Perspectives on the Lake Washington zebra mussel infestation

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Zebra mussels (*Dreissena polymorpha*)

Native range: southern Russia

**Invasive traits**

**High fecundity**
Release eggs and sperm into water: 0.5 million eggs/female

**Broad dispersal**
Veliger larvae develop 2-4 wks. in plankton, drifting long distances in lakes, down streams

**Huge filtering capacity**
Attach with byssal threads to any firm surface (including other mussels)

Dense mussel beds remove $\frac{1}{2} - \frac{3}{4}$ plankton mass from lakes and rivers
North American invasion

- Several introductions to the Great Lakes in ship ballast water

- Appeared in Lake St Clair (1988: arrow)

- Through navigable waters (Great Lakes and Mississippi Basins, Hudson and Susquehanna Rivers)—they reached Louisiana to the south, Quebec and New York to the east, Oklahoma and Minnesota to the west in 5 years!

2011: Brown and Stepien
Spread to date in North America

- As of 2010
  - US and Canada*
    - 131 river systems
    - 772 inland lakes, reservoirs and impoundments
  - Minnesota as of 2016**
    - 28 rivers and streams
    - 103 inland lakes

*Data from A. Benson, USGS (2013)
**From MnDNR AIS Program (K Pennington)
Minnesota’s rate of new inland invasions is now among the highest in the US

From Mallez and McCartney (in review)

We have the time, the will, and the resources to slow spread and prevent infestation of many prized water bodies!

- Prevention works, but must be targeted by
  - Understanding transport pathways to pinpoint invasion sources and routes, and vectors (boats, docks, lifts...)
    - Boat traffic data and models
    - Genetics and genomics
Zebra mussels: impacts

• Ecological
  – Dense mussel beds can
    • Filter ¼ - ½ volume of a lake or river per day
    • 50-75% drop in phyto- & zooplankton biomass
    • Restructure food webs
  – Greater water clarity—may promote plant growth, cascading effects
  – Damage to fish populations (e.g. Hudson River), but not everywhere (e.g. Lake Erie)
  – Decline, local extinctions of native mussels

From Higgins and Van der Zanden (2010)
Zebra mussels: impacts

- Economic and recreational
  - Clog intake pipes for industrial facilities
    - USGS: $5 billion losses in Great Lakes, 2000-2010
  - Waterfront/recreational: docks, boats, lifts, motors...
  - Impacts on recreational industries very high (?)
  - Property “values”: some ups (e.g. water clarity, many downs (e.g. algal blooms)}
• Genetics of spread: where did mussels invading new lakes come from?

• Determine spread routes to plan where and how to best block them

• Long term research on genetic biocontrol: genome sequencing

• Meanwhile, help managers improve existing management techniques (mostly, chemical)
Genetic markers of zebra mussel spread

- Microsatellite markers
  - Repeated motifs – GTTAGTCCAGAGAG… AGAGAGTTCGATCT

- Genotyping of 9 microsatellite markers
  - Obtained from the literature
  - Optimized for this study
Sampling zebra mussels

  - 69 sites - 44 water bodies – 2047 individuals
Sampling zebra mussels

  - 69 sites - 44 water bodies – 2047 individuals
Analysis of genetic diversity

Broad pattern:
Lakes are colonized by large numbers of mussels
Analysis of genetic structure

Some well-defined genetic clusters allows testing invasion models
Mille Lacs Lake – a source for other inland lakes?

- High boater traffic
- Infested early (2005)

N = 35 lakes compared to Mille Lacs Lake
Mille Lacs Lake – a source for other inland lakes?

Analysis of invasion models – “Super-spreade'vers” lakes
Analysis of invasion models – “Super-spreader” lakes

Mille Lacs Lake – a source for other inland lakes?

Independent introductions scenario selected in every case with high probabilities, from 81% to 99%.

