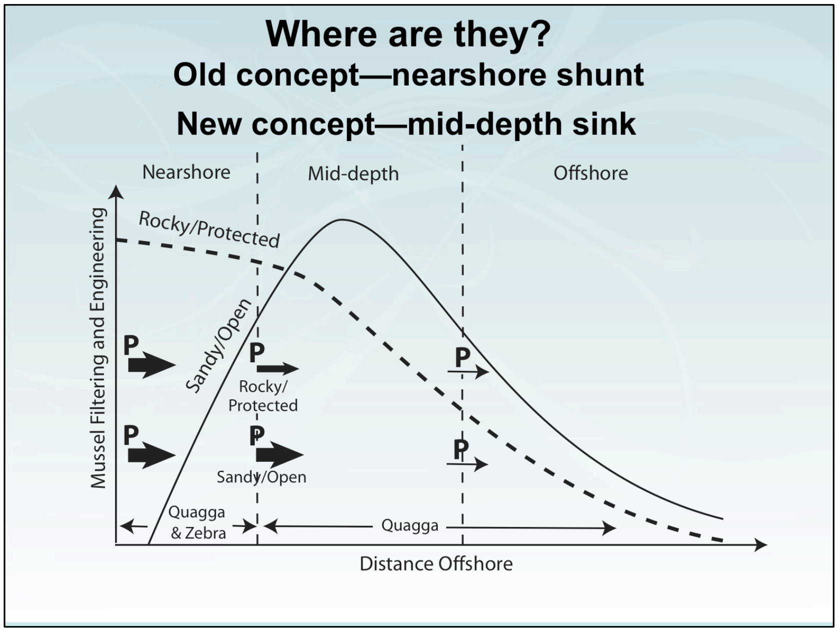
Thermal structure and chlorophyll concentration in April 2000 and April 2010 along a 20-km transect near Muskegon, Michigan. The thermal bar is more developed in 2010. Note the extremely low chlorophyll concentration in 2010, except within the nearshore zone within the thermal bar.



- We looked at clearance rates of mussels at low temperatures in our cinematography lab, where we can control temperature over broad range, which other investigators were not able to do. We offered them two kinds of food:
- *Cryptomonas* is ideal food for dreissenids.
- Seston may or may not be good food.

Paradigm shift:

1. Zebra mussels filtered water at 10 × rate observed in only other published study at low temperature
2. Quagga mussels filtered water at 10 × rate observed in Lake Erie during summer
3. Food quality is dominant factor driving mussel clearance rate
4. Mussel clearance in many depth zones was higher than algal growth rates.



The figure demonstrates the role of mussels in affecting P (and C) flow in the environment. Until now the scenario primarily considered was the nearshore shunt, whereby mussels (and the community associated with them) primarily located in shallow water attached to rocky substrate intercepted P and prevented its flow from inshore to offshore. The increased light associated with the mussels allow luxuriant growth of nuisance algae. Our work has shown that mussels on the sandy shores of lakes are excluded from the nearshore region, but reach high concentration in the mid-depth zone, where their impact is felt and "downstream" in deep water. Both the nearshore shunt and mid-depth sink can operate on different shorelines of the same lake; for example, Lake Michigan.

