The Cal-Sag and Chicago Sanitary and Ship Canal:
A Perspective on the Spread and Control of Selected Aquatic Nuisance Fish Species*

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Background

The city of Chicago was established in its present location because of the site's advantages in gaining navigational access between the country's two major waterways (i.e. the Great Lakes and the Mississippi River). This feature was first recognized in 1673 by the French explorer Joliet who proposed a canal joining the two systems (Cain 1978). Geologically, these two great water bodies were only separated by a small elevation of land left behind after the last glacier receded some 6,000 years ago. In fact, much of Chicago is built on the remnants of former wetlands that were once part of an intricate system of shallow marshes, lakes, and connecting streams that, depending on water elevation and flooding, could flow either into Lake Michigan via the Chicago and Calumet rivers or into the Mississippi River System via the Des Plaines, Kankakee and Illinois rivers.

According to Stoeckel et al. (1996), the two drainage basins were undoubtedly connected through this lake and stream network intermittently over some 14,000 years between periods of glaciation. So exchange of species between the two ecosystems is not a new phenomenon, and what we now call the native fish fauna of the Great Lakes Basin originated in large part from the northward dispersal of species from the Mississippi River Basin as the glaciers receded for the last time some 6000 years ago (Stoeckel et al. 1996). From then until the early 1900's, the aquatic communities of Lake Michigan and the Mississippi River Basin developed in relative isolation from each other, except for seasonal flooding which may have occasionally created small, temporary links between the two systems (Stoeckel et al. 1996).

When engineers reversed the flow of the Chicago River in the late 1800's by creating the 28 mi. long Chicago Sanitary and Ship Canal (Figure 1), the two ecosystems were again connected by a continuous flow of water from Lake Michigan into the canal, and then on into the Des Plaines and Illinois rivers.

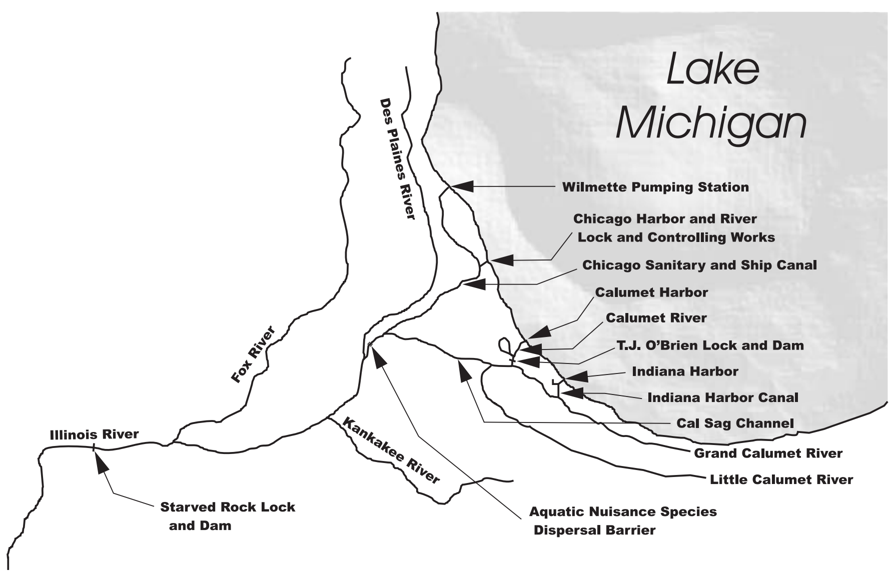

Figure 1. Map of the Cal-Sag and Chicago Sanitary and Ship Canal and its connections to Lake Michigan and the Illinois River.

Impetus for constructing the canal was brought about in the mid 1800's by a series of major typhoid outbreaks caused by sewage buildup along Chicago's Lake Michigan waterfront from where the city also drew its drinking

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water (Changnon and Changnon 1996). The canal, in excess of 23 ft. deep and ranging from 115 to 245 ft. wide, was designed to divert water from Lake Michigan in large enough quantities to essentially "flush" Chicago's sewage and industrial wastes away from the city and the lake, downstream into the Illinois River.

This single engineering action greatly facilitated the potential for exchange of species between the two ecosystems. It also caused the Illinois River to become the recipient of massive quantities of domestic and industrial wastes, creating significant environmental problems for what was once an extremely productive aquatic ecosystem. Over time, as volumes of wastes generated by the growing metropolis increased, so did the amount of diversion water needed to flush them downstream. These increasing diversions not only supported waste stabilization for Chicago, but also a growing commercial navigation industry on the Illinois River. To accommodate navigation demands, the Calumet River was joined to the Chicago Sanitary and Ship Canal via the Cal-Sag Channel; and the Chicago River Locks and Controlling Works, the T.J. O'Brien Lock and Dam, and the Indiana Harbor Canal were constructed (Figure 1). Thus the Chicago Sanitary and Ship Canal became known as the Cal-Sag and Chicago Sanitary and Ship Canal.

Ever increasing diversions of lake water needed to meet domestic and industrial demands eventually culminated in interstate and international controversies over water rights and usage, some of which ended up in and were settled by the courts (Changnon and Changnon 1996). Others continue to this day -- one of which is the significant and far reaching effect that the canal system is beginning to play on the stability of both the Great Lakes and the Mississippi River Basin ecosystems (Figure 2).

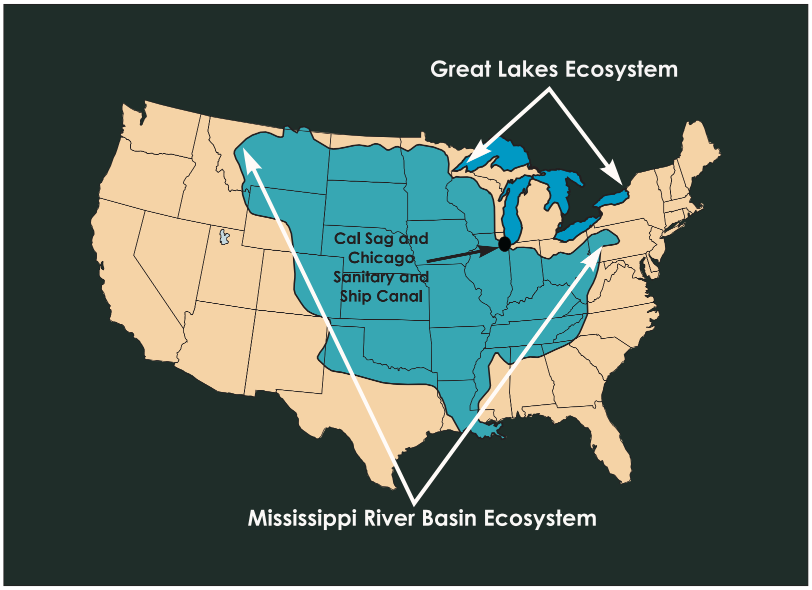


Figure 2. Map of the Great Lakes and Mississippi River Basin ecosystems, showing the location of the connection made between the two by the Cal Sag and Chicago Sanitary and Ship Canal.

Initially, Chicago's wastes were so anoxic or toxic that "clean water" organisms could not survive in the toxic zone they created in the canals and their connecting channels. This toxic zone effectively served as a barrier, preventing the exchange of organisms between the two ecosystems. Anything which entered the toxic zone from either direction could not survive long enough to reach the other side. However, implementation of the Clean Water Act over the past 25 years has reduced the toxicity of Chicago's effluents and the waters flowing through the canals now support many forms of aquatic life. As a result the man-made gateway between these two great ecosystems now serves as a viable pathway for invasive species infestation, and we are beginning to see the biological results in the growing exchange of organisms between the two systems.

Biologists would not be too concerned about this connection if the opportunity for organism exchange was limited to native species as it was in eons past. As noted earlier, colonization of the Great Lakes (beginning some 14,000 years ago) involved species moving from an established ecosystem (Mississippi River System) into a newly created aquatic system (Lake Michigan) which at that time lacked an established aquatic community (Stoeckel et al. 1996). Subsequent eras of organism exchange involved species that had at least evolved on the same continent. But unlike during those times, the current organism exchange features species not native to North America. These alien invaders came to the U.S. as a result of international shipping (i.e. transfer and dumping of organism-infested ballast water between continents); and trade in the aquaculture, aquarium and baitfish industries.

The Invasive Species Process

An invasive species introduction occurs when a species survives transport by a vector (i.e. ship's ballast water, shipment for the aquarium or aquaculture trade, bait bucket, etc.), is released into the new environment, and initially perseveres (Carlton 2001). The invasion is successful when the species reproduces, becomes established, and spreads within its new environment. Factors affecting the survival, spread, and proliferation of an introduced species include its ability to survive the voyage from its native habitat; the basic climatic factors and food resources in the invaded environment; the nature of the reproductive biology of the species; and the presence or absence of competitors, predators, and parasites (Carlton 1996a).

Inoculation of an ecosystem by a new species does not guarantee success of an invasion. Even if the species survives the vector it may die in the new environment or it may not reproduce. Even if it does reproduce, a host of existing conditions may inhibit the species from becoming established and spreading (Carlton 2001). Therefore, to be successful many such inoculations may be required to gain a foothold. Even after success is achieved the species may go unnoticed for a period of time. It usually takes a few years for an organism to reach the critical mass of individuals needed to gain a strong foothold in an invaded habitat. But once these numbers are reached, tremendous population explosions can occur. These are followed by dispersal to any other connected basin, often before control and eradication measures can be developed and implemented (Stoeckel et al. 1996).

Introduced species can fundamentally alter an ecosystem (Carlton et al. 1995, Carlton 1996b, 2000, Carlton 2001). The structure and biodiversity of the ecosystem itself can be affected through the introduction of new predators, competitors, disturbers, parasites, and diseases (Carlton 2001). These introductions lead to vast alterations in species interactions and changes in nutrient cycling and energy flow, which results in cascading and unpredictable effects throughout the entire community (Carlton 2001). After habitat destruction, introduced species are considered the greatest cause of the loss of biological diversity (Vitousek et al. 1997). Introduced species themselves may even facilitate other introductions in a process known as "invasional meltdown" -- a process by which a group of nonindigenous species facilitate one another's invasion in various ways, increasing the likelihood of survival, ecological impact, and possibly the magnitude of the impact (Simberloff and Von Holle 1999).

Additionally, the invasion picture is dynamic and ever changing (Carlton 2001):

- New vectors, such as oil- and gas- drilling platforms, may appear, bringing along a suite of novel species.
- Older vectors may increase in size and frequency.
- The number of donor regions -- the areas from which vectors gain species -- may increase as trade rules change.
- A new species may invade the donor area as well. Each introduction forms a new hub, radiating more spokes of dispersal. New populations may occur at the ends of these spokes and become hubs themselves.
- Recipient regions may also change, providing a suitable habitat for invasion that did not exist before:
    - A power plant can offer warm-water effluent in a cold climate, providing an invasion site for a southern species.
    - Water diverted for agriculture or other purposes may cause salinities to increase.
    - Marinas can create new habitats for introduced species (Connell 2000).
    - Water chemistry may change: the majority of U.S. estuaries now exhibit nutrient enrichment due to agricultural stormwater runoff (Boesch et al. 2001).

Such changes may cause previously abundant native species to decline, reducing the potential for competition with the new invaders (Carlton 2001).

Strategies for post invasion control include mechanical, chemical, physiological, genetic, ecological by habitat modification, and ecological by species introduction or enhancement (Carlton 2001). Some of these strategies will be discussed further, as they apply to the Cal Sag and Chicago Sanitary and Ship Canal, at the conclusion of this report. However, prevention of the invasion in the first place is always the best and most effective action.