Mille Lacs Lake: not the source for any of the 35 lakes invaded after 2005
Analysis of invasion models: clustered invasions in lake-rich regions:
1. Dispersal from outside region (red arrows)  
2. Local spread (shaded colors)
Clustered Invasions – Detroit Lakes

K = 2
K = 3
K = 4
K = 5
K = 6
K = 7
K = 8
K = 9
K = 10

Mille Lacs
Prior Alexandria area Brainerd area Pelican Rapids area
Detroit Lakes: 1
unique genetic cluster
found nowhere else

Includes Orwell Reservoir (> 50 miles downstream)
Clustered Invasions—Brainerd Lakes

Mille Lacs | Prior | Alexandria area | Brainerd area | Pelican Rapids area
K = 2
K = 3
K = 4
K = 5
K = 6
K = 7
K = 8
K = 9
K = 10
Brainerd Lakes: 1 unique genetic cluster found nowhere else

* = Tested lake
ZM = Infested lake

Includes Cass and Winnibigoshish Lakes
Clustered Invasions– Alexandria lakes
Alexandria-area lakes: 2-3 unique genetic clusters found nowhere else

* Tested lake
• Infested lake
Summary and management conclusions

• High genetic diversity: Infestations are founded by many mussels
  • If veligers in residual water are the vector—multiple introductions
  • Vectors that transmit juveniles or adults—docks, lifts, resident boats—are more likely to generate this pattern
Summary and management conclusions

• High genetic diversity: Infestations are founded by many individuals
  • If veligers in residual water are the vector—multiple introductions
  • Vectors that transmit juveniles or adults—docks, lifts, resident boats—are more likely

• “Super-spreaders” lakes: not infestation sources
  • High boater traffic, but genetics shows (so far) that they have not infested other lakes
  • Inspection/decontamination programs are working on Mille Lacs
Summary and management conclusions

- High genetic diversity: Infestations are founded by many individuals
  - If veligers in residual water are the vector—multiple introductions
  - Vectors that transmit juveniles or adults—docks, lifts, resident boats—can introduce large #s of mussels per transport event

- “Super-spreader” lakes: not infestation sources
  - High boater traffic, but genetics shows (so far) that they have not infested other lakes
  - Inspection/decontamination programs are working on Mille Lacs

- Mussels spread locally in lake-rich regions
  - One or more original infestations from outside the region
  - After this—local spread is rapid (overland and downstream)
  - Vectors spreading mussels locally must be identified and blocked
What can be done to control or eliminate zebra mussels?

• Mechanical controls
  – Hand harvest
  – Draw downs

• Chemical treatment

• Biological control
# Zebra Mussels Removed from Lake George

<table>
<thead>
<tr>
<th>Site (year discovered)</th>
<th># Removed *</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG Village (1999)</td>
<td>21,278</td>
</tr>
<tr>
<td>Cleverdale (2004)</td>
<td>1,380</td>
</tr>
<tr>
<td>Mossy Point (2004)</td>
<td>1,816</td>
</tr>
<tr>
<td>Sandy Bay (2006)</td>
<td>451</td>
</tr>
<tr>
<td>Rogers Rock (2007)</td>
<td>231</td>
</tr>
<tr>
<td>Yankee Marina (2007)</td>
<td>36</td>
</tr>
<tr>
<td>Castaway Marina (2007)</td>
<td>47</td>
</tr>
<tr>
<td>Treasure Cove (2008)</td>
<td>188</td>
</tr>
<tr>
<td>Beckley’s (2008)</td>
<td>22</td>
</tr>
<tr>
<td>Middle Bay (2009)</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25,475</strong></td>
</tr>
</tbody>
</table>

* As of the end of 2009. Zebra mussels removed by divers from the Darrin Fresh Water Institute, Bateaux Below, and InnerSpace Scientific Diving.

For more info about zebra mussels or to learn more about the LGA & how to support its work, go to [www.lakegeorgeassociation.org](http://www.lakegeorgeassociation.org).

