2~ Invasive Species in the Great Lakes

Sea lamprey mouth

Over the past two centuries, more than 50,000 foreign plant and animal species have become established in the United States. About one in seven has become invasive, with damage and control costs estimated at more than $137 billion each year.[15] Nationally, about 42% — 400 of 958 — of the species that are listed as threatened or endangered under the Endangered Species Act are considered to be at risk primarily because of predation or competition with exotic species.[16] Indeed, invasive species comprise the second-largest threat to global biodiversity after habitat loss.

The Great Lakes region has been similarly affected by exotic species, and continues to be threatened by existing and potential new species invasions. Since the 1800s, the introduction of over 160 exotic species has irreversibly altered the region's ecosystem, causing dramatic changes in biological relationships and natural resource availability.[17] The effects of some introductions have been particularly acute – for example, sea lampreys played an important role in the collapse of lake trout fisheries in the upper Great Lakes in the 1940s-50s.[18] In addition to worries about the effects of invasive species on individual species, a wider concern is potential effects on the broader food web (see Box 1 for brief overview of Great Lakes food webs).

Introduced species enter the Great Lakes basin by multiple pathways. As of the early 1990s, the breakdown of the routes of introduction for 139 known aquatic invasive species was shipping (41 new species), unintentional releases (40), ship or barge canals, along railroads or highways, or deliberate releases (17), unknown entry vectors (14) and multiple entry mechanisms (27).[19] Unintentional releases can include unintentional fish stocking, aquarium release, and bait handling.[20]

About 70% of the 160 invasive species which have established themselves in the Great Lakes are native to the Ponto-Caspian region (a region of southeastern Europe and southwestern Asia that contains the Black, Azov, and Caspian Seas), with the second highest percentage originating from the Atlantic Coast of the United States.[21] An assessment of shipping patterns indicated that the Baltic and North Seas were the source regions for the majority of cargo-bearing ships — both number of ships and reported tonnage, for ships identified as no ballast on board, or NOBOB — entering the Great Lakes in 1997.[22]

The number of species invading from the Ponto-Caspian region surged beginning in the 1980s, primarily due to increased ship traffic, increased ship speed, and ballast water discharge. Factors such as extensive linkages of inland basins to the seas through canals and rivers, tolerance for wide-ranging salinities in many species, and transformations in the new environment that make habitat more suitable for additional exotic species coming from the same region all have contributed to increased numbers of invasions.[23]

Box 1

Great Lakes Food Webs

The adjoining sketch shows a very simplified food web analogous to what might be found in one of the Great Lakes. From a biological standpoint, the lake can be divided into free, open (“**pelagic**”) waters and deeper (“**benthic**”) zones near and including the sediments. While many species tend to remain in one or another of the zones, other species (e.g. some fish and aquatic insects) sometimes move between them. An important aspect of the food web is the transfer of energy (in the form of nutrients) between organisms. In this case, **phytoplankton** — suspended microscopic plants (algae) or photosynthetic bacteria — grow by processing sunlight through photosynthesis. Phytoplankton can be consumed, either in the water or after they have died and fallen to the sediments, by either **zooplankton** (small suspended animals with limited powers of movement) or by **macroinvertebrates** (small animals lacking a backbone) in the sediments. These organisms can in turn be eaten either by other small animals, such as aquatic insects, or **forage fish**, such as smelt or alewife, which then can be eaten by **predator fish** such as lake trout or Pacific salmon. Changes to the food web can occur in several ways – including “top down” with the introduction of a new predator fish, or “bottom up” with the introduction of species that effect populations of either plankton or benthic organisms. In real lake systems, food webs are more complex, with many interacting components. However, the potential for food web disruption by invasive species or other phenomena always remains.

