The Round Goby (Neogobius melanostomus): Another Unwelcome Invader in the Mississippi River Basin

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Introduction

Transoceanic shipping ports along the Atlantic and Pacific coasts of North America have long been focal points for the initial entry and dispersion of a variety of nonindigenous aquatic taxa to coastal ecosystems of the United States (US). Public awareness of the complementary role which inland ports play in the distribution of exotic species to environmentally sensitive freshwater ecosystems of the mid-continent has been heightened in recent years by the introduction of an increasing number of aquatic nuisance species to the Great Lakes. This list of new and invasive taxa includes several species of invertebrates (Dreissena polymorpha-zebra mussel, D. bugensis-quagga mussel, Potamopyrgus antipodarum-New Zealand mud snail, Bythotrephes cederstroemi and Ceropagis pengoi-spiny water fleas) and fish (Gymnocephalus cernuus-ruffe, Neogobius melanostomus-round goby, Proterorhinus marmoratus-tubenose goby). These organisms were released into US waters with untreated ballast water discharged by ships from foreign ports.

In response to the growing economic costs and ecological concerns raised by the introduction and rapid spread of zebra mussels in the Great Lakes and adjacent aquatic ecosystems, Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Public Law 101-646). This legislation addressed the growing problem of unintended aquatic nuisance species introductions (e.g., zebra mussels) in the Great Lakes region by seeking improved management of ballast water discharges and encouraging the development of methods to control other transmission pathways. The scope of this act was broadened in 1996 when Congress amended and re-authorized it under a new title, the National Invasive Species Act (Public Law 104-332). This act placed a greater emphasis on aquatic nuisance species prevention and control efforts to better protect all US water resources (Cangelosi, 1997; Glenn and LaTourette, 1997). Among the several nonindigenous aquatic species (NAS) introduced to the Great Lakes in the past decade, the round goby is currently considered one of the most serious threats to aquatic ecosystems of mid-America because its geographic range has started to expand into the Mississippi River basin. The round goby thus presents a challenging test case for federal, state, and municipal authorities, private industry and public interest groups, as they work together to successfully implement laws and initiatives to prevent and control the spread of aquatic nuisance species around the country.

This paper will review and briefly highlight (1) the role of the Illinois Waterway System as a pathway for the transmission of NAS between the Great Lakes and Mississippi River basins, (2) the introduction of zebra mussels to the Mississippi River basin and some of the environmental consequences, and (3) the more recent introduction of round goby to the Mississippi River basin and strategies to diminish its continued spread here.

Clean Navigable Waters Aid Dispersion

The development of regional water transportation systems and continuing improvements in surface water quality during the past century have made many freshwater ecosystems across North America vulnerable to the introduction and establishment of NAS. Opportunities for NAS to translocate widely in freshwater ecosystems of the US has long been aided (in part) by canals that have interconnected continental drainages. For example, the Illinois Michigan Canal in Chicago first linked the Mississippi River basin with the Great Lakes basin in the mid-19th century. Other canals built more recently here now form the Illinois Waterway System (IWS) which not only facilitates the waterborne shipment of bulk commodities to regional, national, and international markets, but also permits NAS to passively drift or actively emigrate from one basin to another. Commodity shipments on this waterway, as well as other types of commercial and recreational boating activities, increase the probability of unintentionally translocating a NAS from one river reach or drainage basin to another. These organisms can be transported in bilge water, on hulls, engine components, mooring lines, chains, anchors, live wells, boat trailers, and a host of other navigational components and recreational equipment.

The ability of many NAS to persist, thrive, and expand their range in freshwater ecosystems around the US has also been facilitated by recent nation-wide improvements in surface water quality. As early as the mid-19th century, untreated sewage containing high levels of nutrients and suspended solids was discharged from numerous point sources in rapidly growing cities of the midwestern US (Mockovak, 1990; Changnon and Changnon, 1996). The biochemical oxygen demand created by these inputs would periodically overwhelm the assimilative capacity of receiving waters, creating virtually anoxic conditions in which only the most pollution tolerant of aquatic taxa and virulent pathogens (e.g., Salmonella typhosa) could survive. In addition to excessive nutrient loading, the volume of industrial effluent containing persistent toxic substances continually increased during the industrial boom of the late-19th and early-20th centuries. As a consequence, portions of many urban surface waters were little more than open sewers and unsafe for human contact.

