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Great Lakes Under Stress: Invasive Species as Agents of Ecosystem Change

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Abstract

This case study explores invasive species as agents of ecosystem change in the Laurentian Great Lakes of North America, focusing specifically on Lake Erie and Lake Ontario. Following a brief introduction to the Great Lakes ecosystem, the case study describes several key invasive species and the roles they play in disrupting natural ecosystem behavior and function. It then concludes with an overview of control strategies and mitigation efforts. Discussion questions are provided throughout the text, designed to stimulate critical thinking among students; these can either be examined by students independently, or used to guide class discussion.

INTRODUCTION AND BACKGROUND

The Great Lakes Ecosystem

The Laurentian Great Lakes of North America – Lakes Superior, Michigan, Huron, Erie, and Ontario (Figure 1a,b) – together represent nearly 20% of the surface freshwater resources of the Earth (Atkinson 2002). With horizontal scales of hundreds of kilometers and depths up to several hundred meters, the Great Lakes share a number of characteristics associated with coastal regions and inland seas, including influence of the Earth's rotation on circulation patterns, thermal stratification, wind-generated upwelling and downwelling events, the presence of coastal currents, coupling between the benthic and pelagic regions of the lake, cross-margin transport (between near shore and offshore regions), significant interaction with human populations, and both shallow and deep water environments (Boyce et al. 1989). The Great Lakes are not large enough to experience tides, but wind setup can cause significant short-term water level fluctuations and internal seiches (standing waves), which are characterized by a "rocking" or "sloshing" of the lake waters back and forth, and a cyclic variation of water depths. The circulation is primarily driven by local meteorology (wind speed and direction, air temperature, etc.) and influenced by the proximity of the shoreline, bottom bathymetry, and local inflows and outflows (Boyce et al. 1989). The flow field, in turn, controls transport and distribution of nutrients, contaminants, and planktonic organisms, as well as bottom shear stress and corresponding potential for erosion and sediment transport. All of these features comprise the physical components of the lake ecosystem, controlling habitat and other features of ecosystem structure within which the biological system functions. In general, the lake ecosystem should be defined as the lakes themselves, plus the surrounding drainage areas that impact water quality and incorporate a more complete range of human influences; however, in this case study, emphasis is on the aquatic environment. Environmental stressors have impacted all the Great Lakes, but we are focusing on the lower lakes, Lake Erie and Lake Ontario, since they have high human population and the least volume, which makes them the quickest to respond to changes.

The waters of the Great Lakes provide hydroelectric power, irrigation, drinking water, fishing, recreational activities, and other benefits for millions of people who live in the basin. These benefits are called ecosystem services, since they are support human life through the functioning of natural ecosystems. Changes in an ecosystem, through natural or human-based causes, can lead to changes in the services, or benefits, that the ecosystem can provide. Maintenance of ecosystem services is often at the core of the concept of sustainability, and changes in ecosystem structure affect the way in which the ecosystem functions, thus impacting the ability of the ecosystem to continue to provide the same services as had been provided historically.

Although large, the Great Lakes have been subject to

Discussion Question 1:

What is your definition of sustainability, and how do you think it relates to the concept of ecosystem services? List examples of ecosystem services that are provided by an ecosystem near you (here, define "ecosystem" as a local waterway, lake, or pond, or a terrestrial system such as a forest), and give an example of a situation where an ecosystem service has been harmed because of an unsustainable practice.

significant ecosystem changes, many of which are a direct result of human activities. For example, in the 1960s Lake Erie was often described as being "dead" with massive algae blooms, taste and odor problems, hypoxia, fish kills, and other issues (Atkinson 2002). Studies identified phosphorus as the source for over-fertilization (note that "fertilization" here refers to the supply of food for growing algae), and phosphorus abatement programs were put in place (Atkinson 2002). Following these restrictions, Lake Erie and other Great Lakes showed dramatic reductions in algal production and general improvements in water quality (Makarewicz and Bertram 1991; Mills et al. 2003). However, algae blooms have started to reoccur with greater frequency in recent years, particularly in shallower, near shore areas, and differences in water quality between near shore and offshore regions have been growing (Makarewicz 2000; Makarewicz and Howell 2007). These observations are likely related to changes in ecosystem structure and function, and theories proposed to explain these problems involve possible impacts of invasive species.

Various factors may generate stresses on an ecosystem, causing it to change. These factors are called ecosystem stressors , and in the Great Lakes these stressors include invasive species, as well as sewage and industrial discharges, inappropriate land use, habitat changes, water level fluctuations, agricultural and urban storm water runoff, airborne pollutants, "legacy" contaminants in sediments, water withdrawals and diversions, and climate change (Atkinson 2002; Bails et al. 2005). The response of the ecosystem to these stressors is difficult to predict, especially when there are multiple stressors acting in concert, and when there is uncertainty in each of the stressors, themselves. Given these uncertainties and interacting effects, it is difficult to separate the specific impacts of any one stressor, such as invasive species or multiple invasives acting in concert. However, it is clear that invasive species have played a major role in ecosystem change in the Great Lakes. In the following sections we describe some of the invasive species in the Great Lakes and the roles they play in disrupting natural ecosystem behavior and function.

