ISSN: 2639-7455

Review Article

Earth & Environmental Science Research & Reviews

Alien Invasive Species Impacts on Large Lake Ecosystems and Their Economic Value

Gail Krantzberg

McMaster University, 1280 Main St. W. Hamilton, Ontario L8S 4L8. Canada

***Corresponding author**
Gail Krantzberg, McMaster University, 1280 Main St. W. Hamilton, Ontario L8S 4L8, Canada. Tel: 905 525 3140 x 22153; E-mail: krantz@Mcmaster.ca

Submitted: 21 Nov 2019; **Accepted**: 28 Nov 2019; **Published**: 09 Dec 2019

Abstract

Globalization of trade and travel has made possible the spread of alien species across the planet. Invasive species are presently considered as one of the major threats to biodiversity in many locations throughout the world. Thousands of AIS have been transported globally by a number of anthropogenically-mediated vectors, including ship-mediated vectors (e.g., ballast water, hull-fouling), recreational boating, live bait, aquarium trade, live food fish, and unauthorized introductions. Ballast water is one of the leading vectors for transporting and introducing species, both in Canada and around the world, and is responsible for the transport of at least one third of all documented marine invasions. Since invasive species have no regard for political boundaries, efforts to prevent invasions need to be interjurisdictional. Given, also that invasive species often travel as contaminants of trade transfers, for example, in the ballast tanks of ships, reducing the spread of invasive species via this pathway would either require constraints on where ships travel, or the installation onto all ships of expensive ballast treatment technology, thereby increasing the cost of shipped goods. As such cost benefit analysis involves trade-offs with other activities, complicating decisions about how impacts can best be managed.

Introduction

The Boundary Waters Treaty of 1909 established the International Joint Commission (IJC) as an organization designed to resolve disputes and to avoid conflicts over transboundary environmental matters. Article 4 of the Treaty provides the provision that neither party shall cause pollution that would injure the health or property of the other side. In 1972, the Great Lakes Water Quality Agreement (GLWQA) was created with the goal of enhancing and maintaining the quality of the waters of the Great Lakes basin ecosystem. The Agreement is considered to be a standing reference under the Boundary Waters Treaty [1].

The signators or “Parties” to the GLWQA are the federal governments of Canada and the United States who commit to collaborate with other governmental jurisdictions within the Great Lakes basin.The Laurentian American Great Lakes, shared by Canada and the United States, contain nearly 20% of the world’s surface fresh water [2]. The Great Lakes are an unparalleled natural resource that can be seen from space.

Great Lakes scientists continue to grow their understanding of the extensive set of ecosystem threats that span the loss of species and spaces, climate change, new chemicals of concern, emerging and more virulent pathogens, aging infrastructure, impacts of land use on the receiving waters, invasive species, atmospheric deposition, and more. It is the Great Lakes scientific community that continues to unravel the complex interactions of multiple stressors on this very important place [3].

The GLWQA of 1972 invoked phosphorus loading reductions and proved to be successful as reflected in dramatic improvements in water quality [4, 5]. The GLWQA was revised in 1987 to address the contamination of the Great Lakes basin ecosystem by toxic substances. Non-indigenous or alien species are another major stresses to the system [6]. Great Lakes scientists continue to grow their understanding of the extensive set of ecosystem threats that span the loss of species and spaces, climate change, new chemicals of concern, emerging and more virulent pathogens, aging infrastructure, impacts of land use on the receiving waters, atmospheric deposition, and alien invasive species [3].

Species and Threats

Globalization of trade and travel has made possible the spread of alien species across the planet. Invasive species are presently considered as one of the major threats to biodiversity in many locations throughout the world. Keller et al. point out that as a long-time centre for trade, Europe has seen the introduction and subsequent establishment of at least several thousand non-native species that range from viruses and bacteria to fungi, plants, and animals [7]. Alien Invasive species pose tremendous environmental, economic and human health threats to lake ecosystems and the ecological services they provide to society [8-10]. For example, in the Great Lakes (Figure 1), more than 180 aquatic invasive species (AIS) have been documented, representing one of the most dramatically affected systems on earth [11, 12]. Little is known however, about bacterial, viral, protozoan and algal invaders except where significant impacts have been reported by the disease-causing invaders [13]. Some examples provided by Munawar et al. are the protozoan Myxobolus cerebralis that is the cause of whirling disease in salmonids, the bacterial pathogen Furunculosis that affects fisheries and the protist parasite Glugea hertwigi imported along with its host, the rainbow smelt [6].