In response to several major waterborne disease epidemics during the late-19th century, urban planners around the country initiated a series of new wastewater treatment practices to improve local surface water quality. In Chicago for example, the normal flow of a drainage that transported untreated sewage to Lake Michigan, the drinking water source for the city, was permanently reversed in 1900. This engineering feat permitted water from Lake Michigan to dilute and flush the sewage from this stream into recently excavated canals that flowed downstream into the Des Plaines River. The link that these man-made canals provided for commercial navigation between the Great Lakes and Mississippi River basins was considered an added benefit of this waste treatment option and helped to advance this strategy over several others (Changnon and Changnon, 1996). However, the dilution approach was inadequate to meet the sanitary regulations of this rapidly growing industrial city and was soon supplemented by a sewage treatment program that utilized newly developed and more effective technologies (e.g., sprinkling filters, settling basins, activated sludge).

More recent national improvements in wastewater and stormwater treatment, as well as a uniform permit system to regulate the discharge of conventional and toxic pollutants from point sources, were federally mandated by the Clean Water Act of 1972 and its subsequent amendments. This legislation is acknowledged as a major driving force that has significantly improved the water quality of rivers and lakes across much of the country. As a result, some species of native aquatic fauna (e.g., Hexagenia mayflies, unionid mussels, fishes) have recently expanded their distribution by reclaiming traditional habitats from which they were excluded by pollutants for decades (Fremling, 1989; Fremling and Johnson, 1990; Krieger et al., 1996; Dennison et al., 1998; Whitney and Blodgett, 1999). However, improved water quality conditions may not be entirely to the benefit of certain native aquatic fauna should it reduce or eliminate a barrier that may have been limiting the spread of more competitive, opportunistic

NAS.

The Zebra Mussel: An Alarming Wake-Up Call

The operation and maintenance of a 9-foot navigation channel on the Upper Mississippi River System (UMRS) and its connection to Lake Michigan via the IWS has recently helped expand the range of several NAS from the Great Lakes to distant portions of the Mississippi River drainage basin, and vice-versa, by several modes of transmission (Table 1). The zebra mussel, a mollusc native to the Black and Caspian Seas of Eurasia, is currently the most widely distributed of these exotic species to have translocated from the Great Lakes to the Mississippi River drainage basin.

Zebra mussels were originally introduced to the Great Lakes in ballast water discharges from transoceanic ships in the mid-1980's and by 1991 had spread by various means to several distant portions of the Illinois and upper Mississippi Rivers. The first sighting of zebra mussels in the upper Mississippi River (UMR) occurred near La Crosse, Wisconsin in 1991, approximately 475 river miles (764 km) upstream of the Illinois River confluence near St. Louis, Missouri. Additional sightings the following year further upstream, as well as in portions of several other navigable Mississippi River tributaries (e.g., the Ohio, Tennessee, Arkansas, and Cumberland Rivers) suggested that zebra mussels were being dispersed throughout much of the Mississippi River basin by routine navigation activities. This was confirmed by reports of live zebra mussels attached to barges that had traveled distances of up to 20,000 miles (32,180 km) in a 16-month period, distributing them to portions of the upper Mississippi, lower Mississippi, Illinois, Arkansas, Ohio, and Kanawha Rivers (Keevin et al., 1992; US Army Corps of Engineers, 1993). Routine maintenance inspections of tow boats operating in the Mississippi River System also find that recesses in the boat hull (e.g., sea chest, keel cooler) are common sites for zebra mussel attachment and long-range transport (Allen, 1998). Likewise, submerged components of the propulsion and stabilization systems on large recreational watercraft provide suitable sites for zebra mussel attachment and redistribution in the UMR and adjoining navigable tributaries (S.T. Yess personal communication: 1998). The range of this invasive mollusc has continued to spread upstream, as well as downstream, within the Mississippi River drainage basin and now extends as far west as the Arkansas River in Oklahoma.

The rapid expansion of zebra mussel populations in the Mississippi River basin quickly altered many of the normal ecosystem functions, resulting in a range of adverse impacts to native species. Much of this stems from the remarkable filtering capabilities of zebra mussels which can significantly affect localized water quality. Typically, high densities of zebra mussels result in high water clarity, low phytoplankton levels, an enriched supply of available nutrients, and dissolved oxygen undersaturation (Effler et al., 1996). Reports of unusually low mid-summer dissolved oxygen concentrations (e.g., < 5 mg/L) at main channel sites in the UMR have become more common in recent years and have been associated with the respiratory demands of dense zebra mussel populations nearby (Sparks et al., 1994; Sullivan and Endris, 1998). Severe oxygen depletions could change the composition of the benthic invertebrate community to more pollution-tolerant taxa, alter local food webs, and quickly set back years of ecosystem recovery efforts that were attributed to improvements in water quality (Sparks et al., 1994).

