What have we learned from freshwater invasions?

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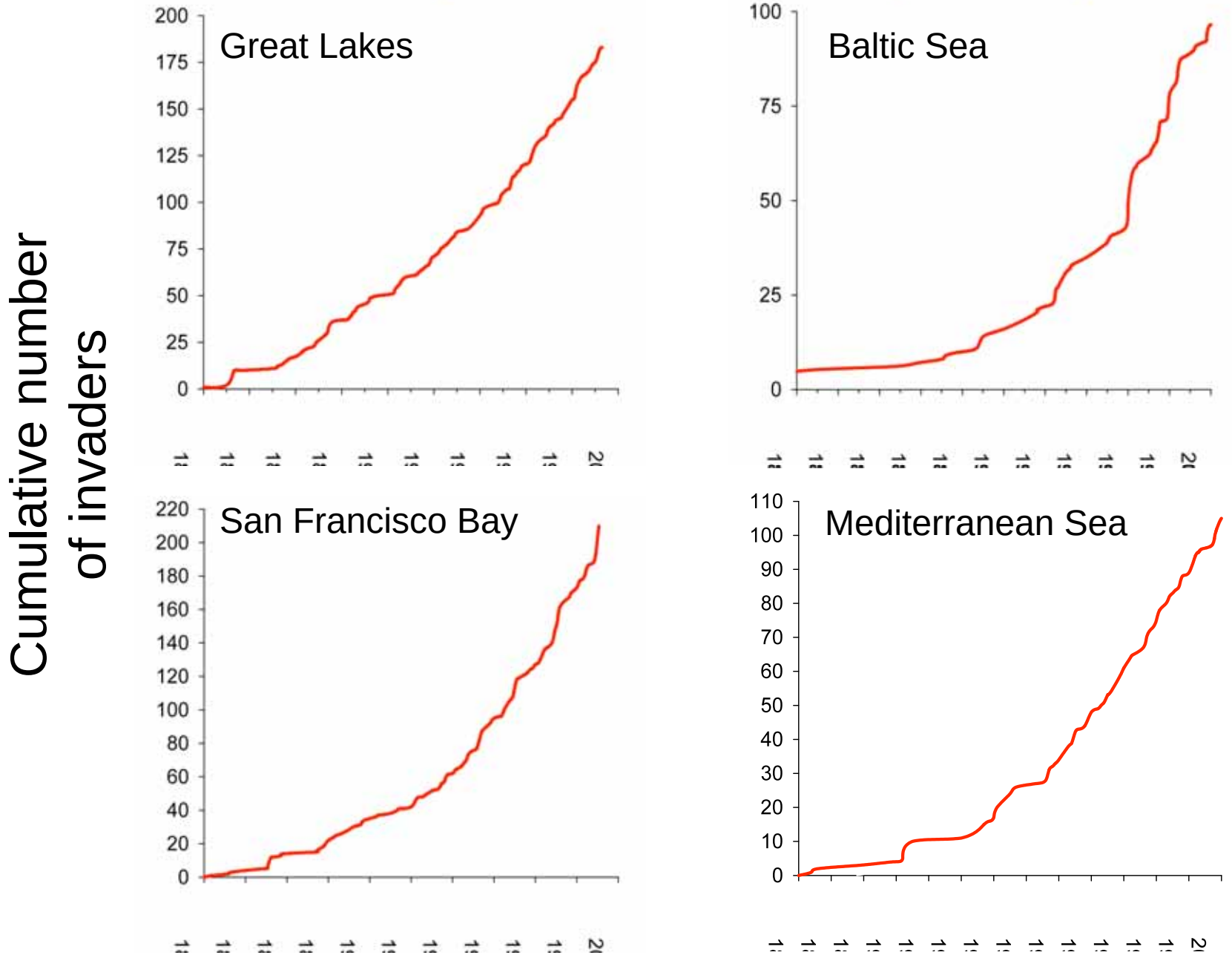
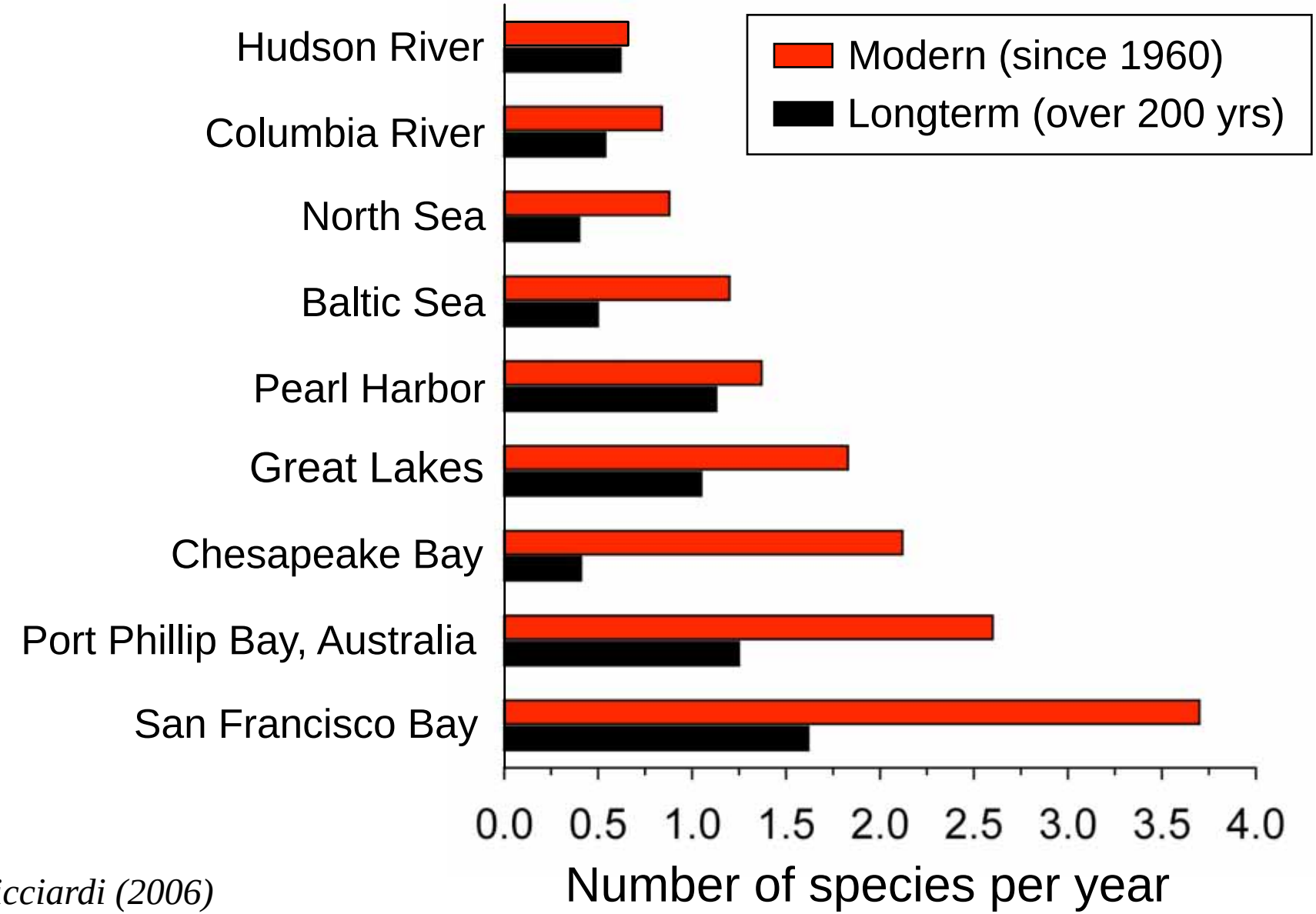
Ten generalizations regarding aquatic invasions

1. Rates of discovery are increasing worldwide.

Rate of discovery of invaders in aquatic systems



Rates of discovery of invaders in large aquatic systems

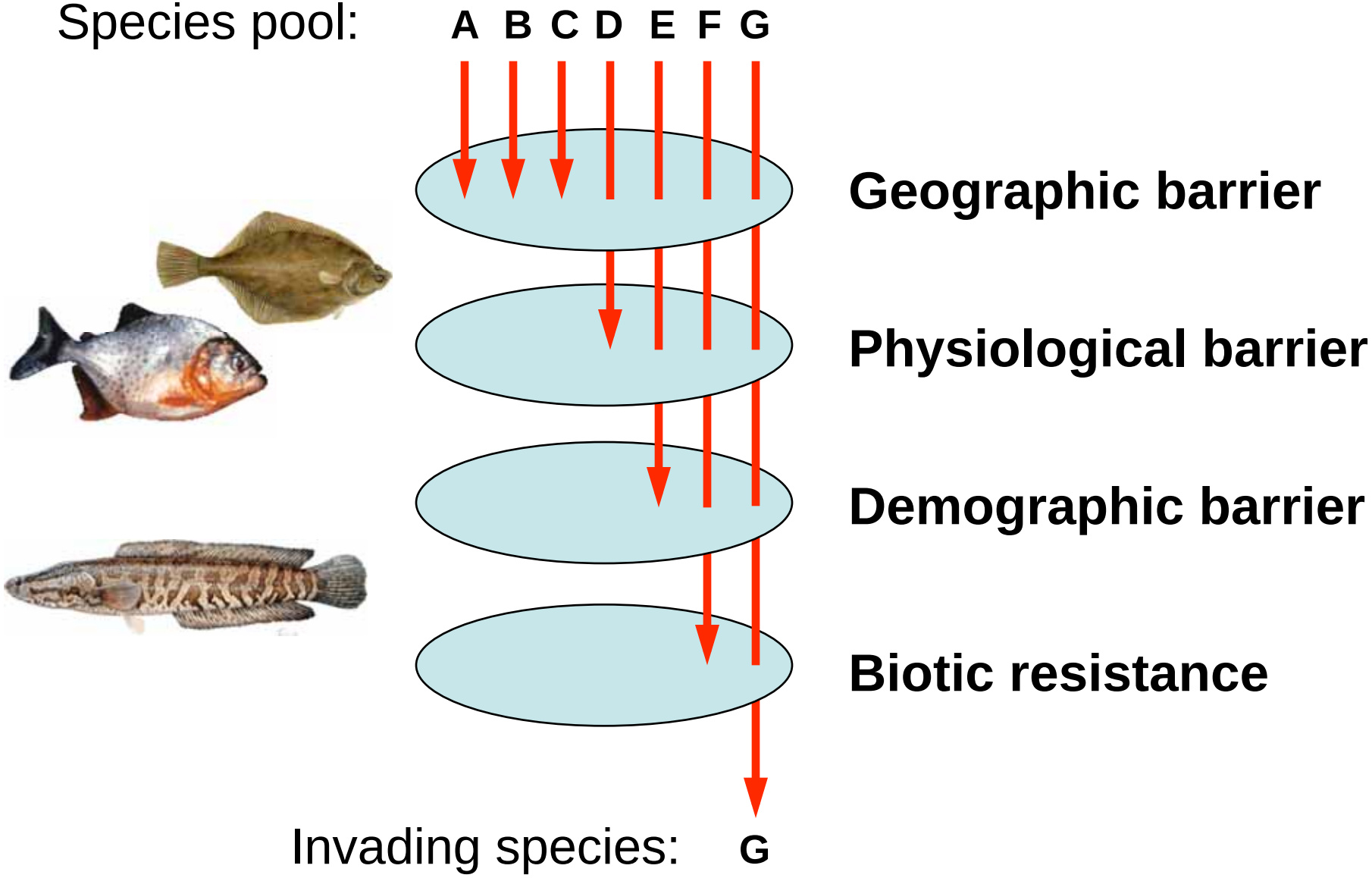


Ricciardi (2006)

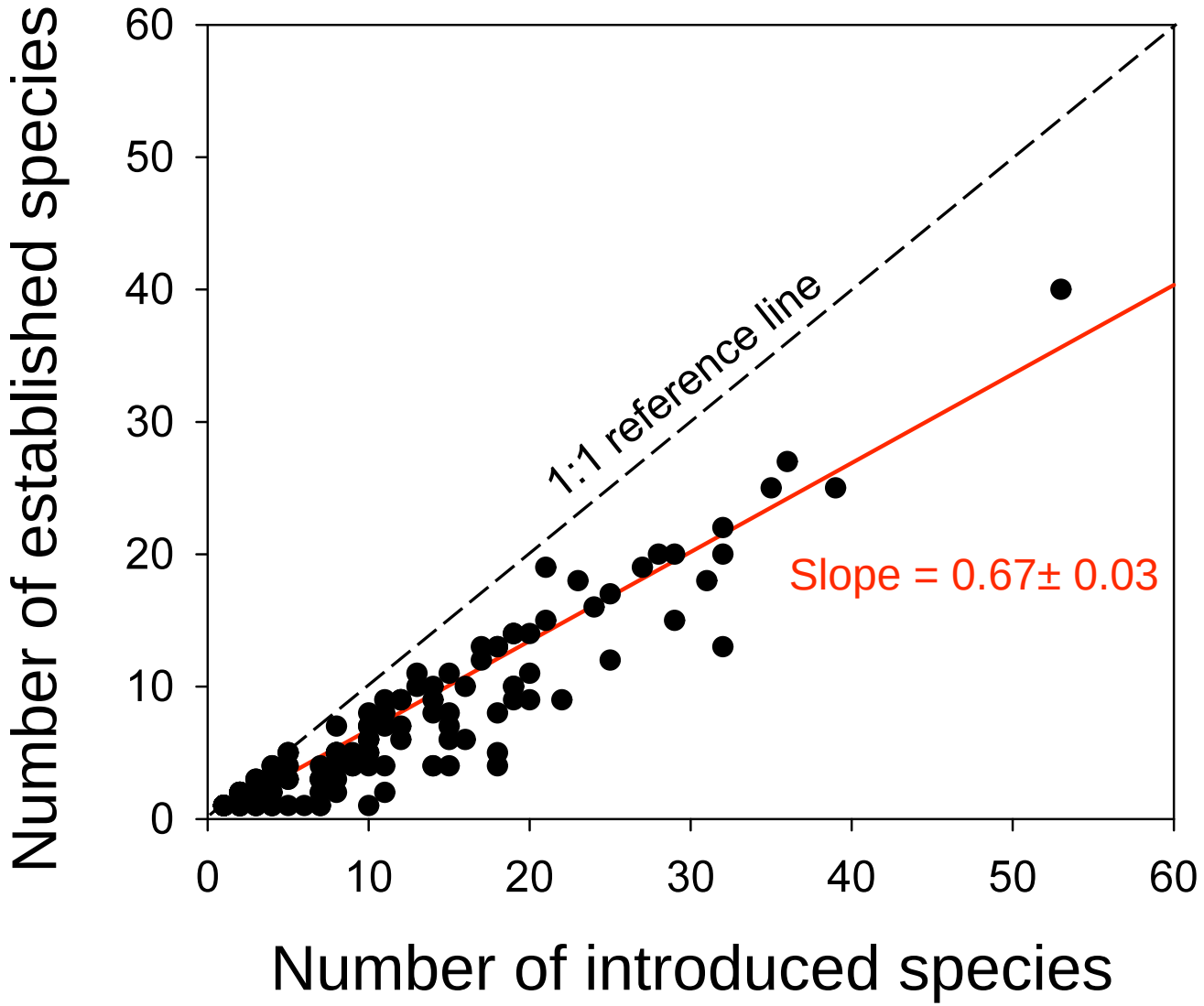
Ten generalizations regarding aquatic invasions

