ILLINOIS NATURAL HISTORY SURVEY
PRAIRIE RESEARCH INSTITUTE

13 SEP 2016

ILLINOIS NATURAL HISTORY SURVEY SEMINAR SERIES

ACHIEVING CONTROL OF ZEBRA & QUAGGA MUSSELS THROUGHOUT ENTIRE LAKES:

NO, THIS IS NOT JUST WISHFUL THINKING

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Molloy & Associates, LLC

Zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*) are the "poster children" of high-impact aquatic invasive species, and there is a growing interest in the selective control of these dreissenids in open waters, like lakes and rivers. To be economically feasible, a control agent is needed that is applied just once, is self-spreading throughout an entire water body, and subsequently gives multi-year lake-wide control. There is only one kind of control agent capable of that — a live control agent. This type of control method is not just wishful thinking, and examples will be presented that support the existence of such a hypervirulent parasite — an organism with the potential to turn the tide against dreissenids across North America — an organism with the potential to so reduce dreissenid populations that their ecological and economic impacts are likewise drastically reduced.

3:00 PM

FORBES NATURAL HISTORY BUILDING, ROOM 1005
1816 S. OAK ST, CHAMPAIGN

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The Illinois Natural History Survey seminar series is organized by the INHS Seminar Committee.

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ACHIEVING CONTROL OF ZEBRA & QUAGGA MUSSELS THROUGHOUT ENTIRE LAKES
(*No, This Is Not Just Wishful Thinking*)

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September 13, 2016

Illinois Natural History Survey Seminar Series

University of Illinois

Urbana-Champaign, Illinois

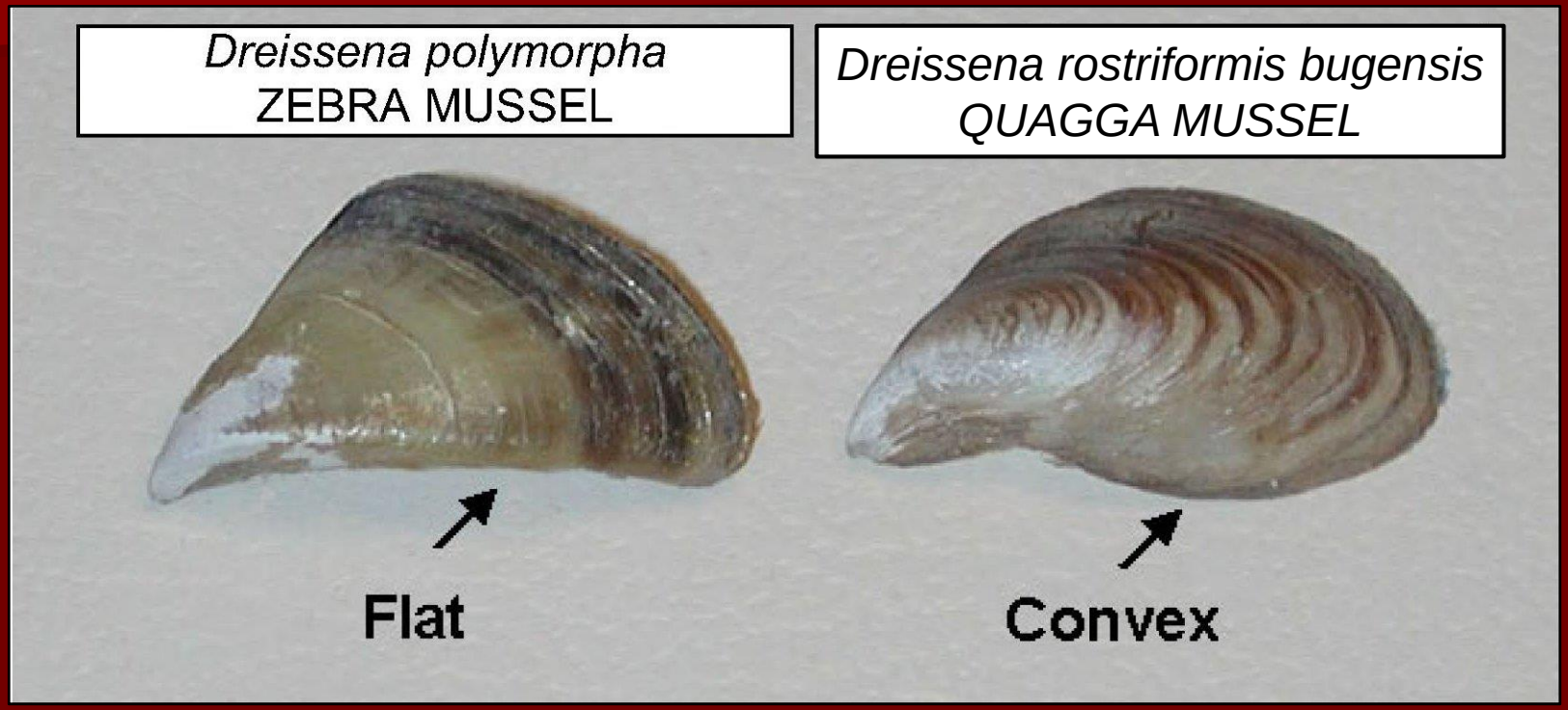
My Background

- Biologist
- Aquatic
- Freshwater
- Invertebrates
- Diseases
- Parasites and pathogens
  - Fundamental: Life cycle, ecology, taxonomy, phylogeny
  - Applied: Potential use for biocontrol of pest species

Some Aquatic Invertebrate Parasite Projects

- Stoneflies
- Rotifers

- Mosquitoes
- Black flies
- Dreissenid mussels (*Dreissena* spp.)
  - Zebra mussel
  - Quagga mussel


Dreissena polymorpha
ZEBRA MUSSEL
Dreissena rostriformis bugensis
QUAGGA MUSSEL
Flat
Convex


S. van Mechelen

BASICALLY THREE MAIN
TYPES OF IMPACTS WITHIN WATER BODIES….