Zebra mussels also assimilate a variety of persistent contaminants as they filter-feed on suspended particles. A variety of native fish and wildlife species may thus be linked to zebra mussels in UMRS food webs, ultimately increasing the risk of enhanced contaminant transfer to and biomagnification among members of higher trophic levels, especially in areas with existing contaminant concerns (Steingraeber et al., 1994; Cope et al., 1999). For example, diving ducks may increase their risk of exposure to toxic contaminants by feeding in areas where zebra mussels are abundant and remaining there for extended periods during seasonal migrations (Wormington and Leach, 1992; de Kock and Bowmer, 1993). Likewise, elevated concentrations of polychlorinated biphenyls in smallmouth bass (<u>Micropterus</u> <u>dolomieui</u>) recently collected near Lake Michigan's Chicago shoreline (T. Hornshaw personal communication: 1998) may be due, in part, to their predation upon a locally expanding population of round goby, which will preferentially feed on zebra mussels (Ghedotti et al., 1995).

Of the ecological consequences that may result from the establishment of zebra mussels, one of the greatest concerns is for adverse impacts to the native benthic fauna with which they directly compete for available resources. The impacts that zebra mussels are having on the diverse native mussel fauna in the Mississippi River basin has been focus of much attention. Like coral reefs in the ocean, native freshwater mussel beds in the UMRS help to create unique ecosystems that support a diverse variety of native fish and wildlife species. Unfortunately, native mussel beds are also one of the primary natural hard substrates available for settlement and attachment of zebra mussel veligers in the UMRS. Zebra mussels colonize the shells of all species of unionid mussels and may reduce both the abundance and diversity of native unionid communities by a variety of physical mechanisms (Mackie 1991). Therefore, zebra mussels represent a serious threat to the survival of several state- and federally-listed endangered or threatened mussel species in the UMRS (D.L. Strayer personal communication: 1998).

The Round Goby: A Call to Action

The round goby, like the zebra mussel, is native to the Black and Caspian Seas of central Asia and was probably introduced to the Great Lakes in ballast water from transoceanic shipping in the late-1980s (Marsden and Jude, 1995). This small, aggressive benthic fish was first reported in the US in the St. Clair River, along the Canadian border, in 1990 (Jude et al., 1992). By 1993 the distribution of round goby had expanded to several Great Lakes' ports (presumably as a result of ballast water exchanges by inter-lake shipping activities) and they are now present in all the Great Lakes. Meanwhile, the round goby population in southwestern Lake Michigan was beginning to expand inland on Chicago's south side via the Calumet River.

A combination of aggressive behavioral traits and prolific spawning abilities give the round goby a distinct competitive advantage over most native species of bottom-dwelling fishes. Round goby may be largely responsible for the decline of mottled sculpin (Cottus bairdi) and logperch (Percina caproides) populations reported in the St. Clair River during the mid-1990s (Jude and DeBoe, 1996). These findings have created concern regarding the potential effect of round goby on functionally similar species of native fish (e.g., darters, sturgeon) that inhabit the Mississippi River drainage basin (Exotic Species Program, 1998). Likewise, the dietary preference of round goby for zebra mussels (Ghedotti et al., 1995) is disturbing as it could enhance the transfer of contaminants in the UMRS to piscivores at higher trophic levels (Exotic Species Program, 1998). Moreover, most of the habitat rehabilitation and enhancement projects (HREPs) completed along the UMRS in the past decade have used rock riprap to stabilize both newly created and existing river banks (K. Beseke personal communication: 1998). The complex network of interstitial spaces provided by this material is the type of habitat most preferred by round goby in near shore riverine environments (Jude et al., 1995; Jude and DeBoe, 1996). This rock also provides attachment surfaces for zebra mussels, an important food item for larger round goby (Ghedotti et al., 1995; Jude et al., 1995). Therefore, if round goby penetrate beyond the Chicago area waterways and further into the UMRS, HREP riprap may provide a longitudinal series of "stepping stones" for its expanded distribution within this drainage basin.

The extent to which navigation activities and water discharges may enhance the downstream distribution of round goby in the Chicago waterways toward the Illinois and Mississippi Rivers is unknown. Yet the recent introduction of round goby from the Volga River upstream into the Moscow River in central Russia may have resulted, in part, due to the transport of goby egg masses on barge hulls through channels connecting these drainages (Sokolov and Tsepkin, 1992; Tsepkin et al., 1992; Sokolov et al., 1994; Moskal'kova, 1996). Thus commercial vessels plying the Chicago area waterways could be vectors for the transport of round goby to other navigable portions of the Mississippi River basin. In addition, the great variety and number of recreational vessels that moor in and pass through goby-inhabited waters here could also contribute to goby range expansion in the UMRS.