2. Many introductions fail to establish sustainable populations.

Barriers to species invasion



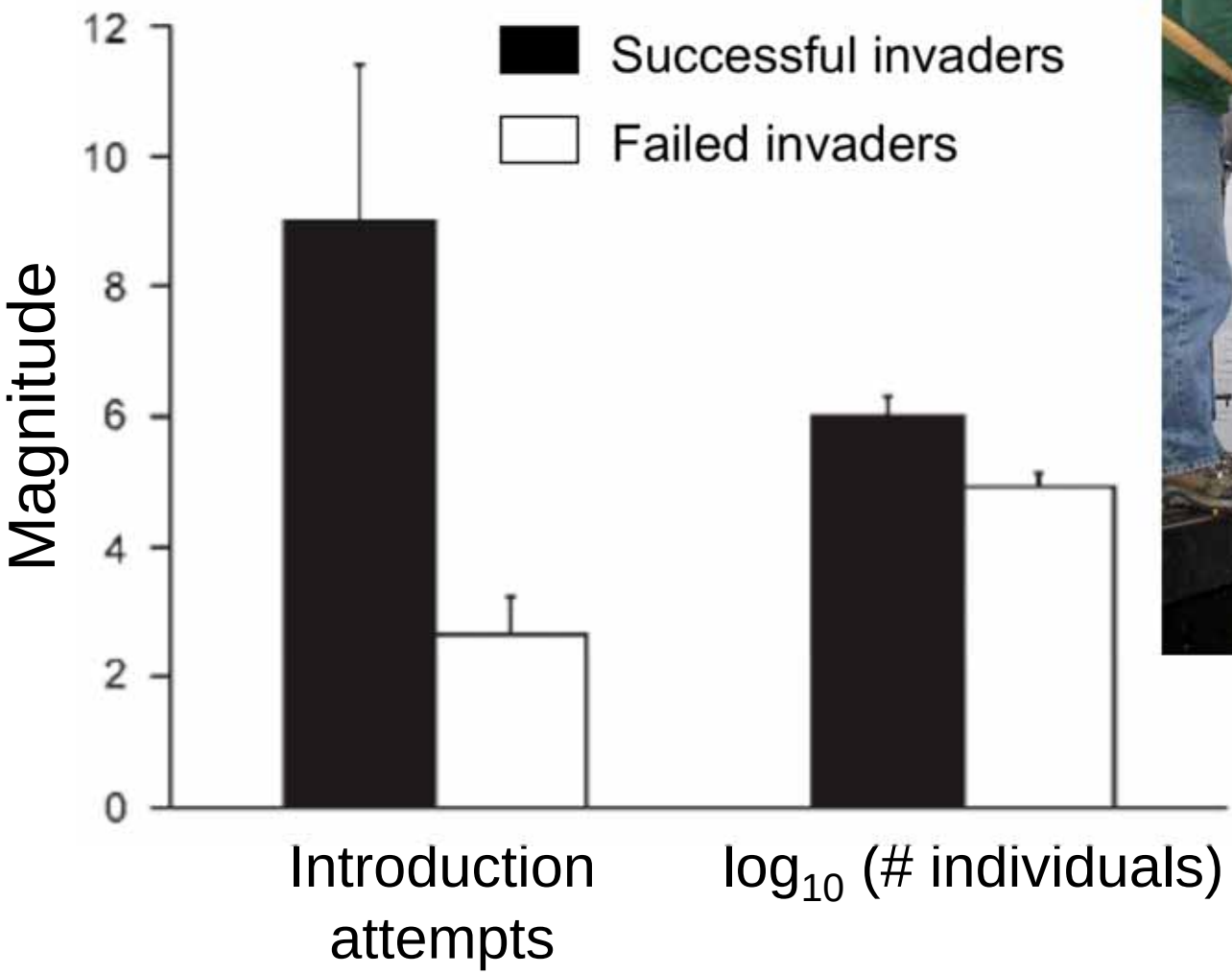
Nonindigenous freshwater fishes introduced to 149 regions worldwide



Ten generalizations regarding aquatic invasions

3. Propagule pressure is the most consistent predictor of establishment success.

Success of introduced salmonids versus propagule pressure

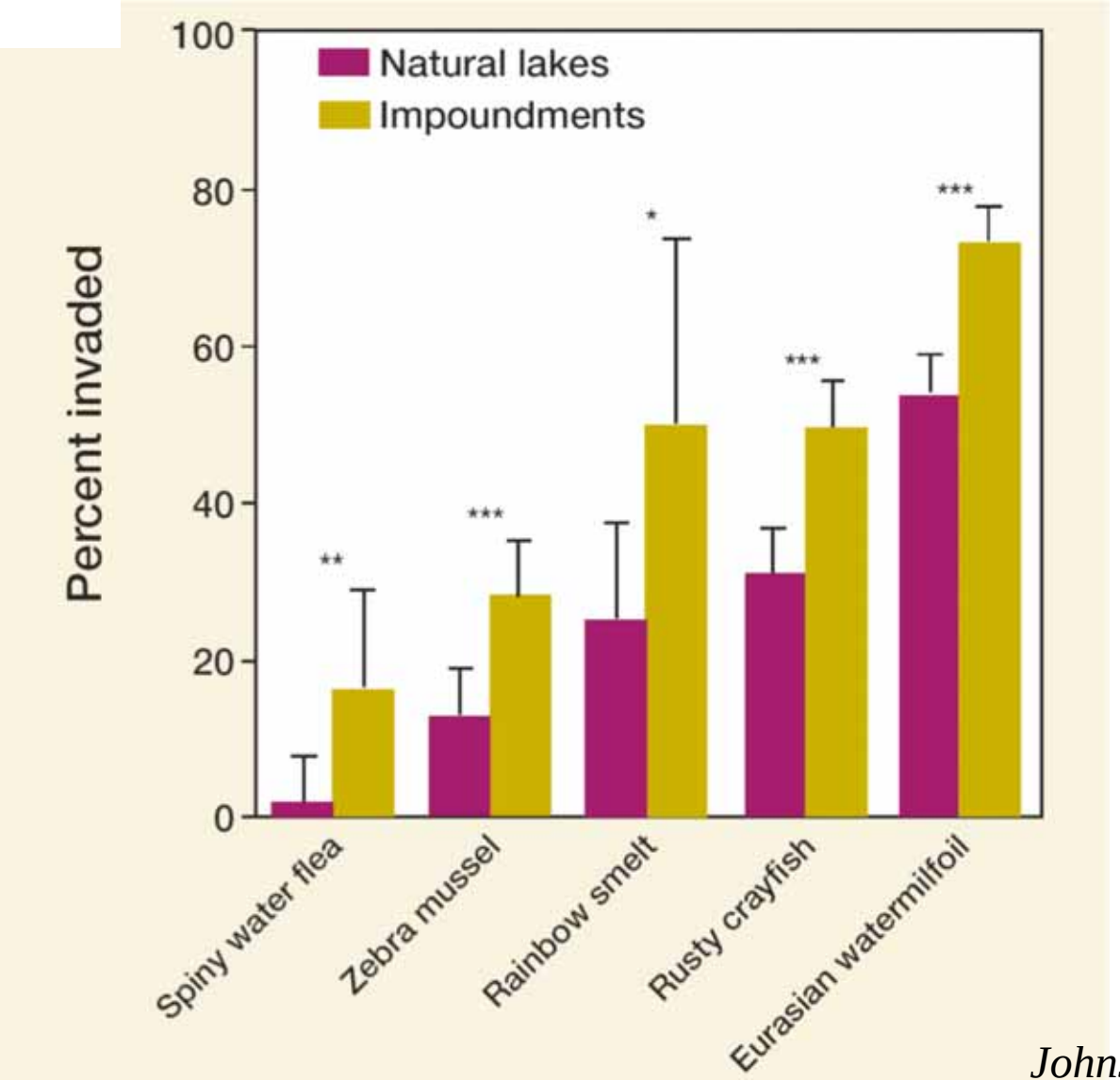


Colautti (2005)

Ten generalizations regarding aquatic invasions

4. All aquatic systems are invasible, but some are more invasible than others.

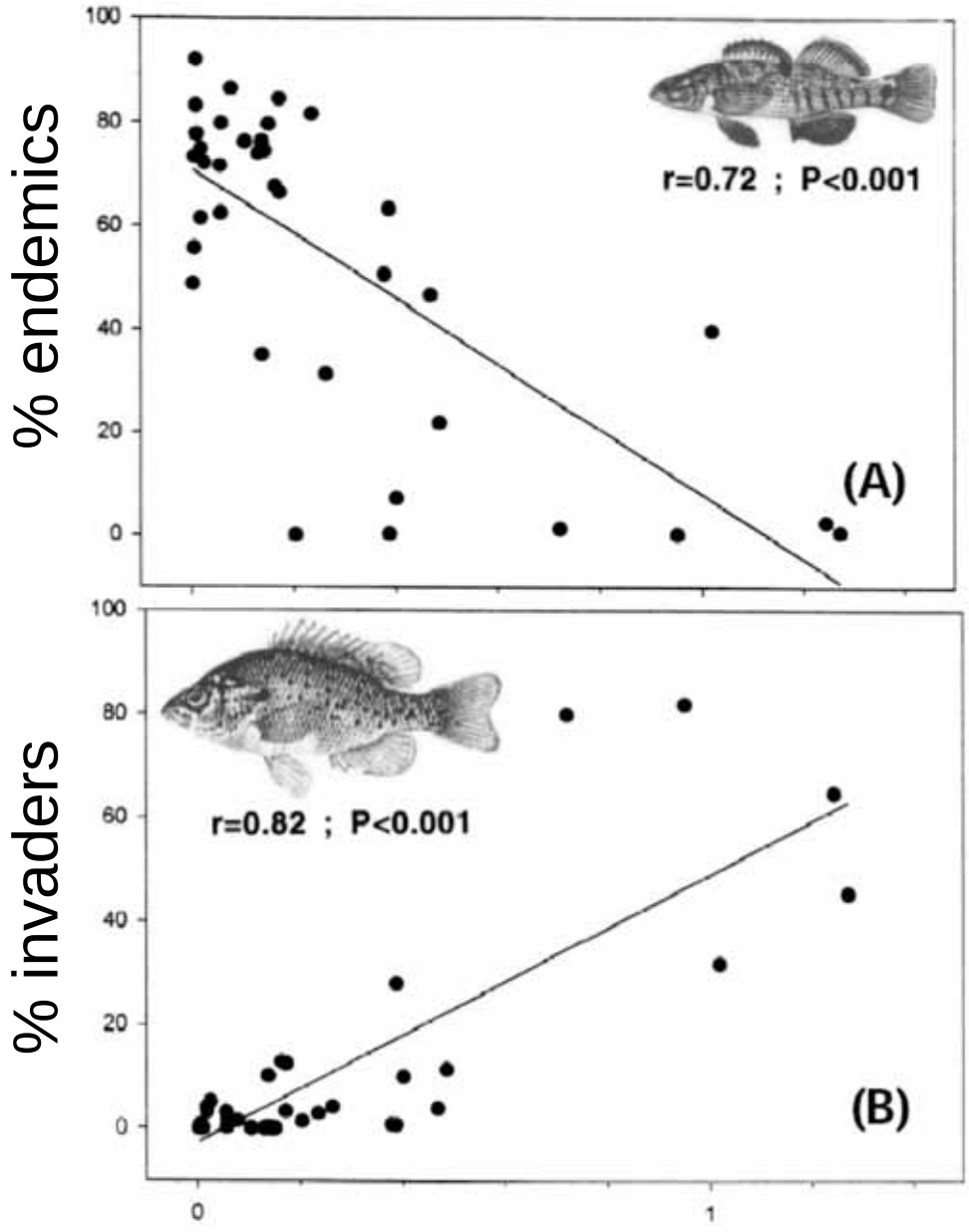
Impounded lakes are invaded more frequently than natural lakes



Johnson et al. (2008)

Effect of land use on the proportion of endemic versus exotic fishes
at 36 sites in two river basins.