Thousands of AIS have been transported globally by a number of anthropogenically-mediated vectors, including ship-mediated vectors (e.g., ballast water, hull-fouling), recreational boating, live bait, aquarium trade, live food fish, and unauthorized introductions [14,15]. Ballast water is one of the leading vectors for transporting and introducing species, both in Canada and around the world, and is responsible for the transport of at least one third of all documented marine invasions [14,16]. Ballast water of commercial ships was until very recently, the major route for AIS imports [12,17]. In addition to the direct impacts on the Great Lakes, the system serves as a source for invasions into inland waterways of Canada and the US (Vander Zanden and Olden, 2008), resulting in additional economic and ecological impacts [18].

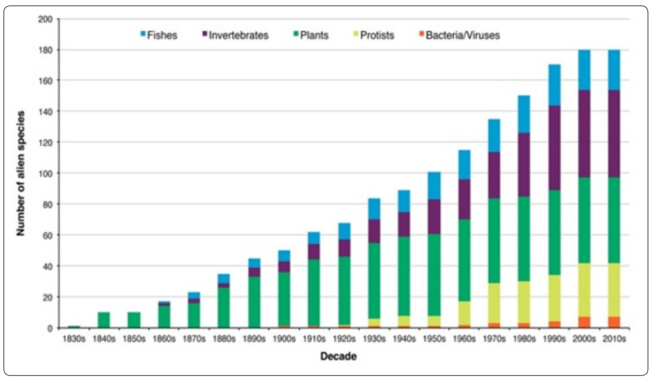

Figure 1: Cumulative Number of Aquatic Alien Species in the Great Lakes, by Decade (Source: Ontario Biodiversity Council)

Impact: Ecological

Munawar et al. summarize the macrophyte invaders that have become well established in the harbours and wetlands of the Great Lakes basin, representing 10 to 30% of the local flora. They report that some of the commonly found species are purple loosestrife (Lythrum salicaria), Eurasian watermilfoil (Myriophyllum spicatum), Phragmites australis, reed canary grass (Phalaris arundinacea), hybrid cattails (Typha x glauca), water clover (Marsilea quadrifolia), fanwort (Cabomba caroliniana), water cress (Rorippa nastrurtium-aquaticum), water chestnut (Trapa natans), yellow floating heart (Nymphoides peltata) and curly pondweed (Potamogeton crispus) [6].

The now infamous Zebra mussel, Dreissena polymorpha was first detected in Lake Erie in 1988. Native to the Baltic Sea, MacIsaac et al. report that it was transported in the ballast water of transoceanic ships. Zebra mussels dramatically alter ecosystem function by increasing water clarity through extensive filtration of algae, thereby decreasing algal abundance [19,20].

Populations of lake sturgeon (Acipenser fulvescens), deepwater cisco (Coregonus johannae), lake trout (Salvelinus namaycush), lake whitefish (Coregonus clupeaformis) and lake herring (Coregonus artedii) have collapsed and been replaced by other less valuable species. The elimination of other indigenous forms include blue pike (Sander vitreus glaucus), Atlantic salmon (Salmo salar), and lake trout [6].

Alien invasive species certainly generate ecological shifts within the Great Lakes, resulting in native biodiversity declines, food web transformations, altered nutrient and contaminant cycling, and changes in productivity [21-23]. A classic example is the invasion of sea lamprey (Petromyzon marinus), which contributed heavily to the decline and collapse of native lake trout (Salvelinus namaycush) populations in the late 1940s and 1950s [22]. Over the span of 20 years the annual commercial yield of lake trout dropped from 15 million pounds to 300,000 pounds in the upper Great Lakes. In the lower Great Lakes the lake trout fishery disappeared by 1960 [24].