The Great Lakes/Mississippi River Basin Invasion

The zebra mussel (*Dreissena polymorpha*) represents an especially devastating invader of both the Great Lakes and Mississippi River Basin ecosystems, in terms of its impact on man. This organism, first introduced into the Great Lakes by ballast water released from ships originating in Eastern Europe, quickly colonized the entire Great Lakes ecosystem. Then drifting larval forms of the organism were carried downstream from Lake Michigan by diversion waters of the Cal-Sag and Chicago Sanitary and Ship Canal into the Des Plaines and Illinois rivers where they settled out, matured, and using their byssal threads (Figure 3), attached themselves to any solid object, including intake pipes, boat docks, and most importantly, barges (Figure 4). From there, barges transported the zebra mussel infestation to the far corners of the Intercontinental Waterway System (Figure 5).

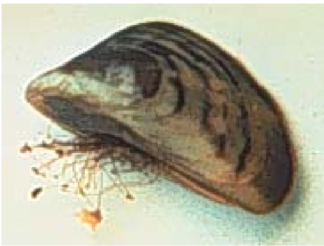


Figure 3. Enlarged view of an adult zebra mussel showing byssal threads used for attachment to solid objects.

Figure 4. View of an Upper Mississippi River barge fleet and closeup of a barge hull literally covered with zebra mussels.

The zebra mussels simply rode along, wherever the barges traveled, constantly inoculating the traversed waters with their eggs and larval forms (nauplia). Anywhere that these offspring found adequate habitats (i.e. hard objects for attachment) became infested. Zebra mussels have devastated Upper Mississippi River freshwater mussel populations (Figure 6). In some locations native mussels (including some threatened and endangered species) are buried a foot or more deep by living zebra mussels as well as by the remains and wastes of zebra mussel colonies. Now a permanent component of both the Mississippi and Great Lakes ecosystems, zebra mussels are literally suffocating many native mussel species and thus threatening their future existence.

Figure 5. Intercontinental Waterway System

Neither the ships that brought the zebra mussel here from Eastern Europe, nor the barges that transported them throughout the Mississippi River Basin did so intentionally, but each played a role in their spread as did the Cal-Sag and Chicago Sanitary and Ship Canal. If any one of the links in that chain (i.e. ships-canal-barges) had been broken, the spread of the zebra mussel from the Great Lakes to the Mississippi River Basin could have been slowed or even prevented.

But the Great Lakes/Mississippi River Basin invasive species problem does not stop with the zebra mussel. A whole host of aquatic organisms (invertebrates and fish) have already found their way into the Great Lakes via ballast water transfers, and more are expected. An arriving vessel may be a virtual "floating

Figure 6. Freshwater mussel covered and being smothered by zebra mussels.

biological island", with hundreds of species living both on and in the ship (Carlton 1985, 1993, 1996b, 2001, Carlton and Geller 1993, Carlton and Hodder 1995, and Wonham et al. 2000).

Since the 1800s, more than 140 exotic aquatic organisms of all types have become established in the Great Lakes (Dermott 1997, Mills et al. 1993, Zaranko 1996). Among those recently identified are the ruffe (*Gymnocephalus cernuus*), round goby (*Neogobius melanostomus*), tubenose goby (*Proterorhinus marmoratus*), spiny waterflea (*Bythotrephes cederstroemi*), fishhook waterflea (*Ceropagis pengoi*), and quagga mussel (*Dreissena bugensis*); all of which are now capable of finding their way into the Mississippi River System by way of the Cal-Sag and Chicago Sanitary and Ship Canal. Fortunately, most of these species will not find it as easy as the zebra mussel did by hitching a ride on barges, but they will still find their way in time. In fact, the quagga mussel has already been collected from the Mississippi River Basin, and the round goby has found its way into the canal system (Steingraeber et al. 1996) moving at least 50 miles inland from Lake Michigan, and is now about 15% of the way down the length of the Illinois Waterway on its way to the Mississippi River.

Unfortunately for the Great Lakes, this exchange of organisms can go in both directions. Just as in glacial times, there is a host of invading organisms headed upstream from the Mississippi River System toward Lake Michigan, only this time the invaders are not all native to North America. Instead, they include at least three species of Asian carps, all native to the far east (i.e. northern climates of China and eastern Siberia). These Asian invaders were first introduced into the U.S. in the 1960's and 70's by commercial fish farmers in several southern states (primarily Arkansas) to control aquatic vegetation and plankton blooms in fish rearing ponds. They were then either released to the wild when no longer needed, or escaped captivity during high water incidents or accidents. In any case, they have reproduced in the wild in large numbers and are now finding their way upstream in the Illinois River toward the Cal-Sag and Chicago Sanitary and Ship Canal, Lake Michigan and points north into Canada.

These fish are highly mobile, very prolific, grow to large sizes (50-110 lbs.), and consume large quantities of aquatic vegetation and plankton. At least one, the grass carp *(Ctenopharyngodon idella)* has been reported from the Calumet River (Steingraeber In Press), and is already present in limited numbers in Lake Michigan (USGS a Online). Another, the bighead carp *(Hypophthalmichthys nobilis)* was recently reported from Lake Erie (Figure 7), and a second from a fountain in Toronto, Ontario, not far from Lake Ontario (Crossman and Cudmore 1999). There is reason to believe that these two bighead carps were escapees and/or intentional releases from shipments of live fish coming into Canada from Southern U.S. states to meet the demand of consumers (largely of Oriental origin) in the Toronto area (Crossman and Cudmore 1999). Fortunately the source of infestation has been limited and populations have not yet reached the critical mass or threshold numbers necessary to gain a strong foothold. That is not the case, however, downstream in the Illinois River. Within less than 100 miles of Lake Michigan (Illinois River - LaGrange Pool), the bighead and a third species, the silver carp *(Hypophthalmichthys molitrix),* are staging in large numbers and in a matter of time they will move farther upstream into the Cal-Sag and Chicago Sanitary and Ship Canal, and from there, into Lake Michigan.

Figure 7. Bighead carp (40-50 lb range) taken in a net in Lake Erie in 2000 (University of Guelph 2000).

For example, between 1988 and 1992 the combined commercial harvest of bighead and silver carp by Illinois commercial fishers in the Mississippi and Illinois rivers was less than 1300 lb. (Chick and Pegg 2001). But by 1994 that total had increased to more than 5.5 tons, and then, since 1997, it has exceeded 55 tons per year (Chick and Pegg 2001). Similarly, scientific collections of bighead carp in Pool 26 of the Mississippi River have increased exponentially (Figure 8), remaining low in the adjacent LaGrange Pool of the Illinois River until 1999 (Koel et al. 2000). By

2000, however, LaGrange Pool numbers had increased 600 fold, indicating that bighead carp now reproduce in the Illinois River within 150 mi downstream of the Cal-Sag and Chicago Sanitary and Ship Canal (Koel et al. 2000). Then this spring, the author observed several large (29-36 in) bighead carp carcasses floating in the Peoria Pool of the Illinois River just 8 mi downstream from the Starved Rock Lock and Dam (See Figure 1), indicating movement even closer (within 80 mi downstream) to the Cal Sag and Chicago Sanitary and Ship Canal than previously known. If and when these species reach Lake Michigan in large numbers, they could have devastating impacts on the already stressed Great Lakes ecosystem as well as its tributary waters. The "take home" message here is that the Cal-Sag and Chicago Sanitary and Ship Canal holds the primary key to stopping large numbers of these and other invaders from moving between and infesting the Great Lakes and Mississippi River Basin ecosystems.

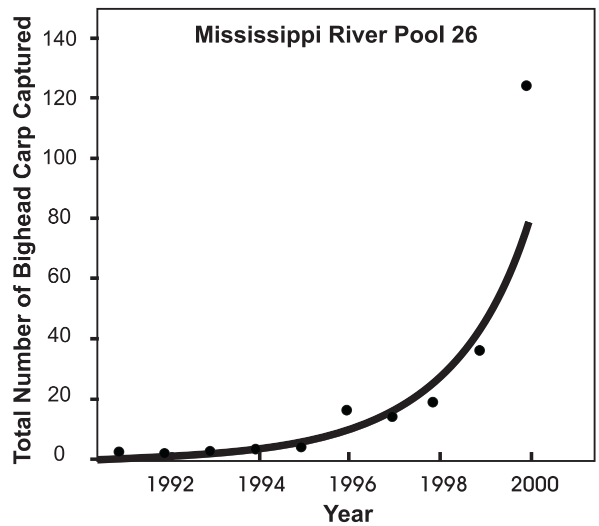


Figure 8. Scientifc collections of bighead carp made for the Upper Mississippi River Long Term Resource Monitoring Program between 1992 and 2000 (Chick and Pegg 2001)

The remainder of this paper provides additional details on six invasive fish species (ruffe, round goby, tubenose goby, grass carp, bighead carp, and silver carp), discusses in more detail some of the biological implications and impacts of the cross-infestation of these two great ecosystems, and lists some mechanisms that have been suggested to stop their further introduction and spread. A fourth Asian carp species, the black carp (*Mylopharyngodon piceus*), is also discussed because it is currently being stocked in fish culture ponds in the South and may soon follow the path of its three Asian cousins. A limited number of black carp reportedly escaped a culture facility in Missouri near Lake of the Ozarks during high waters of the 1994 flood, but the species has not yet been found in the wild.

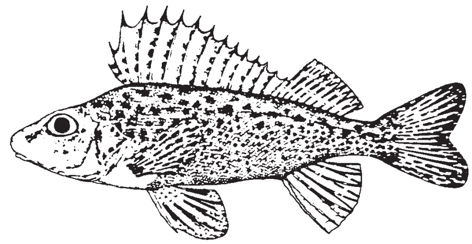
Invasive Fish Species of Concern to Dispersion via the Cal-Sag and Chicago Sanitary and Ship Canal

The seven fish species discussed below do not represent or constitute a complete list of potential piscatorial invaders capable of passing between Lake Michigan and the Mississippi River Basin via the Cal-Sag and Chicago Sanitary and Ship Canal. Other such nonnative fish species may exist, and the reader should keep in mind that simply because fish species are discussed here, numerous other aquatic organisms, including many invertebrates (especially in the Great Lakes) are present in the wild and pose significant threats to both ecosystems.

Ruffe (*Gymnocephalus cernuus)*

The ruffe is a native of Europe (France to eastern Siberia), occurring between 44 and 66 ^{o}N latitude (Froese and Pauly 2001). The species was first collected in the U.S. in 1986 from the St. Louis River at the border of Minnesota and Wisconsin (Pratt et al. 1992). It subsequently spread (Figure 9) into the Duluth Harbor; several U.S. tributaries of Lake Superior (Underhill 1989, USGS b online); Ontario's Kaministiquia River estuary (1991); Thunder Bay River (1995) (USGS b Online); Saxon Harbor, Wisconsin (1994); the upper peninsula of Michigan (1994) at the mouths of the Black and Ontonagon rivers (USGS b online); and into the lower peninsula of Michigan along Lake Huron (USGS b Online). Like the zebra mussel, the ruffe was probably introduced via ships' ballast water discharged from ocean-going vessels arriving from a Eurasian port, possibly as early as 1982-83 (Simon and Vondruska 1991, Ruffe Task Force 1992). Within the Great Lakes, spread of the species is expected to have been augmented by intra-lake shipping (Pratt et al. 1992). Today, the ruffe has become the dominant species in the St. Louis River estuary of Lake Superior and is considered the most abundant of the 60 species found in Duluth Harbor.