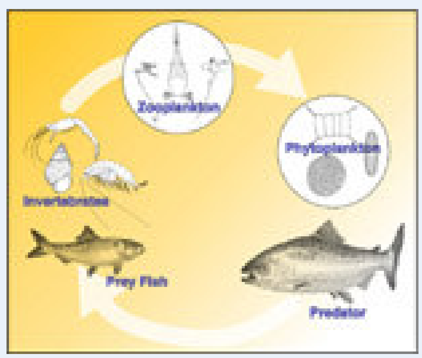


Figure 2: *Food web diagram (NOAA)*

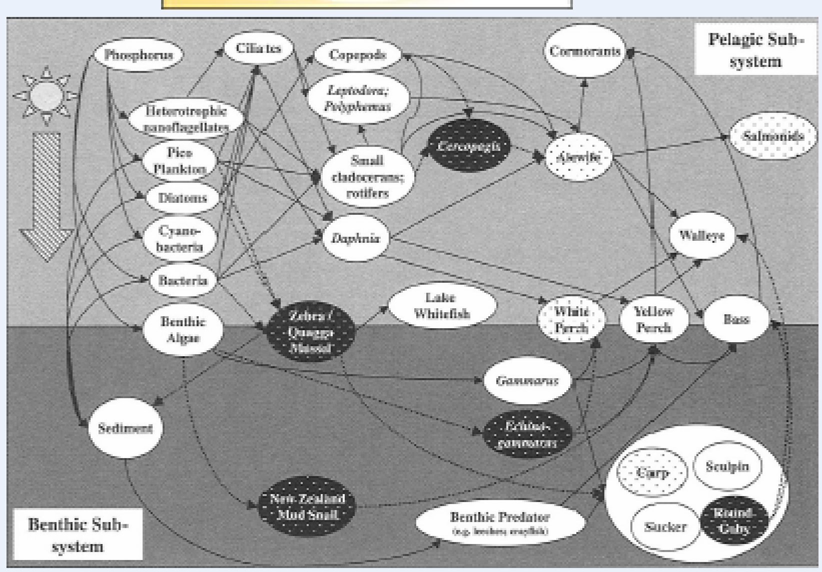


Figure 3: *Sample food web (Mills, et al., 2003)*

Box 2

Exotic Species Can Have Economic Value

Since recorded time began, people have brought plants and animals with them for food and other uses. Many introduced species of plants and animals, such as varieties of corn, wheat, rice, and other food crops, and cattle, poultry, and other livestock, now provide more than 98% of the U.S. food system at a value of approximately $800 billion per year.[24] Some predatory fish species (such as Pacific salmon) originally introduced in the Great Lakes to control invasive fish species have since become popular in the multi-billion-dollar recreational fishing industry. However, these types of introductions can still potentially have costs in terms of broader ecological changes not initially foreseen.

The Rate of Introduction is Increasing

As the use of the Great Lakes as a transportation route for commerce intensified, the rate of introduction of aquatic nuisance species also increased. Since the opening of the St. Lawrence Seaway in 1959, 77% of the new organisms established in the Great Lakes are attributed to ballast water discharge.[25]

Figure 4 shows the relationship between increased shipping activity and the increased rate of successful aquatic species invasions. Figure 5 indicates the increase in the cumulative number of invasive species in the Great Lakes. The rate of increase in recent decades is the highest observed thus far. Nearly 30% of invasive and introduced species in the Great Lakes became established after 1959.[26]

Who are the invaders?

We know of at least 160 exotic species that have invaded the Great Lakes since the 1800s; but in reality, there are probably many more that we have not yet discovered. The invaders we know about represent a wide variety and type of organisms. Based on data through the early 1990s, most of these species include aquatic or wetland plants (42%), invertebrates (20%) fishes (18%), and algae (17%).[27] Although it is difficult to conclusively identify the most damaging invaders because we do not yet know the full extent of the harm they are causing, three broad categories of organisms have already caused dramatic alterations to the ecosystem: fishes, mussels, and zooplankton.

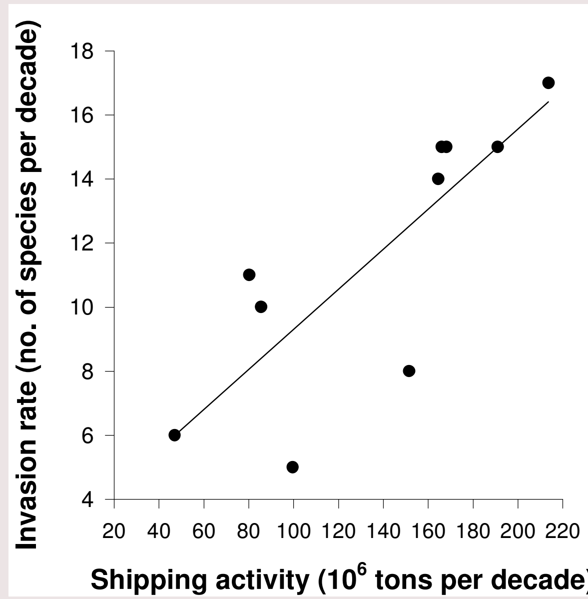


***Figure 4**: Increased shipping in the Great Lakes has led to an increased number of aquatic invasive species introductions — as shown by the relationship between the invasion rate and shipping activity in the Great Lakes (reproduced with permission from Ricciardi 2001)*