Scott & Helman (2001)

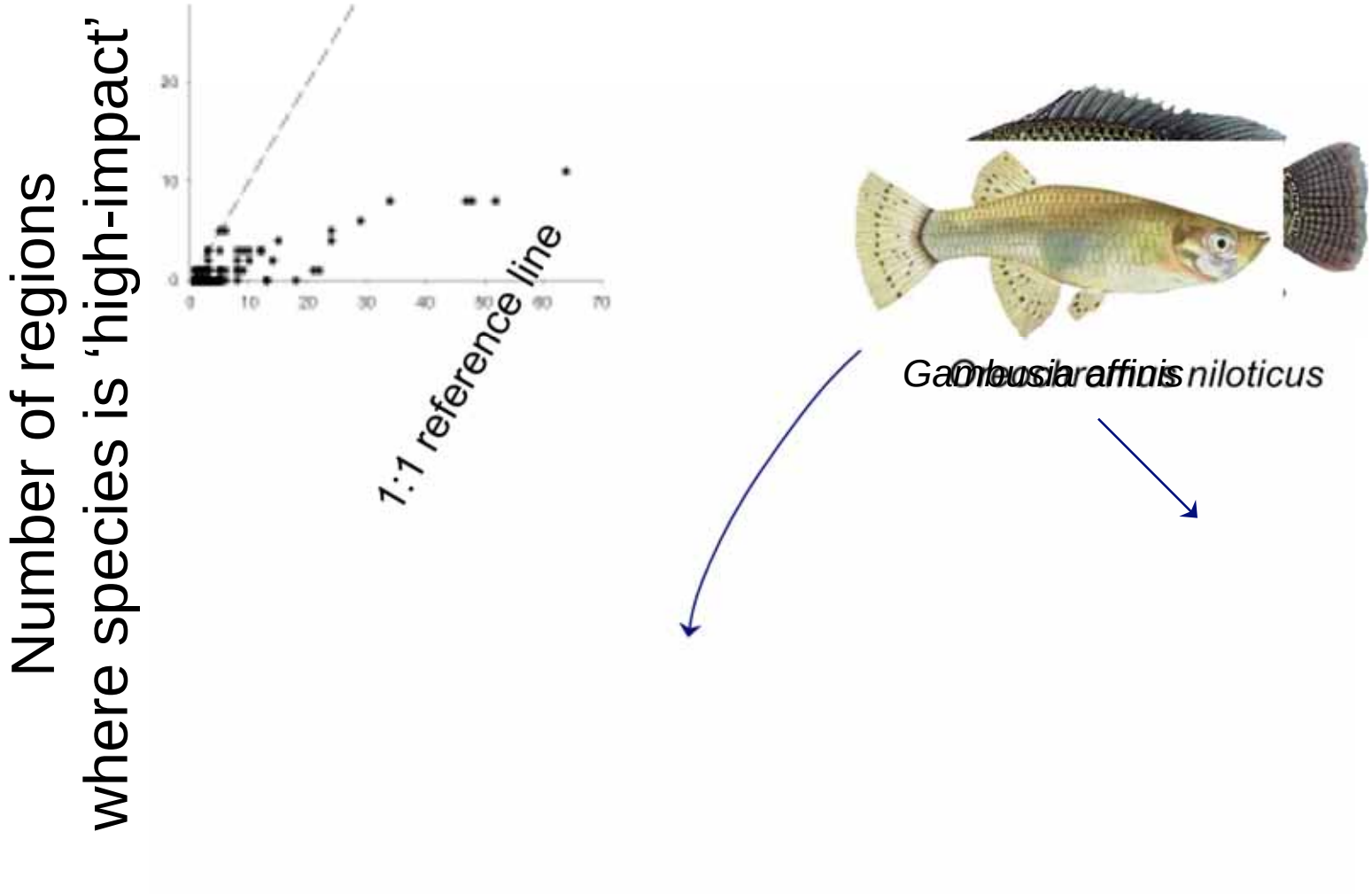


Ten generalizations regarding aquatic invasions

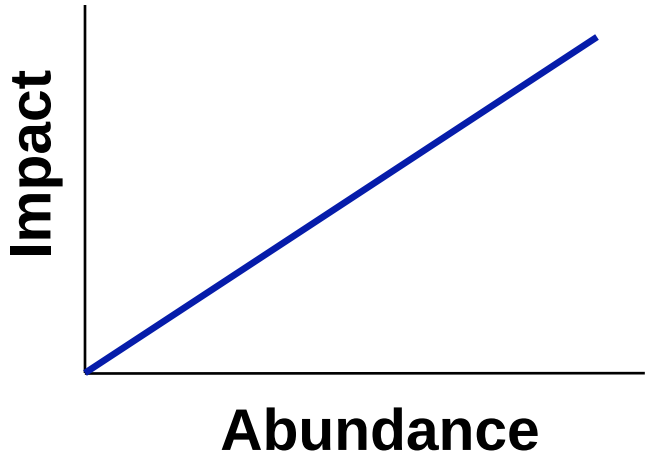
5. The impacts of exotic species are context dependent.

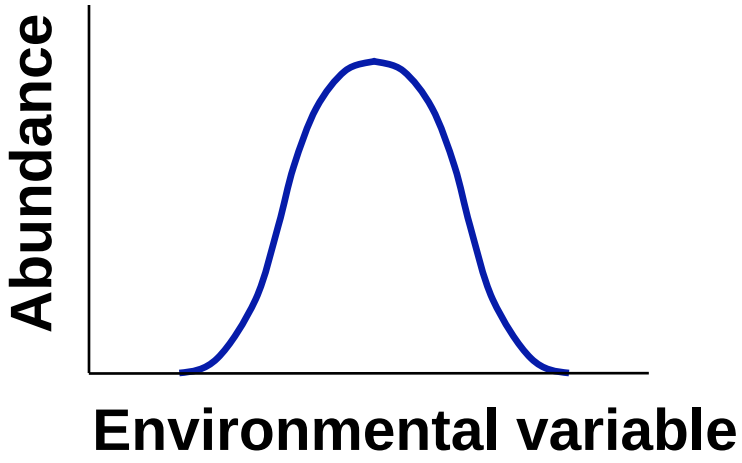
Impacts of invasive fishes vary across regions

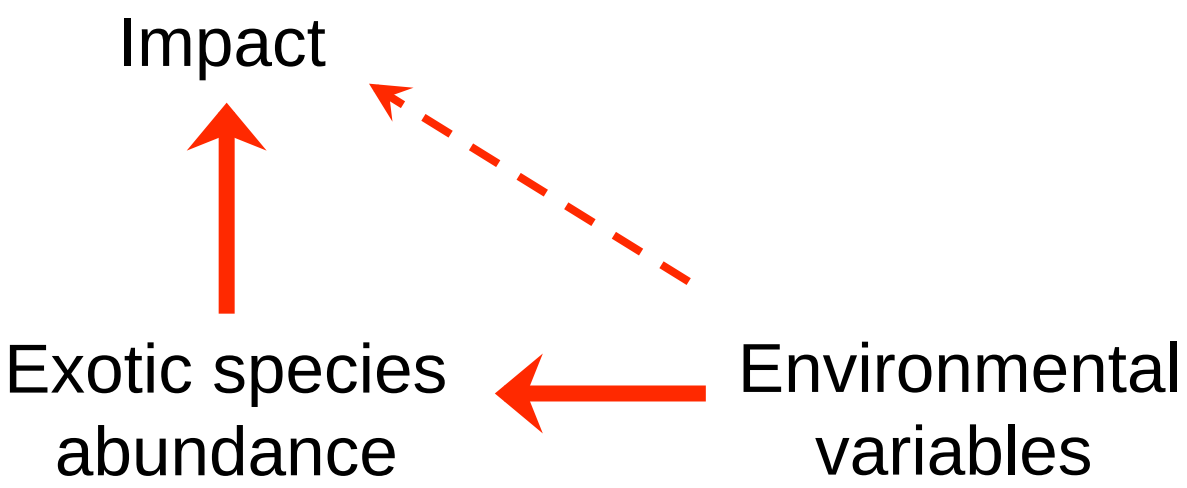
(Data from 153 invaders)



Ricciardi & Kipp (2008)

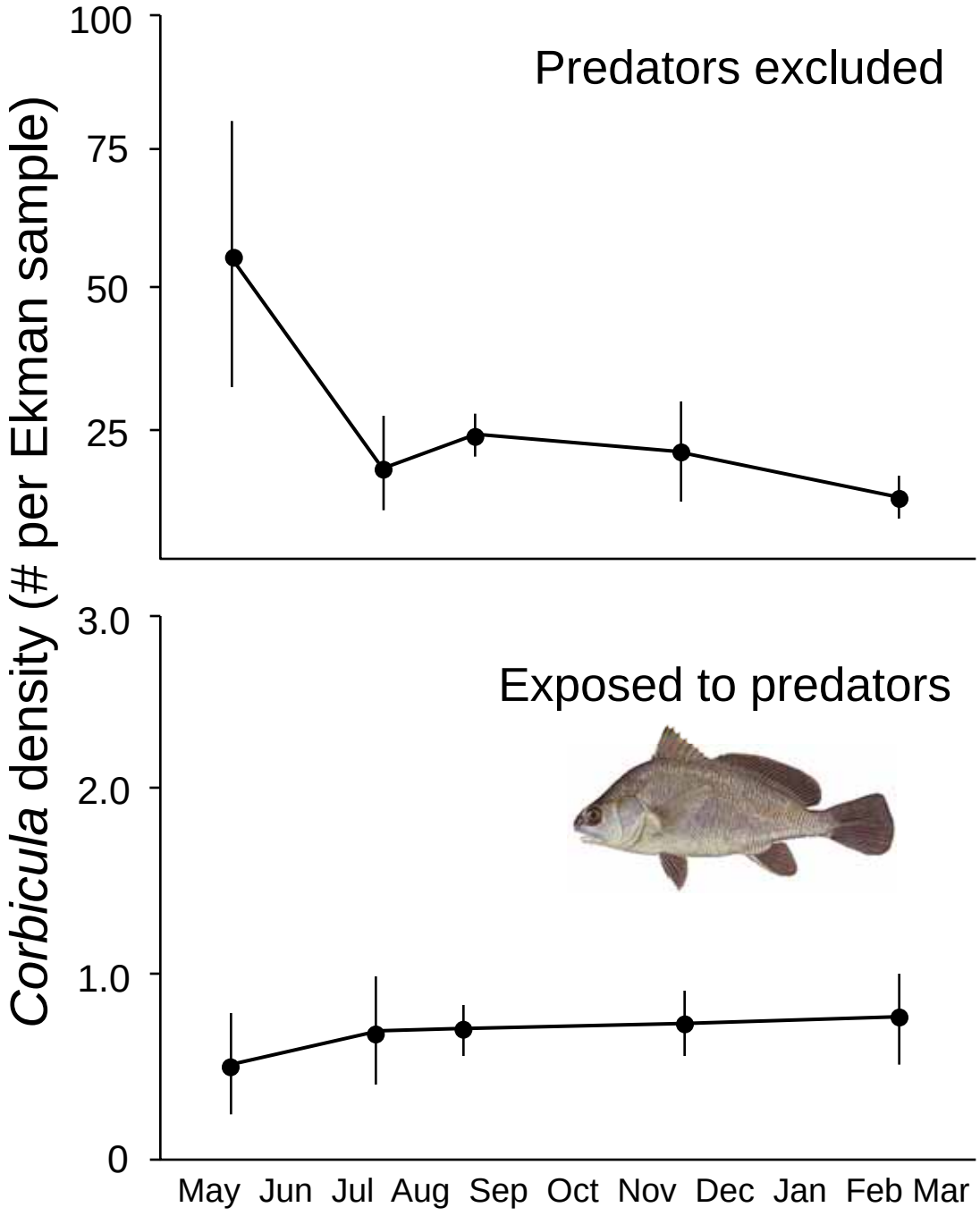

Impact
Abundance


Abundance
Environmental variable


Impact
Exotic species abundance
Environmental variables

Effect of predation on the clam *Corbicula fluminea* in a Texas reservoir

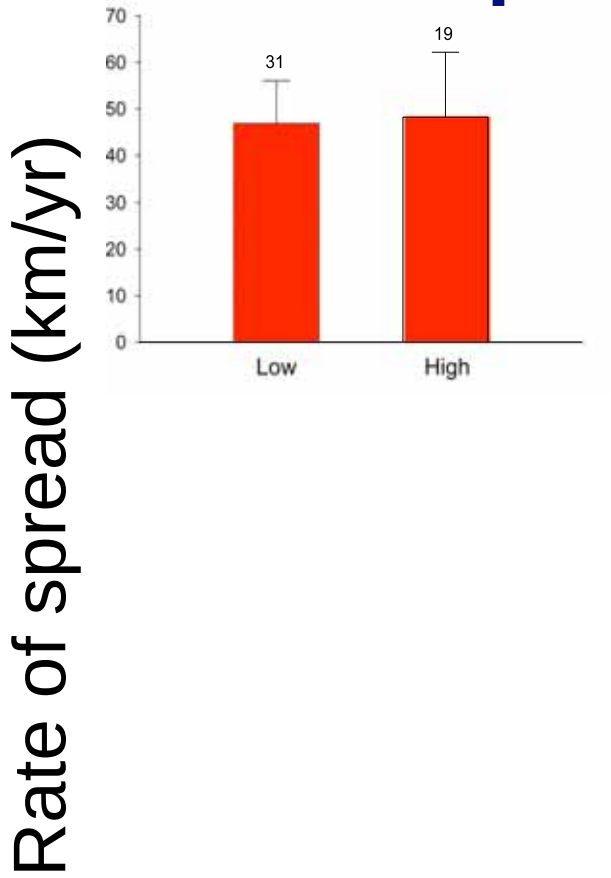
Robinson & Wellborn (1988)



Ten generalizations regarding aquatic invasions

6. The potential impact of an exotic species is not correlated with its invasiveness.

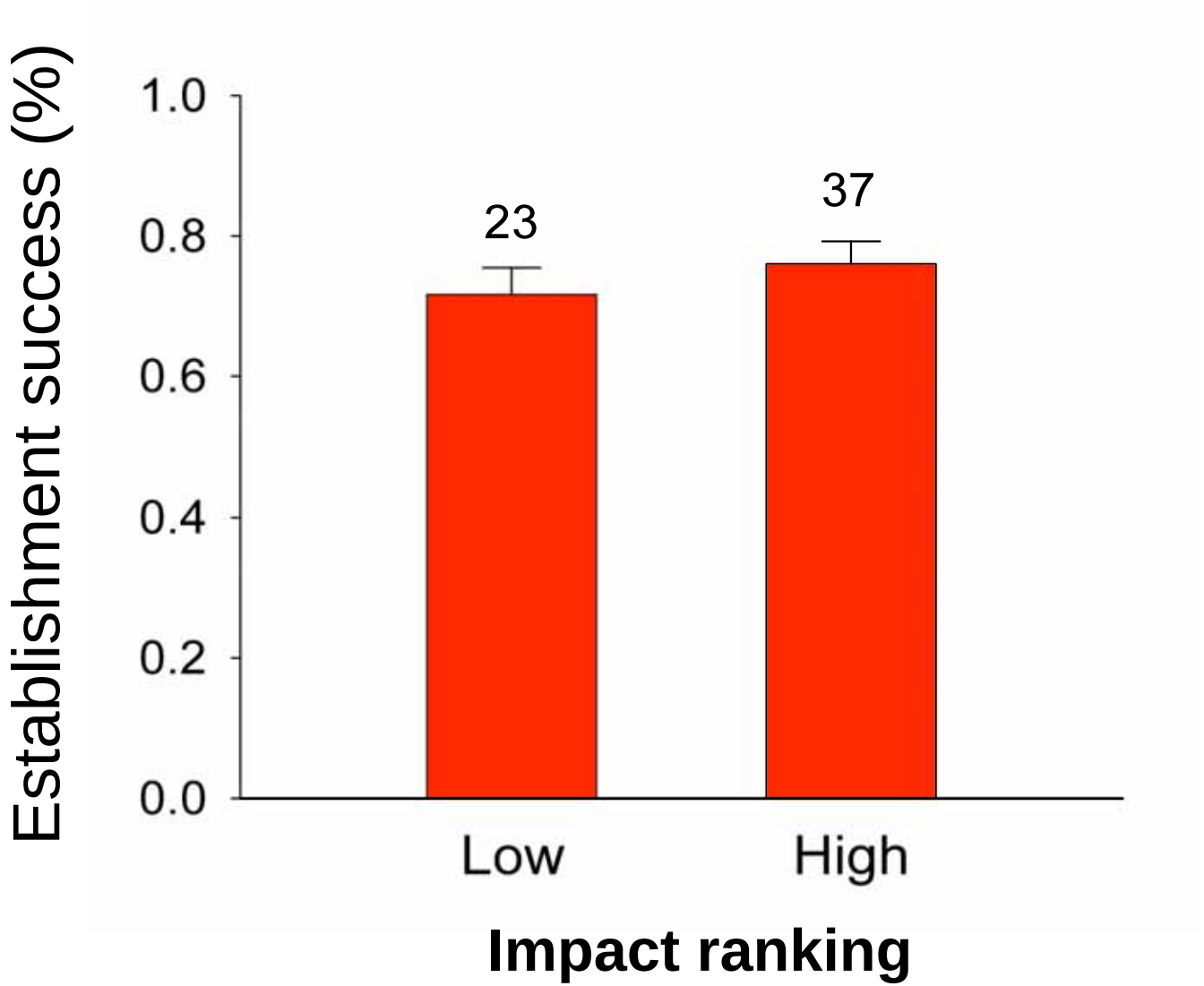
Invasiveness vs impact of exotic species on native species populations



