Halting the Invasion: Maintaining the Health of the Great Lakes and Mississippi River Basins by Preventing Further Exchange of Aquatic Invasive Species

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Over the past century, both the Great Lakes and Mississippi River basins have been economically and ecologically devastated by the establishment of self-sustaining populations of aquatic invasive species. In the Mississippi River basin, some of the most significant damage has been attributed to the presence of reproducing populations of Asian carp in the main waterway and its tributaries. The ability of this nonindigenous invasive fish to outcompete native fish for food and habitat has led to the widespread establishment of Asian carp in the Mississippi River, impacting the natural balance of the aquatic ecosystem. Stakeholders in the Great Lakes region are acutely aware of the destructive impacts that could result if Asian carp become established as self-sustaining populations in the Great Lakes ecosystem, and are particularly concerned with the risk of a potential interbasin exchange of Asian carp through the canals and waterways that connect the Great Lakes and Mississippi River watersheds. A regional consensus has been emerging that ecological separation is the primary long-term solution needed to minimize the potential of a future invasion. However, underlying economic, environmental, social, and political realities raise a complex set of issues that must be addressed in the course of enacting this solution. Through an examination of Asian carp life cycle and behavior, current Asian carp management and prevention efforts, and the implications surrounding the potential invasion of Asian carp, this report explores the multifaceted problems posed by this highly aggressive nonindigenous invader. It also discusses the fundamental reasons why permanent and equitable measures are needed to minimize the potential for an interbasin transfer of all aquatic invasive species for every life stage between the Great Lakes and Mississippi River basins.

Environmental Practice 12:342–356 (2010)

Over the past century, both the Great Lakes and Mississippi River basins have been economically and ecologically devastated by the establishment of self-sustaining populations of aquatic invasive species. In the Mississippi River basin, some of the most significant damage has been attributed to the presence of reproducing populations of Asian carp in the main waterway and its tributaries (Mississippi Interstate Cooperative Resource Association, 2002). The ability of this nonindigenous invasive fish to outcompete native fish for food and habitat has led to the widespread establishment of Asian carp in the Mississippi River, impacting the natural balance of the aquatic ecosystem [US Geological Survey (USGS), 2003]. Stakeholders in the Great Lakes region are acutely aware of the destructive impacts that could result if Asian carp become established as self-sustaining populations in the Great Lakes ecosystem, and are particularly concerned with the risk of a potential interbasin exchange of Asian carp through the canals and waterways that connect the Great Lakes and Mississippi River watersheds [US Environmental Protection Agency (USEPA) et al., 2010]. A regional consensus has been emerging among the Great Lakes stakeholders

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 doi:10.1017/S1466046610000499

that ecological separation is the primary long-term solution needed to minimize the potential for a future invasion. However, underlying economic, environmental, social, and political realities raise a complex set of issues that must be addressed in the course of enacting this solution. Through an examination of Asian carp life cycle and behavior, current Asian carp management and prevention efforts, and the implications surrounding the potential invasion of Asian carp, this report explores the multifaceted problems posed by this highly aggressive nonindigenous invader. It also discusses the fundamental reasons why permanent and equitable measures are needed to minimize potential interbasin transfers of aquatic invasive species between the Great Lakes and Mississippi River basins.

The Great Lakes Region: An Economic and Environmental Powerhouse

Holding just under 20% of the world's surface freshwater, the binational Laurentian Great Lakes consist of the five major lakes—Ontario, Erie, Huron, Michigan, and Superior—as well as smaller lakes, bays, and connecting channels, including Lake St. Clair, the Detroit River, and the St. Mary's River. The Great Lakes watershed extends into the St. Lawrence River and encompasses the jurisdictions of eight states—Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin—and two provinces—Ontario and Québec.

The Great Lakes provide valuable ecological and economic benefits to the more than 33 million Americans and Canadians who live in the basin, including transportation for raw materials and finished goods, freshwater for industries, drinking water for communities, recreational opportunities for residents and tourists, and a dynamic ecosystem supporting diverse communities of plants and animals. The economic health of the Great Lakes region can have a direct effect on the global economy since the Great Lakes region is the world's third largest economy behind only that of the United States (US) and Japan (US Bureau of Economic Analysis, 2008; US Central Intelligence Agency, 2008).[1]

Economic analyses have found that the annual benefit from the Great Lakes recreational boating industry and commercial, sport, and tribal fisheries exceeds 16.4 billion dollars [Southwick Associates, 2007; US Army Corps of Engineers (USACE), 2008]. The value of coastal tourism is also a significant component of the region's economy. In Ohio, alone, tourism in the state's Lake Erie region supported 9.9% of Ohio's jobs and generated $10.1 billion in revenue in 2009 (Tourism Economics, 2010). If Asian carp were to invade and establish reproducing populations in the Great Lakes, the region's tourism, recreational boating industry, and recreational and commercial fisheries would be among the sectors at risk for significant impacts.

Introduction of Asian Carp into the United States

The term *Asian carp* collectively refers to four species: bighead (*Hypophthalmichthys nobilis*), silver (*Hypophthalmichthys molitrix*), black (*Mylopharyngodon piceus*) and grass (*Ctenopharyngodon idella*). In the Great Lakes region, bighead and silver carps are of the greatest immediate concern because they have established self-sustaining populations in the Mississippi River and have expanded their range close to Lake Michigan and Lake Erie. Although grass and black carps also pose a potentially serious risk to the Great Lakes ecosystem, canals and waterways are, currently, not considered the pathway of greatest concern for these species (Hill and Pegg, 2008; Mandrak and Cudmore, 2004). Individual grass carp have already been reported in four of the Great Lakes, and self-sustaining populations of black carp have not yet been discovered in the Mississippi River system (Conover, Simmonds, and Whalen, 2007; Cudmore and Mandrak, 2004; Ferber, 2001; Nico, Williams, and Jelks, 2005). Unless otherwise indicated, "Asian carp" will be used in the article to collectively discuss only the bighead and silver species.

The first documented importation of bighead, black, and silver carps can be traced back to 1972–73, when a private fish farmer in Arkansas mistakenly received the three species in a shipment of grass carp he had ordered for weed control. Although the first importation was a mistake, subsequent importations and breeding practices were not. Private farmers, as well as federal and state agencies, imported and bred grass, black, bighead, and silver carps as biological control agents for aquaculture ponds and sewage lagoons (Chick and Pegg, 2001; Egan, 2006; Nico, Williams, and Jelks, 2005). The voracious consumption habits of these four species of carp were initially considered extremely beneficial because the carps' ability to quickly and efficiently clean the ponds and lagoons contributed to an increase in facility productivity and decrease in maintenance costs.