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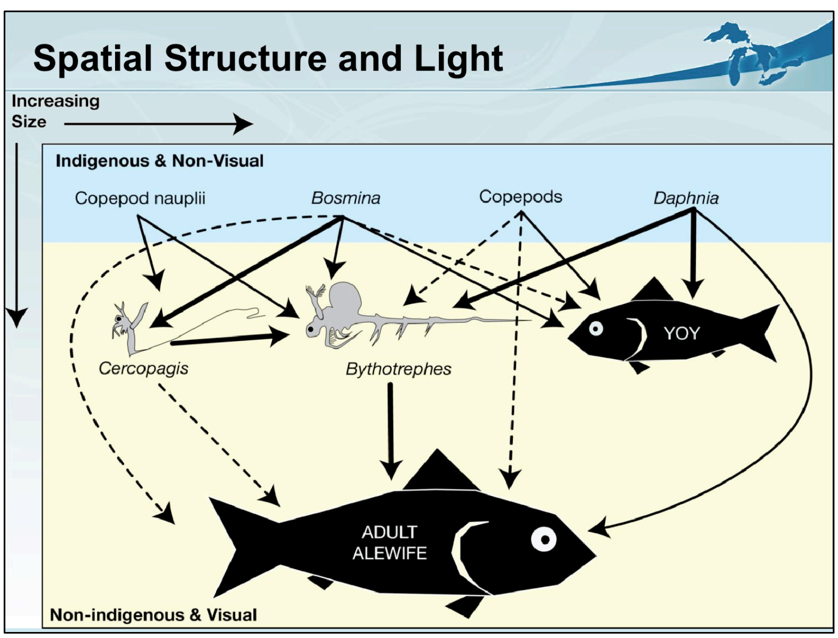
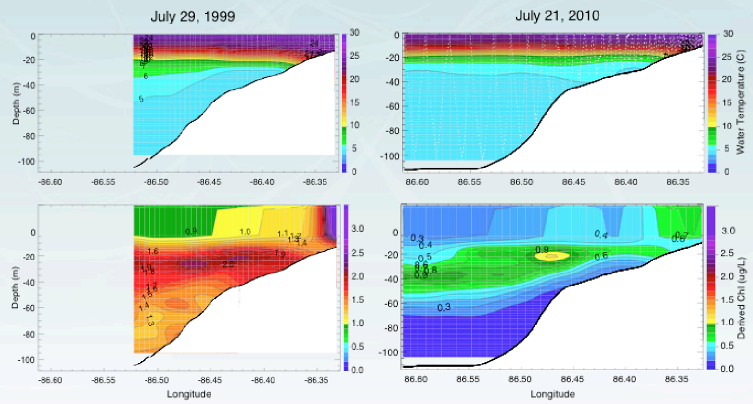


The current Great Lakes epilimnetic (and metalimnetic) food web is dominated by the visually preying non-indigenous vertebrate (alewife) and invertebrate predators (*Bythotrephes* and *Cercopagis*) that prey on the indigenous zooplankton. The thickness of the arrows are the strength of the selectivity coefficients. In the inshore zone adult alewives keep Bythotrephes under control, which relaxes predation on Cercopagis (the other predator). Increased water clarity caused by dreissenid mussel filtering has likely increased predation efficiency by all visual predators. *Bythotrephes* are extremely abundant and because of their high feeding rate have become dominant predators of zooplankton during summer through fall. The increase light in the system also allows *Bythotrephes* to forage at greater depths than before, thus potentially forcing prey to escape by vertically migrating into deeper water, where conditions are less favorable to growth. This and the low abundance of phytoplankton (described below) are putting great stress on the zooplankton community.

Big Change Summer
Where are zooplankton and fish now?



Plankton Survey System Transects: Lake Michigan near Muskegon

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Another PSS transect near Michigan. Note the lowered overall concentration of chlorophyll. What little remains is found in a greatly attenuated deep chlorophyll layer found in the upper hypolimnion as well as chlorophyll found in shallow water of the nearshore region.

Vision for future

1. Ecosystem level studies of processes underlying impacts of invaders
2. Respond to new invaders that will alter the system
3. Great Lakes Ecosystem Management Model (GLEMM)