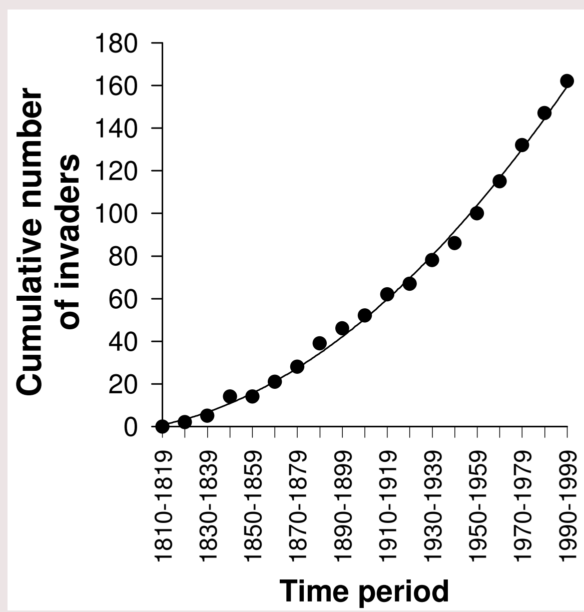
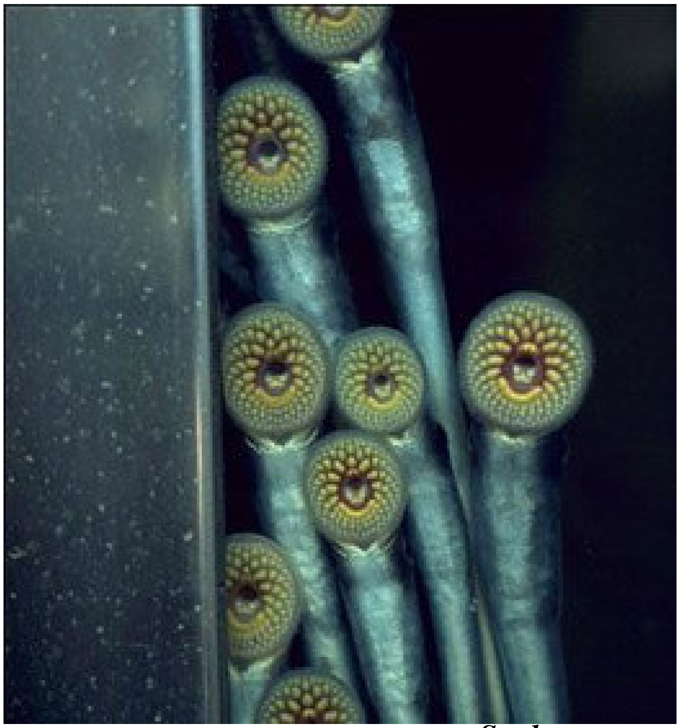


***Figure 5**: Cumulative number of nonindigenous invasive species established in the Great Lakes by decade (reproduced with permission from Ricciardi 2001).*

Invading nuisance fish degrade native fish species

A number of invasive fish species have taken hold in the Great Lakes, either as a result of deliberate introductions or inadvertent invasions. Examples of species or groups of species that have had a significant effect on the fisheries and/ or the broader food web are presented below.