The home range behavior of the round goby may help to limit the "unaided" extent of its downstream distribution in the Mississippi River basin. Individuals at the leading edge of its range may be hesitant to seek out new habitat until density dependent factors limit the localized carrying capacity. However, annual year class production of round goby and an abundance of favorable (i.e., rocky) habitat in the Chicago area waterways are likely promote the continued downstream emigration of this nonindigenous species towards the Illinois and upper Mississippi Rivers (Steingraeber et al., 1996). Annual interagency sampling efforts coordinated by the US Fish and Wildlife Service to determine the downstream leading edge of the round goby's distribution in the Chicago area waterways have found that the apparent downstream extent of the round goby's range has increased by at least 28 river miles (45 km) since 1998 and now extends at least 43 river miles (69 km) inland (Fig. 2). The goby-inhabited reach of the IWS in metropolitan Chicago now comprises the uppermost 13 percent of this 333-mi (536-km) navigation corridor that flows diagonally across Illinois from Lake Michigan to the Mississippi River.

Thus, round goby are poised to disperse, perhaps rapidly, to other areas of the mid-continent unless timely and appropriate management actions are taken to limit continued downstream movements of this nuisance species in the Chicago area waterways.

A Dispersal Barrier Demonstration Study

The development of an ANS dispersal barrier for the Chicago area waterways posed a complex array of interrelated societal concerns caused by both the acute need to stem the range expansion of round goby and the chronic need to prevent the transfer of other nonindigenous fish between the Great Lakes and the Mississippi River basin. An advisory panel of representatives from 28 different federal, state, regional, and municipal agencies, as well as industrial and environmental interests and academia, was convened to identify the most practical dispersal barriers for use in the Chicago area waterways (Moy, 1997; Keppner and Theriot, 1997). Factors affecting the choice of barriers included no interference with barge traffic, no change in the annual volume of water diverted by Chicago from Lake Michigan, variable flows, existing permit requirements to maintain water quality, recreational boating concerns, and public perception. The consensus of this group was that both electrical fields and chemical piscicide treatments could be used to reduce interbasin movements of fish. However, the use of toxicants was recommended only on a limited basis. Therefore, an electrical barrier seemed the most practical strategy for quickly slowing the spread of round goby in the Mississippi River basin and preventing the movements of other nonindigenous fish between the Great Lakes and the Mississippi River basin.

Based on these recommendations and with Congressional appropriations from the National Invasive Species Act, the Chicago District of the US Army Corps of Engineers has been examining potential methods to demonstrate and study the effectiveness of dispersal barriers in the Chicago Sanitary and Ship Canal that are designed to slow or stop the movement of aquatic nuisance species between the Great Lakes and the Mississippi River basin (US Army Corps of Engineers, 1999). Construction of a full water column electrical barrier designed to prevent both downstream and upstream movements of fish in the Canal (native species as well as nonindigenous species) should begin in 2000 (M.A. Kennedy personal communication: 2000). Meanwhile, other government agencies are examining the feasibility of using piscicides to help eradicate round goby in the Chicago area waterways.

Electrical barrier progress.

The planned electrical barrier will consist of a micro-pulsed, direct current array (Smith-Root, Inc., Vancouver, WA) comparable to that used to prevent upstream migrations of spawning sea lamprey (*Petromyzon marinus*) in some Great Lakes tributaries and to prevent fish from entering (or leaving) certain irrigation canals in the western US. Performance tests to determine the ability of prototype electrical barriers to deter round goby passage in confined laboratory and small-scale field settings have achieved success rates of about 80 percent and nearly 100 percent, respectively (J.F. Savino personal communication: 2000). The electrical barrier is scheduled to be installed in the Chicago Sanitary and Ship Canal at river mile 296.25 (river kilometer 476.67), near Romeoville, Illinois (Fig. 2), and may be operational by late in 2000. The canal at this site has a nearly uniform rectangular perimeter that measures 165 ft (50 m) wide by 25 ft (7.6 m) deep (Moy, 1999) and is located about 20 river miles (32 km) downstream from the reach in the Calumet Sag Channel where round goby abundance peaked during 1999 (Fig. 3). By fall 1999, only one round goby had ever been captured downstream of the barrier site, at river mile 290.25 (river kilometer 467.01; Fig. 2). The barrier will consist of a series of electrodes attached to the bottom of the canal and recessed into the canal walls so that barge traffic will not be impeded (Moy, 1999). Supporting electrical equipment and an emergency generator will be kept in a secure shed to provide an uninterrupted power supply. The electrode array will create a graduated, pulsed, direct current electrical field to maintain a continuous barrier throughout the water column. The electrical field is not intended to stun or kill fish but to deter their continued movement (upstream or downstream) beyond the barrier. The effectiveness of the electrical barrier system in preventing the continued downstream movement of round goby will be monitored during annual US Fish and Wildlife Service surveillance operations and its impact on the movements of other fishes will be assessed by the Illinois Natural History Survey with mark-recapture studies (J. Dettmers personal communication: 2000).

