Zebra and Quagga Mussels: Changing North America's Freshwater Ecosystems

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The Most Notorious Aquatic Invaders

- Among the GISP list of the world's 100 worst invaders (only Zebra mussels)
- Eurasian mussels are among the worst aquatic invaders in North America
- Our current laws regarding aquatic invaders (NANCPA 1990, NISA 1996) were motivated by Eurasian mussels
- The have had enormous impacts on regional economies

Initial Invasion

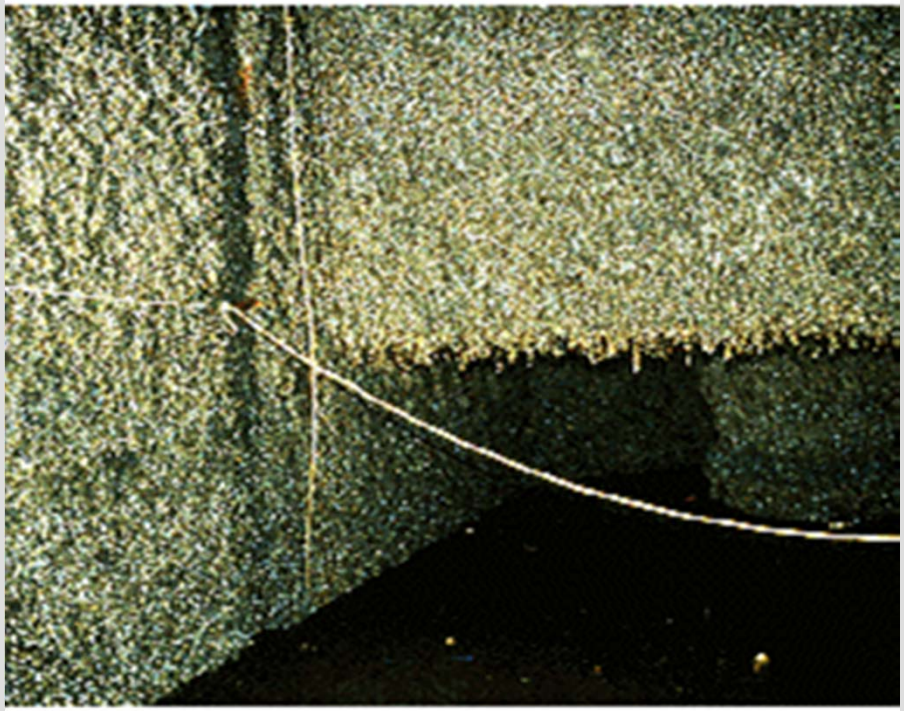
- Zebra mussels (*Dreissena polymorpha*) first invaded the Great Lakes in 1988 in Lake St. Clair
- They are widespread throughout Eurasia including drainages of Baltic, Black and Caspian Seas
- Quagga mussels (*Dreissena rostriformis* bugensis…long story) first invaded the Great lakes in 1991 in the Erie Canal and Lake Ontario
- They are native to the Bug, Dnieper and Prypyat Rivers in the Urkraine but have also spread subsequently

Impacts on Economies and Ecosystems

- The economic impacts on the Great Lakes have been immense
- Zebra mussels in the first several years were responsible for $1 billion annually (OTA 1993)
- They continue to cost $10s million annually in the Great Lakes region

A municipality or industry using Great Lakes water spends $350,000 annually to control zebra mussels

A large power plant typically spends $800,000 annually on control costs



Impacts on Economies and Ecosystems

- Eurasian mussels have resulted in substantial degradation of aquatic ecosystems
- Consequences of their invasion has impacted a wide range of ecosystem functions
- Threatened and endangered species, benthic biodiversity, primary production, disease transmission, concentration of contaminants, etc.

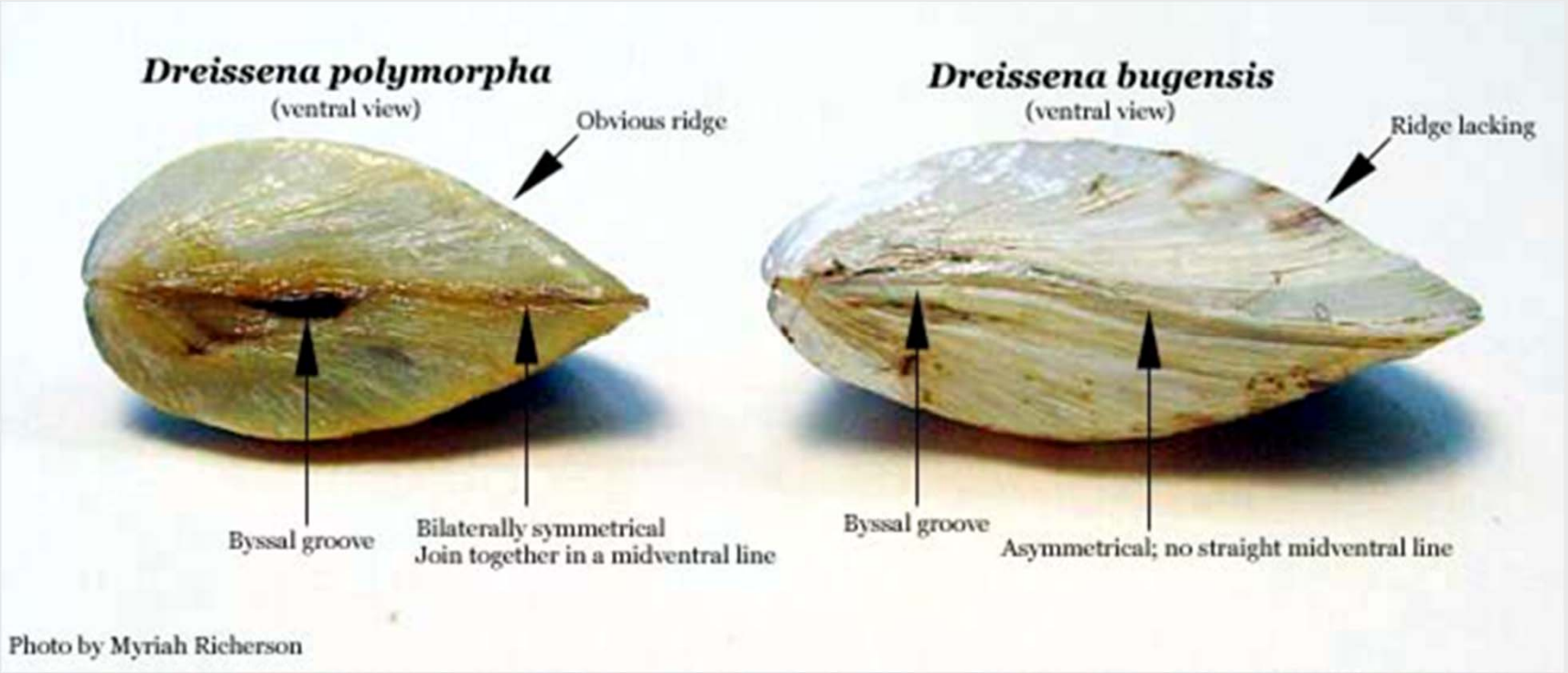
Talk Outline

- **Spread of Eurasian (=Dreissenid) mussels across the U.S.**
  - **Current distribution (native region and US)**
  - **Genetic patterns that describe spread**
- **Impacts in the Great Lakes and East**
  - **Human created structures**
  - **Ecosystem effects**
- **Spread and Impacts in the western U.S.**
  - **Human created structures**
  - **Potential ecosystem effects**

Zebra Mussels

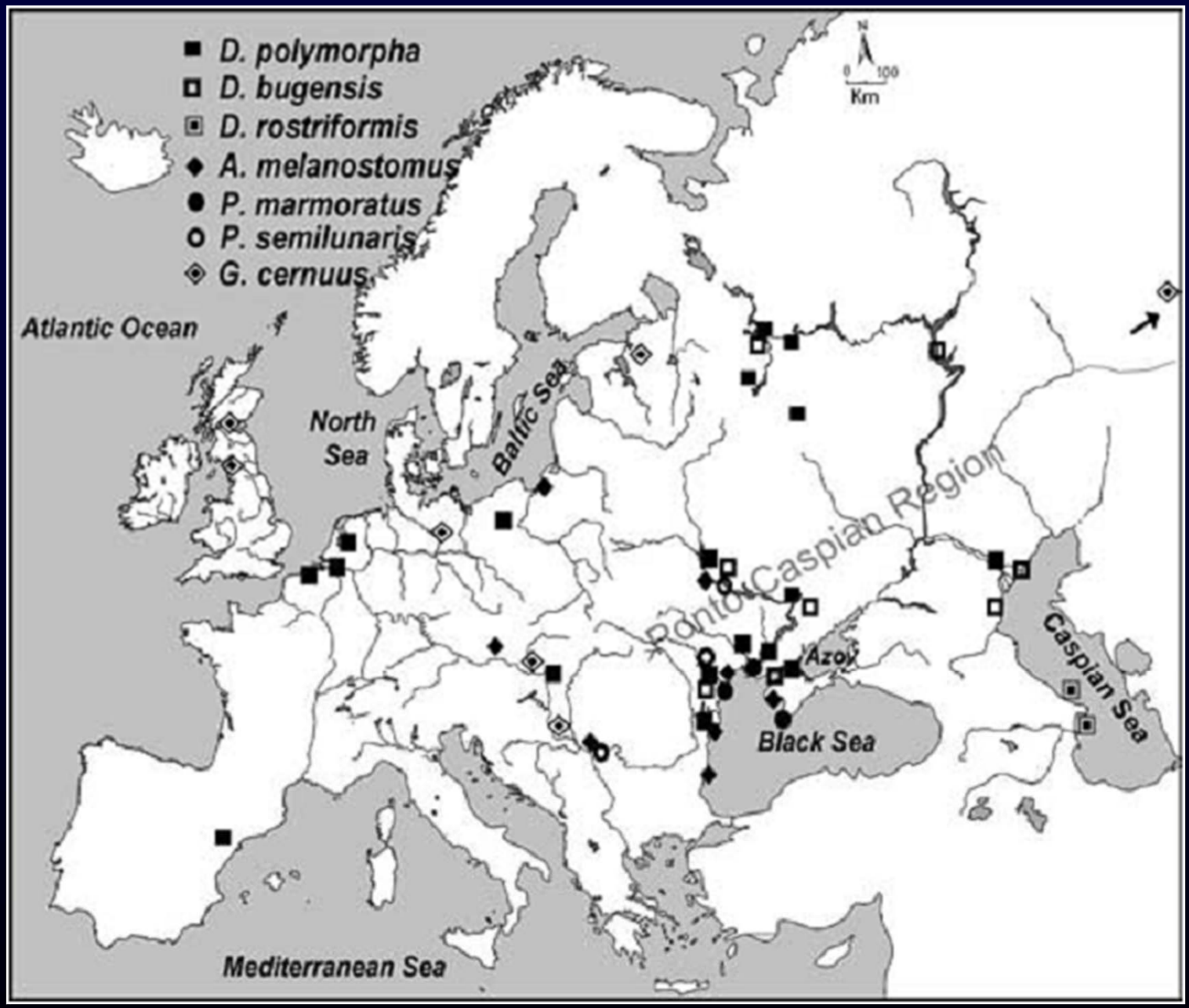
Quagga Mussels


(Actual size is 13 mm)


Dreissena polymorpha
(ventral view)
Obvious ridge
Byssal groove
Bilaterally symmetrical
Join together in a midventral line
Dreissena bugensis
(ventral view)
Ridge lacking
Byssal groove
Asymmetrical; no straight midventral line
Photo by Myriah Richerson