Impact ranking

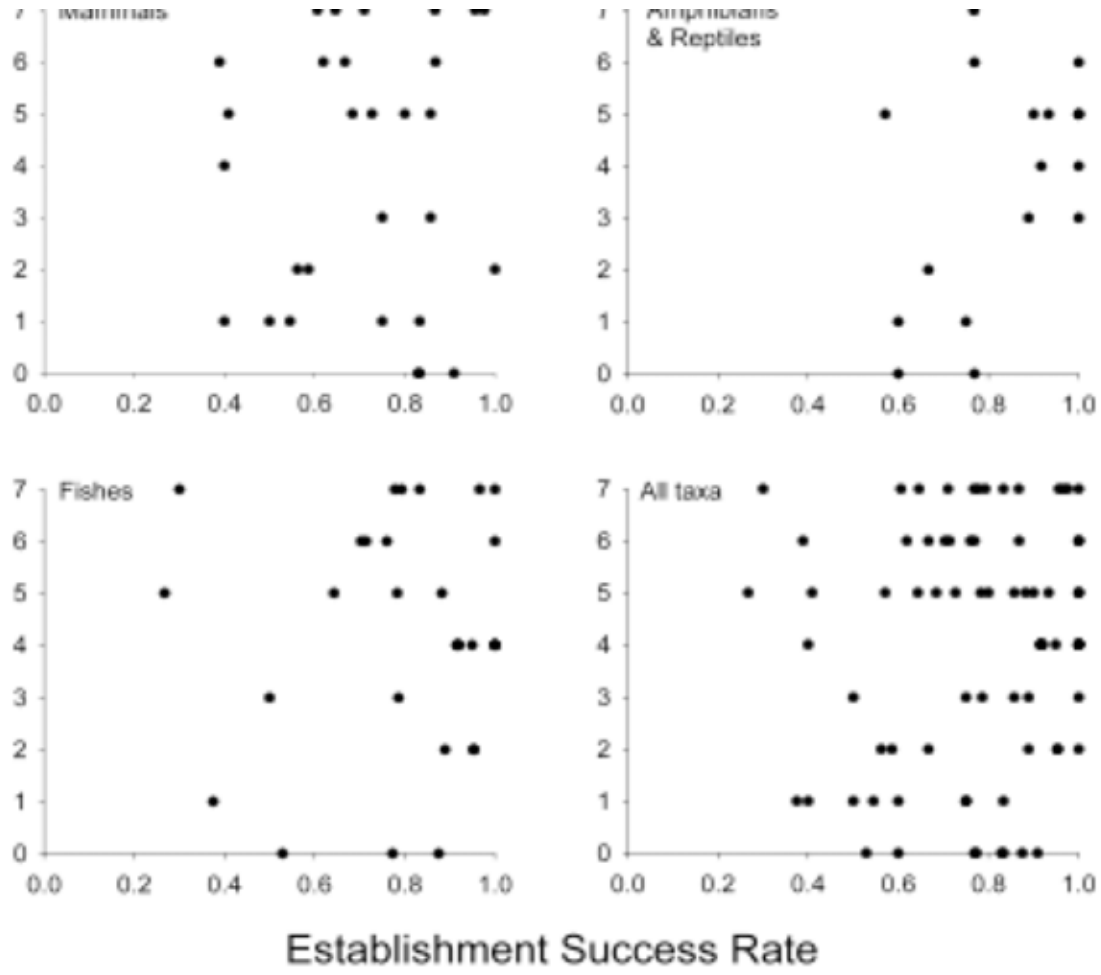
Ricciardi & Cohen (2007)

Invasiveness vs impact of exotic species on native species populations



Ricciardi & Cohen (2007)

Invasiveness vs impact of exotic species

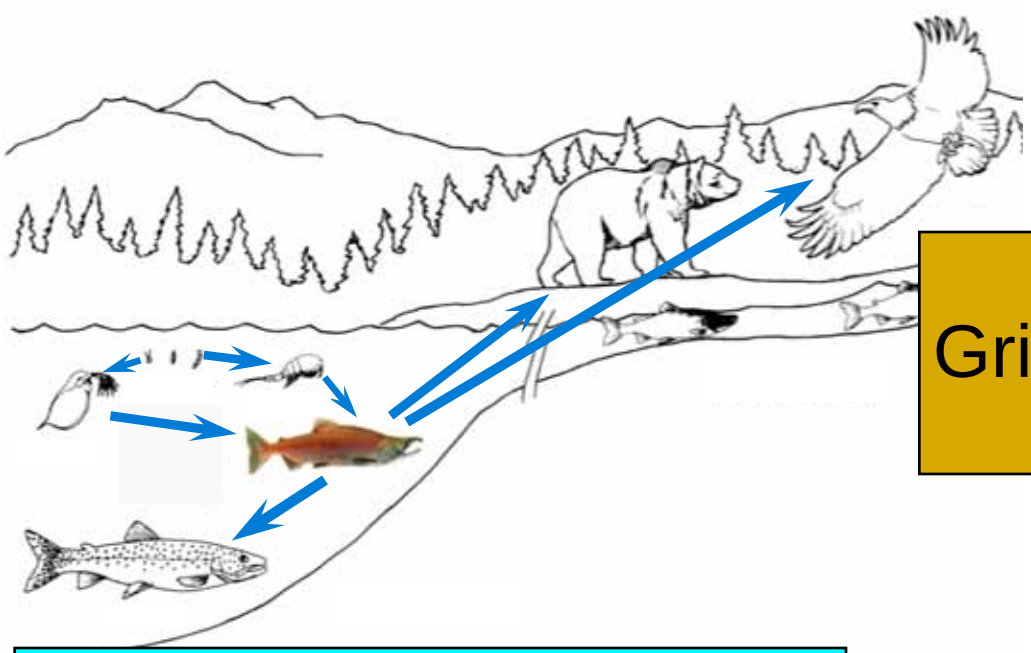


Ricciardi & Cohen (2007)

Ten generalizations regarding aquatic invasions

7. The introduction of an *uncontrolled generalist consumer* often has cascading effects in aquatic food webs.

Food web of Flathead Lake (Montana, USA)



Grizzly bear

Bald eagle

Zooplankton
(cladocerans, copepods)

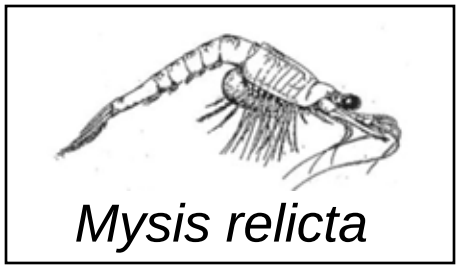
Kokanee salmon

Phytoplankton

Spencer et al. (1990)

Food web of Flathead Lake (Montana, USA)

after introduction of opossum shrimp



Mysis relicta

Grizzly bear

Bald eagle

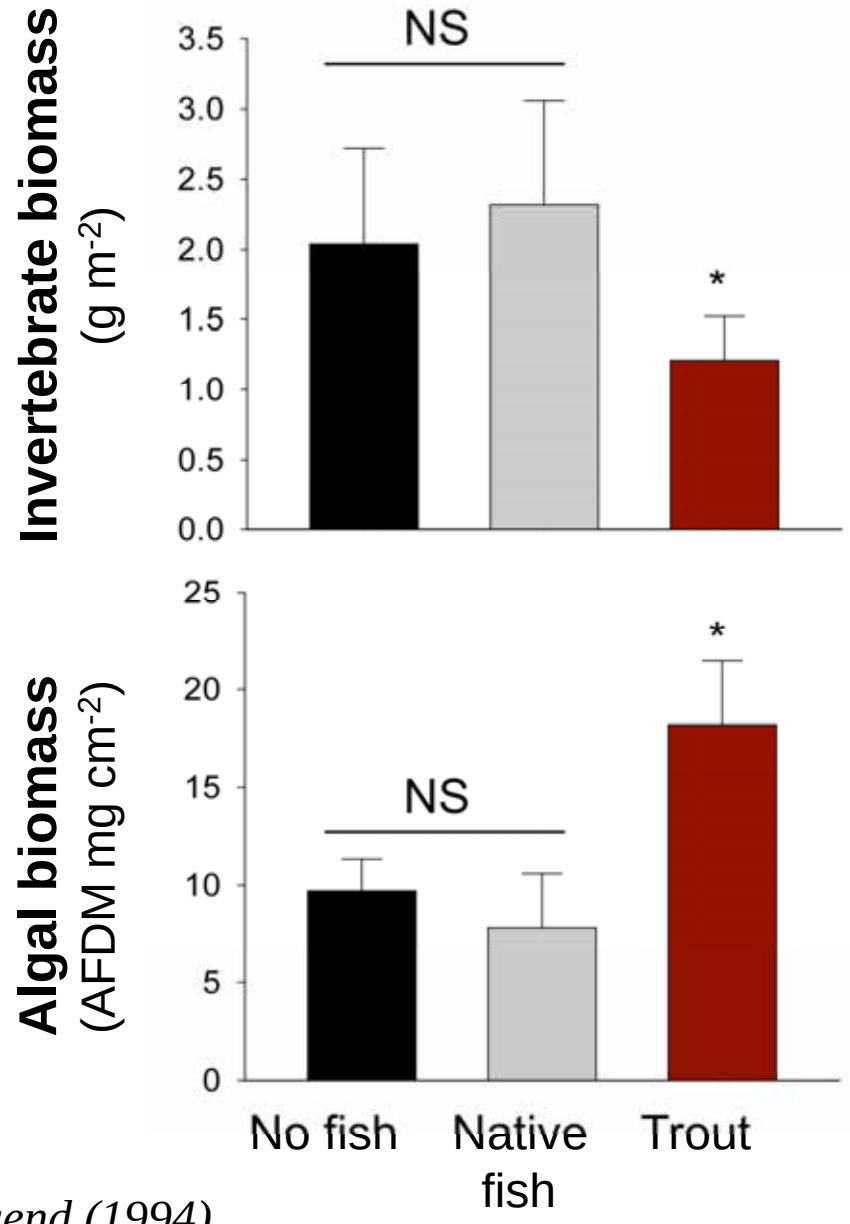
Zooplankton
(cladocerans, copepods)

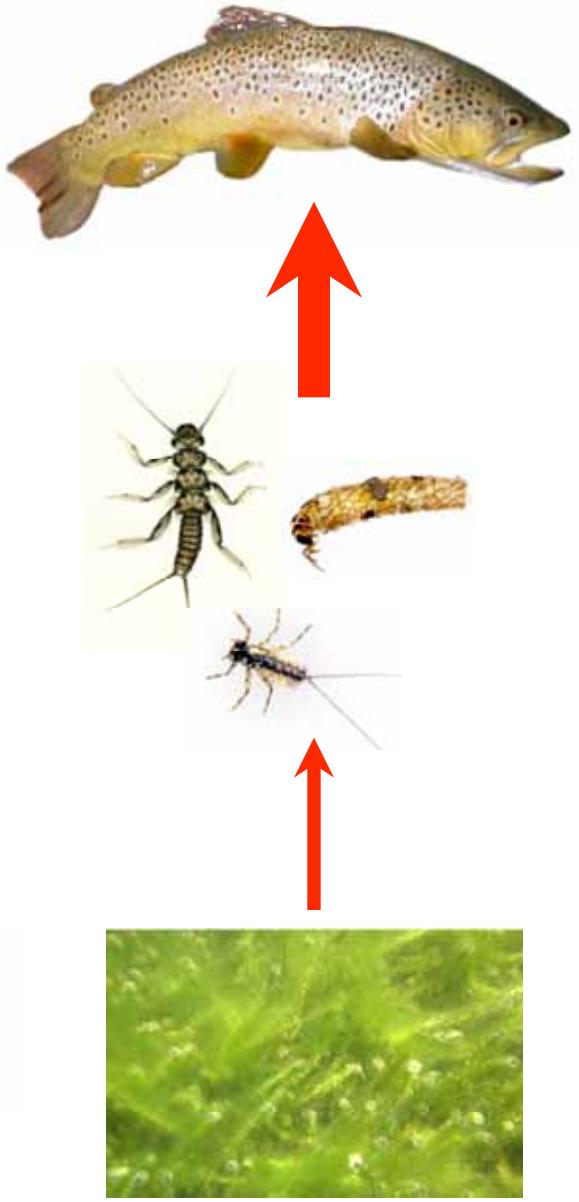
Kokanee salmon

Phytoplankton

Spencer et al. (1990)

