Recent changes in invasive zebra mussel densities in Michigan inland lakes

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Outline

• Zebra mussels: background

• Recent observations, monitoring, and experiments: Gull Lake

• Recent observations: other Michigan inland lakes

• Recent observations: outside of Michigan

• Summary
Zebra mussels: background

- Introduced: 1980s from Europe/Asia
- Transported: ballast water (microscopic, planktonic veliger larvae)
- Adults settle and attach to substrates
- Achieve prolific densities
- Efficient filter-feeders of phytoplankton (algae)

*Zebra mussel* *Dreissena polymorpha*
Biofouling of boats, pipes, and structures

Re-configuration of lake foodwebs (shunt energy from open water to the bottom)

Elimination of native unionid mussels

Promotion of toxic *Microcystis* cyanobacteria (blue-green algae)
Zebra mussels: background

Present day

USGS
Zebra mussels: background

- Confirmed establishments in 255 Michigan inland lakes

http://nas.er.usgs.gov/
Gull Lake, Michigan

• One of the largest, deepest lakes in southwest Michigan

• Many years of study/monitoring by MSU/KBS, & GLQO

• Invaded by zebra mussels in 1994
Gull Lake zebra mussels

- Population data from 1999 (0-25 foot depth)
- ~2,000 mussels per square meter (~11 square feet)
- Population remained rather stable for 16 years

White and Sarnelle (2014, *Freshwater Biology*)
Gull Lake zebra mussels

- Typical density of zebra mussels in the shallows of Gull Lake
Gull Lake zebra mussels

- Unprecedented, sudden die-off in early August, 2010
- Nearly 100% mortality down to ~20 foot depth (mixed layer)
- Deeper, mussels survived & appeared healthy
Shells of dead zebra mussels blanket the bottom of Gull Lake, MI after 2010 mass die-off
What happened in Gull Lake?

• Invasive species often fluctuate, or have initially explosive population growth followed by a decline to more stable density.

But the rapidity and extent of the Gull Lake die-off was surprising: is there more to that story than this?
What happened in Gull Lake?

• Causes of mortality in wild populations

1. Natural causes (“old age”)
   *No: population age structure was stable up to 2010*

2. Predation
   *No: mortality event was too sudden and widespread*

3. Disease / parasitism
   *Maybe! No evidence against this possibility…*
   *But…perhaps it’s odd that mussels survived at deeper depths?*

4. Unfavorable environmental conditions
   *LOTS of physical/chemical data from the lake…good place to start!*
What happened in Gull Lake?

- Environmental variables monitored in Gull Lake that might be important:

  - Water temperature
  - Dissolved oxygen
  - pH
  - Calcium (required for shell building)
  - Chlorophyll (algae—mussel food!)

2010 was very warm: Gull Lake hit 84 °F AND temperature varies greatly from 0-20+ feet.

All of these were normal in 2010, as compared to the ~10-year average.
What happened in Gull Lake?

Summertime daily average air temperature, recorded near Gull Lake
1994-2013 (post zebra mussel invasion)

What does the scientific literature say about zebra mussel temperature tolerance?

Data from Kellogg Biological Station’s Long-Term Ecological Research site
Zebra mussel temperature tolerance

• Many studies focus on using heat to purge mussels from pipes and boats
  • How hot and for how long to achieve 100% mortality?

• Death occurs in:
  • 4 days+ at ~86 °F (30 °C)
  • 2 days at ~90 °F (32 °C)
  • hours at ~93 °F (34°C)
  • minutes at ~100 °F (38 °C)

• Generally extreme and unnatural conditions (*very* hot for *very* short time periods with *abrupt* transitions)

• *What about in nature?*

Iwanyzki and McCauley (1993), Spidle et al. (1995)
Zebra mussel temperature tolerance

- Temperature tolerance varies among populations
- Mississippi River study:
  - Zebra mussels in Louisiana have higher tolerance than those in Minnesota and Illinois

Average 5 °C (~9 °F) difference between the northern and southern sites

What about for Gull Lake zebra mussels?

Elderkin and Klerks (2005)
Gull Lake: caged mussels

- Study of zebra mussel mortality in Gull Lake
- Retrievable cages with temperature loggers

At the surface

Going doooooowwn...