Chemical barrier progress.

Preliminary tests to determine the relative toxicity of several registered piscicide formulations to round goby and certain native fish species were conducted over a range of toxicant concentrations expected to illicit mortality levels of 25, 50, and 99 percent among groups of test fish within a 96-h period. Results of this investigation indicated that although each of the piscicides (3-trifluoromethyl-4-nitrophenol, Bayluscide®, antimycin and rotenone formulations of Noxfish® and Nusyn Noxfish®) was toxic to round goby, the sensitivity of the round goby to these chemicals was too similar to that of native fishes to provide for selective removal of round goby by common application practices (V.K. Dawson personal communication: 2000). However, newly developed delayed-release formulations of Bayluscide® and antimycin may offer substantially greater selectivity for bottom-dwelling fishes like the round goby by toxifying only the lowermost stratum of water rather than the entire water column. Encouraging results from additional tests indicate that round goby are neither attracted to nor repelled by these chemicals. Since round goby do not have a gas bladder and cannot maintain a vertical position high enough in the water column to avoid the delayed-release formulations of these piscicides, they become effectively intoxicated after a relatively brief period of exposure to these chemicals (V.K. Dawson personal communication: 2000). Other laboratory and field studies are needed to determine the feasibility and efficacy of successfully applying these piscicide formulations to control round goby in lotic ecosystems like the UMRS. If eventually registered and approved for use in the Chicago area waterways or other portions of the Mississippi River basin, the delayed-release formulations of Bayluscide® and antimycin may be most effective if applied in reaches where round goby are relatively abundant, thereby helping to reduce possible density-driven range expansion while minimizing adverse impacts to native fish.

Continued vigilance.

Surveillance activities for round goby comprise another integral component of the Chicago area waterways barrier demonstration study. These operations typically consist of brief but intensive sampling to determine the extent of the round goby's distribution and relative abundance within a nearly 75-mi (120-km) contiguous reach of waters that provide sanitary and maritime services, as well as increasing recreational opportunities, for the nations' third largest urban population. Although the multi-use character of this waterway presents a variety of logistic and technical sampling challenges, representatives from a growing number of federal, state, and local government agencies, educational institutions, industries, environmental interest groups, and the media have participated with the US Fish and Wildlife Service in these surveys and are essential to its continued success.

A variety of gear types have been used to sample for round goby since the study began in 1996. Our experience suggests that baited wire-mesh minnow traps offer the most efficient means of detecting this nocturnally active species, especially in the shallow rocky habitats that it seems to prefer. Survey results indicate that while the apparent leading edge of the round goby's distribution in the Chicago waterways advanced only 3 mi (5 km) downstream in the Calumet Sag Channel from mid-1996 to mid-1998, it progressed an additional 15 mi (24 km) further downstream to the Ship and Sanitary Canal confluence by mid-1999, and moved yet another 13 mi (21 km) downstream later that same year (Fig. 2). Sampling efforts in late-1999 also revealed that round goby abundance peaked at river mile 318 (river kilometer 512) in the Calumet Sag Channel and steadily decreased further downstream (Fig. 3).

Surveillance information like this has been essential in focusing public attention to the serious problems created by the round goby, as well as other invasive species now present in the Chicago area (e.g., Anoplophora glabripennis-Asian longhorn beetle). Continued surveillance using standardized sampling methods and mark-recapture studies will be necessary to evaluate the long-term success of the electrical barrier and the need for other management actions to prevent interbasin movements of fish via the Chicago area waterways.

Conclusions

Faced with recurring waterborne disease epidemics that plagued Chicago during the late 19th century, city administrators of that era ingeniously engineered a solution to this public health crisis by reversing the flow of the Chicago River to dilute and flush sewage away from Lake Michigan. In so doing, this massive public works project breached a low geographic barrier that previously separated the Great Lakes and Mississippi River ecosystems. This physical connection has recently facilitated the waterborne exchange of NAS between the two largest freshwater ecosystems in America and jeopardizes the survival of certain native aquatic biota. For example, zebra mussels were spread from Lake Michigan to the Mississippi River via the Chicago area waterways and now appear to be one of the leading factors contributing to the demise of the federally-endangered Higgins' eye pearlymussel (Lampsilis higginsi) in the UMRS (D.L. Strayer personal communication: 1998; A.C. Miller personal communication: 1998). Likewise, round goby have adversely affected native benthic fishes in portions of the Great Lakes and now threaten to do so in the Mississippi River basin unless their disperal can be contained.