Pagnucco et al. describe how the Eurasian ruffe (Gymnocephalus cernuus) and the round goby (Neogobius melanostomus) have displaced native fish, while predatory waterfleas (Bythotrephes longimanus and Cercopagis pengoi) have dramatically altered zooplankton communities [23].

With the changing climate of the region, trends of increasing water temperatures have been detected in all five of the Great Lakes [25, 26]. Some invasive species present in the lower Great Lakes could reasonably advance to northern areas of the basin and alter food webs, including the subtropical species red swamp crayfish (Procambarus clarkii) and the Asian clam (Corbicula fluminea). Other alien species could colonize the Great Lakes basin as temperatures rise include two subtropical plants with extensive invasion histories, sold through the ornamental garden and aquarium trade in the Great Lakes region. These are water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes), which have been found in multiple locations in Lake St. Clair and the Detroit Rivers [27].

Asian Carp

Four species of Asian carps, bighead carp, silver carp, black carp, and grass carp, pose real and present threats to Great Lakes fisheries. Recent peer-reviewed risk assessments for bighead carp and silver carp, and grass carp indicate that the Great Lakes are at substantial risk from these three species. The primary threat from Asian carp is competition with other fish for food resources, and the likelihood that of these invaders would outcompete native fish [28]. All four Asian carps grow to large sizes approaching or exceeding 100 lbs and four feet in length. Bighead carp and silver carp feed on plankton while grass carp feed on macrophytes. Black carp feed primarily on snails and mollusks. All four Asian carps were imported to North America to assist with pest control in aquaculture facilities, and have since escaped into the river and lake systems throughout North America.

Buck et al. point out that native species are at risk because Asian carp compete with them for food and modify their habitat [29]. Buck et al. continue to explain that the locks and waterways of the Chicago Area Waterway System (CAWS) have been a focal point for finding solutions to prevent Asian carp encroachment on the Great Lakes. The CAWS is the only navigable link between the Great Lakes and the Mississippi River, and many note the potential of these waterways to facilitate invasive species transfers from one basin to the other. While the U.S. Army Corps of Engineers has constructed and is currently operating electrical barriers to prevent fish passage, Asian carp may be present upstream of the barriers and in Lake Michigan. As a consequence increased federal funding to prevent fish encroachment was announced by the Obama Administration, and various sectors of society have called for action to permanently separate the two basins. The potential closure of existing navigation structures in the CAWS and the permanent separation of the basins are currently the most contentious issues related to Asian carp control in the region, and a long-term solution has yet to be decided.

However, in the 111th Congress, Section 126 in Title I of P.L. 111-85 directed the U.S. Army Corps of Engineers to implement additional measures to prevent invasive species from bypassing the Chicago Sanitary and Ship Canal Dispersal Barrier Project and dispersing into the Great Lakes.

The Committee of Advisors to the Great Lakes Fishery Commission affirmed if populations of Asian carp become established in the Great Lakes, and in other locations in the Great Lakes region, they will be impossible to eradicate with current technology [24]. They explain that the Mississippi River basin and the Great Lakes basin are physically connected by a system of man-made canals and waterways in the Chicago area, called the Chicago Area Waterway System (CAWS). The CAWS creates a two-way pathway between the Great Lakes — and Mississippi basins, between which aquatic invasive species have and will continue to invade each other unless and until 100% ecological separation has been achieved, according to the Committee. Ecological separation is defined as no inter-basin transfer of aquatic organisms via the Chicago Area Waterway System at any time, and the prohibition of movement or inter-basin transfer of aquatic organisms between the Mississippi and Great Lakes basins [28].

Impacts: Economic

The Invasive Mussel Collaborative documents that dense colonies of Invasive mussels clog intake pipes of water treatment and power plants, reducing pumping capacity and causing significant economic impacts to industries, companies and municipalities. Further, recreation-based industries and activities have also been impacted by invasive mussels as docks, break walls, buoys, boats, and beaches have been heavily colonized by these species. The sharp shells of dead mussels can litter beaches and the smell of decaying mussels discourages recreation and reduces tourism (Invasive Mussel Collaborative n.d.).