The perception of Asian carp as a beneficial species began to change as they escaped from their intended uses into natural waterway systems. By 1980, feral individual bighead and silver carps were being captured in open waterways in Arkansas, Louisiana, and Kentucky (Williamson and Garvey,

2005). Floods in the 1980s increased the number of introduced individuals and enabled bighead and silver carp species to spread further up the Mississippi River system. By 1989, scientists had found evidence of naturally reproducing populations of bighead and silver carps in the Missouri River, a tributary of the Mississippi River (Chick and Pegg, 2001; Kolar et al., 2005).

Once in the Mississippi River system, bighead and silver carp populations grew exponentially. In a three-year span, the commercial harvest of bighead carp in the lower Mississippi River system increased from 5.5 to 55 tons, and, in some portions of the Illinois River, Asian carp now comprise more than 95% of the biomass (Chick and Pegg, 2001; Mississippi Interstate Cooperative Resource Association, 2002).

Biology and Associated Threats Posed by Asian Carp

The growth of bighead and silver carp populations in the Mississippi River basin is tied to a number of factors, including their prolific reproductive capabilities, rapid growth patterns and speed of movement, and voracious consumption habits. Asian carp achieve sexual maturity early (by age 3 for bighead carp and by age 2 for silver carp) and have high fecundity (mean carrying capacity is between 100,000 and 800,000 eggs for bighead carp and between 250,000 and 1,500,000 eggs for silver carp) (Garvey, DeGrandchamp, and Williamson, 2007; Schranka and Guy, 2002; Williamson and Garvey, 2005). Bighead and silver carps are capable of spawning multiple times over a lengthy spawning season which extends from early spring through fall (Papoulias, Chapman, and Tillitt, 2006; Schranka and Guy, 2002). Researchers believe that the carps' high reproductive potentials can be limited by the species' spawning requirements of warm (greater than 18°C/64.4°F), flowing water in tributaries at least 31 miles (50 km) long; observations have further indicated that Asian carp eggs must remain suspended in turbulent water for incubation and development to advance to the point at which hatched young can begin swimming (Chapman, 2010; Garvey, DeGrandchamp, and Williamson, 2007; Kolar et al., 2005; Lohmeyer and Garvey, 2009; Mandrak and Cudmore, 2004; Papoulias, Chapman, and Tillitt, 2006). These requirements are not absolute; scientists on the Mississippi River have caught young bighead carp in colder waters (10°–12°C/50°–53.6°F) and found successful bighead carp spawning events in backwaters with little to no flow (Mandrak and Cudmore, 2004).

Both bighead and silver carps have rapid growth patterns, with bighead carp growing up to 12 inches (30 cm) in one year in some portions of the Missouri River (Hoff, 2004). Over their lifespan, bighead carp can grow up to 60 inches long (152 cm) and weigh 110 pounds (50 Kg), and silver carp can grow up to 39 inches (99 cm) and weigh 60 pounds (27 cm); the bighead and silver carps found in the wild are more commonly sized at 40 and 20 pounds (18 and 9 Kg), respectively (Chapman, 2010; Hoff, 2004). Asian carp also have the ability to move quickly through their environment. In the Mississippi river system, researchers have documented bighead carp migrating 40–50 miles (64–81 km) in one year and silver carp moving more than 50 miles (80.5 km) downstream during December and January, when the water is the coldest (Mandrak and Cudmore, 2004; USGS, 2003).

Bighead and silver carps are voracious, nonselective filter feeders, adapting their diets to their environment to consume a wide range of zooplankton, phytoplankton, algae, and detritus at a daily rate of 2–3 times their body weight (Dong and Li, 1994; Sampson, Chick, and Pegg, 2009). The Asian carp's consumption of organic matter from the base of the food web (see Figure 1) overlaps with the diets of certain native species, leading to the potential for Asian carp to displace native fish, mussels, and other species (Sampson, Chick, and Pegg, 2009; Tucker et al., 1996). Studies indicate Asian carp populations thrive in productive, near-shore habitat where the density of plankton is high; their growth, however, is limited in deep, open-water habitat where their food supply may be scarce (Cooke and Hill, 2010; Hill and Pegg, 2008).

In addition to the threat Asian carp pose to native fauna, silver carp also pose a health and safety risk to people. Silver carp have a propensity to fly out of the water when disturbed by noise and have been documented jumping up to 10 feet (3 m) into the air when reacting to the sound of outboard motors on recreational vessels (Hoff, 2004). Silver carp have caused numerous injuries to boaters and water-skiers in the Mississippi River system, including lacerations and broken bones, as well as property damage to boats and other equipment (Hoff, 2004; USGS, 2003).

The Potential for Asian Carp to Invade the Great Lakes

A number of researchers have conducted risk assessments of whether Asian carp can survive in the Great Lakes. Although an early assessment by Kolar and Lodge (2002) found that silver carp would have a low likelihood of im-

