Minnesota Aquatic Invasive Species Research Center • MAISRC

The status of MAISRC research on zebra mussel prevention and control

Michael A. McCartney, Ph.D.,
Research Assistant Professor, MAISRC
University of Minnesota
mmccartn@umn.edu
612-301-7703

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Park Rapids, MN

MINNESOTA AQUATIC INVASIVE SPECIES RESEARCH CENTER
UNIVERSITY OF MINNESOTA
Driven to Discover℠

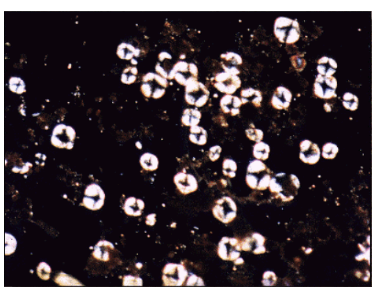
Zebra mussels (*Dreissena polymorpha)*

Native range: southern Russia

Invasive traits

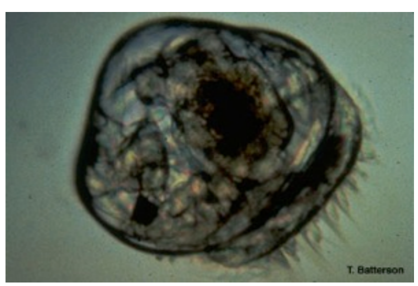
High fecundity

Release eggs and sperm into water: 0.5 million eggs/female

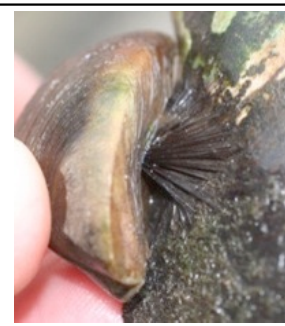


Broad dispersal

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



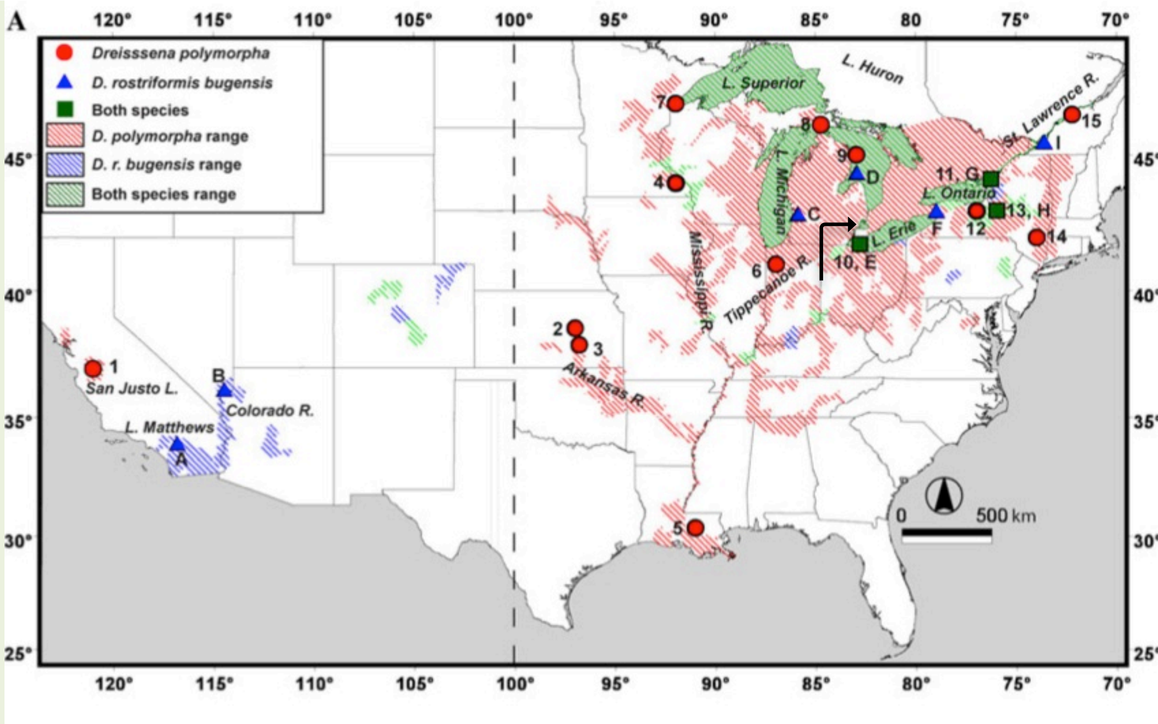
Attach with byssal threads to any firm surface (including other mussels)



Huge filtering capacity

Dense mussel beds remove ½ - ¾ plankton mass from lakes and rivers

North American invasion

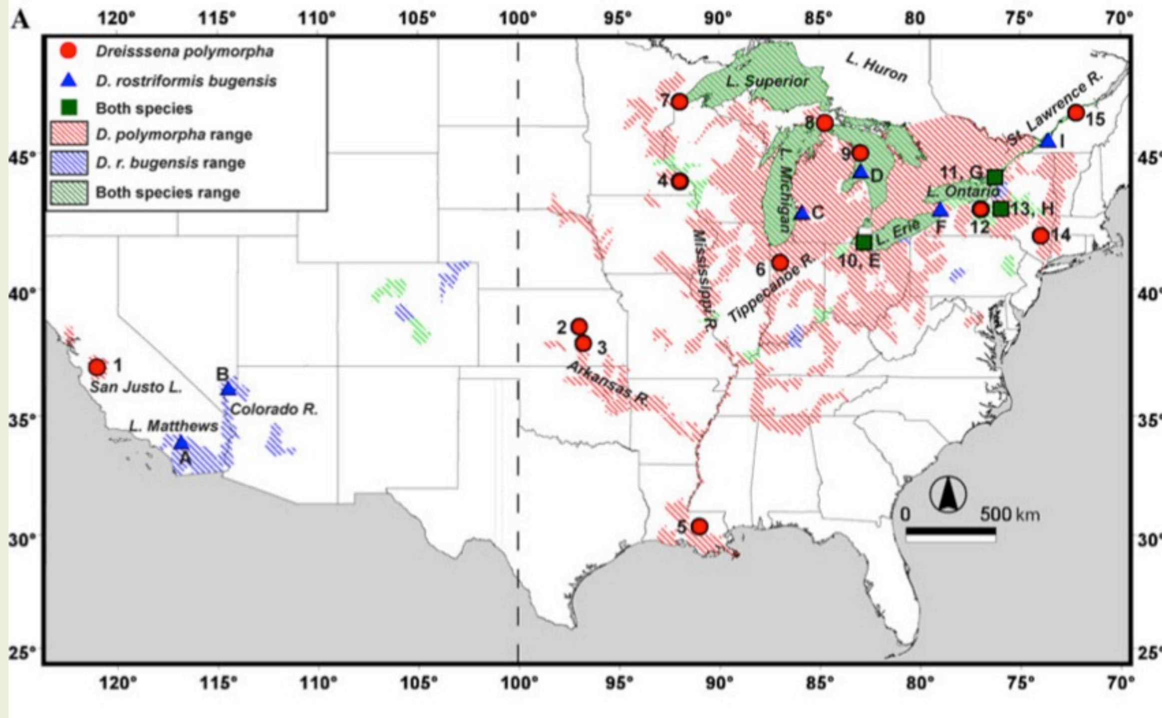


2011: Brown and Stepien

- Several introductions to the Great Lakes by trans-Atlantic ships
- 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!

Spread to date in North America

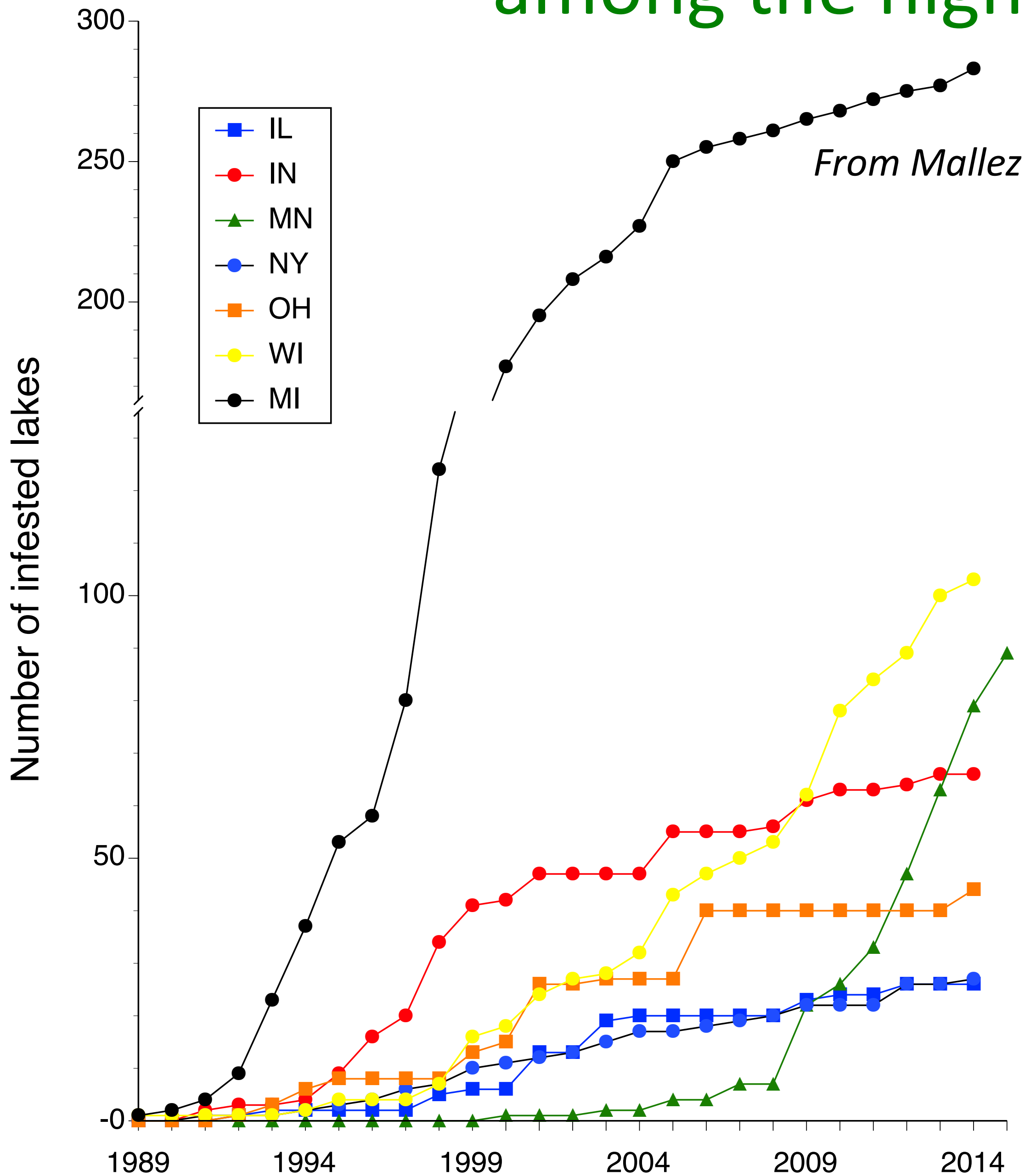
- As of 2010
  - US and Canada*
    - 131 river systems
    - 739 inland lakes, reservoirs and impoundments
  - Minnesota as of December 2016**
    - 16 rivers and streams
    - 114 inland lakes