It has been widely reported that Great Lakes recreational fisheries generate economic activity of approximately $7 billion annually. Asian carp introduction would almost certainly likely to modify Great Lakes ecosystems and cause harm to this important economic resource.

Invasive species represent a largely unquantified threat to ecosystem services. Although investment in the prevention of species invasions may sustain ecosystem services, these effects of invasions are rarely measured in monetary terms useful to decision makers. Walsh et al. quantified the economic damages of the degradation of an important ecosystem service, water clarity, caused by invasion by the spiny water flea [30]. They found that “the costs of restoring this service, US$86.5 million–US$163 million, are comparable with the willingness to pay for the service itself: US$140 million. This finding highlights the severity of invasive species’ impacts when their damages to ecosystem services are considered”.

Regulatory Regime Changes

Keller et al. make a strong case that compared to other environmental problems, invasive species present at several particular challenges [7]. First, they point out that the impacts tend to increase over time as populations become larger and spread, compared to other pressures such as loading of toxic chemicals that generally decrease in severity over time after the discharges are terminated. As a consequence that populations of invasive species can best be managed through rapid eradication of new populations [31]. While the likelihood of success is greatest as soon after AIS species are detected, the type of data and political support to eradicate the species tend to occur once the species has spread and become invasive. There are clearly fewer mechanisms to control the established populations. Figure 2 illustrates the astonishing spread of Zebra Mussel throughout the US as of 2018.

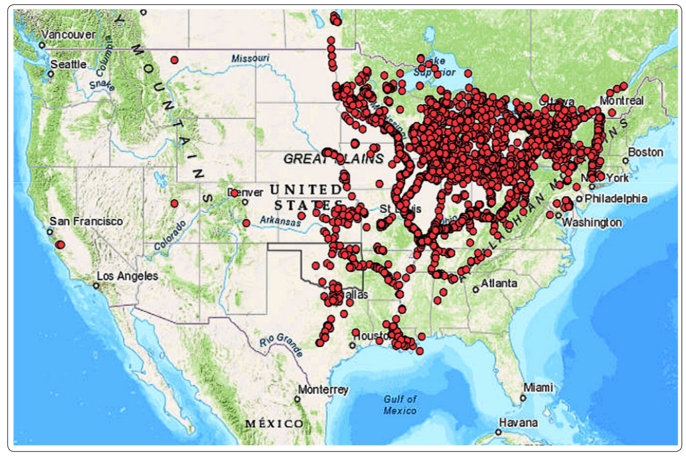

Figure 2: Invasive Zebra Mussel Spread Across Continental US (Source Oklahoma Department of Wildlife Conservation

Since invasive species have no regard for political boundaries, efforts to prevent invasions need to be interjurisdictional. Given, also that invasive species often travel as contaminants of trade transfers, for example, in the ballast tanks of ships, reducing the spread of invasive species via this pathway would either require constraints on where ships travel, or the installation onto all ships of expensive ballast treatment technology, thereby increasing the cost of shipped goods. As such cost benefit analysis involves trade-offs with other activities, complicating decisions about how impacts can best be managed.

Controlling the spread of invasive species requires international cooperation. In response to the risk from ballast water invasions, the International Maritime Organization (IMO) produced the International Convention for the Control and Management of Ships Ballast Water and Sediments in February 2004. This convention requires the establishment of ballast water management systems on ships, with the goal of preventing the movement of live organisms. The dates at which each ship would be required to have ballast water treatment facilities differ based on ship size and age, but fall between 2009 and 2016.

In an effort to address this ship-vector challenge, numerous regulatory regimes have been put in place. In the US, Congress enacted legislation in 1990 requiring ocean-going vessels to exchange their ballast water while still at sea and before entering the Great Lakes and Hudson River. This legislation was reauthorized in 1996 and expanded to apply to all U.S. ports. Further, in 2006 salt water flushing requirements were imposed for ocean-going vessels entering the St. Lawrence Seaway. As of 2019, every ship entering the Seaway from overseas is stopped, boarded and inspected to ensure compliance. No new AIS have been discovered in the Great Lakes since 2006 attributable to this vector.