As we enter the 21st century, there is an impending global need to explore ways to restore the biogeographic barriers that formerly separated species to protect vulnerable native species and ecosystem function. The barrier demonstration study in the Chicago Sanitary and Ship Canal is the first attempt to isolate fish in the Great Lakes from those in the Mississippi River basin. The development of practical, long-term solutions to resolve the environmental dilemmas posed by the introduction and spread of other NAS across North America requires an integrated ecosystem problem-solving process with broad-based support from all levels of government, private industry, and the general public.

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Table 1. Characteristics of several nonindigenous aquatic species recently introduced to the Upper Mississippi River System (UMRS).

Nonindigenous aquatic species recently introduced to the UMRS	Origin and year of introduction to the UMRS	Primary means of range expansion in the UMRS	Control strategy
Ctenopharyngodon idella (grass carp)	Aquaculture releases in the south-central US (1970s)	Density dependant emigration	Commercial harvest
Daphnia lumholtzi (spiny water flea)	Interbasin water transfers in the south-central US (1995)	Transported actively by vessels and passively by water currents	Public education and integrated pest management
Dreissena bugensis (quagga mussel)	Ballast water discharges in the Great Lakes (1995)	Transported actively by vessels and passively by water currents	Public education and integrated pest management
D. polymorpha (zebra mussel)	Ballast water discharges in the Great Lakes (1991)	Transported actively by vessels and passively by water currents	Public education and integrated pest management
Hypophthalmichthys nobilis (bighead carp)	Aquaculture releases in the south-central US (1970s)	Density dependant emigration	Commercial harvest
H. molitrix (silver carp)	Aquaculture releases in the south-central US (1970s)	Density dependant emigration	Commercial harvest
Lythrum salicaria (purple loosestrife)	Horticultural introduction (early 20th century)	Wind, water, and wildlife mediated seed dispersion	Public education and integrated pest management
Morone americana (white perch)	Emigration from the eastern to the western Great Lakes (1990s)	Density dependant emigration	Public education and integrated pest management
M. saxitalis (striped bass)	Aquaculture releases in south-central US (1970s)	Density dependant emigration	Public education and integrated pest management
Myriophyllum spicatum (Eurasian watermilfoil)	Aquacultural introduction (latter 20th century)	Stems fragmented and transported by vessels, wave action, and currents	Public education and integrated pest management
Neogobius melanostomus (round goby)	Ballast water discharges in the Great Lakes (1993)	Density dependant emigration; may also be transported by vessels	Public education and integrated pest management

