This work aligns with the following NOAA Goals:

**Science: Climate Adaptation and Mitigation**
Improved scientific understanding of the changing climate system and its impacts

**Science: Healthy Oceans**
Improved understanding of ecosystems to inform resource management decisions
Sustainable fisheries and safe seafood for healthy populations and vibrant communities

**Science: Resilient Coastal Communities and Economies**
Improved coastal water quality supporting human health and coastal ecosystem services
Foundational GLERL contributions to understanding invasive mussel impacts

- Quagga mussels decimated the spring phytoplankton bloom in Lake Michigan (2010).

References:
What are the new fundamental, mission-relevant questions, directions and progress?

- What are the effects of dreissenids on the phytoplankton community—including harmful algae—during all seasons?
- What are the interactions of Dreissena and the microbial food web?
- How can we predict nutrient excretion in mussels and its impact to harmful and nuisance algal blooms?
- What is the combined impact of feeding and nutrient excretion on food webs?

Logos show institutions of major partners in recent and present studies
Non-GLERL partners include:
Hunter Carrick of Central Michigan University
Tom Johengen of CILER
Orlando Sarnelle of Michigan State
Vincent Denef of the E, E, & B department at University of Michigan
Peter Lavrentyev of The University of Akron
Huijuan Tang of South China Agricultural University
The significance of feeding results for diatoms is that it explains the loss of the large diatoms (microphytoplankton) during the spring phytoplankton bloom (Vanderploeg et al., 2010). This pattern of changes has been observed throughout the Great Lakes in a variety of papers reviewed in Tang et al. (2012). Interestingly small Cyclotella (nanophytoplankton) was fed upon at very low rate. This is in contrast to high feeding rate observed for Cryptomonas of the same size in this and other studies.

The precise microscopic phytoplankton counting that was done for the 5 feeding experiments (spring through autumn) that make up this paper took 1 year.

Reference:
Tang et al. (2014) extended the extensive literature produced by our team on Microcystis to other cyanobacteria ("blue-green algae"). Noteworthy is the preference shown for Anabaena a N-fixer, which we have not seen dominate in western Lake Erie despite nitrate falling to very low levels in late summer. So are dreissenids preventing a shift from Microcystis to Anabaena? More research is necessary. For the record our team has shown that feeding or rejection of Microcystis is strain-specific and not related to microcystin (toxin) content but must be to other secondary compounds. Strains found in Lake Erie, Saginaw Bay, and many inland lakes elicit the rejection response. Strains found in some rivers and hypereutrophic systems (e.g. Dutch Lakes) may be readily consumed. Listed below is some relevant literature on the Microcystis story as well as mussel-microzooplankton interactions in Saginaw Bay. In another study in Saginaw Bay, our team (Lavrentyev et al. 2014) showed that microzooplankton are important grazers of bacteria and Microcystis as well as serving as an important food source to quagga mussels. It is important note that working with natural algal communities is necessary because many species do not do well in culture and cyanobacteria such as Microcystis change their morphology and other characteristics in response to culture conditions.

References:
Not only are chlorophyll and phytoplankton biomass very low now but picophytoplankton (<0.2-2 μm) now dominates over nanophytoplankton (2 – 20 μm) and microphytoplankton (> 20 μm) in offshore zone.

Relevance: How can we best manage nutrient loading and fisheries in the restructured ecosystem if we don’t know how it works?