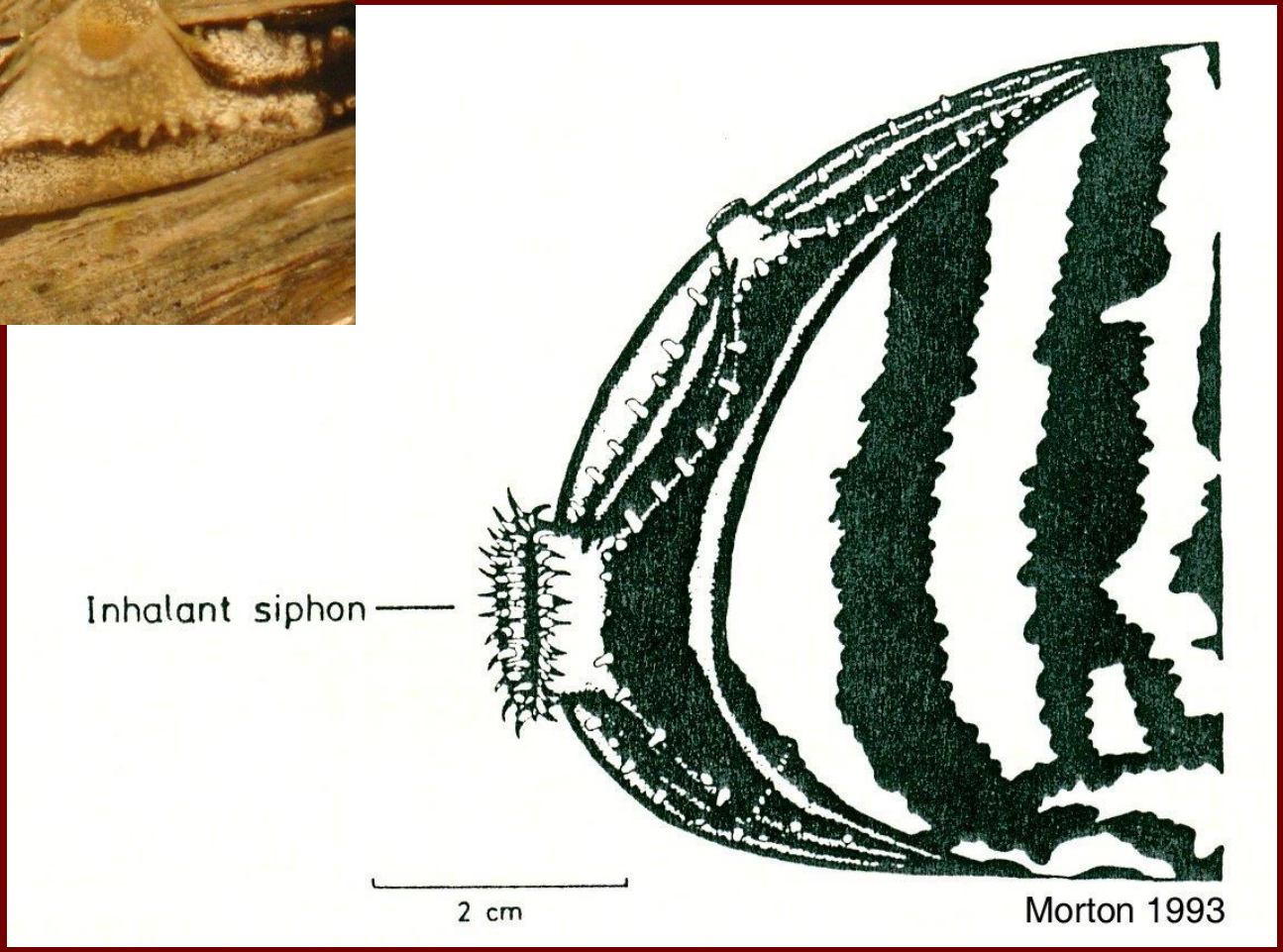
ECOLOGICAL

RECREATIONAL

INDUSTRIAL

KEY ECOLOGICAL IMPACTS

Ecological Impacts



Ecological effects of filtration by *Dreissena* spp.

- Decrease in phytoplankton
- Decrease in zooplankton
- Increase in water transparency
- Increase in macrophytes
- Alteration of fish community
- Alteration of benthic community

Eurasian water-milfoil

Native clam mortality (family Unionidae)

RECREATIONAL IMPACTS

Recreational Impacts

Fouling of recreation equipment…. boats, docks, boat lifts, etc.

Closure of recreational areas due to quarantine

San Justo Reservoir, California

Industrial Impacts

My Background

- Biologist
- Aquatic
- Freshwater
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- Diseases
- Parasites and pathogens
  - Fundamental: Life cycle, ecology, taxonomy, phylogeny
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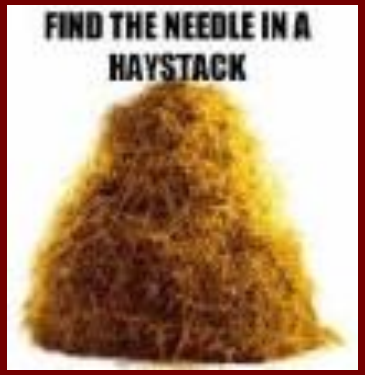
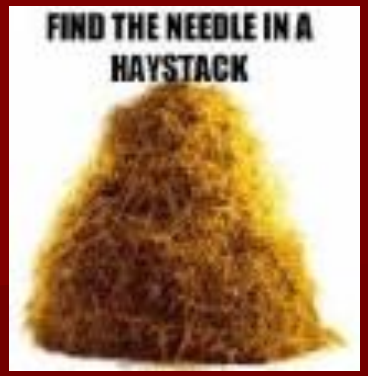
Another of my characteristics as a researcher…

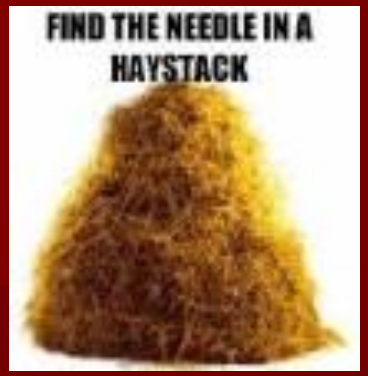
I’m attracted to solving problems that have been considered by many to be UNSOLVABLE

These projects typically involve looking for a needle in a haystack





But I’m picky about the needle-in-a-haystack projects I choose…



I am attracted to haystacks that I am convinced contain a needle that is an environmentally safe solution to an aquatic pest problem

….and the key requirement to finding that needle is being persistent, but also…

… it pays to have some tricks to accelerate finding the needle

… So today I want to tell you about a needle-in-a – haystack project I am pursuing and an unusual research trick/approach I've come up with to find the needle …..