The American Great Lakes Ports Association (n.d.) describe progress in curtailing AIS inports from ballast tanks as follows

"In 2004, the International Maritime Organization (IMO), a part of the United Nations, adopted a global agreement for the regulation of ships' ballast water. This agreement contains a specific, numeric ballast water quality standard. The agreement anticipates that ballast water management systems will be installed onboard vessels to filter and treat ballast water prior to discharge.

While the United States has not ratified the IMO treaty, in 2012 the U.S. Coast Guard implemented new federal regulations requiring all ocean-going vessels discharging ballast water into U.S. waters to install ballast water treatment technology to meet the IMO water quality standard. These rules require that vessels deploy such technology by their first dry-docking after January 1, 2016.

Under authority of the Clean Water Act, in 2008 the U.S. Environmental Protection Agency (EPA) also established ballast water regulations. The EPA's "Vessel General Permit," (VGP) required ballast exchange and additional best management practices. In 2013, the agency updated the VGP to include a regulatory program similar to the Coast Guard's. Specifically, the agency adopted the IMO water quality standard and requires discharges to meet that standard by the vessel's first dry-docking after January 1, 2016. The EPA's 2013 VGP applies to ocean-going vessels and Great Lakes vessels (Lakers) that operate east of Anticosti Island on the St. Lawrence River."

In 2016, 100% of vessels bound for the Great Lakes Seaway from outside the Exclusive Economic Zone (EEZ) received ballast management exams on each Seaway transit. According to the Great Lakes Seaway Ballast Water Working Group (2017), vessels that did not exchange their ballast water at sea or flush their ballast tanks were required to either keep the ballast water and residuals such as sediment on board, treat the ballast water in an environmentally sound and approved manner, or return to sea to conduct a ballast water exchange [32].

The Government of Canada Aquatic Invasive Species Regulations of 2015 prohibit

- Any person to import members of a species set out in Part 2 of the schedule
- Any person to possess members of a species set out in Part 2 of the schedule, including any genetic material capable of propagating the species,
- Any person to transport members of a species set out in Part 2 of the schedule, including any genetic material capable of propagating the species,
- Any person to release, or engage in any activity that may lead to the release of, members of a species set out in Part 2 of the schedule, including any genetic material capable of propagating the species, into a body of water frequented by fish
- Any person to introduce an aquatic species into a particular region or body of water frequented by fish where it is not indigenous unless authorized to do so under federal or provincial law. (Aquatic Invasive Species Regulations SOR/2015-121) [33]

Over the past several decades, the province of Ontario has worked with federal and municipal governments, conservation authorities, Aboriginal communities, the private sector and members of the public to help stop the introduction and spread of invasive species. In response to the increasing threat of invasive species impacts in the province, the Ontario government released the Ontario Invasive Species Strategic Plan (OISSP) in 2012 [34]. Some of the actions identified in the Strategic Plan include "clarifying roles and responsibilities across agencies for invasive species prevention, response and management in Ontario, reviewing and enhancing invasive species policies, increasing the capacity for risk assessments to inform prevention and management actions, strengthening and supporting monitoring programs and scientific research, developing management measures for pathways and species, and expanding communication and outreach initiatives".

Ontario passed the Invasive Species Act (ISA) in November 2015. The Act provides the province a legislative framework to regulate invasive species that threaten Ontario's natural environment, to prevent their introduction and spread, and to support detection, control and eradication efforts. The Act includes the power to make regulations and list invasive species as prohibited or restricted based on the species' biological characteristics, risk of harm to the environment, dispersal ability, and social or economic impacts assessed through the application of risk assessments. These regulations can prohibit the possession, transport, propagation, buying, selling, leasing or trading of listed invasive species. Beyond individual species, the Act also provides the power to regulate carriers, defined as "things capable of moving or facilitating the movement of an invasive species from one place to another".

In addition to the regulation of species and carriers, the Act also provides the power to designate areas of Ontario as Invasive Species Control Areas, allowing for measures to control or prevent the spread of an invasive species within, to or from the designated area. Ontario's Invasive Species Act also sets out details for inspections and provides authority for an inspector designated by the Minister to examine public and private land for the purpose of detection, confirmation, and/or to monitor invasive species. The inspector can quarantine an area or thing when action is required to prevent an invasive species from spreading to other areas.