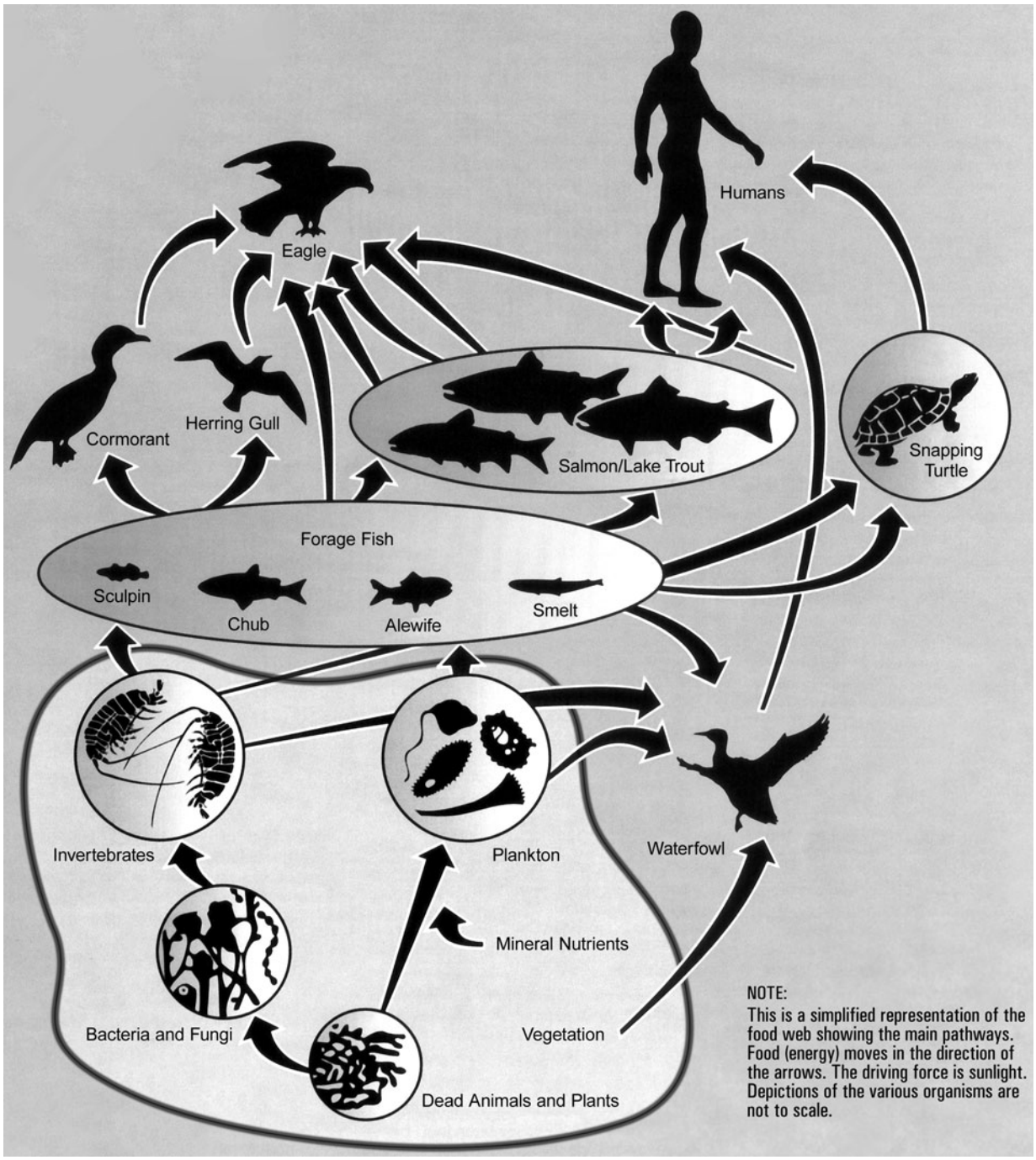

Figure 1. Great Lakes food-web schematic diagram. Asian carp are planktivorous species and consume organic matter at the bottom of the food web as delineated by the irregularly shaped area in the schematic diagram. Image source: Fuller, Shear, and Wittig (1995).

pacting the Great Lakes, the authors declared the assessment was limited because the model failed to account for unique biological characteristics of the species. Later assessments based on behavioral characteristics of native Asian carp populations in China and the established populations in the Mississippi River show a high risk of establishment, spread, and impact in the Great Lakes watershed (Hill and Pegg, 2008; Kolar et al., 2005; Mandrak and Cudmore, 2004).

Given the wide range of environmental conditions that exist in the Great Lakes ecosystem, the predicted risk of Asian carp establishment and associated level of impact varies depending on the temperature and depth of water and the availability of an adequate food supply and suitable spawning habitat (Hill and Pegg, 2008; Kolar et al., 2005; Mandrak and Cudmore, 2004). Researchers have predicted the nearshore areas and tributaries of the Great Lakes are at a greater risk for invasion than the deep, cold portions of the lakes (Cooke and Hill, 2010; Hill and Pegg, 2008; Kolar et al., 2005). There is particular concern that the western basin of Lake Erie, and some embayments and wetlands in other portions of the Great Lakes have sufficient levels of plankton to meet Asian carp food requirements (Cooke and Hill, 2010; Hill and Pegg, 2008). However, scientists have not reached a consensus on whether conditions in the Great Lakes are satisfactory to support Asian carp reproduction (Golowenski, 2010). Some researchers have projected that the potential for Asian carp to establish self-sustaining populations in the Great Lakes has been reduced by existing invasive species, namely, zebra and quagga mussels, which have significantly depleted native plankton supplies (Cooke and Hill, 2010; Flesher, 2010). There is a clear need for more peer-reviewed research regarding the sustainability and potential impacts of Asian carp in the Great Lakes.

Asian Carp Knocking on the Doors of the Great Lakes Basin: History in the Making

Federal officials have identified more than 30 potential pathways by which Asian carp may enter the Great Lakes, including canals and waterways, human activities (e.g., bait bucket release and intentional live release) and natural processes (e.g., bird consuming fish eggs and depositing in other water bodies) (Conover, Simmonds, and Whalen, 2007; Eaton, 2010; Higbee and Glassner-Shwayder, 2004). Of these pathways are of significant concern, the canals and waterways that connect the Mississippi River and Great Lakes basins pose the greatest risk for an interbasin exchange and draw the most political attention (Eaton, 2010; USEPA et al., 2010). Further comprehensive research is needed to identify and address the risk of all specific locations and pathways by which Asian carp could potentially invade the Great Lakes.

Federal agencies have identified at least 32 potential hydrologic connection points where there is a potential for an interbasin transfer of an aquatic invasive species through a canal or waterway of the Mississippi River and Great Lakes watersheds; of those, 19 are rated to have a high, medium, or acute risk of transfer (USACE, 2010e,f). The Chicago Area Waterway System (CAWS) and the Illinois Waterway (see Figure 2) are considered to hold the greatest risk for a potential exchange of aquatic invasive species since these man-made canals form the only known permanent and continuous hydrologic connection between the Mississippi River and Great Lakes watersheds; other connections are largely formed through temporary flooding events (USACE, 2010f).