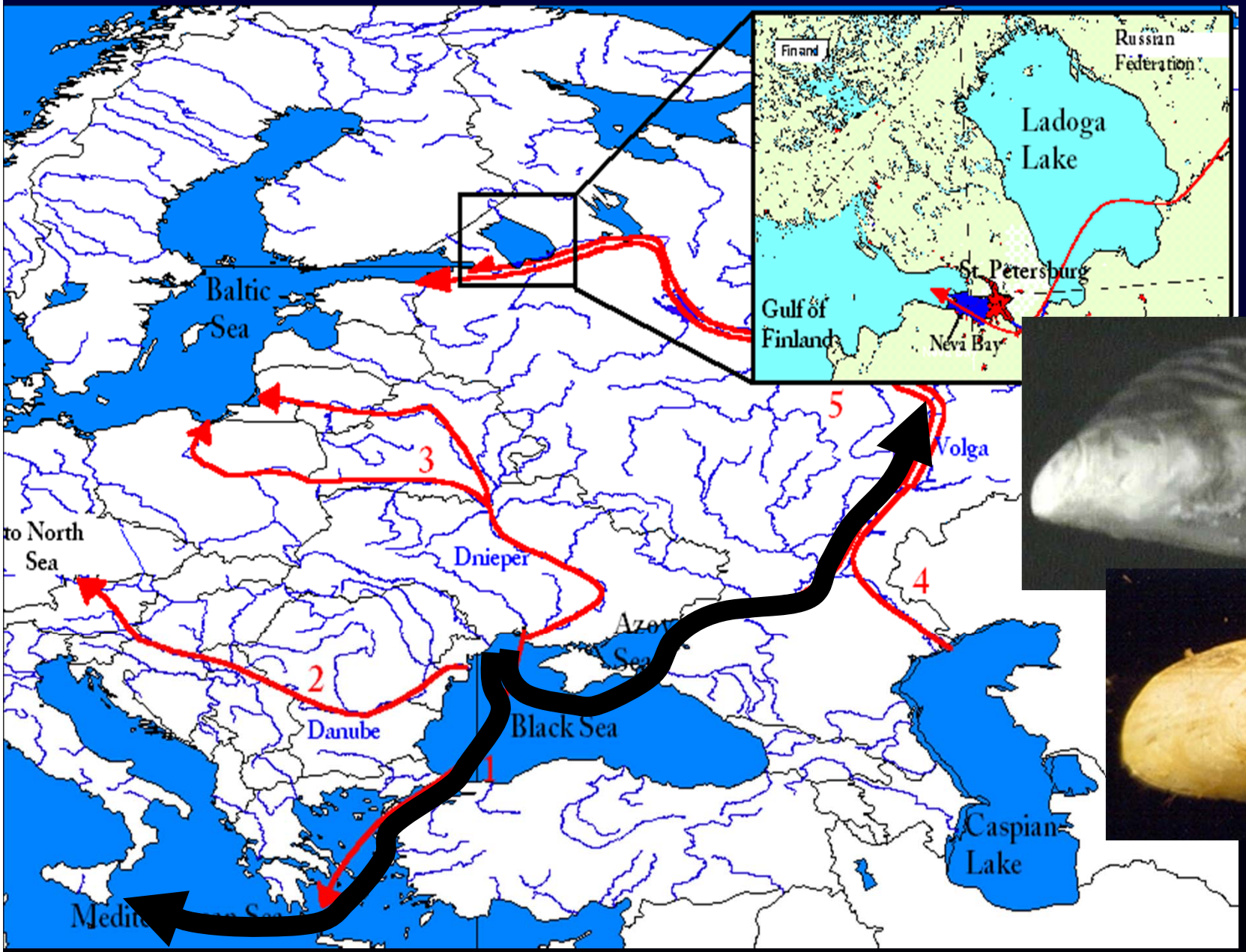
Zebras and Quaggas Can Hybridize

- **Although still separate species, new work (Voroshilova et al. *Biol. Bull.* 2010) have found interspecific hybrids (*D. polymorpha* x *D. bugensis*) using genetic markers**
- **Whether hybridization is likely or even possible in CA or the US is unknown**



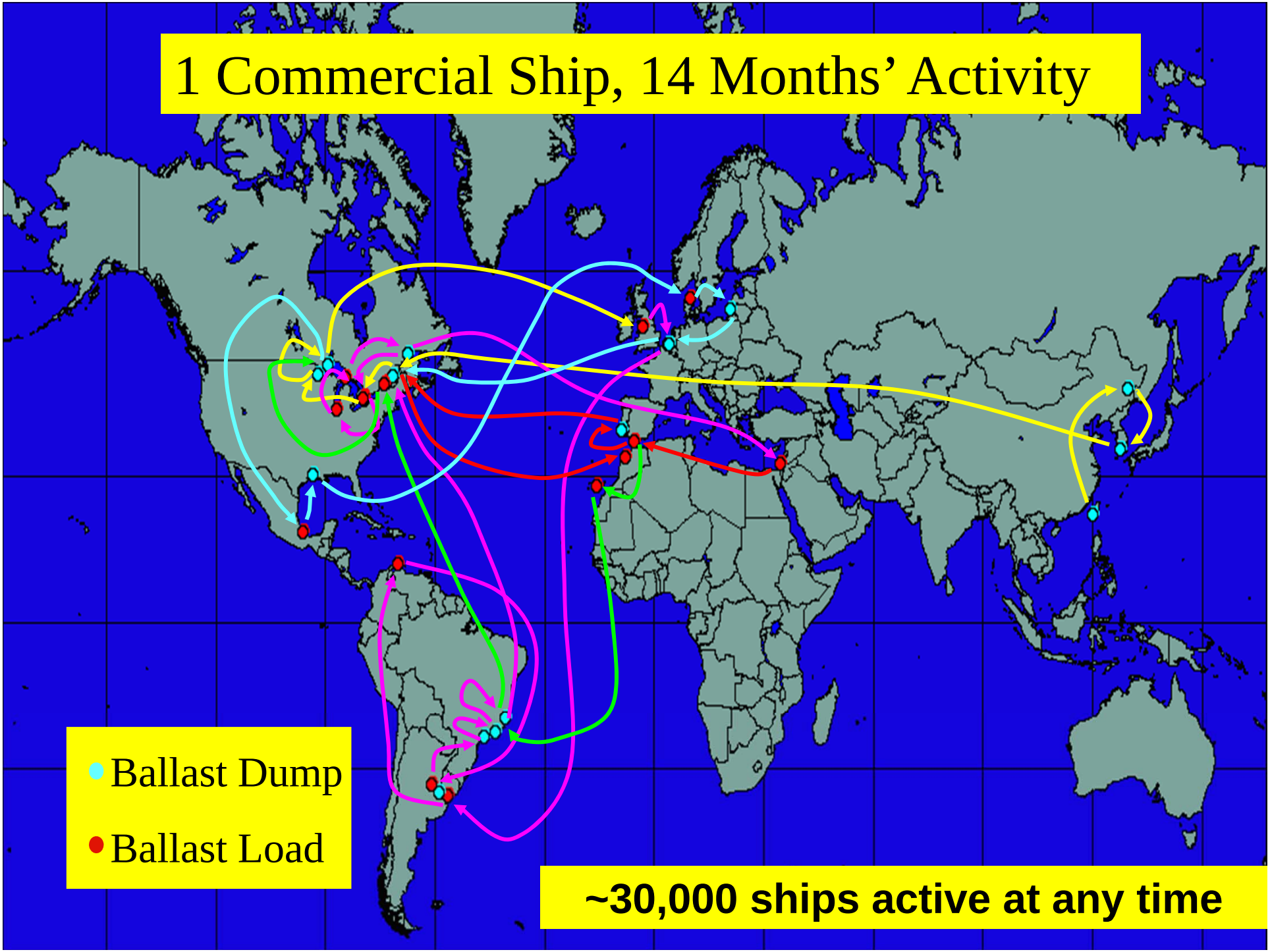
From Stepien et al. 2005

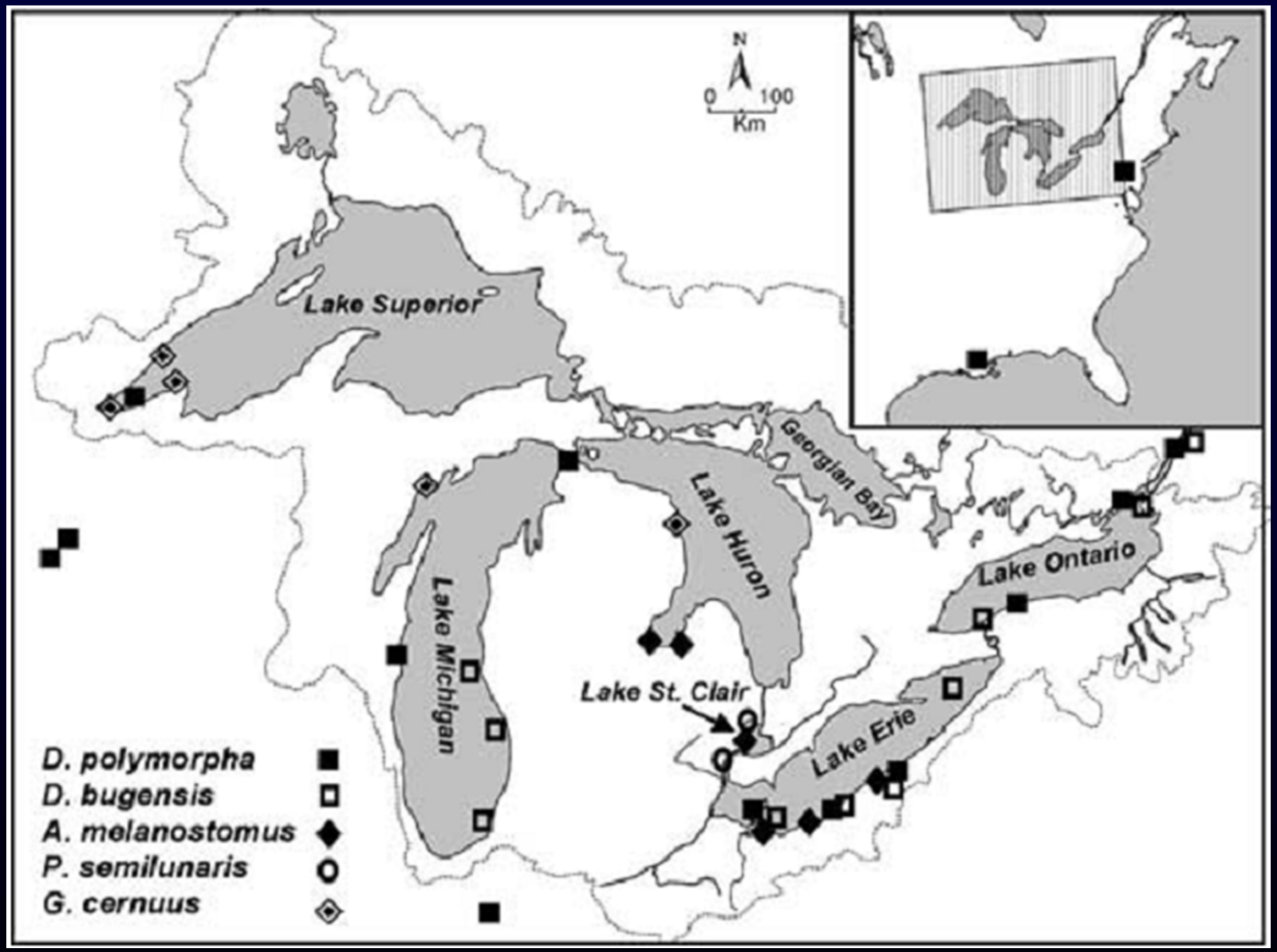
Quagga mussel (*Dreissena rostriformis bugensis*)