Sea lamprey

Sea Lamprey: The sea lamprey has most likely had the most significant impacts on Great Lakes fisheries of any invasive fish species. The lamprey was first identified in Lake Ontario in the 1830s, likely migrating west through the Erie Canal, although more recent genetic evidence indicates the species may be indigenous to Lake Ontario.[28] While the lampreys were not discovered in Lake Erie until 1921, they quickly spread to the upper three Great Lakes, reaching Lake Superior by 1938.[29] Lampreys affect the food web through habitat modification and, to a greater extent, through predation on fish.[30] The eel-like fish attaches to fish and drains them of blood and bodily fluids. An adult sea lamprey can kill up to 40 pounds of fish in 12-20 months. The combination of sea lamprey predation and overfishing led, to varying extents, to substantial declines or complete collapses of populations of lake trout, burbot, and lake whitefish in the middle of the 20th Century. Use of chemical control on sea lamprey larvae began in the late 1950s in Lake Superior and was extended to other lakes over the next three decades, and has eliminated spawning runs from a number of streams.[31] (See further discussion on populations of species affected by sea lamprey in Section 5).

Round Goby: Round gobies look and behave very similarly to the mottled sculpin, a fish native to the Great Lakes. However, these invaders are much more aggressive and out-compete the sculpins, as well as several other fish species, for food and habitat. First reported in the United States in the St. Clair River in 1990, they quickly spread, and now inhabit all five Great Lakes.[32] Once round gobies arrive in an area, a combination of aggressive behavior and prolific spawning allow the species to rapidly increase in abundance. They have been deemed responsible for local extirpation of mottled sculpins in Calumet Harbor, Lake Michigan, through competition for food sources, for space, and for spawning sites.[33] In addition, zebra mussels facilitate the introduction and establishment of round gobies by serving as a readily available food source for the non-native fish – round gobies are one of the few fish species that eat zebra mussels – and by creating habitat for small invertebrates that are the prey of small gobies.[34] The zebra mussel/ round goby relationship thus represents a case of invasional meltdown, the process by which a group of nonindigenous species facilitates one another's invasion in various ways, increasing the likelihood of survival, the ecological impact, and possibly the magnitude of the impact.

Round goby

Alewife

ALEWIFE: Alewives are indigenous to lakes and streams in watersheds along the East Coast of the United States. As was the case with sea lamprey, alewives were abundant in Lake Ontario by the late 19th Century, likely having migrated from East Coast basins through the Erie Canal. The opening of the Welland Canal allowed for migration to the upper lakes, although it was only in 1931 that alewives were reported in Lake Erie. They were reported in Lake Huron in 1933, Lake Michigan in 1949, and Lake Superior in 1954[35], and had a significant affect on the fish community of most of the lakes. Alewives were held responsible for population declines in a number of fish species, including emerald shiner, bloater and yellow perch during the 1960s, and also likely were responsible for low abundances of deepwater sculpin in Lake Michigan by 1970. Alewives also likely contributed to reductions in burbot abundance in Lakes Huron, Michigan, and Ontario. In addition, alewives have continued to hinder the recovery of lake trout populations due to both their predation on lake trout young and reversely through early mortality syndrome (a thiamine deficiency in lake trout offspring caused by the parent's consumption of non-native species such as alewife as opposed to more nutritious native species).[36] A further problem with alewives is that they swim in dense schools and often die off in large numbers, littering beaches with rotting carcasses, and posing health threats. Ironically, some species introduced in the 1960s to control alewife populations (e.g. chinook salmon) are now popular sportfish, and are dependent on adequate alewife populations.[37]

EURASIAN RUFFE: The Eurasian ruffe was first found in the St. Louis River, Minn. in 1986, probably introduced via ballast water.[38] Ruffe can tolerate a wide spectrum of environmental and ecological conditions, ranging from shallow to deeper waters and low- to high-nutrient waters, although their abundance increases with the latter. The fish spawn on a variety of surfaces, and in some cases, more than once per year. Adults feed on macro invertebrates on lake sediments, and their primary predators are pikeperch and northern pike. Since their introduction, they have become the most abundant fish in the St. Louis River estuary – by the mid-1990s, their densities were over 4 times greater than the next most populous species (spottail shiner and troutperch).[39] While research has not indicated any substantial fish community changes in response to the ruffe invasion in the St. Louis River,[40] their tolerance for wide-ranging conditions, potential for widespread distribution, and their diverse diet of organisms on bottom sediments could eventually lead to pressures on other fish populations with similar diets.

