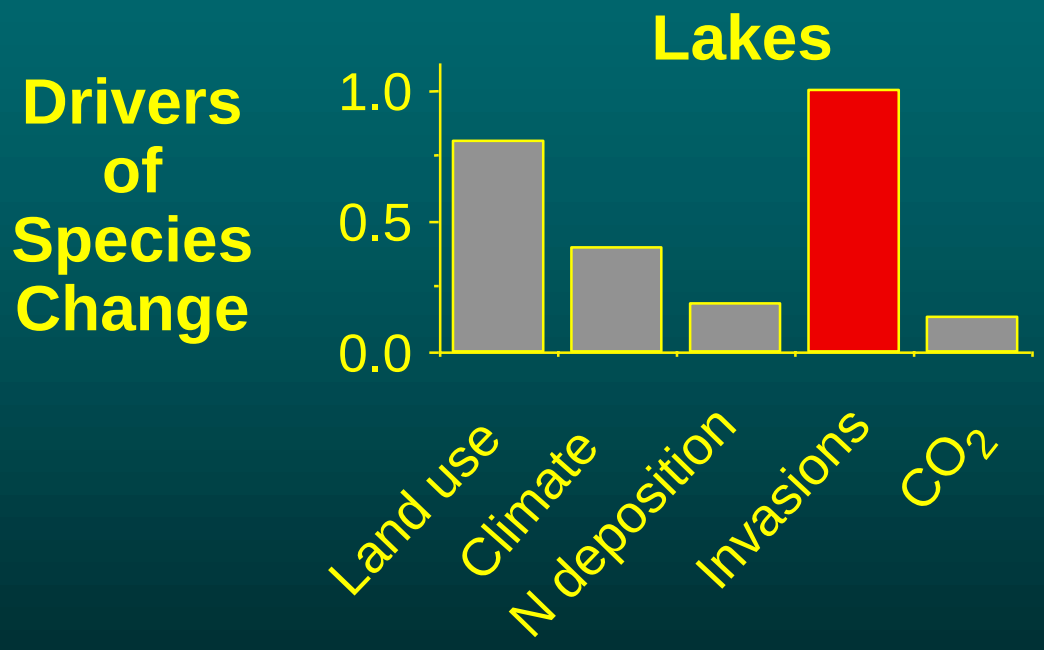
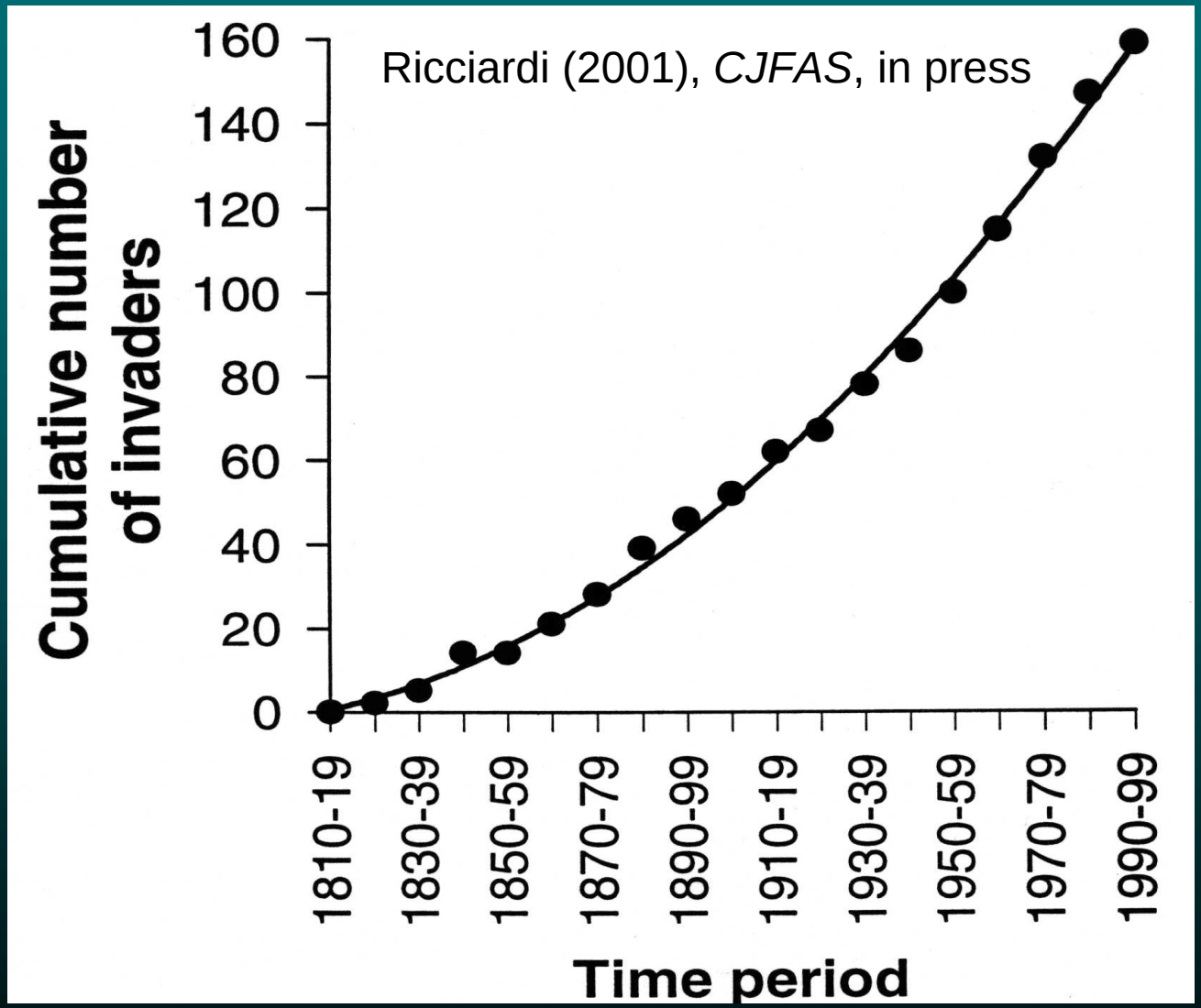
Causes of Biodiversity Change in Lakes during the 21st Century



Introduction of Nonindigenous Species (NIS) is expected to be the leading cause of biotic change in lake ecosystems during the 21st century.