2011 Map : Brown and Stepien

*From A. Benson (2014)
**From MN DNR AIS Program (K Pennington)

Minnesota's rate of new inland invasions is now among the highest in the US



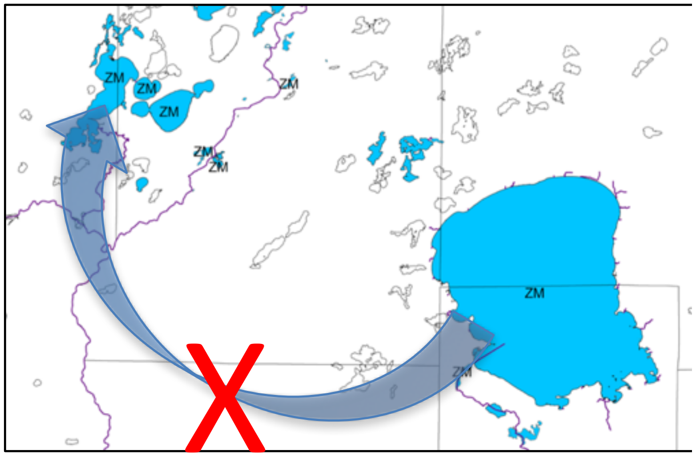
From Mallez and McCartney (in review)

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…)
    - Modeling boat traffic data
    - Genetics and genomics

Research to guide prevention

1. Examine pathways of spread—where did mussels invading new lakes come from?—direct evidence from invasion genetics



2. Examine spread downstream through connected waterways

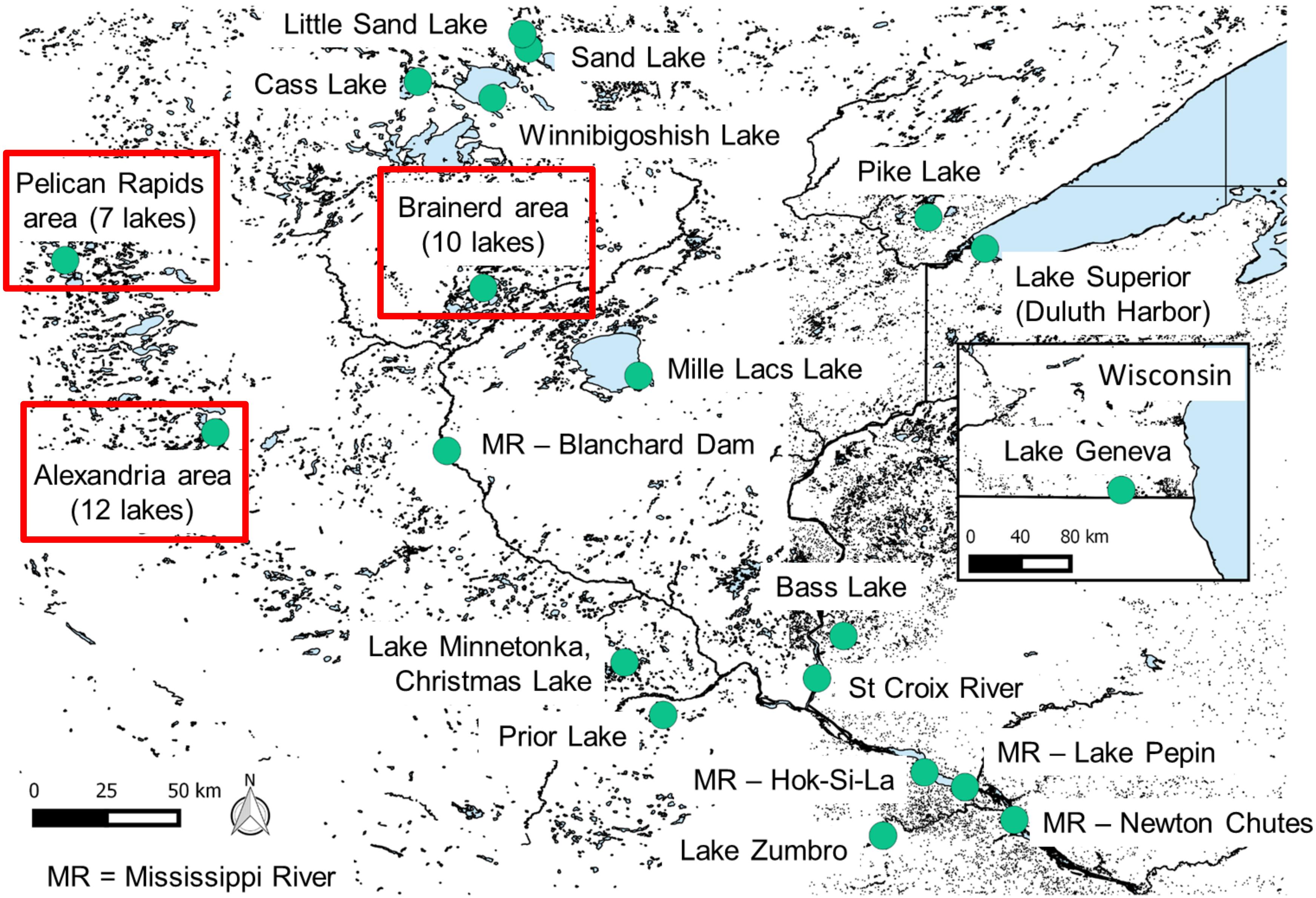
3. Examine the "residual water" vector of spread by watercraft

Invasion genetics at spatial scales useful to management…

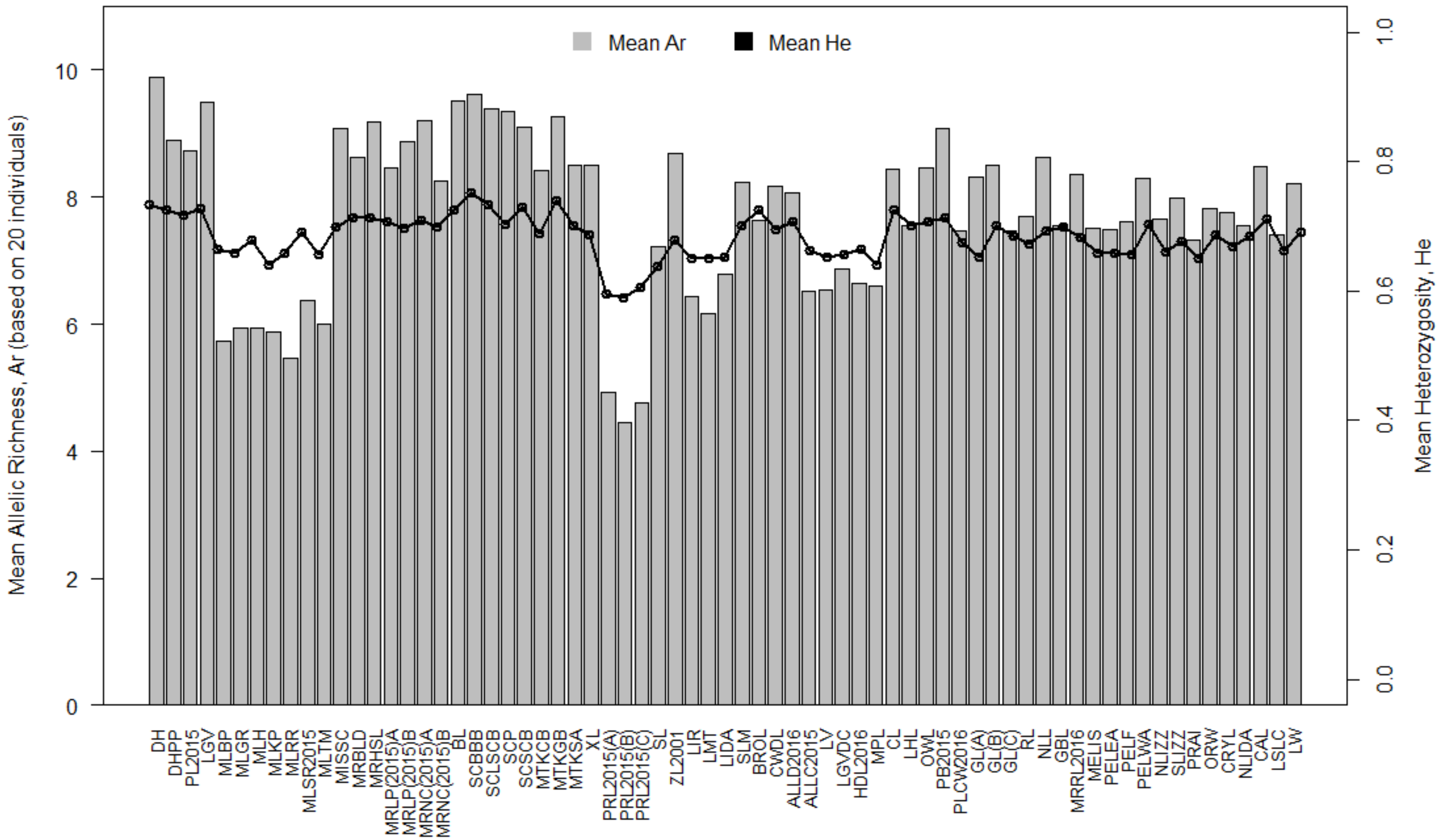
Sophie Mallez, Michael McCartney
(in review) *Biological Invasions*