In regards to the temporary hydrologic connection points, management actions have been implemented at two locations. In 2010, the Indiana Department of Natural Resources (IN DNR) identified and addressed a potential risk for an interbasin transfer of Asian carp through a temporary hydrologic connection between the Wabash River and the Maumee River. The Wabash River is a subtributary of the Mississippi River by way of the Ohio River, and the Maumee River is a tributary of Lake Erie. Under normal conditions, the two rivers flow into separate drainage basins; during floods, however, the rivers can commingle water through a natural 100 year floodplain.[2] Although Asian carp have been in the Wabash River since at least 1996, the IN DNR heightened the risk-assessment level for the potential of Asian carp to breach the watershed divide in May 2010. The change in the assessed risk was due to floods breaching the watershed divide at least twice during 2010 storms and the discovery of a population of juvenile silver carp 105 miles (169 km) downstream from the mouth of the Little Wabash River in Indiana at a location where the juveniles could potentially reach the connecting floodplain (IN DNR, 2010a). In light of the heightened risk, the IN DNR installed 1,200 feet (366 m) of chain-link and mesh fencing in the Eagle Marsh as a temporary measure to impede the potential movement of Asian carp while longer-term monitoring and prevention measures are studied and discussed by federal and state partners (IN DNR, 2010a,b; Tetra Tech, 2010).

At the second location, the Des Plaines River and the Deep Run Creek, upper tributaries of the Illinois River, flow parallel to the Chicago Sanitary and Ship Canal (CSSC), which has a direct connection to Lake Michigan (see Figure 2). Heavy rains and flood events can and have created a temporary hydrologic connection between these segments that has provided invasive species with a pathway to traverse the watershed divide between the Mississippi River and Great Lakes basins (Conover, Simmonds, and Whalen, 2007; USACE, 2010c; USEPA et al., 2010). In 2010, the USACE installed the Des Plaines Bypass Barrier, roughly 13 miles (30 km) of chain-link and mesh fencing along the

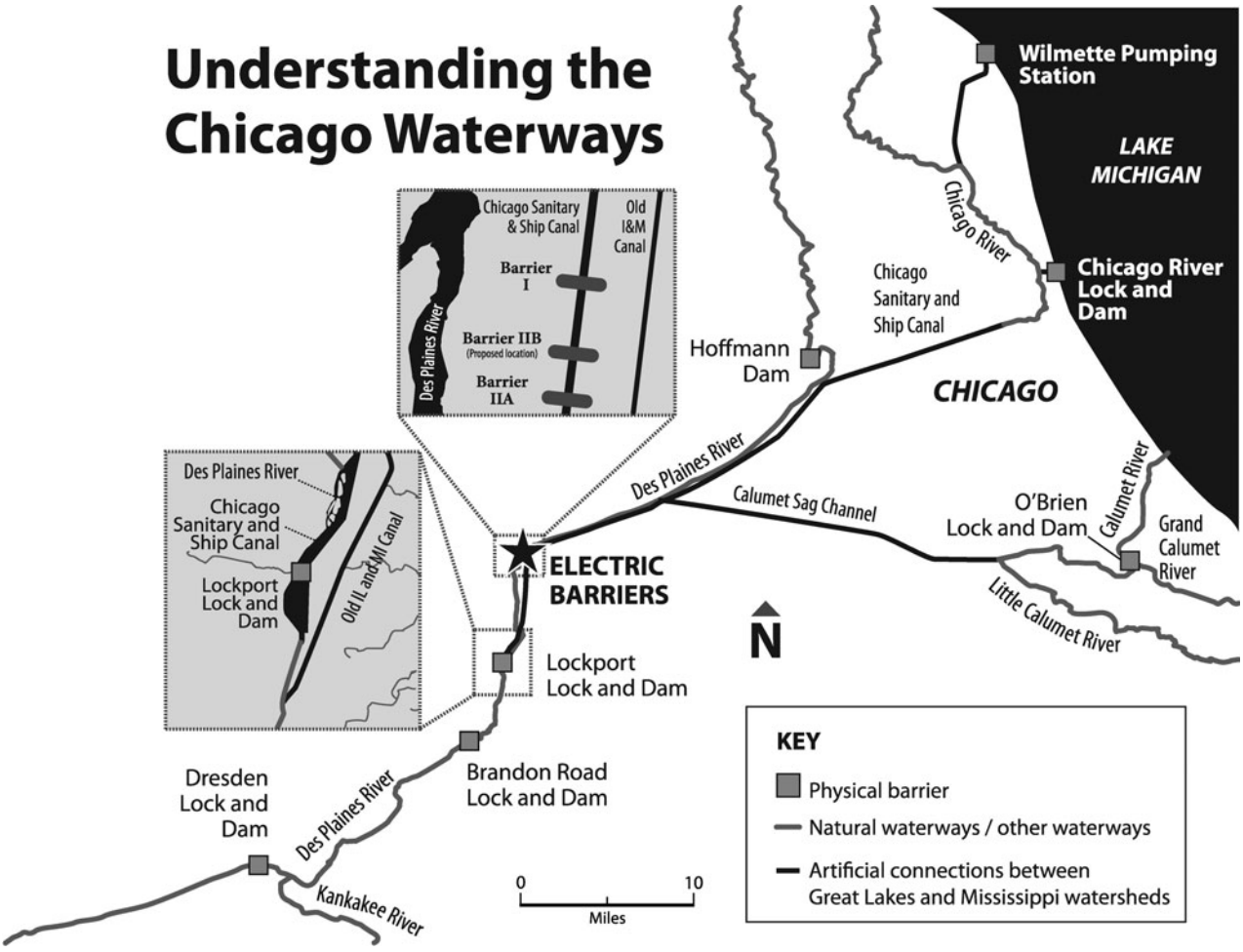

Figure 2. Understanding the Chicago waterways. It took nearly a century to engineer and construct the Chicago Area Waterway System and the Illinois Waterway. These man-made canal systems established a continuous artificial connection between the Mississippi River and Great Lakes basins, increasing the risk of an interbasin exchange of aquatic invasive species. Image source: Michigan Sea Grant (2010).

Des Plaines River and Illinois and Michigan Canal (I&M Canal), as a temporary measure to prevent fish from passing between the waterways (USACE, 2010a,c). Both the Eagle Marsh Fencing and the Des Plaines Bypass Barrier were funded through the Great Lakes Restoration Initiative (IN DNR, 2010b; USACE, 2010a).

The Ohio Department of Natural Resources (OH DNR) has also identified and conducted a preliminary risk assessment on two other potential connection areas where Asian carp can breach the divide between the Mississippi River and Great Lakes watersheds: the Miami and Erie Canal in western Ohio and the Ohio and Erie Canal in eastern Ohio. Both of these areas have a mixture of man-made and natural pathways by which the watersheds can potentially connect during flooding events. In July 2010, the OH DNR determined that these connection points were a low crossing risk because Asian carp had not yet established populations in the waterways of Ohio and several dams and locks could impede the movement of the carp northward (OH DNR, 2010).