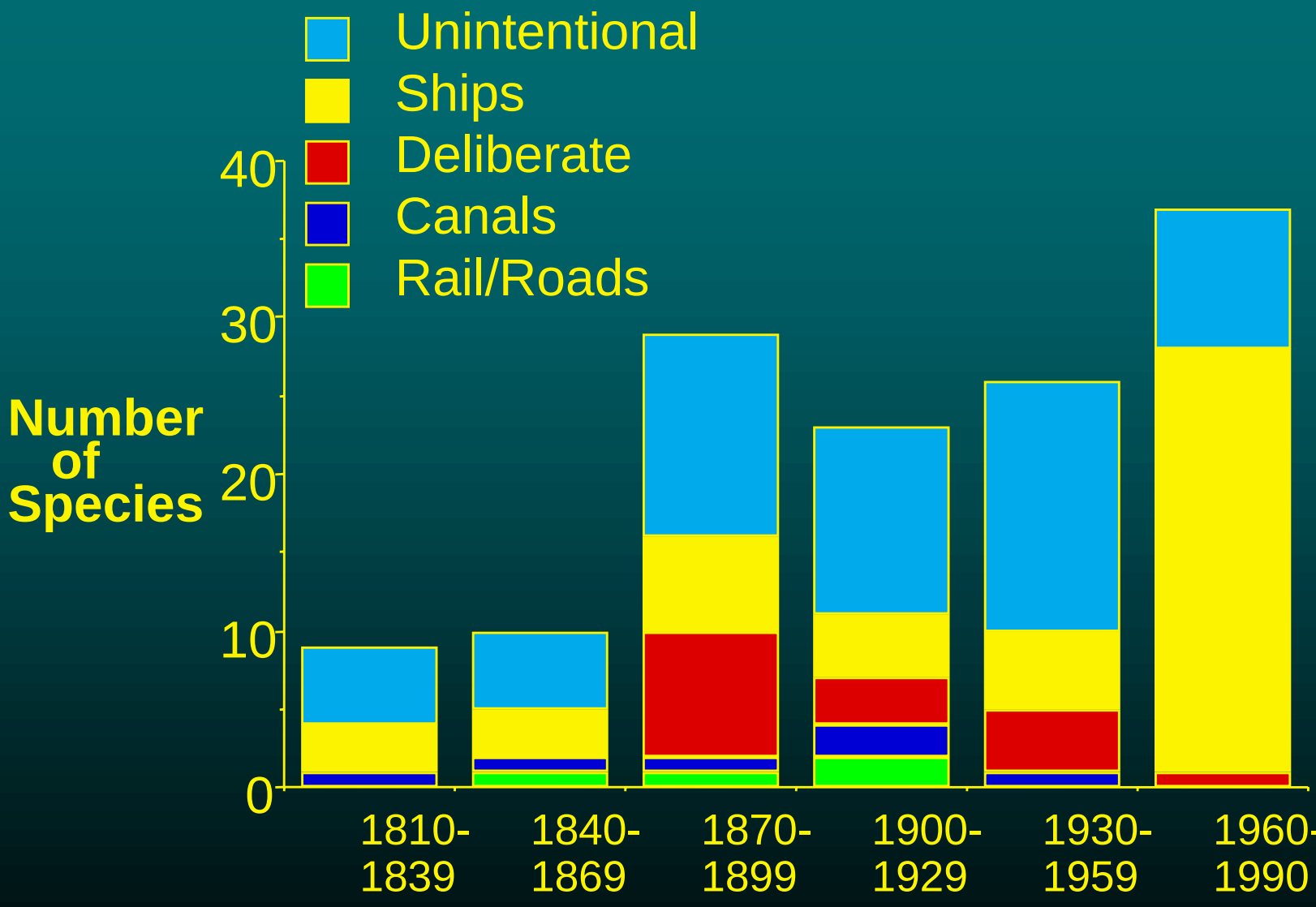
Sala et al., *Science* (2000)

Great Lake Invasions



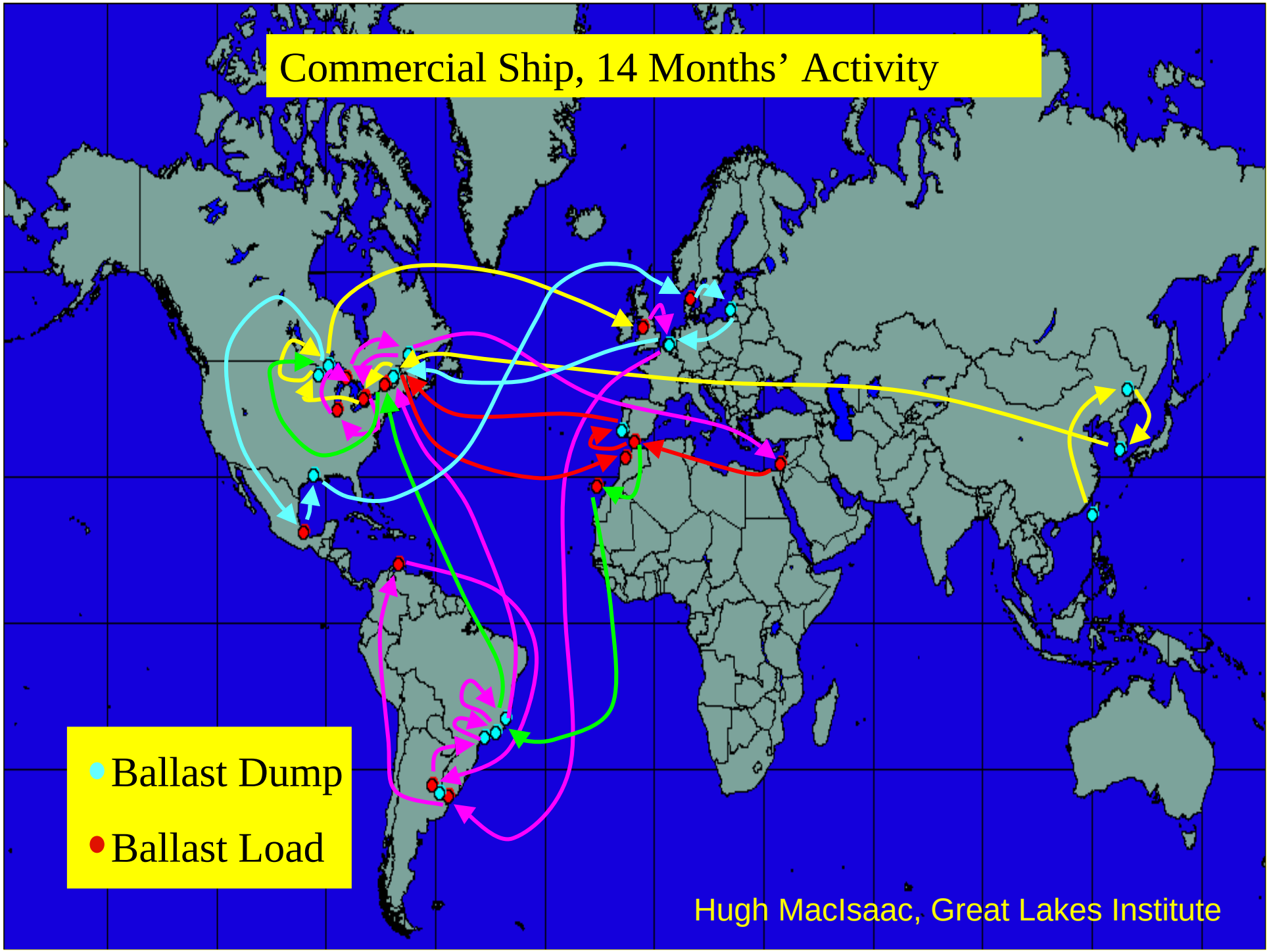
Invaders continue to establish in the Great Lakes, even after establishment of ballast water discharge legislation.

Invasion Mechanisms for the Great Lakes



Mills et al., *J. of Great Lakes Research* (1993)

Ships' ballast water was the major vector of NIS introductions to the Great Lakes during the 20th century.