Image: RPI, Troy NY
## Chemical treatments for zebra mussels in Minnesota

<table>
<thead>
<tr>
<th>Lake</th>
<th>County</th>
<th>Year treated</th>
<th>Agent(s)</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnewashta</td>
<td>Hennepin</td>
<td>2016</td>
<td>EarthTec QZ™ (copper sulfate formulation)</td>
<td>• No mussels found in treatment area after treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status: evaluation in progress; follow up monitoring begins Spring 2017</td>
</tr>
<tr>
<td>Ruth</td>
<td>Crow Wing</td>
<td>2015</td>
<td>EarthTec QZ™</td>
<td>• No mussels found in treatment area after treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• No adults, larvae or settling juveniles found lake-wide through summer 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Fall 2016: one dead mussel found attached to a boat lift pulled from the lake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status: uncertain</td>
</tr>
<tr>
<td>Christmas</td>
<td>Hennepin</td>
<td>2014</td>
<td>EarthTec QZ™, potash (potassium chloride), Zequanox</td>
<td>• No mussels found in treatment area to date (2 years post-treatment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Fall 2015: 16 mussels found on equipment from sites distant from treatment area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Sizes of these mussels suggests that reproduction occurred</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status: the lake population is now growing</td>
</tr>
<tr>
<td>Independence</td>
<td>Hennepin</td>
<td>Fall 2014, Spring 2015</td>
<td>EarthTec QZ™, potash</td>
<td>• 49 mussels found in 2015 (one year after the first treatment)—in the treatment area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Follow-up survey in 2016—only 3 mussels found, no small animals, no reproduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status (tentative): population suppression</td>
</tr>
<tr>
<td>Rose</td>
<td>Otter Tail</td>
<td>2011</td>
<td>Cutrine®-Ultra (liquid chelated copper algicide)</td>
<td>• Survey in spring 2012 found 3 mussels remaining within the treatment area</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Surveys from 2013 through 2015: no mussels found, lake-wide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status: successful population suppression, being monitored</td>
</tr>
<tr>
<td>Irene</td>
<td>Douglas</td>
<td>2011</td>
<td>Cutrine®-Ultra</td>
<td>• Like Rose Lake, Irene was infested by a boat lift, and treated using Cutrine Ultra</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• We are not aware of follow up information prior to Fall 2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Status: population has grown and is widespread</td>
</tr>
</tbody>
</table>
Is Lake Washington a candidate for treatment?

Not without a coordinated effort with Lake Stella
Predators

Several native and non-native species eat zebra mussels, but none can control them in North America.
Assessing habitat suitability for Lake Washington, Meeker Co. MN

Source of the habitat quality categories is Mackie and Claudi (2010)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lake Washington data</th>
<th>Low Potential for Adult Survival</th>
<th>Low Potential for Larval Development</th>
<th>Moderate (survivable, but will not flourish)</th>
<th>High (favorable for optimal growth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (mg/l)</td>
<td>(? Region is in the moderate-high range)</td>
<td>&lt;8</td>
<td>8-15</td>
<td>15-30</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/l)</td>
<td>7.3 – 12 ( ^1 )\n6.11-10.73 ( ^2 )\nA few lower D.O. sites</td>
<td>&lt;3</td>
<td>3-7</td>
<td>7-8</td>
<td>&gt;8</td>
</tr>
<tr>
<td>Temperature</td>
<td>15.1-24.7 ( ^2 )</td>
<td>&lt;10 or &gt;32</td>
<td>26-32</td>
<td>10-20</td>
<td>20-26</td>
</tr>
<tr>
<td>pH</td>
<td>8.27-9.21 ( ^2 )</td>
<td>&lt;7.0 or &gt;9.5</td>
<td>7.0-7.8 or 9.0-9.5</td>
<td>7.8-8.2 or 8.8-9.0</td>
<td>8.2-8.8</td>
</tr>
<tr>
<td>Potassium (mg/l)</td>
<td>&gt;100</td>
<td>&gt;50 (prevents)</td>
<td>40-50</td>
<td>&lt;40</td>
<td></td>
</tr>
<tr>
<td>Hardness (mg/l)</td>
<td>(? Region is in the moderate-high range)</td>
<td>&lt;30</td>
<td>30-35</td>
<td>55-100</td>
<td>100-280</td>
</tr>
<tr>
<td>Alkalinity (mg CaCO(_3)/L)</td>
<td>(? Region is in the moderate-high range)</td>
<td>&lt;30</td>
<td>30-55</td>
<td>55-100</td>
<td>100-280</td>
</tr>
<tr>
<td>Conductivity (umhos)</td>
<td>324-368 ( ^2 )</td>
<td>&lt;30</td>
<td>30-60</td>
<td>60-110</td>
<td>&gt;110</td>
</tr>
<tr>
<td>Secchi depth (m)</td>
<td>.76-1 (1992) ( ^1 )\n0.8-2.1 (2016) ( ^1 )\n.787-1.7 ( ^2 )</td>
<td>&lt;1 or &gt;8</td>
<td>1-2 or 6-8</td>
<td>4-6</td>
<td>2-4</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>26.4 ( ^2 )\n7-22 ( ^2 )\nMost sites in the moderate range</td>
<td>&lt;2.5 or &gt;25</td>
<td>2.0-2.5 or 20-25</td>
<td>8-20</td>
<td>2.5-8</td>
</tr>
<tr>
<td>Total phosphorus (ppb)</td>
<td>37-67 ( ^1 )\n21-56 ( ^2 )\nMany sites in moderate range</td>
<td>&lt;5 or &gt;50</td>
<td>5-10 or 35-50</td>
<td>10-25</td>
<td>25-35</td>
</tr>
</tbody>
</table>
Possible impacts to Lake Washington: ecologic and recreational