In its native range, the ruffe inhabits lakes, quiet pools and margins of streams, preferring deep water with deposits of sand and gravel (Vostradovsky 1973). The species is adapted for night feeding (Collette et al. 1977) on zooplankton, chironomids, oligochaetes, amphipods and fish; and can tolerate some environmental degradation (Froese and Pauly 2001). The ruffe, a spring and early summer spawner, matures at 1 year of age (about 3.2 in. long), with females scattering from 100,000 to 200,000 eggs over open water (Froese and Pauly 2001). Average life span is 4.5 years, with some individuals living up to 11 years of age. Maximum recorded size is 10 in. and 0.88 lb. (Froese and Pauly 2001, McClean 1993). A cool water species, the ruffe prefers temperatures ranging between 50 and 68 ^{o}F (Froese and Pauly 2001).



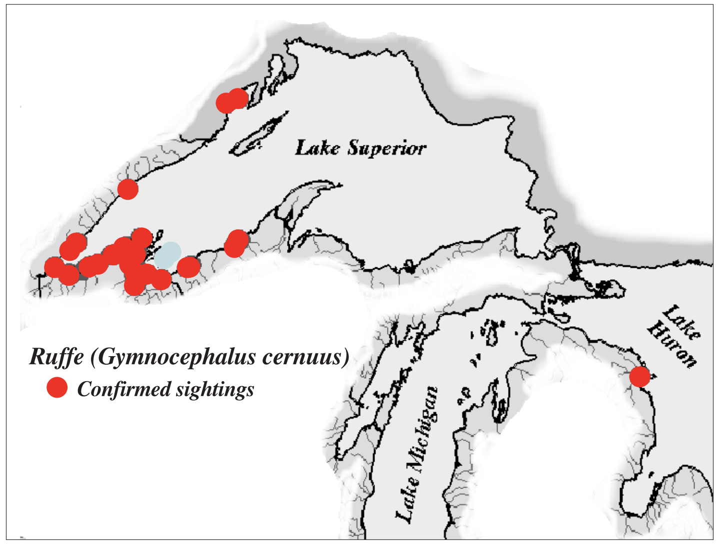


Figure 9. Known distribution of the ruffe in the U.S. (USGS b Online).

Ruffe introductions in Scotland led to native perch declines and in Russia to declines in whitefish numbers. Both declines were the result of egg predation by the ruffe (McLean 1993). Because of its rapid growth, high reproductive output, and ability to adapt to a wide range of habitat types, the ruffe may pose a threat to native North American fish (McLean 1993). Concern has been raised over the ruffe's impact on native and more desirable Lake Superior species such as yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*), by feeding on their young (Raloff 1992) or by competing for food (McLean 1993). Yellow perch, emerald shiner (*Notropis atherinoides*), and troutperch (*Percopsis omiscomaycus*) numbers have all declined since ruffe introduction, but the association remains unclear (McLean 1993). Ogle et al. (1996) found that certain native species preyed on introduced ruffe, but that predation is unlikely to effectively prevent them from colonizing new areas in the Great Lakes.

Methods employed to control the spread of ruffe in Lake Superior have included selective poisoning and physical capture with nets and trawls, a mail survey, and public education (Keppner et al. 1997 and Busiahn 2001). Efforts are ongoing to control its spread through transshipment in ships' ballast water between lakes and ports, and the public education program is intended, in part, to stem the transfer via bait buckets and the aquarium trade. But once an organism is present in an ecosystem there are many places to hide and many ways to escape capture, so it is almost impossible to remove all individuals. Management efforts will thus likely have to continue into the foreseeable future in much the same way as efforts continue to control the Great Lakes' sea lamprey. Busiahn (1993) indicated the potential North American range of the ruffe may well extend from the Great Plains to the eastern seaboard and north into Canada. So if allowed to escape the Great Lakes, the ruffe could produce significant impacts on many species of important gamefish in other North American ecosystems, including portions of the Mississippi River System.

Round goby (*Neogobius melanostomus*)

The round goby is a native of Eurasia (Sea of Azov, Black Sea and Caspian Sea basins) between 39 and 49 ^{o}N latitudes (Froese and Pauly 2001). It was first collected in the U.S. and Canada in the St. Clair River on the Michigan-Ontario border in 1990 (Jude et al. 1992). The species had spread to the north end of Lake St. Clair (Anchor Bay) by 1994 (USGS c Online). Inland catches were taken in 1996, 1997, and 1999 in the Shiawasse River, Flint River and River Raisin, respectively (USGS c Online). By 1998 the round goby was reported from numerous locations along the eastern shore of Michigan in Lake Huron such as Lexington, Tawas City, and Thunder Bay River (USGS c Online). Four years earlier (1994), the species had began appearing in southern Lake Michigan near the

Calumet-Chicago area of Illinois. The species was first collected in Indiana from the Grand Calumet River in 1993; by 1994 it had appeared in Hammond Harbor, and by 1996, it was found in the Port of Indiana and east Chicago and Wolf Lake (USGS c Online). In Ohio, annual surveys have collected the species from Lake Erie at Conneaut, Ashtabula, Cleveland, and Sandusky (USGS c Online). The round goby first appeared in Pennsylvania in 1996 off Walnut Creek in Lake Erie (USGS c Online). In 1995, the species was collected from Wisconsin waters in St. Louis Bay of Lake Superior, and by 1996, it was found in Duluth Harbor, Minnesota (USGS c Online). The round goby has been reported from Lake Ontario as well as in the Welland Canal (USGS c Online). The species was already considered extremely abundant in the St. Clair River in 1994, and short trawls in Lake Erie were collecting 200 individuals in October of that year (USGS c Online). Frequent trawling in 1995 in Fairport Harbor, Ohio, collected over 3,000 individuals, and densities in Calumet Harbor in 1995 were 20 per m^2 (Marsden and Jude 1995). By 1998 the round goby had found its way at least 15 miles inland from Lake Michigan in the Cal-Sag and Chicago Sanitary and Ship Canal (Manz 1998), and by 2001 had moved at least another 35 miles inland, or 15% of the way down the length of the Illinois Waterway toward the Mississippi River (Thiel 2001). Like the ruffe and the zebra mussel, means of introduction to the Great Lakes is thought to be from ballast water carried by transoceanic ships from freshwaters in Eurasia to the U.S. where it is released into the open waters of the Lakes (Robins et al. 1991). The rapid spread and population explosion within the Lakes (Figure 10) likely occurred via transhipment within the Lakes. Some scientists speculate that rapid spread of the species may have been facilitated by the attachment of its adhesive eggs to ship's hulls (Bauer et al. 2001), while others believe the species' use as a bait fish represents the main dispersal mechanism (Sparks 2001).

Round goby (Neogobius melanostomus)
● *Known distribution*

Figure 10. Known distribution of the round goby in the U.S. includes all of the Great Lakes (USGS c Online).

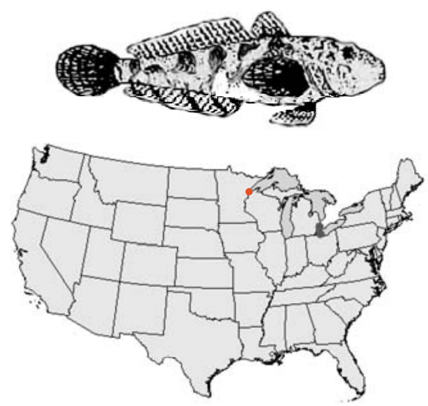
In Eurasia, round gobies prefer shallow, brackish waters, but also occur in fresh waters, and can tolerate water temperatures of 32-86 ^{o}F, but mainly thrive in warmer waters (Skora et al. 1999). The round goby can also tolerate conditions of low dissolved oxygen for several days (Skora et al. 1999). Maximum recorded size is 9.8 in., maturity is reached at age 2, and life span may reach 12 years (Froese and Pauly 2001). In Eastern Europe, round gobies spawn every 20 days during their extended summer spawning period (April to September) (Froese and Pauly 2001). Males aggressively defend their nests (Jude et al. 1992) and reportedly die after the spawning season (Skora et al. 1999). Although initially expected to remain near shore, the species has been captured in the Great Lakes at depths as great as 70.5 ft. (USGS c Online).

According to Crossman et al. (1992), wherever the round goby has become abundant in the Great Lakes, numbers of native fish species have declined. Sculpins are particularly effected (Marsden and Jude 1995). The round goby has preyed on darters, other small fish, and lake trout eggs and fry in laboratory experiments. They also may feed on the eggs and fry of sculpin, darters and logperch (Marsden and Jude 1995). Walleye anglers note that round gobies readily attack their bait, indicating competition for food with gamefish (Marsden and Jude 1995). Diet studies conducted in U.S. waters indicate that the species also feeds on aquatic insects, zebra mussels and some native snails. A single goby can eat as many as 78 zebra mussels per day (USGS c Online). A well-developed lateral line (sensing system) may help the round goby out compete native fish species for food in murky waters. Also their aggressive nature may allow individuals to dominate prime spawning sites, making such sites unavailable to native species (USGS c Online, Marsden and Jude 1995).

As seen in Figure 10, the round goby has established itself over the entire Great Lakes ecosystem, with present densities in the Calumet Harbor (See Figure 1) in the neighborhood of 50-70 gobies per m^2 (i.e. an area about the size of a bathtub). As noted above, the species has also started its invasion of the Mississippi River Basin by entering the Cal-Sag and Chicago Sanitary and Ship Canal. Interagency efforts are underway to monitor this invasion and hopefully to find ways to deter the species from entering the Mississippi River Basin ecosystem. Monitoring efforts have included annual (since 1997) trapping and netting efforts in the Cal-Sag and Chicago Sanitary and Ship Canal, Des Plaines and Upper Illinois rivers; and the installation of an electric aquatic nuisance species dispersal barrier in the canal by the U.S. Army, Corps of Engineers. That barrier, a 160 ft. wide by 60 ft. long concrete and cable structure, is to be operational by November 2001. It is intended to deter fish movements in the canal by stunning them through electroshock. The electric charge (2-3 volts per second per in^3) will not be lethal or even injurious to humans, mammals or fish. Some local conservation leaders in the Chicago area expressed to the author that they question the efficacy of the proposed technology, but experts with the manufacturer (Smith-Root Inc. of Vancouver, WA) have estimated barrier efficiency in the mid 80% range (Moy 1997), and have stated a need for two or three more such barriers downstream to gain 100% efficiency. Cost of the structure is approximately $1.3 million, and budget shortfalls delayed completion for at least one year. Because of this delay, it may already be too late to stop the goby. Biologists have collected several individuals below the construction site (See Figure 1 - River Mile 296.25). If the barrier proves ineffective, or if gobies have already passed the site, conservation officials hope that the species will not be capable of spreading in the river systems of the Mississippi River Basin as quickly as it did in the Great Lakes. However, further introduction and spread through baitfish use or release from aquaria in the Mississippi River Basin remains a major concern.