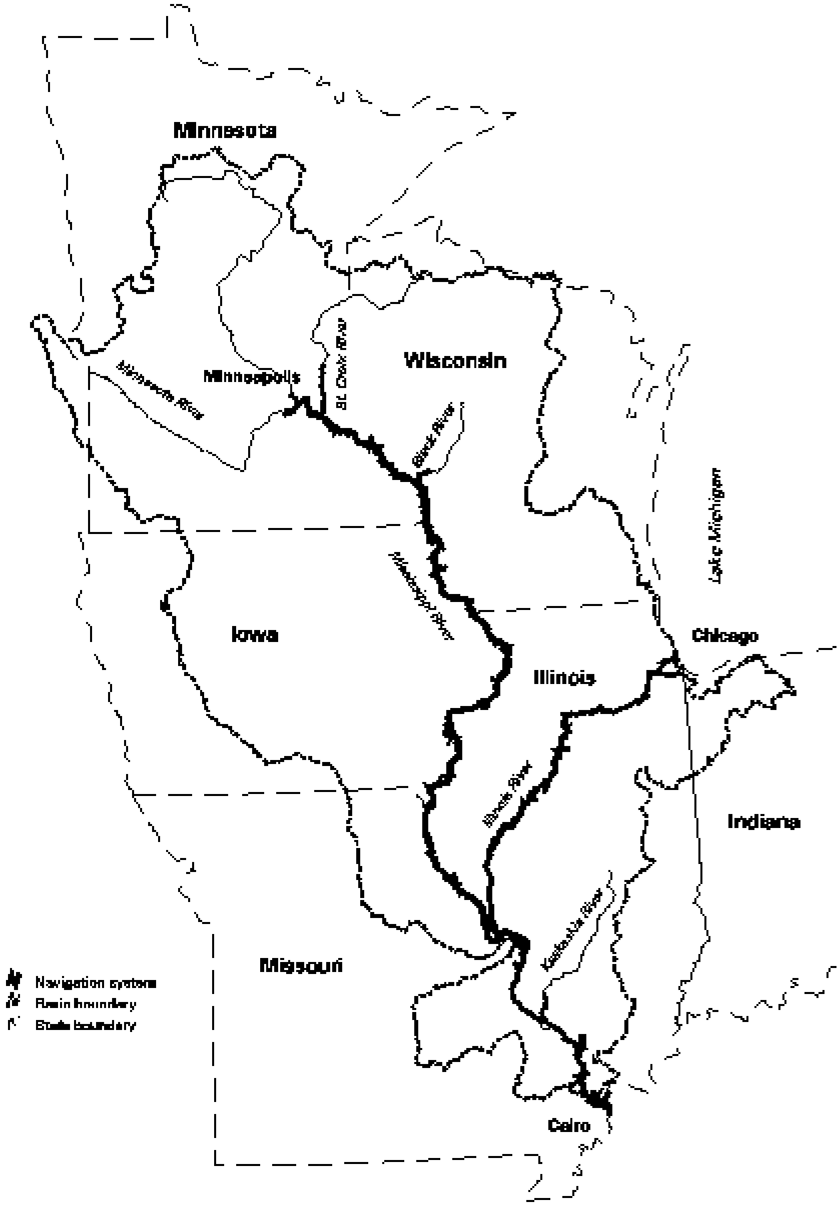

Figure 1. The upper Mississippi River drainage basin and navigation system (*courtesy of the US Geological Survey, Onalaska, WI*). Note: the navigation system includes the upper Mississippi River from Minneapolis, Minnesota to Cairo, Illinois, the Illinois River, the Chicago area waterways, and the commercially navigable portions of the Minnesota, St. Croix, Black, and Kaskaskia Rivers.