- The PROJECT is to drastically reduce quagga and zebra mussel populations across North America…. To be able to control them THROUGHOUT entire water bodies for decades
- My TRICK is to let a hypervirulent parasite do the dirty work

Two parts of my talk today…..

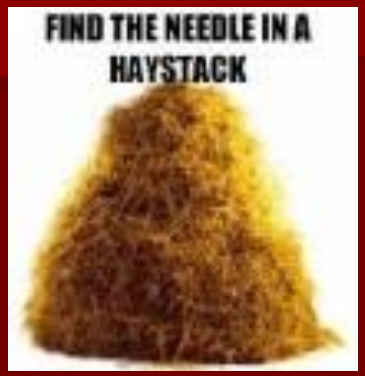
1. Briefly tell you about research projects to develop biocontrol agents for aquatic pests that:

-- have beaten the odds
-- have disproven the doubters
-- have gone all the way to commercialization
-- are environmentally safe

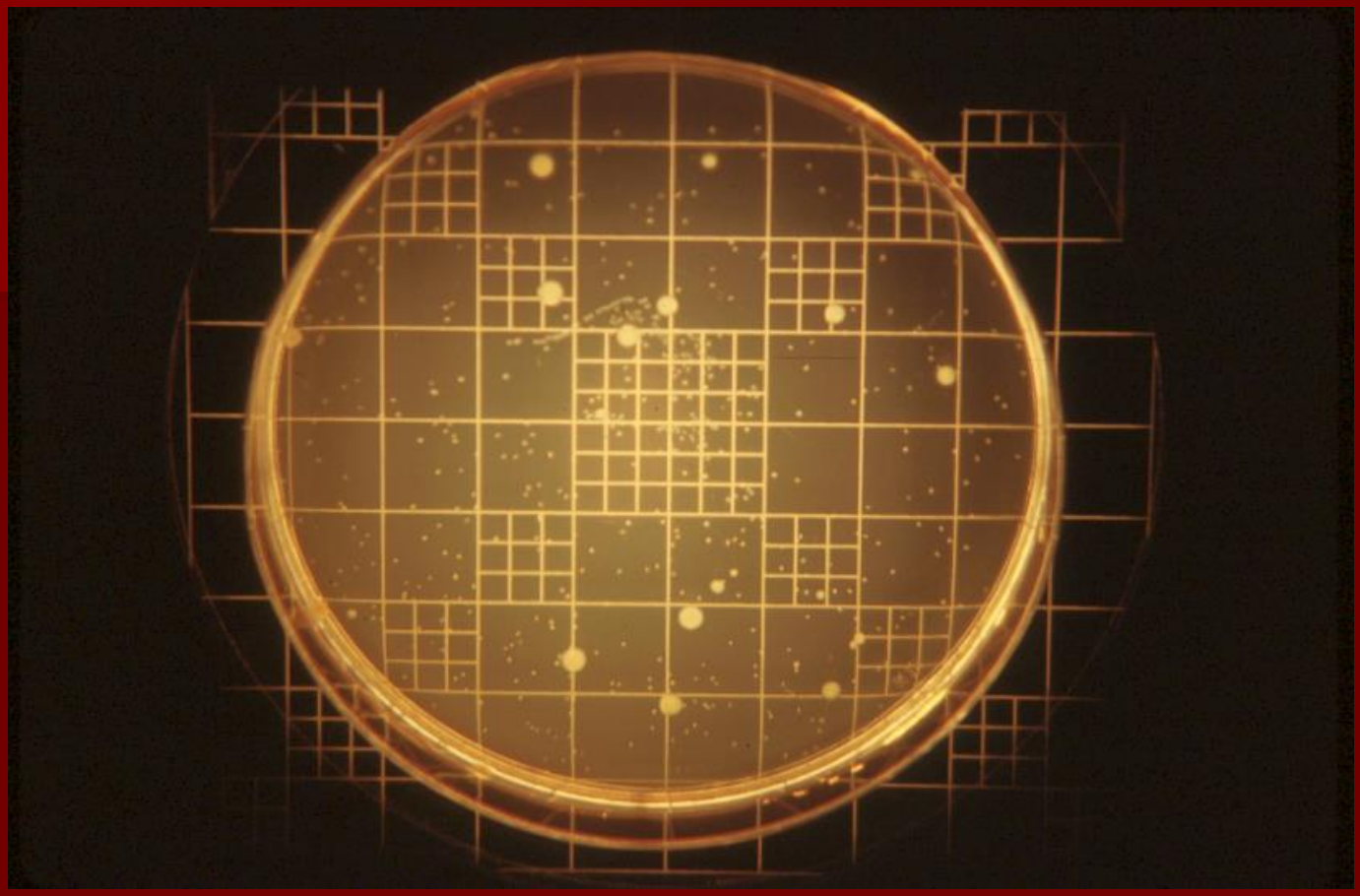
2. Tell you about my ongoing research to develop an OUTSIDE THE SHELL control agent that will achieve lake wide control of dreissenids and be…..