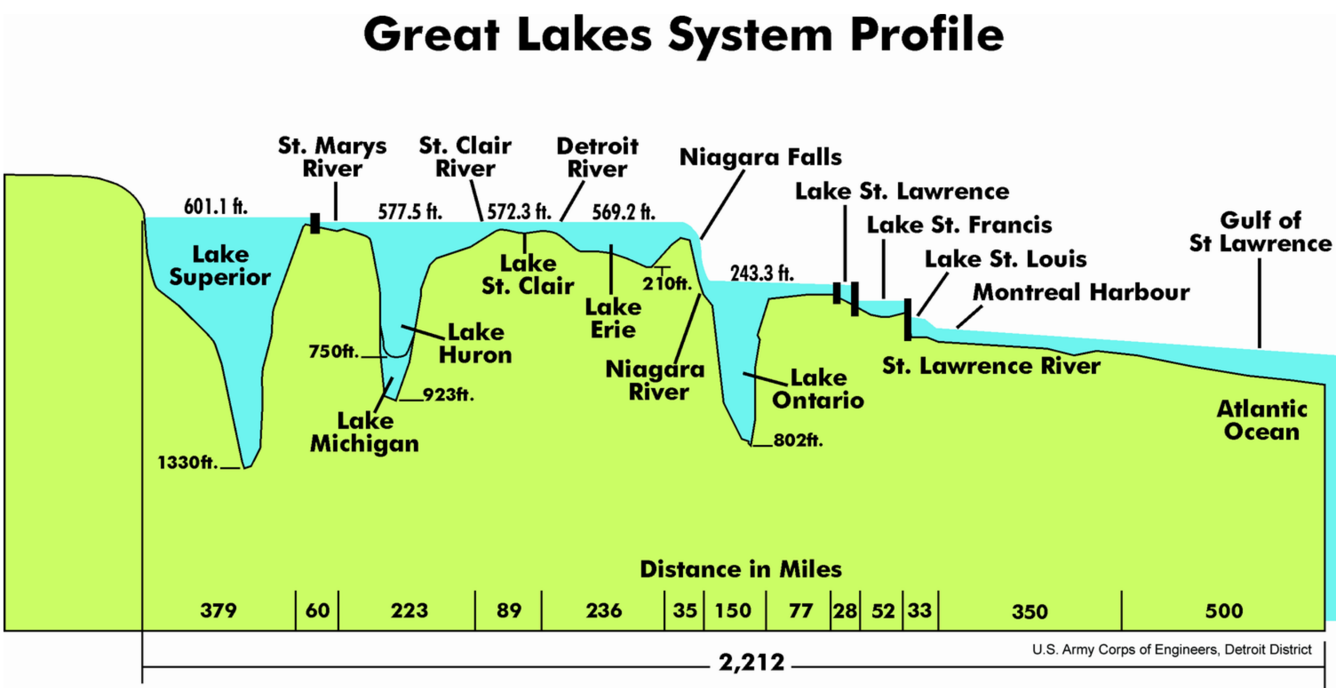


Figure 1a. The Great Lakes System Profile.

Figure 1b. The Great Lakes of North America.

Discussion Question 2:

Given the known causes of ecosystem stressors in the Great Lakes and issues of fertilization, what are some potential strategies for reducing phosphorus input into lake systems? What might be some drawbacks of such strategies?

What Is an Invasive Species?

Habitat destruction, over-fishing, industrial discharges, and toxic chemical releases have been altering the Great Lakes ecosystem for the past 200 years (Bails et al. 2005). In contrast to these (perhaps) more obvious stressors, one of the more important and unusual forms of pollution impacting the Great Lakes is not from industrial sources, municipal sewage, or atmospheric deposition, but in the form of non-native plants and animals. These non-native species are transported by humans and transport can occur over much greater distances and over much shorter time frames than by natural means. The relatively sudden introduction of non-native species in this manner produces a shock to the native ecosystem, which then tries to adjust.

For this Case Study, the term invasive species will be used, with the understanding that the species highlighted are invasive, non-indigenous, and nuisances. Whatever they are called, these species have been transported by human activities – intentionally or unintentionally – into a geographic region outside their native range and are now reproducing and establishing populations throughout the Great Lakes.

More than 180 non-native aquatic species have entered the Great Lakes and many scientists believe that aquatic invasive species are the greatest threat to the Great Lakes ecosystem (Mills et al. 1993; GLANSIS 2012). These species have the ability to spread throughout the ecosystem, limiting food and habitat, and out-competing or even displacing native species, causing them to become extirpated due to competition with invasive species. Some invasive species, such as the sea lamprey and the zebra mussel, have had significant economic impacts, costing billions of dollars in the US (Pimentel et al. 2000).

Invasive species share some or all of a number of biological characteristics (See also the NCEP module, *Invasive Species and Mechanisms of Invasions*), such as:

- High abundance in their native range;
- High fecundity rates (produce many surviving offspring);
- A short generation time (offspring mature to a reproductive age quickly);
- Polyphagous feeding habits (utilize more than one food source);
- An ability to occupy diverse habitats;
- High genetic variability (allowing for "plasticity" in adapting to new environments);
- Proximity to a transmittal vector (exists in a location where it can be acquired and moved).

Origins and Transport Pathways of Invasive Species in the Great Lakes

The Great Lakes have been especially hard-hit by invasive species due to the presence of canals and international ship traffic, which have facilitated the movement of these species into the region. During the early years of European colonization of the Great Lakes Basin, Niagara Falls served as an impenetrable barrier to the dispersal of many non-native species that had been introduced into the Lake Ontario Basin (Mills 1999).

The opening of the St. Lawrence Seaway in 1959 allowed large, ocean-going ships to enter the Great Lakes, carrying millions of gallons of ballast water, which greatly accelerated this process by providing an avenue for introductions of invasive aquatic species from across

Discussion Question 3:

How have man-made structures helped invasive species enter the Great Lakes? How does the movement of invasive species into the Great Lakes compare to the movement of terrestrial invasive species? What are some differences and similarities?

the globe. Ballast water transfers from such ships have introduced invasive species such as zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostiformis bugensis*), spiny waterfleas (*Bythotrephes cederstroemi*), Eurasian ruffe (*Gymnocephalus cernuus*), and the round goby (*Apollonia melanostoma*) (Mills et al. 1993).