Concluding Remarks

In the US, no single federal agency has comprehensive authority for all aspects of aquatic invasive species management. Federal agencies with regulatory authority over the introduction and transport of aquatic species that may be invasive include the U.S. Department of Agriculture Animal Plant Health Inspection Service, the U.S. Department of Agriculture Agricultural Marketing Service, the U.S. Fish and Wildlife Service (USFWS), the U.S. Department of Commerce (DOC), and the U.S. Coast Guard (USCG). Many other agencies have programs and responsibilities that address components of AIS, such as importation, interstate transport, exclusion, control and eradication (California Aquatic Invasive Species Management Plan 2008) [35-37]. The primary federal authorities for managing and regulating AIS derive from the National Environmental Policy Act, the Nonindigenous Aquatic Nuisance Prevention and Control Act, the National Invasive Species Act, the Lacey Act, the Plant Pest Act, the Federal Noxious Weed Act, and the Endangered Species Act. The National Invasive Species Council is charged with developing a comprehensive plan to minimize the economic, ecological and human health impacts of invasive species.

References

1. Krantzberg G, M Bratzel, J McDonald (2006) Contribution of the International Joint Commission to Great Lakes Renewal. The Great Lakes Geographer 13: 26-38.
2. Great Lakes Information Network (GLIN) (2005) Great Lakes facts and figures. http://www. greatlakes.net/lakes/ref/lakefact. Html.
3. Krantzberg G (2004) Science Must Inform Great Lakes Policy J Great Lakes Res 30: 573-574.
4. Burns N (1985) Erie: The Lake That Survived. Rowan and Allanheld, Totowa, NJ.
5. Leach J (1999) Lake Erie: passages revisited. In: M Munawar, T Edsall, and I F Munawar, (Eds) State of Lake Erie (SOLE) - Past Present and Future pp: 5-22. Ecovision world Monograph Series Backhuys Publishers Leiden the Netherlands.
6. Munawar M, I F Munawar, N E Mandrak, M Fitzpatrick, R Dermott, et al. (2005) An overview of the impact of non-indigenous species on the food web integrity of North American Great Lakes Lake Erie example Aquatic Ecosystem Health & Management 8: 375-395.
7. Keller Reuben P, Juergen Geist, Jonathan M Jeschke, Ingolf Kühn (2011) Invasive species in Europe ecology status and policy. Environmental Sciences Europe 2011: 23-23.
8. Lodge DM, Williams SL, MacIsaac H, Hayes K, Leung B, et al. (2006) Biological invasions recommendations for U.S. policy and management. Ecol Appl 16: 2035-2054.
9. Pimentel D, Zuniga R, Morrison D (2005) Update on the economic and environmental costs associated with alien-invasive species in the United States. Ecol Econ 52: 273-288.
10. Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R (1996) Biological invasions as global environmental change. Am Sci. 84: 468-478.
11. Vander Zanden M Jake, Gretchen JA Hansen, Scott N Higgins, Matthew S. Kornis, (2010) A pound of prevention plus a pound of cure: Early detection and eradication of invasive species in the Laurentian Great Lakes Journal of Great Lakes Research 36: 199-205.
12. Riccardi A, (2006) Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity Divers Distrib. 12: 425-433.
13. Sheath R (1987) Invasions into the Laurentian Great Lakes by marine algae. In: M Munawar (Ed) Phycology of Large Lakes of the World Arch Hydrobiol Beih Ergebn Limnol 25: 165-186.
14. Scriven Danielle R, Claudio DiBacco, Andrea Locke, Thomas W, Therriault (2015) Ballast water management in Canada A historical perspective and implications for the future. Marine Policy 59: 121-133.
15. Canadian Council of Fisheries and Aquaculture Ministers Aquatic Invasive Species Task Group (CCFAM) (2004) A Canadian action plan to address the threat of aquatic invasive species. http://www.dfo-mpo.gc.ca/science/enviro/ais-eae/plan/plan-eng.pdf.