Sampling zebra mussels

- Sampling of infested waterbodies in 2014 – 2015 – 2016
  - 69 sites - 44 water bodies – 2047 individuals



I. Pattern 1: mussel genetic diversity in MN lakes is high



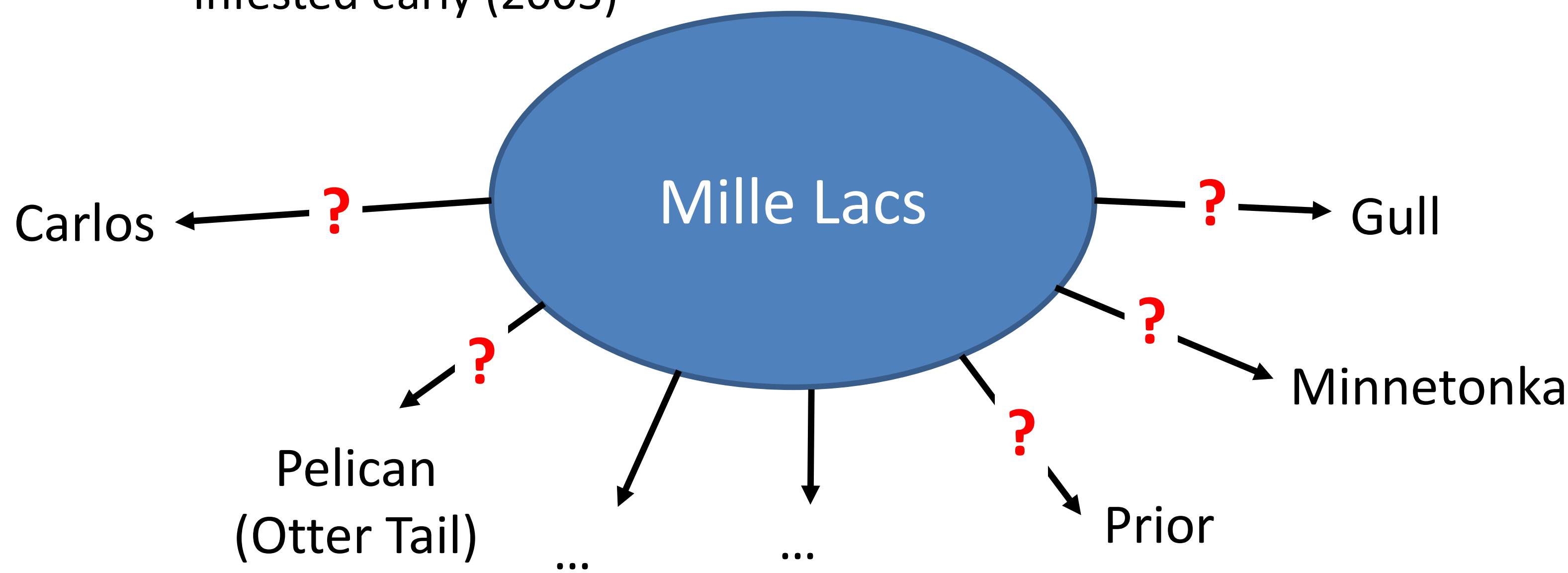
Broad pattern:

Lakes are colonized by large numbers of mussels

II. Pattern 2—role of "super-spreader" hub lakes

Mille Lacs Lake – a "hub" for invasions inland in MN?

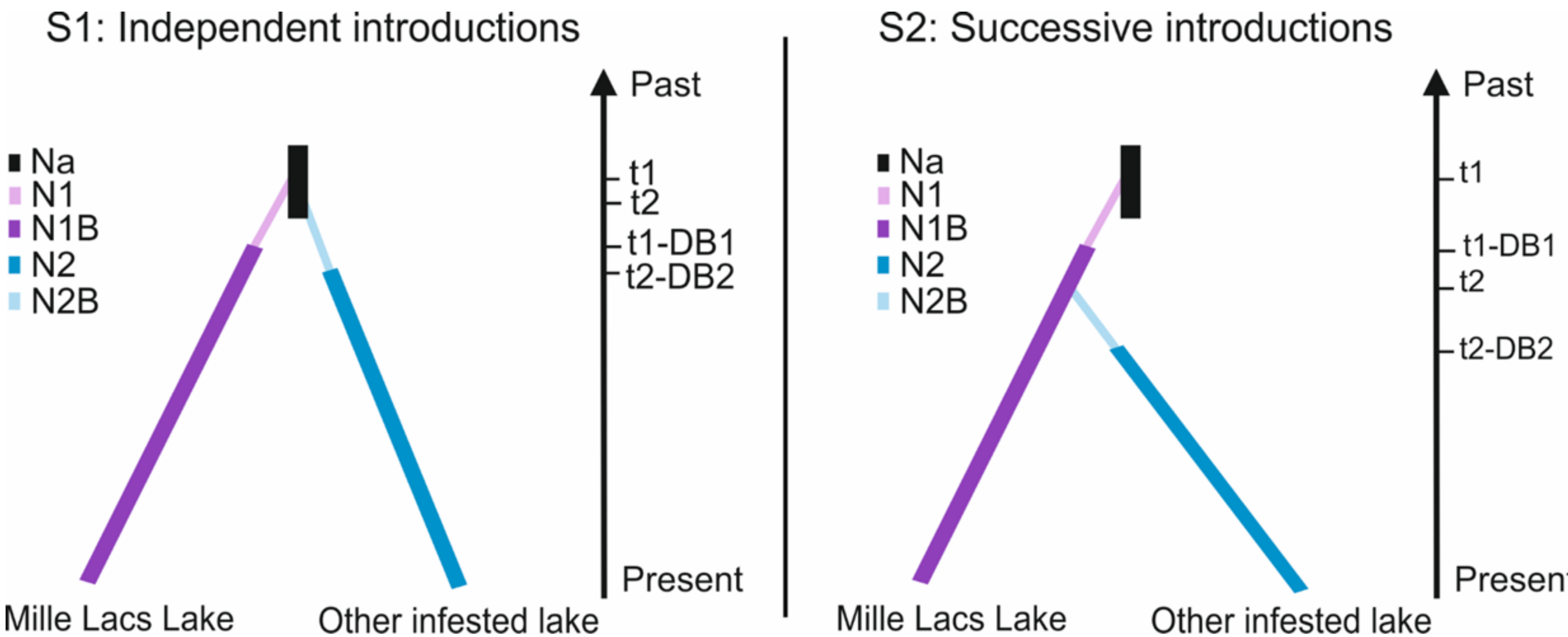
- High boater traffic
- Infested early (2005)



Mille Lacs tested as a source for 35 lakes

Analysis of invasion models – "Super-spreader" lakes

Mille Lacs Lake – a hub for inland lakes?



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

Mille Lacs Lake: *not the source* for a single lake tested (35 lakes invaded post-2005)

Take-home message

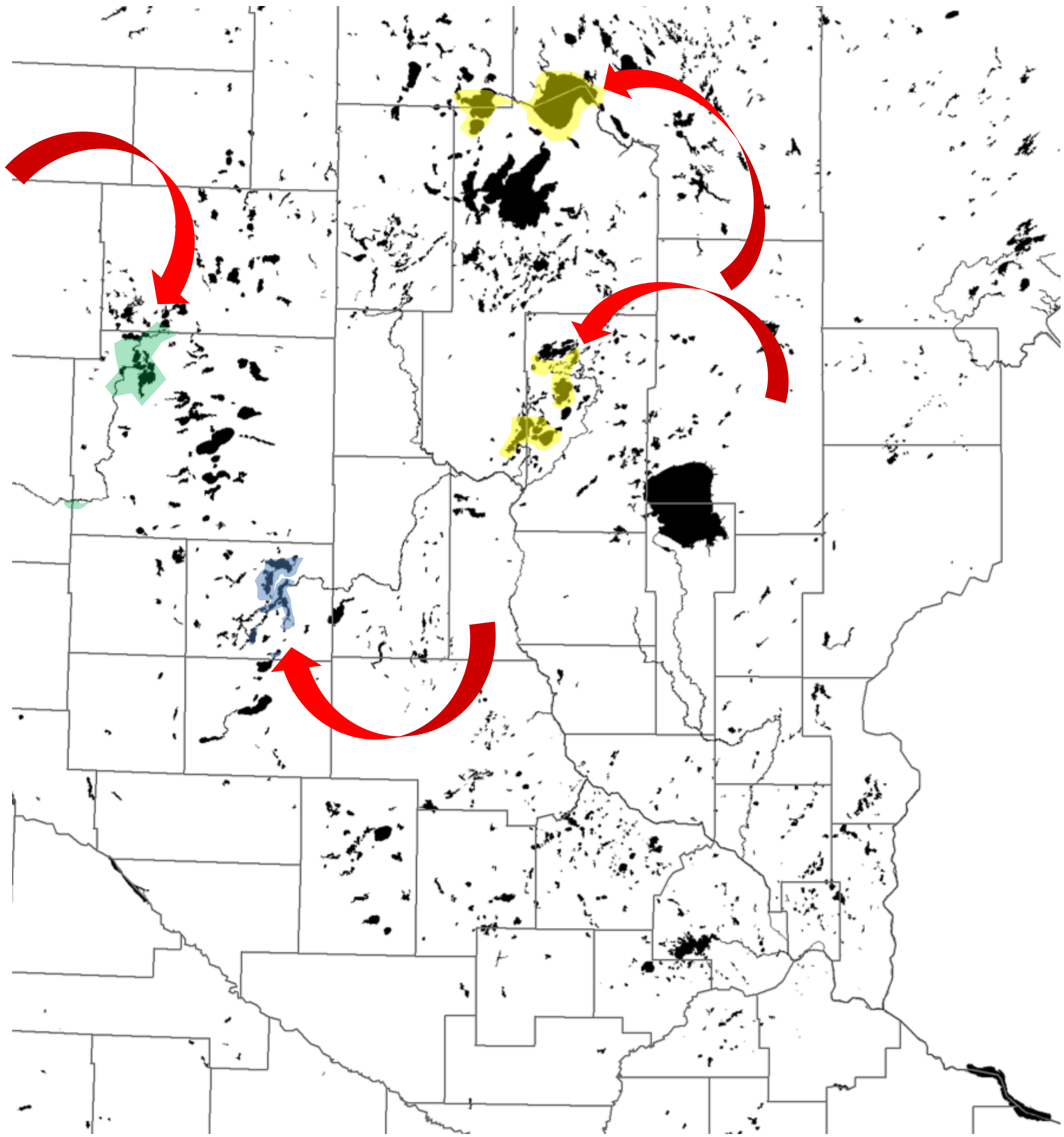
Boater movements: Mille Lacs (and Prior) Lakes have high traffic and are well connected, like “hubs,” to other lakes