Some introductions of invasive plants and animals, however, had no links to waterways or shipping. A number of invasive species have entered the Great Lakes through the release of aquarium pets, fish aquaculture operations, bait-bucket releases, and even intentional releases that proved to be environmental mistakes. The common carp (*Cyprinus carpio*) is an example of an intentional release that went awry. Once released to natural environments, these benthic (bottom dwelling) fishes uprooted native aquatic vegetation, caused excessive turbidity, and competed with native fish for food and habitat (Nico et al. 2011). (For another example, see NCEP case study *Story of An Invasion: A Case Study of Rusty Crayfish in the Great Lakes* available online at ncep.amnh.org).

Discussion Question 4:

What are other examples of the intentional spread of invasive species in the Great Lakes or elsewhere? What has been the result? Can you think of any cases in which invasive species have caused a beneficial result?

In other cases, stocking of non-indigenous fish was implemented to control the spread of other invasive species such as alewives and smelt (Mills et al. 2003). While the stocking of Pacific salmonids has successfully reduced the numbers of those non-indigenous forage fishes, such introductions have contributed significantly to the overall artificiality of the modern Great Lakes ecosystem.

ECOSYSTEM IMPACTS

Direct Impact on Native Species; Changes in Biodiversity

The combined effect of invasive species has been to change the food webs in the Great Lakes, altering trophic levels from small plankton to the top predatory fishes. For example, zebra and quagga (dreissenid) mussels are effective filter feeders and have outcompeted other planktivores, thus altering a critical element at the base of the normal food chain in the lakes (Mills et al. 2003). Filtering of particulate matter by invasive mussels also has led to a significant clearing of the water, allowing greater penetration of sunlight and leading to increased growth rates for benthic algae such as *Cladophora* (Mills et al. 2003; DePinto et al. 2006). In turn, the proliferation of benthic algae has led to unsightly and foul smelling deposits washing up on beaches (Figure 2). Aquatic invaders can have a catastrophic impact on the ecosystem by displacing native species, sometimes to the point of local extinction, thereby reducing biological diversity. Several native species of mussels in Lake St. Clair have been extirpated, and in some areas of Lake Erie, dreissenid mussels jeopardize native populations.

Invasive Species of Lakes Erie and Ontario

The following are several of the important invasive species in Lakes Erie and Ontario, the conservation issues they cause, and, where applicable, some of the management methods that have been used to control them (full details can be found at: www.seagrant.sunysb.edu/ais/pdfs/ais-lerieont.pdf):

Zebra mussel (Dreissena polymorpha) and quagga mussel (Dreissena rostiformis bugensis)
Zebra and quagga larvae were introduced into the Great Lakes in freshwater ballast of freighters from the Black and Caspian Seas (O'Neill and MacNeill 1991). The mussels quickly invaded, as they can produce up to 1,000,000 eggs per year, larvae are easily dispersed through the water currents, and larvae form colonies of over 35,000 per square meter. Mussels filter feed, drawing up to two liters of water per day to consume phytoplankton, substantially clearing the water (O'Neill and MacNeill 1991). Despite the clean look of water invaded by mussels, the filter feeder causes loss of important nutrients for fish and other organisms (O'Neill

Figure 2. Cladophora (benthic algae) that has been dislodged from beds farther offshore and washing up on Lake Ontario beach, near Oak Orchard, New York

(a) decaying algae biomass on shore

(b) algae mat washed up near jetty.

and MacNeill 1991). Further, the rapidly reproducing mussels form dense mats and are referred to as "biofoulers," causing hundreds of millions of dollars in damage and maintenance costs for fouled pipes, drinking water treatment, and industrial and power plant intakes.

Discussion Question 5:

What characteristics of zebra and quagga mussels have made them such successful invasive species? What are some of the possible reasons that the control of these species has been so challenging?

Spiny waterflea (Bythotrephes cederstroemi) and fishhook waterflea (Cercopagis pengoi)
The spiny waterflea is a small (5 - 15 mm in length), predatory crustacean with a long, barbed tail spine that serves as protection from predators. The waterflea competes with fishes for zooplankton. Spiny waterfleas entered Lake Ontario in the early 1980s from their native northern Europe via ballast water discharges. They have now spread to all five Great Lakes. Waterfleas reproduce rapidly, up to 10 offspring every two weeks in warmer months. Another similar species, commonly called the fishhook waterflea (*C. pengoi*) has also now invaded the Great Lakes. Both waterfleas form thick masses that are often found on the fishing lines and nets of anglers. The food web impacts of these invaders are still unknown.

Sea lamprey (Petromyzon marinus)
The sea lamprey is a predatory, eel-like fish native to the coastal regions of the Eastern US. The lamprey was first discovered in Lake Ontario in the 1830s and then Lake Erie in 1921, probably invading via the Hudson River and Erie Canal (GLFC 2000). The sea lamprey predates on fish, including economically valuable sport fish, such as trout and salmon, by attaching itself to the side of its prey with a sucking disk. The sea lamprey then consumes its prey by sucking its blood and body fluids (GLFC 2000). Sea lampreys have been blamed for the decline in many Great Lakes fish species, as a single adult lamprey can kill up to 18.14 kilograms of fish in its lifetime of two years (GLFC 2000). To control sea lampreys, the Great Lakes Fishery Commission constructs barriers and uses chemical lampricide treatments in spawning streams, sometimes spending millions of dollars in lampricide treatments (GLFC 1998). In addition, male sterilization and use of pheromone attractants are being tested as potential controlling methods.

Discussion Question 6:

What challenges do the sea lamprey's unique physical adaptations create for Great Lakes Fishery Commission biologists as they attempt to control this aquatic invader?

Alewife (Alosa pseudoharengus)
The origin of alewife in Lake Ontario is unknown, but they were first "discovered" there in 1873 and may, in fact, be native to the Lake. It is also theorized that alewife may have been misidentified as juvenile shad and stocked into the lake accidentally. Alewives are both able to out-compete other Lake fish as well as readily consume their young, including those of lake trout, yellow perch, walleye, and whitefish. In addition, Alewife populations can increase rapidly and, during bouts of cold water, can create massive die-offs that can foul beaches. In Lake Erie and Lake Ontario, alewives have also become the primary food resource for introduced Pacific salmon and lake trout.