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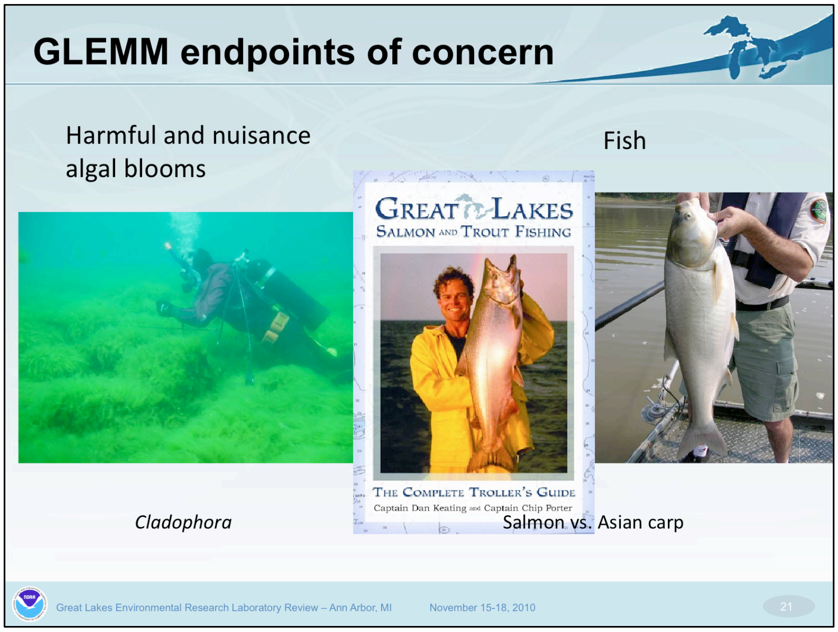
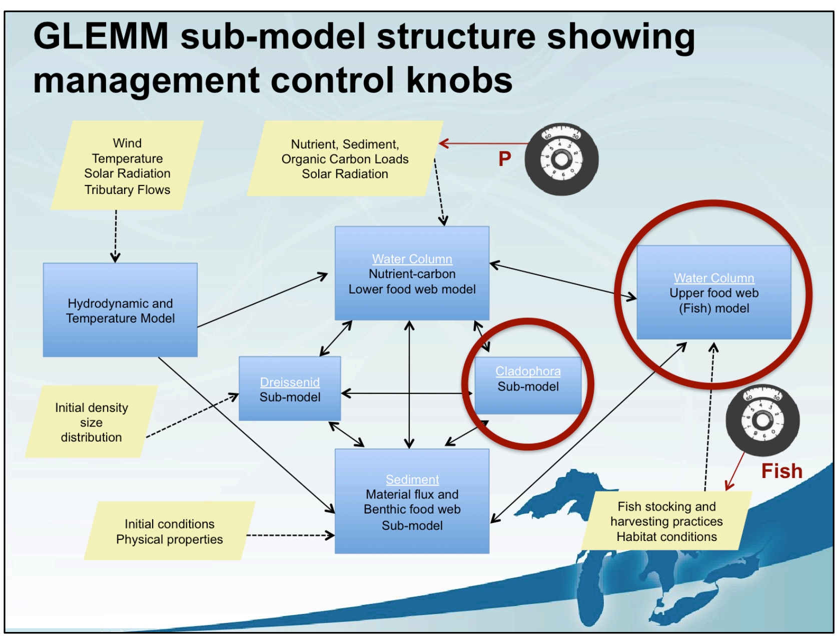
1. Continue ecosystem level study of processes underlying impacts of invaders
2. Respond to research questions that will inevitably arise as existing and new invaders alter the system (e.g. Asian carp and others species poised to enter the system)
3. Build Great Lakes Ecosystem Management Model (GLEMM) aka Adaptive Region-Scale Ecosystem Management Model—build for Lake Michigan GLRI 2011 (and 2012-2014)



How can we adaptively manage the Great Lakes to prevent nuisance blooms of Cladophora in shallow water and at the same time optimize for desired fishes? These endpoints would seem to be at odds with management practices since nutrient reduction would appear necessary for minimizing blooms but would starve the fishery.



Special features of GLEMM:

1. GLEMM is both an empirical and modeling project. For example, research on mussel feeding and nutrient excretion is necessary to complete development of the dreissenid sub-model.
2. The model treats mass balance of C and P in the system and allows examination of the fate of P as enters into the system from tributaries and flows trough the nearshore and offshore regions.
3. The model is specifically focused on evaluating the effects of P management and fishery management on the occurrence of nearshore nuisance blooms and offshore starvation of the offshore fishery as a response to the invertebrate disrupters.
4. Fish models grafted on the lower food web model will allow us to examine the generalized response of the fish community groups for feedback with the lower food web model as well as production potential of key species such as salmon and Asian carp.
5. A user-friendly interface and model will be developed so that this model will be given to managers and scientists so they can personally explore consequences of P and fish management strategies, changes in abundance and distribution of existing and new invaders, and various "climate" change scenarios.

Questions?

Trophic transfer of C and P in GLEMM

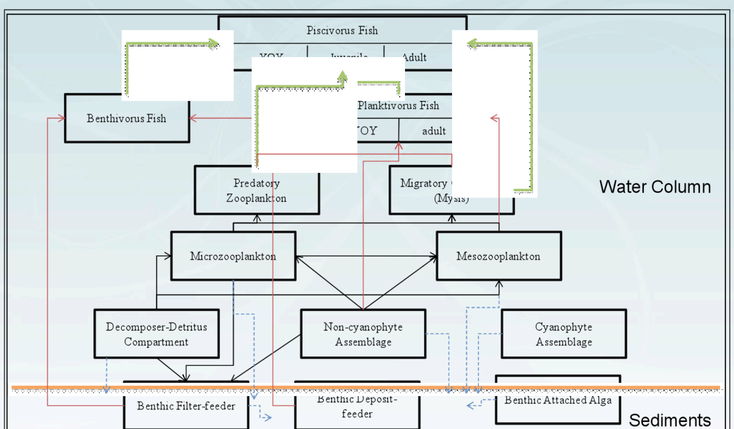


Fig.4. Trophic transfer of carbon in GLEMM.

Further details on GLEMM should questions arise. This shows the trophic transfer of C and P in the water column and its connection with fish.