The Chicago Area Waterway System and Illinois Waterway: Public Benefit or Public Nuisance?

As previously noted, resource managers, researchers, and publicly elected officials continue to rate the CAWS and

the Illinois Waterway as the hydrologic connection with the greatest risk for allowing a potential interbasin transfer of Asian carp (USACE 2010f; USEPA et al., 2010). This assessment is based on the permanency of the hydrologic connection between the Mississippi River and Great Lakes watersheds, along with the mounting evidence that individual Asian carp may have already traversed the divide between the systems and are moving closer to Lake Michigan.

Prior to the construction of the CAWS and the Illinois Waterway, there was no permanent natural hydrologic connection between the Mississippi River and Great Lakes basins. The CAWS and Illinois Waterway created an extensive network of artificial canals and channels that include the North Branch, South Branch, and Main Stem of the Illinois River; the Calumet-Sag Channel; the North Shore Channel; and the CSSC (see Figure 2). Over time, these anthropogenically modified waterways have evolved to provide highly valued economic and societal services especially to Illinois and Indiana.

The original stem of the CAWS, the I&M Canal, was constructed between 1836 and 1848 to facilitate the movement of cargo between the Great Lakes and the Mississippi River basins (see Figure 2). From the late 1870s through the early 1900s, the use and footprint of the CAWS were expanded and the natural flow of the Chicago River was reversed to drain into the Illinois River rather than Lake Michigan. Prior to the construction of the CSSC, the City of Chicago discharged its sewage into Lake Michigan and its tributaries. Because Chicago also obtained its drinking water from the Lake, severe flooding in mid-1880s raised concerns that future flooding could potentially lead to contaminated drinking water and a widespread public health epidemic. The CSSC was engineered to direct Chicago's sewage into the Illinois River rather than Lake Michigan (Hill, 2000). In 1933, the system was completed with the construction of the Illinois Waterway, enabling barges with up to a 9-foot (2.7 m) draft to pass directly from Great Lakes harbors into the Mississippi River waterways. The CAWS and Illinois Waterway now serve as the backbone of the drainage, wastewater, flood control, and waterborne navigation system of the greater Chicago metropolitan area (USACE, 2010f).

Although highly acclaimed in the 20th century for their ability to provide beneficial services related to transportation and wastewater treatment, the CAWS and the Illinois Waterway have led to an environmental crisis in the 21st century. By establishing a hydrologic connection between the Mississippi River and Great Lakes, this engineered waterway system provides a permanent passageway for the exchange of aquatic invasive species. The invasions of zebra mussel and round goby from the Great Lakes into the Mississippi River serve as examples of this phenomenon. Most recently, the risk of an Asian carp invasion from the Mississippi and Illinois Rivers into Lake Michigan and the Great Lakes basin poses an environmental and economic emergency for the Great Lakes region.

The potential risk of an Asian carp invasion of the Great Lakes was first publicly raised in the early 1990s when rapidly expanding Asian carp populations were found migrating through the Mississippi and Illinois Rivers in the direction of the Great Lakes basin (Chick, 2002). The potential for an Asian carp invasion was heightened in 2000 when thousands of immature bighead carp were caught in the lower portion of the Illinois River. In the spring of 2002, survey teams found Asian carp at a site in the Des Plaines River, only 52 miles from Lake Michigan [Dispersal Barrier Advisory Panel (DBAP, 2002)]. Since then, carp have been steadily migrating closer to Lake Michigan. In the fall of 2009 and spring of 2010, environmental deoxyribonucleic acid (eDNA)[3] monitoring results matching the DNA of bighead and silver carps were confirmed in water samples from the Calumet-Sag Channel, the North Shore Channel, and the outlet of the Chicago River (Lodge Laboratory, 2010; USACE, 2009, 2010b,g). In December 2009, a dead bighead carp was retrieved within the CSSC, 500 feet (152 m) above the Lockport Pool and Dam, about 43 miles (69.2 km) from Lake Michigan. This was the first specimen of carp found within the CAWS since earlier eDNA testing had indicated the presence of Asian carp in the area [Illinois Department of Natural Resources (IL DNR, 2009)]. In June of 2010, a live 19.6-pound bighead carp was discovered in Lake Calumet, 6 miles (9.6 km) from Lake Michigan. Evidence from eDNA and the June 2010 capture of a live bighead carp in Lake Calumet suggest the presence of individual carp upstream (north) of the electric dispersal barrier system, discussed further in the subsequent section [Asian Carp Regional Coordinating Committee (ACRCC, 2010)]. However, the absence of Asian carp in follow-up monitoring efforts is an indication that the number of Asian carp near the Great Lakes is relatively small (USACE, 2010d,e).

The collected eDNA and fish specimens provide compelling evidence that Asian carp have traversed the Great Lakes–Mississippi River watershed divide through the CAWS and Illinois Waterway and serve as the primary bases for implementing immediate regulatory and management action (Lodge Laboratory, 2010; USACE, 2009). However,

given the potential for Asian carp to be introduced into the Great Lakes watershed through other anthropogenic and natural pathways, this evidence does not provide 100% certainty that live Asian carp have breached the divide through the canals and waterways (Eaton, 2010; Egan, 2010). Despite the lack of scientific certainty as to the proximity of Asian carp to the Great Lakes and the pathway(s) responsible for facilitating their movement, multiple stakeholders agree that the precautionary principle should guide the management practices and policies aimed at preventing an invasion and averting future, irreversible damage (USEPA et al., 2010). As defined during the 1992 United Nations (UN) Conference on Environment and Development, the *precautionary principle* holds that

> [w]here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (UN, 1992)

Current Management Practices and Policies

The cornerstone of management measures to impede the movement of Asian carp into the Great Lakes has been the construction and operation of an electric dispersal barrier system in the southern end of the CSSC (river mile 296.5) near Romeoville, Illinois, approximately 25 miles (40.2 km) from Lake Michigan. Originally authorized by the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (P.L. 101-646), as amended by the National Invasive Species Act of 1996 (P.L. 94-132), the USACE was given the responsibility "to identify an environmentally sound method for preventing the exchange of aquatic invasive species between the Mississippi River and Great Lakes basins" (USACE, 2010d). The resulting Dispersal Barrier System consists of three separate barriers, which are designed to emit a low-voltage, pulsing electric current through steel cables secured to the bottom of the canal; the current creates an electric field to deter both the upstream and downstream movement of fish (Stokstad, 2003; USACE, 2010d).