Common carp (Cyprinus carpio)
Carp were originally stocked into the Great Lakes region from Asia as a future food source, which has not panned out as hoped. Initially, the fish were kept in farm ponds, but they entered the Great Lakes during floods and quickly spread throughout the US. Carp feed by rooting aquatic plants and disturbing the lakebeds. This feeding behavior can dramatically alter the aquatic environment by causing excessive turbidity, leading to declines in submerged aquatic plants and the many organisms that depend on them. It is also hypothesized that common carp prey on the eggs of other, native, fish species (Nico et al. 2011).

Round goby (Apollonia melanostoma – formerly Neogobius melanostomus)
Originally from the Black and Caspian Seas, round gobies were first discovered in the Great Lakes (St. Clair River) in 1990. These benthic fish have many adaptations that allow them to outcompete native fish and spread throughout the Great Lakes region including: a highly developed sensory system that allows them to

find food and avoid predation as well as feed at night; an aggressive nature; the ability to spawn several times each year; paternal care and guarding of nests reduces predation and increases survival rates. To view the spread of round gobies from their discovery site near Lake St. Clair, see: http://nas.er.usgs.gov/taxgroup/fish/roundgobydistribution.aspx.

Purple loosestrife (Lythrum salicaria)
Purple loosestrife is an emergent aquatic plant native to Eurasia, first introduced into North America in the early 1800s, most likely as both an ornamental plant and medicinal herb, and as a seed in soil. Purple loosestrife was found throughout the northeastern United States and southeastern Canada by the late 1800s in wetlands. Purple loosestrife invades disturbed habitat and forms dense stands in which few other plant species can survive. This loss of native vegetation is followed by a loss in native wetland wildlife, as loosestrife provides little nutritional value and can reduce the productivity of shallow waters utilized as spawning habitat by native fish. Hand pulling, treatment with broad-spectrum herbicides, and flooding can control small, newly introduced patches of purple loosestrife; however, these methods are generally ineffective, too costly, or physically difficult to be used against well-established stands. Biological control (explained in further detail in the Control Strategies and Mitigation Efforts section) has proven to be somewhat effective and five species of insects have been approved for control of purple loosestrife, including a root-mining weevil, two leaf-eating beetles, a flower-feeding weevil, and a seed-feeding weevil.

Water chestnut (Trapa natans)
Water chestnut was first introduced to North America as an ornamental plant as well as for the food and medicinal value of its fruit. The first Great Lakes basin introduction of water chestnut was in Collins Lake in New York around 1884; since then, the plant has spread in waterways throughout the Northeast and has been found along the south shore of Lake Ontario since the 1960s. Water chestnut grows in lakes, ponds, and in slow moving streams and rivers, preferring shallow, calm, nutrient-rich waters with soft, muddy bottoms. The plant's cord-like stems can reach up to ~4.88 meters and, if uncontrolled, can develop dense mats across wide areas, creating a hazard for boaters. Dense mats of water chestnuts create a floating canopy that shades out native plants. Water chestnut also out-competes native vegetation and is of little nutritional value to wildlife.

Eurasian watermilfoil (Myriophyllum spicatum L.)
Eurasian watermilfoil, native to Europe and Asia, is believed to have been brought into the United States intentionally as an ornamental plant in the early 1900s and can now be found in 45 states and three Canadian provinces. Watermilfoil favors disturbed habitat and forms colonies that rapidly spread in by stem-like branches via water currents, recreational boating, and intentional harvesting. Watermilfoil is not a food source for waterfowl and its dense colonies shade out native vegetation as well as reduce the abundance and diversity of invertebrates. While Eurasian watermilfoil cannot be completely eradicated, the spread can be stemmed by removing all fragments of the plant from boats and ensuring fragments do not reenter any body of water. Other control measures have included bottom barriers, suction harvesting, and raking the lake bottom to remove roots, stems, and fragments.

The Role of Invasive Species in Broader Ecosystem Changes

In the previous section a number of invasive species in the Great Lakes are described, along with the direct impacts they have on the native ecosystem, as well as broader changes in food web structure. As previously described, broader ecosystem changes may occur as a result of the combined impacts (with possible multiplicative effects) of invasive species and other components of the ecosystem. Here we describe several examples of such ecosystem impacts.

Botulism outbreaks and the link to invasive species
Since 1999, botulism has caused large die-offs of fish and waterfowl in Lake Erie, Lake Ontario, and Lake Michigan. Botulism is a disease caused by the bacterium *Clostridium botulinum*, and has been a major cause of mortality in migratory birds since the 1900s. Botulism spores are naturally found in anaerobic habitats, can remain in the ecosystem for extended periods of time, and under the right conditions, can produce a powerful neurotoxin (Leighton 2000).