Eurasian Ruffe

BOX 3

ASIAN CARP JUMPING TOWARDS THE GREAT LAKES

The closely-related bighead carp and silver carp (commonly referred to jointly as Asian carp) are a looming threat to the Great Lakes. Bighead carp are known to reach 90 pounds and silver carp 60 pounds. Because they are filter feeders that eat primarily plankton and they can attain such a large size, scientists suggest that these carp have the potential to deplete zooplankton populations. This can lead to reductions in populations of native species that rely on this food source, including all larval fishes, some adult fishes, and native mussels. Species of fish with high recreational and commercial value, including salmon and perch, are at risk from such competition in large rivers and the Great Lakes.

Asian carp likely escaped from catfish farms in the South during flooding in the 1990s or through accidental release. In less than 10 years they have spread up the Mississippi River system and have been collected in the Chicago Sanitary and Ship Canal only 25 miles away from entering Lake Michigan. In some of the big pools along the Mississippi River, Asian carp have multiplied so quickly that in less than a decade they make up 90 percent or more of the fish life. To stem the potential movement of fish between the Mississippi and Great Lakes waters, the Army Corps of Engineers has constructed an electrical barrier across the canal to repel fish in both directions. The barrier is not fail-safe and will require either backup generators or a second barrier for added security. A plan is currently in place to construct a second barrier.[41]

The silver carp have become infamous for their tendency to panic when they hear a boat motor, hurling themselves out of the water and into the path (or onto the deck) of passing vessels and personal watercraft. As dangerous as they may be to recreational boaters and anglers, they are even more perilous to the Great Lakes fishery. Despite some efforts by commercial anglers and state management agencies, no viable market for the large crop of carp has developed along the Mississippi River and its tributaries. If the Great Lakes are transformed into a "Great Carp Pond," there is no indication that a fishing industry would develop to replace losses to the current $6.89 billion industry.

Asian carp

Exotic mussels re-make the bottom of the Great Lakes

Several invasive mussels have established themselves in the Great Lakes. The two most significant are the zebra and quagga mussels.

Zebra Mussel: The zebra mussel is a highly opportunistic mollusk that reproduces rapidly and consumes microscopic plants and animals from the water column in large quantities. Zebra mussels were first discovered in the Great Lakes in 1988 in Lake St. Clair, where they had been discharged in the ballast water from ocean-going vessels.[42] Because zebra mussels have a larval stage as plankton, they can easily be taken up in ballast water and passively distributed within a lake or downstream in rivers.[43] The adults can also attach to vessels and be transported to new water bodies as the boats enter them either directly or following overland transport. About the size of a fingernail, zebra mussels excrete a strong adhesive that allows them to attach to virtually anything, from rocks to municipal water intake pipes. The mussels can form thick colonies, acres in size, which cover the lakebed and occupy the habitat needed by native species. Even more damaging, zebra mussels are incredible filter-feeders, capable of consuming large quantities of microscopic aquatic plants and animals from the water column – and depriving native species of needed nutrients. Research indicates that zebra mussels remove suspended matter from the open water at a rate of up to 30 percent per day, and their filtering rate is over 10 times higher than that of native unionid mussels.[44] Such filtering fundamentally shifts the location of the food and energy in the Great Lakes, from the water column down into the sediments. While this shift has resulted in much clearer water in many parts of the Great Lakes, this clearer water means less nutrients for many fish species.

Scientists are just beginning to understand the impacts that zebra mussels are having on the Great Lakes. Researchers suspect that zebra mussels are a major factor in the collapse of a fundamental food source in the Great Lakes food web – the tiny, shrimp-like *Diporeia* (see Section 4). Scientists also believe the zebra mussel invasion has had negative impacts on a variety of fish species (see Section 5).

Quagga Mussel: A second mussel may be as damaging to the Great Lakes as the zebra mussel: the quagga mussel. Quagga mussels first appeared in the Great Lakes in 1989.[45] In size and appearance they are similar to zebra mussels, and like zebra mussels they colonize in thick mats over acres of lakebed. The major difference – and the one that alarms scientists – is that quagga mussels can colonize in deeper, colder water than zebra mussels. Zebra mussels thrive in the shallower and warmer lakebed areas along huge stretches of Lakes Michigan, Erie and Ontario, and Saginaw Bay. Now quagga mussels have begun to colonize additional lakebed areas, further decreasing the overall nutrients available to organisms important in the food web (see Section 4).[46]