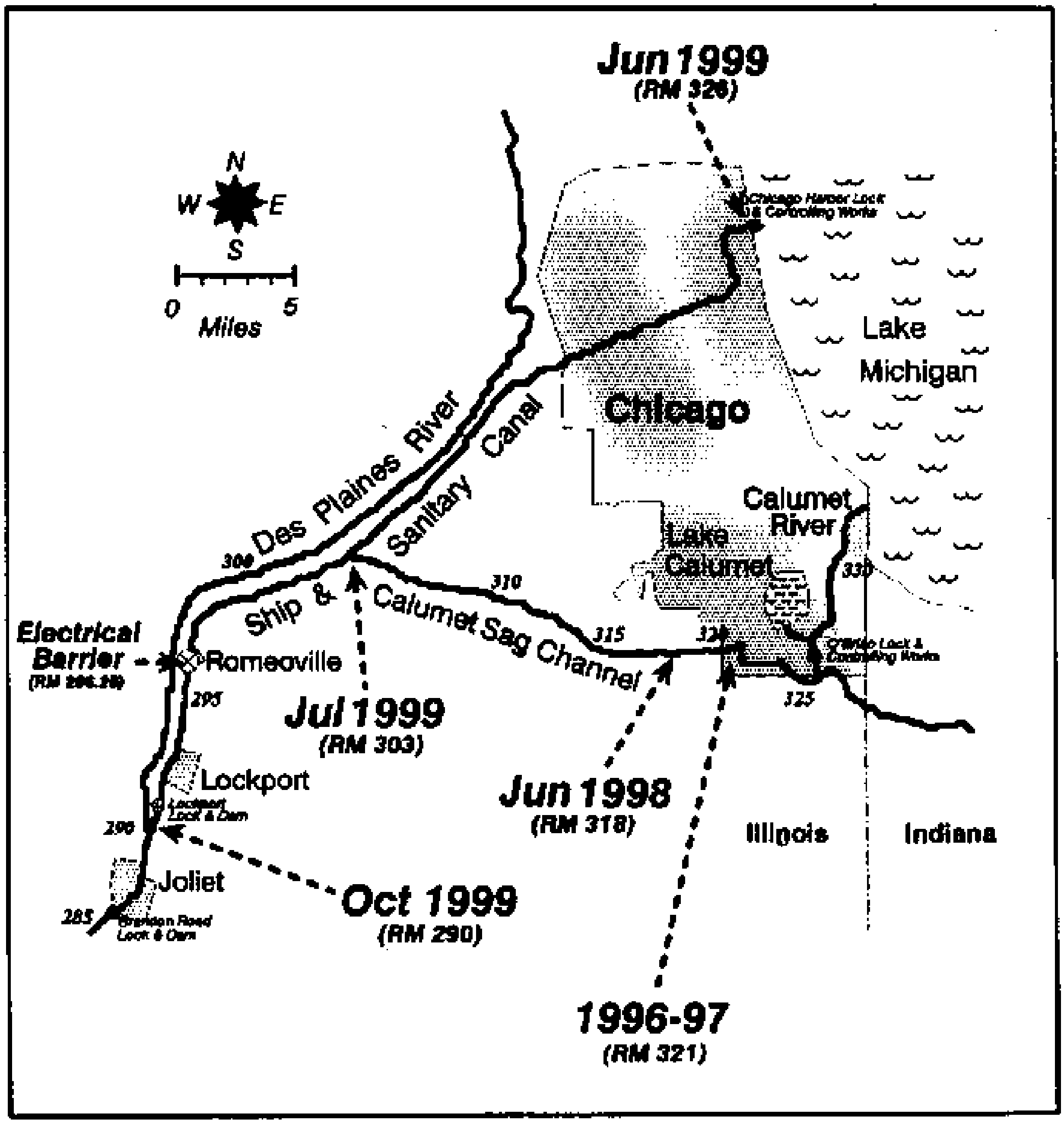

Figure 2. The annual known downstream extent of the round goby's distribution in the Chicago area waterways.

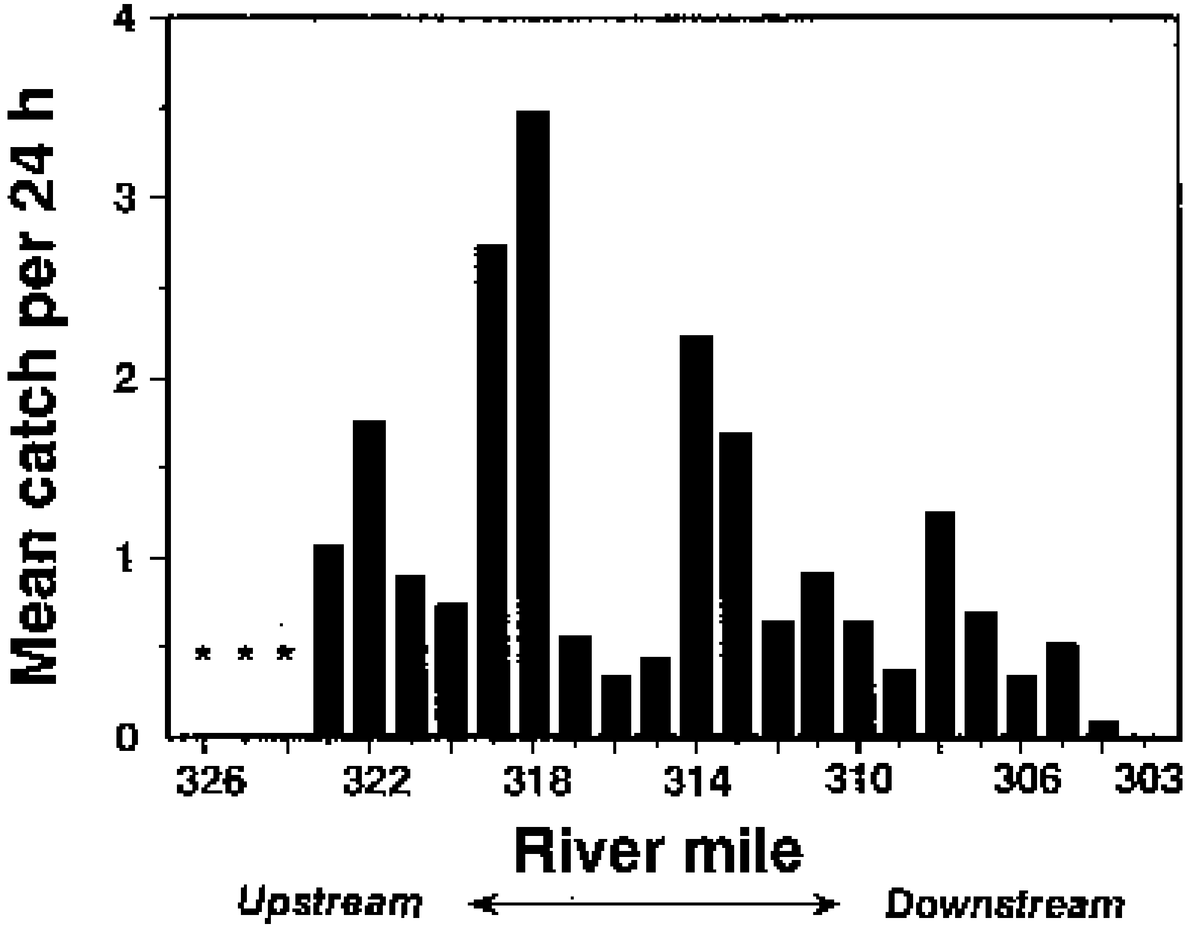

Figure 3. Mean daily catch of round goby in baited minnow traps deployed in the Little Calumet River (river mile 319-326) and the Calumet Sag Channel (river mile 303-319), 18-22 October 1999. Note: * indicates no sampling effort at this location.