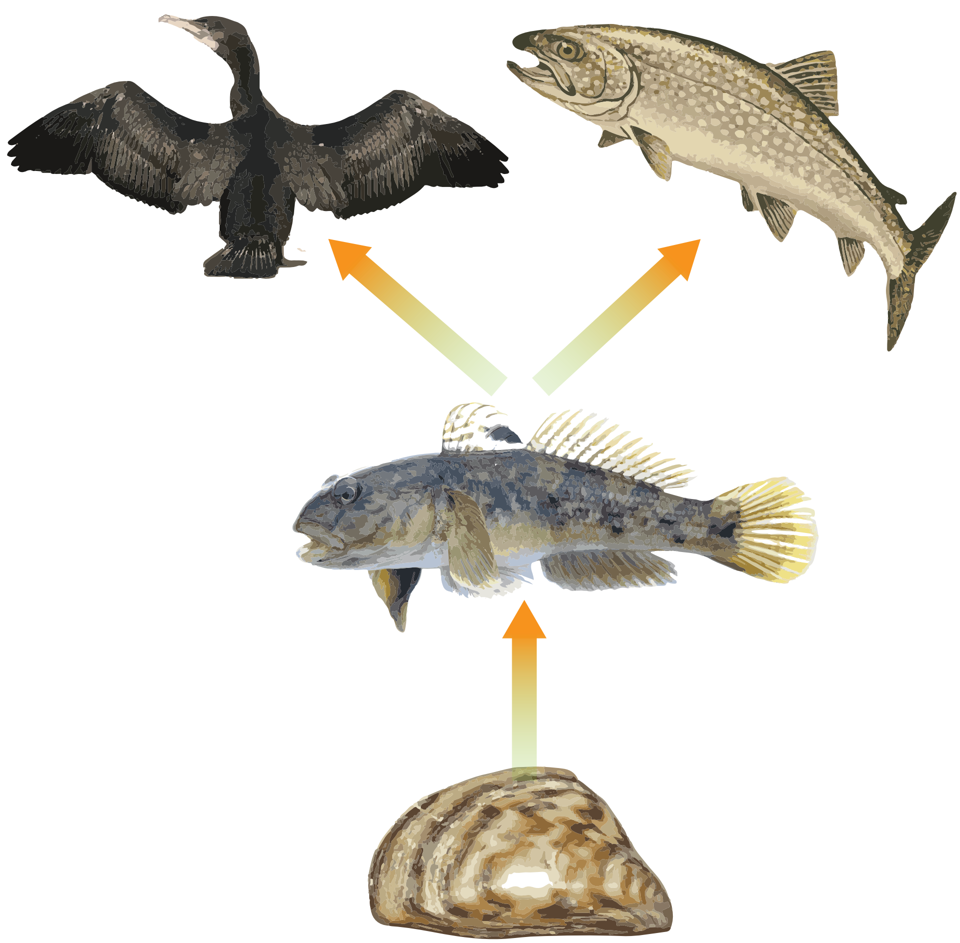
There is speculation that recent botulism outbreaks in the Great Lakes have a connection to abundances of zebra and quagga mussels and the round goby (Leighton 2000), as the mussels disturb the sediment where *Clostridium botulinum* can be found. The mussels also release pseudofeces that, when decaying, creates anoxic conditions that favor anaerobic *Clostridium* bacteria. Diet studies have shown that large round gobies feed primarily on the mussels and sure enough, botulism has been found in round gobies. Thus, these invasive species are collectively increasing the prevalence of botulism and moving the toxin up the food web, as fishes or waterfowl consume the infected round gobies (Figure 3).

Further information on botulism may be found at www.seagrant.sunysb.edu/botulism/article.asp?ArticleID=139 and www.miseagrant.umich.edu/downloads/habitat/botulism-FAQ-030107.pdf

Discussion Question 7:

What combination of ecosystem stressors has (most likely) led to the botulism problem in the Great Lakes?

Figure 3. Transfer of C. botulinum bacteria through the food chain: dreissenid mussels filter water in anaerobic benthic areas at the sediment bed where bacteria grow, round gobies eat the mussels and are in turn eaten by predator fish (lake trout is pictured here) or water fowl (cormorant is pictured here). Illustration by Nadav Gazit.



Phosphorus distributions and nearshore/offshore water quality differences

In the 1970s research determined that phosphorus was the primary limiting nutrient for algae growth (Atkinson 2002). Since then, multiple billions of dollars have been spent on phosphorus abatement programs to clean up the Great Lakes (GLWQA 1978; DePinto et al. 1986; Makarewicz and Bertram 1991). On a volume-weighted average basis, the lake concentrations are either at or are approaching the long-term phosphorus targets determined by mathematical models of eutrophication in the lakes. Results of those early models were used to determine the amount of phosphorus that could be accommodated in a sustainable manner. However, many near shore areas, where the public most often interacts with the lakes, are experiencing a return to eutrophic conditions along with significant deterioration of water quality. At the same time, offshore ecological productivity is below the level expected based on nutrient loadings (DePinto et al. 2006). Recent changes in the ecology and land use patterns along the coastal zones of these lakes, particularly with respect to agricultural practices, appear to be causing the reappearance of eutrophic conditions similar to those existing prior to the phosphorus reductions. Managers, resource beneficiaries, and other stakeholders are becoming increasingly frustrated in their efforts to understand the deteriorating coastal environment. Better controls on tributary, municipal and industrial outfalls, and non-point sources related to agricultural activity were a primary element in reversing the overall decline in Great Lakes water quality, so why is the nearshore experiencing this relatively new problem with water quality?

<u>Discussion Question 8</u>:

Why is eutrophication an undesirable condition in a waterway?

<u>Discussion Question 9</u>:

For eutrophication problems in the Great Lakes (and elsewhere), why is there a major focus on phosphorus? What are some of the factors that should be considered in developing phosphorus loading goals?

One of the possible explanations for these observations has been suggested in terms of a near shore "biological filter", also known as the "near shore shunt" hypothesis, whereby nutrients are filtered out and sequestered in the near shore region, reducing their transport into deeper waters (Hecky et al. 2004). This process has been observed in lakes around the world, is apparently exacerbated by invasive mussel species, and has recently been hypothesized as the cause of near shore/offshore water quality differences observed in the Great Lakes (Hecky et al. 2004; Depew et al. 2006; Makarewicz and Howell 2007). The "filter" effect is especially relevant to phosphorus, since much of the total phosphorus input to the lake is in particulate form, originates from land adjoining the near shore, and is more susceptible to being retained in the near shore by dreissenid mussels. The reduction of phosphorus transport offshore could thus be a result of the removal and retention of material in the Dreissena and Cladophora beds. Therefore, the combination of changed land use patterns, proliferation of non-native mussels, and possible changes in water temperatures due to climate change (leading to increased growth rates) is a likely explanation for near shore water quality problems.