A zebra mussel and quagga mussel

BOX 4

Zebra mussels Contribute to Toxic Algae Blooms

An Example of an algae bloom

Researchers have found that zebra mussels can promote the growth of a toxic algae that is responsible for human and wildlife health concerns and the fouling of drinking water supplies. *Microcystis* is one of a class of algae that produce toxins (termed microcystins) that can cause harm and even death in fish, wildlife and people – for example, 55 people in Brazil died following exposure to microcystins. Blooms of this type of algae were common in parts of the lower Great Lakes before phosphorus reduction measures were taken in the 1970s. However, recent research indicates that zebra mussels may be contributing to a resurgence of the blooms in areas such as Saginaw Bay and Lake Erie. Zebra mussels consume and break down some algae, but selectively reject *Microcystis*, which can contribute to blooms of the toxic algae. In addition to the potentially harmful consequences on wildlife and people, the blooms can also effect the food web – the low intake rates and poor nutritional quality of *Microcystis* lead to decreased survival of zooplankton (microscopic animals) consuming the algae, which can then affect fish consuming the zooplankton.[47]

Unpalatable zooplankton thrive in the water column

Zooplankton are tiny animals that float in the water and feed on small, usually microscopic, floating plants called phytoplankton. Zooplankton are a significant source of food for many fish at some stage of their lifecycle – especially young fish. Because of their small size, easing their entry into ballast tanks, and the phenomenon of "resting stages," some zooplankton can easily become invaders into new ecosystems. As was the case with exotic mussels mentioned above, recent invasions by exotic zooplankton species have indicated the potential for nonindigenous species to disrupt the Great Lakes ecosystem.

One type of zooplankton of significant importance in

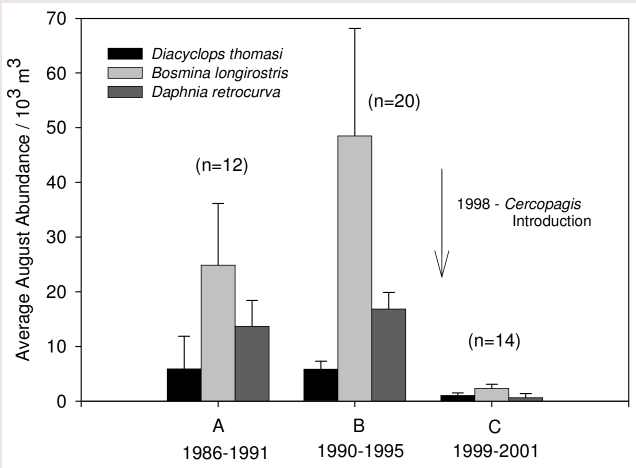
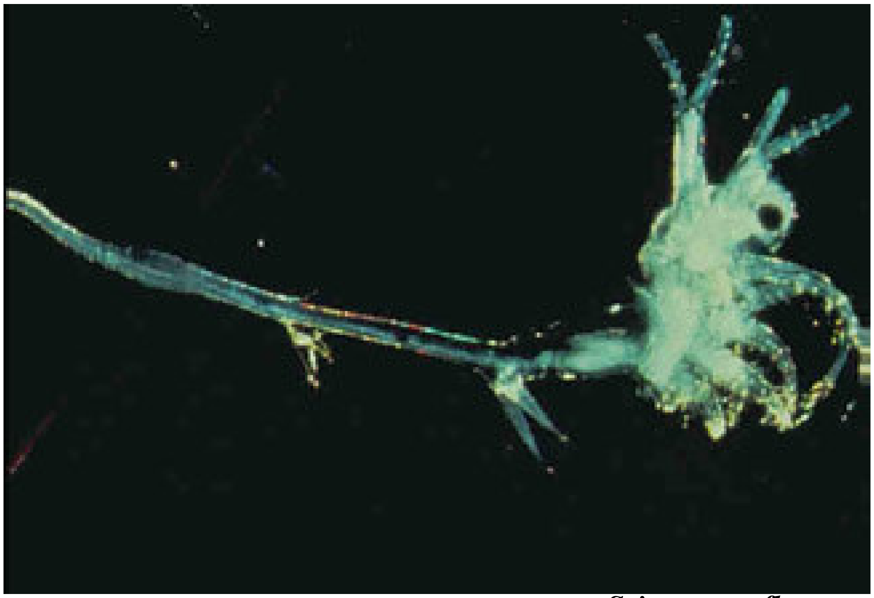