Data from MacIsaac

Pattern of spread based on genetic and distributional studies


1 Commercial Ship, 14 Months' Activity
Ballast Dump
Ballast Load
~30,000 ships active at any time

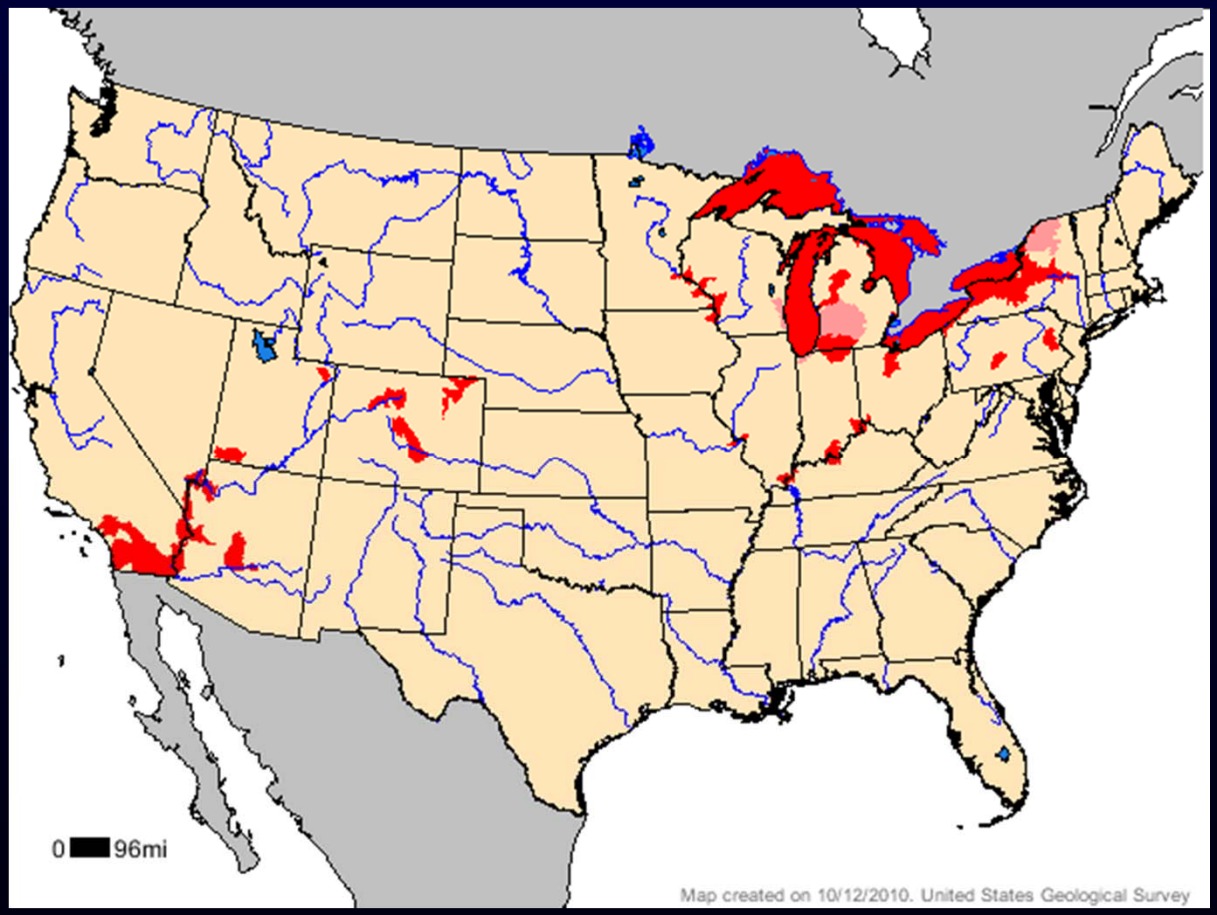


From Stepien et al. 2005

Spread of Mussels to US

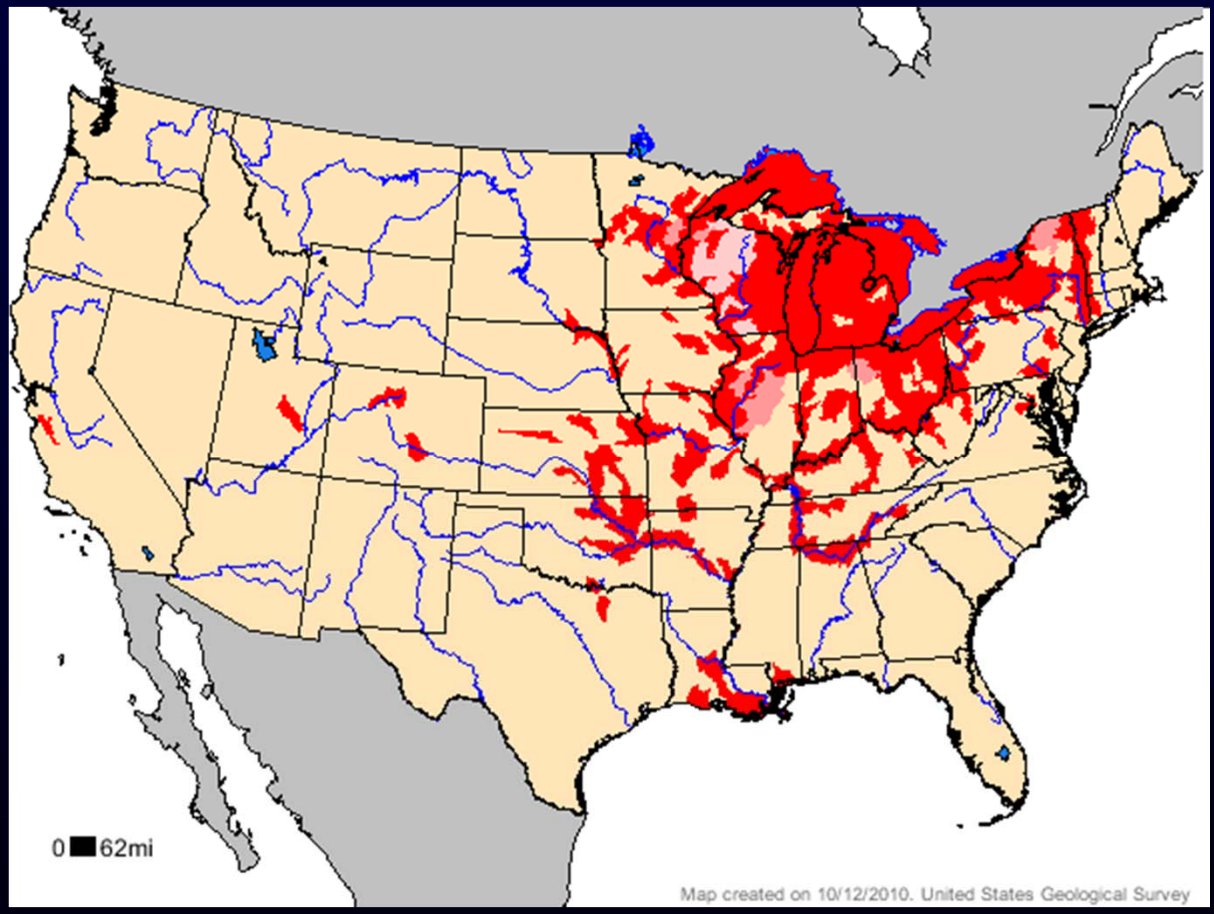
- Evidence from genetic studies strongly supports origin of zebra and quagga mussels from Ponto-Caspian region
- The introduced populations of both species in the US have high genetic diversity (Therriault et al. 2005)
- This suggests that there were multiple introductions over time or a very large pulse that initiated the introduction

Distribution of Quagga Mussels



From USGS 2010

Distribution of Zebra Mussels



From USGS 2010

Talk Outline

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  - Potential ecosystem effects

Zebra mussels (*Dreissena polymorpha*) in the Great Lakes

P.A. Berkman et al.

Long-Term Impacts in Great Lakes

- Recent summaries support long-ternm and dramatic impacts of Dreissenid mussels in Lake Michigan over a 20 year period (1988-2008) (Fahnenstiehl et al. 2010)
  - Loss of spring diatom bloom
  - Declines in phytoplankton productivity
  - Declines in some zooplankton (*Mysis*)
  - Increases in nitrogen and phosphorous
  - Increases in benthic plant productivity

Phytoplankton In Water Column

Rooted Aquatic Plants

Shift to Benthic Productivity

- Reduction of phytoplankton has increased the light penetration in several Great Lakes areas (Hecky et al. 2004)
- This has resulted in a substantial increase in macroalgae in the nearshore (Hecky et al. 2004)
- Among the consequences of is the production of anoxia or hypoxia (no or low oxygen) when algal mats decay

Contributing to Avian Botulism

- Among the potential consequences of hypoxic or anoxic areas is the contribution to the production of spores of *Clostridium botulinum* which causes 'Botulism'
- Avian botulism (Types C and E) have become a serious problem for loons, grebes, mergansers and other water birds in the Great Lakes (Riley et al. 2008)
- Dreissenid mussels may help to concentrate botulism toxins that may then be transferred to fish and then birds (Riley et al. 2008)
- However, the exact role of mussels in this disease pathway are uncertain

Concentrating Contaminants and Facilitating Invasions

- **Mussels changed contaminant concentrations and movement in the food web (Morrison et al. 1998)**
- **Mussels have facilitated the invasion of other non-native species (Ricciardi 2001)**
  - **The round goby *Neogobius melanostomus* became established, which preys on mussels**
  - **The amphipod *Echinogammarus ischnus* also became established, which uses habitat associate with mussels**