….. effective in drastically reducing dreissenid populations
….. economical
….. environmentally safe

In this regard, my lab has had major commercial successes in R&D for the …



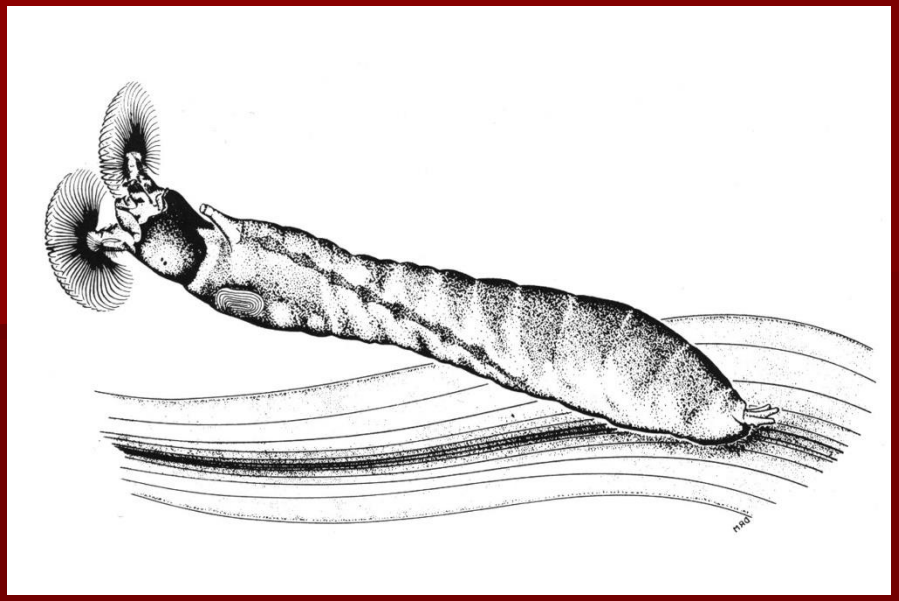
Biocontrol of black flies with the bacterium *Bacillus thuringiensis israelensis* (BTI) – a leader in this international effort



Bacillus thuringiensis israelensis

B t i

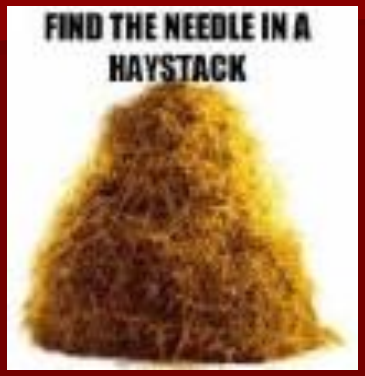
Treating streams and rivers with Bti to kill black fly larvae



Black fly larvae are filter feeders, using their cephalic fans to capture food particles moving downstream

The Bti particles are also captured by the cephalic fans and ingested…. leading to the larva's death following intoxication of midgut epithelial cells

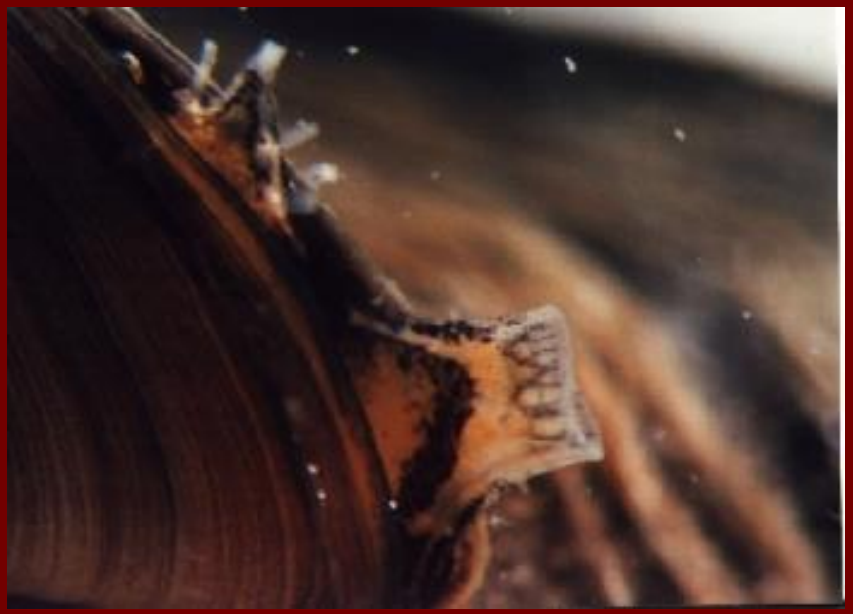
…. and my lab has also had major commercial successes in R&D for the …



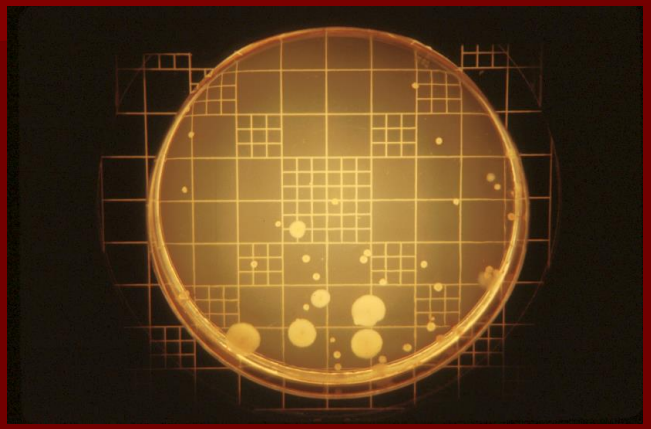
Biocontrol of dreissenids with the bacterium *Pseudomonas fluorescens*

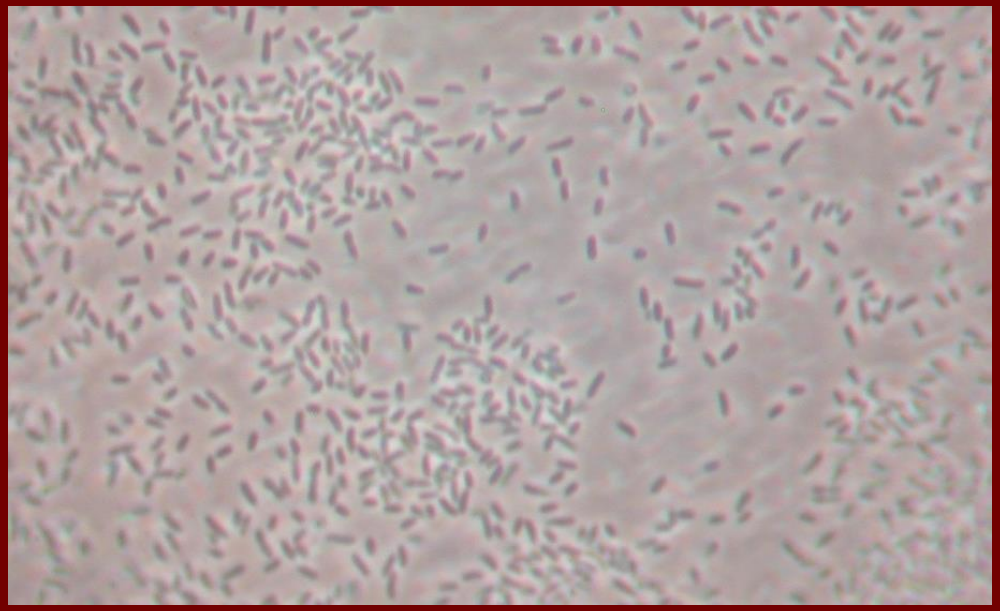
Like black fly larvae, mussels are also filter feeders