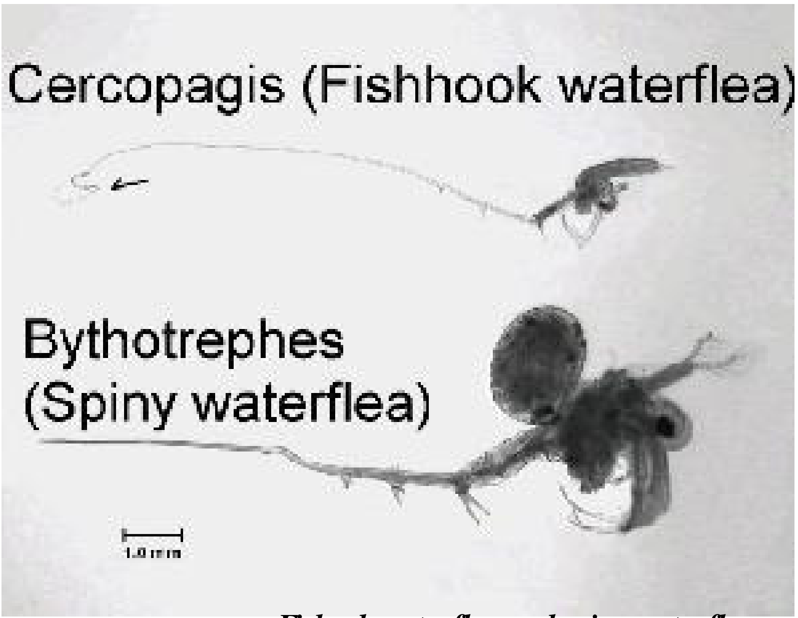
Figure 6: *Driven out: The introduction of the fishhook water flea in Lake Ontario in 1998 led to the dramatic reduction in three dominant zooplankton. (Reproduced with permission from Laxson, 2003.)*

freshwaters are cladocerans, also known as water fleas. Two recent zooplankton invaders of the Great Lakes come from this family – the spiny water flea and fishhook water flea. Both of these water fleas possess long sharply barbed tail spines that comprise upwards of 80% of the organisms' lengths. Many fish that otherwise eat zooplankton avoid both of these spiny creatures as prey and most of the smaller fish cannot effectively swallow them because of the long hooked tail spine. In addition, these larger zooplankton eat smaller zooplankton, competing directly with some fish for this important food source.



Spiny water flea

SPINY WATER FLEA: The spiny water flea native to northern Europe and Asia, was first found in the Great Lakes in Lake Ontario in 1982.[48] Over the next five years, this water flea was found throughout the Great Lakes and in some inland lakes in nearby states. Establishment of the spiny water flea in Lake Michigan was followed in 1987 by significant declines in abundance of three species of an important group of zooplankton, the Daphnia.[49] In a more recent study of smaller Canadian lakes, it was found that lakes invaded by the spiny water flea had significantly lower total amounts of the cladoceran zooplankton group, and on average 23 percent fewer of these species than the uninvaded lakes.[50]



Fishook waterflea and spiny waterflea

FISHHOOK WATER FLEA: The fishhook water flea is native to the Ponto-Caspian region (southeast Europe). It was first found in Lake Ontario in 1998 and quickly spread through lakes Ontario, Michigan, and Erie by 2001. The pattern this expansion took is consistent with the inter-lake transfer of ballast water; in addition, pleasure-craft are likely responsible for transfer from the Great Lakes to inland lakes.[51] Research on Lake Ontario indicated that the abundances of three dominant zooplankton declined dramatically after the introduction of fishhook water fleas in the lake (see Figure 6).[52]

GIANT CLADOCERAN: A third exotic zooplankton species, the giant cladoceran, is native to Africa, Asia, and Australia and most likely entered North America with African fish imported for the aquarium trade or to stock reservoirs.[53] Since 1995, it has been found in the Illinois River and a connecting channel to Lake Michigan through Chicago and now appears close to invading Lake Michigan; it was found in Lake Erie in 1999.[54] The giant cladoceran is much larger and has more numerous spines than similar native species making it difficult for young fish to eat; this could result in a reduction of food available in lakes, streams, and fish hatcheries where this zooplankter invades.