Related References
New discovery: Mussels fed on picophytoplankton (< 2μm)

Clearance rate ($F_A$) on chlorophyll in <2μm vs. > 2μm size fractions

Preliminary study, subject for future research.
We used size fractioned chlorophyll method to calculate feeding (clearance rate).
Vulnerability of bacterial community to mussel grazing as shown by changes relative abundance in final relative to initial concentrations in experimental containers (red bars) as compared with the proportion of the bacterial classes’ association with particles (blue and green bars). The 10 most abundant (sub-)phyla, which on average included 95.2% (±1.3%, 95% C.I.) of each sample’s sequences are ranked by most over- to most underrepresented after three hours of feeding relative to initial concentrations. In addition, differential representation of these phyla was determined in the field in the free-living (FL) relative to particle-associated (PA) fractions in bottom water samples taken at the 110 m and 15 m stations of GLERL LTR transect at Muskegon. Field data represents the average (error bars = standard deviation) of DNA and cDNA data from two sample times taken during the stratified period (July and September). Water used in the laboratory experiment were taken from a site between these two stations (45 m depth), 10 days after the July field samples were taken. Field data ratios were log_{10} transformed, while experimental data ratios were log_{2} transformed. * denotes statistically significant differential representation. (*) denotes statistically significant when removing outlying replicate 1.

During the experiment the bacteria with higher proportion association with particles (>3 µm size) decreased in relative abundance. Both Chloroflexi and Actinobacteria are free-living in the sense that they are smaller than < 3 µm, i.e. not stuck on particles. Actinobacteria are very small and would be expected not to be grazed by mussels. Chloroflexi, although very large for a bacterium (0.7 – 0.9 µm), was not apparently grazed, which could be related it its cell wall characteristics (Denef et al., 2016).

Collections of the bacterial community were part of our “Spatial Studies and Microbes” seasonal cruises (Vanderploeg and spatial team) that were designed to examine the spatial structure of the food web from microbes to fishes. The characterization of Chloroflexi genetic traits and its capacity to thrive in hypolimnia of large cold lakes is described in Denef et al. (2016).

Reference:
Light and nutrients are the main controllers of Cladophora growth (e.g. review of Bootsma et al., 2015). Some ecosystem models and conclusions of impact have assumed constant excretion rates of P in mussels, and some values used in the models have been based on experiments of dubious methodology. The factors that regulate P and N ingestion as well as the factors that affect both soluble excretion and egestion of nutrients are not well defined. Another important question is the time lag and availability of nutrients from egested material for both Cladophora and Microcystis. Egested N and P is usually higher than soluble excretion.

In the case of Microcystis, we have shown that selective rejection by mussels is an important part of their promotion of toxic Microcystis blooms. The role of nutrient excretion on promotion of toxic Microcystis is less clear.

Reference
Mussels are key in nutrient recycling. Nutrient excretion affects proliferation of Cladophora and abundance and toxicity of Microcystis. Therefore, necessary to understand mussel impacts on nutrients for models.

Phosphorus excretion depends on the quality of the seston and the rate it is ingested. A low N:P ratio (near Redfield ratio) results in higher soluble P excretion. In this figure, the N:P range end points are representative of values found in Western Lake Erie (~10-18) and Saginaw Bay, Lake Huron (~32-40), and excretion rates observed in mussels from the enclosures are in the same ballpark. Some ecosystem models and conclusions of impact have assumed constant excretion rates based on experiments of dubious methodology. We did our “standard” feeding experiments in water from the enclosures and then placed the mussels in filtered water for 2 h to determine their excretion rate of soluble reactive phosphorus and ammonium. The story is different for ammonium (not shown). It is not very sensitive to feeding rate or N:P ratio.

Future research should focus on nailing down the whole process in the lab under controlled feeding and seston stoichiometry conditions tracing flow with radioisotopes. The other issue is rate at which egested material becomes available to primary producers.
Summary

- Dreissenid mussels have affected algal and microbial food web structure in all size categories with surprising results.
- Feeding and nutrient excretion may be working together to affect cyanobacterial and phytoplankton community structure.
- More work is necessary to quantify results and develop a new generation of water quality and fisheries models.
The challenges mentioned here for this particular project are emblematic of general challenges to recapture GLERL’s traditional strengths in biogeochemistry and lower food web dynamics.

Infrastructure investments needed:
Renew radioisotope license to be able to clarify uptake, excretion and fate of ingested C and P.
Questions?