Commercial Ship, 14 Months' Activity
Ballast Dump
Ballast Load
Hugh MacIsaac, Great Lakes Institute

Sources of Ship Traffic to the Great Lakes, 1986-1998

- Belgium
- Netherlands
- Baltic Sea
- West Germany
- Sweden/Norway
- Medit./Atlantic Europe
- England & Scotland
- Latin America
- Brazil
- Japan/China

About 50% of vessels inbound to the Great Lakes originate in the North or Baltic Seas

Rob Colautti, Great Lakes Institute

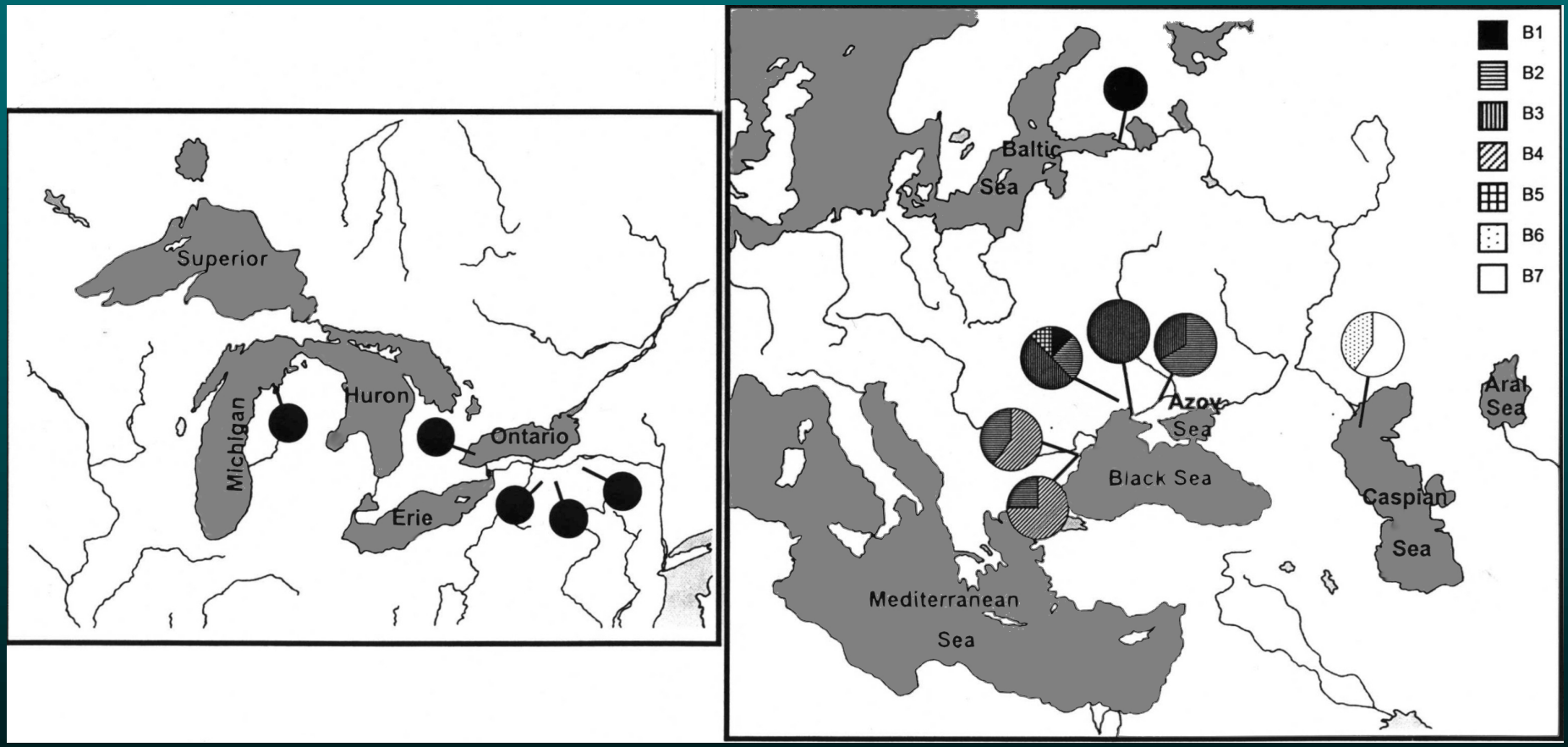
Nonindigenous animals established in the Great Lakes drainage since the mid-1980s

Common name	Year of Discovery	Endemic region	Mode of transfer	Probable donor region
Ruffe	1986	Ponto-Caspian	Ballast water	Danube River
Zebra mussel	1988	Ponto-Caspian	Ballast water	Baltic Sea
Quagga mussel	1989	Ponto-Caspian	Ballast water	Black Sea
Rudd	1989	Eurasia	Bait release	--
Round goby	1990	Ponto-Caspian	Ballast water	Black Sea
Tubenose goby	1990	Ponto-Caspian	Ballast water	Black Sea
New Zealandmudsnail	1991	New Zealand	Ballast water	Baltic Sea
Blueback herring	1995	Atlantic, N.A.	Canal	Atlantic N.A.
Echinogammarus amphipod	1994	Ponto-Caspian	Ballast water	Baltic Sea
Acineta noticrae ciliate	1997	Eurasia	Ballast water	Black Sea
Cercopagis waterflea	1998	Ponto-Caspian	Ballast water	Baltic Sea
Daphnia lumholtzi	1999	Africa, Asia, Aust.	Boat ?	Ohio Reservoirs
Schizopera borutzkyi	1999	Ponto-Caspian	Ballast water	Danube River
Heteropsyllus nr. nunni	1999	Atlantic N.A.	?	Atlantic N.A.

A disproportionate percentage of recent invaders have come from the Ponto-Caspian region (Black, Azov, Caspian Seas)

Modified from Ricciardi & MacIsaac, *Trends in Ecology and Evolution* (2000)