16. DiBacco C, D B Humphrey, L E Nasmith, C D Levings, (2012) Ballast water transport of non-indigenous zooplankton to Canadian ports ICES .J Mar Sci 69: 483-491.
17. Holeck KT, Mills EL, MacIsaac HJ, Dochoda MR, Colautti RI, et al. (2004) Bridging troubled waters biological invasions transoceanic shipping and the Laurentian Great Lakes. Bio Science 54: 919-929.
18. MacIsaac H, SprulesW, Johannsson O, Leach J (1992) Filtering impacts of larval and sessile zebra mussels (Dreissena polymorpha) in western Lake Erie. Oecologia 92: 30-39.
19. Vander Zanden MJ, Olden JD (2008) A management framework for preventing the secondary spread of aquatic invasive species. Can. J Fish Aquat. Sci 65: 1512-1522.
20. Holland R (1993) Changes in planktonic diatoms and water disparity in Hatchery Bay Bass Island area western Lake Erie since the establishment of the zebra mussel. J Great Lakes Res19: 617-624.
21. Nicholls K, Hopkins G (1993) Recent changes in Lake Erie (north shore) phytoplankton cumulative impacts of phosphorus loading reductions and the zebra mussel introduction. J. Great Lakes Res 19: 637-647.
22. Hogan LAS, Marschall E, Folt C, Stein RA (2007) How non-native species in Lake Erie influence trophic transfer of mercury and lead to top predators. J Great Lakes Res 33: 46-61.
23. Mills EL, Leach JH, Carlton JT, Secor CL (1993) Exotic species in the Great Lakes a history of biotic crises and anthropogenic introductions. J Great Lakes Res 19: 1-54.
24. Pagnucco Katie S, George A Maynard, Shannon A Fera, Norman D Yan, Thomas F Nalepa, Anthony Ricciard, (2015) The future of species invasions in the Great Lakes-St. Lawrence River basin J Great Lakes Res Journal of Great Lakes Research 41 Supplement 1: 96-107.
25. Great Lakes Fishery Commission (GLFC) (2010) Status of Sea Lamprey http://www.glfc.org/sealamp/status.php.
26. Austin JA, Colman SM (2007) Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: a positive ice-albedo feedback. Geophys. Res. Lett 34: 1-5.
27. McCormick MJ, Fahnenstiel GL (1999) Recent climatic trends in nearshore water temperatures in the St Lawrence Great Lakes. Limnol. Oceanogr 44: 530-540.
28. Adebayo AA, Briski E, Kalaci O, Hernandez M, Ghabooli SA, et al. (2011) Water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes) in the Great Lakes: playing with fire? Aquat. Invasions 6: 91-96.
29. Committee of Advisors to the Great Lakes Fishery Commission (2010) A Resolution in support of Ecological Separation of the Mississippi and Great Lakes basins. www.glfc.org/pubs/pdfs/resol2010_1.pdf.
30. Buck Eugene H, Upton Harold F, Stern Charles V and Nicols James E (2010) Asian Carp and the Great Lakes Region. Congressional Research Service Reports. 12. http://digitalcommons.unl.edu/crsdocs/12.
31. Walsh Jake R, Stephen R Carpentera, M Jake Vander Zanden (2016) Invasive species triggers a massive loss of ecosystem services through a trophic cascade. www.pnas.org/cgi/doi/10.1073/pnas.1600366113 PNAS 113: 4081-4085.
32. American Great Lakes Ports Association (2015) Ballast Water Regulation. http://www.greatlakesports.org/issues/ballast-water-regulation/.
33. Keller Reuben P, Lodge DM, Lewis M, Shogren J (2009) Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy and Management New York: Oxford University Press.
34. Great Lakes Seaway Ballast Water Working Group (2017) www.greatlakes-seaway.com/en/pdf/2016_BW_Rpt_EN.pdf.

35. Aquatic Invasive Species Regulations SOR/ (2015)-121. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2015-121/FullText.html#.
36. Nienhuis, Sarah and Richard Wilson (2018) Invasive species in Ontario The threat the strategy and the law The Forestry Chrocicle 94: 2 -97-102.
37. California Aquatic Invasive Species Management Plan (2008) https://www.wildlife.ca.gov/Conservation/Invasives/Plan