- ZM effects on fish populations
  - Impacts in the Great Lakes and major rivers: mixed bag
    - Lake Oneida perch: none
    - Lake Erie walleye: none
    - Lake Michigan: some
    - Hudson River: several
  - We would not predict a *rapid decline* in any fisheries population to be caused by this zebra mussel invasion
  - Longer term—very difficult to predict
  - WE NEED MORE RESEARCH ON IMPACTS OF ZEBRA MUSSELS ON FISH POPULATIONS IN INLAND LAKES
Possible impacts to Lake Washington: ecologic and recreational

• Nevertheless, the lake will likely change in character, and ecologically be “restructured”

• Increased water clarity is likely

• Changes in aquatic plant populations are possible

• Nuisance: shoreline areas with rocks will become encrusted with mussels
Future prospects for control

• Once an infestation is established: few options

• We need population control agents that we can spread throughout an infested lake

• Genetic biocontrol technology is rapidly becoming an option
The Zebra Mussel Genome Project

• Sequencing the zebra mussel genome
  • 100s of millions of fragments of DNA sequence, some very short, others very long
  • Piled up and “stitched together” using bioinformatics
  • Describe and name zebra mussel genes that control important functions

• Searching the genome for target genes
  • Critical genes for development and reproduction
  • Genes controlling byssal thread attachment
  • Gene for shell formation (calcium threshold)

• Genetically edit target genes, insert into zebra mussels for eventual trial releases in lakes
Some take home thoughts

Your actions now can limit further spread to other lakes on trailered boats or other equipment
Some take home thoughts

• Later this year, remember:

  – As you remove docks and lifts, check carefully for zebra mussels. Note where on the lake the lift was pulled from, and approximate number of mussels. Report your findings to your regional MN DNR Invasive Species Specialist:

  • Chris Jurek, St. Cloud Christine.Jurek@state.mn.us
    – 320-223-7847
Some take home thoughts

• This year and in the future, remember:
  – Regulations say that docks, lifts, swim rafts, and other equipment need to be out of the water for 21 days (“dry time”) before they can be placed into another water body
  – If you must sell e.g. a boat lift to another person who will be placing it into another lake, the approach you should take is to overwinter it.
  – Freezing is the only certain way to kill ZM in the nooks and crannies and hollow areas, and is far superior to 21-day dry treatment.
  – Then sell it right away in the spring.
  – Best approach: don’t move structures from Washington to other lakes
Thanks

**MnDNR** Keegan Lund, Mark Ranweiler, Dan Swanson, Rich Rezanka Heidi Wolf, Adam Doll for educating me about prevention

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**MN Supercomputing Institute** (K Silverstein)

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