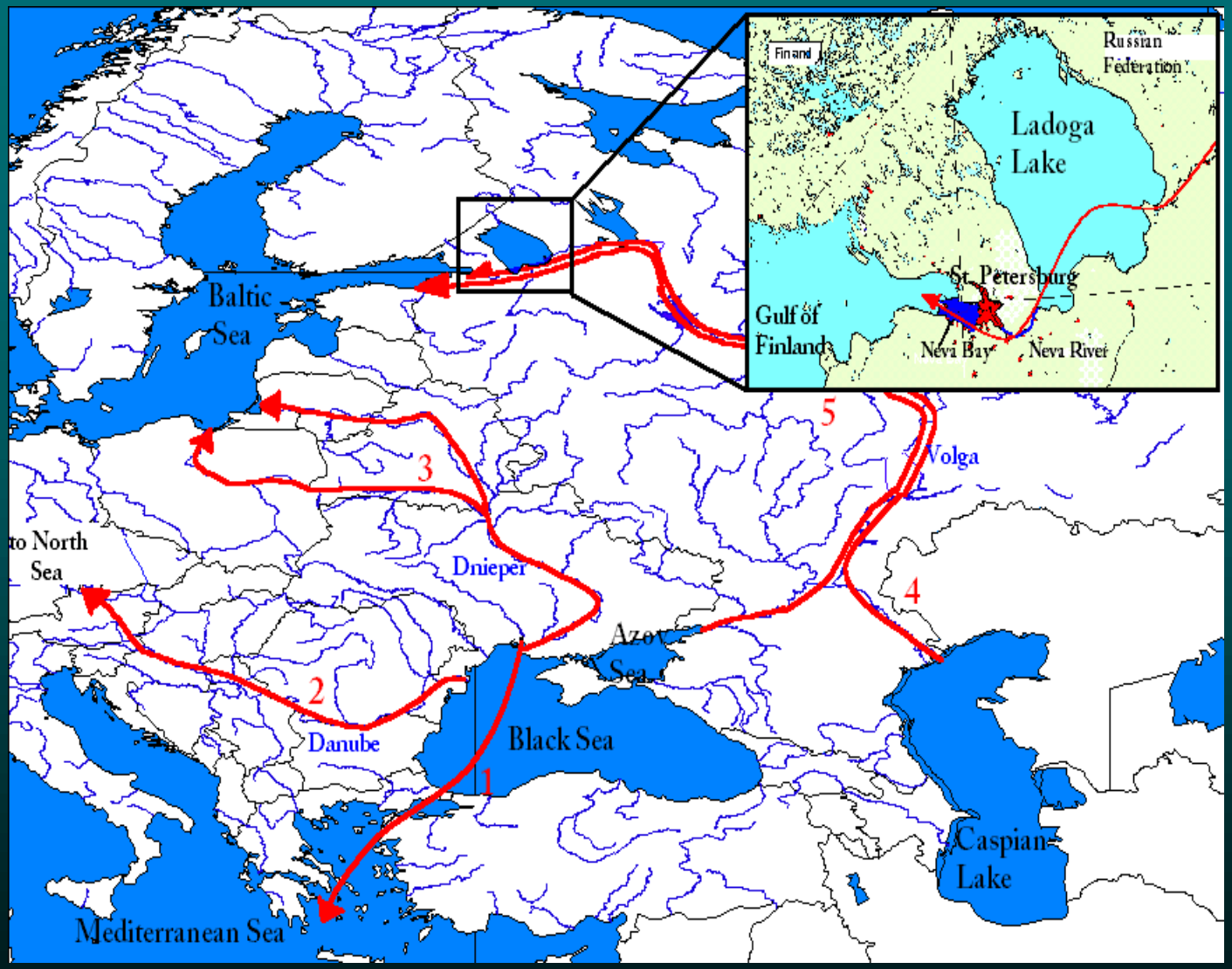
Cercopagis invasion forensics



Analysis of mitochondrial gene sequences suggest the Baltic Sea was invaded from the northern Black Sea, and the Great Lakes from the Baltic Sea

Cristescu et al., *Limnology and Oceanography* (2001)

Invasion ‘Corridors’ to the Great Lakes



5 invasion corridors may transfer Ponto-Caspian species to the Great Lakes

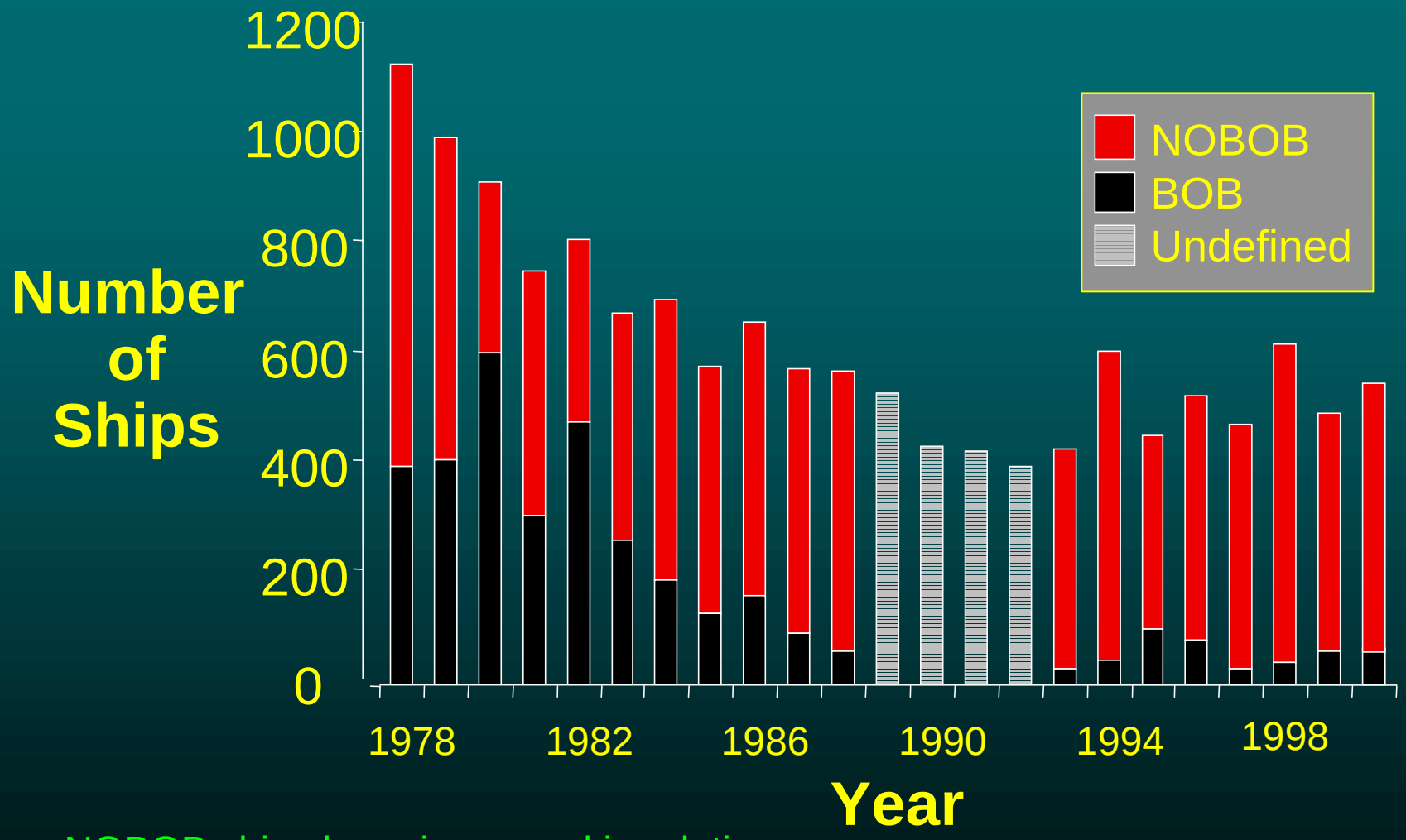
MacIsaac, Grigorovich & Ricciardi, in press

31 Possible invaders to the Great Lakes

Common Name	Scientific Name	Present Distribution
waterfleas	Daphnia rosea, Bosmina hagmani	New Orleans (NO)
copepods	Acanthocyclops americanus, A. robustus	Belgium, NO
amphipods	Corophium curvispinum, C. sowinskyi, Gmelinoides fasciatus, Dikerogammarus haemobaphes, D. villosus, Gammarus pulex, Pontogammarus crassus, P. obesus, P. robustoides, P. maeoticus	Europe
isopod	Jaera sarsi	Ponto-Caspia (PC)
mysids	Limnomysis bendeni, Paramysis intermedia, P. lacustris, P. ullskyi, Hemimysis anomala	PC
Asian mytilid	Limnoperna fortunei	Asia, S. America
rams-horn snail	Marisa cornuarietis	Florida, Texas
golden (apple) snail	Pomacea caniculata	S. America, Asia
bloodfluke planorb	Biomphalaria glabrata	semi-tropical
red-rimmed melania	Melanoides tuberculata	semi-tropical
planorbid snail	Indoplanorbis exustus	semi-tropical
hydrozoan	Polypodium hydriforme	PC
polychaete	Hypania invalida	PC
Caspian kilka	Clupeonella caspia	PC, Volga River
gobies	Benthophilus stellatus, Neogobius fluviatilis	PC

Ricciardi & Rasmussen, *CJFAS* (1998); MacIsaac, *State of Lake Erie* (1999)

Great Lakes Inbound Ships



NOBOB ships have increased in relative and absolute importance in the Great Lakes over the past 25 years and now constitute > 90% of the inbound traffic.