In place on the bottom
Gull Lake: caged mussels

- 20-24 zebra mussels per cage

- 2 size classes:
  
  **“Large”**: ≥ 17mm (0.7 in)

  **“Small”**: ≤ 16 mm (0.6 in)
Gull Lake: caged mussels

- 3 depths, 4 replicates:
  
  **6 ft**: warmest; largest daily variation
  
  **16 ft**: warm; slightly less variation
  
  **30 ft**: below the thermocline—cool; very little variation
Caged mussels

Gull Lake temperature distribution at different depths, June-October 2010-2013

- Protracted maximum (80-84 °F) in 2010 (die-off)

- Very warm again 2011, 2012 (80-88 °F)

- Cooler in 2013 (75-80 °F)

- More constant, cooler temperatures at deeper depths

77 °F 86 °F
Gull Lake: caged mussels

- Temperature explains variation in mussel mortality in Gull Lake
- Mortality 65-100% at 6 feet in warm years (2010, 2011, 2012)

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R^2 = 0.7643
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Temperature explains variation in mussel mortality in Gull Lake.

Mortality 65-100% at 6 feet in warm years (2010, 2011, 2012).

**Small mussels**
Gull Lake 2012-2013

**Large mussels**
Gull Lake 2010-2013

Base temperature = 26 °C (79°F)
Gull Lake: caged mussels

- Temperature explains variation in mussel mortality in Gull Lake
- Mortality only 7-47% at 30 feet in warm years (2011, 2012)

![Small mussels](Gull Lake 2012-2013)

- Small mussels
- Gull Lake 2012-2013
- Mean mortality rate vs. degree hours
- $R^2 = 0.7643$
- Base temperature = 26 °C (79°F)

![Large mussels](Gull Lake 2010-2013)

- Large mussels
- Gull Lake 2010-2013
- Mean mortality rate vs. degree hours
- $R^2 = 0.6352$
- Base temperature = 26 °C (79°F)

2011: 30 feet
2012: 30 feet
2012: 30 feet
Lab experiment

- Can the results be replicated in the lab?

- Gull Lake zebra mussels

- Heated tanks with temperature ratcheted up 1°C / day from 23 °C (73 °F) until all mussels dead

- Control tanks at constant 23 °C (73 °F)

- Monitored mortality
Lab experiment

- Mortality increased dramatically only after reaching 32 °C (89 °F)
- 100% mortality by 33 °C (91 °F)
- Large mussels were slightly more sensitive

**Temperature**

- Control
- Treatment
- Incubator

**Zebra mussel mortality**

- Control juvenile
- Treatment juvenile
- Control adult
- Treatment adult
Lab experiment

• Gull Lake zebra mussels survived to much higher temperatures in the lab than in the lake

• Possible explanations
  • Acute (lab) vs. accumulated (lake) heat stress
  • Otherwise optimal conditions in the lab

• Lab experiment is needed to address whether food limitation interacts with heat stress
Was it just Gull Lake?

- Have zebra mussels declined in other Michigan inland lakes during the same time period of observations from Gull Lake?

- October 2013: electronic surveys
  - Michigan Lake & Stream Association (MLSA)
  - Michigan Clean Water Corps (MiCorps)
Not just Gull Lake...

“I observed a die off in 2011-12 to the point where mature mussels were rarely observed during the summer”
-- Dr. John Wilks, Indian Lake (Kalamazoo County)

“the zebra mussels have disappeared to the degree that it's almost safe to go in the water without shoes”
--John Roberts, Burt Lake (Cheboygan County)

“August 2011 and 2012: Didn't have to look very hard to find them....August 2013: Unable to find any, even when actively looking”
--Betse Stuart, Torch Lake (Antrim County)

“We have noted a die off of the zebra mussels in the lake over the last few years. We are very certain that their population is down”
--Linda Davis, Payne Lake (Barry County)
Not just Gull Lake...

“...people around the lake have been commenting on how few mussels are on their docks...”

Photo & quote from Julie Stivers, Stony Lake, MI, October 2013 (Oceana County)
Reports received from 40 inland lakes all over the Lower Peninsula.

Declines or die-offs observed in 33 (83%) of the cases during the period 2010-2013.

Not just Gull Lake...
What about the Great Lakes?