Thus… a project was launched to find another bacterium….
…. One capable of killing zebra and quagga mussels that could be used to control them in infested pipes



…. and a bacterium was found: *Pseudomonas fluorescens* strain CL145A





Specificity of *Pf*-CL145A cells (ai)

Freshwater ciliate
Colpidium colpoda

Zooplankton
Daphnia magna

Freshwater shrimp
Hyalella azteca

Trout
Salmo trutta

Mallard duck
Anas platyrhynchos

Fathead minnow
Pimephales promelas

7 Bivalve species

Bluegill sunfish
Lepomis macrochirus

Mytilus edulis, Pyganodon grandis, Lasmigona compressa, Strophitus undulatus, Lampsilis radiata, Pyganodon cataracta, Elliptio complanata

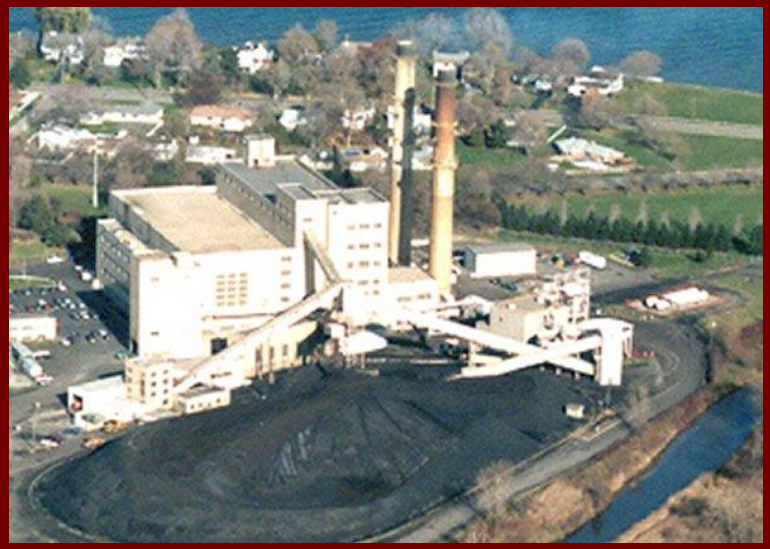
Degree of efficacy and selectivity of the commercial product Zequanox® to dreissenids now being comprehensively evaluated by USGS (Lacrosse, WI) and others labs in North America and Europe

Remains the most selective molluscicide for dreissenid control

Grateful acknowledgement to funders of this dreissenid control project

As its patent inventor, I take great pride that we now have the selective, eco-friendly, biocontrol agent Zequanox®……

…..that I see particularly useful for reducing dreissenid densities …



…. in infrastructures

…. and also in open waters for reducing dreissenid fouling in small, high-value areas, such as around marinas, beaches, and docks

…and in native mussel beds

Do we really need research on another dreissenid control agent in addition?

Yes, we do…

Here's why….

Unfortunately there is currently still no control method capable of drastically reducing dreissenid populations throughout an entire water body.

Why?

With little exception, successfully treating an entire water body is currently either:

- technically unfeasible
- economically prohibitive

or

- too environmentally degrading

Yes, there are commercially available control agents like Zequanox® capable of reducing dreissenid populations in small, high-value areas within infested water bodies, but these control efforts are so localized that they have little effect on reducing:

1) the continual spread of dreissenids from lake to lake

2) the ecological perturbations in the lake as a whole caused by the vast multitude of dreissenids still thriving elsewhere in the lake

3) the negative impacts on infrastructure operations

So…. Want to address these above three problems?

Then, we still need a control agent developed to drastically reduce dreissenids <u>throughout an entire lake</u>

And now the second part of my talk today…..

1. Briefly tell you about research projects to develop biocontrol agents for aquatic pests that:

-- have beaten the odds

-- have disproven the doubters

-- have gone all the way to commercialization

2.Tell you about my ongoing research to develop an OUTSIDE THE SHELL control agent that will achieve lake wide control of dreissenids and be…..

….. economical

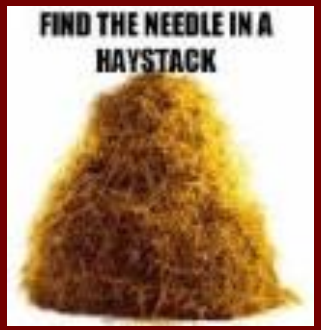
….. environmentally safe

….. effective in drastically reducing dreissenid populations

This will not be an easy task….!

These mussels have been migrating into Western Europe for a couple of hundred years and nobody has come up with as effective lake-wide control method

Thus, …..
--- control of dreissenids in entire lakes will be a very daunting challenge
--- another classic NEEDLE IN A HAYSTACK project



…and what might be key characteristics of such an extraordinary control agent?