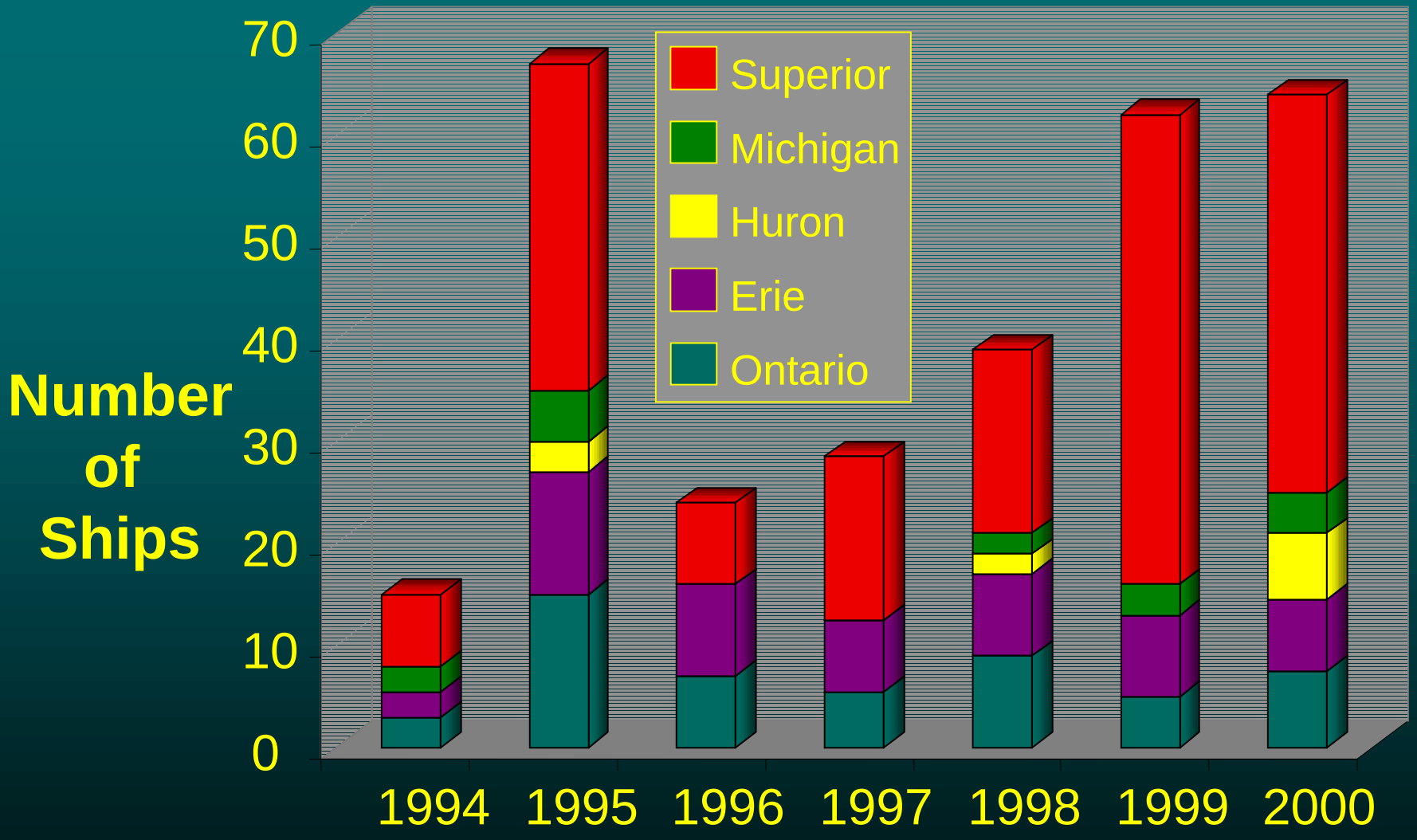
Rob Colautti, Great Lakes Institute

Transit of a Ballasted (BOB) bulk carrier

BOB vessels enter the Great Lakes loaded with saline ballast water, which is discharged at the destination port of call.

Rob Colautti, Great Lakes Institute

BOB Ships' Deballast Sites



Lake Superior receives more saline ballast water discharges than any other Great Lake.

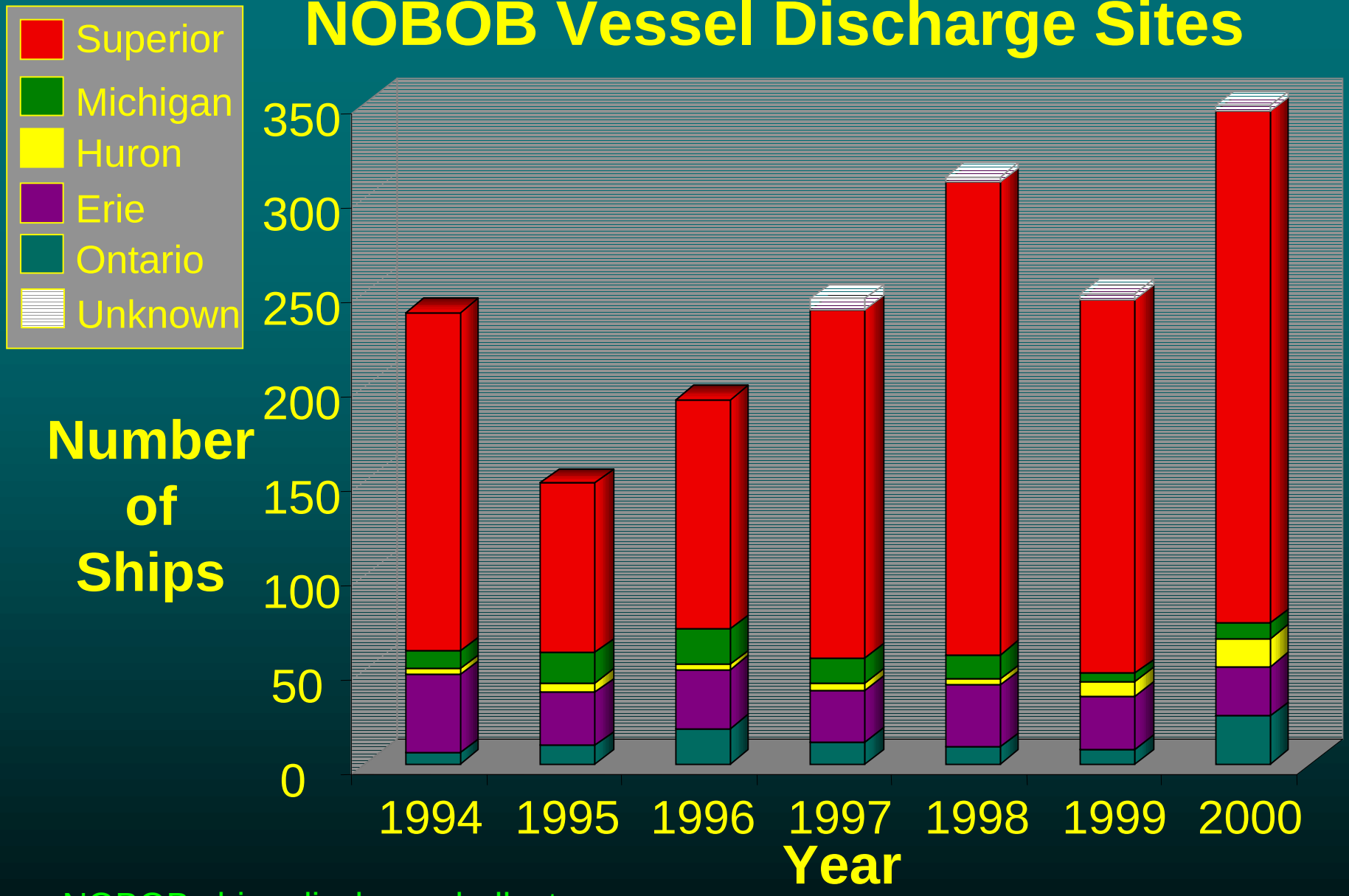
Rob Colautti, Great Lakes Institute

Transit of a NOBOB steel carrier

NOBOB ships may stop at a series of ports, discharging cargo and loading ballast water. Many of these ships load cargo at a terminal port of call (Duluth) and discharge water (and species?) before leaving the Great Lakes.