<u>Tubenose Goby *(Proterorhinus marmoratus)*</u>

The tubenose goby is native to the slightly brackish and freshwaters of Eurasia between 39-49 °N latitude, including rivers and estuaries of the Black Sea, Caspian Sea, Sea of Azov, Aegean Sea and Aral Sea (Miller 1986 ; Froese and Pauly 2001). The species first appeared in U.S. waters in 1990 in collections taken in the St. Clair River, Michigan, near the Detroit Edison Company's Belle River Power Plant (Jude et al. 1992, USGS d Online). By 1994 the tubenose goby occurred at the north end of Lake St. Clair at Anchor Bay, and in 1997, a single specimen was taken in Lake Erie at Port Glasgow, Canada (USGS d Online). Since then, specimens have been taken in the area of Kingsville Marsh and the species may be established on the northwestern shore of Lake Erie (Figure 11), and may be present but undetected in Ohio waters (USGS d Online). Then in 2001, the species was collected by Wisconsin biologists from the lower St. Louis River during a standard survey of the Duluth/Superior Harbor on the Western end of Lake Superior (Pratt 2001). The specimen measured about 1.75 in. long and was less than one year old. It is not known whether this fish is the result of natural reproduction within the harbor or was an individual transported this summer as a very young fish from the lower Great Lakes. Like the round goby, the tubenose goby was introduced via ballast water, but has not spread as rapidly. While it is worthy to note that the tubenose goby is endangered in its native range (USGS d Online), possibly signaling some trait or habitat requirement which may also limit its spread in the U.S., its recent discovery (Pratt 2001) in the Duluth Harbor raises a "red flag", signaling the potential ability of the species to spread throughout the Great Lakes.



Tubenose goby (Proterorhinus marmoratus)
Known distribution ●

Figure 11. Known distribution of the tubenose goby in the U.S. (USGS d Online).

According to T. Cavender (Ohio State University, Museum of Biological Diversity) tubenose goby eggs attached to vegetation were brought up during a 1994 trawl, taken into the laboratory and hatched (USGS d Online). Like the round goby, this species builds and guards its nests (Lelek 1987). It can achieve a maximum size of 4.4 in. and reaches maturity at 2.4 in. (Froese and Pauly 2001). The tubenose goby's life span is unknown, but it is known to feed on benthic crustaceans and insects (Miller 1986), and like the ruffe, is a cool water species preferring temperatures ranging from 50-65 °F (Froese and Pauly 2001).

<u>Grass carp *(Ctenopharyngodon idella)*</u>

The grass carp is native to Eastern Asia from the Amur River of Eastern Russia and China south to the West River of Southern China from 25 to 65 °N latitudes (Lee et al. 1980 et seq., Shireman and Smith 1983, Froese and Pauly 2001). The species was first imported into the U.S. in 1963 to aquaculture facilities in Auburn, Alabama, and Stuttgart, Arkansas, (Robison and Buchanan 1988) for research in the control of aquatic vegetation. The Auburn stock came from Taiwan, and the Arkansas stock was imported from Malaysia (Courtenay et al. 1984). The first release into open waters occurred as a result of escapement from the U.S. Department of Agriculture Fish Farming Experiment Station in Stuttgart (Courtenay et al. 1984). By the mid-1960's the Arkansas Game and Fish Commission had cultured the species at a state fish hatchery in Roanoke; and by 1978 Arkansas biologists had stocked it in more than 100 state lakes (Robison and Buchanan 1988). Pflieger (1975, 1997) cited many reports of grass carp captures in the Missouri and Mississippi rivers in the early 1970's. Since that time, the species has spread rapidly to 45 states (Figure 12) through the accidental and intentional, legal and illegal release by numerous state and federal agencies, private groups and individuals (Pflieger 1975, Lee et al. 1980 et seq., Dill and Cordone 1997). Grass carp began to appear in the catches of Arkansas' commercial fishermen in the early 1970's, and by 1976, 25 tons were reported taken statewide (Robison and Buchanan 1988). Reported commercial harvest in the Missouri reaches of the Mississippi and Missouri rivers in 1996 totaled 22 tons (USGS a Online). The grass carp has been reported in both Lake Michigan and in the Calumet River (USGS a Online)

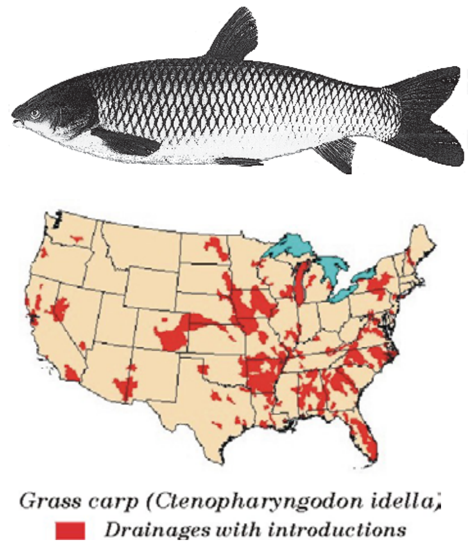


Figure 12. Known distribution of the grass carp in the U.S. (USGS a Online).

Grass carp occur in lakes, ponds, pools and backwaters of large rivers (Page and Burr 1991), preferring large, slow flowing or standing water bodies with vegetation, including rice fields. This large (up to 100 lbs.), elongate, stout-bodied, blunt-headed, pale gray member of the minnow family is known to reproduce in the Mississippi (lower and upper), lower Missouri, Illinois, Ohio and Trinity (Texas) rivers (USGS a Online). Grass carp prefer temperatures between 50 and 79 ^{o}F, but tolerate a wide range of temperatures (32-100 ^{o}F), salinities to 10 ppt and dissolved oxygen levels down to 0.5 ppm (Froese and Pauly 2001). Grass carp spawn during one major annual event, with each female scattering 50,000 to 200,000 eggs over gravel beds in rivers (Froese and Pauly 2001) with currents as low as 0.9 ft./sec. (Leslie et al. 1982). Spawning has been reported from April to September in Asia. Maximum recorded size is 59 in. (99 lbs.), maturity is reached at 22.8 in., and life span can reach 26 years (Froese and Pauly 2001). Growth is rapid with grass carp in ponds recorded to reach sizes of 3.1 in. (.009 lb.), 4.7 in. (0.046 lb.), 11.0 in. (.829 lb.) and 19.7 in. (11.9 lb.) at ages of 3, 6, 9, 12 and 18 months, respectively (Laird and Page 1996).

While introduced to consume troublesome aquatic plants, grass carp are known to clean entire lakes of aquatic plants, and to consume organic detritus, insects and other invertebrates (Froese and Pauly 2001). Grass carp have been reported to consume 40% of their body weight each day, and foods have included small fishes, earthworms, silkworm pupae, other insects, and other non-plant foods (Laird and Page 1996). Pflieger (1978) reported that grass carp have been taken by hook-and-line fishermen in Missouri and with trotlines baited with small fishes. The species has limited potential as a gamefish, and as a food fish, the flesh is often said to be tainted with a strong algal flavor (Robison and Buchanan 1988). Negative impacts on native organisms include: interspecific competition for food with invertebrates (i.e. crayfish) and other fishes; significant changes in the composition of macrophyte, phytoplankton, and invertebrate communities; interference with the reproduction of other fishes; decreases in refugia for other fishes; modification of preferred fish habitats; enrichment and eutrophication of lakes; disruption of food webs and trophic structure; and introduction of nonnative parasites and diseases (USGS a Online). It is believed that grass carp imported from China were the source of introduction of the Asian tapeworm (*Bothriocephalus opsarichthydis*) (Hoffman and Schubert 1984, Ganzhorn et al. 1992). As such, the species may have indirectly infected the endangered woundfin (*Plagopterus argentissimus*) by way of the red shiner (*Cyprinella lutrensis*) (Moyle 1993).

Despite efforts to control the spread of grass carp through the stocking of sterile individuals (triploids), breeding populations, as noted above, are occurring in the wild. Use of triploids may have failed, in part, because evidence exists that triploid grass carp can produce some viable gametes (USGS a Online) even though the proportion of such gametes is extremely low. Furthermore, techniques used to induce triploidy are not always totally effective, and since triploid grass carp cannot be visibly distinguished from fertile diploids by any physical feature, every individual needs to be genetically checked for its ploidy using blood or tissue analyses (USGS a Online). That technology is usually not readily available or used in the field where shipping checks are conducted.

While grass carp are reported from Lake Michigan (USGS a Online), they have apparently not yet reached the threshold numbers needed to set off a population explosion, or a large portion of those in the wild may be triploids. But like their cousins, the bighead and silver carp, grass carp numbers are expanding in the nearby waters of the Illinois River (Koel et al 2000) and other Midwestern portions of the Mississippi River Basin. In fact, during the annual round goby "roundup" (June 12-15, 2001) in the Upper Illinois River and Waterway, the author observed several large (20+ in.) grass carp carcasses floating in the waters of the Peoria Pool just downstream from Starved Rock Lock and Dam (i.e. within 80 miles of the Cal Sag and Chicago Sanitary and Ship Canal - see Figure 1). Commercial fishers may have discarded these individuals from nearby catches because their bodies were not badly decayed and they appeared to have been in good health immediately before death .

Bighead carp *(Hypophthalmichthys nobilis)*

The bighead carp is native to the large rivers and lakes of eastern China, between 18 and 64 ^{o}N latitudes (Froese and Pauly 2001, Li and Fang 1990, Robins et al. 1991). The species was first brought into the U.S. in 1972 by a private fish farmer in Arkansas for use in improving water quality and increasing fish production in culture ponds (USGS e Online). By 1974, bighead carp were being evaluated by the Arkansas Game and Fish Commission and Auburn University for their potential biological benefits and impacts (Jennings 1988). After concerns were raised, regulations were mandated to restrict stocking of the species in Arkansas waters, and the control of accidental introductions was investigated (Freeze and Henderson 1982). Bighead carp first began to appear in open public waters (i.e. the Ohio and Mississippi rivers) in the early 1980's, likely the result of escapement from fish farms and aquaculture facilities (Jennings 1988). Spread to other states such as Oklahoma and California were reportedly the result of illegal introductions (Pigg et al. 1997, Dill and Cordone 1997). The species has now been recorded from within, or along the borders of, at least 19 states (Figure 13), including Lake Erie (See Figure 7). Fishers are also catching large individuals in the navigation reservoirs of the Tennessee Valley Authority as far upstream as Nickajack Reservoir, near Chattanooga and the Tennessee-Georgia border (Reeves 2001). Reproduction in the wild is evident from Louisiana (Douglas et al. 1996) north to at least Missouri and Illinois (Pflieger 1975, Tucker et al. 1996, Koel et al. 2000). In fact, in October 1999 a fish kill was reported on an Upper Mississippi River National Wildlife Refuge near St. Louis that consisted of 97% Asian carp (most of which were bighead and silver carp). Among fish killed, only four native species were found and these were represented by only one individual each (River Crossings 1999), the latter suggesting that native species are being displaced by the invading Asian carps. Adult bigheads are also reported to be "piling up" in large numbers below dams on many Midwestern rivers (Iowa to Indiana), and filling the nets of commercial fishers to the point that the nets are too heavy and difficult to lift, so the fishing sites have to be abandoned (River Crossings 1999). As noted earlier, the combined annual commercial harvest of bighead and silver carp in the Illinois reaches of the Mississippi and Illinois rivers increased from less than 1300 lbs per year between 1988 and 1992 to in excess of 55 tons per year since 1997 (Chick and Pegg 2001).

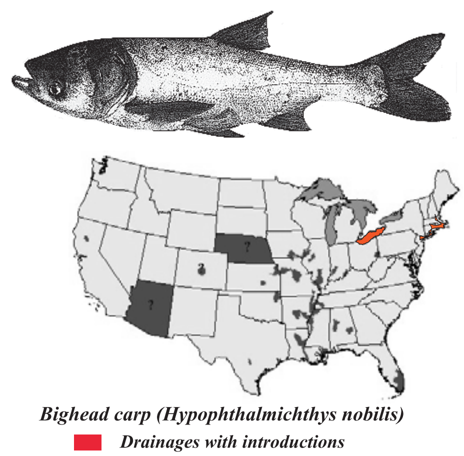


Figure 13. Known distribution of bighead carp in the U.S. (USGS e Online).