To be ECONOMICALLY feasible it's got to be INEXPENSIVE

No organization has the money for lake-wide treatments and subsequent re-treatments of entire lakes

To be ENVIRONMENTALLY SAFE it's got to be very HOST SPECIFIC (the most essential and important characteristic of this control agent)

Thus the control agent ideally must be applied only once in a small area and be:

- self-perpetuating
- self-spreading

Thus, this control agent must be LIVE

It must be a biocontrol agent

…. and among all types of biocontrol candidates, parasites (not predators) are the most host-specific killing agents

Reviews in Fisheries Science, 5(1): 27–97 (1997)

Natural Enemies of Zebra Mussels: Predators, Parasites, and Ecological Competitors

Daniel P. Molloy,[1] Alexander Y. Karatayev,[2] Lyubov E. Burlakova,[2] Dina P. Kurandina,[3] and Franck Laruelle[1]

[1]Biological Survey, New York State Museum, The State Education Department, Cultural Education Center, Albany, NY 12230, [2]Lakes Research Laboratory, Belarusian State University, F. Skoryna Ave. 4, Minsk, 220050 Belarus; [3]Institute of Hydrobiology, Ukrainian Academy of Sciences, 12 Prospect Geroyev Stalingrada, Kiev-210 254655 Ukraine

ABSTRACT: This paper reviews the international literature on the natural enemies of *Dreissena* spp. and discusses the biology and ecology of organisms known to be involved in their predation (176 species), parasitism (34 species), and competitive exclusion (10 species). Research on natural enemies, both in Europe and North America, has focused on predators, particularly birds (36 species) and fish (15 and 38 species eating veligers and

So what is this “outside-the-shell” new bold approach using a LIVE biocontrol agent to drastically reduce dreissenid populations ????

Here are some clues….

What happened to American chestnut trees?

Fungus : American chestnut blight

What happened to elm trees?

Fungus: Dutch elm disease

In these two examples of drastic host population decline……

These species were/are "naïve" hosts infected by "novel" lethal parasites

"Novel" parasites are species or strains that the "naïve" host:

-- has not co-evolved with

-- has not developed an immunity to

-- has often been geographically separated from for millions of years

But… neither of these two “naïve” species examples were bivalves……..

You might be thinking … show me that this could happen with a bivalve …

…. and I’ll start to believe that maybe a “novel” parasite could be used to cause drastic population declines in naïve” North American dreissenids….

Eastern oyster
Crassostrea virginica

Up until the 1950s, eastern oyster populations were abundant and the industry thrived

Within a few years in the 1950s, 95% of the eastern oysters were lost in high salinity areas to a spore-forming disease called MSX…..

….and that spore-forming disease is still killing eastern oyster populations today in those areas …

… but now over 60 years later, resistance has increasingly developed…. following several initial decades of severe population suppression

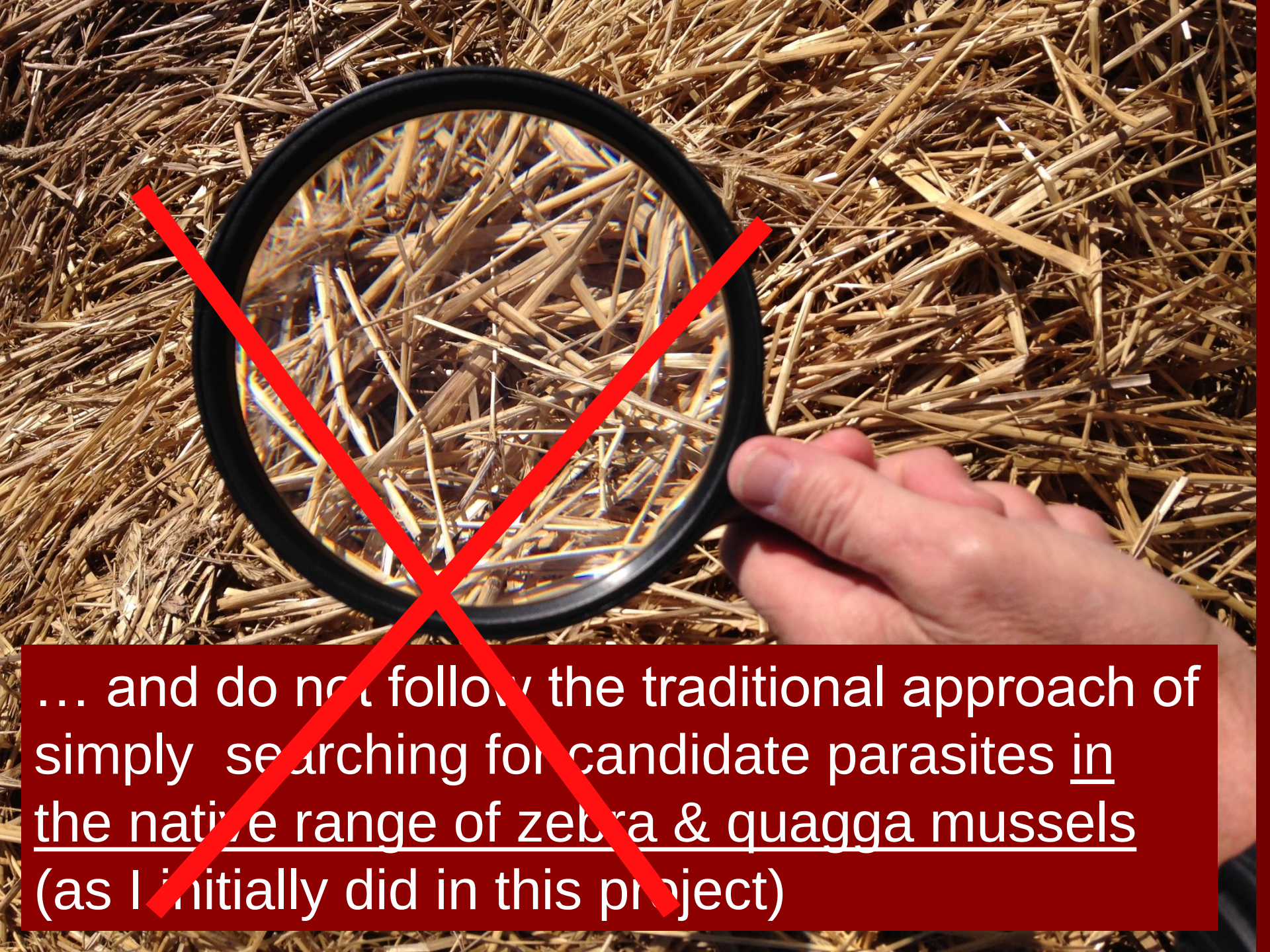
Now we know why this disease caused catastrophic declines in eastern oyster *Crassostrea virginica* populations

The parasite that caused this disease was actually a species that normally infects a related oyster, the Pacific oyster, *Crassostrea gigas,* in Asia.