The first component of the system, Barrier I, was funded in 1996 as a demonstration barrier to impede the movement of invasive fish, with a particular emphasis on preventing the movement of invasive Eurasian ruffe (*Gymnocephalus cernuus*), round goby (*Neogobius melanostomus*), and white perch (*Morone americana*) from the Great Lakes into the Mississippi River basin (DBAP, 2002; Raloff, 1999; Ruffe Control Committee, 1996; USACE, 2010d). By the time Barrier I became operational in April 2002, round goby and white perch had already breached the watershed divide, and feral Asian carp had been found approximately 22 miles (35.4 km) south (downstream) of Barrier I, these developments shifted the focus of prevention efforts to Asian carp (DBAP, 2003; Stokstad, 2003; USACE, 2010d).

In 2005, the USACE was provided authorization through the Water Resources Development Act (WRDA) of 1986 (P.L. 99-662), as modified by section 345 of the District of Columbia Appropriations Act of 2005 (P.L. 108-335), to upgrade the original demonstration barrier, originally built to function for a limited 3-year span. Under this modification, the USACE was also authorized to build and operate permanent Barriers IIA and IIB, located 800–1,300 feet (243.8–396.2 m) downstream of Barrier I (see Figure 2) in order to reinforce the original barrier and generate a more powerful electric field over a larger area. Barrier II was completed in 2006 and put into operation in April 2009; Barrier IIB is scheduled to become operational in late 2010 (USACE, 2010d).

To provide guidance in the development of the dispersal barrier system, a multi-stakeholder group, the DBAP, was convened by the USACE in 1996. The DBAP is comprised of members with a wide variety of expertise, including field and research biologists, engineers, regulators, barge operators, and commercial water users, representing multiple international, federal, state, regional, municipal, commercial, academic, and environmental groups and agencies [University of Wisconsin Sea Grant Institute (UWSG), 2006]. Since 2002, the focus of the DBAP has been concentrated on developing rapid response plans to prioritize actions if and when Asian carp were discovered in close proximity to the dispersal barrier system (Moy, 2010). From its inception, the DBAP has recognized the importance of impeding the exchange of *all* aquatic invasive species between the Mississippi River and Great Lakes basins (Moy, 2010; UWSG, 2006). The DBAP has also acknowledged the dispersal barrier may not effectively prevent interbasin exchanges of every life stage of invasive fish or other genera of aquatic invasive species (UWSG, 2006). Nevertheless, public officials and researchers agree that the barrier system has played a key role in impeding the establishment of self-sustaining populations of Asian carp upstream (north) of the barrier (USEPA et al., 2010).

In addition to the electric dispersal barrier, federal and state agencies have also been engaged in a number of other management activities in attempts to stop Asian carp populations in the Mississippi River from expanding their range. In 2007, the Aquatic Nuisance Species Task Force (ANS

Task Force) Asian Carp Working Group developed a comprehensive national Asian carp management and control plan. Developed by private and public sector fisheries professionals, aquaculturists, and aquatic ecologists—delineates goals and strategies to prevent, control, and mitigate adverse effects of Asian carp and addresses public outreach, research, and evaluation methods for Asian carp management and control (Conover, Simmonds, and Whalen, 2007). Although the ANS Task Force approved of the Asian carp management and control plan in 2007, implementation of the plan's strategies and recommendations, estimated at $286 million over a 20-year period, has yet to be comprehensively financed.

The Asian carp management and control plan and the work of the DBAP Committee helped provide a foundation for the 2010 Asian Carp Control Strategy Framework (hereafter, Framework). In response to the Asian carp threat to the Great Lakes, the Framework was developed as a collaborative effort of the ACRCC, comprised of representatives from the USEPA, the IL DNR, the US Coast Guard (USCG), the USACE, the US Fish and Wildlife Service (USFWS), and the USGS. Released in draft form in February 2010 and updated in May 2010, the Framework provides a blueprint for federal, state, and local agencies to work together on monitoring, control, and removal efforts. The Framework includes short-term and long-term strategies for combating the invasion of Asian carp; a clarification of the roles and responsibilities of the federal, state, municipal and other agencies involved; and an identification of funding sources to pay for immediate action (USEPA et al., 2010).

One of the management priorities of the Framework is to establish a comprehensive monitoring system for Asian carp in the CAWS. The monitoring plan is focused in the following areas: systematically determining the distribution and abundance of Asian carp in the waterway system, removing any Asian carp found in the CAWS, defining the location of the leading edge and reproduction of Asian carp populations, and identifying where there is a need for specific response actions in portions of the CAWS (Rogner, 2010). Monitoring techniques being used include water sampling for eDNA and conventional sampling for actual specimens.

Use of eDNA as an early detection and monitoring tool was developed by researchers affiliated with the University of Notre Dame and the Nature Conservancy to rapidly screen water samples for DNA fragments (e.g. shed scales, excrement) of silver and bighead carps (Lodge Laboratory, 2010). This technique is based on extracting DNA in the lab from water samples collected in the field to identify genetic markers unique to bighead and silver carps. While this monitoring technique is considered critical in the early detection of Asian carp, it is limited to providing information on whether a species is present or absent (Blume et al., 2010; Lodge Laboratory, 2010). Current analysis of eDNA results does not determine how many fish are present, their size or age, or the actual location of the fish in relation to where the eDNA sample was taken (Lodge Laboratory, 2010; USACE, 2010b). Researchers are working on further studies to improve scientific understanding and analysis of eDNA (USACE, 2010b).

Conventional techniques being used to monitor and control Asian carp populations include electroshocking, netting, fishing, and the use of piscicides (USEPA et al., 2010). Resource managers have been using rotenone for Asian carp monitoring and control operations that require the use of piscides due to its relatively low toxicity to non-aquatic organisms and short half-life when applied correctly (0.005–0.250 mg/liter) (American Fisheries Society, 2000; IL DNR, 2009; US Bureau of Reclamation, 2007). However, rotenone's effectiveness as a monitoring mechanism may be limited when a channel or river is deep, since Asian carp sink when exposed to lethal doses (Chapman et al., 2003). Resource managers have also recognized electroshocking, netting, and fishing techniques may have limited success when Asian carp are present in a system in low numbers (USACE, 2010d). In December 2009, the Asian Carp Rapid Response Workgroup, led by the IL DNR, applied rotenone in the CSSC to control and monitor Asian carp while the electric barrier was shut down for routine maintenance. As mentioned previously, this extensive monitoring operation retrieved one bighead carp north of the Lockport Lock and Dam but south (downstream) of the electric barrier system (IL DNR, 2009).