The bighead carp (also a member of the minnow family) is a very large, deep-bodied, somewhat laterally compressed (narrow) fish with a very large head. Scales are very tiny, resembling those of trout, and the eyes are situated below the midline of the body, giving the species a very alien appearance. The species occurs in open water areas ranging in temperatures between 39-79 ^{o}F, moving about in the euphotic (surface) zones of large lowland rivers. The bighead carp is benthopelagic, feeding primarily on zooplankton, but also consuming large quantities of bluegreen algae, aquatic insects (adults and larvae) and detritus (Robison and Buchanan 1988). Gill rakers are long, comblike and close-set allowing it to strain plankton organisms from the water for food. According to Henderson (1976) the species has no real stomach and likely must feed almost continuously. Bighead carp can grow to maximum lengths of 58-59 in. (88 lbs.) (Laird and Page 1996), reaching maturity at lengths of about 21.6 in. In China, under presumably natural conditions, the species reaches weights of 1.6-3.3 lbs. and 6.6-8.8 lbs. by their second and third years of life, respectively (Etnier and Starne 1993). Average total lengths (in.) reported from a Polish study were 4.9, 9.5, 15.4, 19.8, 22.8, 26.3 and 28.2 at ages 1-7, respectively (Etnier and Starne 1993). Spawning habits in U.S. rivers are not documented, but in Asia, bigheads typically spawn between April and June with a peak in late May (Verigin et al. 1978, Jennings 1988). During rising water levels, they often migrate upstream to spawn (Verigin et al. 1978), but spawning is also reported at the confluence of two rivers, behind sandbars, stonebeds, or islands. These areas are characterized by rapid current (2.6 ft./sec.) and mixing water (Huet 1970). Bigheads produce eggs that are semi-buoyant and require a current to float (Soin and Sukhanova 1972, Pflieger 1997). One day after fertilization, larval forms hatch and enter the ichthyoplankton drift (Etnier and Starne 1993). Seven days after hatching, bighead carp larvae migrate to shore (Jennings 1988), and floodplains associated with rising water levels provide nursery areas for larvae and juvenile forms (Huet 1970). Jennings (1988) and Pflieger (1997) found evidence of multiple spawning events in the Missouri River, suggesting an extended spawning period. Fertility increases with increasing age and body weight and is directly related to growth rate (Verigin et al. 1990). Vinogradov et al. (1966) found that first-time spawners average 288,000 eggs, while Sukhanova (1966) and Jennings (1988) documented egg production to range from 478,000-1,100,00, respectively.

Bighead carp are far more prolific and abundant than grass carp, and their movements seem to be prevented only by major barriers such as high dams. Laird and Page (1996) suggest that because bighead carp are planktivorous and attain large sizes, they have the potential to deplete the zooplankton populations which many native species such as paddlefish rely upon for food. In the Mississippi River Basin these include the paddlefish (*Polyodon spathula*), bigmouth buffalo (*Ictiobus cyprinellus*), and gizzard shad (*Dorosoma cepedianum*) (Burr et al. 1996, Pflieger 1997; Whitmore 1997, Tucker et al. 1996); as well as all larval and juvenile fishes and native mussels. Despite its use in many parts of the world (in combination with silver carp) to improve water quality in sewage lagoons and aquaculture ponds (Jennings 1988), Stickney (1996) points out that studies have not confirmed that bighead carp actually do improve water quality in culture ponds. The latter may be the reason why the fish culture industry seems to have largely abandoned the species, and why so many individuals have apparently escaped or been allowed to escape to the wild. Flesh of the bighead carp may have some food value, but no commercial markets exist in the U.S., largely because the fish is said to be most desirable if kept alive until immediately before cooking. As noted earlier, however, a market apparently does exist among people of Oriental origin living in Canada, with shipments of live fish apparently coming into that country from fish farms in the Southern U.S. (Crossman and Cudmore 1999).

Fish coming from that origin (aquaculture trade) may be responsible for the one bighead carp that has been documented in Lake Erie (see Figure 7). But of much greater concern to the Great Lakes is the presence of large wild populations of bighead carp in the Illinois River. In fact, during the annual round goby "roundup", June 12-15, 2001, the author observed several large (29-36 in) bighead carp carcasses floating in the Peoria Pool of the Illinois River within 8 miles downstream of Starved Rock Lock and Dam (See Figure 1) and approximately 80 miles downstream of the Cal-Sag and Chicago Sanitary and Ship Canal. These fish, in a state of decomposition, apparently died from various causes during a Spring spawning migration somewhere upstream of the point of observation. Offspring from these individuals can be expected to continue to push the range of the species farther and farther upstream toward Lake Michigan.

Silver carp _(Hypophthalmichthys molitrix)_

The silver carp is also native to China and eastern Siberia, including the Amur and other lowland rivers of China, between 43 and 64 ^{o}N latitudes (Froese and Pauly 2001, USGS f Online). Silver carp were also first brought into the U.S. by an Arkansas fish farmer in 1973 (Freeze and Henderson 1982), apparently for use in phytoplankton control in ponds and as a food fish (Froese and Pauly 2001). By the mid 1970's, the species was raised at six state, federal, and private facilities in Arkansas; and by the late 1970's it had been stocked in four municipal sewage lagoons (Robison and Buchanan 1988). By 1981, the silver carp appeared in Arkansas' natural waters at seven different sites (Robison and Buchanan 1988), including the White, Arkansas and Mississippi rivers, likely the result of escapement from aquaculture facilities. Introduction of silver carp into Florida (and other states) was probably the result of stock contamination when grass carp were stocked for vegetation control (Middlemas 1994). The species is established in Louisiana (Douglas et al. 1996) and Illinois (Burr et al. 1996, Koel et al. 2000) and spreading rapidly throughout the large rivers of the Mississippi River Basin (Figure 14), with huge numbers and significant natural reproduction (Figure 15) being documented by biologists in off-channel and backwater habitats (River Crossings 1999).

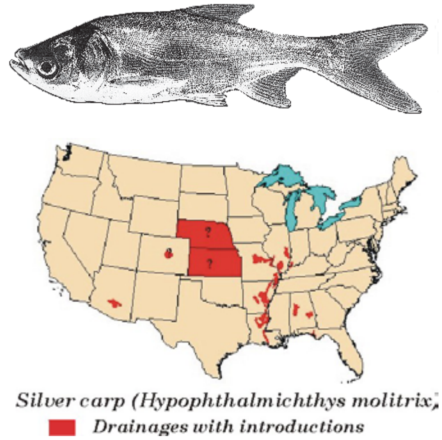


Figure 14. Known distribution of the silver carp in the U.S. (USGS f Online).

This deep-bodied, laterally compressed (narrow), very large member of the minnow family is similar to the bighead carp. However, it is much more efficient at straining suspended material (as small as 4 microns in diameter) from the water through use of gill rakers that are fused into sponge-like porous plates (Robison and Buchanan 1988). Also like the bighead, the silver carp feeds on phytoplankton and zooplankton (Froese and Pauly 2001, USGS f Online). Estimates indicate that food passes through the gut in as little as four hours, being filled and evacuated six times in a 24-hour period, with much of the food passing through undigested (Laird and Page 1996). Silver carp prefer standing or slow-flowing water of impoundments or river backwaters waters ranging in temperature from 43 to 82 °F. A very active species, it swims just beneath the water surface (Man and Hodgkiss 1981) and is well known for its habit of leaping clear of the water when disturbed (Skelton 1993). Thousands of individuals (18-20 in long) were observed by the author exhibiting this behavior in off-channel areas of the Mississippi River just downstream from St. Louis, Missouri, during the summer of 2000. Silver carp can grow in length to 39-40 in. and weigh up to 110 lbs. In culture, the species has attained weights of 12 lbs. at age I and 40-50 lbs. at ages IV and V (Henderson 1979). Silver carp can live to 20 years of age. Maturity is reached at 18 in., and 50,000 to 200,000 eggs are scattered by females over the substrate in open water (Froese and Pauly 2001). In its natural range, the silver carp migrates upstream to spawn and eggs and larvae drift downstream to floodplain zones (Froese and Pauly 2001). Spawning has been observed in Thailand from May through September (Froese and Pauly 2001), and in the U.S. multiple spawning events may be evidenced by the size classes of individuals observed in fish kills (Figure 15) documented in Upper Mississippi River backwaters in 1999 and 2000 (Surprenant 2000). As noted above, when held in captivity, these fish are known to reach weights of 12 lbs. in one growing season, so growth is extremely rapid.

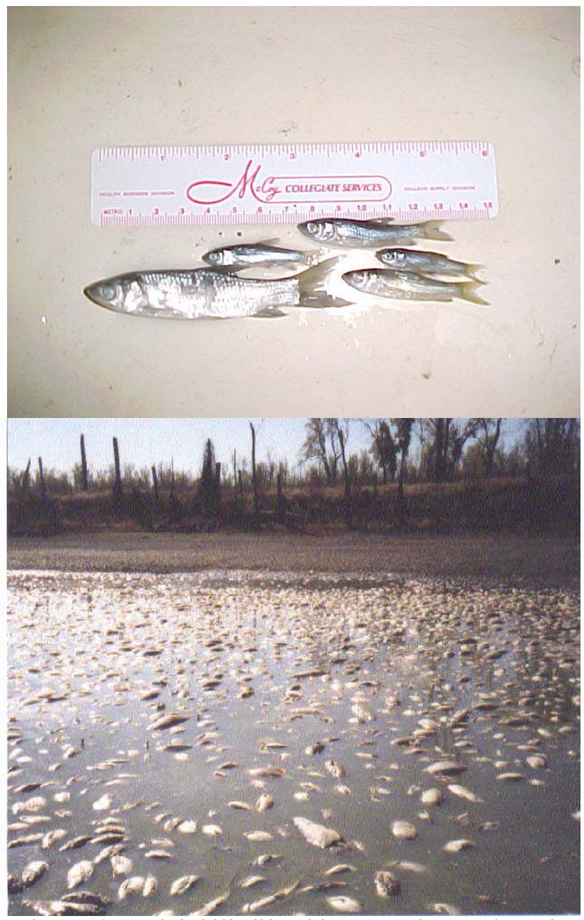


Figure 15. Fish kills like this were observed on the Wilkinsin Island Unit of the Mark Twain National Wildlife Refuge in the fall of both 1999 and 2000. Note that the sizes of individuals in the top photo, indicate the likelihood of multiple spawning events (Surprenant 2000).

The silver carp's history and use in Arkansas is closely intertwined with that of the bighead carp, but the silver carp has less potential as a food fish (Robison and Buchanan 1988). Due to its feeding habits, the species is a direct competitor with all native fish larvae and juveniles; with adult paddlefish, bigmouth buffalo; and gizzard shad; and with native mussels. Pflieger (1997) considered the impact of this species difficult to predict because of its place in the food web. But in numbers and biomass, the species has the potential to cause enormous damage to native species because it feeds on the plankton required by larval fish and native mussels (Laird and Page 1996). Like the bighead carp, the silver carp appears to be adapting very well to the temperate climates of the U.S. Its numbers are rapidly increasing in the Illinois River, and also like the bighead, it is colonizing in a northward direction and will likely find its way into Lake Michigan through the Cal-Sag and Chicago Sanitary and Ship Canal unless action is taken to prevent such entry.