Genetics: no detectable new infestations from these hubs

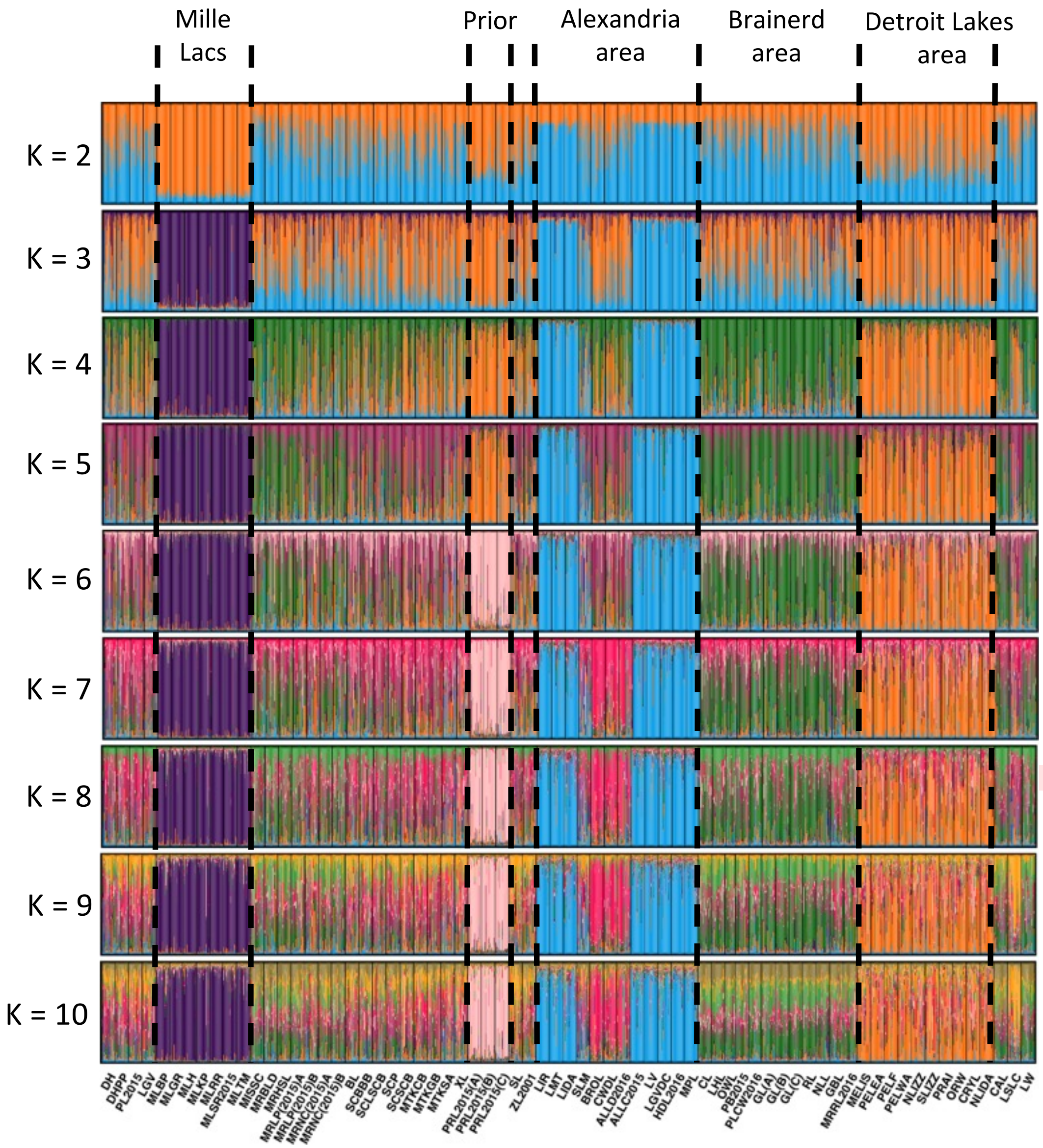
Bottom line: boat inspection/decontamination *must be* working and should be continued and expanded

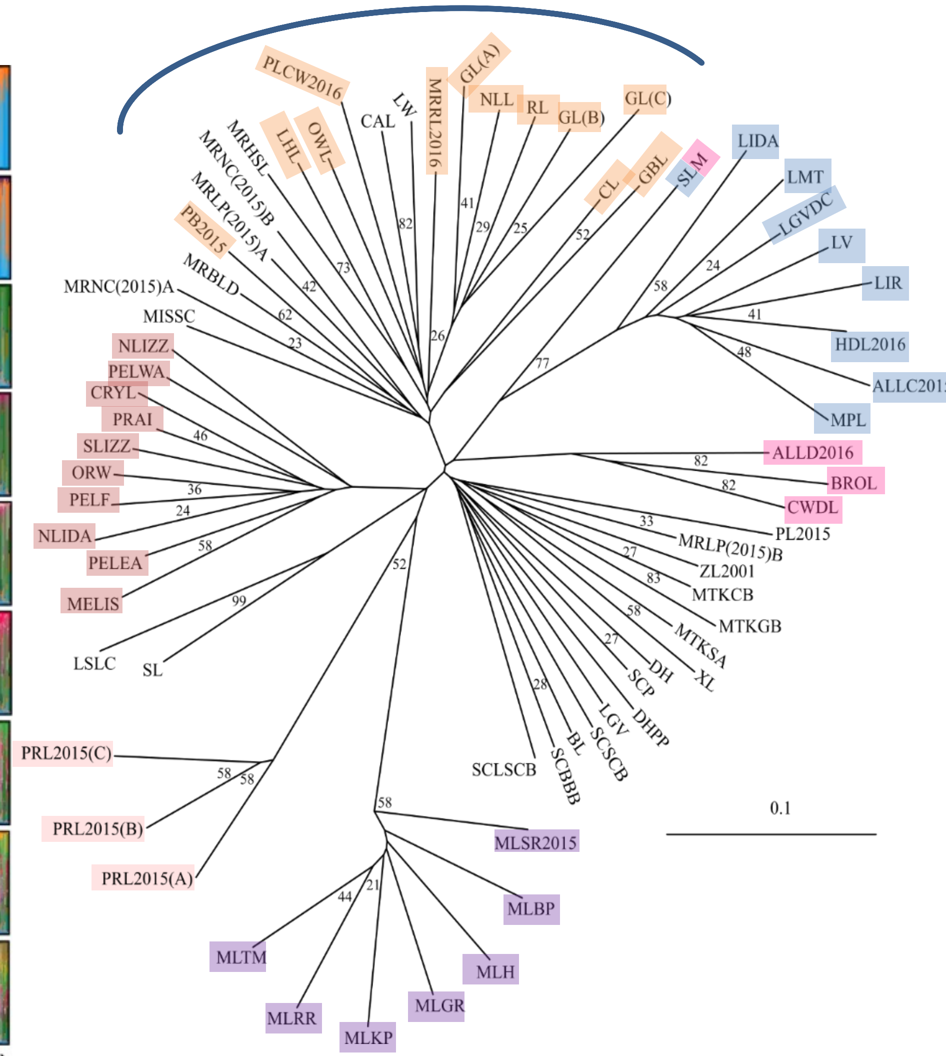
III. Pattern 3: clustered invasions in lake-rich regions, due to:

A. Dispersal from outside region (red arrows) B. Local spread (shaded colors)



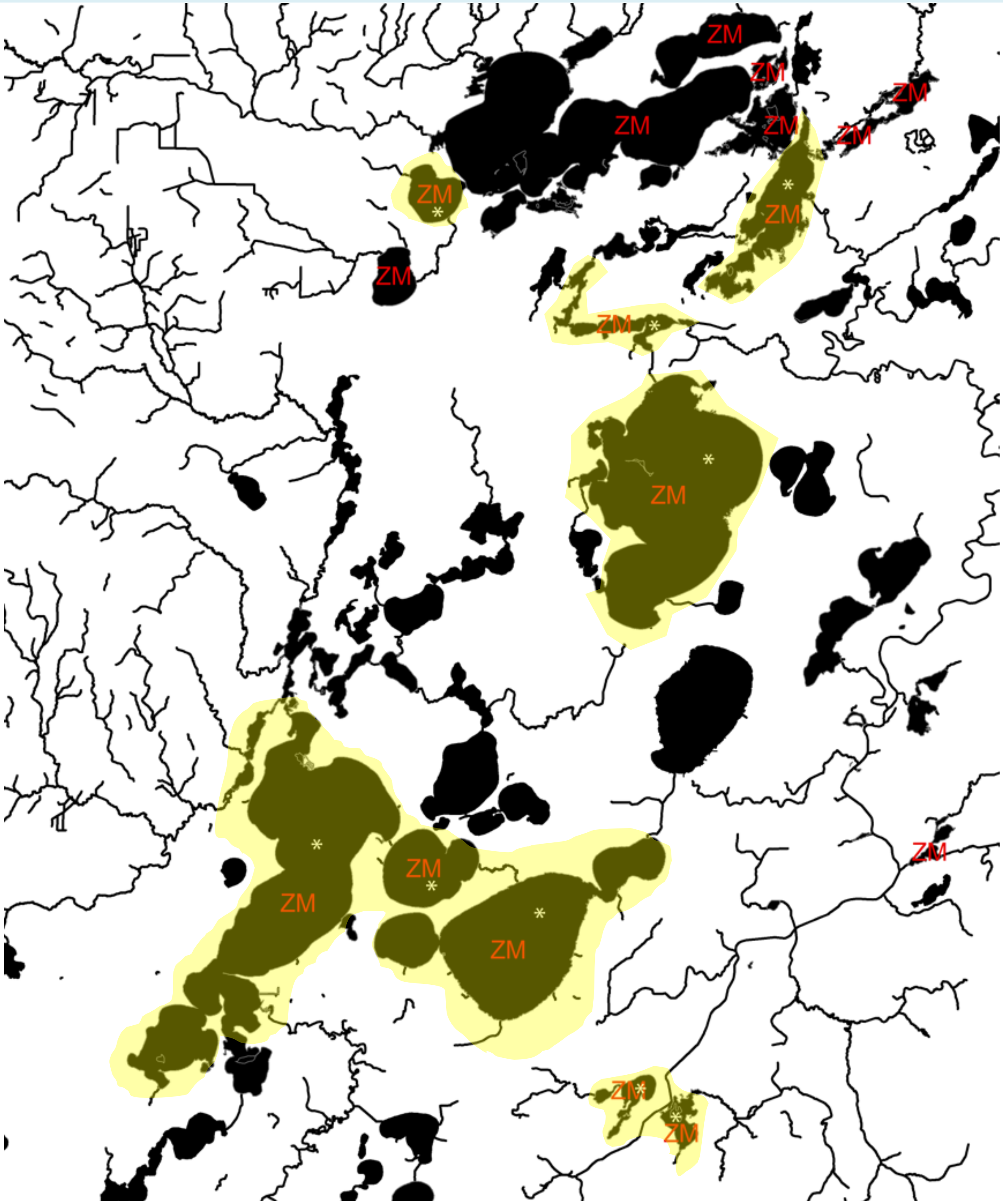
Clustered Invasions– Brainerd Lakes





Clustered Invasions– Brainerd Lakes

Brainerd Lakes: 1 unique genetic cluster (yellow shading) found nowhere else



* = Tested lake
ZM = Infested lake

Summary and management conclusions

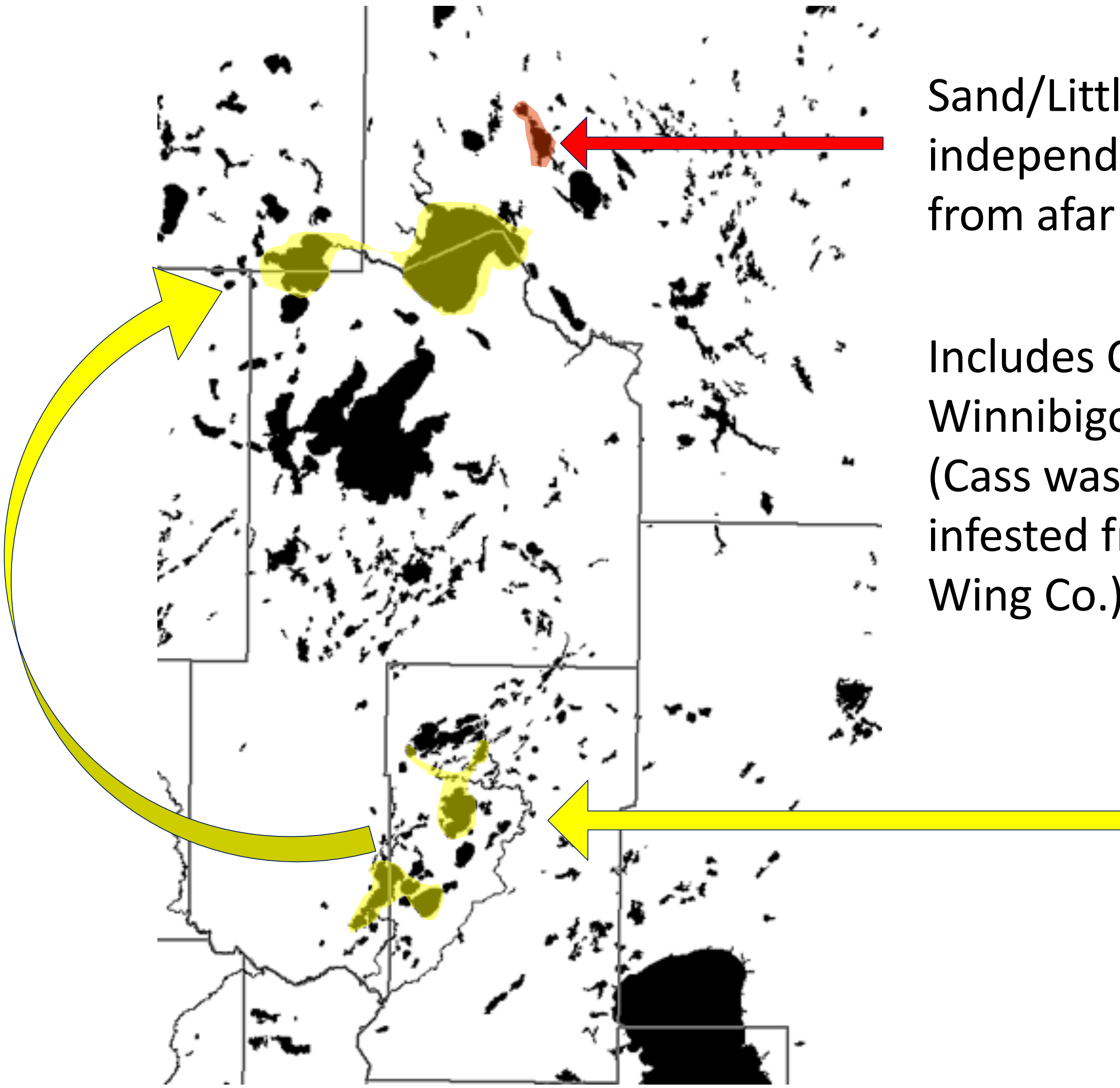
1. High genetic diversity: Infestations are founded by many individuals
    a. If veligers in water moved by boats are the vector—multiple and/or massive introductions
    b. Vectors that transport juveniles or adults—plants on trailered boats, docks, lifts, resident boats—seem more likely

2. “Super-spreader” lakes: not infestation sources
    a. High boater traffic, but genetics shows (so far) that they have not infested other lakes
    b. Inspection/decontamination programs must be working (on Mille Lacs and Prior), should be continued and expanded

3. Mussels spread locally in lake-rich regions
    a. One or more original introductions from outside the region
    b. After this—local spread (overland and downstream)
    c. Vectors spreading mussels locally must be identified and blocked

Invasions in Cass and Itasca Counties

Brainerd Lakes: 1 unique genetic cluster (yellow shading) found nowhere else



Sand/Little Sand lakes: independent invasion from afar

Includes Cass and Winnibigoshish Lakes (Cass was likely infested from Crow Wing Co.)

Management implications for Mississippi headwaters

- Invasions of northern Cass and Itasca County lakes
  - Cass Lake was likely infested from Crow Wing source
  - Downstream spread to Winnie
  - But Sand Lake: independent invasion from afar
  - Vectors and pathways spreading mussels into this new lake rich region must be identified and blocked

Vectors of zebra mussel spread to inland lakes

- "Natural" spread through interconnected waterways
  - Downstream dispersal of veliger larvae or other life stages (e.g. rafting juveniles)

- Overland via recreational boating
  - Veligers in water (in hulls, live wells, etc.)
  - Mussels attached to vegetation (entangled on trailers, motors, etc.) or to docks, lifts, boat hulls