The mathematical models initially used to establish phosphorus goals were based on an abstraction of the physical system in the form of a set of mathematical statements developed to represent the main system processes of interest. In this case the main concept is that of mass balance. In other words, we can formulate a statement for a particular system, or control volume , that equates the rate of change of mass of a particular material of interest (like phosphorus) to the rate at which that material is transported into the volume, minus the rate at which it is transported out of the volume, plus or minus the rates of mass production or decay due to

<u>Discussion Question 10</u>:

Test your ability to formulate a simple mass balance statement, using mass of water as an example. If a hose is used to fill a bucket, but the bucket has a hole in the bottom, how would you express a statement based on water mass balance that would describe the amount of water in the bucket?

any internal sources or sinks of that material. In other words, the mass does not have to remain constant, but any transport or transformations must be accounted for explicitly. Mathematical modeling is explained in greater detail in the Modeling Supplement for this Case Study and in the NCEP module *Mathematical Modeling and Conservation* (ncep.amnh.org).

Anoxic zones

One further example of the impact of invasive species on an established ecosystem may be associated with the recurrence of anoxic regions in the hypolimnion of the central basin of Lake Erie (Figure 4) (Conroy et al. 2005). The hypolimnion is the region near the bottom, below the summer thermocline as shown in Figure 5, which is a schematic of the general thermal structure of the lake in summer. Lakes with this sort of vertical temperature distribution are called stratified. The upper layer, or epilimnion, is usually relatively well-mixed due to wind action, is warmer because of greater solar radiation intensity and absorption near the surface, and has greater levels of dissolved oxygen because of its contact with the air. The hypolimnion is cooler and less well-mixed. The thermocline is in a region called the metalimnion, which separates the epilimnion and hypolimnion, and is characterized by steep temperature gradients (leading to strong density variations) that inhibit mixing and transport of materials such as heat and dissolved oxygen between the upper and lower layers. The thermocline is usually defined as the location where the temperature gradient (where "gradient" means rate of change of temperature with changes in depth) is the largest.

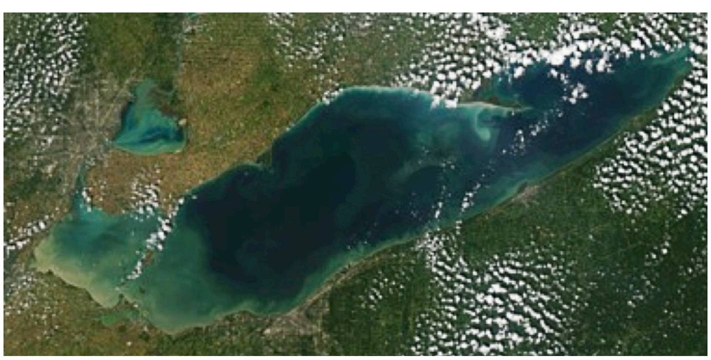


Figure 4. Central basin of Lake Erie. Image source: NOAA

<u>Discussion Question 11</u>:

What is the relationship between temperature and density in freshwater? What is the significance of the fact that ice is lighter than water at temperatures near freezing?

Due to the reduced transport rates across the thermocline, the dissolved oxygen in the hypolimnion is often reduced, relative to the epilimnion, since various biological processes (respiration, decomposition) deplete oxygen. In addition, the supply is limited because the only appreciable source of oxygen is the atmosphere, and oxygen cannot be moved downward because of the density increase through the metalimnion. Although this condition does not directly depend on invasive species, it is believed that invasive mussels exacerbate the problem because (i) by clearing the water, more sunlight can reach the bottom and cause algae growth and decomposition (any photosynthetic production of oxygen is overshadowed by respiration

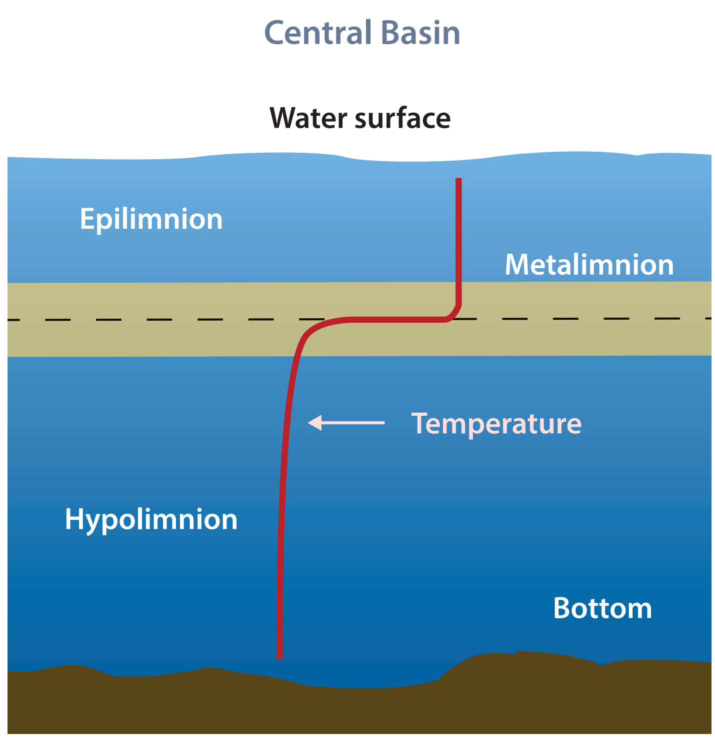


Figure 5. General thermal structure of a stratified lake in summer; the maximum rate of change of temperature (i.e., the maximum gradient) in the metalimnion is called the thermocline. Illustration by Nadav Gazit.

and decomposition); and (ii) they create additional organic material for decomposition through excretion of pseudofeces, and partially undigested material from their filter feeding may drift into the central basin from mussel beds located elsewhere in the lake. Further discussion of the oxygen dynamics in Lake Erie is provided by Edwards et al. (2005).