Black carp (*Mylopharyngodon piceus*)

The black carp, snail carp or black amur is native to most Pacific drainages of eastern Asia between 15 and 53 ^{o}N latitudes, from the Pearl River basin in China north to the Amur River and its major tributaries of China and far eastern Russia, including possibly the Red River of northern Viet Nam (Nico and Williams 1996, Frimodt 1995). The species was first brought into the U.S. in the early 1970's as a "contaminant" in imported grass carp stocks delivered to a fish farm in Arkansas (Nico and Williams 1996). A second, intentional importation occurred in the early 1980's, this time for use as a food fish and as a biological control agent to combat the spread of a trematode parasite (*Clinostomum margaritum*) in cultured catfish (Nico and Williams 1996). The first and only known record of black carp escapement or release to the wild in the U.S. occurred in Missouri in 1994 when thirty or more individuals, along with several thousand bighead carp, escaped into the Osage River (Figure 16) when high water flooded holding ponds at a private aquaculture facility near Lake of the Ozarks.

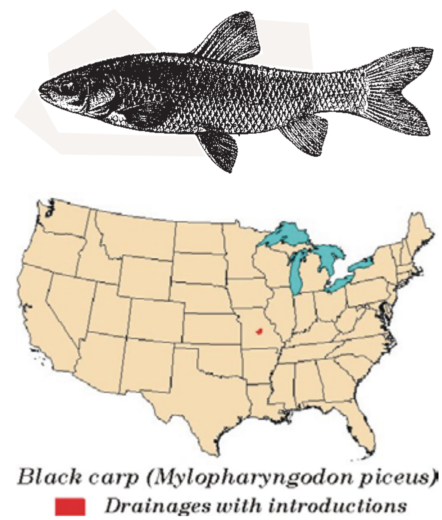


Figure 16. Known distribution of black carp in the U.S. (USGS g Online).

Black carp inhabit rivers (Frimodt 1995), but no temperature (climate) preference data could be found in the literature. The species closely resembles the grass carp in appearance, except that the pharyngeal teeth are fused and hardened (looking almost like human molars) for use in crushing the shells of mollusks and crustaceans, the black carp's primary food. Juveniles, in particular, are difficult to distinguish from grass carp young. Black carp grow to lengths of 39-40 in. and weights of 70+ lbs. (Berg 1964), reaching maturity at lengths of 20 in.

Black carp are currently proposed for widespread use by fish farmers for the control of snails, the intermediate host of the trematode parasite in catfish. Use of the species to control the zebra mussel has been debated (French 1993, Rubinshtein 1994, Ricciardi 1994), but to date there is no experimental evidence to indicate that black carp would be an effective control (USGS g Online). Since the black carp do not have jaw teeth and their mouths are relatively small, it is unlikely that they are capable of breaking apart zebra mussel rafts (Nico and Williams 1996). Trade of black carp is restricted in Germany and several countries have reported adverse ecological impacts after introduction (Froese and Pauly 2001). Nico and Williams (1996) expressed concern that black carp could be mis-identified and unintentionally introduced as "grass carp" in some areas. They also indicated that there is a high potential that black carp would negatively impact native aquatic communities by feeding on, and thus reducing, populations of native mussels and snails, many of which are endangered or threatened, especially in the Southeastern U.S.

Mississippi River Basin states have requested, through the Mississippi Interstate Cooperative Resource Association (MICRA), that the U.S. Fish and Wildlife Service regulate the use of black carp by placing it on the federal list of injurious wildlife under the Lacey Act (River Crossings 2000a, 2000b). This would prohibit interstate sale or shipment of the species. Most states feel that black carp pose a serious threat to threatened and endangered native mollusk and snail species. However, at least Mississippi, Arkansas, Texas and Missouri permit stocking of presumably sterile, triploid black carp in fish farm ponds. Missouri also recently initiated a 5-year program to supply limited numbers of triploid black carp to fish farmers in the hope that state officials will be more successful in preventing escape and spread of diploid (fertile) individuals than would private operators. But, as noted earlier for the grass carp, the whole issue of the effectiveness of inducing triploidy and monitoring to insure its effectiveness continues to be debated by biologists.

Even though the black carp does not yet appear to have established itself in the wild, based on the history of the other three Asian carp species and the questionable value of inducing triploidy, many biologists feel that escapement to and establishment in the wild is inevitable. If and when that occurs, the black carp will likely follow the same paths that its three Asian cousins are following to occupy every available habitat in the U.S. and Canada.

Likelihood and Potential Impacts of Invasion

Information regarding the seven fish species discussed above is summarized in matrix form in Table 1. These data provide clues as to where these fish might be expected to establish populations in North America and what effect they might have on native organisms.

The first data column in Table 1 summarizes native ranges (country and latitude) of the seven species discussed above. However, before looking at these data, it must be pointed out that latitude of origin alone only provides one clue to the ability of a species to infest another geographic area. Barriers (i.e. dams, watersheds, water pollution, etc.) to movement may exist in the home range that could be limiting the ability of the species to exploit other habitats outside of the latitudes listed for its of home range. Temperature preferences (discussed below) must also be taken into consideration. With these caveats in mind, the latitudes of origin in Europe and Asia indicate that all seven species under consideration are capable of greatly expanding their current distribution in the U.S. and Canada. Latitude of origin suggests that the ruffe may be limited to a northern U.S. range, not extending as far south as Chicago. This may leave some hope that this species would not use the southwesterly route of the Cal-Sag and Chicago Sanitary and Ship Canal as a pathway to invade the Mississippi River Basin, even though the ruffe's eventual U.S. distribution will probably include all of Lake Michigan. According to latitude of origin, the other six species could readily occur both north and south of the southern tip of Lake Michigan, including the Cal-Sag and Chicago Sanitary and Ship Canal and Illinois River. The goby species, colonizing from the north, could thrive in latitudes as far south as St. Louis, while the Asian carps, moving north from southern states could thrive in latitudes well north of the Great Lakes and into Canada, presumably north to near Hudson Bay.

The second data column of Table 1 looks at habitats and preferred temperatures or climate. Figure 17 displays preferred climates (temperatures) according to Froese and Pauly (2001) for six of the invading species as well as nine well known species common to the Great Lakes and/or the Mississippi River Basin. The 50 °F line is drawn to mark the lower end of preferred temperatures for most of the species shown. The ruffe and tubenose goby appear to be true cool water species, preferring temperatures of 50-68 °F. Temperature preference may not limit the ability of these two species to colonize extreme southern portions of Lake Michigan, but could discourage them from invading very far south into the Illinois River. This could at least slow their expansion into other parts of the Mississippi River Basin, but their spread by baitbucket and aquarium trade to other waters is likely. The round goby, while shown as preferring cool waters in Figure 17, has also been described as "thriving in warmer waters" -- as high as 86 °F. This would indicate a strong ability and desire to leave the Great

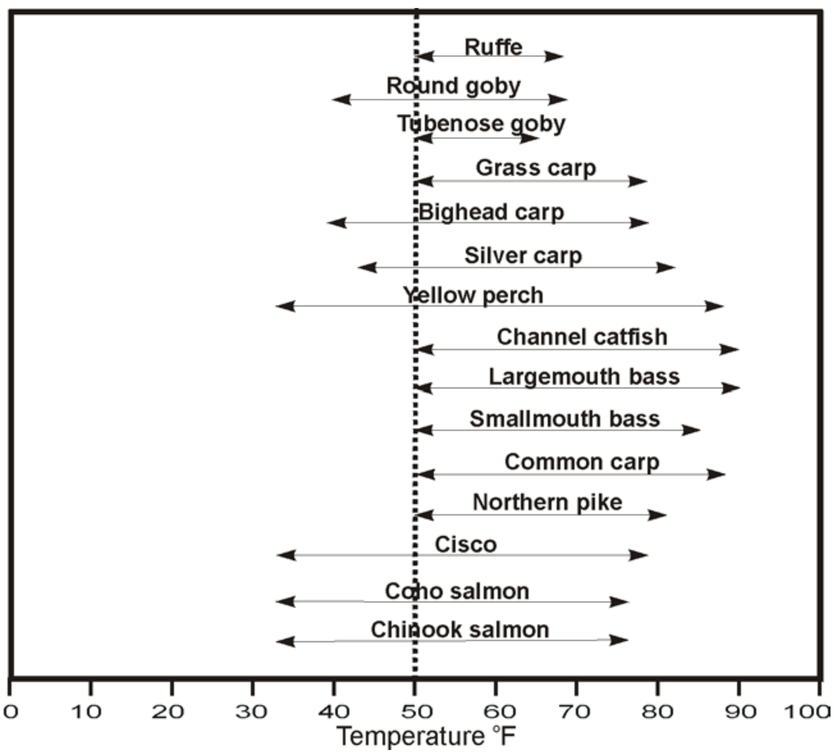


Figure 17. Preferred climate (temperature range) of six of the seven invading fish species compared to those of several well known North American species as reported by Froese and Pauly (2001). No temperature preference data was listed for black carp.

Table 1. Summary of selected information for seven invasive fish species posing an ecological threat to the Great Lakes and Mississippi River ecosystems.