Stream connections greatly increase risk for invasion of MN lakes

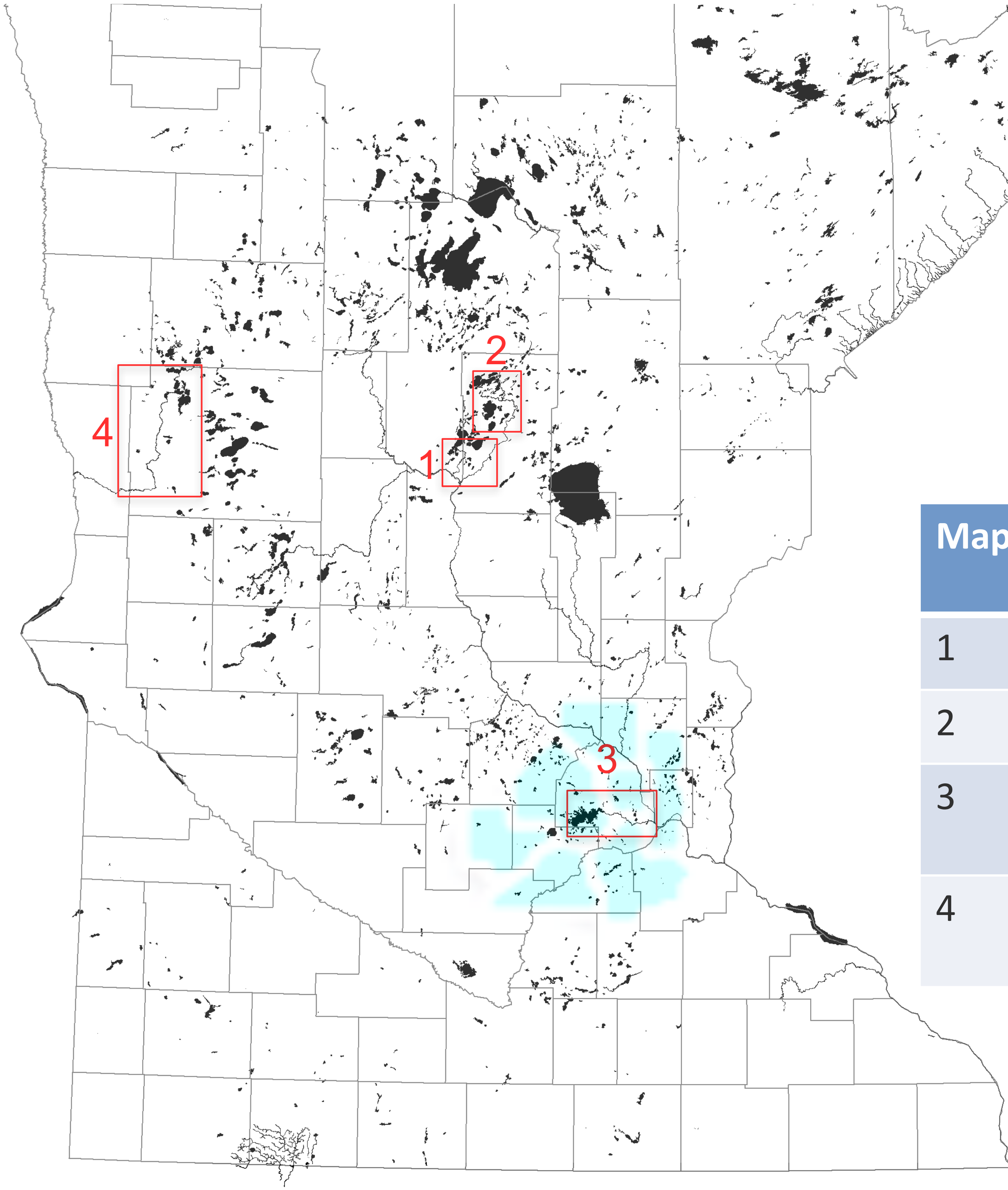
Infested	Not connected	Connected
No	12851	1742
Yes	391	604
% Infested	2.95	25.7

Lake connectivity and zebra mussel infestations in MN. Values in cells are numbers of comparisons (n > 15,500) between focal infested lakes [n = 91 (as of 2015)] and all other lakes located ≤ 30 km from the focal lakes. Lakes that are connected to focal infested lakes are infested with zebra mussels 8.7 times more frequently that lakes that are not connected to focal infested lakes. A G-test of independence shows that infested/not-infested status was highly dependent on whether lakes were connected: $G_{adj} = 1199.4$, $P < 0.001$.

Downstream lakes are more likely invaded than upstream lakes

Infested	Upstream	Downstream
No	1663	79
Yes	451	153
% Infested	21.3	65.9

Location up or downstream of infested lakes influences the likelihood of infestation for connected lakes. Values in cells are numbers of comparisons between focal infested lakes and other connected lakes ≤ 30 m from the focal lakes (see text for details). For downstream connected lakes, the per cent that are infested was found to be 3.1 times the per cent of upstream connected lakes that are infested. G-test of independence: $G_{adj} = 187.06$, $P < 0.001$.



Map	River/stream	Study years
1	Gull River	2014
2	Pine River	2015
3	Minnehaha Creek	2015
4	Pelican River	2014, 2015

Downstream drift studies in Minnesota

- Samples, at increasing distances downstream from the infested lake, ending near the inlet:
  - **Settlement** of juvenile mussels; reproductive season (June-October)
  - **Veliger** concentrations (June-October); 150 L water pumped and 50-micron filtered

Bottom line for management

- In small streams (< 30 feet wide) settlement is limited to stream bottom just downstream of source lake
  - Adult populations will not establish on stream bottom far downstream
  - Limits threat e.g. to freshwater mussel populations

Bottom line for management

- Instead, streams are high-risk "conduits" for spread to downstream lakes by larvae
  - Millions to billions of larvae per day travel to lakes over short stream distances
  - Rapid decline with distance, but long distance transport occurs (e.g. Pelican, Pine River systems)

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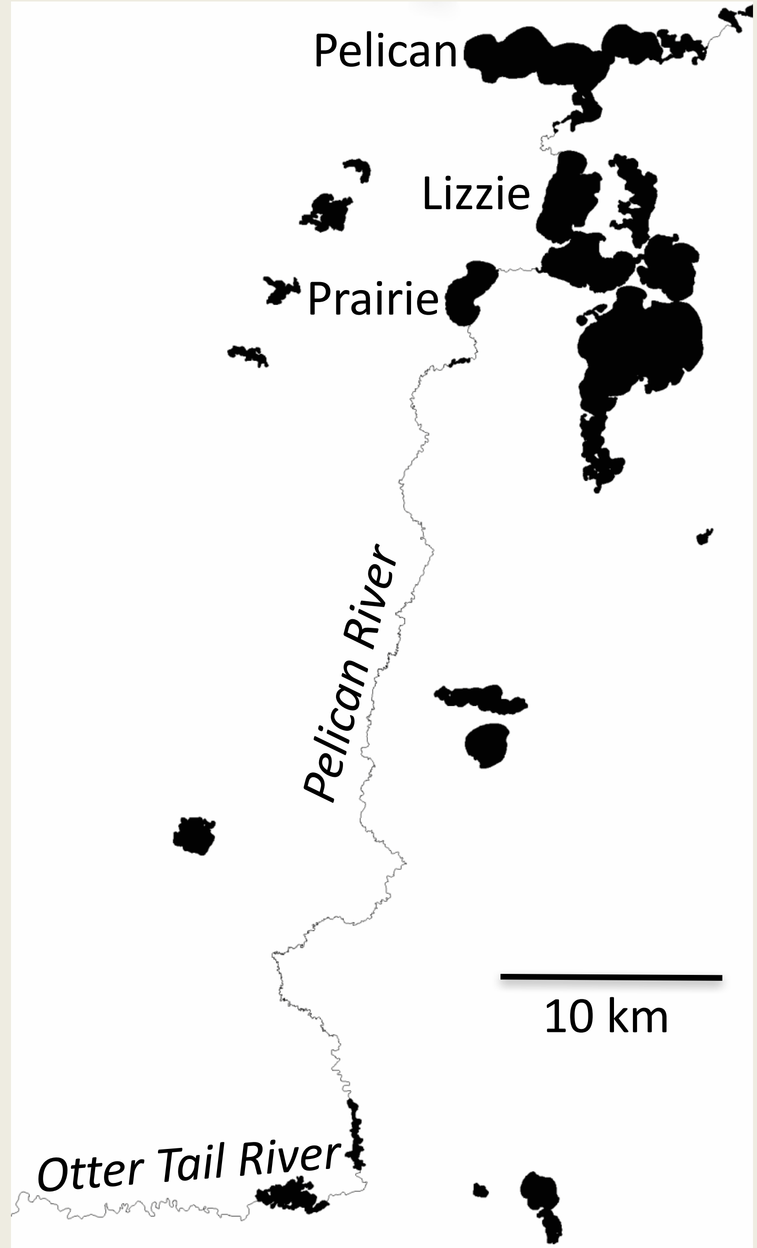
Bottom line: management

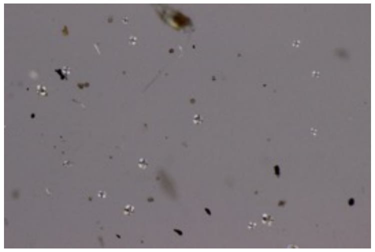
- Instead, streams are high-risk “conduits” for spread to downstream lakes by larvae
  - Headwater lakes should be prioritized for prevention and treatment

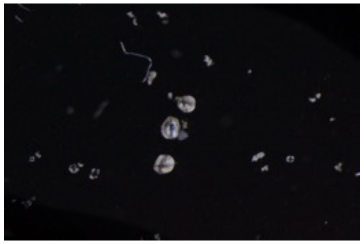


Spread of zebra mussel veligers in residual water

- Residual water remains in boats after reasonable attempts to drain

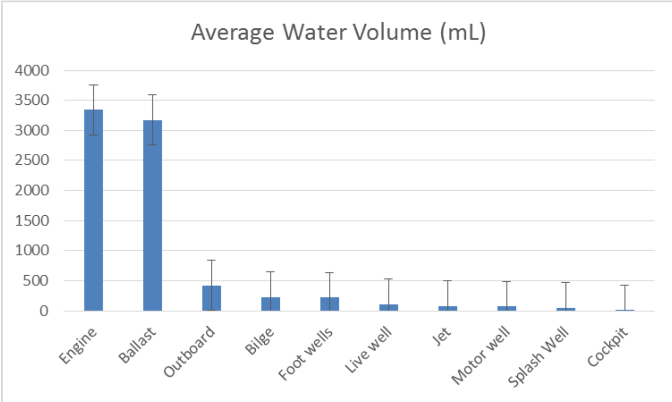
- Water contains veliger larvae
  - How many?
  - Variation across vessel types, compartments
  - Survival upon arrival at next water body



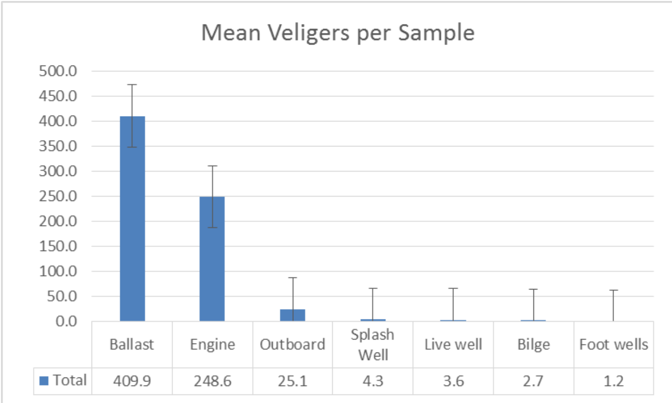


Spread of zebra mussel veligers in residual water

1. Live wells and other recreational boat compartments:
   a. Low residual water volumes
   b. Veliger numbers are small



2. I/O engines and ballast tanks
   a. Higher volumes and veliger counts
   b. Veligers do not survive (in field samples)