Researchers and government officials are continuing to investigate the efficacy of several new management techniques to impede the migration of Asian carp toward Lake Michigan, including, but not limited to, building and operating an acoustic sound barrier, encouraging commercial and recreational harvesting, and developing selective biological control agents (USEPA et al., 2010).

The Sustainability of the Current Management Model Is Questionable

In assessing whether the current management model is sustainable, it is necessary to examine both its economic

feasibility and the level at which it can effectively prevent the movement of Asian carp into the Great Lakes. As to the economic side, the current management model is resource intensive. If implemented fully, the Framework is projected to cost $78 million (USEPA et al., 2010). Expenditures for construction of the electric dispersal barrier have also been significant. Through fiscal year 2007, $4 million had been spent on the planning, design, construction, and ongoing operation and maintenance of Barrier I. Prior to 2007, the bulk of the operating and maintenance costs were primarily shouldered by the Great Lakes states, especially Illinois (DBAP, 2003). In WRDA of 2007 (P.L. 110-114), Congress authorized the USACE to operate the barriers at full federal cost. Barrier II, originally authorized for $9.1 million, has a projected total project cost of $16 million for completion of both Barrier IIA and Barrier IIB (USACE, 2010d). These construction costs do not take into account the hefty annual operating and maintenance costs for the entire dispersal barrier system.

In addition to funding, Asian carp management involves intensive human resources. Between February and July of 2010, the IL DNR deployed 3,200 hours of labor for monitoring and sampling the waters above (north) the electric barrier for Asian carp (Rogner, 2010). Given the level of expenditures invested thus far to prevent Asian carp invasion into the Great Lakes, the economic sustainability of management efforts is an important issue to be considered, especially in determining how this problem can be addressed cost effectively.

Another factor that needs to be taken into account is the technical feasibility of preventing the Asian carp from invading the Great Lakes through canals and waterways. Despite the commitment of state and federal agencies to continue implementing monitoring and management measures, the current management regime does not guarantee complete protection. Both the electric dispersal barrier and conventional monitoring techniques have inherent limitations in their abilities to impede movement of all life stages of Asian carp and to provide comprehensive management support (USACE, 2010d). As a discussion on acoustic barriers summarizes:

> Unlike fish protection wherein any reduction in stress, delay, or mortality is beneficial, the barrier that protects a waterway from a robust, prolific, and harmful invader must be very nearly perfect because even one gravid female getting through can, as a worse case, lead to a successful invasion and establishment of a population beyond the barrier. (Popper and Schilt, 2008)

Given the different pathways of introduction for Asian carp, no single management technique will provide 100% protection against an Asian carp invasion of the Great Lakes. Nevertheless, a sustainable solution is needed to move the region closer toward the goal of permanently preventing the passage of aquatic invasive species—including but not limited to the Asian carp—between the Great Lakes and Mississippi River basins.

As evidence mounts that Asian carp are on the threshold, or may already be present, in the Great Lakes watershed in low numbers, the federal and state governments are facing increased pressure to design and implement a sustainable solution to prevent the transfer of invasive species between the watersheds. In December 2009, several Great Lakes states, led by Michigan, took the issue to the Supreme Court with a request that included temporarily closing the O'Brien Lock in the Calumet-Sag Channel and the Chicago Controlling Works in the Chicago River. After the Supreme Court declined to hear the matter [*Michigan v. Illinois*, 130 S. Ct. 2397 (2010); *Michigan v. Illinois*, 130 S. Ct. 1166 (2010)], the states turned to the US District Court in Northern Illinois (*Michigan et al. v. US Army Corps of Engineers et al.*, Case No. 1:10-cv-04457, N.D. Ill.). As of November 2010, the District Court has heard oral arguments from the parties and is in the process of considering whether the operation of the CAWS constitutes a public nuisance and, if so, which temporary remedies should be granted until a permanent solution can be implemented.

Ecological Separation: A Growing Regional Consensus

Despite the disagreement over the closure of the locks, a consensus has been building, especially among state agencies, governors tribes, congressional representatives, municipalities, nongovernmental organizations, portions of the business sector, and private citizens, that ecological separation is the most prudent way to halt the interbasin transfer of aquatic invasive species via the canals and waterways connecting the Mississippi River and Great Lakes basins. The method for achieving this goal, however, is challenging. There is concern among some stakeholders that implementing ecological separation is neither economically nor technically feasible (UnLock Our Jobs, 2010). Nevertheless, the state and provincial governments in the Great Lakes region, through the Great Lakes Commission (hereafter, Commission), have unanimously agreed that "ecological separation is the best permanent solution to preventing the exchange of invasive species" and are ac-

tively pursuing efforts to develop and analyze realistic options to implement this goal (Commission, 2010).

Although the term *ecological separation* has been defined in a number of ways by different stakeholders in the region, the ultimate goal is to enact measures that permanently halt the movement of all aquatic organisms life stages of aquatic organisms between the Great Lakes and Mississippi River basins.

An early and politically significant articulation of support for ecological separation emerged from the 2003 Aquatic Invasive Species Summit cohosted by Chicago Mayor Richard M. Daley and the USFWS. This event convened experts from around the world to discuss long-term solutions to prevent the exchange of aquatic invasive species between the Great Lakes and Mississippi River basins and concluded with the clear message that the basins "should be restored as separate and distinct systems" (Chicago Department of Environment et al., 2004). The summit focused clearly on hydrologic separation and the urgent need for permanent action:

> The [CAWS] provides an opportune location to permanently alter a man-made connection to halt the spread of aquatic invasive species between these two basins. It is vital to identify approaches that can be implemented effectively, efficiently and economically while also maintaining commerce and protecting water quality. Now is the time to demonstrate leadership and commitment by permanently closing this revolving door on aquatic invasive species. With each delay, another opportunity is lost to permanently protect the health of the Great Lakes and Mississippi basins. (Chicago Department of Environment et al., 2004)

The call for permanent separation of the Great Lakes and Mississippi River systems was voiced again in 2004 as part of the Great Lakes Regional Collaboration (GLRC). Established by executive order under President George W. Bush, the GLRC has functioned as a multistakeholder initiative led by the federal Interagency Great Lakes Task Force. Under the GLRC, more than 1,500 federal, state, and local officials and interested stakeholders collaboratively produced a blueprint for a comprehensive restoration and protection program for the region. One of the GLRC's key initiatives calls for the preventing the introduction and spread of aquatic invasive species in the Great Lakes region and recommends the completion of "a study of options for permanent hydrological and/or biological separation of the Great Lakes and Mississippi River systems" (GLRC, 2005).