Species	Native Range (country/latitude)	Native Habitat and Preferred Temperature	Feeding Habits	Threats	Known Impacts	Location and Time of U.S. Introduction	Current U.S. Location
Ruffe	Europe (France to eastern Siberia) Latitude 44-66 °N	Lakes, quiet pools, and margins of streams, preferring deep water over deposits of sand and gravel. 50-68 °F	Adapted for night feeding on zooplankton, chironomids, oligochaetes, amphipods, fish, and fish eggs.	Rapid growth, high reproductive output, highly adaptable, tolerate some environmental degradation.	Yellow perch, emerald shiner, and troutperch have declined in numbers after ruffe introductions.	St. Louis River (Lake Superior) in 1986.	Lake Superior, (most abundant species in Duluth, MN harbor) and Lake Huron.
Round goby	Eurasia (Sea of Azov, Black Sea, and Caspian Sea basins) Latitude 39-49 °N	Prefers shallow brackish water, but also occurs in freshwater and tolerates low dissolved oxygen for several days. 39-68 °F, but tolerates water temperatures from 32-86 °F, thriving in warmer waters.	Aggressively feeds on darters; other small fish; lake trout eggs and fry.; aquatic insects; zebra mussels and some native snails. May also take eggs of sculpin, darters and logperch.	Aggressive and adapted for life in murky waters. Dominates spawning sites of other fish, spawns every 20 days from April to September, and tolerates low dissolved oxygen for several days.	Preys on other small fish and fish eggs, dominates spawning sites and prevents use by other species.	St. Clair River (Lakes Huron and Erie) in 1990.	Entire Great Lakes ecosystem and the Cal-Sag and Chicago Sanitary and Ship Canal. May be present in the Des Plaines and Illinois rivers.
Tubenose goby	Eurasia (Black Sea, Caspian Sea, Sea of Azov, Aegean Sea, Aral Sea) Latitude 39-49 °N	Slightly brackish and freshwaters, including rivers and estuaries. 50-65 °F	Benthic crustaceans and insects.	Competes with native species for food and guards its nest , so may exclude other species from spawning sites.	Unknown, species is endangered in its native range.	St. Clair River (Lakes Huron and Erie) 1990.	Northwestern shore of Lake Erie and possibly Ohio., as well as St. Louis River Duluth/ Superior Harbor, Lake Superior.
Grass carp	Eastern Asia (Amur River of eastern China and Russia south to the west River of southern China). Latitude 25-65 °N	Lakes, ponds, pools and backwaters of large rivers; preferring large, slow flowing or standing water bodies with vegetation, including rice fields. 50-79 °F, but tolerates temperatures between 32 and 100 °F.	Higher aquatic plants, submerged grasses, detritus, insects and invertebrates.	Grows to large sizes (i.e. 59 in, 100 lbs) and tolerate salinities to 10 ppt and dissolved oxygen levels down to 0.5 ppm. Known to cause significant disruption of food webs, destruction of desired habitats, disruption of spawning habits and locations, eutrophication and enrichment of waters.	Interspecific competition for food with invertebrates and other fishes; significant changes in composition of macrophyte, phytoplankton, and invertebrate communities; interference with reproduction of other fish; decreases in refugia for other fishes; modification of preferred fish habitats; enrichment and eutrophication of lakes; disruption of food webs and trophic structure; introduction of non-native parasites and diseases.	Arkansas 1963.	45 states including the Upper Illinois and Calumet rivers and some Lake Michigan tributaries.
Bighead carp	Eastern China. Latitude 18-64 °N	Large rivers and lakes. 39-79 °F	Phytoplankton and zooplankton.	Grows to large sizes (i.e. 39-40 in and 50+ lbs), and has the potential to deplete the zooplankton populations that support native species (i.e paddlefish, buffalo, gizzard shad, etc.) populations.	Reproducing in large numbers in the Midwest, piling up below dams, disrupting food chains of, and displacing native species, and disrupting commercial fisheries.	Arkansas 1972.	Illinois River upstream to at least the Starved Rock Pool (i.e. less than 80 mi from the Cal-Sag and Chicago Sanitary and Ship Canal.
Silver carp	China and eastern Siberia, including the Amur and other lowland rivers Latitude 43-64 °N	Standing or slow flowing water of impoundments or river backwaters. 43-82 °F	Phytoplankton and zooplankton.	Large (i.e. 39-40 in and 110 lb), very active, mobile species capable of multiple spawning events and reaching large population size in a short period of time. Very efficient at straining suspended material (including bacteria) from the water and has the potential to deplete the zooplankton populations that support native species (i.e paddlefish, buffalo, gizzard shad, etc.) populations.	Reproducing in large numbers in the Midwest, piling up below dams, disrupting food chains, displacing native species and disrupting commercial fisheries	Arkansas 1973.	Illinois River upstream to at least the La Grange Pool (i.e. less than 150 mi from the Cal-Sag and Chicago Sanitary and Ship Canal).
Black carp	Most Pacific drainages of eastern Asia (Pearl River basin in China to Amur River drainages of China and Russia, possibly including the Red River of northern Viet Nam). Latitude 15-53 °N	Rivers.	Molluks and crustaceans.	Large (39-40 in and 70+ lb) species has a high potential of negatively impacting native aquatic communities by feeding on, and reducing, populations of native mussels and snails.	Preys on mussels and snails in its native range. If released or escaped to the wild in the U.S., many threatened or endangered crustaceans and mollusks would be impacted.	Arkansas 1970's.	Currently being used by fish farmers in southern states to control a trematode parasite in pond raised catfish. Northernmost known location is central Missouri (Osage River).

Lakes, moving southwesterly down the Illinois River to its confluence with the Mississippi, and then both north and south from there, colonizing many rivers and streams of the Mississippi River Basin. Three of the carp species (grass, bighead and silver) all prefer a wide temperature range, indicating their ability to thrive from the northernmost waters of the Great Lakes to the waters of the middle Mississippi River Basin. The bighead and silver carps even prefer temperatures well into the preferred range of salmon and trout (Figure 17). No temperature data could be found for the black carp, but based on its similarity to the grass carp and its native range in Asia, this species may also thrive over much of the U.S. and Canada. All seven species prefer large river and lake habitats, with a propensity toward access to some standing or slow flowing water, both of which are abundant in the Great Lakes and Mississippi River Basin ecosystems. All of the Asian carp species that became adapted to life in the Great Lakes would also likely invade the Lakes' tributary streams and rivers where they would most likely spawn.

Column three in Table 1 summarizes feeding habits. The grass carp's preference for feeding on aquatic vegetation may limit its spread in the Great lakes, but once present in an ecosystem, the species has shown an ability to shift its feeding habits to other available foods when plants become scarce. So the spread of its range into the Great Lakes remains an open question, but the other six species should be able to find adequate food resources in either ecosystem. As noted earlier, the Great Lakes have already provided a home for at least 140 alien aquatic nuisance species, and the basin itself was colonized after the ice age by species moving north from the Mississippi River Basin. Also, recent improvements in water quality have only enhanced its attractiveness to new biological invaders.

As for the threats and potential impacts of these species (data columns 4 and 5 of Table 1) temperature preferences of the ruffe and tubenose goby may cause them to remain in the Great Lakes, not venturing into the Cal-Sag and Chicago Sanitary and Ship Canal. The round goby, on the other hand, has spread rapidly across the Great Lakes and will likely use any route to expand its range, including the Cal-Sag and Chicago Sanitary and Ship Canal. Manz (1998) described the round goby as possibly the "perfect" invader, and, once established in the rivers of the Mississippi River Basin, it can be expected to be an aggressive predator and spawner, excluding native species from spawning habitats and reproducing about every 20 days. Rapidly expanding goby populations can be expected to prey heavily on small fish and fish eggs in many parts of the Mississippi River Basin. If viable goby eggs can, in fact, become attached to ship's hulls, as some people speculate, the species may find an easy ride to the far corners of the Mississippi River Basin via barge transportation. Of far greater concern at this moment, however, are its ability to use the Cal-Sag and Chicago Sanitary and Ship Canal as a route to colonize the rivers of the Mississippi River Basin on its own, and its spread to other areas through use as both an aquarium fish and bait fish.

In terms of temperature tolerance and habitats, the Asian carps all, except possibly the black carp (no data available), seem well suited to life in the Great Lakes. Once populations are established in the Lakes, they would pose significant threats to the ecosystem's food web. Because of their fast growth, large size (50-110 lbs), and huge appetites, these species would consume vast quantities of zooplankton, phytoplankton and vegetation. Thus vast amounts of the Lakes' biomass could become tied up in their bodies. With successful reproduction in Great Lakes tributaries, these fast growing, large fish could achieve large population numbers in just a few years. If this happens, the Great Lakes' sport and commercial fisheries would undoubtedly be impacted by displacement of other species (both forage and gamefish). In the Mississippi River Basin the bighead and silver carp are direct food competitors with all species of larval fish as well as with adult plankton feeders such as the paddlefish, bigmouth buffalo and gizzard shad.

If the black carp escapes captivity and follows the path of its three Asian cousins, vast quantities of mussels, snails and crustaceans would be consumed. It is not known at this time whether the black carp could adjust to feeding on zebra mussels. But if it could, it would obviously find huge amounts of food resources available in either the Mississippi River Basin or the Great Lakes ecosystems.

Urgency of Action

As to timing and urgency of action, the round goby poses the most immediate threat to the Mississippi River ecosystem (Table 2). The species has been documented in the Calumet River and the Cal-Sag and Chicago Sanitary and Ship Canal and may already be in the upper Illinois River. Based on its lightning-like infestation of all five Great Lakes (facilitated by ballast water transfers), the species can be expected to rapidly produce large population numbers wherever it becomes established in the flowing waters of the Illinois River. Although the round goby isn't necessarily known for its rapid swimming ability, downstream movements will be facilitated by river currents. And since the round goby seems to make a desirable bait fish, its spread into other portions of the Mississippi River Basin will likely be facilitated by the bait fish and aquarium industries, and perhaps via barges, if egg attachment to barges similar to zebra mussel, is possible.

Table 2. Liklihood of transfer of seven invasive fish species between the Great Lakes and the Mississippi River Basin and ugency of action.

Species	Present Location	Adaptability	Possible Limitations to Spread	Likelihood of Spread between Great Lakes and Mississippi River Basin	Urgency of Action
Ruffe	Northern Great Lakes	Northern U.S. lakes and rives	Temperature tolerance and access to connecting waters.	Moderate. May have to rely on spread by bait dealers and fishermen.	May not enter theChicago diversion canals for some time. Immediate action is, however, needed to prevent spread via bait dealers and fishermen.
Round goby	Cal-Sag and Chicago Sanitary and Ship Canal	Rivers, lakes and esturaries of Northern two-thirds of U.S.	None known, may be limited by swimming speed	Extremely High. Eggs may attach to barges and speed spread to new habitats.	Immediate action is needed to prevent spread to Mississippi River Basin.
Tubenose goby	Northern Great Lakes	Northern U.S. lakes and rivers	Temperture tolerance, access to connecting waters	Minimal. May have to rely on spread by bait dealers and fishermen. The species is threatened in its native range, and this may signal some limiting factor in U.S. waters.	Needs to be watched.
Grass carp	Calumet River and some Lake Michigan tributaries	All of U.S.	Preference for feeding on aquatic vegetation.	Moderate. Has been in close proximity to the lakes for a number of years. May not find adequate food resources available in the Great Lakes.	Immediate action is needed to limit access to the Great Lakes.
Bighead carp	Illinois River	All of U.S.	Barriers and obstructions to movement	High	Immediate action is needed to prevent access to the Great Lakes. Expected to arrive in adacent waters within 1-3 years.
Silver carp	Illinois River	All of U.S.	Barriers and obstructions to movement	High	Immediate action is needed to prevent access to the Great Lakes. Expected to arrive in adacent waters within 1-3 years.
Black carp	Captivity (hatcheries, culture facilities and fish farm ponds in Southeastern U.S.)	All of U.S.	Being held in captivity under close scrutiny.	High if allowed to escape to the wild.	Immediate action is needed to insure that escape to the wild is prevented.

The Asian carps, all natives to portions of northern China and Siberia, will likely find the cool waters of all five Great Lakes acceptable for habitation. When compared to several species of popular North American gamefish (Figure 17), the bighead and silver carp clearly prefer cooler temperatures, reaching well into the range of salmon and trout, the Great Lakes' premier gamefish. The grass, bighead and silver carps thus appear to pose the greatest and most immediate threat to the Great Lakes (Table 2). Grass carp have already been reported from Lake Michigan (USGS a Online) and the Calumet River (about 6 miles from Lake Michigan), but not yet in large numbers. Additionally, a single bighead carp has been reported from Lake Erie (See Figure 7), and another individual is reported from a fountain pool in Toronto, Ontario not far from Lake Ontario (Crossman and Cudmore 1999). It is suspected that these two individuals came from the shipment of live fishes for human consumption trucked into Canada from fish farms in the Southern U.S. for sale alive to consumers of Oriental origin in Toronto. But most importantly, the bighead and silver carps are rapidly reproducing, and staging in large numbers in the LaGrange Pool of the Illinois River, within about 80-150 miles downstream of the Cal-sag and Chicago Sanitary and Ship Canal. Evidence has shown that the instinct of the Asian carps is to colonize ever northward into cooler waters, swimming upstream to spawn. In other Midwestern rivers, the only thing to date, which has stopped their upstream movement has been high dams, where they can be found "piling up" in large concentrations (River Crossings 1999). So it is easy to speculate that the Asian carps will navigate the Cal-Sag and Chicago Sanitary and Ship Canal system with ease, and unless control measures are taken soon, they should easily find their way into Lake Michigan within 2 to 3 years where they will likely find desirable feeding habitats within much of the top 15-20 ft. of the water column. Spawning will likely occur in many Great Lakes tributaries, and then its just a matter of time until critical mass is reached, population expansion occurs, and impacts become evident to fishers and the general public.