CONTROL STRATEGIES AND MITIGATION EFFORTS

Control and Mitigation

Preventing the introduction of invasive species into the ecosystem is always better than trying to control species once they have become established. Once non-native plants and animals have been introduced into the wild, it is often difficult and expensive to control them. Control strategies include biological, chemical, and mechanical methods – several examples of these methods are discussed in the "Invasive Species of Lakes Erie and Ontario" section.

Biological control involves the purposeful release of a predator, parasite, or pathogen that can be used to control the invasive plant or animal. An example of biological control in the Great Lakes is the use of *Galerucella* beetles for the control of purple loosestrife. These leaf-eating beetles have been successfully used by managers in selected regions of the Great Lakes to reduce stands of purple loosestrife (Wilson et al. 2009). Often, however, the use of biological controls means introducing yet another non-native species, so this approach must be taken with extreme care.

Chemical control involves the use of herbicides or pesticides to control invasive species and is routinely used for the control of terrestrial plants. There is concern about the addition of noxious chemicals to aquatic ecosystems, so this method of control is seldom used in a lake environment. However, chlorination has been extensively used in water treatment and industrial settings to control zebra and quagga mussels and to prevent their fouling of pipes (O'Neill and MacNeill 1991).

Mechanical control involves the physical removal of invasive species. These controls include hand-pulling, cutting, or the use of machinery such as harvesters. Although mechanical control can be effective, it is often expensive due to the high cost of special machinery or the labor costs involved. In addition, this approach is usually a temporary solution, since the invasive is rarely completely eliminated. In certain areas of the Great Lakes, floating mechanical harvesters are used to control Eurasian watermilfoil on a continuing basis.

Public Efforts and Stewardship

Stakeholders need to become aware of this biological pollution and join in efforts to limit the introduction and spread of invasive organisms. Education and outreach are important elements, especially since many "invasions" occur accidentally, when the people involved do not know they may be contributing to the spread of a non-native species. In addition, research, monitoring, and management must be utilized in the battle to stop the spread and mitigate the impacts of invasive non-indigenous species on our environment.

Once informed of the ecosystem damage caused by aquatic invasive species, most stakeholders will eagerly take steps to reduce their spread. Informed anglers, boaters, and scuba divers realize that their actions are helping to protect the environment they depend on for their recreational pursuit or livelihood. The Great Lakes Sea Grant Network has a listing of resources that stakeholders can use to learn more about aquatic invasive species and what they can do to mitigate the damage from the spread of these invaders.

Spreading information, rather than spreading invasive species, has become a goal of many agencies and organizations around the Great Lakes. Many boat launches and marinas now have signs warning boaters and personal watercraft operators about the threat of aquatic invasive species and steps that they can take to prevent the movement of these unwanted invaders. Sea Grant programs and state agencies have created flyers and factsheets that are distributed at bait shops, park offices, and marinas to help inform boaters and anglers what they can do to reduce the spread of aquatic invasive species.

Many successful stewardship projects have been developed by the Great Lakes Sea Grant Network, including AIS HACCP (Hazard Analysis and Critical Control Point) and Nab the Aquatic Invader. The AIS HACCP program focuses on the spread of invasive species through aquaculture, hatchery, scientific, natural resource, and baitfish harvesting activities. The program is a self-inspection effort based on plans that are created, followed and periodically evaluated for effectiveness.

<u>Discussion Question 12</u>:

How might mitigation efforts for dealing with invasive species in the Great Lakes, or other aquatic ecosystems, be similar or different to efforts made for terrestrial invasive species?

On-Going Issues

Perhaps the most well known on-going issue with respect to invasive species is that of ballast water exchanges. It is hoped that governmental agencies in the United States and Canada will continue their efforts to prevent new invasive aquatic species from entering the Great Lakes. Ballast water management efforts (mainly exchange of freshwater ballast for saltwater ballast 200 miles offshore prior to entry into the St. Lawrence River) are already underway, but have not yet proven to be totally effective at keeping out new invaders. New technologies for ballast water management are being researched and tested. Many Great Lakes states are also exploring legislative means to reduce the introduction of invasive species through ballast water release. The Northeast-Midwest Institute has initiated the Great Ships Initiative to control ship-mediated introductions of invasive species in the Great Lakes.

A number of states around the Great Lakes have decided to take matters into their own hands by developing legislation focusing on stricter ballast water regulations and control. The legislation is in its early stages and the powerful shipping industry may challenge these legislative efforts due to added costs and regulations, but it is a positive step. It seems that Great Lakes legislators realize the additional costs for industries (water and hydroelectricity) and the ecosystem damages are good reasons to make these ballast water regulations a part of the law. The next few years should bring about some interesting changes in the way ballast water is treated and or discharged in the Great Lakes.

The other current issue related to aquatic invasive species in the Great Lakes is concern over the introduction of Asian carp. Both the bighead carp (*Hypophthalmichthys nobilis*) and the jumping silver carp (*Hypophthalmichthys molitrix*) were originally imported by fish farmers in the southern United States to reduce algae growth in their fish ponds. Unfortunately, as a result of flooding near the Mississippi River these fish escaped the ponds and eventually made their way into the environment. Both species have continued to move northward towards the Great Lakes. An electric barrier that was originally designed to keep the round goby from leaving the Great Lakes and heading down the Mississippi River, was seen as a way to stop the fish from entering the Great Lakes. Due to concern over the possible impacts of these plankton-eating fish on the food web of the Great Lakes, the electric barrier system was enlarged and improved.

Recently, E-DNA (environmental DNA) from Asian carp was discovered in Lake Michigan, creating much concern from scientists and stakeholders alike. Although the impact of such plankton-hungry fish on the environment of the Great Lakes is unknown, managers and researchers agree that it is essential to keep reproductive numbers of these fish out of Lake Michigan and the rest of the watershed.

How Can You Help Stop the Spread of Invasive Species?

People who fish, own boats, or have backyard water gardens or aquariums, can either help spread aquatic invasive species or take steps to reduce the spread of these plants and animals by their actions. Although many of the aquatic invasive species in the Great Lakes originally entered through the ballast water of ships, individuals have contributed to the spread of some of these invasive species from one area of the basin to another.