Rob Colautti, Great Lakes Institute

NOBOB Vessel Discharge Sites



NOBOB ships discharge ballast water primarily into Lake Superior.

Rob Colautti, Great Lakes Institute

Invasions *via* NOBOB shipping?

Daphnia ephippium

Sediment in NOBOB ballast tanks may harbour species' resting stages; these eggs may pose an invasion risk to the Great Lakes.

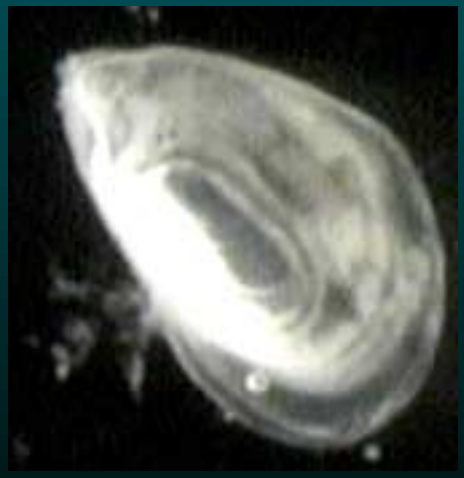
Sarah Bandoni, Great Lakes Institute

Invertebrates in NOBOB ships

Plumatella

Bryozoa

Daphnia ephippia



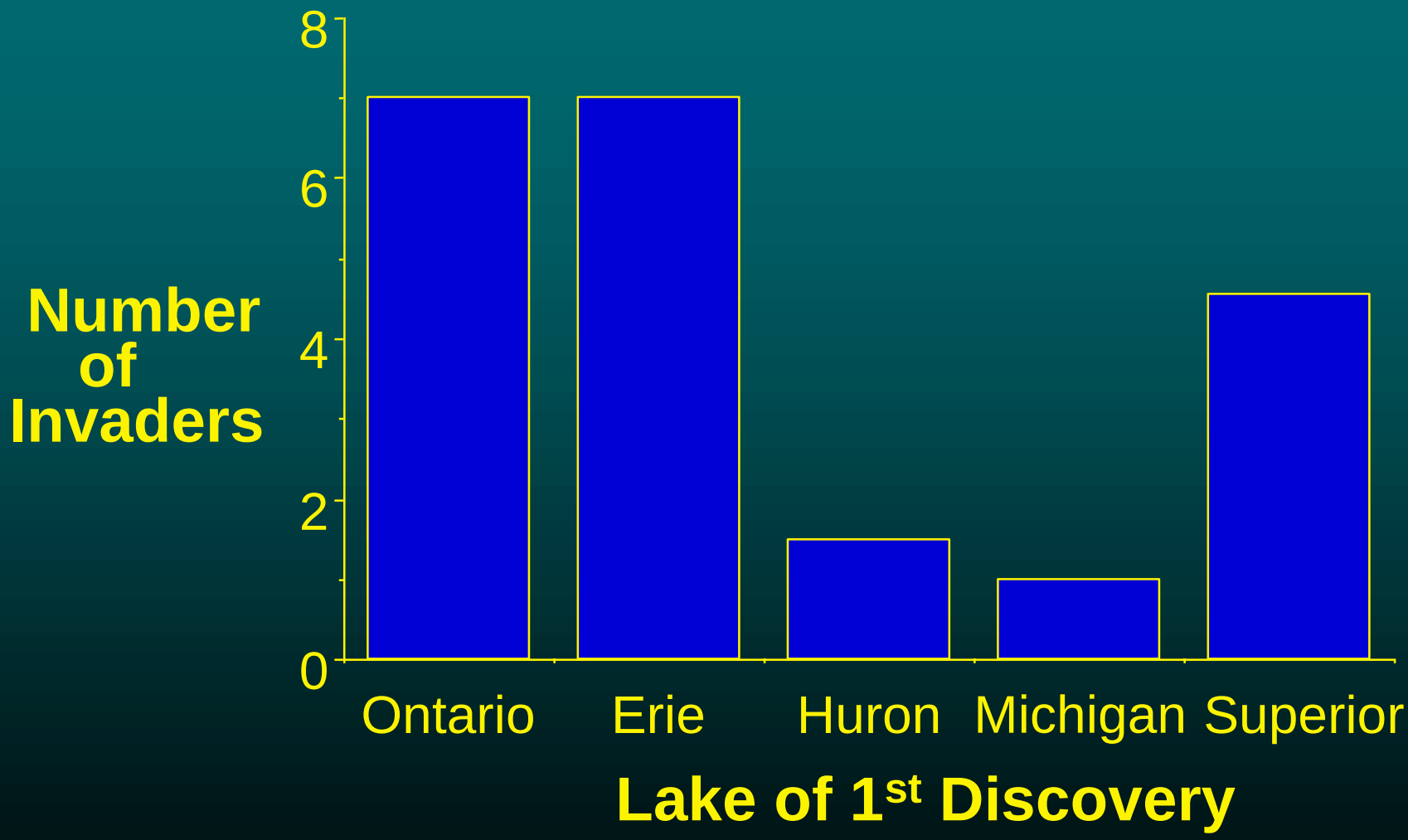
Bivalve

Polychaeta (Annelida)