The Great Lakes Commission has viewed the threat of Asian carp invasion of Great Lakes as an urgent priority for nearly two decades. Established in 1955 as a public agency, the Commission facilitates collaboration among its 10 Great Lakes member states and associate member provinces to protect the region's environmental and economic health. The Commission first went on record to address the Asian carp invasion threat in 2002 with a resolution urging the USACE and the USFWS, in cooperation with other appropriate federal and state agencies, to complete phase II of the electric dispersal barrier system immediately and to include installation of backup power capability (Commission, 2002). In February 2010, the Commission unanimously adopted a resolution that recognized ecological separation of the Great Lakes and Mississippi River watersheds as the best, permanent solution to preventing the movement of aquatic invasive species between the watersheds. The 2010 resolution calls for a unified, immediate, and substantial commitment of resources to investigate and identify alternatives to achieve ecological separation and address existing uses of the CAWS (Commission, 2010).

Meeting the Challenges to Ecologically Separate the Watersheds

The process of ecologically separating the watersheds raises a complex set of political and engineering issues because of the numerous stakeholder interests in protecting an array of beneficial uses, including commercial shipping and recreational boating, wastewater treatment, navigation, flood control, and private property ownership. Achieving ecological separation likely will require modifying existing water infrastructure and/or the construction of physical barriers to prevent the exchange of water while maintaining the system's benefits.

In section 3061(d) of WRDA 2007, Congress authorized the USACE to conduct a Great Lakes and Mississippi River Inter-Basin Study (GLMRIS), a feasibility study of "the range of options and technologies available to prevent the spread of aquatic nuisance species between the Great Lakes and Mississippi River Basins through the Chicago Sanitary and Ship Canal and other aquatic pathways." In November 2010, the USACE released a draft project plan, announced that it will hold public scoping meetings, and described the two parallel tracks it will follow to conduct the study (Kirksey, 2010; USACE, 2010f). The first track will focus specifically on the CAWS and evaluate the challenges and options for enacting permanent measures to prevent the exchange of *all aquatic invasive species via the CAWS*. The second track will identify and characterize the potential risk of exchange at *all other hydrologic connections* between the Great Lakes and

Mississippi River basins (USACE, 2010e,f). In November 2010, the USACE also released a preliminary report providing an overview of the "Other Pathways" study sites (USACE, 2010f). The USACE has projected that final recommendations for the first track of the report will not be released before 2015, assuming congressional authorization and funding is maintained (Kirksey, 2010; USACE, 2010f).

In response to the perceived slow progress and protracted time frame for the publication of GLMRIS, the Great Lakes states and cities have led a call to expedite action on implementing effective long-term solutions to minimize the exchange of aquatic invasive species between the Mississippi River and Great Lakes basins. At the behest of several Great Lakes governors, President Barack Obama appointed John Goss, a former head of the IN DNR, to the position of Asian Carp Director in September 2010 to better coordinate federal Asian carp control efforts (Council of Environmental Quality, 2010). Furthermore, in June 2010, Senators Debbie Stabenow (D-MI) and Richard Durbin (D-IL) introduced the Asian Carp Permanent Prevention Act, which would order the USACE to accelerate their study of hydrologic separation [S. 3553, 111th Cong. (2010); H.R. 5625, 111th Cong. (2010)].

The Great Lakes states, provinces and cities believe that ecological separation is the primary mechanism needed to safeguard the Great Lakes basin from further economic and ecological damage that may result from the establishment of Asian carp or other aquatic invasive species via the canals and waterways that connect with the Mississippi River basin. Consequently, the Commission and the Great Lakes and St. Lawrence Cities Initiative (GLSLCI) are leading a collaborative study to provide technical guidance on how ecological separation can be achieved (Commission and GLSLCI, 2010). Funded by several of the Great Lakes region's largest foundations this collaborative effort will work toward engaging all interests—shippers, water managers, government agencies, citizen groups, and recreational and commercial boaters, among others—in exploring and evaluating options to achieve ecological separation between the basins. A primary objective of the study team is to develop plans to protect natural resources, especially water quality, while enhancing the economic and commercial benefits provided by the system.

Shutting the Door Tightly

History has shown that the invasion of aquatic invasive species can be permanent. Once invaders take hold, they can forever alter the ecosystem, causing irreparable impacts. This process has been demonstrated by the establishment of self-sustaining populations of invasive zebra mussel, sea lamprey, round goby, and a myriad of other species that have been introduced into the Great Lakes (Mills et al., 1993, 1994). If Asian carp were to invade the Great Lakes, predicted impacts include irreversible damage to the Great Lake's ecological food web and commercial and recreational fisheries, and safety hazards for boaters. Prevention is essential because control will likely not be an economically or environmentally viable option for managing an Asian carp invasion.

The Great Lakes and the Mississippi River basins both host a number of aquatic invasive species that pose a risk of an interbasin exchange; the potential invasion of Asian carp is just one example. A permanent ecological barrier is critically urgent not only to minimize the spread of Asian carp but also to cut off the pathway for future invasions of other aquatic invasive species. There is a growing recognition that ecological separation must be comprehensive, taking into account the potential movement of all life stages and genera of invasive species, inclusive of plants, animals, and microbes. In achieving ecological separation, there are challenges to surmount and difficult problems to address. However, if designed and implemented effectively, ecological separation will not only contribute to mitigating a serious threat to the ecological health of both the Great Lakes and the Mississippi River systems, but will also improve the overall transportation and water management system of the greater Chicago metropolitan area.

Notes

1. Canadian dollars adjusted to US dollars by 2008 yearly average exchange rate ($1 US = $1.067 Canadian).
2. A 100-year floodplain is "the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year" (Federal Emergency Management Agency, 2010).
3. eDNA analysis is a water-sampling method to detect the presence of a species by identifying DNA from cells shed by the animal into the environment. Further discussion on the use of eDNA as a monitoring technique for Asian carp is presented later in this report.

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Submitted August 2, 2010; revised September 7, 2010; accepted October 12, 2010.