The eastern oyster was a **naïve** host and it was exposed to a **novel** parasite *!!!*

YEP, THAT'S THE BOLD NEW PARADIGM OF THE BIOCONTROL APPROACH I'M TAKING

INTRODUCE A NOVEL PARASITE THAT OUR NORTH AMERICAN DREISSENIDS WILL BE NAÏVE TO

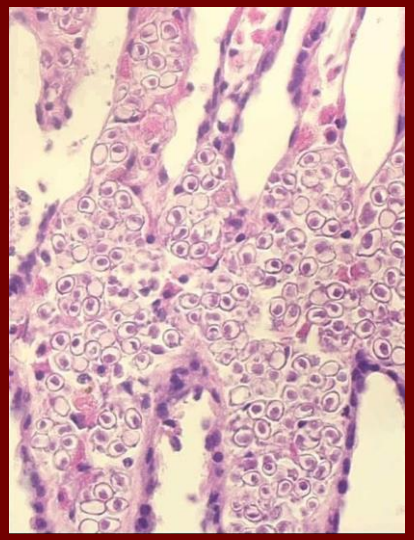


… and do not follow the traditional approach of simply searching for candidate parasites <u>in the native range of zebra & quagga mussels</u> (as I initially did in this project)

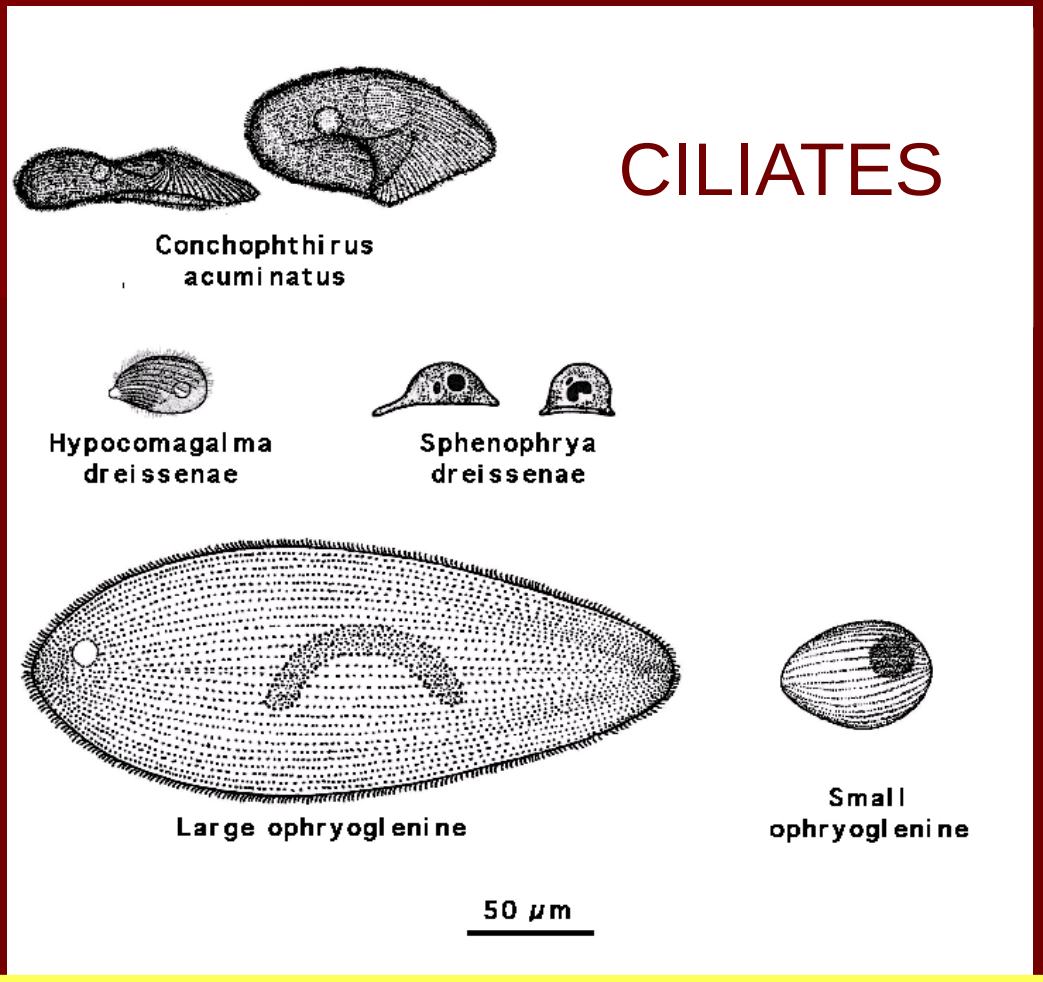
Instead… use an outside-the-shell approach, by searching for candidate parasites in the native range of a geographically-distant closely-related dreissenid species


Area in past that we have focused on looking for parasites in zebra and quagga mussels
Sweden
Finland
Norway
Russia
Estonia
Latvia
Lithuania
Belarus
Kazakhstan
Ireland
United Kingdom
Den-mark
Nether-lands
Belgium
Germany
Poland
Ukraine
Luxembourg
Czech Republic
Slovakia
Mol-dova
France
Switzer-land
Liecht.
Austria
Hungary
Romania
Slove-nia
Croatia
Georgia
Azerbaijan
Armenia
Monaco
San Marino
Bosnia and Herzego-vina
Serbia
Andorra
Portugal
Spain
Italy
Monte-negro
Bulgaria
Iran
Vatican City
Mace-donia
Al-ba-nia
Turkey
Greece
Syria
Iraq
Cyprus
Leba-non
Morocco
Algeria
Tunisia
Malta
Israel
Jordan
Saudi Arabia

Over those last 20 years we have found a variety of parasites in zebra and quagga populations… <u>but none with hyper-virulence</u>



Haplosporidian spores consume connective tissues



Trematode flat worms in dreissenid tissues


Area we have switched to… focusing on possible “novel” parasites from other dreissenid species
Iceland
Sweden
Finland
Norway
Estonia
Latvia
Den-mark
Lithuania
Kazakhstan
Ireland
United Kingdom
Belarus
Nether-lands
Poland
Belgium
Germany
Ukraine
Luxembourg
Czech Republic
Slovakia
Mol-dova
France
Switzer-land
Liecht.
Austria
Hungary
Romania
Slove-nia
Croatia
Georgia
Azerbaijan
Armenia
Monaco
San Marino
Bosnia and Herzego-vina
Serbia
Andorra
Portugal
Spain
Italy
Vatican City
Monte-negro
Bulgaria
Mace-donia
Al-ba-nia
Turkey
Greece
Syria
Iraq
Cyprus
Leba-non
Israel
Jordan
Saudi Arabia
Morocco
Algeria
Tunisia
Malta

There are about a half-dozen recognized ***Dreissena*** spp. in Europe and Asia Minor. Some are in saline habitats and will not be initially considered.