Zebra Mussels Overgrowing Native Mussel

Mussels in Hudson River, NY

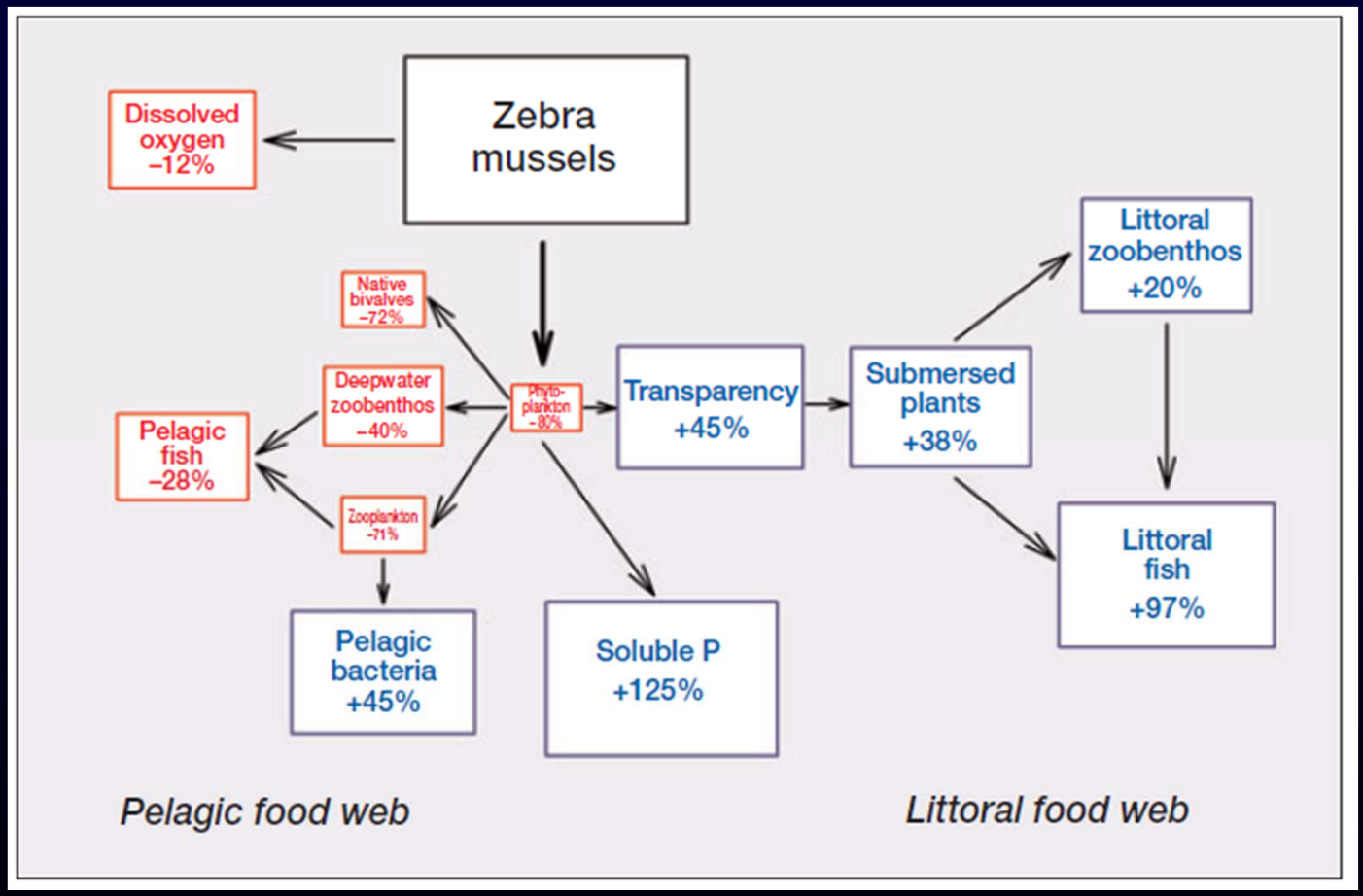
Impacts in Hudson River, NY

- One of the best studied systems regarding Eurasian mussel impacts
- By 1991, mussels were >50% of the live biomass in the river
- Zebra mussels created a clearance rate of 25-50% per day of river volume (Strayer et al. 1999)

Impacts in Hudson River, NY

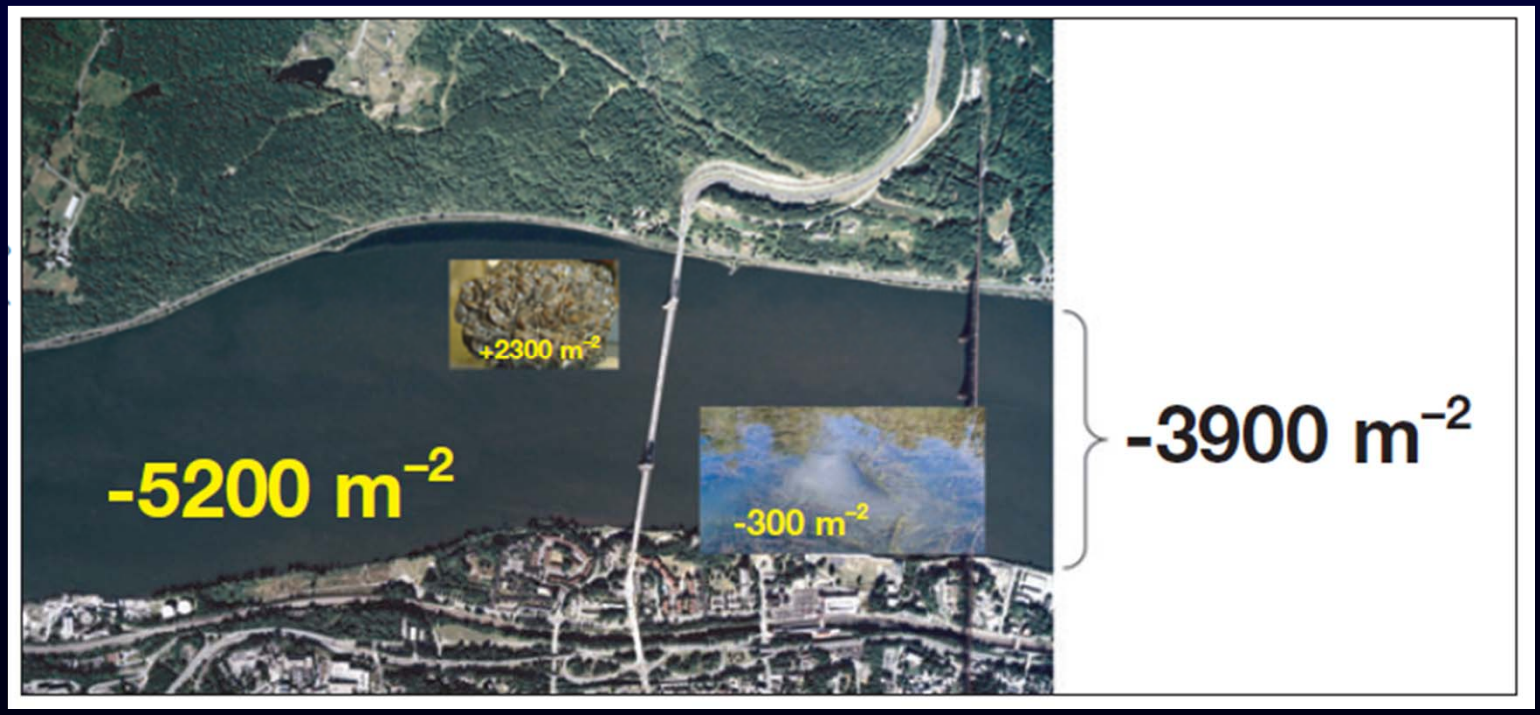
- Clearance of the water column reduced phytoplankton by 80% (Strayer 2010)
- This resulted in increased nitrogen and phosphorous leading to greater growth of rooted plants and macroalgae (Caraco et al. 2000)
- Shells can build to >2 kg per m^2 affecting benthic substrate and habitats (Strayer and Malcolm 2006)

Shift from Pelagic to Littoral Foodweb



From Strayer 2010

Overall Loss of Invertebrates



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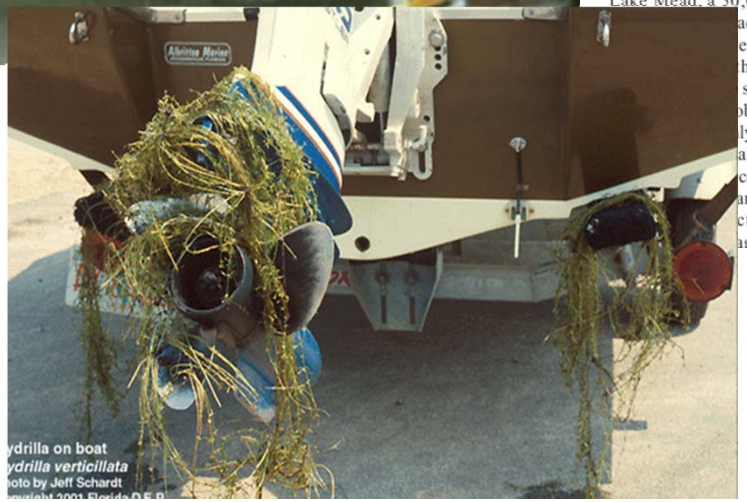
Boats Trailering Mussels

Photo from L. Johnson et al. 2001

Photo OF Ladd Johnson

Overland dispersal of weeds & mussels on boat trailers (Johnson et al. 2001 *Ecol. Appl.*)



Science (26 January 2007)

INVASIVE SPECIES

Feared Quagga Mussel Turns Up in Western United States

Scientists are trying to assess the potential for ecological and economic damage after finding a relative of the infamous zebra mussel in the Colorado River

For 2 decades, the zebra mussel has tormented the Great Lakes. Along with its close cousin, the quagga mussel, the fantastically prolific mussels have clogged the intake pipes of power plants, coated the hulls of boats, and thrown ecosystems out of whack. Western states have been so concerned that in 1998, they started a major campaign, called the 100th Meridian Initiative, designed to prevent boaters from accidentally transporting the mussels or other exotic species to their waters.

Now the initiative has suffered a major defeat. Earlier this month, quagga mussels were found in Lake Mead, a 50,000-hectare
ada. And last
e confirmed
he Colorado
sign of zebra
bservers fear
ly a matter of
als in Nevada
convening sci-
anels to figure
ct and how to
gga. "This is

been on the alert after several close calls. In 2004, for example, they found dead zebra mussels on a half-dozen houseboats arriving at Lake Mead, 1800 kilometers from the most westerly sighting of zebra mussels.

Now it's clear that the quagga mussel already beat the zebra across the Great Divide. On 6 January, a diver doing a routine inspection of a breakwater found a quagga mussel at a Lake Mead marina, a few kilometers upstream from Hoover Dam. "I was heartbroken,"

on the two drinking-water plants that also draw water from Lake Mead. Another big concern is the potential effect on sport fisheries in the lake. The mussels filter huge volumes of water, removing phytoplankton and boosting nutrients. This seems to have harmed commercial fish stocks in some but not all of the Great Lakes.

An emergency task force of NPS and state agencies in California and Nevada is scrambling to prevent further spread. As a temporary measure, Park Service boats have been grounded and concessionaires have been told not to transport rental boats. They have ramped up inspections of private boats at the lake as well. California is trying to increase boat inspections at its three border stations that receive traffic from Lake Mead. Ann Malcolm, general counsel for the state's Department of Fish and Game, says the agency will ask the legislature for the authority to inspect any possible sources of water on boats and force owners to drain them.

But the mussel seems to have already spread downstream. On 17 January, divers with the Metropolitan Water District (MWD) of Southern California found quagga mussels in Lake Havasu, near the intake to the Colorado River Aqueduct, which supplies water to 18 million people. "We are going to be taking aggressive action," says Debra Man, MWD's chief operating officer. They plan to use chlorine or copper sulfate to kill any mussels or larvae in the 386-km-long canal. Luckily, quagga mussels

Macrophytes and Mussels

- Johnson et al. (2001) found 36% of boats in Lake St. Clair in 1992 had macrophytes
- They found 16% of boats had zebra mussels associated with the macrophytes
- Very important for boats with short time in water