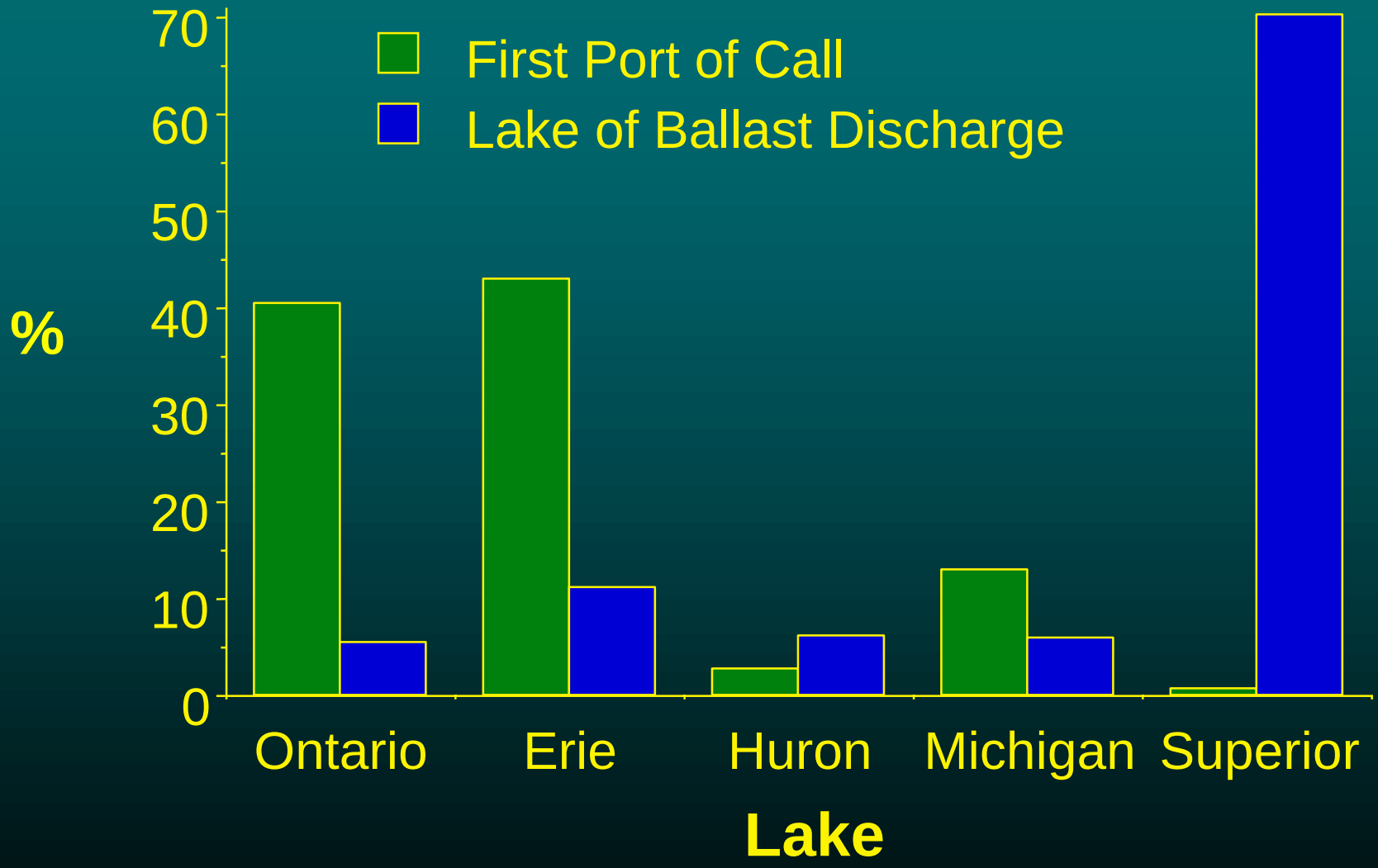
Chironomid pupa (Insecta)

Sarah Bandoni, Great Lakes Institute

Animal Invaders *via* Ballast Water Discharge



NOBOB Ships on the Great Lakes



The lake of first discovery of NIS animals bears little relationship to the first port of call for NOBOB vessels.

NIS may cause Ecological, Economic, or Health (human, animal, or plant) Problems

- sea lamprey may devastate lake trout populations;
- purple loosestrife dominates wetland ecosystems;
- pathogens (cholera bacteria and toxic dinoflagellates) have been transported by ships;
- spiny waterfleas may indirectly reduce water clarity and cottage values;
- zebra and quagga mussels profoundly alter some of the ecosystems they invade

Dreissena impacts in the Great Lakes

Ecological Engineers

Physical Changes:

- fouling of water intakes
- increased light transmittance

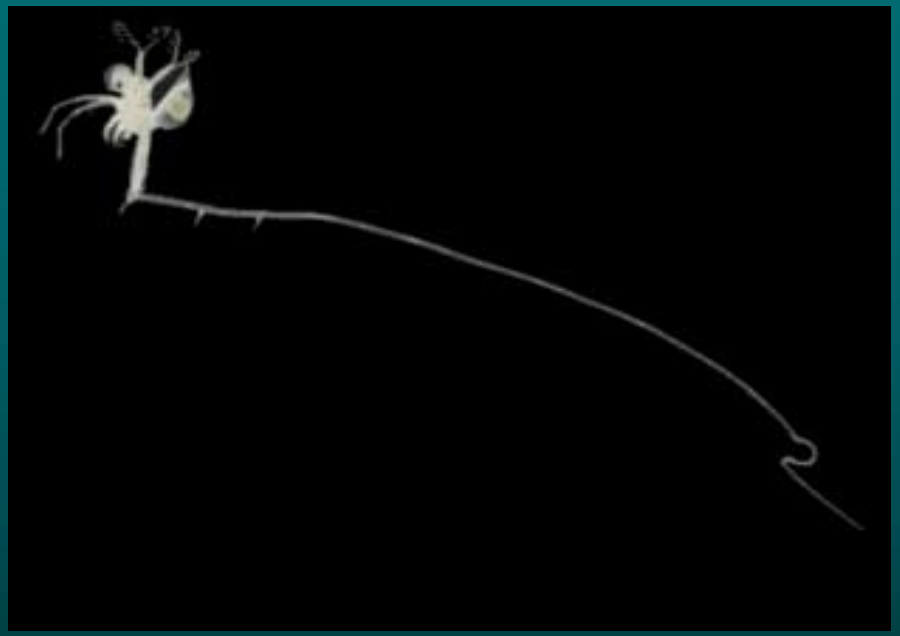
Chemical Changes:

- reduced summer total P
- reduced summer/fall NH_4 and NO_2:NO_3 ratios
- alteration of organic and metal contaminant cycling

Biological Changes:

- elimination of unionid molluscs
- enhanced diversity & abundance of other inverts
- reduced algal and microzooplankton biomass
- induction of *Microcystis* blooms
- enhanced food supply to ducks, benthivorous fishes and some invertebrates
- increased biomass of macrophytes