There are recorded cases of "bearded" boats, or boats on trailers full of aquatic plants being moved from one area of the Great Lakes to another. Not only could the aquatic plants prove to be invasive, but other invasive species like zebra or quagga mussels could be attached to the plants and these aquatic hitchhikers could begin an invasion in a new area. The live wells or bait buckets on trailer-pulled boats could also hold the microscopic larvae (veligers) of mussels, helping to spread these unwanted invaders to a new location.

It is believed that the 2007 introduction of the quagga mussel into Lake Mead came from a pleasure boat that was moved from the Great Lakes. Since that time, the mussels have been spreading quickly throughout connected waterways, even proving a threat to Hoover Dam and the water supply systems for Las Vegas, Nevada.

Discussion Question 13:

Knowing the ways that invasive species have been, and continue to be introduced to the Great Lakes, what are some precautions that boat owners, or recreational users of the Lakes can take to reduce the spread of these species? What might be the pros and cons of each strategy?

CONCLUSION

The Great Lakes face a challenging future. Issues associated with habitat destruction and global climate change will create challenges to the ecosystem, but the 180 aquatic invasive species that have entered the Great Lakes will continue to cause ecosystem changes that will have a dramatic impact on the basin for years to come. As described above, these impacts can go beyond local effects on habitat or direct competition with native species, and have resulted in ecosystem-wide consequences. It is likely that new invaders will appear in the future, and although the specific impact of a new invader is impossible to predict, it may be concluded that ecosystem changes will result. In addition, many of the impacts of invasive species have very significant economic as well as ecological ramifications.

It is important to educate stakeholders about the impact of invasive species and the changes that aquatic invasive species have created in the Great Lakes. Although individuals often feel that their actions have little impact, this is one situation in which individuals play an important role. Will it be a home aquarist who releases the next aquatic invasive plant or animal into the Great Lakes? Or, will an angler fishing in Lake Erie unknowingly dump the contents of a bait bucket into Lake Huron as he moves his boat into Lake Huron during his vacation? These actions may seem insignificant, but the potential harm of aquatic invasive species is dramatic. To illustrate the impact of aquatic invasive species, scientists have coined the term "benthification" to refer to changes that have occurred in Lake Erie and other of the Great Lakes. The actions of zebra and quagga mussels have changed the food web in Lake Erie from a system that was driven by interactions in the open water to a system that is driven by benthic (bottom surface) interactions. This is an extreme example of the type of ecosystem change that can be brought about by invasive species. When an entire lake ecosystem is changed by an invader, it is time for scientists, citizens and legislators to realize that the probable impact of aquatic invasive species can be dramatic.

GLOSSARY

Anaerobic (habitat): Areas where there is no oxygen

Anoxia: Condition where the dissolved oxygen of the water drops to zero

Bathymetry: The distribution of water depth (or bottom elevation) below the water surface

Benthic (region of the lake): Relating to the near-bottom environment

Control volume: A volume, or system, with well-defined boundaries over which fluxes of mass or other properties can be characterized

Cross-margin transport: Movement of water and other materials in the water between nearshore and offshore regions of the lake

Detritus: Organic "litter," usually found at the bottom in or on sediments

Downwelling: A physical phenomenon caused by wind, where surface (warmer) water is "piled up" at one end of the lake and lower (colder) water is pushed downward

Ecosystem services: Benefits for human life that are derived from the basic functions of natural ecosystems

Ecosystem Stressor: A physical, chemical or biological process that causes a significant response on the (lake) ecosystem in some way; "stressor" is often used to indicate a process that disrupts the normal ecosystem functioning, and may affect the long-term sustainability of a particular ecosystem

Epilimnion: Upper layer of water in a lake, bounded by the thermocline below; this layer is generally well mixed (it is often called the upper mixed layer) and warmer than the water below the thermocline

Eutrophication: A process that results when a water body receives an excessive amount of nutrients, usually phosphorus and/or nitrogen, that result in over-fertilization and productivity (growth) of plant species such as algae

Extirpated: Extinct in a given area

Fecundity: Ability to reproduce

Gradient: Rate of change of a quantity, or variable, such as temperature; while usually a gradient refers to a change over a spatial dimension (such as depth), it also can refer to a rate of change with time

Hypolimnion: Region of lake water below the thermocline; generally this water is colder and often has less dissolved oxygen than the overlying water

Hypoxia: A state in which the dissolved oxygen in the water column is reduced to such a level that it may adversely impact organisms that depend on oxygen to live

Legacy (contaminants): Contaminants previously deposited in sediments, usually by industry

Mass balance: A conceptual or mathematical statement that expresses the fundamental concept that mass is neither created nor destroyed; this is the basic starting point for building many water quality models, which are related to a particular system, or control volume of interest

Non-point source pollution: Air and water pollution from non-specific, diffuse sources.

Pelagic (region of the lake): Relating to open (deep) water areas

Salmonids: Top predator fish species (also valuable sport fish) such as trout and salmon

Shear stress: A frictional force acting along the direction of flow; a determining factor in calculating whether sediment will be eroded or not

Stratification (or stratified lake): A condition where the density changes with vertical position, with less dense (generally warmer) water closer to the surface, and more dense (generally cooler) water near the bottom – see Figure 5

Sustainability: The potential for long-term maintenance, in this case for ecosystem services.

Thermocline: Region of strong temperature variation with depth, generally forms in summer and separates the upper mixed layer of a lake (the epilimnion) from the lower, hypolimnion water – see Figure 7

Transmittal vector: Process by which an organism (invasive species) may be moved from one location to another

Turbidity: Cloudiness or “mudiness” in the water caused by suspended silt and other solids

Upwelling: A physical phenomenon caused by wind, where lower (colder) water is pushed upwards at one end of the lake

Veligers: Larval stage for zebra and quagga mussels

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