Dreissena mulliganensis

Environmental Limits

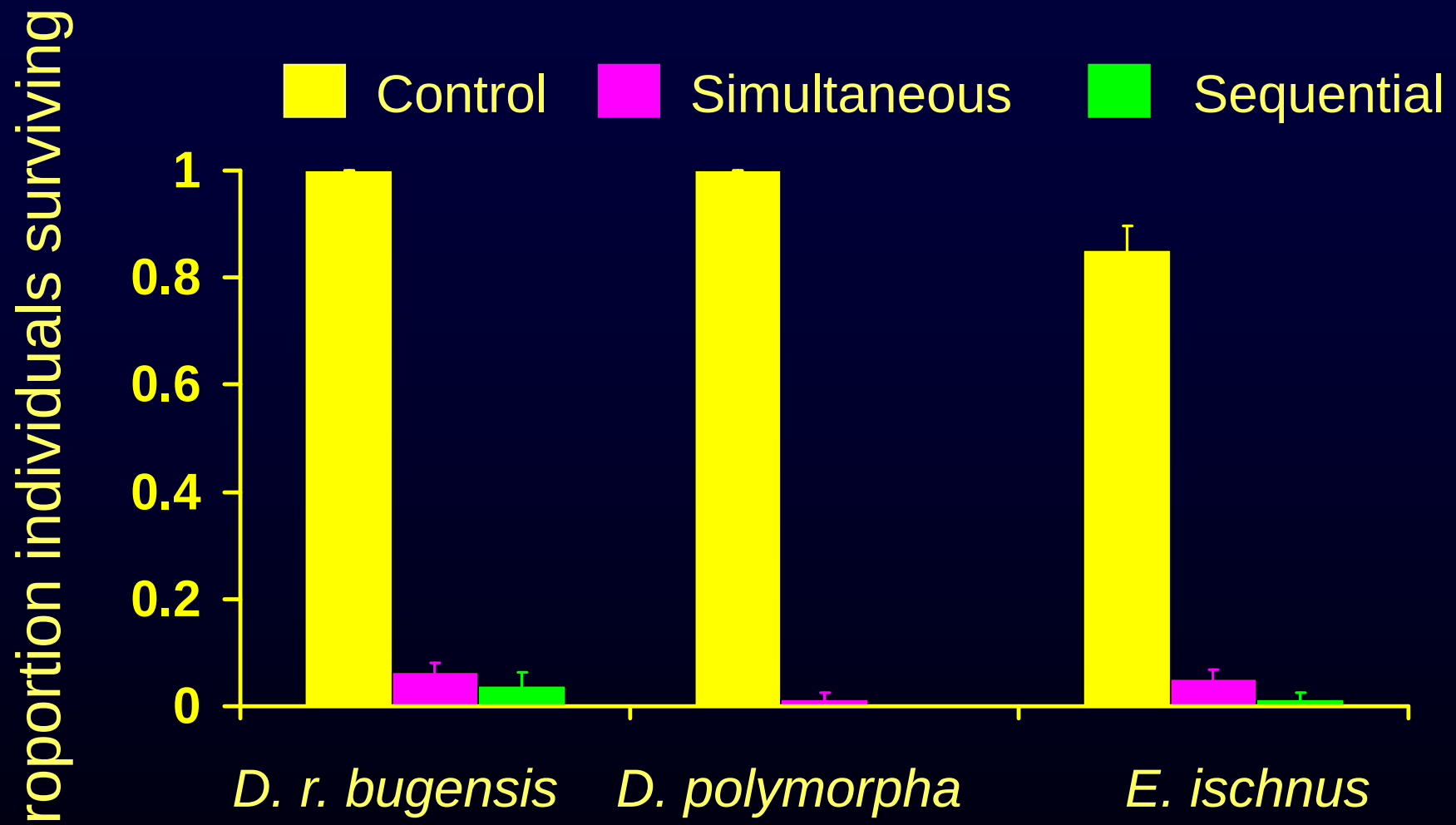
- We don’t know to what degree past limits to mussel spread apply to western populations
- Many examples of rapid evolution and expanded tolerances of physical limits
- Temperature, salinity, pH, calcium, dissolved oxygen, substrate
- Predators, disease, competitors are also unique and unknown in west

Salinity Tolerance Experiments

Species	Year of Discovery	Salinity Tolerance ‰
Bosmina coregoni	1966	0-7.5
Bythotrephes longimanus	1982	0.04-8
Cercopagis pengoi	1998	0-14
Dreissena rostriformis bugensis	1989	0-4
Dreissena polymorpha	1988	0-13
Echinogammarus ischnus	1994	0-23
Hemimysis anomala	2006	0.1-18
Neogobius melanostomus	1990	0-40.5

NIS used in retrospective salinity test to determine if ballast flushing could have killed them (data from MacIsaac)

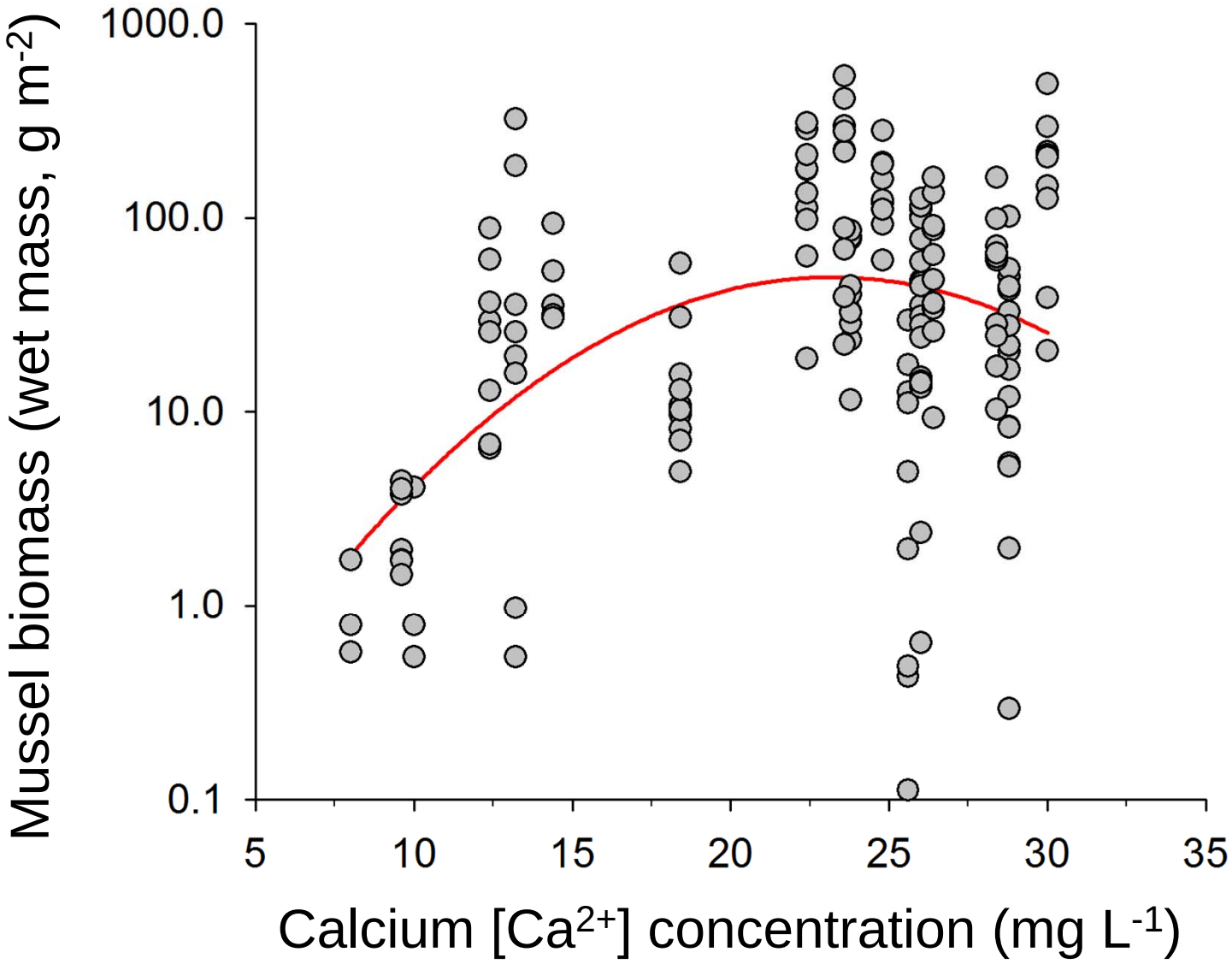
Proportion surviving after 1 hr in freshwater
(after 48hr in 30‰ in Instant Ocean)



Study suggests that none of recent GL invaders tested could have invaded had we had mandatory ballast exchange 25 years ago

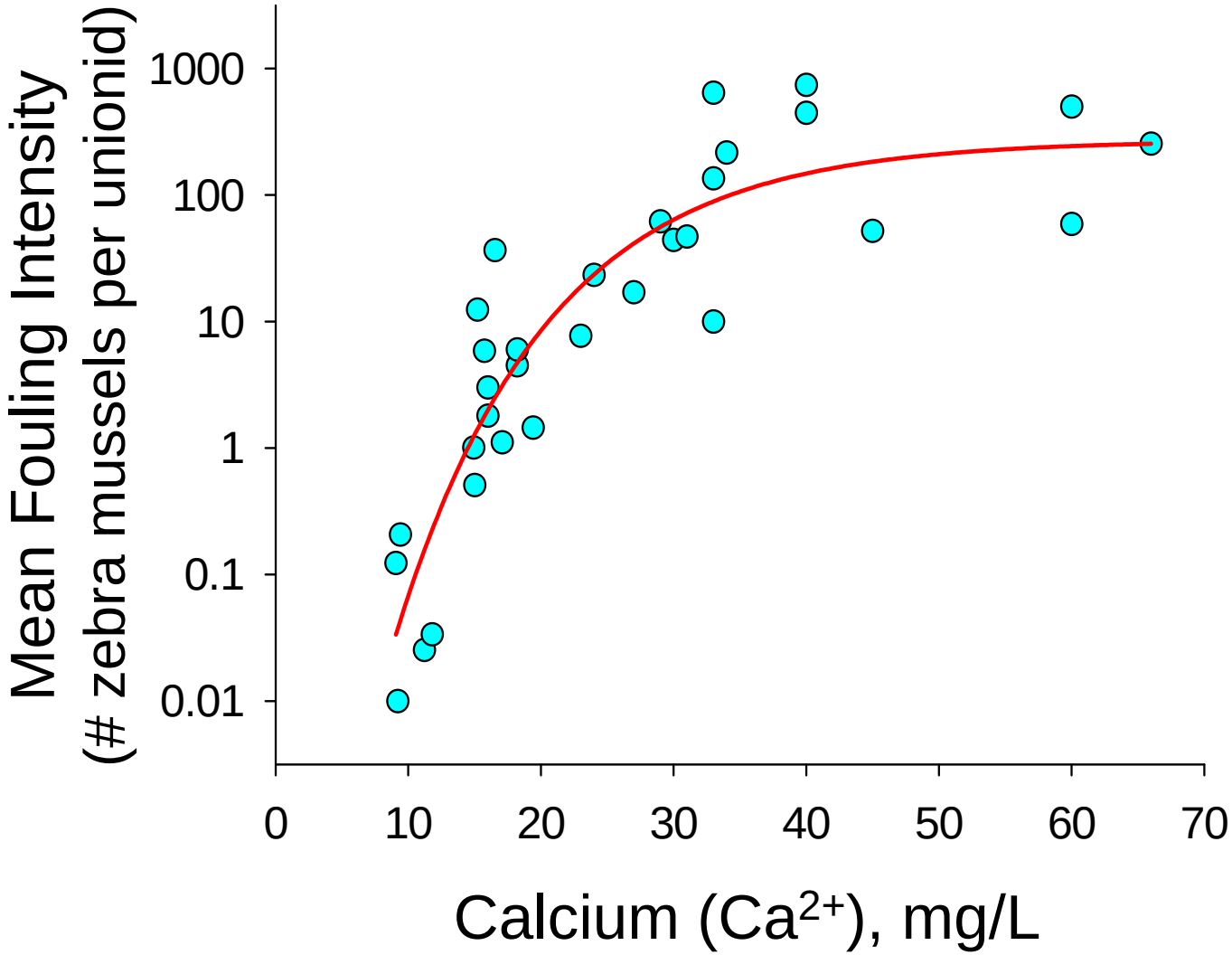
Ellis & MacIsaac (2009) Freshwater Biology