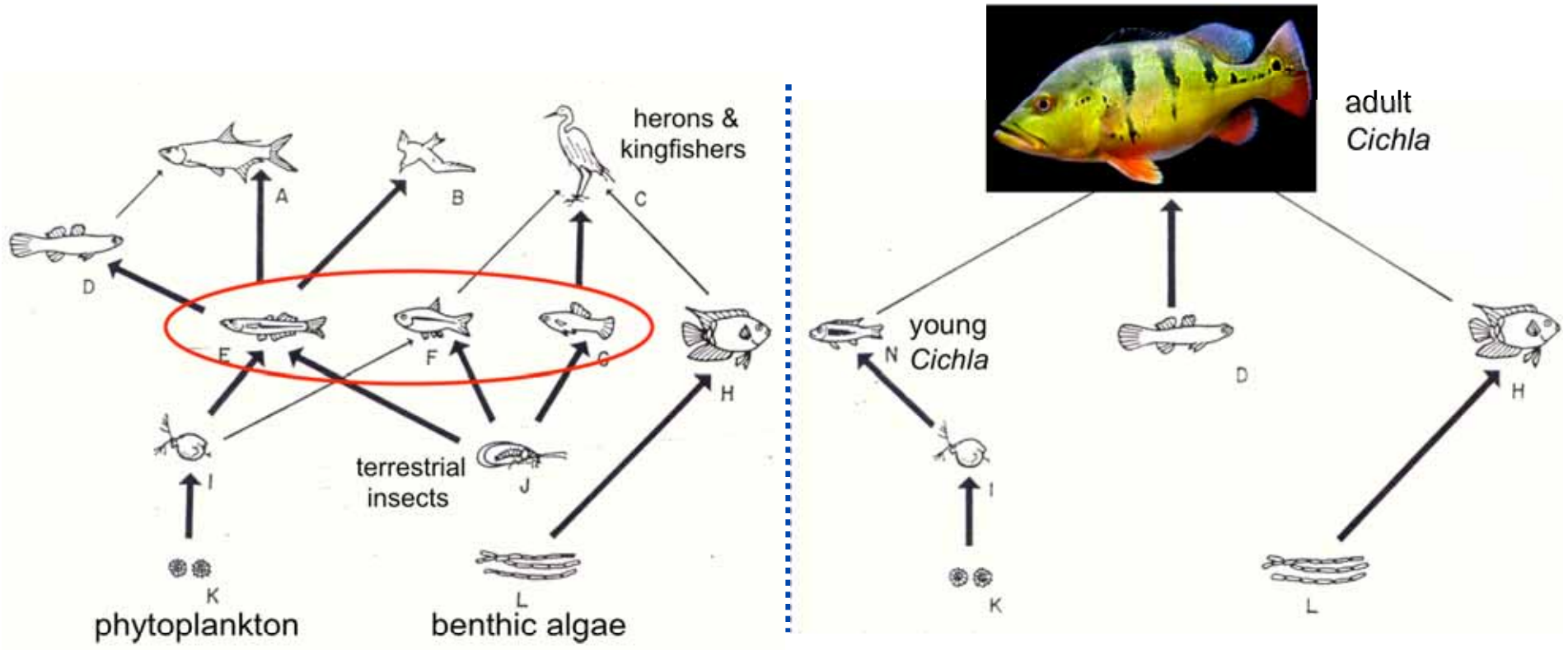
Trophic cascade caused by introduced brown trout





Flecker & Townsend (1994)

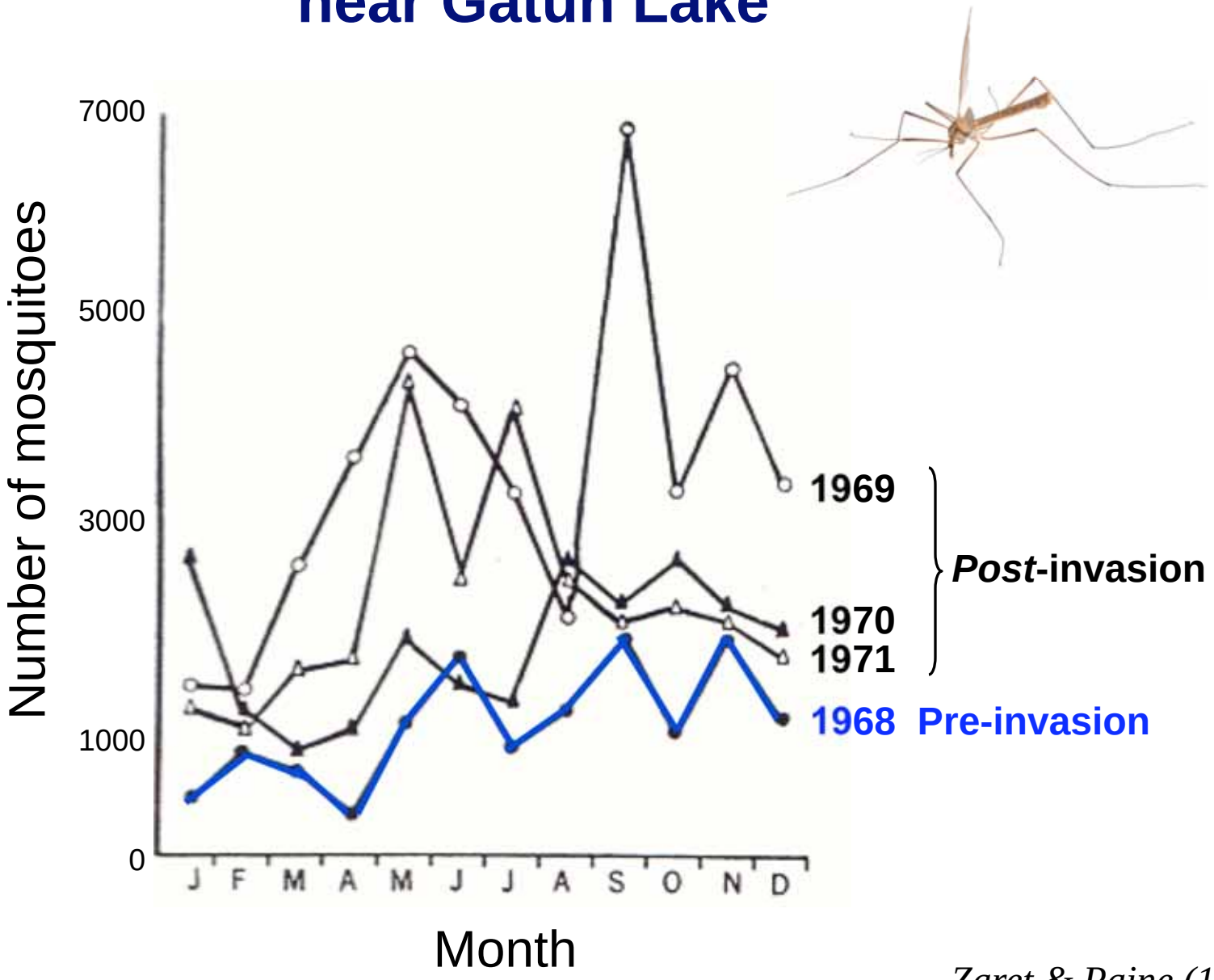
The effect of Peacock Cichlid *Cichla ocellaris* on the food web of Gatun Lake, Panama



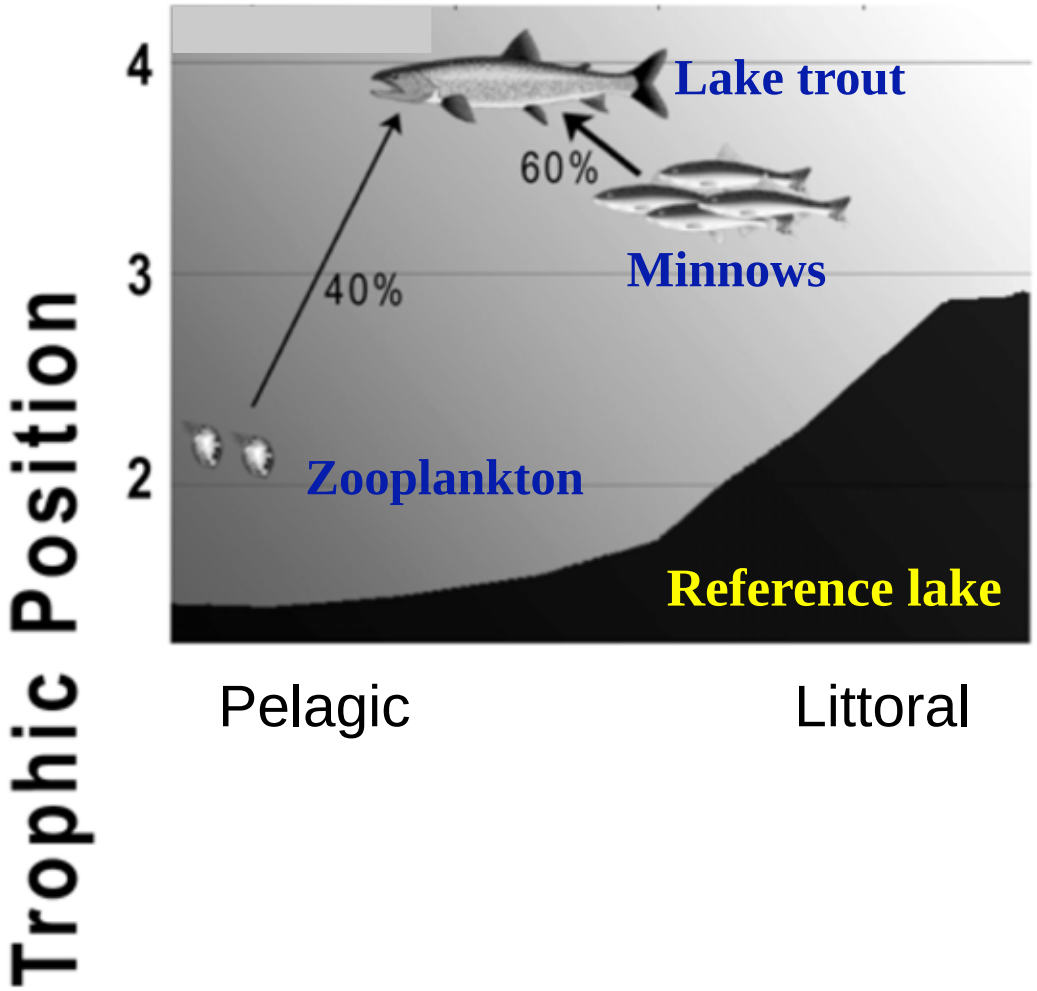
Before introduction **After introduction**

Zaret & Paine (1973)

Seasonal abundance of malarial mosquitoes near Gatun Lake

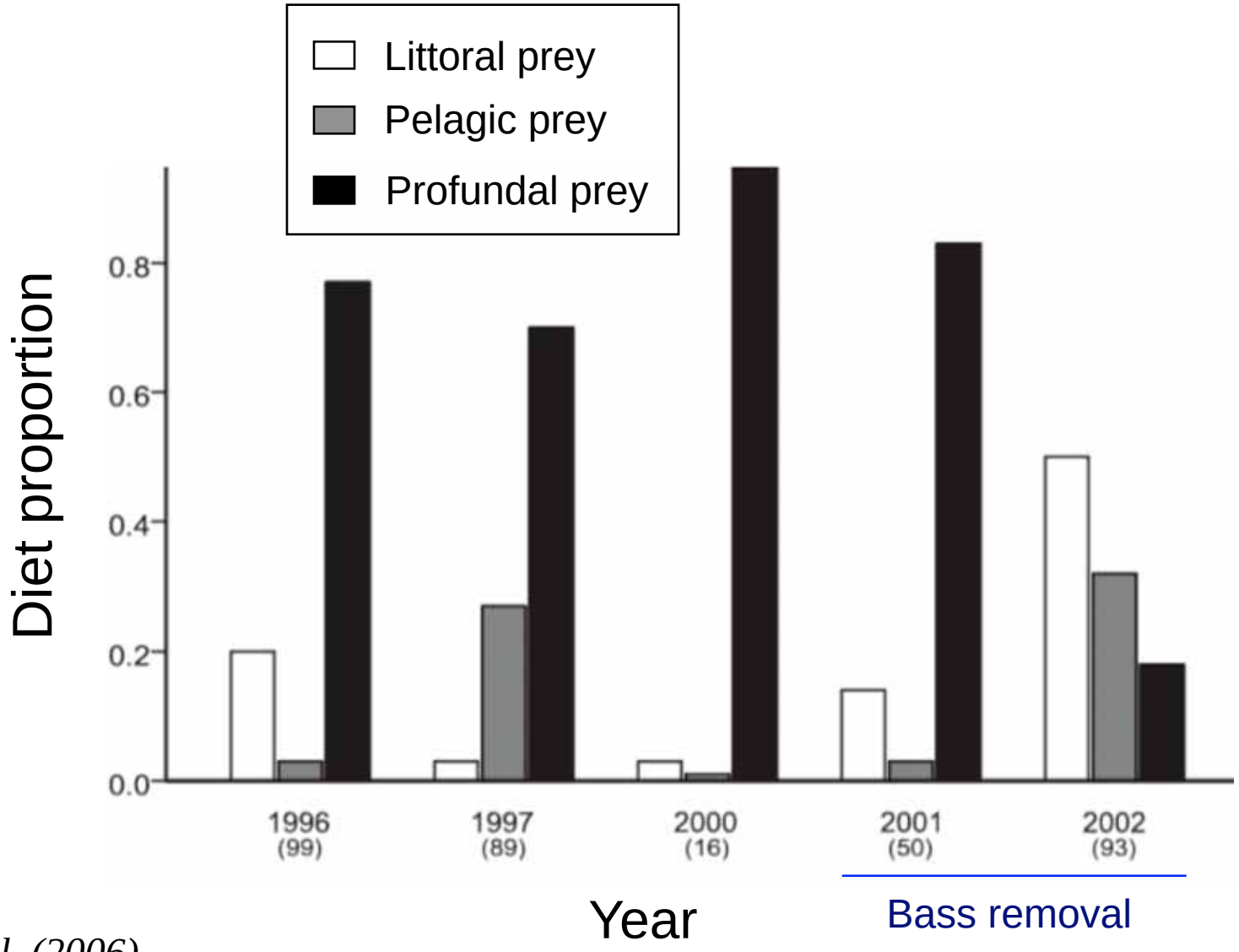


Zaret & Paine (1973)



Vander Zanden et al. (1999)

Lake trout response to smallmouth bass removal:
Changes in proportion of prey in lake trout diet