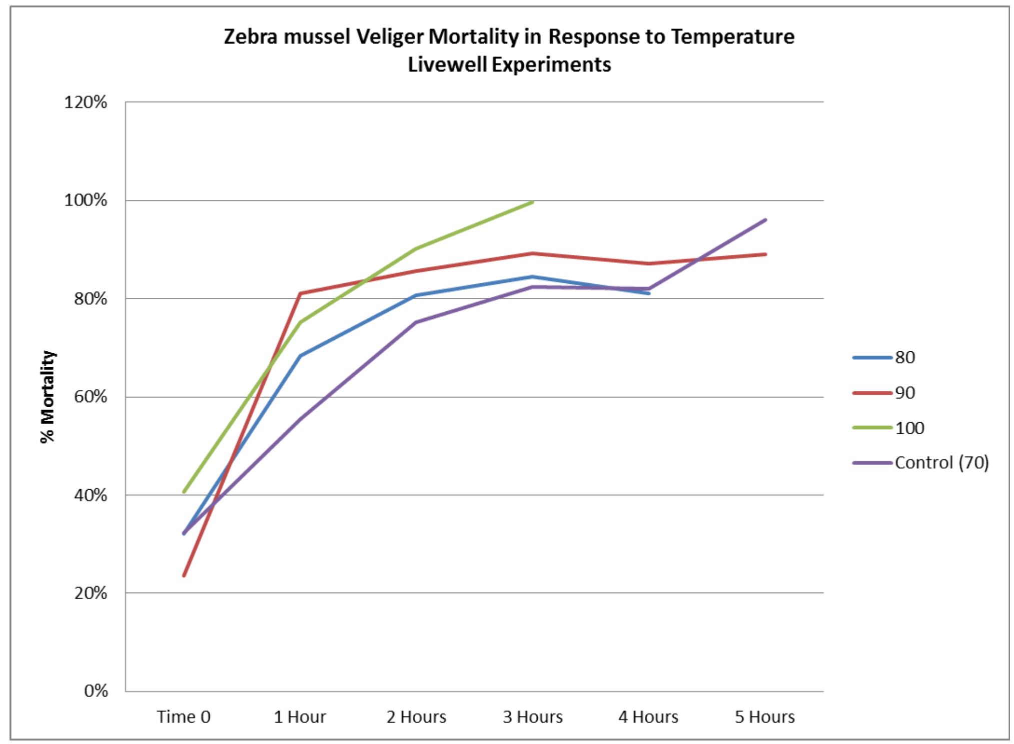


Experiments on zebra mussel veliger survival

3. Experimental live well chambers

   a. Survival declines across realistic temperature range

   b. >/= 90% mortality after 6 hours



Sampling larvae pumped from Lake Minnetonka into a ballast bag Adam Doll, Rosie Daniels

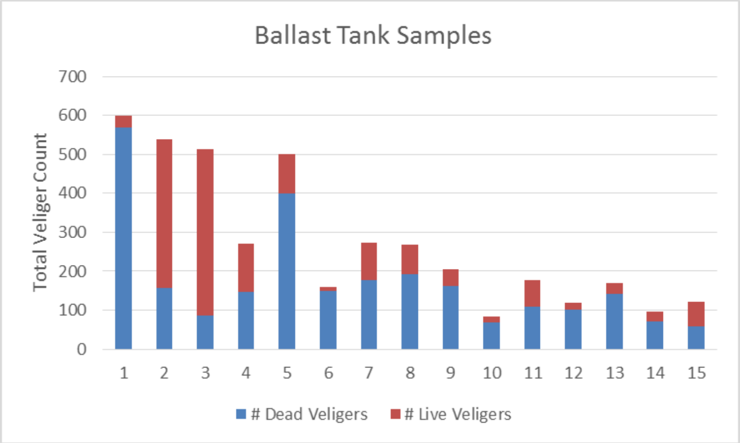
Photos by David Hansen

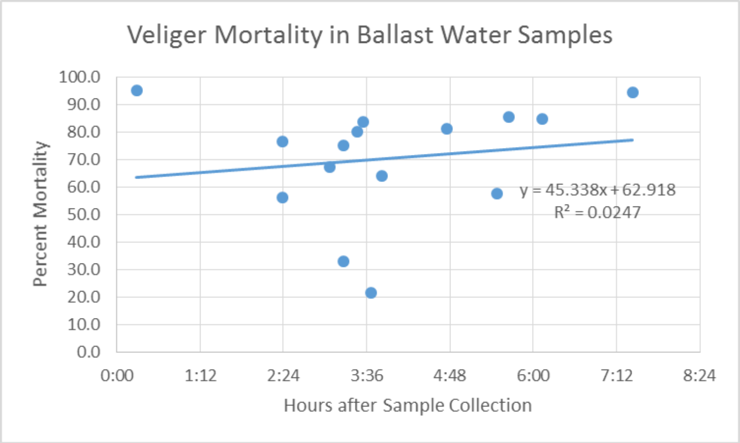
Experiments on zebra mussel veliger survival

4. Experimental ballast bag samples

    a. High variation in veliger counts and survival

    b. A few samples contain moderate numbers of live veligers (hours after collection)





What can be done to control or eliminate zebra mussels?

- Mechanical controls
  - Hand harvest
  - Draw downs

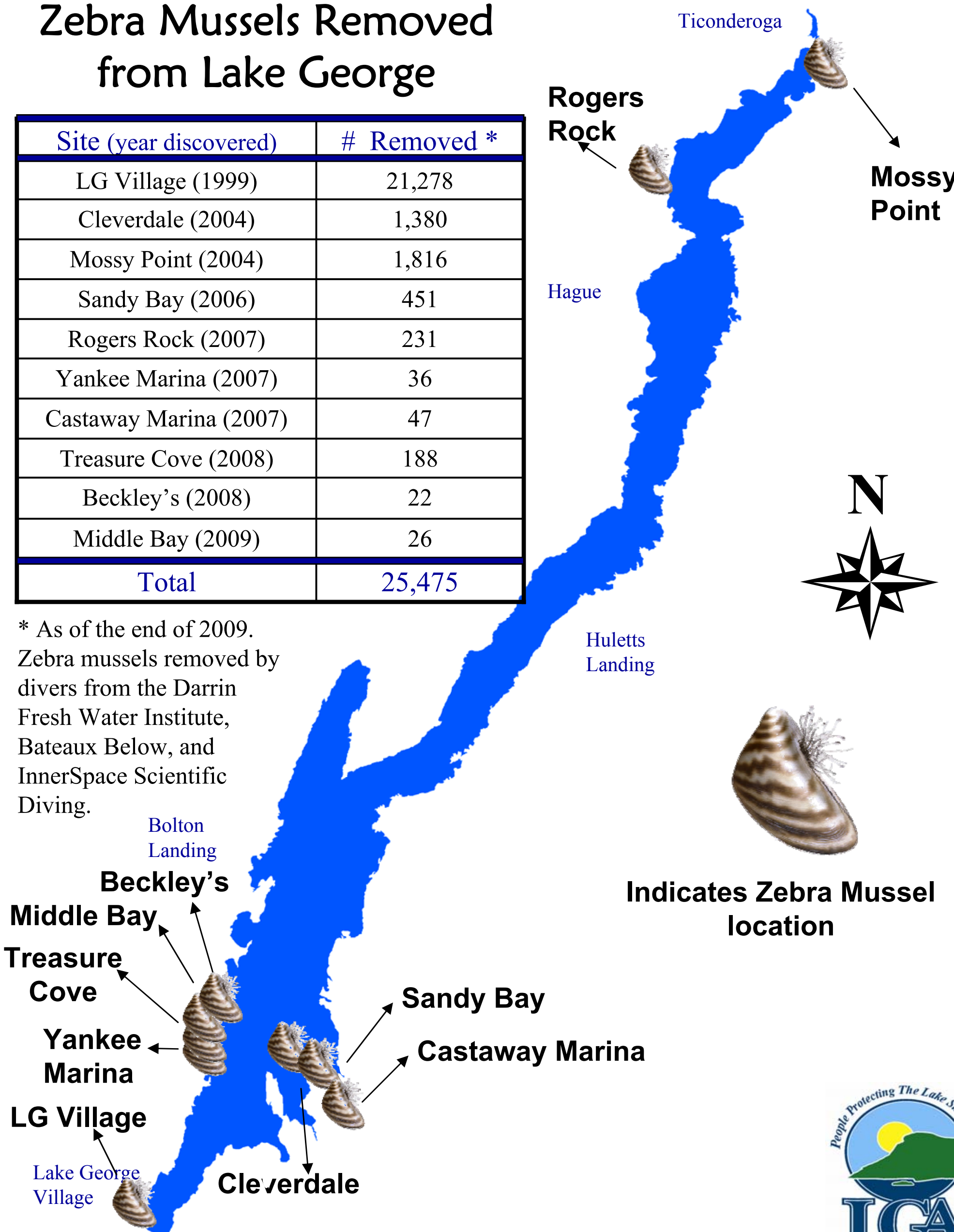
- Biological control

- Chemical treatment

Zebra Mussels Removed from Lake George

Site (year discovered)	# Removed *
LG Village (1999)	21,278
Cleverdale (2004)	1,380
Mossy Point (2004)	1,816
Sandy Bay (2006)	451
Rogers Rock (2007)	231
Yankee Marina (2007)	36
Castaway Marina (2007)	47
Treasure Cove (2008)	188
Beckley's (2008)	22
Middle Bay (2009)	26
Total	25,475

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



Indicates Zebra Mussel location

Image: RPI, Troy NY

For more info about zebra mussels or to learn more about the LGA & how to support its work, go to www.lakegeorgeassociation.org.