Zebra Mussel biomass vs. Calcium concentration in the St. Lawrence River



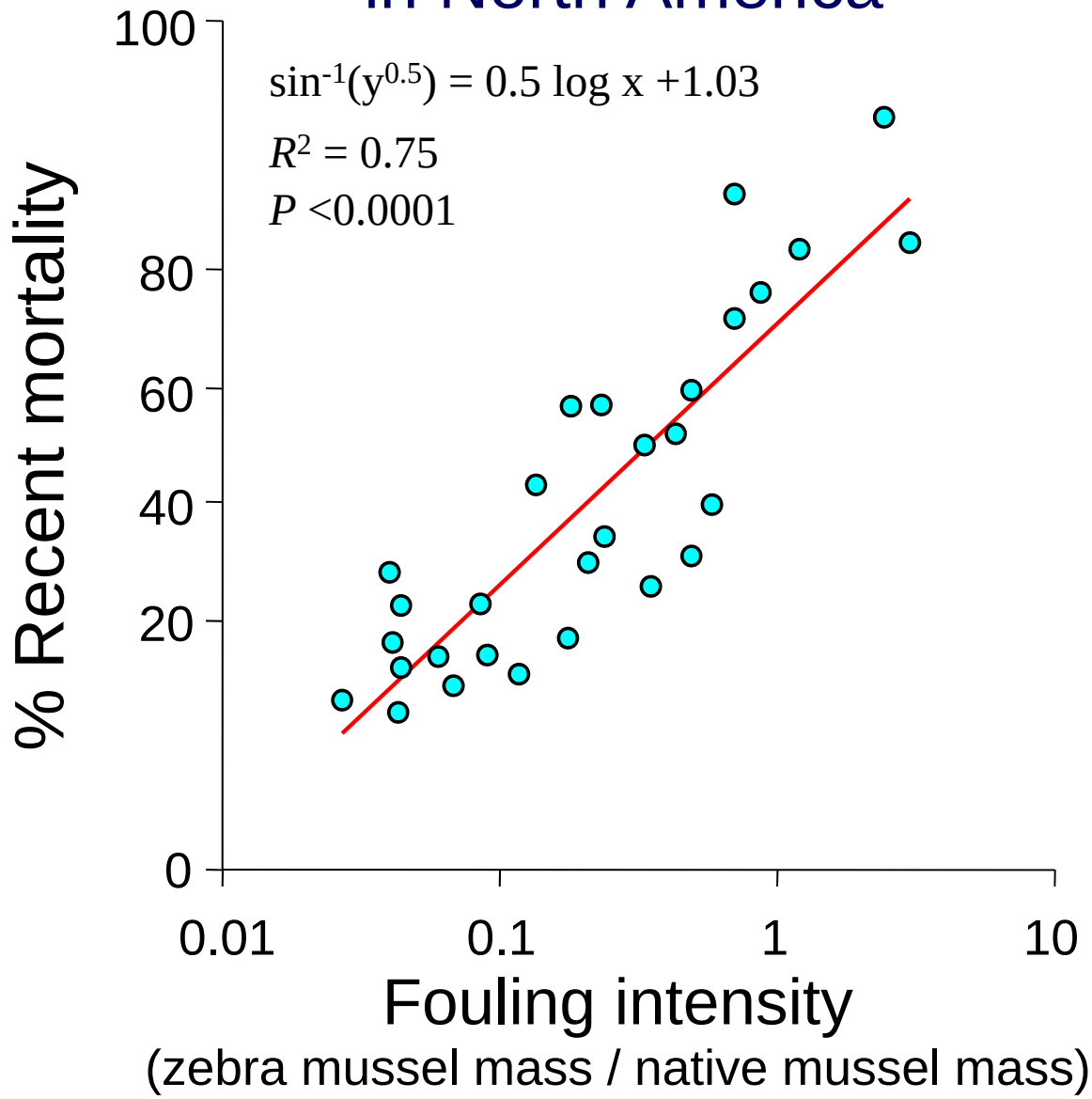
Jones & Ricciardi (2005) *Can. J. Fish. Aquatic Sci.* 62: 1953-1962

Fouling intensity of zebra mussels on native mussels varies with calcium concentration



Jokela & Ricciardi (2003) *Freshw. Biol.* 53: 1845-1856

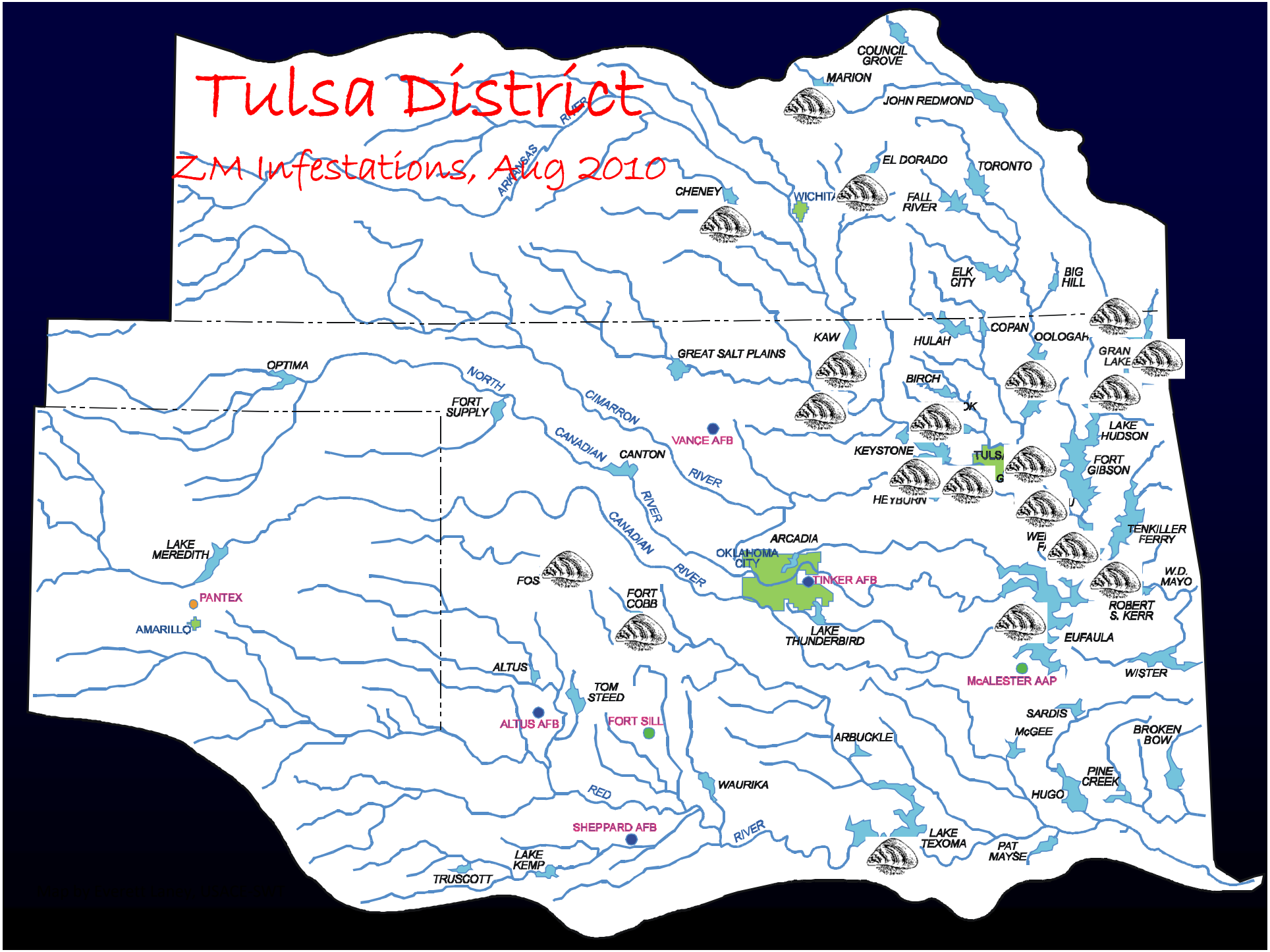
Native mussel mortality versus zebra mussel fouling in North America



Ricciardi (2003) *Freshwater Biol.* 48: 972-981

Zebra Mussels in Texas, Oklahoma, Kansas and Beyond

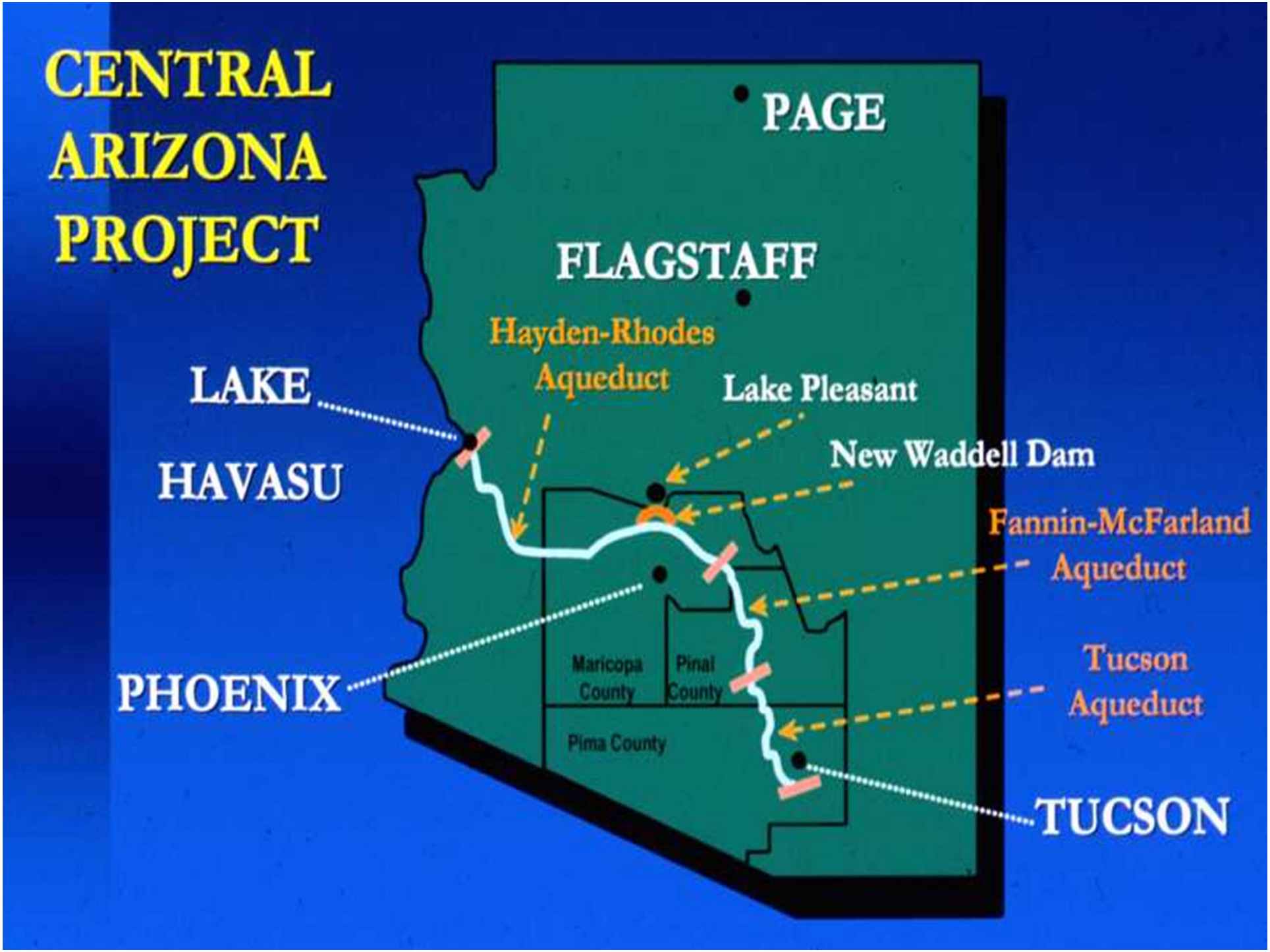
- Westward spread of zebra mussels has included significant dispersal from the Great Lakes into the Mississippi River and connecting watersheds
- Rivers such as the Missouri, Arkansas and Colorado have been extensively invaded