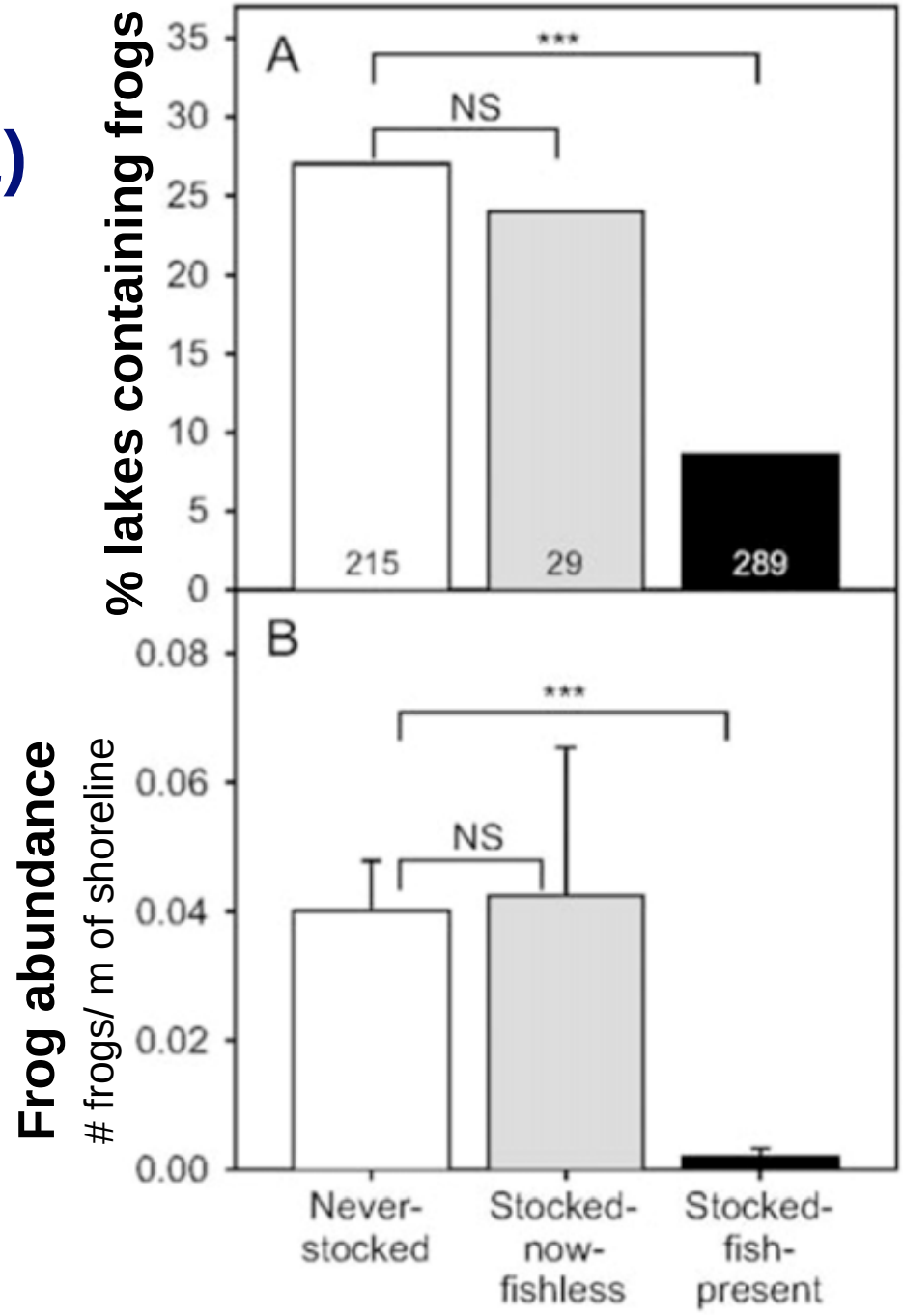


Lepak et al. (2006)

Ten generalizations regarding aquatic invasions

8. The largest impacts are caused by species introduced to systems where no similar species exist.

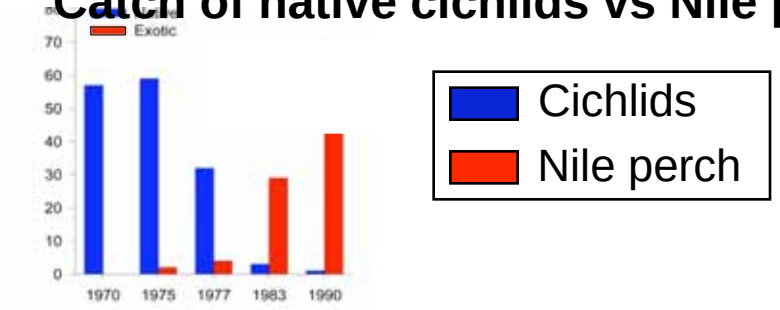
Impact of exotic trout on frogs (*Rana muscosa*) in alpine lakes in California



Knapp et al. (2001)

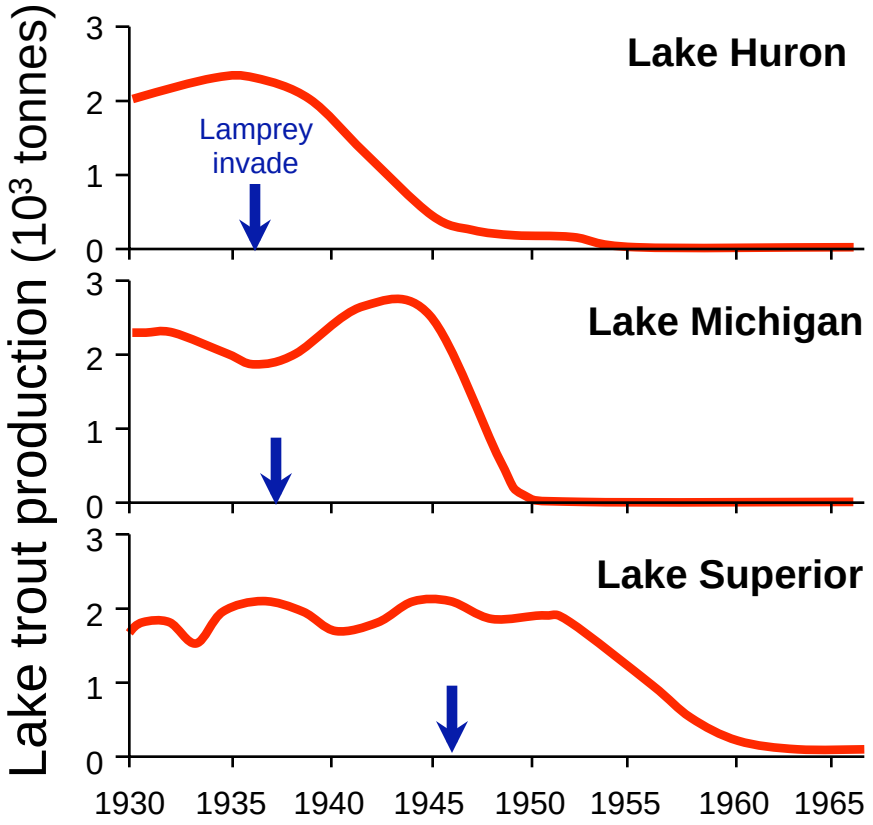
Impact of Nile perch (*Lates niloticus*) on Lake Victoria cichlids

Catch of native cichlids vs Nile perch



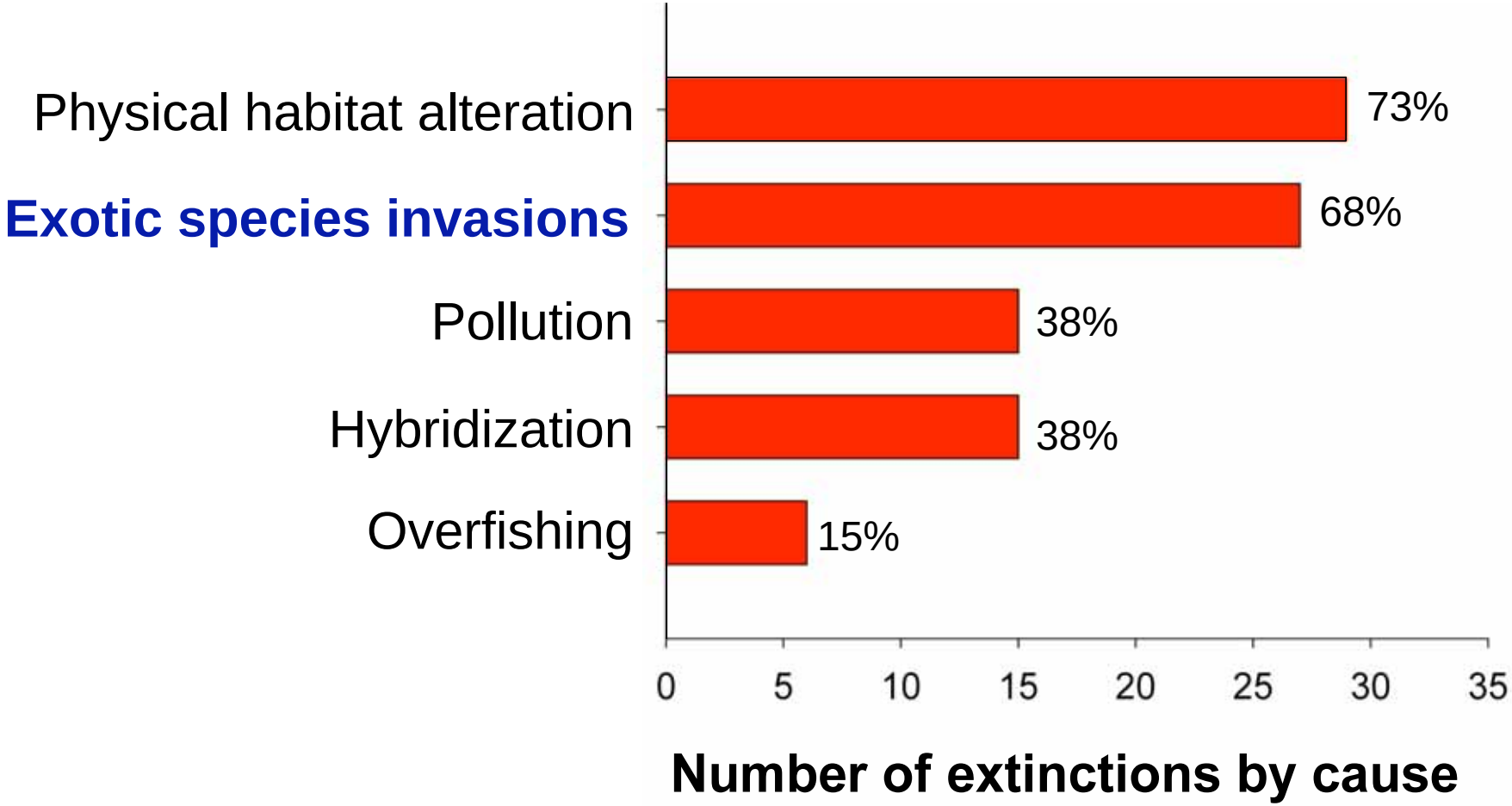
Kaufman et al. (1992)

Impact of sea lamprey on lake trout in the Great Lakes



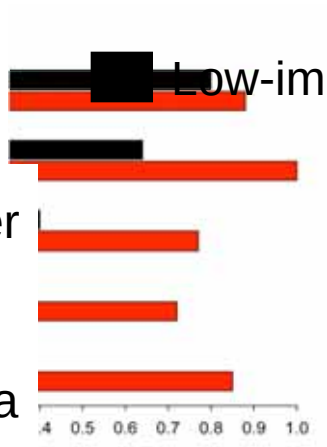
Lawrie (1970)

Causes of freshwater fish extinctions in North America



Miller (1989)

High-impact invaders tend to belong to novel taxa



Potomac River

Hudson River

Great Lakes

NS (p=0.49)

NS (p=0.23)

NS (p=0.07)

p=0.0007

p=0.00002

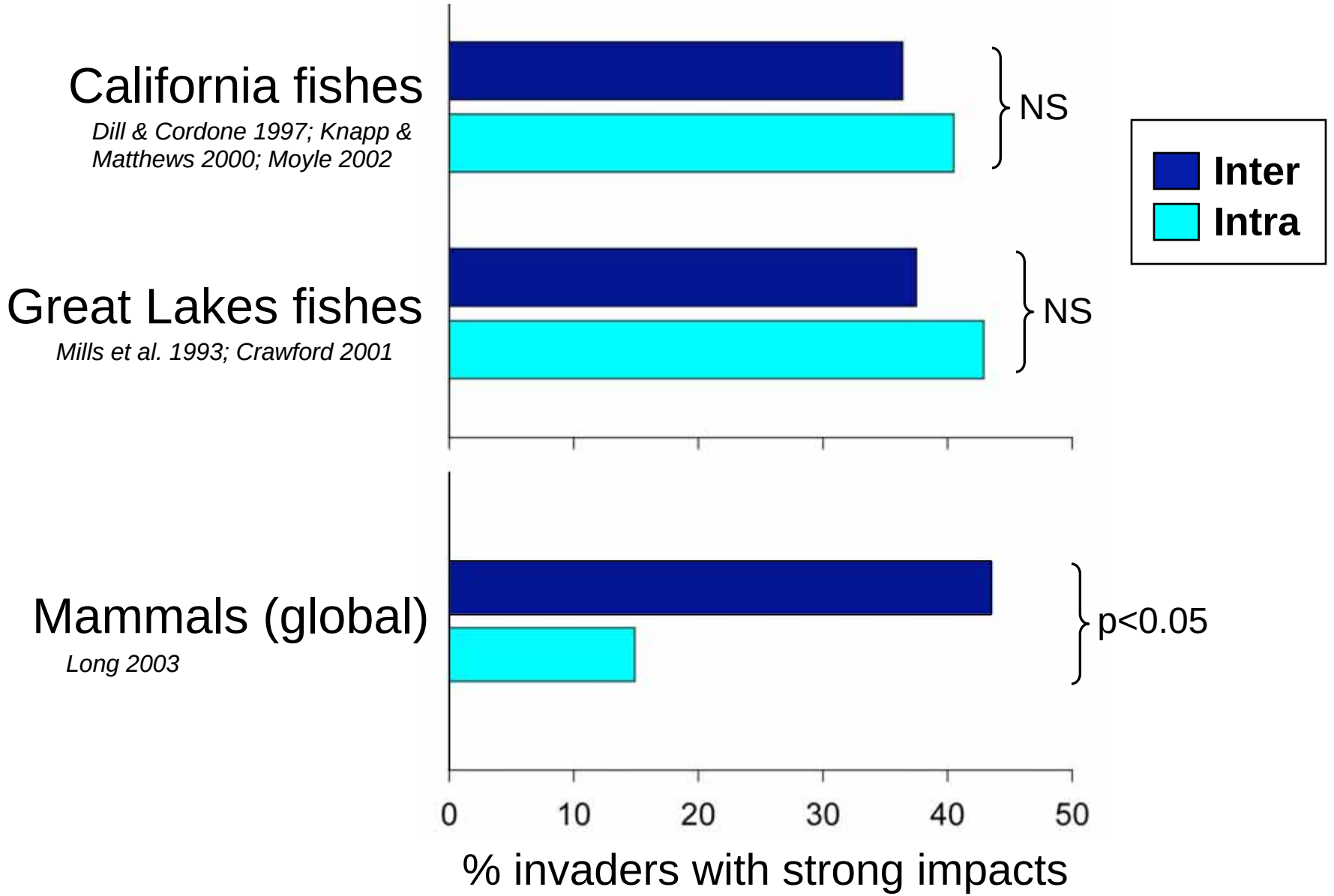
Proportion of genera that are novel

After *Ricciardi & Atkinson (2004)*

Fisher's Combined Test: $\chi^2 = 45.8$, $P<0.0001$

Colonization of the Great Lakes by invaders from the Black Sea

Impacts of inter- vs intra-continental invasions



Ricciardi & Simberloff (2009)