Dreissena presbensis - Macedonia, Albania & Greece

Dreissena blanci - Greece

Dreissena caputlacus - Turkey

Populations of ***Dreissena polymorpha*** (zebra mussels) and ***Dreissena rostriformis bugensis*** (quagga mussels) with evidence of long-term isolation will also be considered.

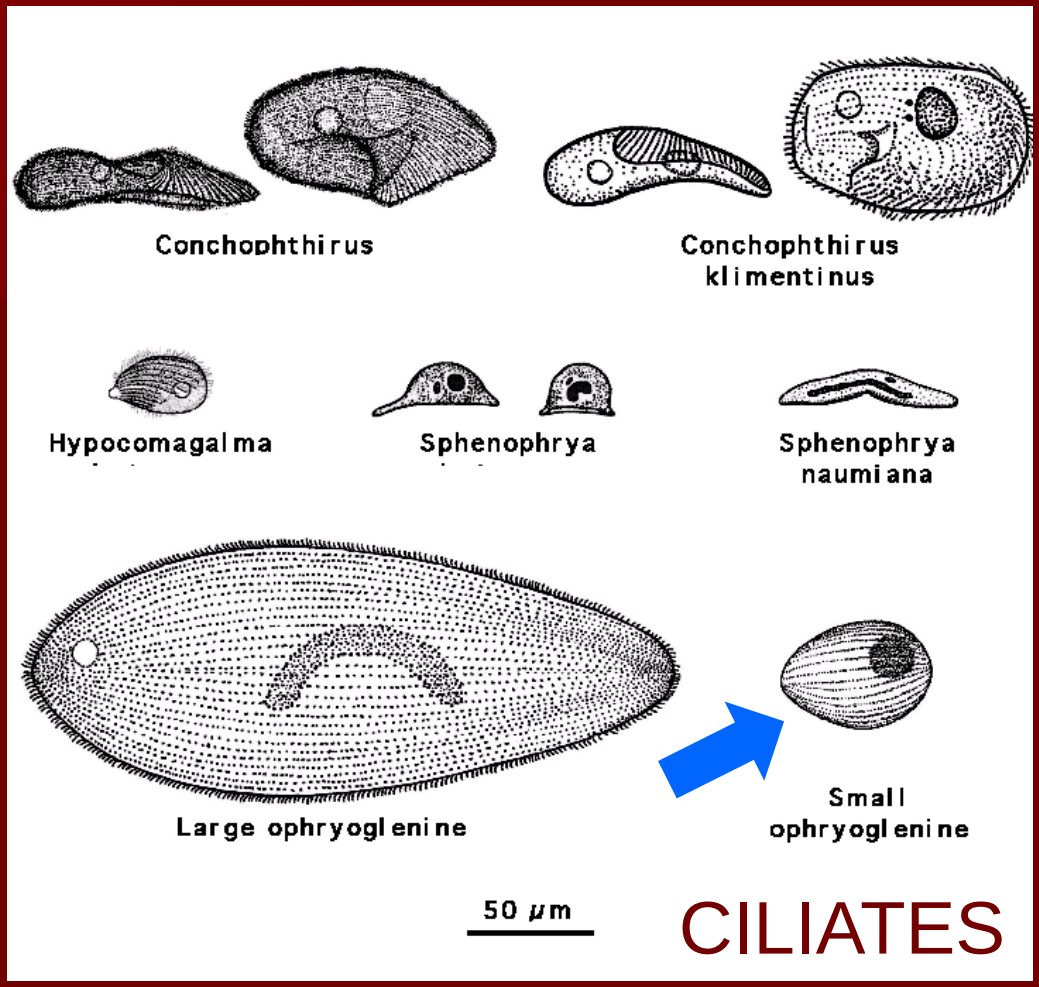
Lake Ohrid in Macedonia -- My favorite place to look for “novel” candidate parasites for controlling our “naïve” North American zebra and quagga mussels

There’s only one dreissenid species in this lake: *D. presbensis*

…and we have already found parasites in this dreissenid!

…. and in Lake Ohrid in *D. presbensis* in Macedonia we are finding morphologically similar parasites …… that sequencing indicates are NOT the same species as in zebra and quagga mussels

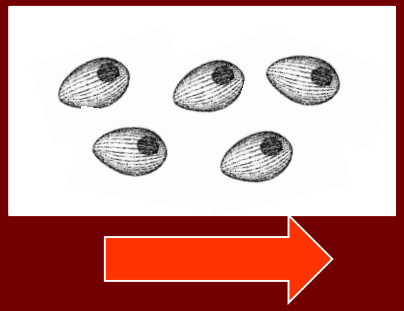
These are examples of potentially “novel” parasites that need to be screened for possible “hypervirulence” to zebra and quagga mussels



Next logical research step is to try to infect zebra and quagga mussels with parasites that have co-evolved with the Macedonian *D. presbensis*

Could some relatively harmless parasite from *D. presbensis* be hypervirulent to “naïve” zebra/quagga mussels and kill them?

D. presbensis



TAKE HOME MESSAGE

Will there ever be lake-wide biocontrol of dreissenids in North American waterbodies?

Don’t give up on the use of parasites for that purpose, as they can have long-term devastating impacts on naïve host populations.

To achieve this goal, I believe the solution will likely involve exposing our North American dreissenid populations to a parasite they have never ever encountered before…

…a parasite from a distant related dreissenid species found outside the native range of the zebra mussel or quagga mussel, as for example from *Dreissena presbensis* in Lake Ohrid, Macedonia