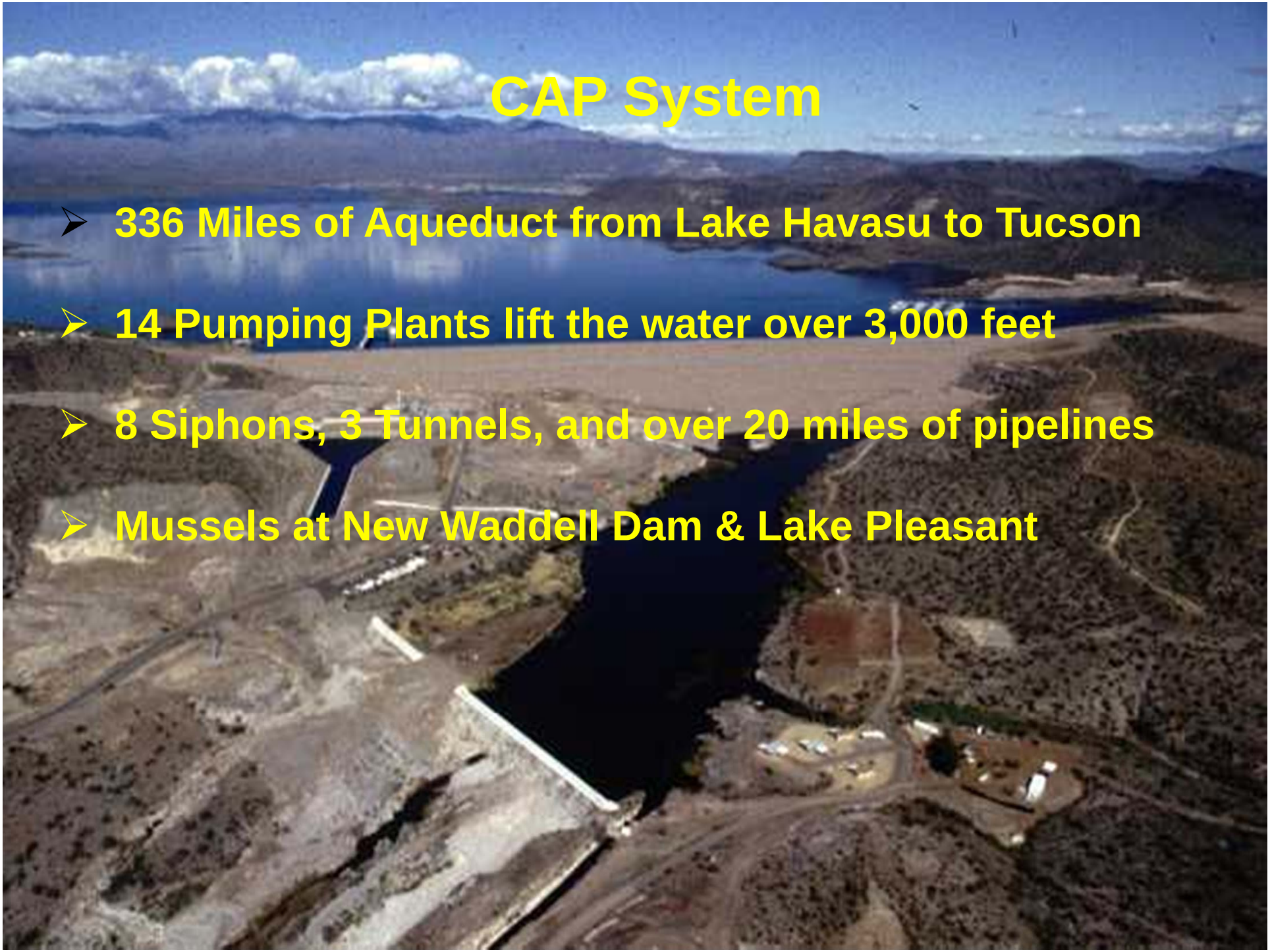

Tulsa District
ZM Infestations, Aug 2010
COUNCIL GROVE
MARION
JOHN REDMOND
EL DORADO
TORONTO
CHENEY
WICHITA
FALL RIVER
ELK CITY
BIG HILL
COPAN
OOLOGAH
KAW
HULAH
GRAN LAKE
GREAT SALT PLAINS
BIRCH
OPTIMA
NORTH CIMARRON
FORT SUPPLY
LAKE HUDSON
VANCE AFB
KEYSTONE
CANTON
CANADIAN RIVER
FORT GIBSON
TENKILLER FERRY
ARCADIA
LAKE MEREDITH
OKLAHOMA CITY
TINKER AFB
W.D. MAYO
PANTEX
AMARILLO
FOS
FORT COBB
ROBERT S. KERR
LAKE THUNDERBIRD
EUFAULA
ALTUS
McALESTER AAP
WISTER
TOM STEED
SARDIS
ALTUS AFB
FORT SILL
McGEE
BROKEN BOW
ARBUCKLE
PINE CREEK
WAURIKA
HUGO
RED RIVER
SHEPPARD AFB
LAKE TEXOMA
PAT MAYSE
LAKE KEMP
TRUSCOTT

USACE, El Dorado Lake, 2003
Photo by Jason Goeckler, KDWP


Photo by Paul Shockley, USACE
From Oologah Lake 2003

R. S. Kerr L&D 15, Arkansas River
Photo by Everett Laney, USACE-SWT


CENTRAL
ARIZONA
PROJECT
PAGE
FLAGSTAFF
Hayden-Rhodes
Aqueduct
Lake Pleasant
LAKE
HAVASU
New Waddell Dam
Fannin-McFarland
Aqueduct
Maricopa
County
Pinal
County
Tucson
Aqueduct
PHOENIX
Pima County
TUCSON



CAP System

- 336 Miles of Aqueduct from Lake Havasu to Tucson
- 14 Pumping Plants lift the water over 3,000 feet
- 8 Siphons, 3 Tunnels, and over 20 miles of pipelines
- Mussels at New Waddell Dam & Lake Pleasant

Fast increase in population Density – Parker Dam Lake Havasu

August/07

November/07

From Albert Graves et al.

Adult Mussel Densities
(from Graves et al.)

- Highest adult settlement 25,000 – 32,000 ind/m^2
- Settlement subject to periodic die-off –
- Up to 50% mortality observed on the deepest annual plates counted


C. Ramcharan

Environmental Parameters – Results
(from Graves et al.)

- Salinity and conductivity always within region of “Massive Infestation Potential”
- Summer water temperature reached 85 ^{o}F + in the western portion of the system
- Adult Quagga mussels at Lake Mead have been reported to experience 100% mortality in two weeks if kept in 28 ^{o}C (82 ^{o}F) water.

Environmental Parameters – Results

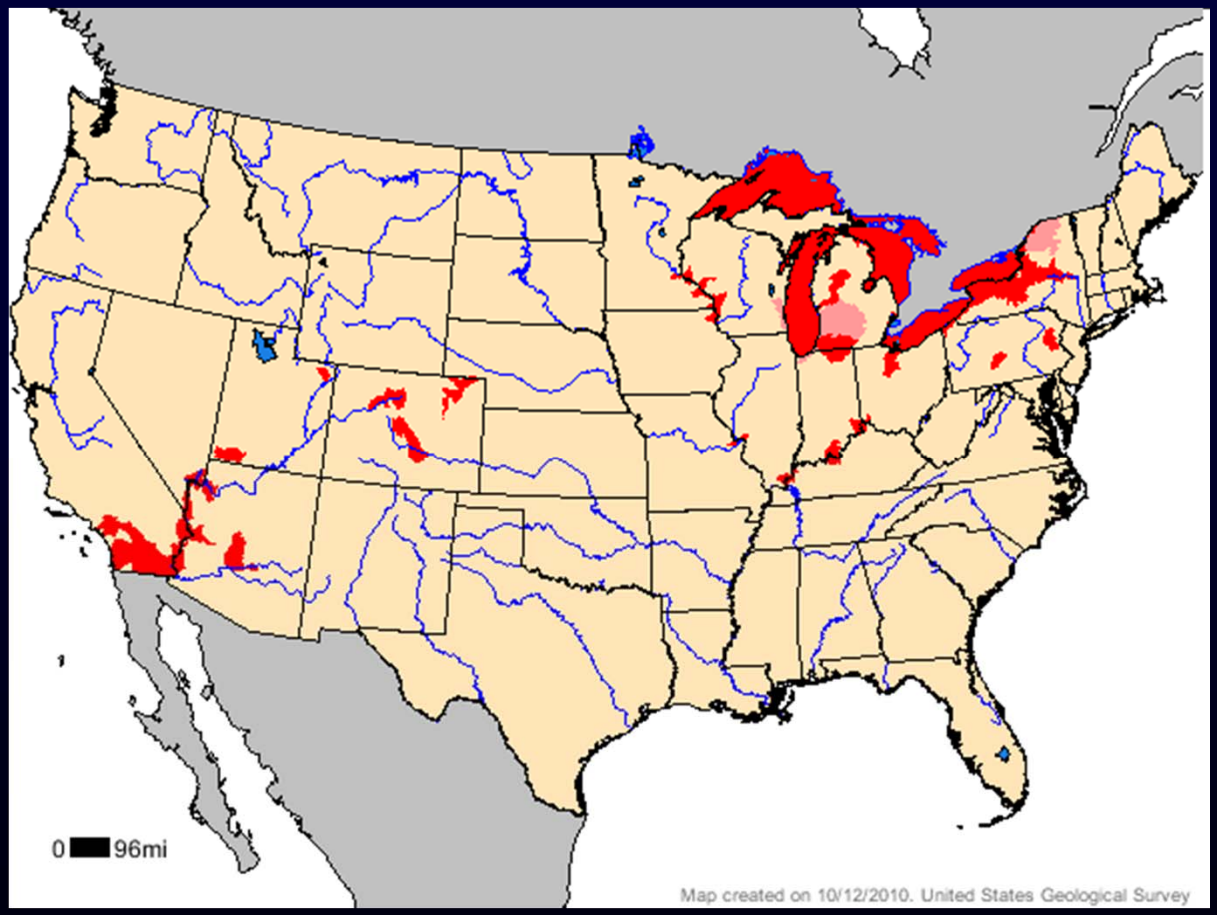
(from Graves et al.)

- Low pH and low DO at south end of the system associated with deep water release from Lake Pleasant
- Dissolved oxygen as % saturation was otherwise high
- Periodically high levels of chlorophyll *a* were detected
- High turbidity was detected at some locations, primarily in the southern portion of the canal.