Ten generalizations regarding aquatic invasions

9. The invasion history of a species is the best predictor of its invasiveness and impact.

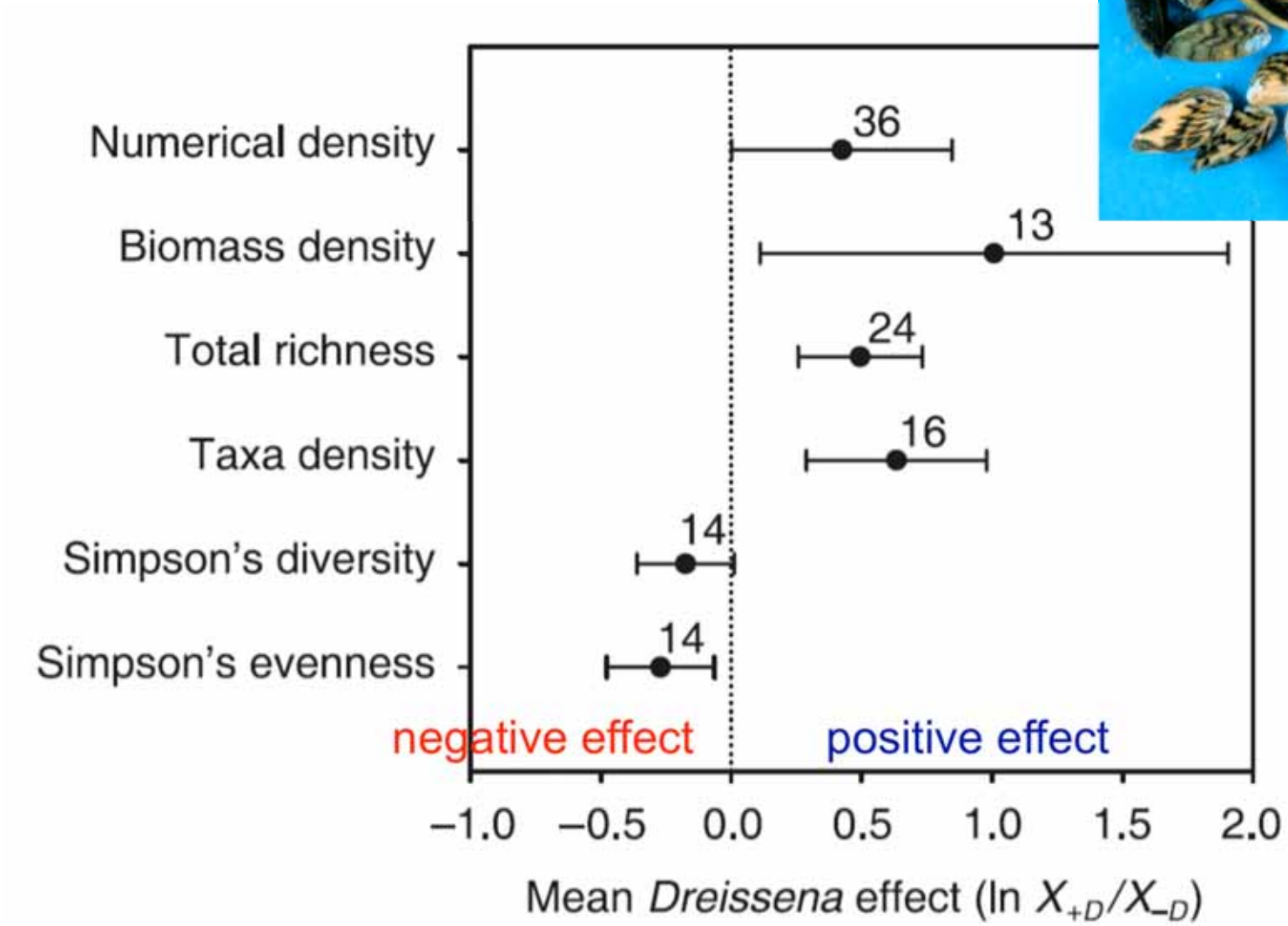
Ecosystem impacts of the zebra mussel

	European lakes	N. American lakes
Suspended particles	↓	↓
Transparency	↑	↑
Phytoplankton Production	↓	↓
Macrophyte Biomass	↑	↑
Zooplankton Biomass	↓	↓
Benthic Invertebrate Density	↑	↑
Waterfowl Density	↑	↑

↑ = increase, ↓ = decrease

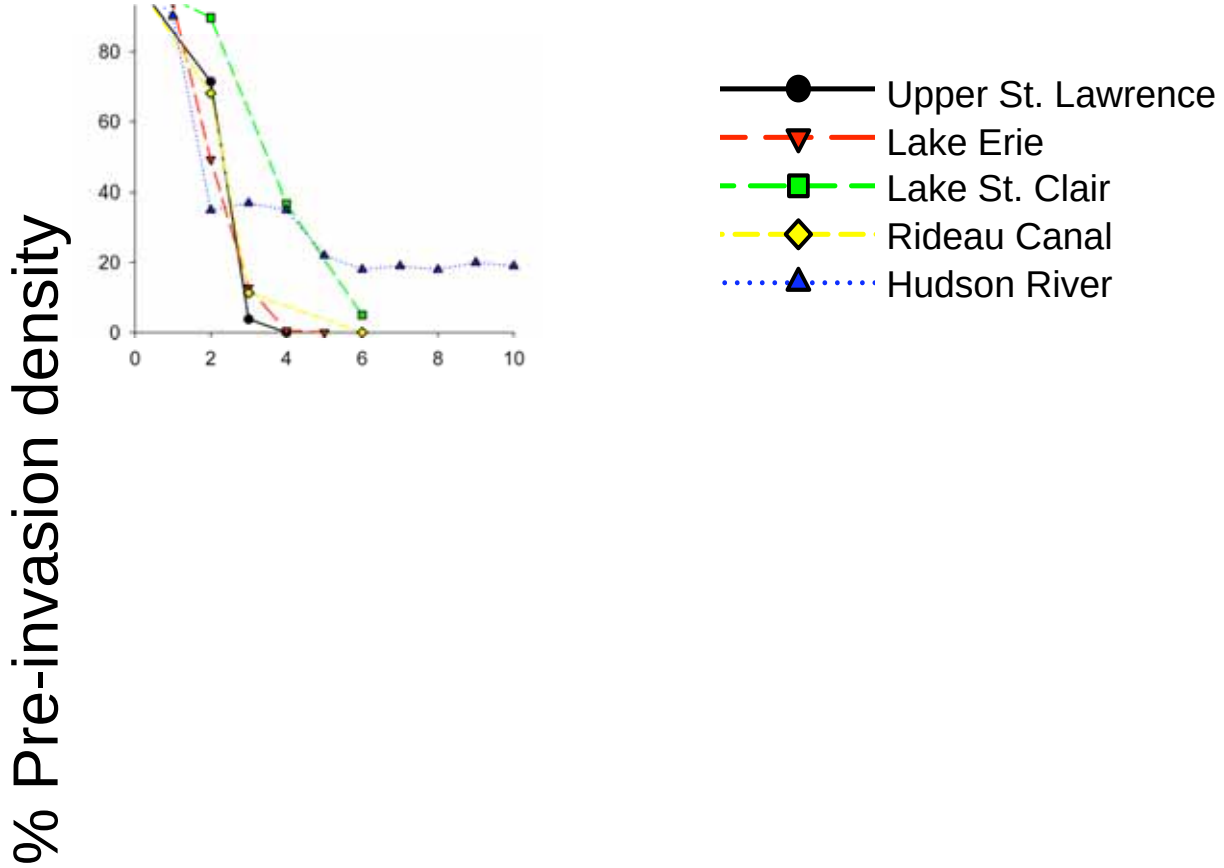
Effects of *Dreissena* on invertebrate communities

(as revealed by meta-analysis)



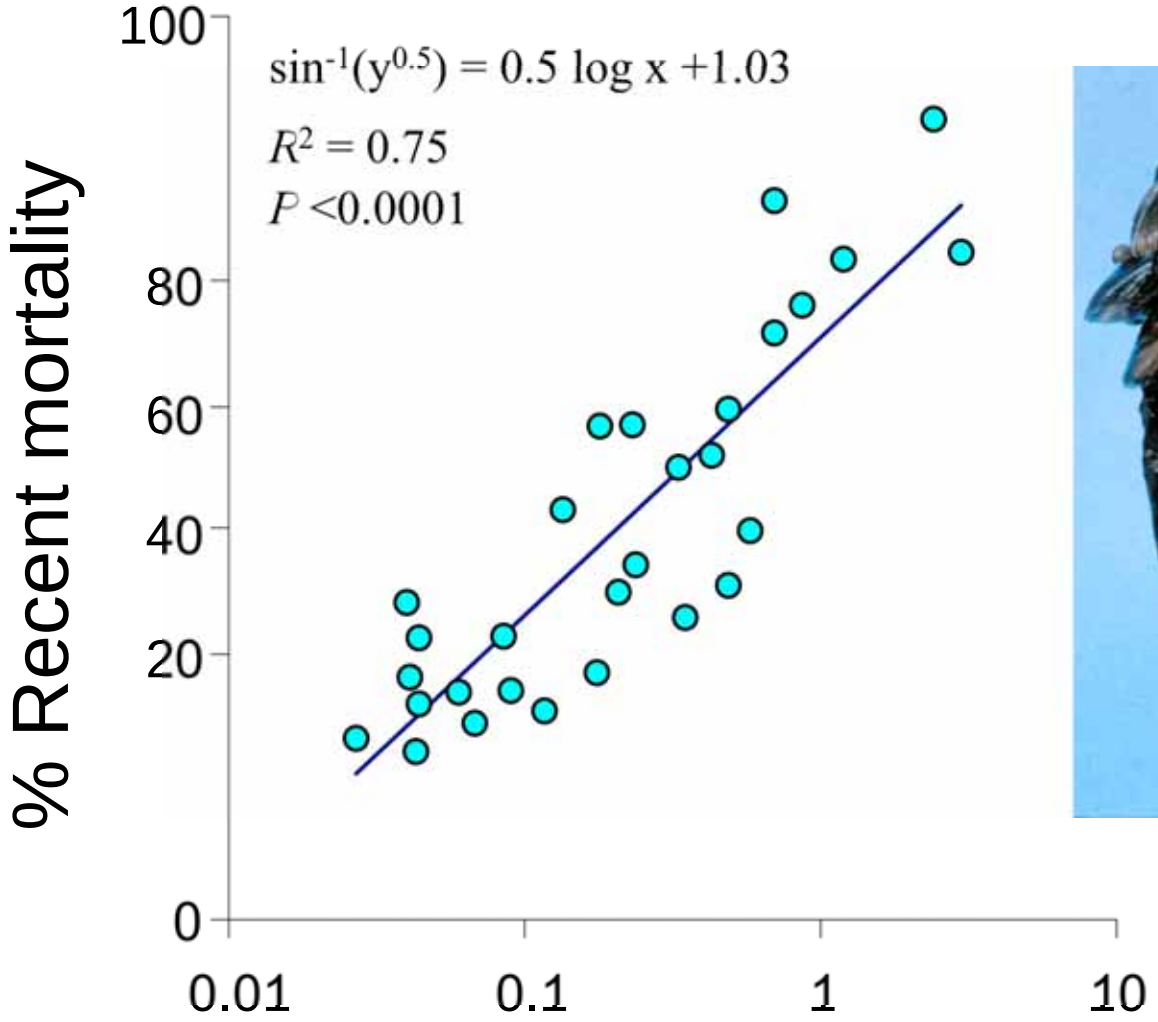
Ward & Ricciardi (2007)

Declines in N. American native mussel populations following zebra mussel invasion



After *Strayer & Malcom (2007)*

Native mussel mortality versus zebra mussel fouling in North America



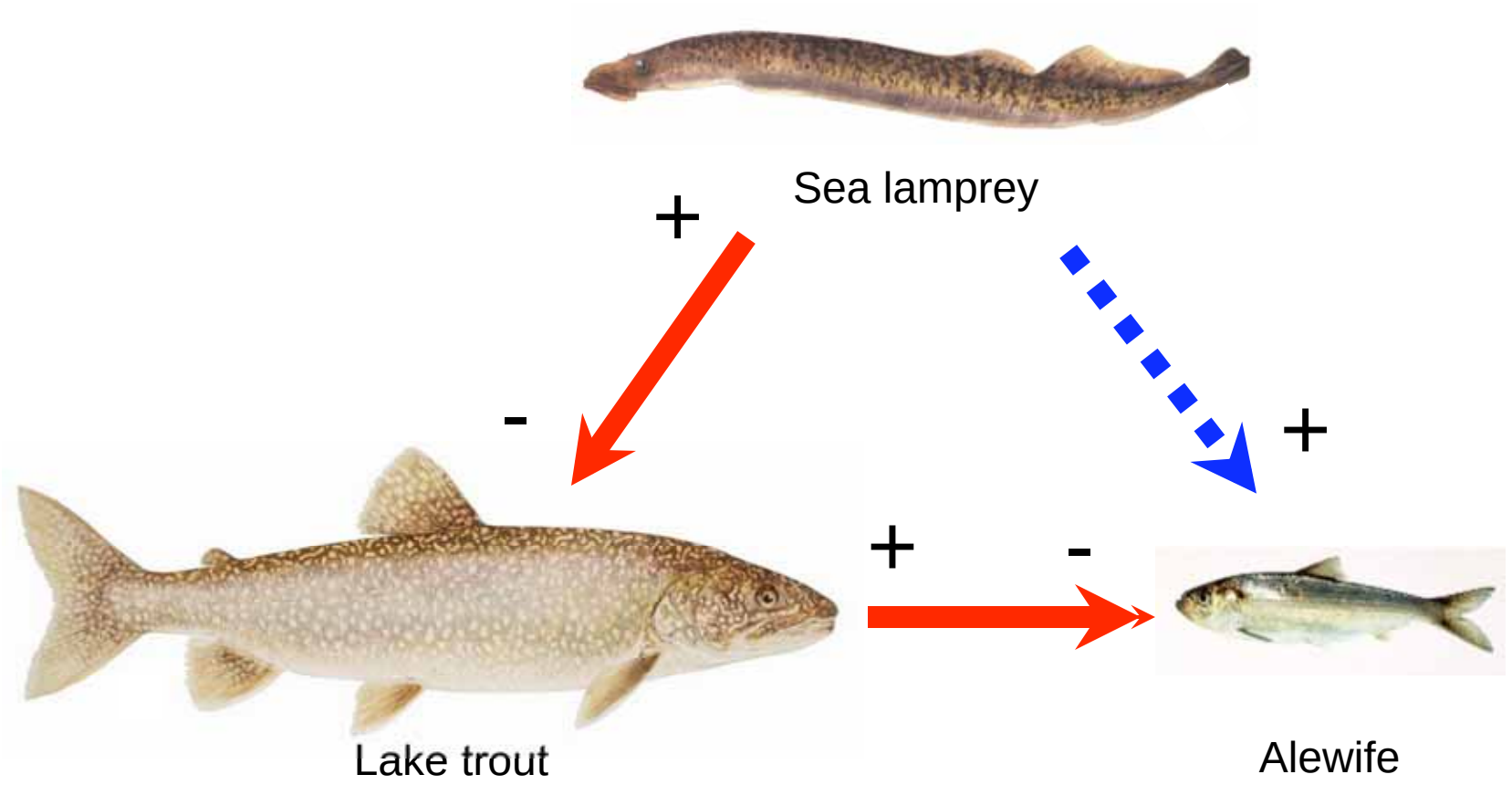
Ricciardi (2003)