- Recent (since 2005), near-complete replacement of zebra mussels by quagga mussels (a close relative) in the Great Lakes
  - Seems to be driven by ecological competition

  So...the Great Lakes case looks to be different

- No reports of quagga mussels in any Michigan inland lakes

Zebra mussel density through time

Quagga mussel density through time
Observations outside Michigan

- Recent declines (since 2005) of Hudson River zebra mussels (especially large individuals)
  - Seems to be driven in part by predation by native blue crab

So...the Hudson River case looks to be different
Observations outside Michigan

- Mass die-off of zebra mussels occurred in the northern Mississippi River system in 2001 after temperatures exceeded 31 °C (89 °F) for a few days.

Divers discover zebra mussel die-off

The cause of this die-off is unknown but there are several possibilities. The high water temperatures that existed in the main channel on the river this summer are one of the prime suspects.
Observations outside Michigan

- Recent (2012) declines of zebra mussels in Lake of the Ozarks, Missouri

"...for the last couple of years, zebra mussels have declined or disappeared altogether...the warm water temperatures during the summer is probably a factor"
Observations outside Michigan

- Recent (2011-2013) crash of zebra mussels in the St. Croix River, Minnesota

Zebra mussel population decline in St. Croix puzzles scientists

Stephanie Hemphill · St. Paul, Minn. · Apr 5, 2012

A few years ago, a sudden die-off in Lake Zumbro surprised Montz and other researchers.

"Our theory is that the zebra mussels were stressed by hotter water temps, lower water, perhaps dissolved oxygen getting lower in some of the areas they were surviving in," Montz said. "And it just pushed the population over the edge and a lot of them died off."
What about cooler years?

- **Prediction:** *if recent summer mortality events have been largely driven by high temperatures, then mortality should be lower with the return of more favorable temperatures*
What happens in cooler years?

- Mortality of caged Gull Lake mussels at 6 feet was greatly reduced (< 50%) when temperatures were cooler in 2013.

![Graphs showing mortality rate vs. degree hours for small and large mussels in Gull Lake from 2010 to 2013.](image-url)
Juveniles re-colonize the shallows of Gull Lake, MI for the first time since the die-off event (fall 2013).

Densities are still substantially below historical levels.
Re-colonization?

“...this year they seem to be back, not in the numbers that were evident during the first infestations, but much more than the last two or three years”
--Julie Stivers, Stony Lake (Oceana County)

“[In] 2013, the population seemed to increase [from significantly reduced numbers] but not to the extent of earlier”
--Claudia Kerbawy, Lake Lansing (Ingham County)
Summary

• Gull Lake evidence is consistent with recent high temperature-driven mortality of zebra mussels

• Anecdotal reports from inland lakes around the Lower Peninsula point to obvious recent declines of zebra mussels

• Zebra mussels have been reported to have declined recently in other areas, though the explanations vary
Lingering questions

• Will zebra mussels rebound to historical densities?

• What are the implications for the long-term impacts and dynamics of zebra mussels?

• Could declines in zebra mussels facilitate the expansion of quagga mussels (a close relative) from the Great Lakes into suitable Michigan inland lakes?
Remain vigilant: don’t spread invasive species

**ZEBRA MUSSELS HIDE HERE.**

Clean, drain and dry your boat.

*Clean your boat. Save your lake.* Zebra mussels are a small, destructive invasive species threatening to spread across Texas on boats like yours. Already established in Lake Texoma, zebra mussels start out as microscopic larvae and grow to about 10 inches, but what they lack in size they make up for in the damage they do. They can hurt aquatic life, damage your boat, hinder water recreation and even affect your water supply. It’s up to you to stop the spread of zebra mussels. Always clean, drain and dry your boat, trailer and gear for at least a week before traveling to another body of water.

Don’t be a carrier.

**HELLO ZEBRA MUSSELS. GOODBYE TEXAS LAKES.**

[Website](http://www.texasinvasives.org)

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**DON’T MOVE A MUSSEL**

**STOP AQUATIC HITCHHIKERS!**
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Thank you!

If you have any recent observations of zebra mussels in your inland lake (die-offs, declines, or lack thereof)...

Please see me at the break, or send me an email at whitej82@msu.edu

- Lake (name, county)
- What you noticed
- When you noticed