Quaggas in Central Arizona

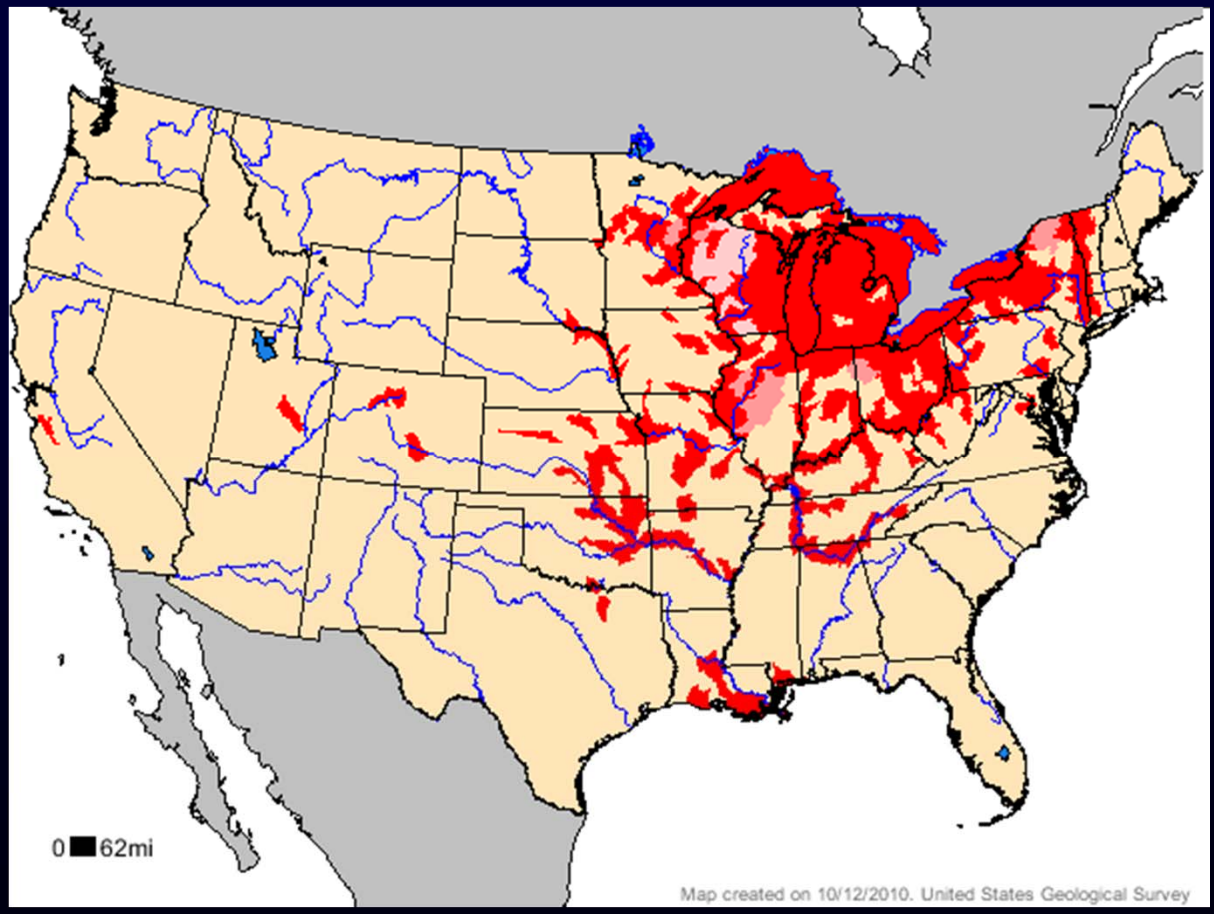
- Adult quagga mussels have limited distribution and modest densities (so far) in the water conveyance system in the Central Arizona project
- Veliger larvae are found through much of the western portion
- Impacts on distribution system are currently minor
- No impacts have been assessed in natural areas outside of the distribution system

Distribution of Quagga Mussels



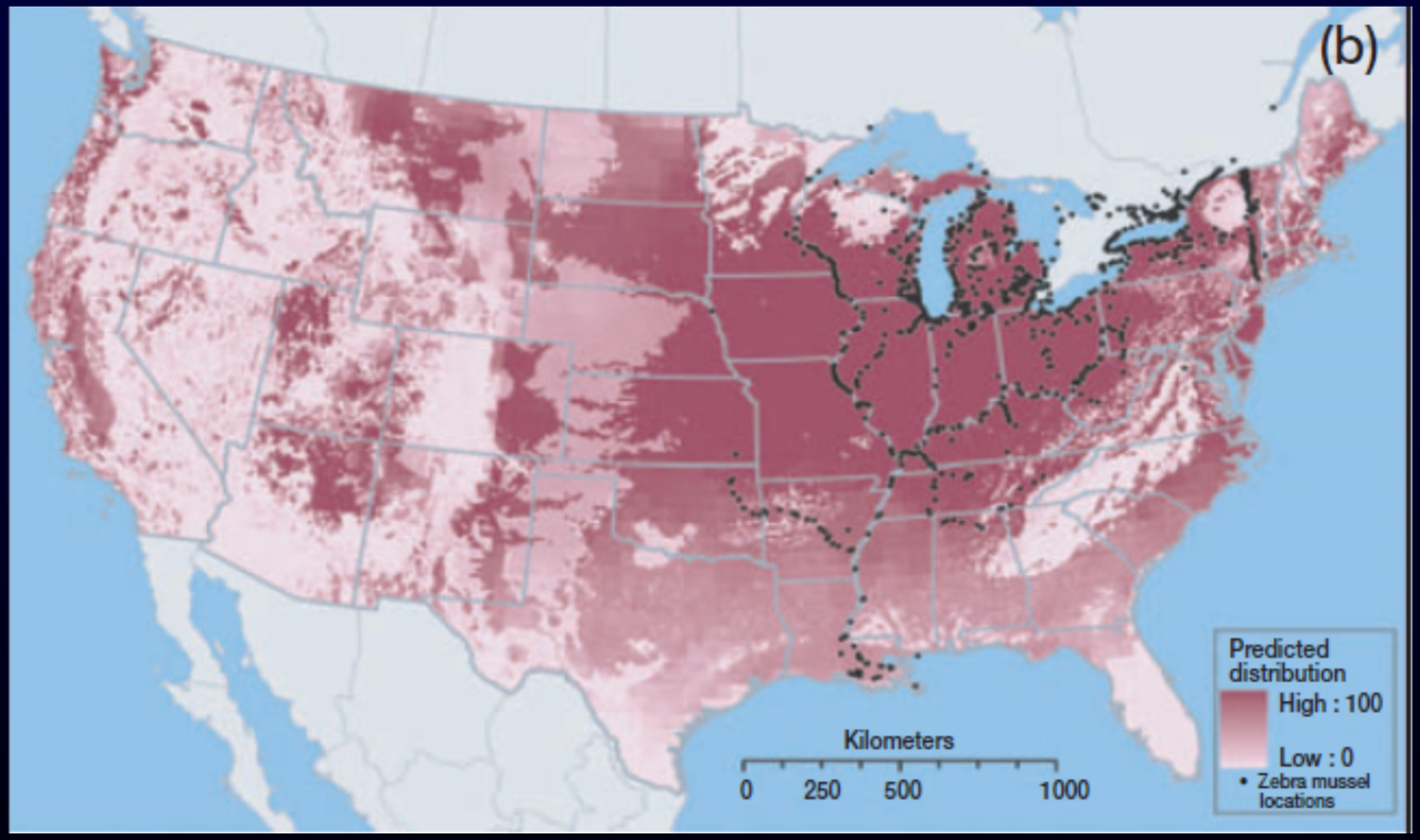
From USGS 2010

Distribution of Zebra Mussels



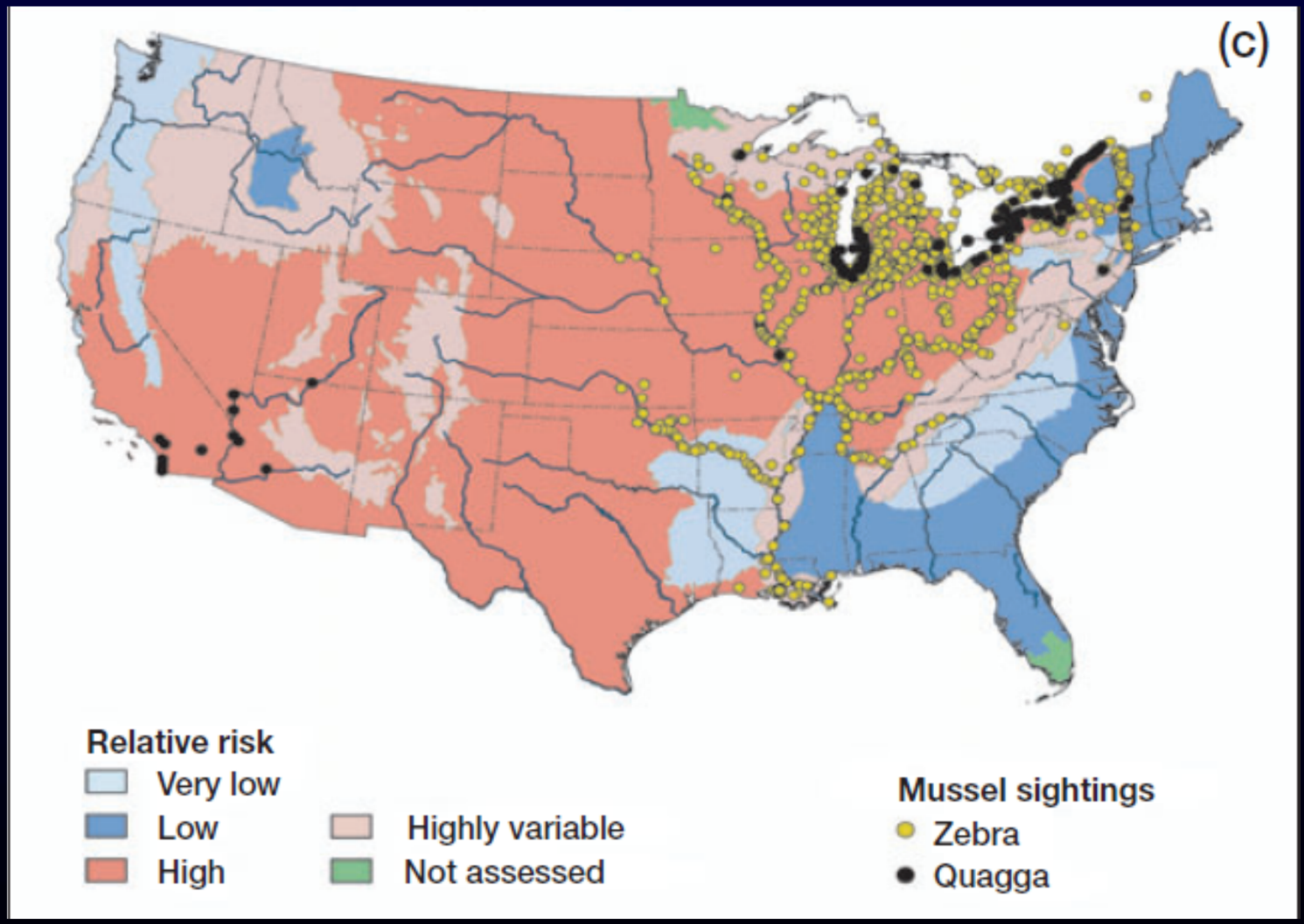
From USGS 2010

Predicted Distribution of Zebra Mussels



From Drake and Bossenbroek 2004

Predicted Risk for Eurasian Mussel Invasion



From Whittier et al. 2008

Future Distribution in California and the West

- The future distribution of Eurasian mussels will define their broader impact
- Their distribution in the next twenty years is very uncertain
- The same range of factors will limit them: water temperature, salinity, pH, calcium, dissolved oxygen, substratum, etc.

Conclusions

- **The impacts of zebra and quagga mussels have had dramatic impacts on both ecosystems and human economies in the Great Lakes region**
- **Similar impacts are likely in western regions and in California as mussels become more widespread and reach high densities**
- **Substantial impacts on water distribution systems, boating and waterways are likely**
- **Ecosystem impacts are less well understood**

Conclusive Uncertainty

- We know the most about variables that are easily measured and respond on short time scales
- We know little about the impacts of Eurasian mussels on commercial or sport fisheries (see Strayer et al. 2004)
- The most important impacts of Eurasian mussels, particularly the recent western invasions, may not be apparent for many years to come