Ten generalizations regarding aquatic invasions

10. Synergistic effects may result from the interactions of multiple invaders.

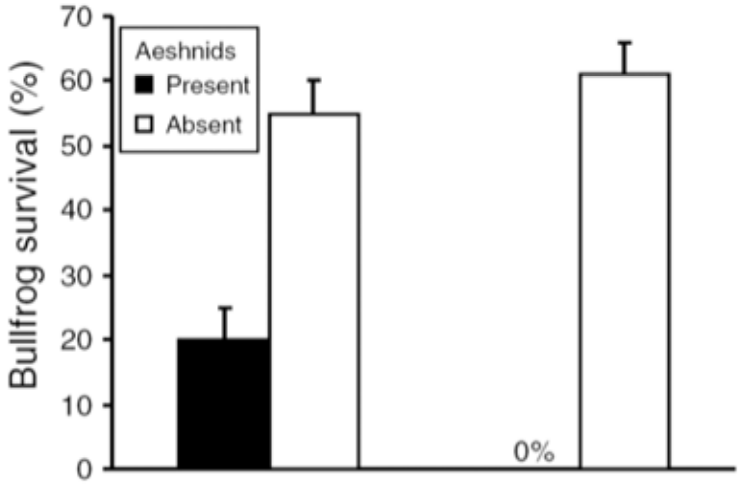
Facilitation of alewife invasion by sea lamprey in the Great Lakes

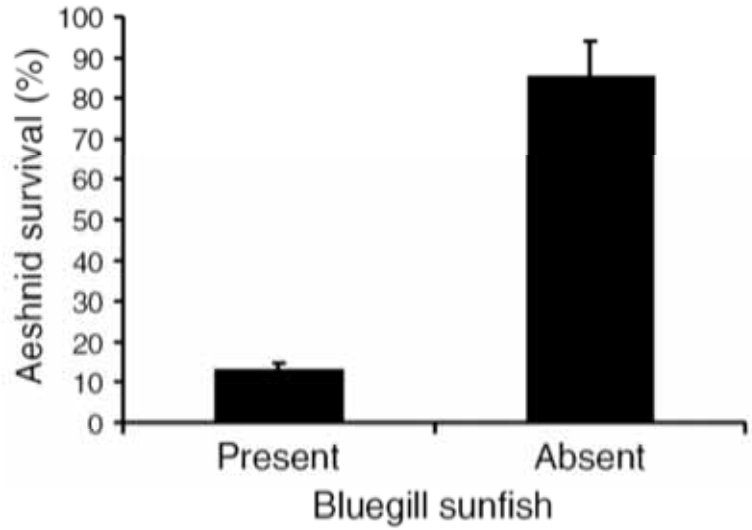
Lawrie (1970); Kitchell & Crowder (1986)

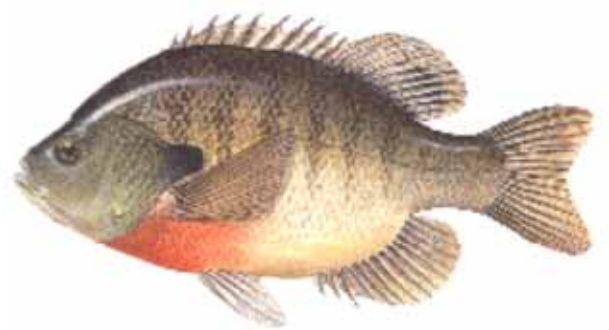


Facilitation of bullfrog invasion of ponds by nonindigenous fish

Adams et al. (2003)







Bluegill

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Dragonfly nymphs
(Aeshnids)

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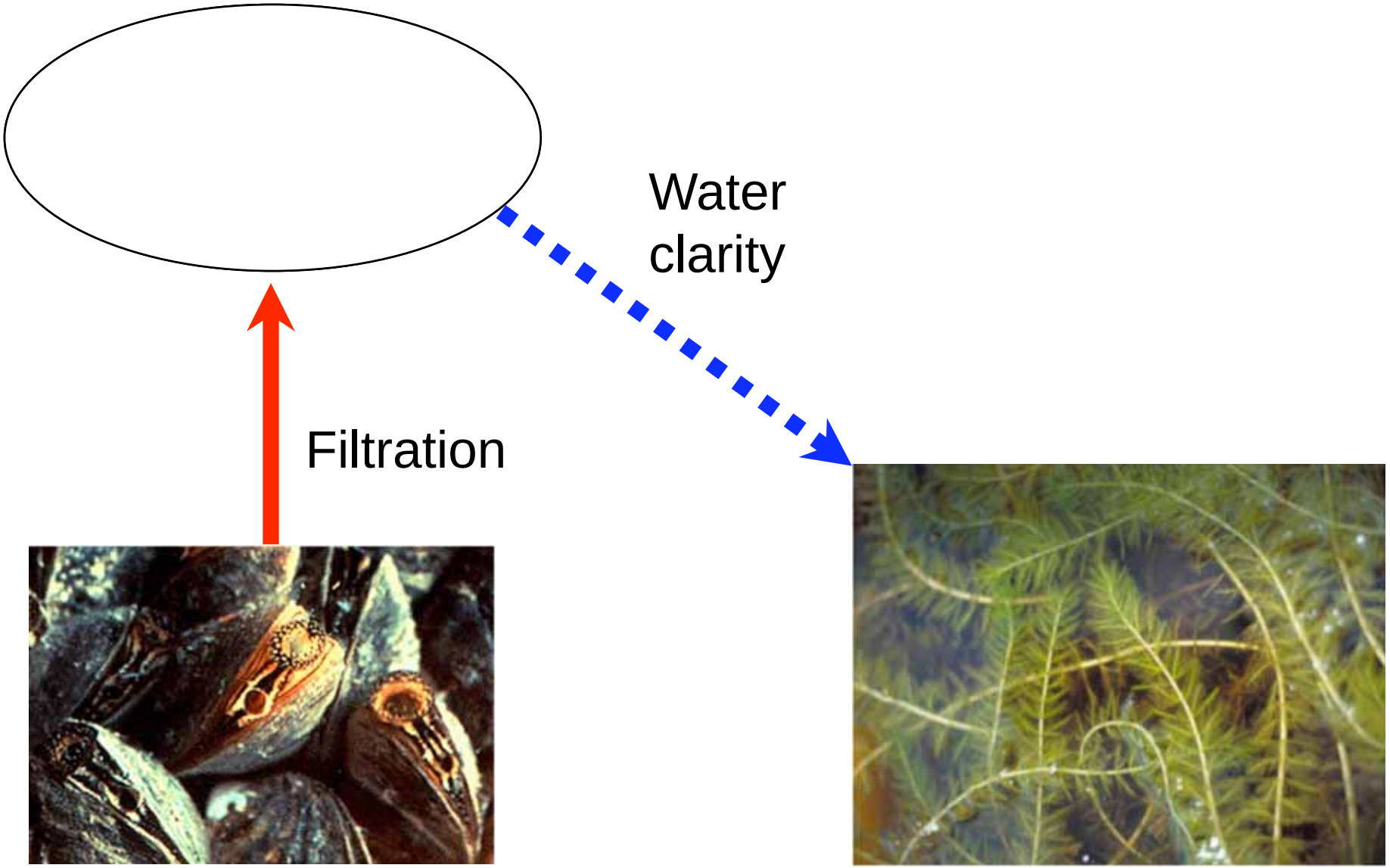
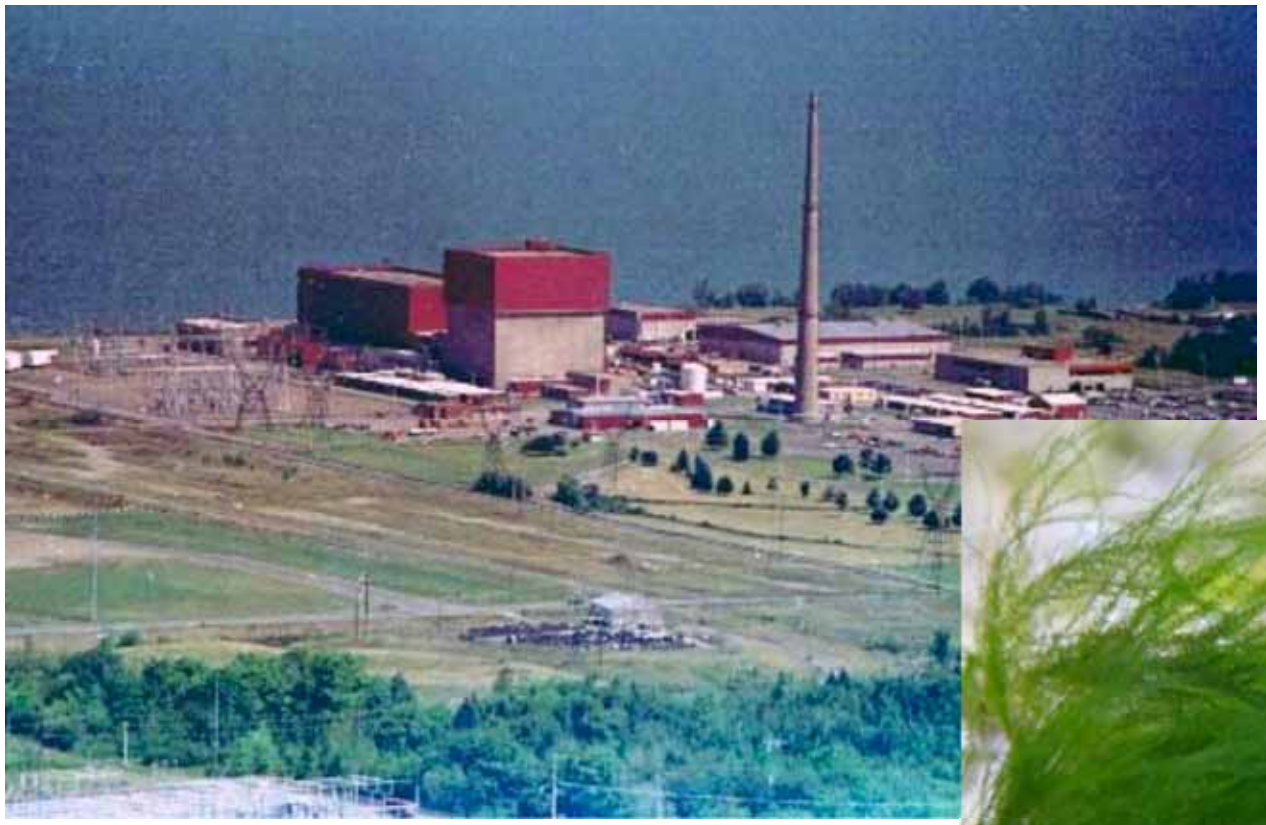
Bullfrog tadpoles

Facilitation of exotic plants by zebra mussels

Skubinna et al. (1995); Vanderploeg et al. (2002)



Dreissenid mussel activities forced the
James A. Fitzpatrick nuclear reactor at Oswego, N.Y.
to shut down **3 times** in Fall 2007



Cladophora (filamentous algae)

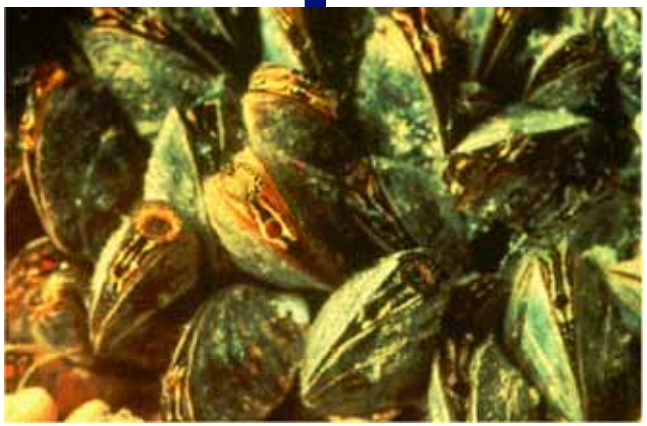
Recent outbreaks of avian botulism in the Great Lakes

- > 90,000 birds (fish-eating waterfowl) killed since 1999
- Also affects benthic fishes
- Cause: Type-E botulism from dreissenid mussels

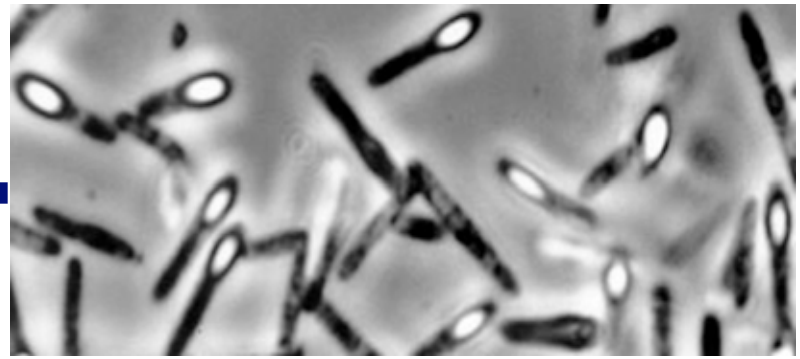
Transfer of botulism from dreissenid mussels to fish & birds in Lake Erie

Round goby

Waterfowl



Zebra & Quagga mussels



Clostridium botulinum

Conclusions

- All aquatic systems are invasible, given sufficient propagule pressure.
- An invader's impacts are context dependent, but its invasion history may reveal patterns.
- Ecologically-distinct invaders are more likely to disrupt food webs.
- Multiple invaders may interact synergistically.

Acknowledgements

- Natural Sciences and Engineering Research Council (Canada)

- Canadian Aquatic Invasive Species Network

NSERC CRSNG

CAISN CANADIAN AQUATIC INVASIVE SPECIES NETWORK