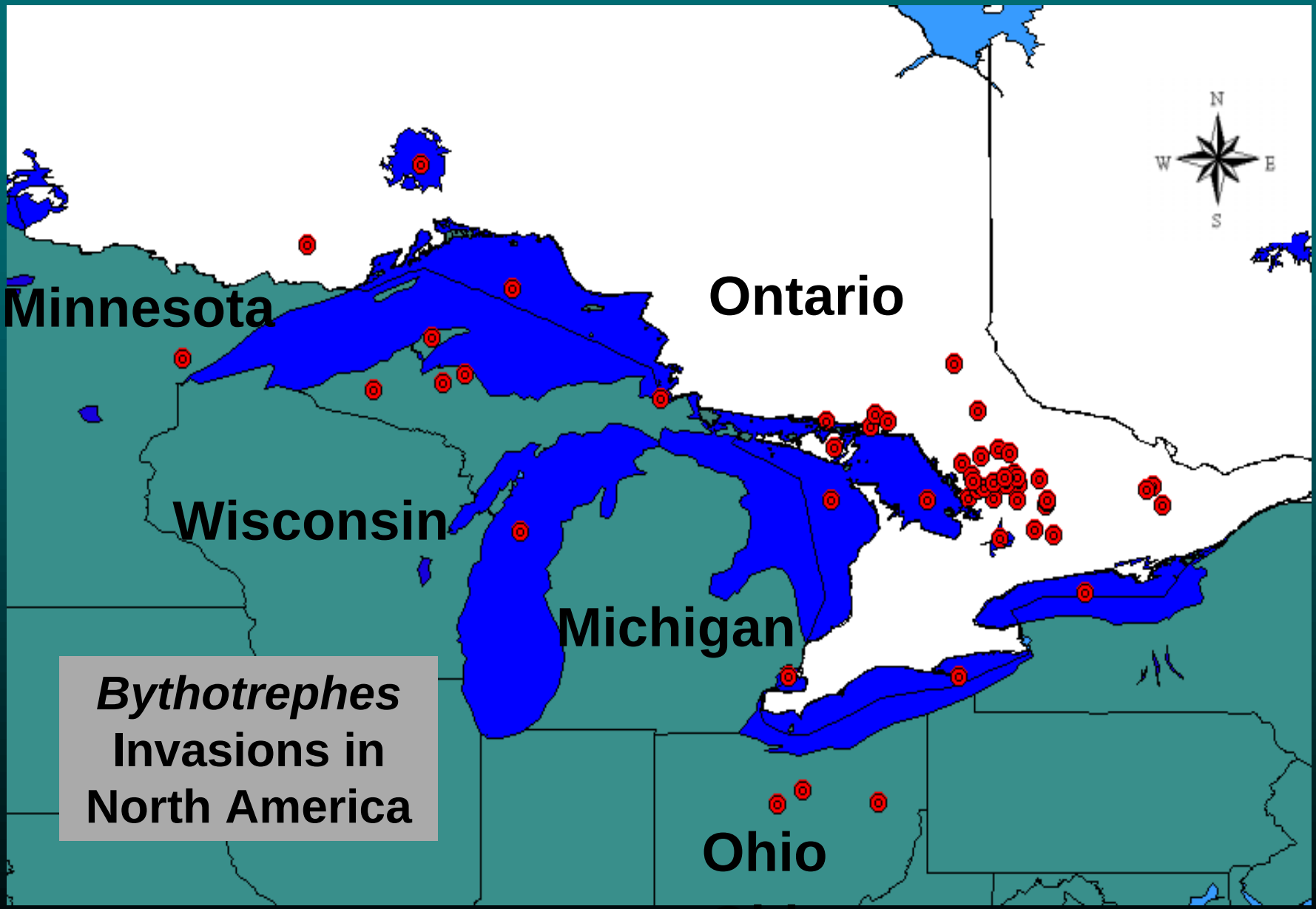
Fishhook waterflea, *Cercopagis pengoi*



- 2 different forms of the species occur in Lake Ontario. The species is also found in Lakes Michigan and Erie (as of 2001), and in the Finger Lakes (NY).
- Its effects are not yet fully established, although it is a fouling nuisance on fishing lines and nets, and it seems to adversely affect small zooplankton (Dr. J. Makarewicz, Kerry McPhedran, pers. comm.)
- readily spread when carried as resting egg (right image) on fouled fishing or scientific gear

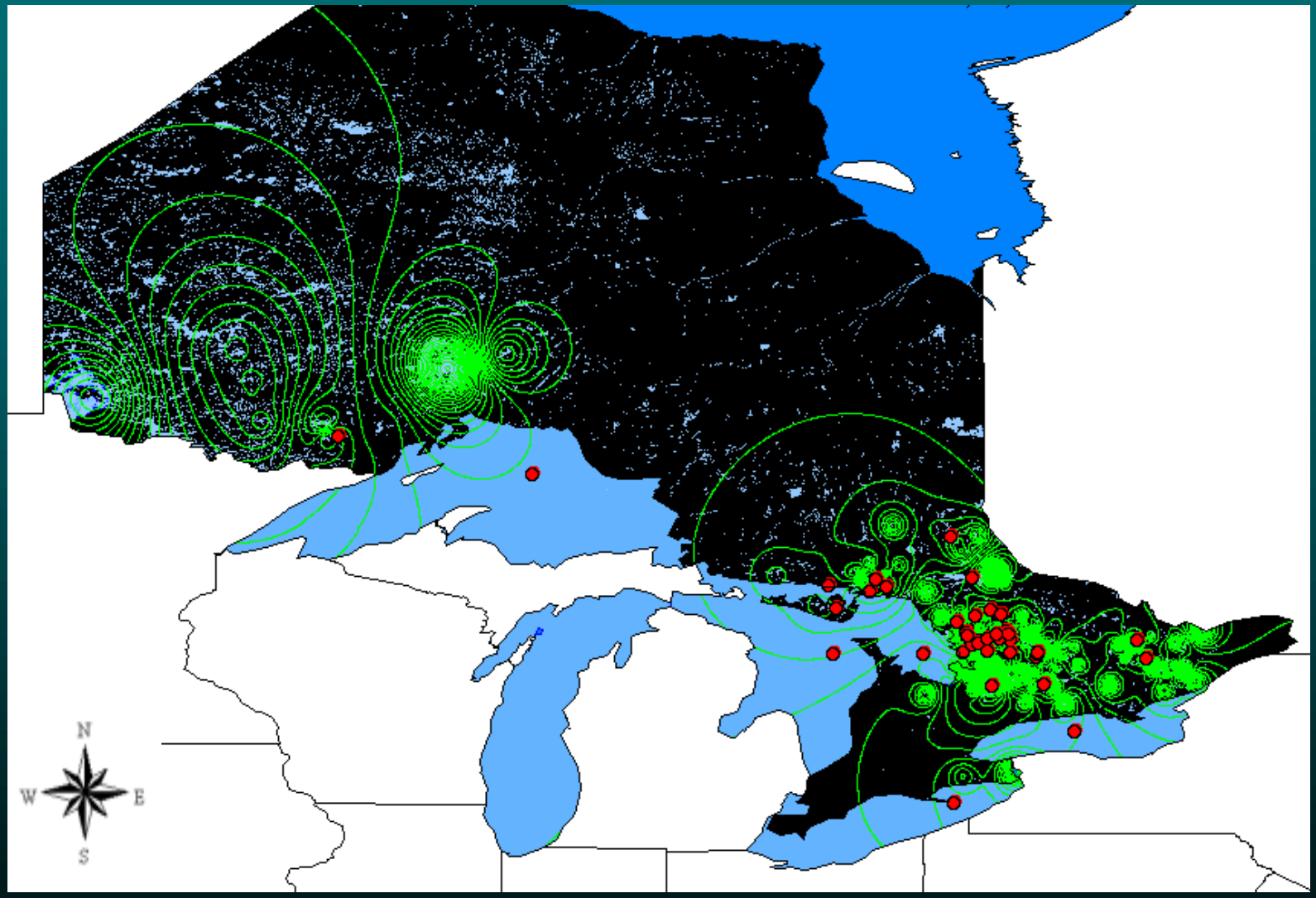
Dr. Igor Grigorovich, Great Lakes Institute

Occurrence of *Bythotrephes* in North America



Julianna Borbely, Great Lakes Institute, MSc thesis (2001)

Projected Spread of *Bythotrephes* in Ontario



Bythotrephes is expected to spread wherever human vectors move it (green areas).

Borbely and MacIsaac, in review

Economic Damage of Invaders in the Great Lakes

?

	$	
Zebra mussels:	3,000,000,000	Pimentel et al. 2000
Sea lamprey	25,000,000	GLFC
Bythotrephes	200,000,000 (L. Muskoka)	N. Yan

Most economic effects are undefined or poorly defined

Great Lakes Invasion Studies Supported by:

Personnel:

- Postdoctoral Fellows: Igor Grigorovich, Tom Therriault, Helen Limen
- Graduate Students: Sarah Bandoni, Julianna Borbely, Rob Colautti, Kerry McPhedran
- NOBOB team (Drs. D. Reid, F. Dobbs, G. Fahnenstiel, M. Doblin; P. Jenkins, Colin van Overdijk) and FedNav ship company

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