LGA Lake George Association

Chemical treatments for zebra mussels in Minnesota

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

Strategies for chemical control

1. Research on chemical treatment of newly infested lakes

   a. Assisting in management efforts—new information on treatment methods, efficacy

   b. Developing monitoring protocols for trial lakes (MN DNR “Pilot Projects”)

Christmas Lake pesticide treatment trials, 2014-2015

Lessons learned: Lund et al. (in press) *Lake and Reservoir Management*

Strategies for chemical control

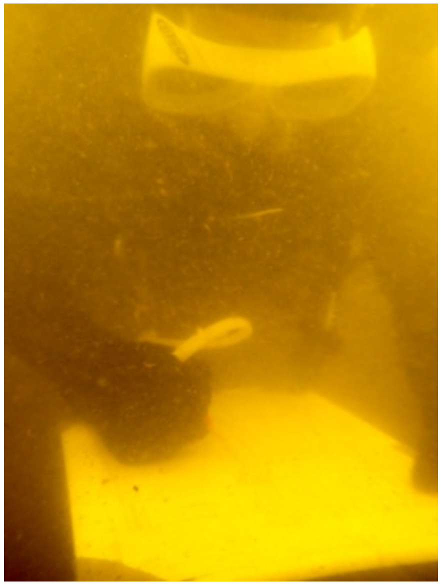
c. MAISRC-funded research on SCUBA survey designs for mussels at low density (when they are treatable)

K Cattoor, MN DNR

Rensselaer Polytechnic Institute, Troy NY

Strategies for chemical control

c. MAISRC-funded research on SCUBA survey designs for mussels at low density (when they are treatable)



<u>Quantitative ecology</u>
John Fieberg, Co-PI
Jake Ferguson (Postdoctoral)

<u>Zebra mussel biology/ecology</u>
Michael McCartney, Co-PI

<u>Field crew</u>
Divers: Naomi Blinick (lead), Leslie Schroeder.
Sarah Baker (field assistant)

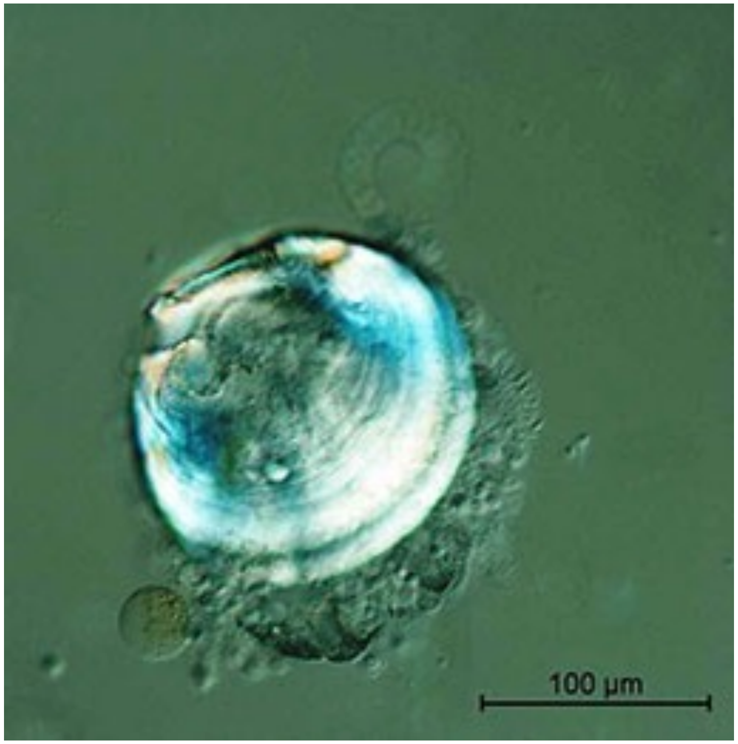
Strategies for chemical control

2. Reducing populations by targeting larvae with low dose chemical treatments

Photos by David Hansen

Strategies for chemical control of mussel larvae

- If higher sensitivity of larvae, in lab, is found with in-lake testing:
  - Larvae could be targeted with lower doses, larger treatment areas, fewer effects on native animals
  - Control of zebra mussel populations by reducing annual "settlement" of larvae may be feasible



CA Dept. Fish and Wildlife

Larval toxicity testing in an infested lake

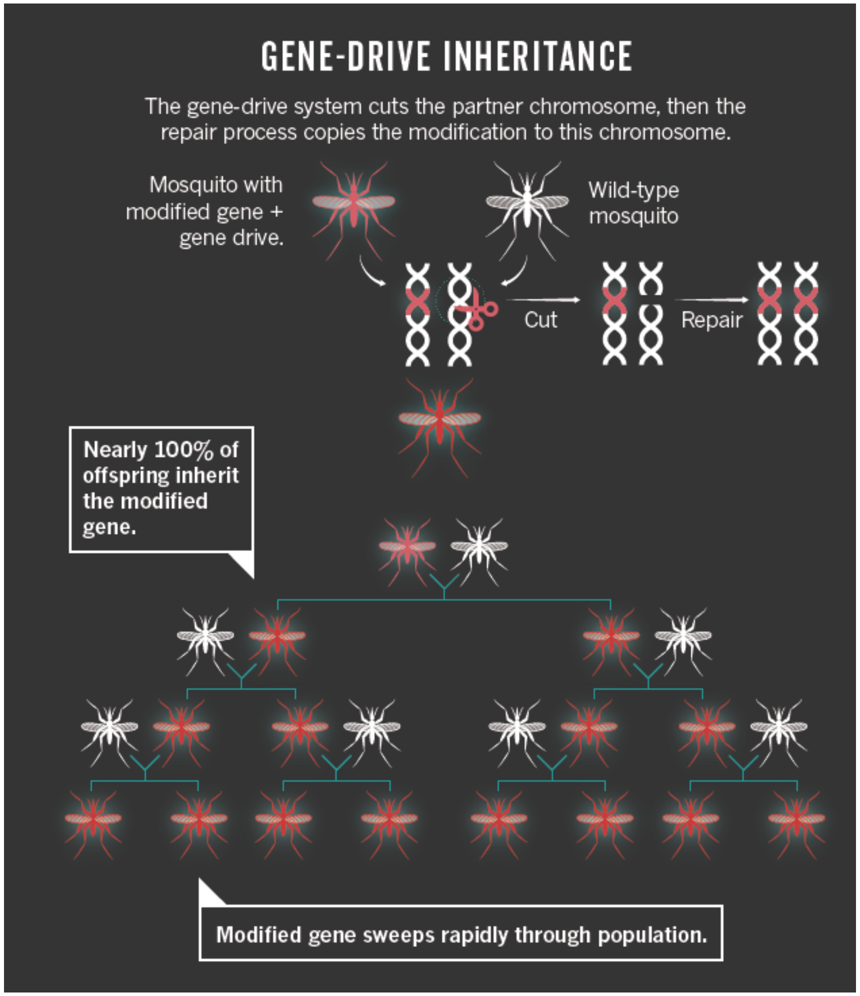
- We tested EarthTecQZ^{TM} (a highly toxic zebra mussel pesticide) on larvae, in Lake Minnetonka
  - Dose-response (2016): > 100 times more toxic to larvae (in-lake) than to adults (in-lab)
  - Exposure time (2017): 100% of larvae removed from the water column in about 3 days at low dose (1/16th dose used in MN lake treatments)

2016: Robinson's Bay

2017: Minnetonka Regional Park (by David Hansen)

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
  - Genes for shell formation (calcium threshold)
- Genetically edit target genes, insert into zebra mussels for eventual trial releases in lakes

Thanks: genetics and genomics

MnDNR Keegan Lund, Mark Ranweiler, Dan Swanson, Rich Rezanka and several others for help collecting

USGS Dr. Wendylee Stott, Dr. Mary Anne Evans **NOAA** Ashley Baldridge Elgin; **INHS** Jeremy Tiemann for collecting from lower Great Lakes

McCartney Lab Dr. Sophie Mallez, Melody Truong

UMN Genomics Center K Beckman, D Gohl, S Anderson, J Garbe, B Auch

MN Supercomputing Institute K Silverstein

Funding: Clean Water, Land and Legacy Fund (2014-2016); Environment and Natural Resources Trust Fund (current), MAISRC, Gull Chain of Lakes Association, Pelican Lakes Association.

CLEAN WATER LAND & LEGACY AMENDMENT

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Thanks: downstream spread

UMN Grace Van Susteren, Sarah Peterson, Sendrea Best, Peter Xiong, Max Kleinhaus (field and lab assistants)

RMB Labs Moriya Rufer for discharge data, help and advice in the Pelican River Watershed

MnDNR Joshua Prososki for discharge data on the Pelican River

USACE Corrine Hodapp for discharge data on the Pine River

Funding Clean Water, Land and Legacy Fund, MAISRC, Gull Chain of Lakes Association, Pelican Lakes Association

CLEAN WATER LAND & LEGACY AMENDMENT

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

Thanks: residual water

MnDNR Ann Pierce, Heidi Wolf, Adam Doll, Watercraft Inspection Program staff

McCartney Lab Adam Doll, Rosemary Daniels

MAISRC Becca Nash

Brunswick FWBG, New York Mills Plant for constructing experimental live well chambers (for free)

Tonka Bay Marina For sampling of I/O engines, ballasts and other logistical support

Funding: MAISRC, Tonka Bay Marina, Brunswick Freshwater Boat Group, MN DNR, Mr. Gabriel Jabbour

TONKA BAY MARINA

BRUNSWICK
New York Mills Operation

DEPARTMENT OF NATURAL RESOURCES

Thanks: chemical control projects

UMN Max Kleinhaus, Melody Truong, Sarah Baker, Sonia Ehrlich (field and lab assistants); Sophie Mallez

Minnehaha Creek Watershed District E Fieldseth, J Sweet

BlueWater Science Consulting Steve McComas; **Dan Molloy** for histological work**; PLM Lake & Land Management Corp.** Patrick Selter, for performing the molluscicide treatments; **Christmas Lake Homeowner's Association** Joe Schneider (President), Christmas Lake residents, and the city of Shorewood for the Christmas Lake project

Three Rivers Park District B Vlach, A Smith for Minnetonka work

MnDNR Rich Rezanka, Marc Bacigalupi for SCUBA survey work, Keegan Lund, K Pennington, H Wolf and several others in the EWR program

Funding Hennepin County AIS Grants Program, MAISRC

Questions??

www.maisrc.umn.edu

Email: mmccartn@umn.edu

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

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