If the bighead and silver carps successfully establish themselves in the Great Lakes they would compete directly for food with important salmon and trout forage species. All three species of Asian carp feed at very low trophic levels (i.e. zooplankton, phytoplankton and aquatic macrophytes), and such fish species (i.e. minnows) usually form the basis of many North American aquatic food chains (i.e. food for larger predators). But because the Asian carps grow so fast (up to 12 pounds in one year), they quickly become too large for most native North American predators to consume. Beyond that, the Asian carps are very prolific, multi-year spawners, which almost guarantees the survival of significant numbers of offspring. So, as demonstrated in the rivers of the Mississippi River System, it doesn't take long for an invaded ecosystems to become overwhelmed with large numbers of large individuals, tying up huge amounts of biomass in their bodies. If this occurs in the Great Lakes, the trout/salmon food chain could be significantly impacted, and trout and salmon populations could decline. This could leave sports anglers with snagging for Asian carp rather than casting and trolling for trout and salmon (Figure 18). Such Great Lakes snag fisheries might occur at the mouths of tributaries as the Asian invaders concentrate there for upstream spawning migrations, or as sport and charter boats drag snagging gear through open water, pelagic schools of carp.

Figure 18. Bighead carp (50 lbs) caught by fisherman in the Cumberland River, Tennessee (River Crossings 2000b).

Since black carp are presently being held in captivity, no impacts on native U.S. ecosystems are documented at this time. However, because of its potential for escape to the wild and the subsequent threat it poses to threatened and endangered mollusk species, measures should be strengthened to keep it in captivity, or better yet while it is still possible, measures should be taken to eradicate it from the North American continent. If escaped or released to the wild, the species poses major threats to the mussel and snail populations of every ecosystem it invades.

Measures should continue to be taken to control the spread of ruffe in the Great Lakes, and even though (because of its preferred temperature range) spread of the species may not be facilitated by the Cal-Sag and Chicago Sanitary and Ship Canal precautionary measures should be taken there as well. Also careful watch should be kept on the aquarium fish and bait fish trades to prevent its spread in that manner.

The tubenose goby seems to pose the least threat of escapement from the Great Lakes to the Mississippi River Basin at this time, especially since the species is threatened in its home range and may be expected to meet similar limitations in the U.S. However, the species does merit continued surveillance, especially since it was recently collected form the St. Louis River in the Duluth-Superior Harbor of Lake Superior.

Conclusion

As noted above, to predict that future impacts will occur from the continued two-way exchange of invasive species between the Great Lakes and Mississippi River Basin is not difficult. What is difficult to predict is when those impacts will occur, how they will occur, and to what extent they will affect humans. Whether species are transferred through ballast water; by water diversion; in bait buckets; in live wells; by release from aquariums; attached to barges; or through direct importation, stocking, or escapement; all methods of introduction and spread bear the fingerprints of man. These fingerprints can usually be traced to those who were ignorant of the implications of their actions, weren't required by law to address them, found a loophole in the laws and regulations, or ignored the laws and regulations altogether. In any case, the taxpayers and consumers are the ones who are left holding the bill for control and clean up after the fact. So it is in the best interest of taxpayers and society to tighten the hold on the importation and spread of invasive species, stopping them in their tracks, while there is still time.

Less than 20 years ago, few people could have foreseen the far reaching impacts that we now know and accept as the result of the zebra mussel invasion. Had we known then what we know now it might have been easy for us as a society to make the appropriate economic trade-offs and attempt to contain the zebra mussel within the Great Lakes, preventing its escape into the Mississippi River Basin. The ability of zebra mussels to attach themselves to solid objects and thus use barges as a means of transportation to the far corners of the Intercontinental Waterway System is but one example of the adaptability of invasive species. Such species often possess some unique feature or competitive advantage which allows them to capitalize on some niche or ecosystem feature that native species are not using. In that way they gain a competitive advantage over the natives, infecting new ecosystems with lightening-like speed, and overwhelming the natives with shear numbers because without natural predators the invaders have an extremely high reproductive potential.

To date, the Mississippi River Basin has been the recipient of most of the aquatic invaders moving downstream along the water pathway provided by the Cal-Sag and Chicago Sanitary and Ship Canal to the Illinois River. But as discussed earlier in this report, many biologists agree that the Great Lakes "escape door" for invasive species represents a two-way street or "revolving door", with the Great Lakes likely to soon join the fray by becoming the victim of an upstream Asian carp invasion (Figure 19). These species, natives of northern climates on the other side of the earth (China and Siberia), seem to be retracing the paths of the original species that colonized the Great Lakes after the last ice age. If they find the Great Lakes habitats to their liking, as previous invaders have, they too may soon become a common component of the Lakes' fauna which our children and grandchildren will come to know as natives.

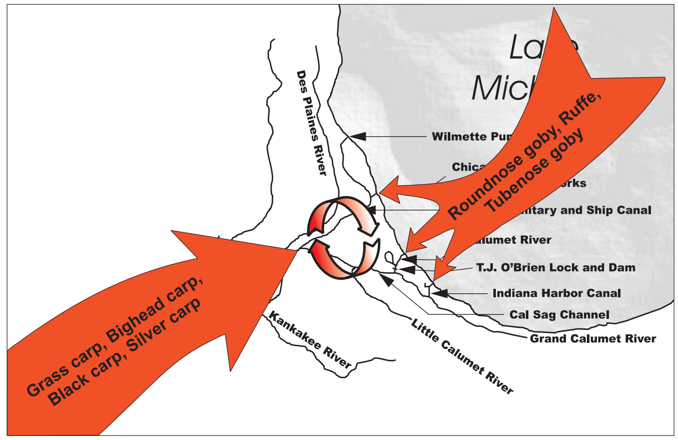


Figure 19. The Cal-Sag and Chicago Sanitary and Shipping Canal, providing a major water connection between the Great Lakes and Mississippi River Basin, may soon become a "revolving door" for exchange of invading exotic species .

Just as the shipping industry was responsible for the introduction and spread of zebra mussels and other foreign species into the Great Lakes and Mississippi River Basin, so was the aquaculture and fish farming industries responsible for introducing the Asian carps to the Mississippi River Basin, and now those species threaten to invade the Great Lakes. In both instances, the Cal-Sag and Chicago Sanitary and Ship Canal serves as a primary conduit facilitating mass transfer of organisms between the two ecosystems. None of those involved (i.e. shipping, canal, or aquaculture) intentionally infected either ecosystem with invasive species, but each played a significant role in making the organism transfer possible through the course and pursuit of their own special business interests.

The key to stopping the spread of these and other such invasions is, of course, to prevent them in the first place. But once an invasion occurs, in order to prevent its spread, every avenue of escape from where the invading organisms are established must be closed. The Cal-Sag and Chicago Sanitary and Ship Canal is one such avenue. Suggested alternative solutions that need to be evaluated and considered by decision makers in addressing these important issues are discussed in the following section.

Suggested Alternatives for Stopping the Transfer of Aquatic Nuisance Species Between the Great Lakes and Mississippi River Basin Ecosystems

<u>Organism Barriers</u>

- Complete the electric barrier in the Cal Sag and Chicago Sanitary and Ship Canal designed to prevent the spread of the round goby and test its efficacy in controlling the passage of a wide range of species, representing all sizes of fish. If necessary, increase the electrical charges used to deter the fish and/or construct additional barriers to increase efficiency to 100%.
- Design, develop, construct, test, operate and maintain a barrier or combination of barriers (i.e. electrical, chemical, bubble, toxic, anoxic, etc.) which will kill all aquatic organisms attempting to move upstream or downstream in the canal. A suitable location for such a multifaceted barrier may be at a location adjacent to the new partial barrier (electric), discussed above.

Water and Waste Treatment Improvement

- Temporarily allow water quality in a reach (2 miles or more long) of the Cal-Sag and Chicago Sanitary and Ship Canal to return to the toxic/anoxic conditions of the past, destroying all aquatic life and creating a toxic barrier to movement of organisms until other measures can be effectively employed and tested.
- Take measures (chemical, physical, etc.) at Chicago's water treatment facilities to cycle all diversion waters drawn from Lake Michigan through the city's water processing system in order to ensure that all living organisms are destroyed before being released into the Illinois River and Waterway.
- Increase efforts to complete the Chicago tunnel and reservoir project. This would enhance the city's ability to treat waste and runoff waters in order to return them to Lake Michigan, thus providing a closed system of water use and waste treatment, and eventually eliminating the need to divert wastes down the Illinois River.

Hydraulic Separation

- Employ engineering techniques to hydraulically separate the Great Lakes and Mississippi River basins, essentially reversing or amending the engineering feats of the past (not unlike the Kissimmee River Project in Florida). Such a project could replumb the system, using new technology to better treat the city's wastes and to create new navigation alternatives where water from each respective ecosystem would be channeled to the locks and used to sequentially fill and drain the locks, ensuring that drain water flowing from each lockage flowed back toward the watershed from whence it came.

Navigation Project Changes

- Eliminate navigation connections between Lake Michigan and the Illinois River and Waterway (i.e. Chicago River lock, T.J. O'Brien lock, Hammond canal, etc.). These could be filled with dredged material and replaced with terminals or harbors for off-loading of ships and barges over levees or barriers between the two ecosystems using conveyors or other physical means similar to that used to off-load ships at Great Lakes power plants and terminals.
- Temporarily close and retrofit locks with devices which would prevent invasive species passage. Such devices might include electric, bubble or chemical barriers to fish movement, use of heated power plant effluents or treated (organism free) diversion waters to fill locks, or on-going use of fish toxicants for each lockage to destroy any fish entering the locks.
- Close locks to commercial traffic, as above, establishing off-loading terminals, and allow only recreational navigation through smaller, more closely monitored and controlled locks using the treatments (physical and chemical barriers) described above.

Regulation Changes

- Develop federal codes of conduct, pre-clearance or compliance agreements as described by the National Invasive Species Council (2001) to formulate realistic and fair phase-in evaluation of intentional introductions of new species currently moving into the U.S., in consultation with state governments, scientific and technical experts and societies, and other stakeholders, including affected industries and environmental groups.
- Develop species (i.e. white and black lists) and enforce any future species introductions which could (white list) and could not (black list) be imported into, or possessed within the borders of the U.S. Place all exotic species not white or black listed on a "grey list" and bar them from importation into the U.S. until adequate studies are completed to conclusively determine that introduction into the U.S. will not harm any native species.
- Strengthen regulations to place the "burden of proof of no harm" on the importing agent for any species not black or white listed. Require that detailed studies be funded by the importing agent to determine the potential impacts of a species on U.S. ecosystems before being imported. Simply described, this measure would become a "cost of doing business for importation" that would assumed by the importer and eventually passed on to the consumer.
- Strengthen regulations and penalties for illegal interstate transport and trade of nonnative species.

Whatever alternatives are considered, a combination of solutions will be needed to solve this difficult issue. Any one of the alternatives described above will not form an effective organism barrier in and of itself. For example, the electric barrier may be improved enough to block the movement of larger organisms (i.e. fish), but will never be efficient enough to kill or block the downstream drift of smaller organisms (i.e. plankton). The latter could be addressed by a method of chemical or physical treatment such as passing all diverted waters from Lake Michigan through the city's drinking water treatment plant.

Fortunately, today's technology provides more options than were available in the past, so there is more that can be done now than there was before. But the problem remains that every solution requires a will, a trade-off and funding; and in this case, we have the added element that time is of the essence. Asian carps may soon invade Lake Michigan in large numbers. As noted earlier, once a species enters an ecosystem and becomes established, its too late, there is no turning back. We need to act and act now in order to keep the "genie in the bottle" and thus prevent another disastrous zebra mussel-like infestation of either ecosystem.

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